A TWO-PHASE ANAEROBIC DIGESTION PROCESS (UASB-UASB) FOR SIMULATED SEWAGE SLUDGE

by

PRAYOON FONGSATITKUL

B.Sc.(Sanitation), Mahidol University, 1975
M.Sc.(Environmental Technology and Management),
Asian Institute of Technology, 1978

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE STUDIES

(Department of Civil Engineering)

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

April 1992

ABSTRACT

The objectives of this research program were to demonstrate the feasibility and effectiveness of a "two-phase" anaerobic sewage sludge stabilization (UASB-UASB) process. A bench-scale experiment, consisting of two completely mixed sealed upflow anaerobic (A-UASB and M-UASB) reactors, designed to operate inside a walk-in temperature controlled room at 35°C, was employed. The system was first seeded and acclimatized, and then used in a series of different experimental runs, emphasizing the effects of influent Sludge Ratio (SR) of primary to secondary sludges and Recycle Ratio (RR) of fluidized sludge from sludge blanket portion of the reactor, on process performance. The vicinity of "best known" running condition was located by an application of 2 by 2 factorial design and Response Surface Method (RSM). Maximum system loading capacity, optimum operating conditions, and system failure/recovery process were further investigated.

The results of this research study showed that a two-phase UASB-UASB process appeared to be feasible and effective in stabilizing sewage sludge at high organic loading rates, while maintaining an acceptable level of supernatant quality and CH_4 gas production. The system had a high potential to recover effectively, after a serious failure, by applying a step-loading reduction and internal recirculation (RR) approach. The "Two-phase" concept has proved to be successful in treating sewage sludge. Hydrolysis-acidification predominated in the A-UASB, while acetogenesis-methanogenesis

dominated in the M-UASB. Most of the reactions occurred at the lower parts (sludge blanket and bed) of both reactors.

A combination of system hydraulic and organic overloading in the M-UASB reactor was a major cause of process failure. This was indicated by a washout of MLVSS, an increase in the total VFA concentration, a reduction in the system removal efficiency, a cessation of CH_4 gas production, a drop of pH, and an increase in total VFA/alkalinity ratio. Applying a two-step approach to increase the HRT of the M-UASB by 1.5 and 5.8 times that of the process failure HRT (M-UASB), the system COD (sol) removal efficiency recovered exponentially with an increase in HRT, while the CH_4 gas production recovered logarithmically (r^2=0.81-0.99). The optimum operating HRTs for the M-UASB, regarding COD (sol) removal efficiency and CH_4 gas production, were 2 and 2.7 days during the maximization and recovery period, respectively. For design purposes, the optimum operating HRTs of 1 and 2 days as well as RR of 2 and 3 times that of the influent flow rate are recommended for the A- and M-UASB reactors, respectively. A reactor diameter to height ratio of 1:8 to 1:10, and an organic loading rate of 19 kg COD(total)/m^3-d at 35°C, with the feed sludge ratio of 4 to 1 (80/20) are also recommended. Modified design criteria, start-up and acclimatization processes, and system operation, for the two-phase anaerobic digestion of sewage sludge (UASB-UASB), were finally developed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I wish to take this opportunity to express my sincere thanks for the morale, encouragement, and understanding received from my wife, Ladda and my parents throughout the completion of my research.

I also would like to extend my appreciation to the following, who enthusiastically supported and encouraged me in one way or another :

Dr.D.S.Mavinic, my advisor and Head of the Environmental Engineering Group, U.B.C.and Dr.V. Lo, Co-advisor and Head of the Bio-Resource Engineering, U.B.C. for their critical technical advice and faithful support throughout the completion of the research.

Dr.W.K.Oldham, Head of the Civil Engineering Department and Dr.K.Hall, Wastewater Research Centre for their invaluable comments and advice during the preparation of the research proposal and thesis.

Susan Liptak, Manager of the Environmental Engineering Laboratory, U.B.C., Paula Parkinson and Romy Lo for their understanding, assistance, and guidance of all analysis involved in the research.

Guy Kirsch, Civil Engineering Workshop Technician, for his suggestion and assistance in building and fixing all the components of the experimental system reactors.

Panagiotis (Takis) Elefsiniotis, Ph.D candidate in the Environmental Engineering Group, U.B.C. for his true friendship, encouragement, and technical assistance.

Finally, I would like to sincerely thank my sponsorship, Canadian International Development Agency (CIDA) and my employer, Thailand National Environmental Board (NEB). Without these sponsors, this research would not have been possible.

LIST OF ABBREVIATIONS

UASB-UASB	A Two-phase Upflow Anaerobic Sludge Blanket Process
A-UASB	Acid-phase Upflow Anaerobic Sludge Blanket Reactor
M-UASB	Methane-phase Upflow Anaerobic Sludge Blanket Reactor
RR	Internal Recycle Ratio
SR	Feed Sludge Ratio
HRT/Θ	Hydraulic Retention Time
SRT	Solids Retention Time
RSM	Response Surface Method
MLGH	Multiple Linear Regression Hypothesis
ln	Natural logarithm
COD	Chemical Oxygen Demand
MLVSS	Mixed Liqueur Volatile Suspended Solids
TS	Total Solids
TVS	Total Volatile Solids
TSS	Total Suspended Solids
TVSS	Total Volatile Suspended Solids
TP	Total Phosphorus

TKN	Total Kjeldahl Nitrogen
PO_4-P	Ortho-Phosphorus
NH_4-N	Ammonia Nitrogen
VFA	Volatile Fatty Acid
HAc	Acetic acid
HPr	Propionic acid
HBu	Butyric acid
HVr	Valeric acid
mg/L	Part per million
hrs.	Hours
ml	Milli-litre
L/d	Litre per day
OHPA	Obligate Hydrogen Producing Acetogens
Rh	Hydrolysis rate
Kh	First-order hydrolysis constant
F	Effluent Particulate COD concentration, mass/vol.
Fo	Influent Particulate COD concentration, mass/vol.
k	Maximum rate of substrate utilization per unit weight of microorganisms, $time^{-1}$
Ks	Half velocity coefficient, mass/vol, equal to substrate concentration when $\delta L/\delta t = (1/2)k$
L	Influent Substrate mass concentration, mass/vol.

Le	Effluent Substrate mass concentration, mass/vol.
$\delta S/\delta t$	Net growth rate of microorganisms, mass/vol-time
a	Growth yield coefficient, mass/mass
$\delta L/\delta t$	Substrate utilization rate, mass/vol-time
b	Microorganisms decay coefficient, time^{-1}
S	Microbial mass concentration, mass/vol.
V	Reactor Volume
Q	Flow rate
R_{COD}	System COD (sol.) removal efficiency, %
R_{PO4-P}	System PO_4-P removal efficiency, %
R_{CH4}	CH_4 gas production, m^3/m^3-d
HRT_{A-UASB}	Hydraulic retention time of A-UASB
HRT_{M-UASB}	Hydraulic retention time of M-UASB
HRT_{System}	Hydraulic retention time of system

CHAPTER ONE

INTRODUCTION

1.1 RESEARCH NEEDS AND BACKGROUND

Many wastewater treatment processes, whether primary or secondary, yield large quantities of waste materials in the form of a dilute solid mixture, known as sludge; this sludge usually contains a significant amount of organic wastes. Treatment and disposal of this sludge is recognized as one of the most critical areas of water pollution control, and accounts for almost 40-50 % of the total capital and operating costs at a municipal sewage treatment plant. (U.S. EPA 1979; Gloyna, 1982; Benefield, 1980).

Anaerobic sludge stabilization is one of the most successful and promising treatment processes, exhibiting several significant advantages over aerobic stabilization: reduction of pathogenic organisms and sludge production, saving on air supply, prevention of nuisance-odour conditions after digestion, and formation of high methane content in the gas production (Pohland, 1975). With an increase in worldwide energy costs during the last 20 years, the advantage of producing highly recoverable methane (serving as an additional energy source) has attracted a great deal of research effort, mainly to increase the ability and reliability of this process. However, many unanswered problems still exist in stabilizing sewage sludge anaerobically, especially using conventional, two-stage, completely-mixed digesters. These include poor supernatant quality, which generally requires further treatment, and the relatively low level of methane production possible under this conventional two-stage treatment.

To help solve these problems, two broad approaches can be employed : (i) increase bacterial activity by creating optimum digester operating conditions and ensuring an adequate supply of all known essential nutrients; (ii) increase the density of bacterial populations in the digesters (Callander, 1983). The former approach incorporates the basic mechanism of anaerobic sludge stabilization, which is, in fact, a di-phasic process - acidogenesis and methanogenesis. Therefore, providing an optimal environmental conditions (adequate supply of nutrients) for each predominant group of bacteria in the two-phase system is expected to enhance both the methane yield and increase the process performance and reliability (Pohland and Ghosh, 1971a; Massey, 1978; Cohen, 1979; and Bull, 1984). The second approach aims at maintaining or increasing the biomass and retaining it within the digester for a longer period of time, while undergoing stabilization. This can be achieved by a careful design of the floc-based digester with an appropriate sludge recycle ratio (RR). The Upflow Anaerobic Sludge Blanket (UASB) process is one of the most promising processes of the floc-based system digesters. With careful design, it can retain and increase biomass within the digester, without any additional mixing requirements.

The purpose of this research was to initiate a feasibility study for enhancing the efficiency of anaerobic sludge stabilization and increase the quality level of the final supernatant through development of a modified design criteria, start-up process, and operation of a two-phase, upflow anaerobic sludge stabilization (UASB-UASB) process.

1.2 RESEARCH OBJECTIVES AND APPROACH

The principle goals were to evaluate the **feasibility, effectiveness, and suitability** of this two-phase, UASB-UASB process for anaerobic sludge stabilization. The primary objectives were to achieve superior supernatant quality and to maximize % methane content and production, through a two-phase separation (UASB-UASB) process. Secondary objectives included identifying the optimum operating conditions, examining the effects of influent Sludge Ratio (SR) of primary to secondary sludges and Recycle Ratio (RR) of fluidized sludge from sludge blanket portion of the reactor on process performance and gas production, and investigating the maximum acceptable loading rate and associated system recovery. Time permitting, other objectives included developing a set of system design criteria and determining effective and reliable parameters for indicating process failure and system steady state conditions.

It is generally recognized that a research approach must be developed in the context of a particular situation. A " point-in-time statement " with a continuous flow of information (data sets of response parameters) as shown in Figure 1.1, represents a specific discrete work effort, which must be achieved prior to permitting continuance of further work tasks. As shown in Figure 1.1, emphasis was initially placed on the preparation of a realistic research proposal. It covered the whole range of problem identification, rationale, research objectives and approach, experimental program, as well as work schedule and cost estimation. After approval of the research proposal, two major tasks - synthetic sludge preparation and system design and construction, were carried out simultaneously; this was followed by system seeding and acclimatization requiring at least 40-60 days to reach steady-state conditions. The sampling program and response parameters were undertaken as shown in Figure 4.2. Along with each sequence of the

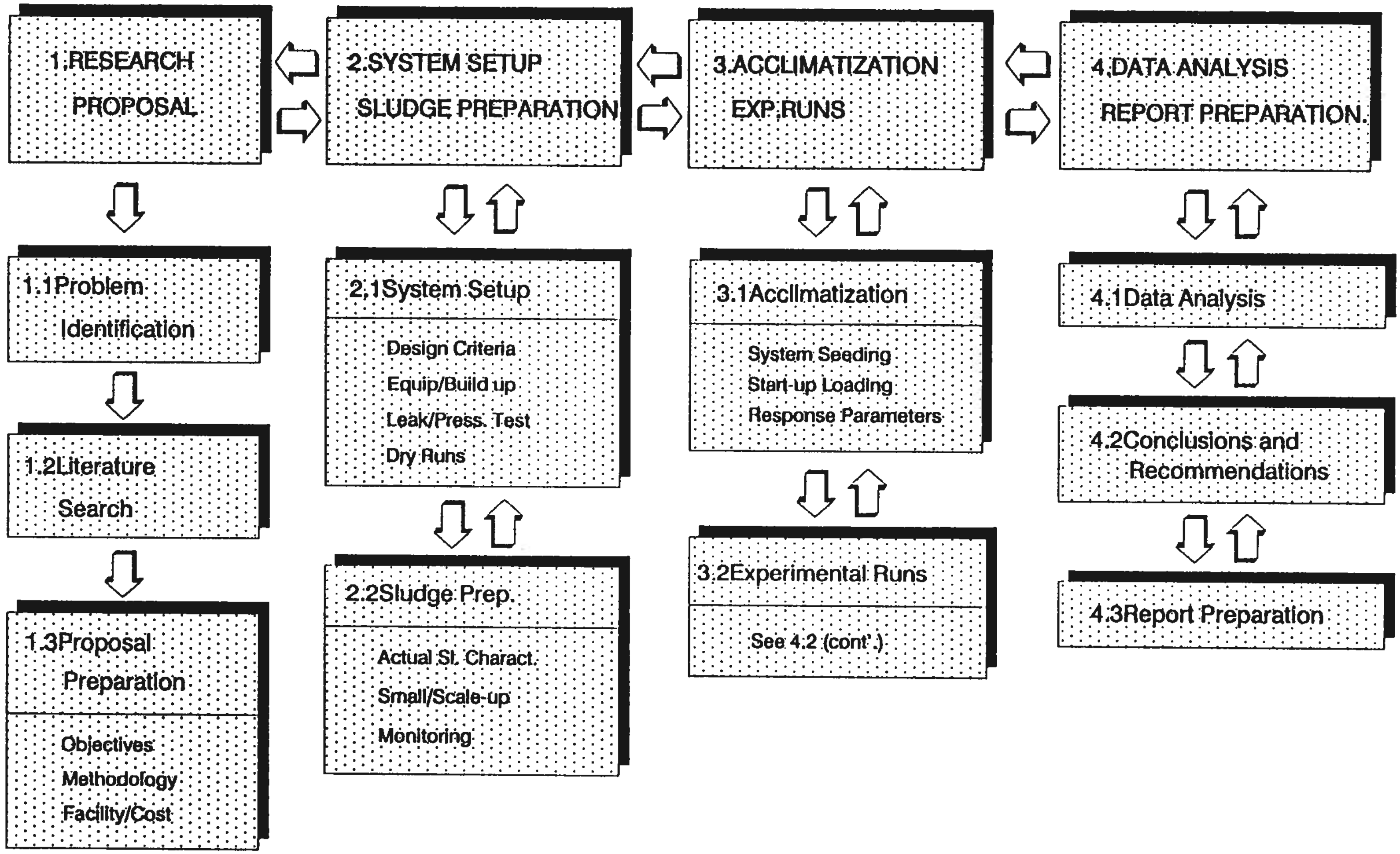


Figure 1.1 Research Strategy and Approach

experimental run, data analysis and results interpretation were made, using a spreadsheet software program (Symphony Version 1.2), Response Surface Method (RSM) and Yate's Algorithm Method. The " best known " optimum operating condition that generated the maximum % methane content and production, with superior supernatant quality, was then identified ; whereas, system maximum loading capacity and the recovery process were carried out afterward. Finally, the feasibility and effectiveness of this two-phase UASB-UASB process, to stabilize the sludge anaerobically, together with the difficulties and problems faced throughout the experiment and their remedial actions (shown in Table A1.1 of appendix A), were conclusively evaluated and reported on. The details of each task are discussed in Chapter 4.

CHAPTER TWO

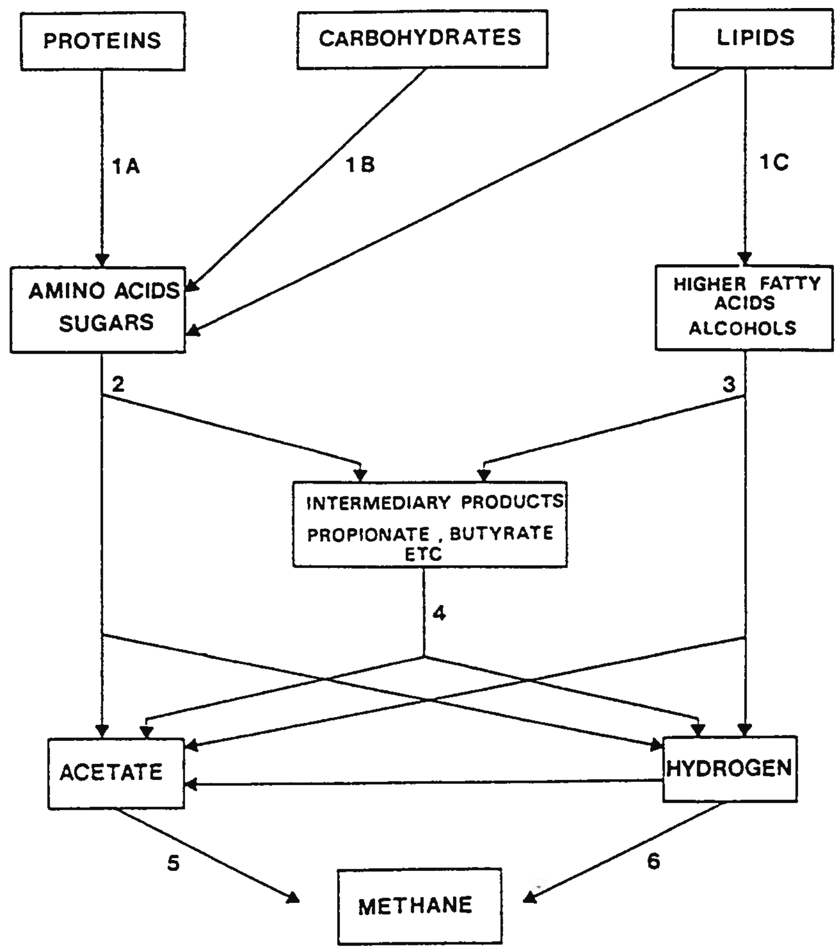
BACKGROUND AND BRIEF LITERATURE REVIEW

The purpose of this chapter is to briefly overview and update theoretical concepts on anaerobic sludge digestion and process development. The review will be used as background to formulate a framework for further investigation and the experimental program. In case of any particular references that are closely related to the result of the research, they will be discussed separately in the main text of Chapter 5 - Results and Discussion.

2.1 ANAEROBIC SLUDGE DIGESTION

(Biochemistry and Rate Limiting Step)

The overall anaerobic conversion of biodegradable organic solids to the end products of carbon dioxide (CO_2) and methane (CH_4) is initially believed to involve 3 processes which occur simultaneously: hydrolysis of insoluble biodegradable polymers; the production of fatty acids from smaller soluble organic molecules; and CH_4 generation (Stronach, 1986). But Gujer and Zehnder (1983) proposed a six-step system in the anaerobic conversion of high molecular weight degradable organics to CH_4 and CO_2 as shown in Figure 2.1. Two groups of bacteria, acid- and methane- producing bacteria, are, in principle, responsible for the overall anaerobic conversion of biodegradable organics. Acid-producing bacteria are responsible for converting heterogeneous substrate into fatty acids. The primary acids produced during acid fermentation are acetic, propionic, and



1. Hydrolysis
2. Fermentation
3. Anaerobic (β) Oxidation
4. Anaerobic Oxidation
5. Decarboxylation of Acetate $CH_3COO^- + H_2O \longrightarrow CH_4 + HCO_3^-$
6. Hydrogen Oxidation $CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$

Figure 2.1 Pathway of anaerobic biodegradation
Source : After Gujer and Zehnder, 1983

butyric; however, smaller quantities of formic, valeric, iso-valeric, and caproic acids are also frequently found (Malina, 1980). These acids are subsequently decomposed by methane-producing bacteria, resulting in the production of methane.

Approximately 85% of the CH_4 results from the fermentation of acetic and propionic acids with the remainder generated from primarily butyric and formic acids, as well as the reduction of CO_2 by H_2; some CH_4 is generated from the fermentation of long-chain fatty acids via anaerobic (β) oxidation (Stronach, 1986). The pathways for the formulation of CH_4 are mostly dependent on the nature of influent substances and fall into three subgroups : lower fatty acids (C_1-C_6, ie. formic, acetic, propionic, butyric etc.); normal or iso-alcohols (C_1-C_5, ie. methanol, ethanol, propanol, butanol etc.); and inorganic compounds (ie. H_2, CO, CO_2). The biochemistry of these basic reactions can be summarized as follows:

(1) Biochemical decomposition of lower fatty acids:

(1.1) Acetic acid decomposition

$$CH_3COOH \longrightarrow CH_4 + CO_2 \quad \text{.......... (1)}$$

(1.2) Propionic acid decomposition

Two-step requirement:

$$4CH_3CH_2COOH + 2H_2O \longrightarrow 4CH_3COOH + CO_2 + 3CH_4 \quad \text{.......... (2)}$$

$$4CH_3COOH \longrightarrow 4CH_4 + 4CO_2 \quad \text{.......... (3)}$$

Overall: $$4CH_3CH_2COOH + 2H_2O \longrightarrow 5CO_2 + 7CH_4 \quad \text{.......... (4)}$$

(1.3) Butyric acid decomposition

Two-step requirement:

$$2CH_3CH_2CH_2COOH + 2H_2O + CO_2 \longrightarrow 4CH_3COOH + CH_4 \quad \text{......(5)}$$

$$4CH_3COOH \longrightarrow 4CH_4 + 4CO_2 \quad \text{......(6)}$$

Overall: $$2CH_3CH_2CH_2COOH + 2H_2O \longrightarrow 3CO_2 + 5CH_4 \quad \text{......(7)}$$

(1.4) Microbial reduction of CO_2 formed from reduction

$$CO + H_2O \longrightarrow CO_2 + H_2 \quad \text{......(8)}$$

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O \quad \text{......(9)}$$

$$CO + 2H_2 \longrightarrow CH_4 + H_2O \quad \text{......(10)}$$

$$4C_2H_5COOH + 8H_2O \longrightarrow 4CH_3COOH + 4CO_2 + 24H \quad \text{......(11)}$$

$$3CO_2 + 24H \longrightarrow 3CH_4 + 6H_2O \quad \text{......(12)}$$

$$4C_2H_5COOH + 2H_2O \longrightarrow 4CH_3COOH + CO_2 + 3CH_4 \quad \text{......(13)}$$

$$CH_3COOH \longrightarrow CH_4 + CO_2 \quad \text{......(14)}$$

Conversion of volatile fatty acids (VFAs) to the production of CH_4 is considered to be a rate-limiting step for soluble organic matter, whereas hydrolysis of insoluble organics is believed to be a rate-limiting step for particulate matter (Eastman, 1981; Cohen, 1983; and Pavlostathis, 1986).

2.2 OPERATING PARAMETERS AND RESPONSES

Anaerobic stabilization is recognized as a sequential, di-phasic process: hydrolysis and acidogenesis, followed by methanogenesis. Phase separation is then a logical choice to stimulate the growth of these two groups of bacteria. Acid- and methane-producing bacteria are strict anaerobes and extremely sensitive to changes in temperature and pH.

These bacteria are active in two temperature zones: mesophilic range (30-35 °C) and thermophilic range (50-60 °C). The optimum pH range for methane-producing bacteria is 6.4-7.2, whereas it is 5.5 for acid- producing bacteria. Above pH 8 or below 6, the growth of methane formers falls rapidly. A sudden change in environmental conditions and/or an introduction of toxic substances into the system, may cause the imbalanced growth rate of these two groups of bacteria. Once the balance is upset, intermediate organic acids accumulate and the pH drops. As a result, the methanogens are further inhibited and the process eventually fails, unless corrective measures are taken. This imbalance can be indicated by various parameters: an increase in % CO_2 content of the gas produced and a corresponding decrease in % CH_4 content; a decrease in the pH and total daily quantity of gas produced; an increase in the concentration of VFAs; an overall decrease in the efficiency of waste stabilization; and the ratio of volatile acids/alkalinity > 0.5 (Graef and Andrews, 1974a/b; US. EPA, 1979). Toxic materials and other matters can also upset the system; these include oxygen, volatile acids (2,000 mg/L), total NH_3-N (1,500-3,000 mg/L at pH 7.4-7.6 or >3,000 mg/L at any pH values), and soluble metals eg. 3 mg/L Cr, 2 mg/L Ni, 1 mg/L Zn, and 0.5 mg/L Cu. However, if sufficient time is available, methane-producing bacteria can acclimatize to the toxic materials (Stronach, 1986; Malina, 1980; Capri, 1975; Ziekefoose, 1976; Kujelman, 1981; Graef, 1974; Cortinovis, 1984; US. EPA, 1979; Chiu-yue, 1986).

In a typical anaerobic sludge digester, approximately 72 % of the methane produced evolves through acetate splitting, and the remainder comes from the reduction of CO_2 with H_2 (Jeris and McCarty, 1965). Hydrogen is then an important intermediate in methanogenesis and a build up of hydrogen may alter the electron flow during fermentation of carbohydrates and other polymers. Accumulation of hydrogen further inhibits other important intermediates being formed during anaerobic sludge digestion, such as propionate and butyrate (Scheifinger and Wolin, 1972; Chung, 1976; Kasper and Wuhrmann, 1978). Therefore, Mosey, (1983a) has suggested that hydrogen gas might be a simpler and more effective prime indicator for monitoring the anaerobic digestion process. However, Hickey, (1987) concluded that there appeared to be some limitations on the potential of using hydrogen as a prime indicator of process upset, resulting from the application of organic toxicants. He found that severe inhibition of methane production occurred at high organic loading rates, resulting in an accumulation of hydrogen and VFA's; however, at lower loading rates, inhibition was less severe and hydrogen accumulation was slightly above controls. He finally recommended monitoring hydrogen, in consert with other conventional process indicators, would provide an effective indication of process upset due to toxic shocks.

2.3 ANAEROBIC PROCESS DEVELOPMENT
(Stability/Performance/Kinetics)

Anaerobic process development has recently advanced in two directions: improvement of the gas yield and satisfactory substrate removal efficiency, while, at the same time, minimizing the system capital and operating costs. A thorough investigation of the best "system operating condition" is necessary to achieve the goals of process development.

A rapid escalation energy shortages and heightened environmental awareness have increased the pressure to improve anaerobic digestion performance where applicable and feasible. Two broad approaches are generally employed - one providing preferably optimum environmental conditions for each group of bacteria and the other concerned with increasing bacteria population density and retaining it within the digester. The former approach can be achieved through the use of two-phase anaerobic digestion, with an adequate supply of nutrients. The latter one can also be accomplished through an increase in the system SRT by means of solid-liquid separation and appropriate sludge recycle. Either floc-based (suspension) or an attached-fixed film system can increase digestion performance and provides promising results (Callander, 1983).

Two-phase anaerobic stabilization is capable of providing the optimum conditions for the growth of both acid- and methane- formers, the latter preferring widely different environmental conditions from the former. The merits of this process are an increase in the production rate of CH_4, maximum loading rates for the methane-phase reactor, a decrease in recovery time after shock loading, and enhancement of process efficiency and reliability (Pohland and Ghosh, 1971; Cohen, 1979; Massey et al., 1978). Although a two-phase stabilization process seems best suited for the treatment of soluble-type wastewaters producing a high potential for volatile acids accumulation (Pipyn et al., 1979; Ghosh et al., 1981; Ghosh et al., 1983a), superior performance has also been demonstrated for particulate-type substrates such as sewage sludge and agricultural wastes (Ghosh, 1983b; Keenan, 1976; Normann, 1977; Rijkens, 1981; Datta, 1981; Colleran, 1983).

The limiting step in anaerobic stabilization of complex organic macromolecules, such as contained in sewage sludge, is hydrolysis-acidification, whereas for stabilization of shorter chain soluble organics wastewater, it is methanogenesis. Phase-separated digestion (hydrolysis-acidification independent of methanogenesis) has demonstrated several practical advantages: better stabilization of the sludge and a greater quantity of gas, reduced digestion time and reduced reactor size (Ghosh, 1987; Dichtl, 1987). Perot, (1989) concluded that two "optimized" steps had several advantages over a single-phase digester: start-up period was not as long (45 days instead of 75 for a single-step process); higher volatile matter degradation yield (60% instead of 40%); and the HRT could be half of that of the single-step process, without risking the system gas production and performance. He also indicated that gas production was linked primarily to the quantity of biodegradable organic matter.

Another promising approach to enhance the anaerobic sludge stabilization process is to increase the density of bacteria in the system and retain it within the digester, with adequate supply of nutrients. This can be done by an appropriate design and selection of a proper anaerobic stabilization process and recycle ratio. One of the main criticisms of anaerobic waste treatment is the difficulty of retaining a sufficient amount of active anaerobic sludge under high loading conditions, using the present anaerobic treatment technology. Recently, this difficulty has been addressed through the development of the Upflow Anaerobic Sludge Blanket (UASB) process (Holsoff-Pol et al., 1986).

Upflow Anaerobic Sludge Blanket (UASB) technology is credited as an effective process in stabilizing soluble organic waste, as well as producing superior supernatant quality without any mixing requirements. It also provides the advantage of developing and retaining a highly settleable biomass within the digester known as "sludge blanket"; this is a granular sludge media, with high settleability and methanogenic activity. This biomass decomposes the VFA's generated from hydrolysis-acidogenesis for the production of CH_4, CO_2, and small amounts of N_2, H_2, etc. The rising gases and influent flow rate are significant factors in maintaining biomass granules and flocs in more-or-less fluidized states, and the resulting turbulence also aids in detaching gas bubbles from flocs in the upper part of the digester. The biogas is removed by a three-phase, gas/liquids/solids separator (GSS-device) at the top of the reactor (Figures 3.1-3.2), whose main functions are to retain a highly settleable biomass within digester and also to provide an effective separation of the gas produced during stabilization as well as to return the dispersed sludge back to the sludge bed situated below the GSS-device (with the help of 50° inclined wall of the settler). A gas-free zone above the collector allows for the settling of finely- dispersed solids to the reactor bottom, while clarified effluent exits from the top. A simple baffle arrangement can assist in retaining biomass within the digester, through the creation of a quiescent region; as such, entrained flocs separate from the liquid before it leaves the digester via a number of weirs. (Lettinga, 1980).

To date, it is not known which factors trigger the growth and development of granular sludge, including how and when this biomass will develop. Dolfing, (1986) suggested that acetoclastic *Methanothrix-like* organisms play an important role in determining which type of sludge would develop under methanogenic conditions. He also suggested that extracellular material undoubtedly played a major role as a matrix, which kept the cell together. Phosphorus and sodium may also influence the filament length of *Methanothrix-like* organisms as they have on the filament length of *Methanospirillum hungatei* (Patel, 1979). The sludge granulation process generally involves 3 sequential processes: start-up, say with a loading rate up to 5 kg COD/m^3-d; then granulation sludge appearance and floc-formed sludge washout process; and finally continued formation of granules under a volumetric loading rate up to 16 kg COD/m^3-d (Lettinga, 1986; Wu, 1985). Cultivation of the granular sludge can be obtained through a careful selection of organics, with an optimum COD : N ratio of between 30 to 55 : 1. Additions of Ni, Co, Mo, and $ZnSO_4$ into the digester also yielded positive effects (Hulsoff-Pol, 1986; Wu, 1985). The granular sludge begins to appear at a COD loading rate of approximately 0.6 kg COD/kg VSS-d or higher, after which the granulation process develops very quickly. The optimum conditions for cultivation can be achieved under elevated mesophilic conditions (30-50 °C), a pH in excess of 6.5-7.2, sufficient buffering capacity, and the absence of inhibitory and toxic substances such as Na^+, K^+, and NH_3-N; these substances should be lower than 3,500, 2,500, and 1,700 mg/L respectively (Wu, 1985). Wiegant (1985) also stressed that a superficial biogas loading rate (biogas velocity, m/hr) was an important factor in the granulation and selection process.

Appropriate start-up loading rates plus the addition of Ca^{++} have also proven to be beneficial to the sludge flocculation and thickening process. Cail and Barford (1986) stated that the presence of Ca^{++} in the range of up to 150 mg/L stimulated sludge granule formation and thickening. Also, Mahoney (1987) found that the sludge granules formed inside the reactor with calcium addition, settled 3-4 times faster than that without calcium addition. A high rate of biomass accumulation was also evident in the calcium-positive reactor. An optimum start-up process, involving favourable conditions for the flocculation/growth/high settleability and specific activity of the biomass sludge, are the main prerequisites in achieving successful treatment with high loading rates in the UASB process. The loading potential of a UASB can be maximized through a careful consideration of an appropriate design for uniform feed inlets, a 50° angle inclined-wall settler, with a surface loading velocity of less than 0.7 m/hr, and an average flow through the aperture between gas collectors below 2.0 m/hr (Lettinga, 1983c; Schwartz, 1982). Also recommended is periodic wasting of small amounts of sludge, to maintain a constant level of biomass sludge within the reactor (Lettinga, 1979b).

However, conventional separation can be inadequate for the buoyant, flocculant sludge. It is sometimes replaced by alternatives like surface clarification (Hamoda, 1984), ultrafiltration (Choate, 1982), and coagulants (Cail, 1986). DLA Inc. (Olthof, 1982) have placed the biofilter media in the upper zone of the reactor of a conventional UASB process, to increase the system SRT and to dampen the short circuiting; this procedure has also improved gas/solids/liquid separation, as well as provided a surface for the attachment of biomass. This system has worked very well and is marketed under the trade name "Anhybrid". Further, Oleszkiewicz (1988) has demonstrated that a reactor, with random media in the upper 40 % of the volume, showed better COD removal efficiency and gas generation, as well as less washout of the flocculant sludge through shortcircuiting, than those reactors with media oriented vertically and/or no media.

Development of anaerobic reactors using attached biomass, such as the fluidized bed and the anaerobic filter, has resulted in the ability to increase the loading rate from 20 to 50 kg COD/m^3-d and from 10 to 30 kg COD/m^3-d respectively. However, problems with attached biomass systems include clogging and high operating costs, due to external energy requirements (Maat, 1987). He also found that the UASB overcame many of these limitations by introducing granulated suspended biomass and the GSS-device. This system could achieve 75-94 % removal efficiency, with a sludge concentration of 8-13 % dry solids at temperatures ranging from 20-40 °C (even if the reactor loading is 30 kg COD/m^3-d or higher). The UASB reactor has been successfully commercialized as the BIOPAQ wastewater treatment system. The design loading for several BIOPAQ installations is about 10 kg COD/m^3-d, while actual capacity limits for volumetric loading have exceeded 20-30 kg COD/m^3-d (Maat, 1987). Current design practices for UASB reactors, are effective for several types of wastewaters, regardless of whether it is sewage or industrial wastewaters (with either dilute or concentrated wastes). There are three basic considerations for the design of the UASB reactor: volumetric organic load applied, liquid velocity on the settler surface, and reactor height. Based on a specific study of a typical UASB process, Souza (1986) recommended that maximum safe design values be about 15-20 kg COD/m^3-d, 1.2-1.5 m/hr, and a height of less than 6.0 metres, respectively. Minimum and maximum superficial gas release rates were recommended to be 1 and 3-5 m^3 gas/m^2-hr, respectively. It was also suggested that the feed inlet distribution area be 7-10 m^2/inlet. Lettinga et al. (1983 and 1986) attempted to increase the superficial liquid velocity up to 5-15 m/hr, by increasing the sludge loading rate and recycling the effluent back to the system using the expanded granular sludge bed reactors (EGSB). The attempt appeared to be feasible. Sludge recirculation helps inoculate the fresh sludge inside the digester and also increase the system SRT. Finally, Dold (1987) used a UASB to treat apple juice waste, at the temperature less than optimum (25 ° and 30 °C) and a maximum loading of 12-16 kg COD/m^3-d. He concluded that the UASB system worked very well, even at a low temperature of 25 °C and the maximum loading rate employed.

An application of two-phase separation, to treat particulate materials (such as crop residuals, manure, and municipal refuse) wherein hydrolysis is the rate-limiting step, is also showing promise. A variety of approaches has been proposed, such as using the UASB as a modified acid reactor (Zoetemeijer et al., 1982; Therkelsen, 1979), to accelerate the rate of hydrolysis and acidogenesis. However, for slurries like sewage sludge and slaughter-house wastewater, the application of phase separation, using UASB is still questionable in term of real benefits, when compared to a single-UASB process (Lettinga, 1983a). Ghosh, (1984), however, reported that a two-phase UASB process was very effective in stabilizing sewage sludge. The methane yield was nearly 77% of theoretical values at an HRT of 5.5 and 5.9 days, in the sequential reactors; the optimum HRT's for the acid- and methane-phase reactors were 0.9-1.5 and 4.0-5.0 days, respectively.

Several models has been initiated to explain and predict the mechanism and performance of anaerobic digestion. Arbitrarily, the models can be classified into 4 groups: Monod, substrate inhibition kinetics, first-order kinetics, and Contois-derived kinetics. Conceptual comparisons among these models is well documented with Monod kinetics being the most popular and accepted among researchers, to explain the anaerobic digestion process (Mosey, 1983b; Ripley, 1983). For example, Monod kinetics are frequently used to explain the mechanism of anaerobic digestion of sewage sludge and particulate materials (Pavlostathis, 1986; Massey, 1987). In addition, a mathematical model for the UASB, serving as methane-phase reactor only, is well established. The principle element of the model involves dynamic behaviour and distribution of the fluid pattern, anaerobic sludge in the reactor, kinetic conversion of organic wastes, and formulation of bacterial end products and CH_4. The use of a mass balance for substrate, CH_4, and bacterial end products in the system, is carefully made in formulating a mathematical model for the UASB process (Buijis, 1981; Buijis, 1982; Heertjes, 1978/1982; and Van Der Meer, 1983). An indepth review of these kinetic models is beyond the scope of this project and the reader is referred to the literature as cited above.

From this brief literature review, it is apparent that there have been several major studies completed, with the basic goal of enhancing the efficiency of anaerobic sludge digestion using the two-phase separation and/or the UASB process. However, very few have taken full advantage of combining these two concepts, to enhance the overall effectiveness of anaerobic stabilization. To maximize the benefits, it appeared logical to evaluate the feasibility and effectiveness of using a two-phase UASB-UASB process, one with an internal recycle of fluidized sludge known as sludge blanket in order to enhance the efficiency of anaerobic sludge stabilization. The basic idea was to take advantage of the di-phasic phenomenon of anaerobic stabilization by using phase separation to provide a preferred environment for growth stimulation of the two different groups of bacteria.

By using the UASB process and internal sludge blanket recycle concepts, it was hoped to increase the contact between micoorganisms and substrates as well as to increase the system bufferring capacity. Thus the system can retain the granular biomass within the digester, without any mixing requirements and provide a promising system performance and stability. The research program was initiated and formulated along these lines.

CHAPTER THREE

SYSTEM SET-UP AND OPERATION

3.1 RATIONALE AND DESIGN CRITERIA

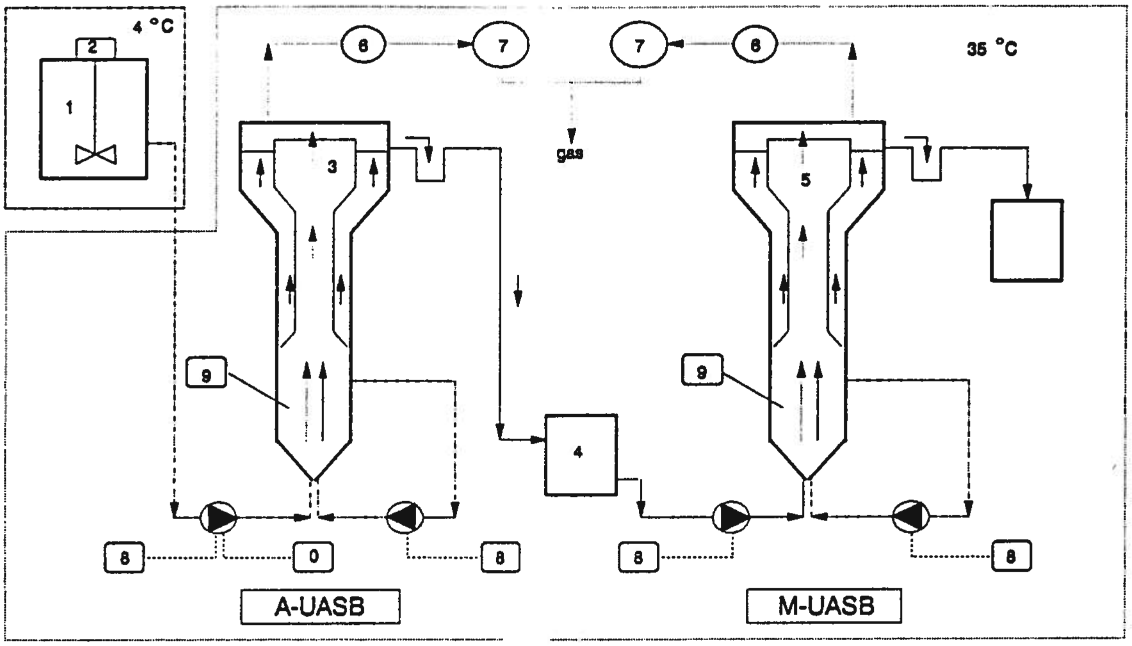
The principle goals of this research were to evaluate the feasibility, effectiveness, and suitability of using a two-phase, UASB-UASB process to enhance the efficiency of anaerobic sludge stabilization. To achieve these goals, a schematic flow diagram of experimental designs was delineated as shown in Figure 4.1. The rationale and design criteria were then conceptually formulated. To enhance the efficiency of anaerobic stabilization, two broad approaches are generally employed - one providing preferably optimum environmental conditions for each group of bacteria and the other concerned with increasing bacteria population density and retaining it within the digester.

The former approach can be achieved through the use of two-phase anaerobic digestion, with an adequate supply of nutrients. A two-phase UASB-UASB process was selected to treat a synthetic sludge, under the specific control of temperature at 35 °C and pH's of 5 and 7 for the acid-phase (A-UASB) and methane-phase (M-UASB) reactors respectively. By controlling the temperature and pH, as well as separating their environments, the acidogens and methanogens were expected to dominate the mixed cultures of bacteria within the A-UASB and M-UASB units, respectively; it was also expected that there would be a rapid utilization of organic matter, an effective production of volatile fatty acids (VFAs) and finally methane production. To enhance the stabilization process and methane gas formation, nutrient requirements must be sufficient. Variation in feed sludge ratio (SR) of primary to secondary synthetic sludges, means a significant difference in feed sludge characteristics (COD/VSS, TKN, TP, etc. as shown in Table 3.1). Since it is known that primary sludge contains mostly organics while secondary sludge contains organics, nutrients (N and P) and bacterial cells. This would strongly affect the system performances and methane formation. A careful combination of these two sludges, with an optimum SR, could result in a maximization of CH_4 gas production and removal efficiency. This would be of particular interest to those waste treatment plants that produce both a primary and secondary waste sludge requiring further stabilization.

The latter approach can be accomplished through an appropriate design of UASB system configuration to help keep the biomass inside the reactor with the optimul recycle ratio (RR). New technologies have incorporated changes, which allow SRT and HRT to be varied independently. Typically, the solids in the reactor effluent are allowed to settle and recycle back to the reactor influent in order to increase the ratio of SRT/HRT (Christensen, 1984). Several other factors (feed characteristics, seed sludge and start-up process, operating condition (SR, RR, mixing, wasting, etc.) , and process configuration) are also separately considered to improve the system performances in this experiment. In principle, UASB composes of 3 main components (sludge bed, sludge blanket, and settler). A very concentrated sludge bed develops near the bottom of the reactor. The blanket varies from very dense and granular particles with high settling velocities near the bottom, to the lighter, more diffuse particles at higher level of the blanket. Most of the reactions occurs throughout the entire sludge bed and blanket zones. The system is mixed by hydraulic upflow and rising gas bubbles. The potential of UASB reactor, are mainly dictated by the amount of sludge that can be retained in the reactor. In the internal settler, a quiescent zone is created to enable the sludge particle released from the blanket to settle rather than being washed out. Sludge separated by settling is recirculated into the reactor and thus being retained in the system. To help increase this sludge retaining ability, internal recycling ratio (RR) of this fluidized sludge known as sludge blanket back to the reactor influent can significantly enhance the system performance. Increasing the RR means an increase in not only the contact between microorganisms and substrates but also the system bufferring capacity, which finally can lead to the improvement of system stability and removal efficiency; however; too high an RR can break down the sludge bed and seriously damage the system performance.

The success of system performance depends not only on the optimal level of operating conditions such as loading rate, RR, and SR, but also on the system configuration. Since the UASB-UASB process is quite new, detailed microbial and kinetic data are not yet available. Conceptual and preliminary designs of this two-phase configuration have to be made through a modification of existing design criteria of UASB process and theoretical conceptual ideas. Overall schematic diagrams of the system configuration are shown in Figures 3.1 and 3.2, respectively. The detailed sizing of the system components is shown in Table A3.1 of Appendix A. As shown in Figure 3.1, the diameter of the settling section is double that of the sludge bed and blanket sections, and

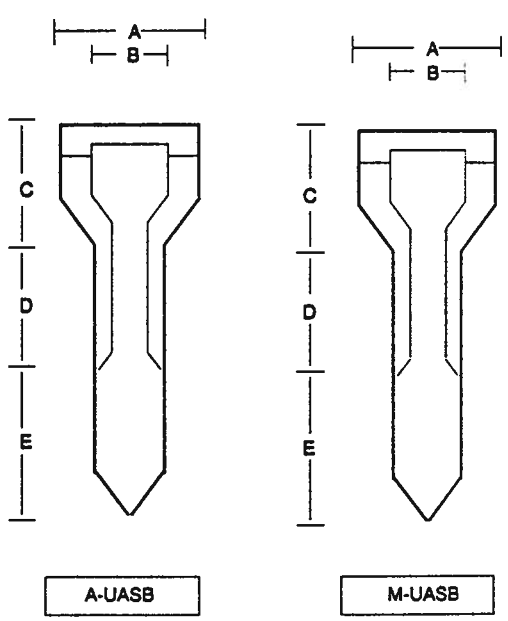
Figure 3.1 Schematic Flow Diagram of a Modified Two-phase Anaerobic Sludge Digestion (UASB-UASB) Process



Legends : (1) Sludge blender
(2) Mixers
(3) Acid-phase reactor
(4) Storage tank
(5) Methane-phase reactor
(6) Gas trap (water)
(7) Wet gas flow meters
(8) Pump controllers
(9) pH controllers
(0) Timer

Note: Liquid flow   Gas flow   Solids flow

Figure 3.2 Detailed Dimensions of UASB Reactors used in the experiment



Legend	A-UASB (cms)	M-UASB (cms)
A	20	25
B	10	15
C	20	30
D	50	50
E	50	50

(A,B) = Diameter, cms
(C,D,E) = Height, cms

Note: 50 degree inclined wall
Mixer @ A-UASB
1.27 cms.india.@ in & outlet

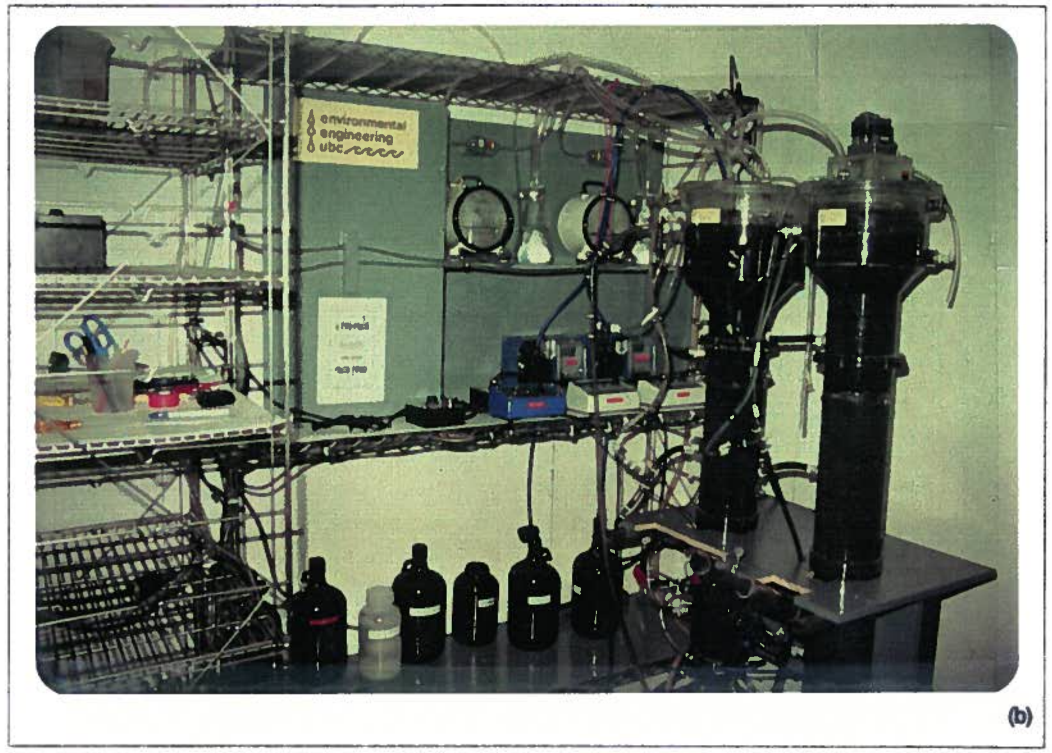


Figure 3.3 Photographs of A Two-phase UASB-UASB Process
(a) During a leak testing run; (b) During Aclimatization Process

has a 50° inclined-wall; it was designed to reduce the upflow velocity and help settle the solids back to the lower parts. This also reduces significantly the amount of supernatant solids, especially in the A-UASB reactor. Too high a concentration (> 500 mg/L SS), can affect the M-UASB performance adversely (Christen, 1984). To ensure a homogeneous feed sludge and also to prevent the potential stabilization of the influent feed before entering the system, mixed primary and secondary sludges were mixed continuously (at 60 rpm) inside a 30-litre, plexi-glass storage vessel, installed in a walk-in temperature controlled room, at 4 - 6 °C.

In addition, maximum system loading capacity and system failure and recovery are also worth investigated. Accidental shock load (and/or overloading) and/or temporary system cessation (stoppage) may reduce the system performance or even be a major cause of a complete system failure. Appropriate prime indicators of system failure must be identified and quantified and then system recovery alternatives can be formulated. These additional information and results will be used as a part of a final recommendation on system design and operation of the two-phase anaerobic digestion process (UASB-UASB) for sewage sludge.

3.2 EXPERIMENTAL APPARATUS AND OPERATION

As a lab scale experiment, two completely sealed upflow anaerobic (A-UASB and M-UASB) reactors were designed to operate inside a walk-in temperature controlled room at 35 °C. Their height and capacity were 1.3 meters, with 20 and 25 litres for A-

UASB, and M-UASB, respectively, as shown in Figure 3.2. Whenever the measured pH was under the setpoint values of 5 and 7 for the A- and M-UASB reactors, a signal was sent to the controller, which subsequently directed the diaphragm pump to start pumping a 0.1-0.2 N NaOH solution into the digester to maintain the pH at the set values.

As shown in Figures 3.1 and 3.2, the influent synthetic primary and secondary sludges were mixed within a 30-litre storage vessel located in a walk-in temperature controlled room of 4-6 °C; the mixture was subsequently pumped to the bottom of the A-UASB reactor by a peristaltic pump. The liquid passed through sludge bed, blanket, and settler, and finally left the reactor via the weir. The effluent from the A-UASB reactor was then pumped to the M-UASB reactor, via peristaltic pumps. The liquid then followed a similar pattern to that of A-UASB and it eventually overflowed as the system final effluent. Concurrently, the fluidized sludge blanket of both reactors was recycled back into the digester. The gas produced from both reactors was entrained in a gas capture facility attatched to the upper part of each reactor. The gas was then monitored by two wet gas flow meters via water trap flasks. To ensure that there was no leakage of gas and/or fluid, rubber o-rings and one-inch bolts were placed around the digester covers. A 1.27 cm (ID) food and beverage tube, with straight connecters and metal clamps, was used, where necessary, throughout the system to prevent clogging and/or fluid spillage. Also, a two-week schedule of tightening the clamps was implemented. After the completion of the system set up, a test run with tap water was made to check the possibility of any liquid leaking and/or improper operating equipment. A gas leaking test, using nitrogen gas at 2-3 psi and foaming agents, was also carried out several times to ensure that there was no gas leakages from within the digester.

3.3 SYNTHETIC SLUDGE PREPARATION

To avoid potential problems of toxicity from actual wastewater sludge and supply reliability for both primary and secondary sludges, a synthetic sludge mixture was used. The initial constituents of synthetic primary sludge were partly based on those reported in the literature (Therkelsen, 1979). The main constituents, based on percentage by weight of total dry solids (% by wt of dry solids), were composed of dog food (76 %), soap (4 %), corn oil (6 %), $CaCO_3$ (2 %), and $MgCO_3$ (2 %). The chemical analysis of dog food ("No Name"-Special-dinner for Dogs) used in the preparation of both primary and secondary synthetic sludges, is shown in Table A2.2 (b) of the Appendix A. The proportion of these ingredients was further modified by using numerous trial-and-error techniques to ensure that the characteristics of prepared synthetic sludge were in the typical range of actual primary and secondary sludges, respectively. The final modified constituents of primary and secondary synthetic sludges are shown in Table A2.2 (a) of Appendix A. The amount of each ingredient was calculated based on its proportion, total liquid volume (30 and 24 litres), and total dry solids (4 and 2 % by weight) for primary and secondary synthetic sludges, respectively.

To ensure sufficient mixing and solubility of the prepared mixture as well as consistency of the prepared sludge characteristics, several designed preparation techniques were developed and modified. The synthetic sludge was prepared inside a 60-litre plexi-glass reactor with a mechanical mixer. The fine-ground, dog food, together with all other ingredients, was dissolved with tap water to make the total volume of 12 litres and was mixed continuously at 90-95 rpm for 2 hours; it was then left overnight inside the walk-in temperature controlled room at 4 °C. After that, the prepared sludge was transferred to several 1.4-litre beakers and warmed up to 65-70 °C inside a water bath for 1.5 hours; it was then mixed at 90-95 rpm for a further 1 hour and settled for 10 minutes. After settling, a portion of the settled solids was wasted, to ensure that the remaining solids level were at the assigned level of P and S for primary and secondary synthetic sludges, respectively; and finally, the volumes were made up to 30 and 24 litres, for primary and secondary synthetic sludges, respectively.

A series of small scale (1-litre) and scale up (30-litre) experimental evaluations was carried out, to determine the characteristics of the prepared sludge, and to compare with those of actual domestic wastewater sludge. As shown in Figure 3.4 and 3.5, a series of run-and-compare experiments were undertaken for more than three months, before the characteristics of the synthetic sludge corresponded reasonably to those of actual sanitary waste sludges. During the scale-up experiment, an addition of urea and Na_2HPO_4 was necessary to increase the concentration of TKN and TP up to the actual range for secondary sludge. Numerous trial-and-error efforts were spent on wasting of settled solids, in such a way that the COD/VSS ratio of both primary and secondary sludges was in the typical range for actual sludge. A comparative summary of the basic characteristics of synthetic and typical "actual" domestic sludges is illustrated in Table 3.1.

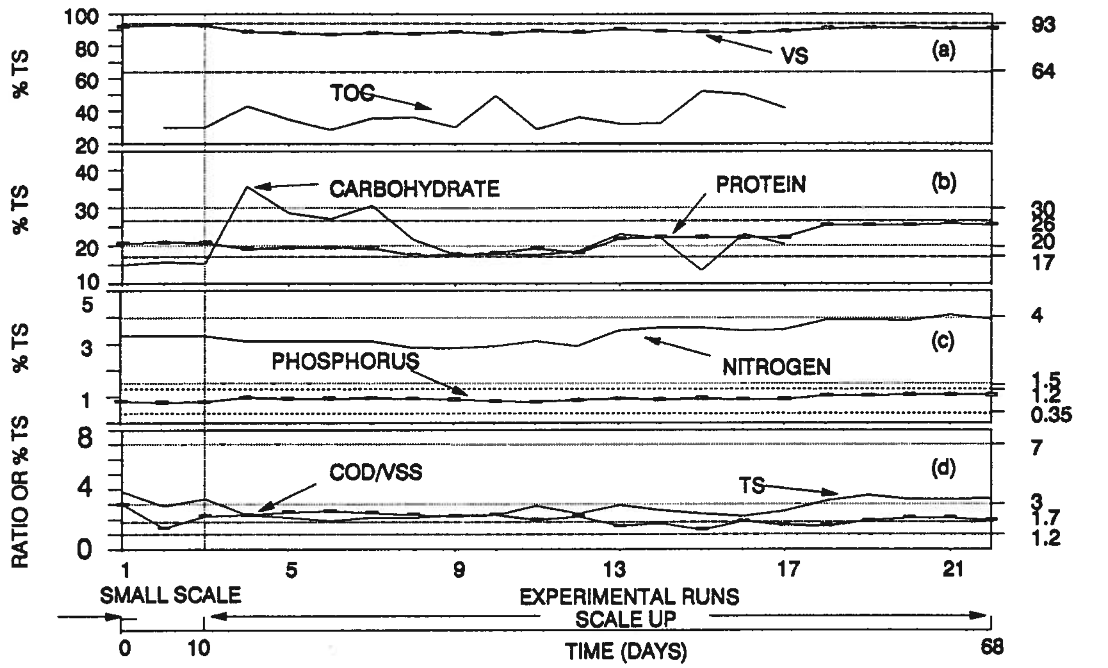


FIGURE 3.4 CHARACTERISTICS OF PRIMARY SYNTHETIC SLUDGE :

(a) TOC,VS; (b) CARBOHYDRATE,PROTEIN; (c) N,P; (d) COD/VSS,TS

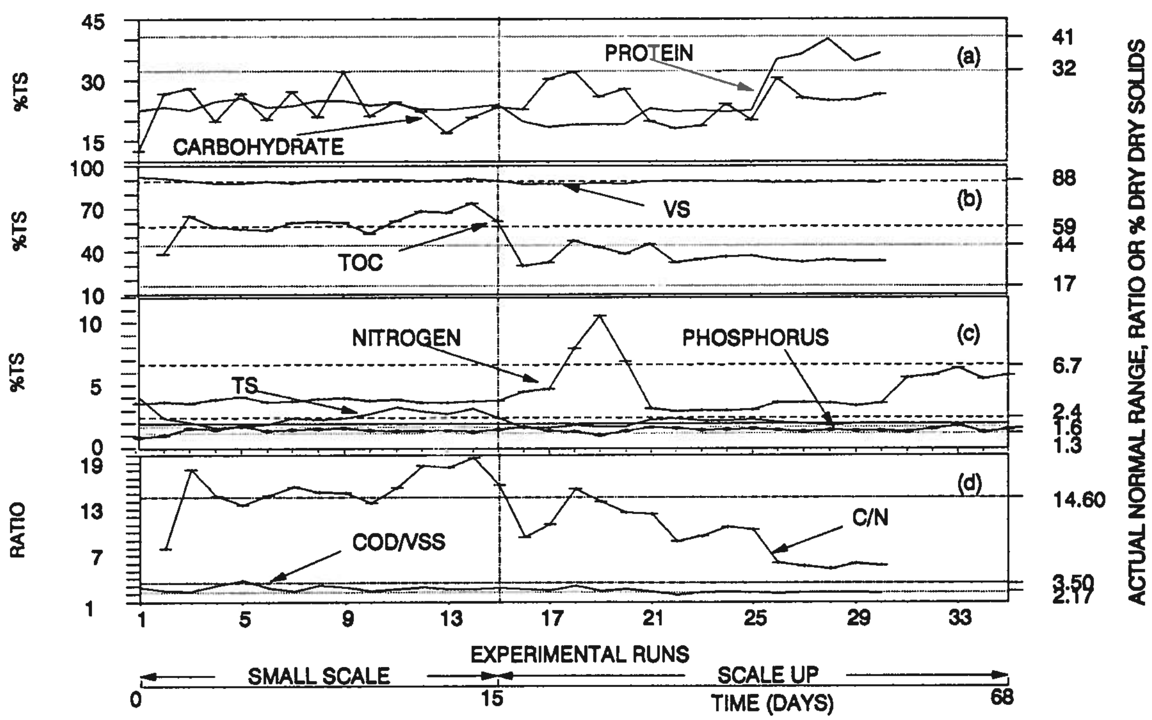


FIGURE 3.5 CHARACTERISTICS OF SECONDARY SYNTHETIC SLUDGE:

(a) PROTEIN,CARBOHYDRATE; (b) TOC,VS; (c) N,P; (d) COD/VSS,C/N

Table 3.1 Comparative Characteristics of Prepared Synthetic Sludge and Actual Primary and Secondary Sludges

Charact.	US.EPA (1979) Typical Range #		Synthetic Sludges			
			Primary		Secondary	
	Primary	Secondary	mg/L	wgt % of TS	mg/L	wgt % of TS
COD			32900		25470	
TS	[3-7]	[1-2]	33370	3.35	19980	1.99
VSS			17300	0.50	11780	0.59
VS	[64-93]	[59-88]	30330	91.00	17600	88.14
COD/VSS	[1.2-1.6]	2.17		1.90		2.16
TKN	[1.5-4.0]	[2.4-6.7]		3.95		5.84
TP	[0.35-1.2]	[1.3-1.6]		1.10		1.52
PROTEIN	[20-30]	[32-41]		25.00		36.55
CARBO.	[17-26]			20.00		26.49
TOC		[17-44]		41.00		33.44

NOTE: # = Selected Parameters, percent by weight of dry solids (%TS)

Throughout the experimental program, monitoring of key parameters of the prepared sludge was undertaken at least once a month; this monitoring showed that the constituents and characteristics of the sludge used in the experiment were maintained within 10-15 % variation. As shown in Figure 3.6 and 3.7, throughout the Sludge monitoring period of 620 days, the characteristics of the prepared sludge were very consistent and fell into the typical range of both actual primary and secondary sludges.

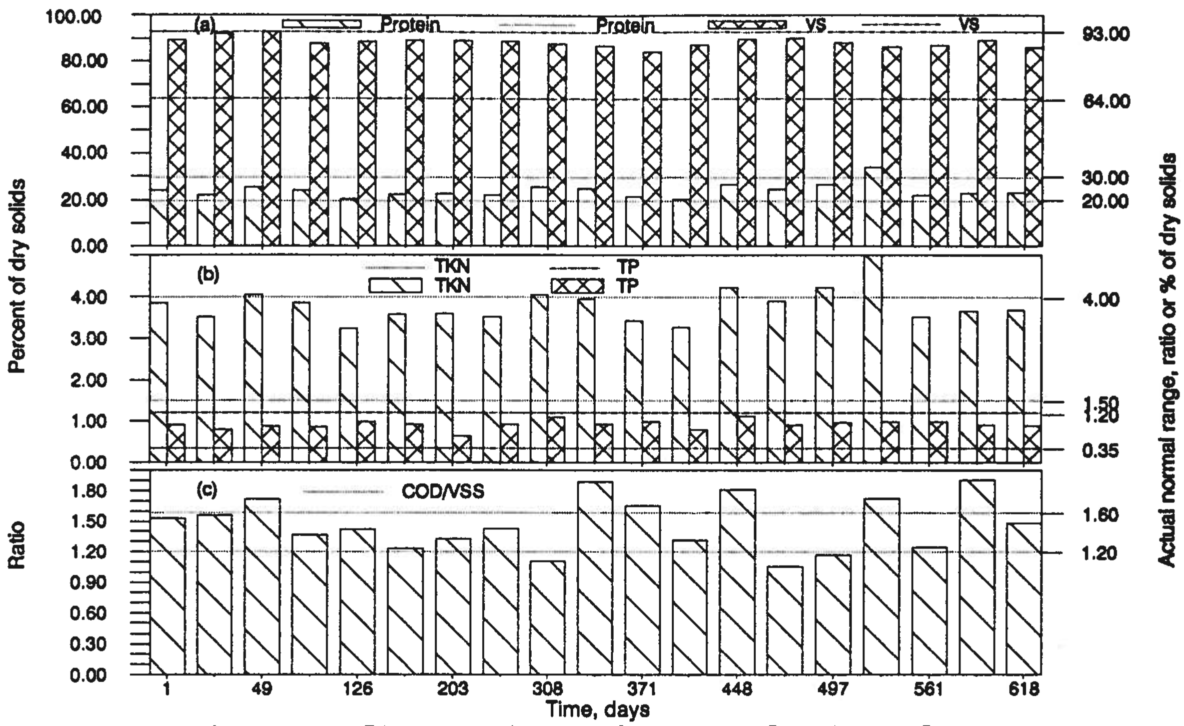


Figure 3.6 Characteristics of Primary Synthetic Sludge
monitored throughout the experimental program:
(a) Protein,VS; (b) TKN,TP; (c) COD/VSS

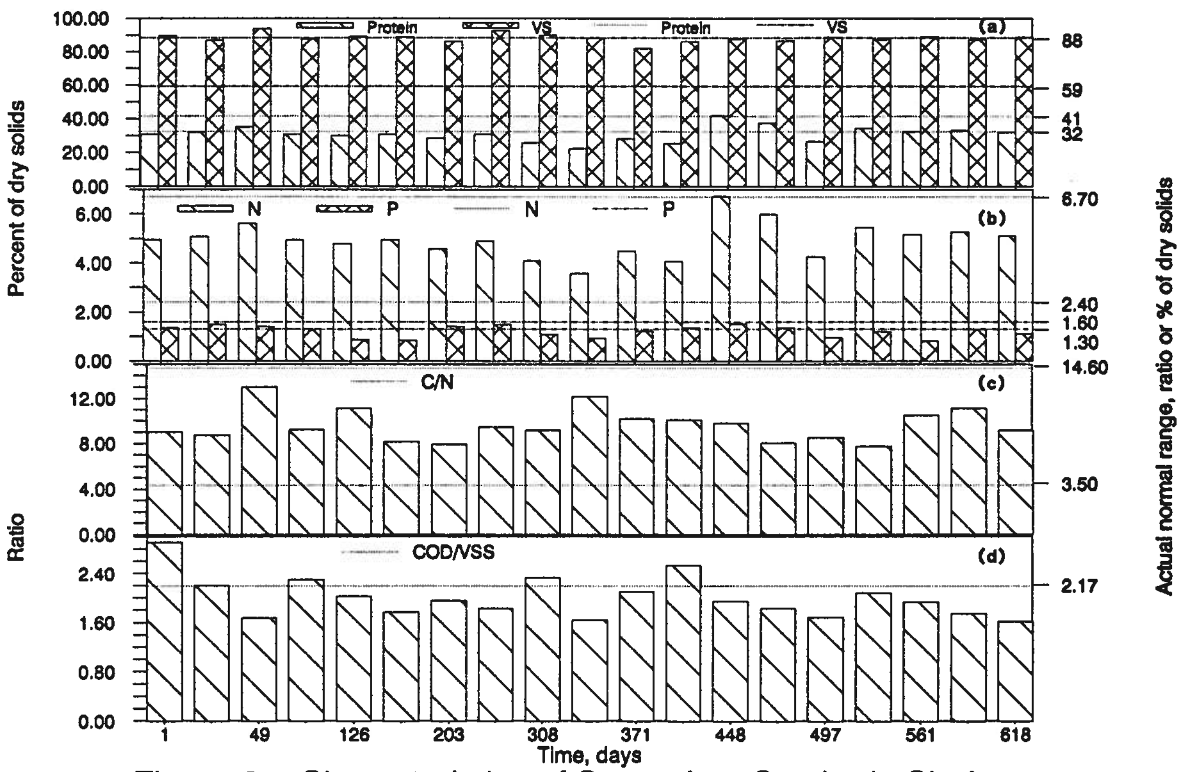


Figure 3.7 Characteristics of Secondary Synthetic Sludge
monitored throughout the experimental program:
(a) Protein,VS;(b) TKN,TP;(c) C/N;(d) COD/VSS

CHAPTER FOUR

EXPERIMENTAL PROGRAMS

This chapter presents details of system seeding and acclimatization, followed by a series of experimental designs emphasizing the effects of influent feed sludge ratio (SR) and recycle ratio (RR) on the process performance. Maximum system loading capacity and the recovery process after a complete failure, are further investigated. An overview of the sampling program, analytical techniques, and data / statistical analysis complete the chapter.

4.1 ACCLIMATIZATION PROCESS

Acclimatization is an important step in determining the success or failure of the process. A careful seeding and start up of the system is required.

4.1.1 System Seeding and Start up Loading

In April 1988, sludge taken from the anaerobic primary sludge digester of the Lion's Gate treatment plant (whose characteristics are shown in Table 4.1) in North Vancouver, B.C., was used to seed both reactors with a ratio of 1:1 for seed sludge and tap water. Following the seeding, the system was fed initially at a flow rate of 2 litres/day, with a ratio of primary and secondary synthetic sludges of about 80:20 (by volume); this was approximately equivalent to a sludge loading rate of 0.1 gCOD/gVSS/d and a

Table 4.1 Characteristics of Anaerobic Sludge used in Seeding the System [Anaerobic sludge digester/Lion's Gate treatment plant]

Characteristics	Concentration		
	mg/L		% Dry solids
pH		7.2	
Total Alkalinity,		2740	
mg/L as $CaCo_3$			
COD			
Total COD	12490		
Soluble COD	3150		
Solids			
TS	9300		
TVS	6900		74
SS	8100		
VSS	6100		75
Nitrogens			
NH_4-N	600		
NOX	0.25		
TKN	800		5
Phosphorus			
PO_4-P	65		
TP	80		2.5
Volatile acids			
HAc	45		

volumetric loading rate of 1.2 gCOD/L/d, as recommended by Zeeuw, (1980). The calculations of seed sludge volume and starting loading rate are shown in Table A2.1 of Appendix A. The loading rate was not increased unless more than 80% of the influent soluble COD was digested. After the system stabilized, the flow rate was increased to 5 L/day and loading optimization was started.

4.1.2 System Operating Conditions

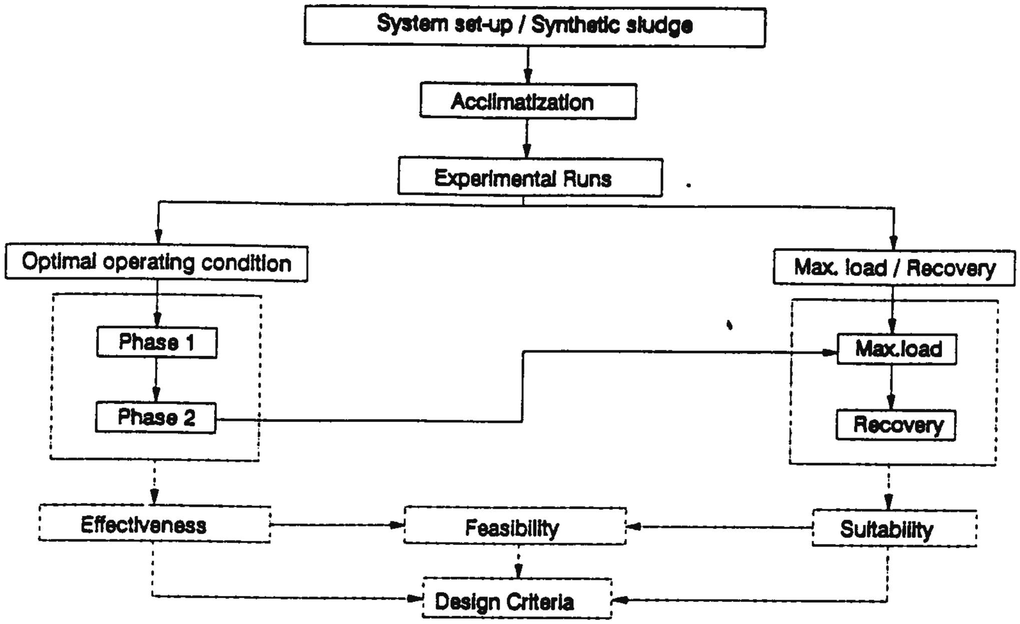
During the acclimatization process, the system was operated at pH values of 5 and 7 for the A-UASB and M-UASB reactors, respectively. The A-UASB reactor was equipped with a mechanical mixer, running for only the first two weeks of acclimatization at the rate of 20 rpm, to ensure sufficient contact between bacteria and incoming feed; the settled sludge of the sludge bed was wasted daily at 5-10% of the influent flow rate, to maintain sufficient active volume in the reactor. However, no sludge wasting was necessary for the M-UASB reactor. Also, the fluidized sludge blanket effluent was recycled continuously back to the sludge bed (RR) at the rate of 4 and 7 times of the influent flow rate for the A-UASB and M-UASB reactors, respectively.

4.2 EXPERIMENTAL DESIGN

The design aimed to accomplish the research objectives as mentioned earlier. The relationships of each component in the experimental design are illustrated in Figure 4.1. The process effectiveness can be evaluated mainly in terms of the process performance, at different 2 by 2 factorial design running conditions (SR and RR) and optimal operating condition; whereas, the process suitability can also be ascertained through the maximum system loading capacity and recovery process after a severe failure. The process feasibility and design criteria are

finally initiated. It was assumed that the system reached a pseudo steady-state condition when the gas production, % CH_4 content, and effluent COD reached appropriately steady values, with less than 10 % variation (about 2-3 system HRT).

Figure 4.1 A Schematic Flow Diagram of Experimental Designs



4.2.1 Optimum "Best known" Operating Conditions

A 2 by 2 factorial design was applied to optimize the feed

SR and RR within the A-UASB and M-UASB reactors. After the acclimatization process appeared to reach a pseudo steady-state at about 40-50 days, a number of different running conditions was commenced (as shown in Table 4.2), to maximize the gas production, % CH_4, and also to achieve a reasonable supernatant quality.

Samples were taken and analyzed twice a week for COD, TKN, TP, TS, TVSS, `TSS, TVSS, NH_4,PO_4, VFA, and % gas components. The influent flow rate and gas production were recorded daily. The actual sampling program and schedules are shown in Figure 4.2. Each running condition was not changed, unless pseudo steady- state, with a minimum 2-3 system HRT and/or more than 80 % soluble COD removal efficiency (10-15 % variation in effluent soluble COD) was achieved.For the first step in loading

Table 4.2 Experimental Running Conditions During the Optimal Operating Condition and Maximum Loading Capacity and Recovery Period

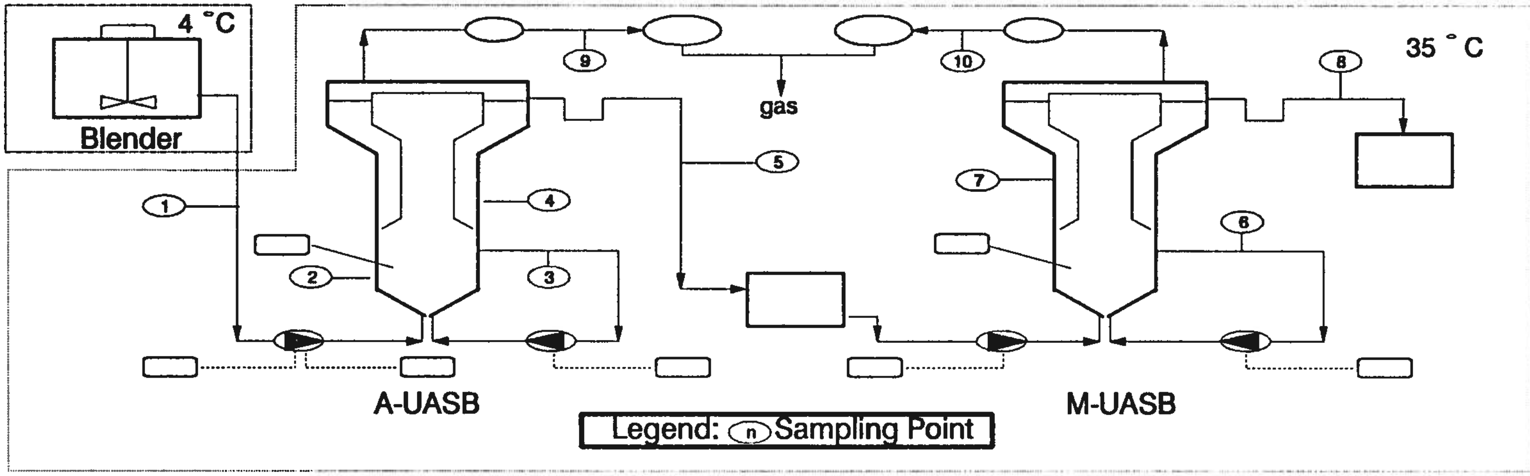
Experimental Runs	Sludge Feed Ratio (SR)	Recycle Ratio (RR)	Flow Rate,L/d (FR)
Phase 1: Reference Condition (Acclimatization)			
0	80/20	4/7	5-6
1	80/20	2/4	5-6
2	80/20	6/10	5-6
3	50/50	6/10	5-6
4	50/50	2/4	5-6
Phase 2: Best known condition			
5	70/30	3/6	5-6
6	70/30	5/8	5-6
7	60/40	5/8	5-6
8	60/40	3/6	5-6
9	80/20	5/8	5-6
Phase 3: Additional Runs			
10	80/20	4/7	5-6
11	90/10	5/8	5-6
12	90/10	3/6	5-6

Maximum Loading capacity:
HRT, days @ 9.0, 4.5, 3.0, 2.25, 1.5
Recovery Periods:
HRT, days @ 1.5, 2.25, 3.0, 4.5, 9.0

SR = Ratio of Primary/Secondary Sludges
RR = Ratio of Qr/Qin
where Qr, Qin = recycle and influent flow rate
ie. 4/7, Qr = 4*Qin in the A-UASB
and Qr = 7*Qin in the M-UASB

optimization, an arbitrary reference running condition (SR80/20 and RR4/7), used in the acclimatization process, was adopted as an initial running condition for the design of the experimental runs. The first four running conditions followed and the response parameters for each one was monitored and analyzed continuously, until a pseudo steady-state was obtained.

Figure 4.2 Sampling Programs:Response Parameters/Sampling Points and Frequency/Preservation and Storage



Response Parameters	Preservation/ Storage	Sampling Points and Frequency											
		01	02	1	2	3	4	5	6	7	8	9	10
1.Solids													
TS	No	*	*	–	–	–	–	–	–	–	–		
VS	No	*	*	–	–	–	–	–	–	–	–		
SS	No	*	*	–	–	–	–	–	–	–	–		
VSS	No	*	*	–	–	–	–	–	–	–	–		
2.Organics													
Total COD	No	*	*	–	–	–	–	–	–	–	–		
Filter COD	No	*	*	–	–	–	–	–	–	–	–		
3.Inorganics													
NH4-N	Yes	*	*	–	–	–	–	–	–	–	–		
PO4-P	Yes	*	*	–	–	–	–	–	–	–	–		
TKN	Yes	*	*	–	–	–	–	–	–	–	–		
TP	Yes	*	*	–	–	–	–	–	–	–	–		
4.Volatile Acids													
HAc	Yes	*	*	–	–	–	–	–	–	–	–		
HPr	Yes	*	*	–	–	–	–	–	–	–	–		
Iso-HBr	Yes	*	*	–	–	–	–	–	–	–	–		
HBr	Yes	*	*	–	–	–	–	–	–	–	–		
A-HVr	Yes	*	*	–	–	–	–	–	–	–	–		
Iso-HVr	Yes	*	*	–	–	–	–	–	–	–	–		
HVr	Yes	*	*	–	–	–	–	–	–	–	–		
HHe	Yes	*	*	–	–	–	–	–	–	–	–		
5.Gas													
Composition	No											–	–
Production	No											–	–
Yields	No											–	–

Legends: * = Once a month for Primary/Secondary Synthetic Sludges (01,02)
– = Twice and/or three times a week

The average response values of each running condition were calculated in terms of main effects and interaction of each parameter, phase mean, reference mean, and change in mean response by an application of Yate's algorithm. With these results, coupled with 2 SE (standard errors) for each individual average and an application of Response Surface Method (RSM), identification of the "**best known**" running condition that generated the maximum methane gas production and good supernatant quality was achieved and the effects of SR and RR were also calculated. This best known condition was then reassigned as an arbitrary reference running condition for thenext four runs.

4.2.2 Maximum Loading Rate and Recovery Periods

The loading rate increased gradually, step-by-step until the system was overloaded, causing VFA's to accumulate within the system. The pH dropped from the desired range, resulting in an imbalance of acid-and methane-forming population; this subsequently led to a system upset. By increasing the loading rate from the optimum conditions obtained from the previous experiment, the maximum loading rate was determined. In addition, the loading rate was designed to increase gradually step-by-step, while the pH controller was off, until the system crashed. Then the loading rate was decreased gradually in order to recover the system as shown in Table 4.2.

4.2.3 Sampling Program and Analytical Techniques

4.2.3.1 Sampling Program

The sampling program, analytical techniques, and data interpretation were carefully designed to ensure reliable and accurate results, for evaluation of the process performance. An extensive sampling program was set up to characterize and monitor the synthetic sludge and system performance, as shown in Figure 4.2. The proposed program was strictly followed during the acclimatization process and the first four running conditions (Sequence 1), however; the sampling program was modified slightly to "suit the facts" obtained during the first four running conditions. The results of the first four runs indicated that the system could reach a pseudo steady-state condition within 2-3 HRT's and that there was very little change in the response parameters during the first few weeks of each running condition. It was then felt justified to reduce the sampling frequency of the next four running conditions, to once a week, for the first few weeks after changing the running condition and twice a week afterward, until the system reached a pseudo steady-state condition (more than 80 % removal efficiency, 2-3 HRTs, and/or 5-10 % variation of the effluent quality). However, monitoring of the gas production, influent flow rate, and gas content were undertaken as scheduled, so that they could be used as indicators to predict the pseudo steady-state condition of each run.

The sampling program functioned in two major parts; that for acclimatization periods, and that for experimental periods. Liquid samples were taken from eight different points along the height of the A-UASB and M-UASB reactors. Two gas sampling rigs were used. In general, a liquid sample of 250 ml was collected, preserved, and analyzed for various response parameters twice a week. In addition, system maintenance, tightening of all clamps and reactor's cover, changing of all tubing lines and pump heads, and checking of the water level and tubing of the gas flow meters, etc., were carried out regularly, to ensure that proper system operation was maintained and to prevent any incidents of leaking and/or spillage which might occur during the experimental runs.

4.2.3.2 Analytical Techniques

Analytical methods for all response parameters were in accordance with Standard Methods (16^{th} edition, 1985), unless specifically described separately. For soluble sample analysis, sample preservation and storage were required prior to any further analysis. A sample of 150 ml collected from each sampling point was centrifuged at 2,500 rpm. for about 15 minutes, in an International Equipment Company Mode CS Centrifuge and the supernatant was then filtered through a no.4 Whatman filter. A filtrate aliquot was analyzed for soluble COD and the remainder was preserved and stored, as shown in Figure 4.2, for further analysis. Analytical methods for each response parameter can be summarized as follows:

Chemical Oxygen Demand (COD)

Sample sizes of 0.1-0.5 and 1.0-2.0 ml were used to analyze for total and soluble COD using the dichromate oxidation reflux method as outlined in the Standard Methods.

Solids

A sample of 30-60 ml of each sampling point was used for the analysis of solids content as follows:

TS/TVS - A sample of 10-30 ml collected from the sampling point number 1,2,3,and 6 was poured separately into the known weight of evaporating dish, which was heated for 2 hours at 550 °C inside the muffle furnace and then weighed after cooling. Samples were then dried overnight in a Fisher isotemp oven (Model 350) at 104 °C. After cooling the samples inside a vacuum desiccator, the samples were then weighed and burnt for about 2 hours, for volatile solids, in a Linberg muffle oven at 550 °C. The samples were finally cooled inside a vacuum desiccator and weighed again.

TSS/TVSS - A sample of 10-20 ml collected from the sampling points numbered 1-8, was treated similarly to that of TS/TVS, except that a 934-AH Whatman glass microfiber was used to filter the sample instead of using the evaporating dish. Calculation of the weight and concentration of solids was made according to Standard Methods.

Total Organic Carbon (TOC)

The filtered samples were preserved as described in the COD section, and analyzed in an automatic Shimadzu Total Organic Carbon Analyzer, TOC-500, using the combustion-infrared method (TOC-500 Instruction Manual, Shimadzu Scientific Instruments, Inc.).

Proteins

The crude protein content of the samples can be determined from the TKN value by multiplying it with a factor of 6.25. This is based on the assumptions that all the nitrogen of the organic matter is due to protein, and that protein contains 16 percent nitrogen on average (100/16 = 6.25).

Carbohydrates

The total soluble carbohydrates were determined by the ferricyanide method as outlined in the Handbook of Micromethods for the Biological Science (1974).

Inorganic/Acids

A soluble sample, after being preserved and stored for up to a week, was analyzed for NH_4-N, PO_4-P, TKN/TP, and VFAs as follows:

NH_4-N - Aliquots of soluble samples collected from the sampling points numbered 1-8 were analyzed for NH_4-N, using the Automated Phenate Method (A.P.H.A., 1980). Appropriate dilutions ranging from 1/50 - 1/100 were made prior to determining the intensity of the sample colours using a Technicon Auto Analyzer II and then compared with those of prepared NH_4-N standards, ranging from 1.0-3.0 mg/L in order to estimate the concentration of NH_4-N in the sample.

PO_4-P - The automated ascorbic acid reduction method (Technicon Industrial System, 1973) was used to analyze PO_4-P. In an acid medium, ammonium molybdate and potassium antimonyl tartrate react with PO_4-P to form an antimonyphosphomolybdate complex; this is further reduced with ascorbic acid, yielding an intense blue colour. The intensity of the sample colour was determined by a Technicon Auto Analyzer II. Calculation of PO_4-P concentration was made by comparing the sample responses with those of prepared standards of PO_4-P.

TKN/TP - A series of known TKN/TP standards, soluble samples, and dried solids samples (after being dried at 104 ° C) were digested in the Technicon Block Digester 40 with concentrated H_2SO_4 and K_2SO_4.This procedure liberated all bound organic nitrogen and particulate TP to NH_4-N and PO_4-P, respectively. The TKN/TP concentrations of the samples and standards were measured colorimetrically, using the Technicon Auto Analyzer II and calculated by comparing the responses of both samples and standards.

Volatile fatty acids (VFA)

Samples taken from sampling points numbered 1-8 were filtered using no.4 Whatman filters and frozen in sealed plastic pipets. After the time of analysis, the samples were thawed at room temperature and diluted 1:10 with distilled water. A 1.0 μl sample, after being acidified by a drop of 1 % solution of phosphoric acid to bring the pH below 3.0, was injected into a computer-controlled Hewlett Packard 5880A gas chromatograph equipped with a flame ionization detector (FID), using helium as the carrier gas. To achieve accurate and reliable results, microsyringes (Hamilton Model 701N, 10 μl) and a Hewlett Packard auto-sampler (Model 7672A) were used. The glass column (0.91 m long with a 6.0 mm (OD) and 2.0 mm (ID)) packed with 0.3 % Carbowax/0.1 % H_3PO_4 on Supelco Carbopak C (supplied by Supelco Inc.), was conditioned according to the procedure outlined in the Supelco Bulletin 751E (1981).

The operating conditions for the chromatograph were maintained as follows:

Injection port temperature	=	150 °C
Detection port temperature	=	200 °C
Isothermal oven temperature	=	120 °C
Flow rate of carrier gas (helium)	=	20 ml/min

The response peaks of each sample were quantified by comparing with external standard methods, using reagent grade standards.

Gas content

Gas samples were extracted from sampling points 9 and 10 (See Figure 4.2) using a 1-ml Hamilton Syringe. The injection syringe was flushed twice, before the injection sample was taken. The plunger was depressed to expel the excess gas prior to inserting the syringe needle through the diaphragm of the sample injection port of the Fisher Model 29 Gas Partitioner. The sample was then rapidly injected and a mixture of gas was swept through two chromatographic columns, packed with a liquid phase is on a solid support known as DEHS and 42-60 mesh Molecular Sieve for column 1 and 2 respectively, by a continuous flow of the helium carrier gas. The gas components were separated and eluted from the system at different retention times. A thermal conductivity detector then sensed the differences in conductivity of the separated components, which was amplified and integrated for quantification.

The retention time elapsed from the point of injection to the emergence of a peak is characteristic of a particular gas. The area of a peak is also proportional to the concentration of the gas. Calculation of the gas concentration was made by comparing the peak areas of measurable samples and the standard.

4.2.4 Data and Statistical Analysis

All data in this research were analyzed and plotted by using an integrated software program, Symphony version 1.2 and Lotus version 2.2 with an add-in program (Allways). Some of the graphics were imported into the Freelance software program, version 3.0, for further modifications. For the report preparation and statistical analysis, a Word Perfect 5.1 program and Systat/Sygraph programs were used.

CHAPTER FIVE

RESULTS AND DISCUSSION

This chapter deals with two main sections :(i) the acclimatization mode; and (ii) the experimental mode. The development of the acclimatization process and a comparison of different acclimatization alternatives is followed by the effects and interaction of Sludge Ratio (SR) and Recycle Ratio (RR) on the responses and process performance, maximum loading capacity, and system recovery process. System feasibility, design criteria, and effective and reliable system indicators are also discussed.

5.1 ACCLIMATIZATION PROCESS

It has long been recognized that the acclimatization process has a great impact on the success or failure of system operation. Understanding the conceptual development of the process and acclimatizing the system properly are extremely important, in order to achieve the desired level of the system performance.

5.1.1 Development of the Acclimatization Process

One of the main difficulties in the treatment of sewage sludge appears to be in the development of suitable and efficient mixtures of microbial cultures to treat this particular type of waste in this typical reactor. To alleviate this problem, it is necessary to understand the principle/behaviour/response of the UASB process under different operating conditions.

5.1.1.1 Behaviour and Response

The UASB is a suspended-growth biomass system composed of three main portions: (i) sludge bed; (ii) sludge blanket; and (iii) settler. Most of the reactions occur in the lower part of the system (sludge bed and blanket). In the two-phase UASB-UASB process, complex influent substrates such as carbohydrates, proteins, and lipids are first hydrolysed and acidified inside the A-UASB reactor by a predominantly acidogenic bacteria population; this produces simple compounds such as volatile fatty acids (VFAs). These VFAs then pass through the M-UASB reactor, where they are subsequently converted to CH_4 and CO_2 gases by predominantly methanogenic bacteria. Small amounts of N_2 gas and other by-products are also produced.

Using a step-loading approach rather than continuous (constant) loading for system start-up, the system was carefully acclimatized with an increase in influent loading to keep pace, as close as possible, with an increase in system biomass (Bull et al., 1983). The influent substrate was, therefore, started and maintained initially at a low loading rate (sub-crucial level) to ensure greater conversion and biomass growth rates than washout one. The system loading rate was not increased until more than 80 % removal efficiency of the system influent COD had been achieved. Over-or-under hydraulic and/or organic loading a UASB can adversely affect the start up process. Over-loading tends to produce excessive gas, causing a gas-lift in the reactor, floatation of the sludge solids, and finally, a system washout process. Under-loading results in the formation of a massive compacted sludge, thus reducing the efficiency of the system significantly (Hulsoff-Pol et al., 1983).

Initially, the start up of non-attached biomass processes, like UASB, relying heavily on suspended biomass and attached microflora, appears to induce a " washout " phenomenon. Large quantities of the UASB biomass were washed out of the system during the first couple of weeks of this research, followed by development of small granules or pellets. Then, the remaining biomass showed better settleability and served as a surface medium for active microbial mass growth. Minimization of biomass washout is, therefore, crucial to reactor activity during the start up process. A suitable type of seed sludge, seeding ratio and acclimatization, seem to be effective in compensating for the solids washout phenomena. Precipitation of salts of $CaCO_3$ and PO_4^{-3} inside the reactor is also credited for an increase in sludge settleability, as these salts weigh down the pellets, and increase the settling capacity (Klapwijk et al., 1981). Considering all these points and behaviours, a careful system seeding and start up of the UASB-UASB process was selected as outlined in Chapter 3.

5.1.1.2 Acclimatization Alternatives

To develop an effective start up and acclimatization process, the system was seeded with a high ratio of seed sludge to tap water (1:1 by volume), to compensate for the solids washout problem. In addition, three acclimatization alternatives were investigated in detail; samples were taken regularly and analyzed for several parameters, as shown in Figure 4.2. These alternatives were: (A) Seeding both A-and M-UASBs with sludge from the Lion's Gate treatment plant anaerobic sludge digester and using a step-loading approach; (B) Seeding both reactors with acclimatized synthetic seed sludge and using a constant-loading approach; (C) Seeding the A-UASB with acclimatized synthetic seed sludge, but the M-UASB with sludge from the Lion 's Gate anaerobic sludge digester, using a step-loading approach. The results of this investigation are summarized as follows:

(a) Washout Phenomenon

In suspended-growth biomass systems like UASB, where the treatment potential is dictated by the dual parameters of the biomass quality retainable in the system and the specific activity of biomass (such as methane production and settleability), an inoculation of about 30-50 % reactor volume of active sludge is required. Start-up and acclimatization of UASB reactors requires about 4-8 weeks to develop an active microbial mass sludge (Lettinga, 1979; Zeeuw, 1980). Start-up, therefore, is dependent upon an equilibrium between loading and washout as well as the selection of a suitable seed sludge, wastewater characteristics, and careful management. Initially, large portions of biomass are washed out of the system; later, the microstructural granules or pallets are developed with the help of precipitated salts of carbonate and phosphate. These weigh down the pellets, increasing the sedimentation capacity. As shown in Figure 5.1, the system with the step loading rate of 0.10-0.21 m^3/m^3-d, demonstrates the washout phenomenon of the MLVSS (points 1,2, and 3) at day 23-45, 1-15 and 1-7 for alternatives A, B, and C, respectively. Active biomass settles at the sludge blanket (sampling point no. 6, 50 cms from the bottom) of the M-UASB, then starts to build up to a concentration of 5750, 1265, and 2580 mg/L of MLVSS for alternatives A, B, C, respectively. It is believed that development of granule sludge and pelletization do occur at the sludge bed. Accidentally, there was a case of sludge spillage due to clogging inside the recycle line during the experimental program. Fortunately, there was still sufficient biomass remaining at the bottom of the reactor; this was characterized by very hard and dense pellets. Also, Jing-Qing Yan (1991) studied a sludge concentration profile along the height of UASB and indicated that there were 2 distinct layers of sludge concentration profiles. These included a dense sludge bed (from 0-30 cms.) with 18-58 g/L VSS and a sludge blanket (above 37 cms.) with 2-10 g/L VSS. The author also mentioned that system start-up process with a sludge loading rate of less than 0.2 kg COD/kg VSS-d was crucial for a successful development of pelletization. As mentioned earlier, the start-up sludge loading rate in the present case (UASB-UASB) was about 0.1 kg COD/kg VSS-d and the concentration of MLVSS at sludge blanket level (50 cms. height) was in the range of 1300-5800 mg/L. Since similar patterns of start-up process and MLVSS concentration range were observed in the present study, it is believed that development of sludge concentration profile (pelletizatioon) did occur in the system.

It is quite clear that acidogenic and methanogenic bacteria play an important role

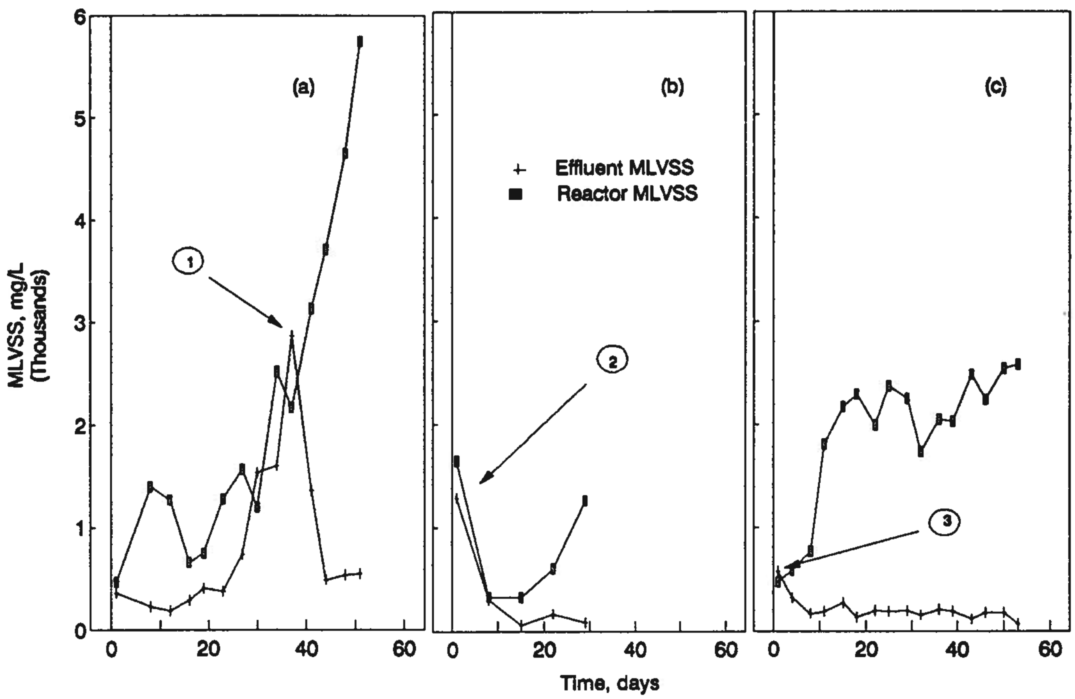


Figure 5.1 An Acclimatization Washout Phenomenon
Under different running conditions (a,b,and c),
Mentioned in section 5.1.1.2 Acclimatization Alternatives

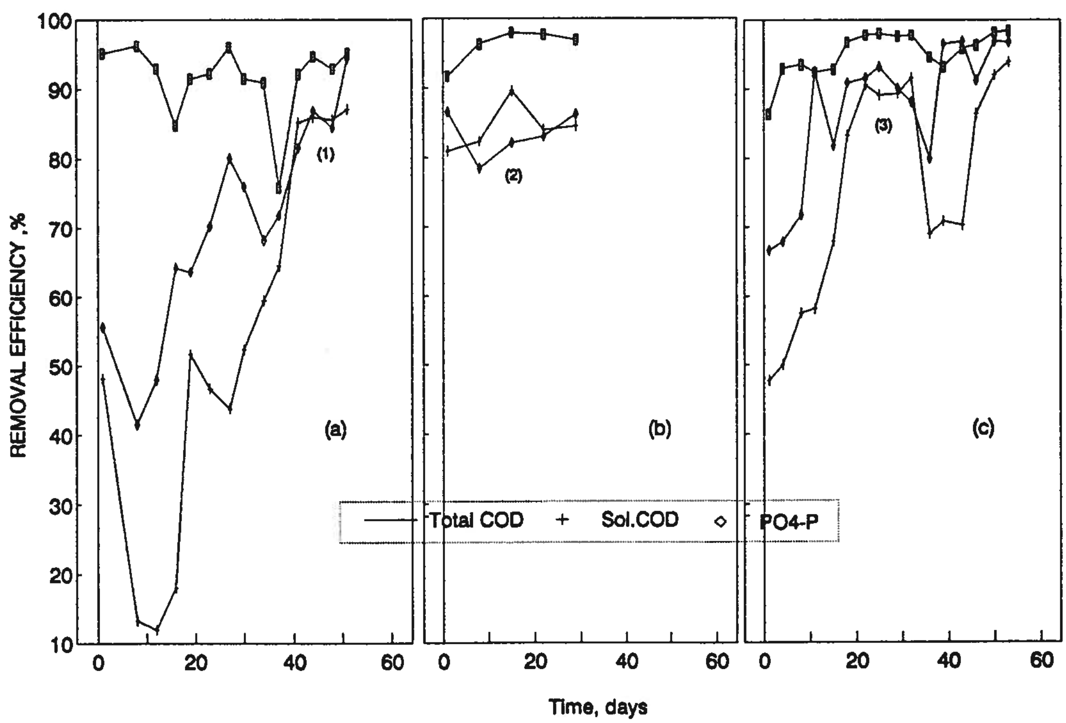


Figure 5.2 System Removal Efficiency During Acclimatization:
Under different running conditions (a,b,and c),
Mentioned in section 5.1.1.2 Acclimatization Alternatives

in the initial wash out phenomenon. As shown in alternative A, Figures 5.1, it took approximately 23 days to develop active and sufficient amounts of acidogenic and methanogenic bacteria to dominate within A- and M-UASB reactors, respectively. As a result, influent substrate is hydrolysed and acidified in the

A-UASB, producing low to medium molecular weight VFA's such as HVr, HBu, HPr, HAc etc.; these are further broken down to CH_4, CO_2, and H_2 by methanogenic bacteria in the M-UASB. Figures 5.3-5.4 showed a decrease of influent total VFA from 4,070 to 1,120 mg/L with an HAc/HPr concentration ratio of 1:40, corresponding to an increase of VFA removal efficiency of the M-UASB up to 71 %. The produced gas (CH_4, CO_2, H_2, and etc.) then caused a gas-lift, solids sludge floatation, and finally, a system washout phenomenon in the M-UASB reactor at point (1) of the Figure 5.1. Conversely, alternatives B and C demonstrated the washout phenomenon immediately after day 1 (points 2 and 3, respectively), and it took only a week for alternative C to start up, compared to two weeks for alternative B; however, the acclimatization process was completed within 4 weeks for both alternatives. Lettinga (1978) found a similar result whereby, when he acclimatized a UASB at 30 °C with 1250 mg/L HAc and 1000 mg/L HBu, a distinct granulation appeared 5 weeks after the start-up of the process.

The time reduction, compared with alternative A, may result from the effectiveness of well acclimatized synthetic sludge seeded in A-UASBs, generating sufficient volume of VFAs ready for methanogenesis to proceed further in the M-UASB. Comparing alternatives B and C at day 20-30 (same range of loading rate in both alternatives as shown in Figure B2.1 of Appendix B), it is interesting to point out that

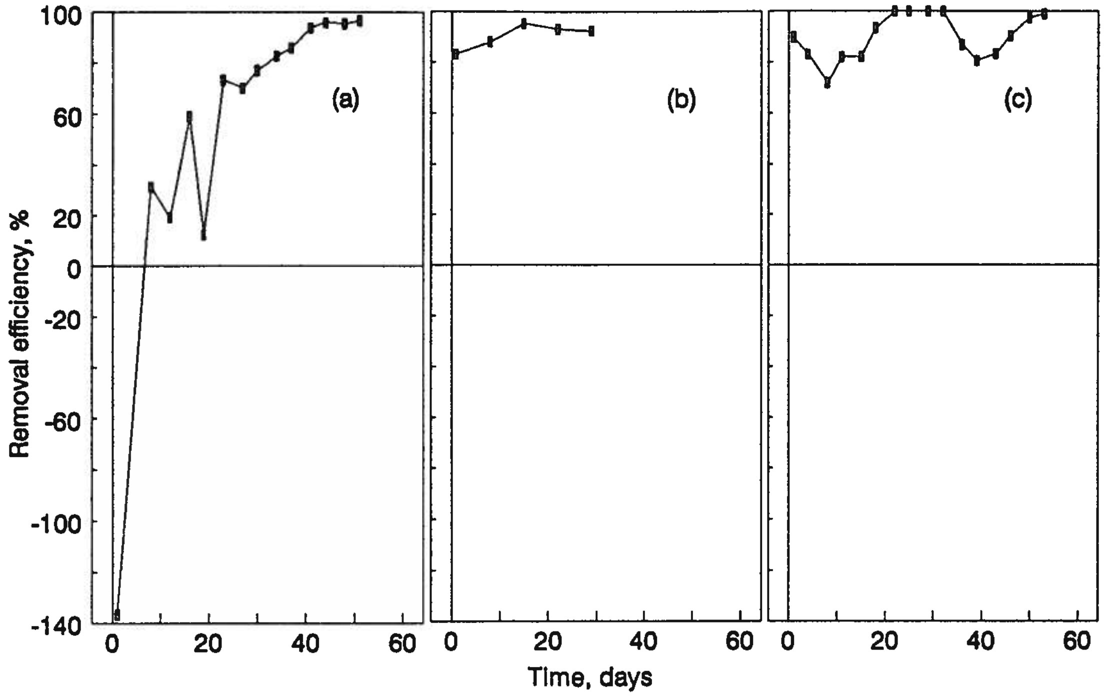


Figure 5.3 VFA Removal Efficiency of the M-UASB:
During the acclimatization under different running conditions (a,b, and c), Mentioned in section 5.1.1.2 Acclimatization Alternatives

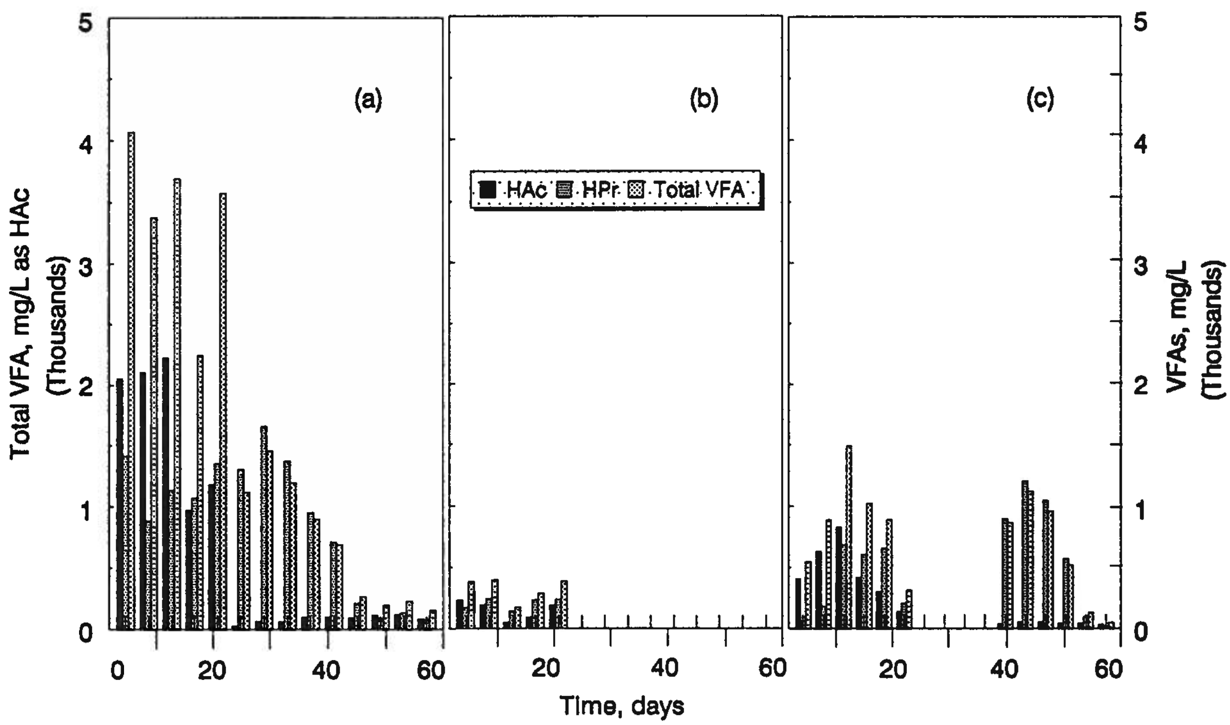


Figure 5.4 Efluent VFAs of the M-UASB:
During the acclimatization under different running conditions (a,b, and c), Mentioned in section 5.1.1.2 Acclimatization Alternatives

alternative C had better performances than those of alternative B in terms of system and VFA removal efficiencies and effluent VFA as shown in Figures 5.2-5.4. This may be caused by a more diversified structure of bacterial community due to the step-loading approach (starting from low loading rate with seed sludge from Lion's Gate anaerobic digester used in alternative C, compared with a constant loading scheme (high loading rate) and acclimatized seed sludge in alternative B. Pavoni (1972) and Encina (1987) indicated during the start-up process that a low F/M ratio of the influent helped promote floc formation and also induce the greatest washout rate in a typical UASB. The reason is that floc and granules can be formed effectively if substrate feed rates are kept as close as possible to that of bacterial growth rates. However, there appeared to be a sudden increase in total effluent VFA of A-UASB (sampling point no.5) beyond day 30, ranging from 4,950-5,150 to 5,200-6,200 mg/L as HAc as shown in Table B2.5 of Appendix B. This sudden increase as a shock load to the M-UASB resulted in a decrease in system performances as illustrated in Figures 5.1-5.4. Combination of a difficulty in controlling the system loading rate beyond day 30 and an attempt to maintain the pH of M-UASB which destroyed the sludge bed and blanket, was responsible for this particular situation. This washout phenomenon during the start-up process was also mentioned by several other researchers. Zeeuw (1980) concluded that the acclimation process of an UASB reactor included roughly 3 stages of adaptation : (a) adaptation of sludge to the substrate composition - an initial loading rate should be kept close to the maximum potential of seed sludge (0.04 kg COD/kg VSS/day) in order to prevent an inhibition of the break down of HPr; (b) increasing of the specific activity of the sludge as a result of bacterial growth, retention time and washout process which occurred in the first week of operation; (c) sludge pelletization - appeared approximately 6-7 weeks after the start-up and the sludge bed concentration increased from 7 to 18 kg VSS/m^3.

(b) System Performance

In accordance with the start-up of different acclimatization procedures, as shown in Figures 5.1-5.4, the results indicated that a well-adapted sludge could form within a period of 4-5 weeks. The organic loading up to 1.0-3.4 and 0.56-1.8 kg $COD.m^{-3}/d$, equivalent to a hydraulic loading up to 0.10-0.24 and 0.06-0.13 m^3/m^3-d or an organic loading of 0.36-0.60 and 0.20-0.33 kg COD/kg VSS-d for the M-UASB and the entire system respectively, could be successfully accommodated at 35 °C. This results have agreed with the studies carried out by Hulsoff-Pol et.al (1983) on the effect of sludge loading rate on granulation in the UASB system. He found that pellets formed only at loading rates in excess of 0.6 kg COD/kg VSS-d, while at 0.3 kg COD/kg VSS-d, bulking and washout occurred.

During acclimatization, it was interesting to note that there was a lag period of about 2 weeks for alternative A, before the system started to break down the substrate, whereas no lag period appeared in either alternative B or C (as shown in Figure 5.2-5.4). The reasons explaining this lag period have already been noted earlier. The system appeared to take about 52, 35, and 30-52 days for alternative A, B, and C to reach pseudo steady-state, at a removal efficiency of 86-91 % soluble COD and 94-100 % VFA (as shown in Figure 5.2 and 5.3), respectively.

The acclimatization period for alternative C took almost two months (approximately 30-52 days), longer than expected. The possible major causes of this particular situation are a sudden increase in system loading and/or a disturbance of sludge bed and blanket as mentioned earlier. A rapid increase in the HPr/HAc ratio, as shown in Figure 5.4, indicated that the system was interrupted and/or under stress, causing the accumulation of HPr (because H_2-utilizing bacteria, to form CH_4, are inhibited). As such, the excess of reduction equivalents is diverted into less favourable biochemical routes (using organic acids as an electron sink) resulting in the accumulation of HPr (Zoetemeijer, 1982). However, it took only a couple of weeks for the system to recover by itself, naturally.

Despite this problem, alternative C (between days 20-30) seems to be slightly better than alternatives A and B, in terms of average system removal efficiency and effluent quality as shown in Table B1.1 of Appendix B. A possible explanation is that the A-UASB of the alternative C was properly acclimatized and loaded step-wise, with well adapted seed sludge. This helped to generate sufficient volume of readily biodegradable VFA's for methanogenesis in the M-UASB; which was seeded with sludge from the anaerobic digester of Lion's Gate treatment plant. With greater varieties of acetogens and methanogens in this type of digester sludge, coupled with a proper start-up of the A-UASB, alternative C appears to acclimatize the system more effectively and efficiently than either alternative A or B. In terms of nutrient requirements, it appears that effluent levels and removal efficiency of PO_4-P tend to follow the patterns of both COD and

VFA effluent levels and removal efficiency; however, TKN seemed to have no relationship at all with the system removal efficiency, as shown in Figure B1.1 of Appendix B. The summary of average system performance during the acclimatization process, under different running conditions was illustrated in Table B1.1 of Appendix B.

5.1.2 Conclusions

System acclimatization is one of the most crucial steps to secure a reliable system performance. Careful and proper system start-up and acclimatization results in the production of an active and effective granular biomass sludge (pellets), which subsequently creates an effective system removal efficiency and generates significant amounts of CH_4 gas. According to the results obtained during the acclimatization process, the following conclusions can be made:

(1) A step-loading scheme, starting at a sludge loading rate of 1.2 gCOD/L-d with a seed sludge ratio of 1:1 (by volume), appears to be an effective measure to acclimatize the system. Salts of Ca^{+2} and PO_4^{-3} seem to play a major part in the increase of the sludge settleability.

(2) The "washout phenomenon" occurs within 2 weeks of the process acclimatization, at a sludge loading of less than 1.2 gCOD/L-d or 0.36 kg COD/kg VSS-d.

(3) Acclimatization alternative C, seeding the A-UASB with acclimatized synthetic seed sludge and the M-UASB with sludge from the Lion's Gate anaerobic sludge digester, is the most effective and practical method to accelerate the acclimatization

process, since anaerobic digester seed sludge is already available at sufficient volumes for a typical full scale UASB process. The system starts to wash out the MLVSS immediately after acclimatization and completes the process within 4-5 weeks, with 86-91 % COD (sol.) and 94-100 % total VFA removal efficiencies.

5.2 EXPERIMENTAL DESIGN

This section describes with a search for an optimum "best known" operating condition by determining the effects and interaction of SR and RR on the responses and process performance under different running conditions. The results are then used to locate the "best known" running condition, which provides superior supernatant quality and reasonable methane gas production, by an application of Yate's algorithm and Response Surface Method (RSM) (Box, 1969). These application techniques of experimental designs are initially used as major tools to help direct the next appropriate and effective moves of the experimental design toward the optimal "best known" operating condition. The effectiveness of a two-phase anaerobic digestion (UASB-UASB) system to stabilize the particulate substrate under different running conditions is then evaluated. Step-loading rate experiments are further undertaken to locate the optimum and maximum system hydraulic and/or organic loading capacities. Furthermore, the experiments should provide information on the required recovery period, after a serious washout of the active biomass has occurred. Evaluation of basic kinetics is also made. The feasibility of this two-phase (UASB-UASB) process can then be evaluated in terms of system effectiveness (acclimatization and performance) and system suitability (maximum and optimum hydraulic and/or organic loading capacity and system recovery). Modifications to design criteria and operation procedures are proposed at the end of this section.

5.2.1 Optimum "best known" Operating Condition

The term "best known" in this particular situation, is defined as a running condition that provides the maximum system COD removal efficiency and CH_4 gas production under a certain regime of pH, temperature, and influent flow rate. To locate the optimum "best known" operating condition, regarding SR and RR, a previously successful running condition, during the acclimatization process, was used as a starting condition; also, another set of running conditions, as shown in Table 4.2 of Section 4.2.1, was also implemented. The responses and efficiency of each running condition were used to evaluate the effects of SR/RR on system performance, the effectiveness of the two-phase (UASB-UASB) concept, and the location of the "best known" running condition.

5.2.1.1 Effects and Interaction of Sludge Ratio (SR) and Recycle Ratio (RR)

Too high an RR can destroy the sludge bed and wash out the active biomass from the system, but too low an RR can also reduce the system removal efficiency by reducing the chances of better contact between microorganisms and substrates and decreasing the system buffering capacity. Equally important, too-high and -low an SR can significantly affect the system performance, since the primary and secondary sludges are composed of extremely different nutrient concentrations, thus affecting organic loading capacity. The effects and interaction of both RR and SR, as well as the initial optimum range of these two influential control parameters, must be analyzed and identified prior to proceeding any further toward optimum and maximum loading capacity of the UASB-

UASB system.

In this particular situation that only the acclimatization running condition is known, an "Evolutionary Operation Process (EOP)" using Yate's algorithms with 2 standard errors (S.E.) is an effective technique to lead the experimental design toward the optimal "best known" running condition providing superior supernatant quality and reasonable system removal efficiency. At each step of EOP, a reference running (best known) condition with another four appropriate running conditions is designed and implemented. Calculations of effect, interaction, phase mean, and change in mean of these data are made and analyzed with an application of Steepest Ascent technique. If necessary, another set of experimental design (best known running condition of the previous set plus another four designed running conditions) has to be set up if magnitudes of effect and change in mean are significant, compared with 2 S.E.. On the other hand, if these magnitudes are not significant compared with 2 S.E., it means the reference best known condition is closed to the vicinity of the optimal system operating condition.

By applying a Yate's algorithm with two standard errors (Box, 1969) on the selected parameters of Sequence 1 and 2 experiments, the effect, interaction, phase mean, and change in mean were calculated and summarized in Table 5.1. A detailed calculation of the above statistical parameters, based on the replicated values at pseudo steady-state condition of each running condition in Sequence 1 and 2 experiments, is demonstrated in Table C2.1 of Appendix C. From Table 5.1, it is apparent, apart from the effect of 2 standard errors, that SR and RR have a significant effect on the effluent

Table 5.1 Summary of effects (SR and RR) /interaction (SR*RR)/ change in mean during the sequence 1 and 2 experiments

Response parameters	Effects		Interaction	Phase	Change in	2 S.E.
	RR	SR	RR*SR	mean	mean	1*/2#
Sequence 1						
Effluent, mg/L or mg/L as HAc						
COD(sol.)	1454	-3460	486	3207	2357	186/167
VFA(tot.)	1262	-1196	-802	1965	1734	1441/1288
PO4-P	85	-213	-8	142	122	72.33/64.64
System Rem., %						
COD(sol.)	-24.46	59.75	-1.4	52.93	-30.56	6.42/5.75
PO4-P	-51.52	81.28	16.99	24.28	-60.31	21.76/19.44
CH4 gas						
%CH4	-7.49	5.31	-5.31	67.9	16.3	2.79/2.5
Yields	0.77	-0.61	0.04	1.77	0.06	1.05/.95
Sequence 2						
Effluent, mg/L or mg/L as HAc						
COD(sol.)	-36	-15	-84	430	-146	173/155
VFA(tot.)	-13.5	63.5	-13.5	83	-205	197/176
PO4-P	-43.5	-78.5	40.5	39	33	38.49/34.4
System Rem., %						
COD(sol.)	1.01	-0.83	1.15	93.81	2.46	2.07/1.85
PO4-P	10.31	29.21	-8.54	83.83	-10.2	11.27/10.07
CH4 gas						
%CH4	-3.09	-0.38	-1.81	72.62	0	0.98/0.88
Yields	0.27	-0.34	-0.53	1.94	0.1	0.29/0.27

Note: 1* = 2 standard errors of effect, interaction, phase mean
2# = 2 standard errors of change in mean
Negative (–ve) response magnitude, if significant, compared with 2 S.E., mean better performance can be achieved by decreasing SR, RR, and/or a combination of both.
Detailed calculation was illustrated in Table C2.1 of Appendix C.

and removal efficiency of COD(sol.) and PO_4-P in the Sequence 1 experiment. However, the effect of SR appears to be of a greater magnitude than that of RR and only the interaction (SR*RR) of effluent COD is significant. This may suggest that the system COD removal efficiency is probably governed by the anaerobic stabilization processes and depends largely on the SR and RR factors to increase the contact between microorganisms and substrates, bufferring capacity, and nutrient requirements; whereas, the removal of PO_4-P, without any interaction, is mostly a chemical reaction, affected strongly by the influent TP in the feed SR, thus resulting in the precipitation of Ca^{+2} and PO_4^{-3} salts inside the reactor.

The large relative magnitudes of the main effect, interaction, and change in means on most of the responses in the effluent and removal efficiency, compared with 2 SE. in the Sequence 1 experiment, indicated that the optimum "best known" running condition was still not reached. An additional sequence of running conditions was needed to move toward the optimum condition. Under these circumstances, a "steep ascent" method is the most effective preliminary procedure to direct the next appropriate move of the experimental operation and thus approaches the optimum running condition. Once the linear effect becomes small, further application of the method is unprofitable (Box et al, 1969).

A graphical contour plot, using data from each pseudo steady-state of the Sequence 1 experiment, was made, as shown in Figure 5.5. The sequence 2 experimental operation was then made by assigning the "best known" condition in sequence 1 experiment as a reference running condition, plus another 4 different running conditions

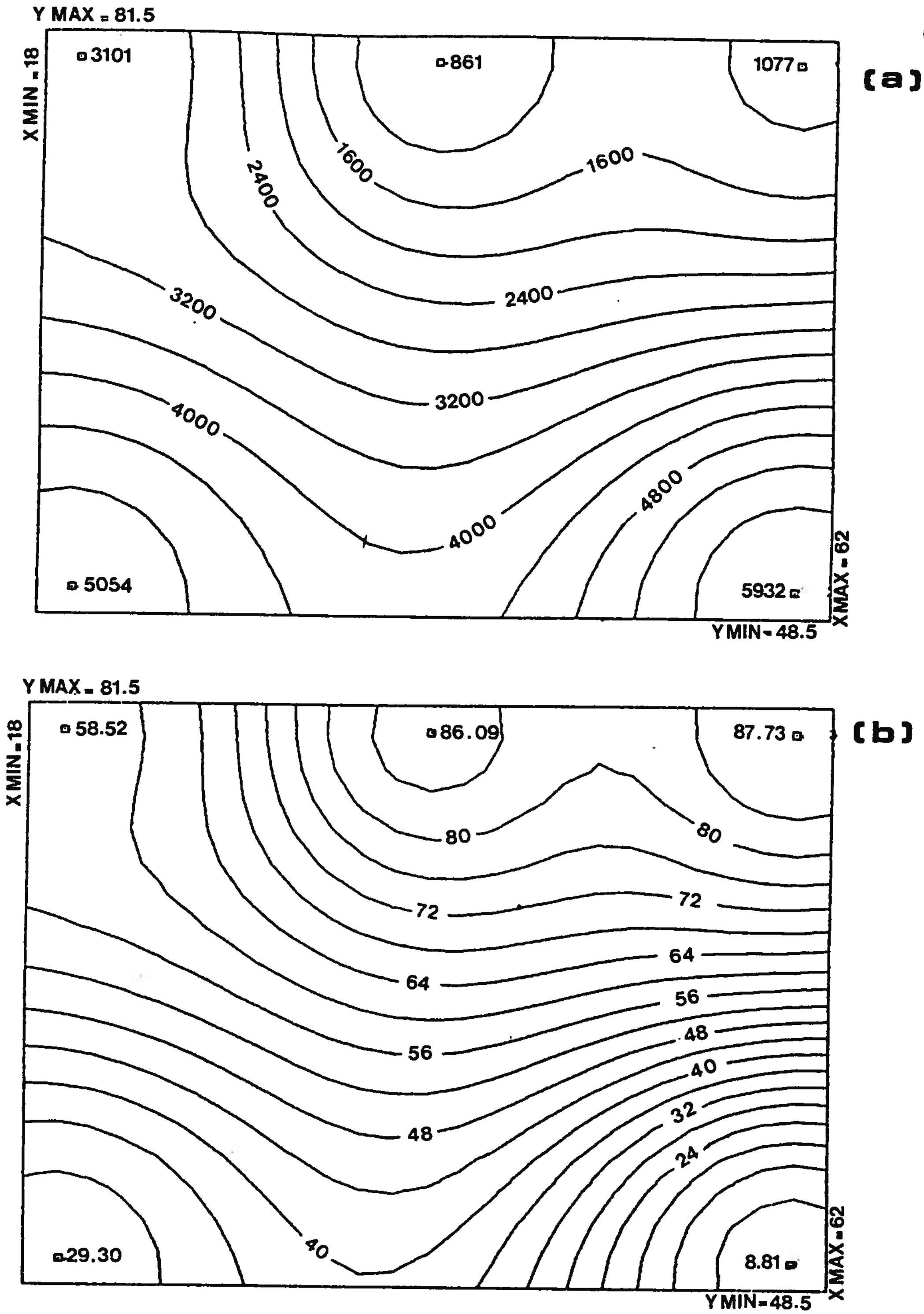


Figure 5.5 Surface Responses of Phase I Experiment:
(a) Effluent COD (sol.); (b) COD Removal Efficiency
At Pseudo Steady-state under Different Running Conditions
Note: x = Recycle Ratio (RR); y = Sludge Ratio (SR)

as shown in Table 4.2. The details of this "best known" condition will be discussed in the next section. Comparing the phase means of both Sequence 1 and 2 experiments, the system performed much better in terms of effluent quality, COD removal efficiency, and CH_4 gas content and yield, in the Sequence 2 experiment (as shown in Table 5.1). There was also no significant effect of SR and RR on all the responses, when compared with 2 S.E..

These combinations indicated that the system was now in the vicinity of the optimum "best known" condition providing the maximum COD removal efficiency. However, there were still some effects of SR on the content and removal efficiency of PO_4-P and the effect of RR and interaction (SR*RR) on the CH_4 gas content. An additional run (Sequence 3 experiment as shown in Table 4.2) was then carried out to ensure that the system really reached the optimum "best known" running condition.

5.2.1.2 "Best Known" Running Condition

By applying the steep ascent technique as mentioned earlier, a response surface of the Sequence 1 experimental runs as shown in Table 4.2, with respect to effluent COD (sol.) and COD removal efficiency, is illustrated in Figure 5.5. As shown, the contour lines of both COD removal efficiency and effluent COD tend to move towards the best known running condition (experimental run no. 0 : SR80/20 and RR4/7), where 86.09 % COD (sol.) removal efficiency and 861 mg/L of effluent COD (sol.) were obtained. It is quite interesting to note that the running condition of SR50/50 and RR2/4 was the worst

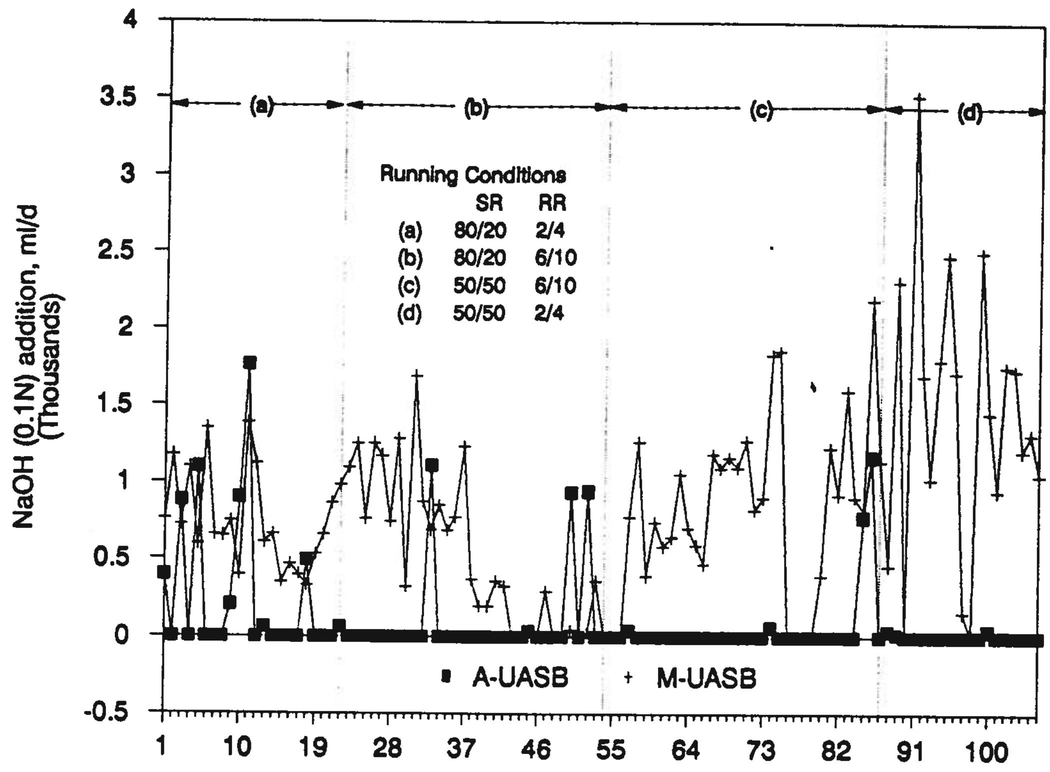


Figure 5.6 NaOH (0.1 N) Addition
During the Sequence 1 Experiment

scenario in the Sequence 1 experiment, with 8.81 % COD removal efficiency and the effluent (sol.) COD of 5950 mg/L. This may have been the result of a large volume of 0.1 N NaOH automatically pumped into the reactor to neutralize and maintain the pH at 7.0-7.2 (as shown in Figure 5.6), thus destroying the sludge bed and diminishing the CH_4 gas production and the system removal efficiency (as shown in Figure 5.7). It is speculated that a malfunction of the pH sensor in the M-UASB might have played a major role in this unusual situation. Although results of the worst running condition were suspected and even without considering them, the overall picture of sequence 1

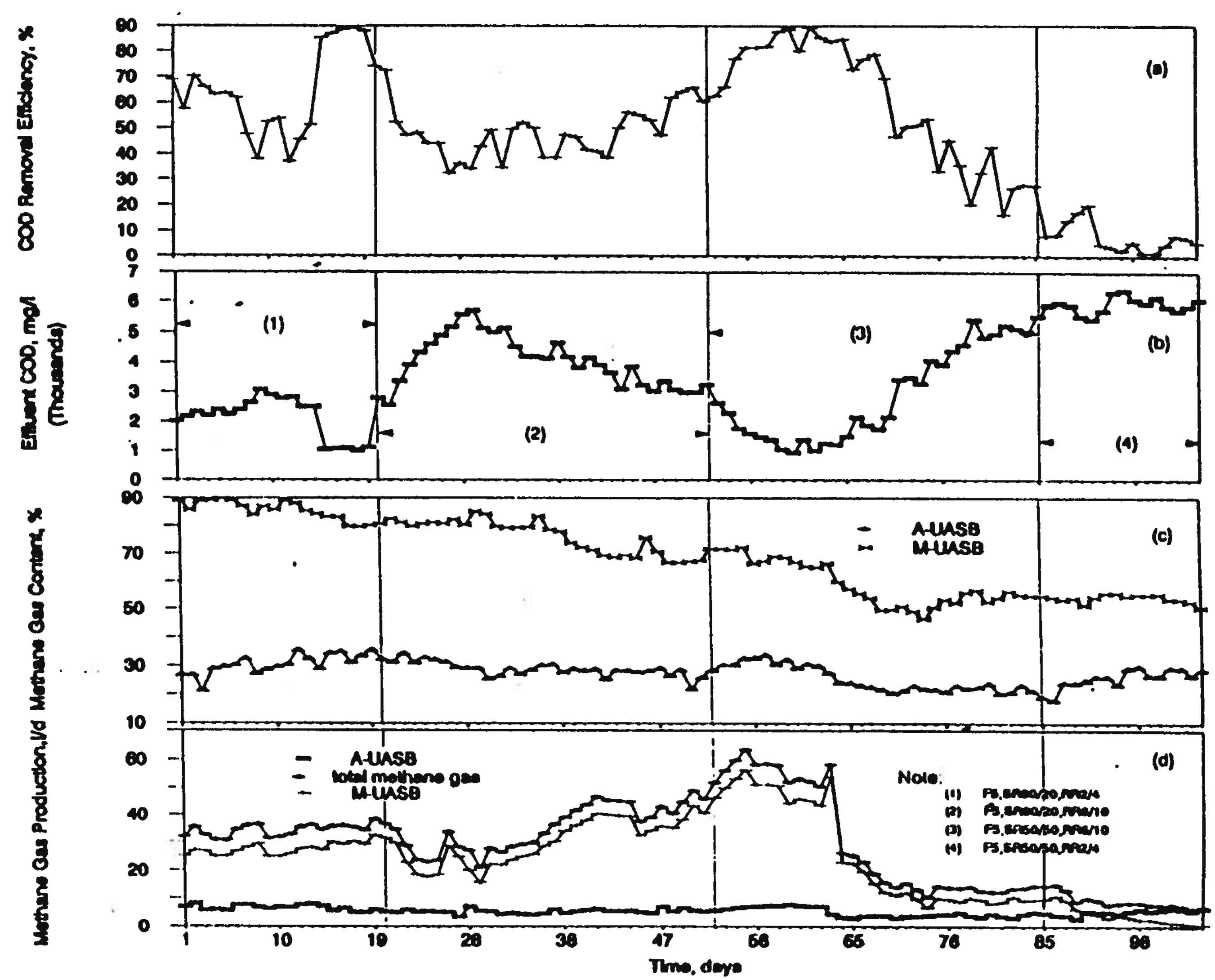


Figure 5.7 System Responses and Performance of Sequence 1 Experiment:
(a) COD Removal Efficiency;(b) Effluent COD;(c) CH4 Content;(d) CH4 GasProduction

experiment still remained moving toward the acclimatization running condition (SR 80/20 and RR 4/7). Reseeding and repeating the acclimatization process of the M-UASB, using a new pH sensor, were made before starting the experiments in Sequences 2 and 3, as detailed in Table 4.2.

A summary of average responses and system performance under different running conditions (Sequence 1-3) is shown in Table 5.2. As also shown, running condition no.7 (SR60/40 and RR5/8) appeared to perform better in terms of better effluent quality and higher CH_4 gas productivity than those of running condition no.10 (SR80/20 and RR4/7); however; condition no.10 provided a better PO_4-P removal efficiency. Finally, as shown in Table 5.2, the choice of running condition no.9 (SR80/20 and RR5/8) was the optimum "Best known" condition with respect to PO_4-P removal efficiency, specific CH_4 gas productivity, and CH_4 gas production, compared to all other running conditions. A summary of average responses and performance of the "best known" running condition is illustrated in Table 5.3. Under this "best known" condition, the system appears to provide a promising performance with 95, 99, and 90 % removal efficiencies of soluble COD, total COD, and PO_4-P, respectively. A low level of soluble effluent COD of 308 mg/L is also indicated.

5.2.1.3 Two-phase Separation (UASB-UASB)

To avoid confusion between a conventional, completely mixed "two-stage"

Table 5.2 Summary of Average Responses Under Pseudo Steady-state of the Different Designed Running Conditions (Sequence 1, 2, and 3 Experiments)

Average Responses		Experimental Running Conditions											
		Sequence 1				Sequence 2				Sequence 3			
		1	2	3	4	5	6	7	8	9	10	11	12
		Loading Rate											
cu.m/cu.m-d		0.10	0.14	0.10	0.12	0.12	0.12	0.08	0.12	0.09	0.11	0.09	0.10
Kg COD(Sol)/cu.m-d		0.63	0.97	0.62	0.76	0.75	0.78	0.63	0.91	0.69	0.59	0.59	0.62
Kg COD(Total)/cu.m-d		5.70	6.00	4.50	6.35	5.60	4.80	3.95	4.70	4.30	4.25	4.25	3.85
		Effluent Quality											
Solids, mg/L													
	TS	7140	6500	3480	5440	3130	3600	2355	2635	2610	2600	2660	2600
	VS	4030	4200	1300	2645	900	1430	815	1175	1050	620	930	880
	TSS	270	580	190	280	210	200	230	730	300	300	340	230
	TVSS	180	330	160	260	65	100	100	430	155	140	120	100
COD, mg/L													
	COD(Total)	2780	3380	5135	6480	490	400	420	445	470	400	425	400
	COD(Sol)	2755	3055	4870	6030	460	325	355	350	300	305	280	290
Inorganics, mg/L													
	NH4-N	270	360	425	405	455	400	525	515	510	410	390	425
	TKN	300	385	435	466	459	420	492	483	489	387	557	420
	TP	60	124	230	364	176	74	76	85	91	32	140	27
	PO4-P	20	91	230	340	9	6	34	74	20	23	11	11
Total VFA,mg/L HAc		1460	2050	1780	3507	80	50	0	0	0	0	0	20
		System Removal Efficiency											
Solids, %													
	TS	85	80	91	82	91	89	93	91	91	91	93	92
	VS	91	80	96	90	97	95	97	95	96	97	97	97
	TSS	99	98	99	99	99	99	99	96	99	99	99	99
	TVSS	99	99	99	99	100	100	99	98	99	99	100	100
COD, %													
	COD(Total)	95	92	89	83	99	99	99	99	99	99	99	99

Inorganics, % COD(Sol)	54	57	23	4	93	95	95	95	96	94	96	95
TP	66	31	-6	-66	14	63	65	57	50	76	40	83
PO4-P	85	40	33	-94	95	97	81	58	91	88	94	92
Methane Gas												
Flow, l/d												
Total Gas	53	80	35	30	95	91	107	126	120	87	85.00	83
CH4 Gas	34	46	14	10	60	58	62.20	71	69	50	54	49
CH4 Productivity												
l/d	34	46	14	10	60	58	62	71	69	50	54	49
cu.m/cu.m-d	0.75	1.00	0.30	0.20	1.35	1.30	1.38	1.60	1.55	1.10	1.20	1.10
cu.m/cu.m-d @ SC	0.70	0.90	0.25	0.20	1.20	1.15	1.25	1.40	1.40	0.90	1.00	0.95
cu.m/kgCOD(Total) added@SC	0.12	0.15	0.05	0.03	0.20	0.25	0.30	0.30	0.32	0.25	0.25	0.25

Note:

SR = Sludge Ratio (Primary and Secondary Sludges)
RR = Recycle Ratio (Recycle and Influent flow)
operated @ walk-in controlled room temperature at 35 o
and pH of 5.0-5.3 and 7.0-7.3 for A- and M-UASBs
Influent feed @ 4-5 o C

Experimental Running Conditions

	SR	RR		SR	RR
1	80/20	2/4	7	60/40	5/8
2	80/20	6/10	8	60/40	3/6
3	50/50	6/10	9	80/20	5/8
4	50/50	2/4	10	80/20	4/7
5	70/30	3/6	11	90/10	5/8
6	70/30	5/8	12	90/10	3/6

Table 5.3 Performance of A Two-phase Anaerobic Sludge Digestion (UASB-UASB) Process at 35 degree C / 9-day HRT / SR 80/20 / RR 5/8

Operating Conditions / Performance	UASB-UASB
Running HRT, days	9 - 10
Loading rate,	
kg COD(total)/cu.m-d	5.00
kg VS/cu.m-d	2.00
Supernatant quality,	
Solids,mg/l	
TS	2600
VS,(%TS)	1050(40)
SS	300
VSS,(%TS)	155(58)
Organics,mg/l	
(Total) COD	470
(Fil.) COD	310
Inorganics,mg/l	
NH4-N	510
PO4-P	20
TKN	490
TP	90
Volatile acids,mg/l	
HAc	nil
HPr	nil
Iso-HBr	nil
HBr	nil
A-HVr	nil
Iso-HVr	nil
HVr	nil
HHe	nil
Total VFA,mg/l as HAc	nil

Table 5.3 Performance of A Two-phase Anaerobic Sludge Digestion (UASB-UASB) Process at 35 degree C / 9-day HRT / SR 80/20 / RR 5/8 (cont'd)

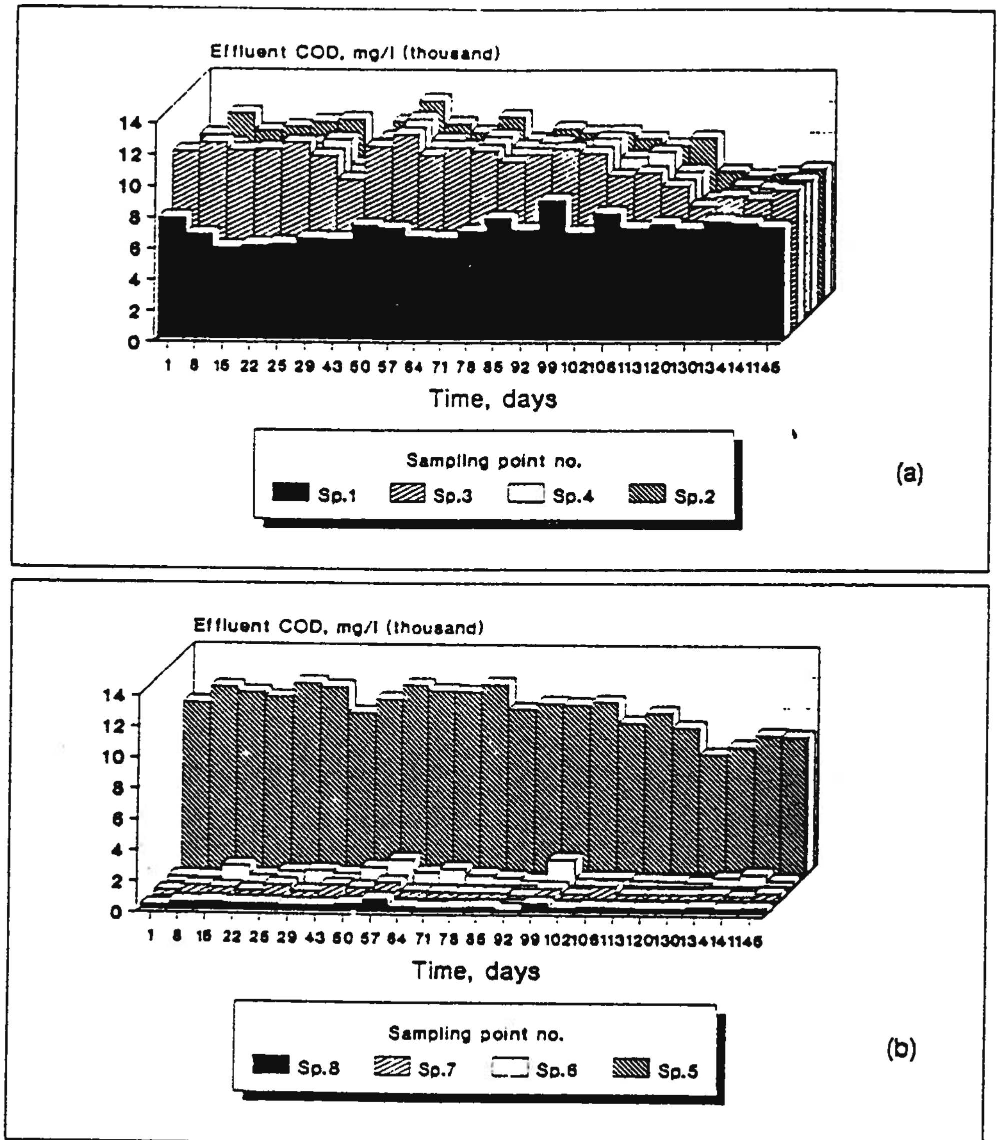
Operating Conditions / Performance	UASB-UASB
Methane gas	
CH4 yields	
cu.m/kg VS removed	0.90
cu.m/kg COD (Total) added	0.32
CH4 production rate	
cu.m/d	75
vol/culture vol-d	1.70
% theoretical CH4	95
Gas composition,mol %	
CO2	27
N2	1.00
CH4	72
Removal Efficiency, %	
Organics	
(Total) COD	99
(Fil) COD	97
Solids	
TSS	98
Inorganics	
PO4-P	87
TP	56
VFA	100

anaerobic digestion process and a "two-phase" anaerobic digestion process, it is appropriate to clearly distinguish these two concepts. The "two-stage" process consists of two completely mixed reactors connected in series. The first reactor serves as a fermenter while the second one acts mainly as a settler and/or a reserved fermenter, in case of emergency or failure of the first one. Often, the second digester performs poorly as a thickener, producing dilute sludge and a high solids supernatant. This may be the result of a high proportion of fine- sized particles in the first digester. They are produced generally by mixing and natural breakdown of particle size through biological decomposition, and become saturated with digester gas. When the gas is transferred into the second digester, it will come out of the solution, forming small bubbles; these become attached to sludge particles and create a buoyant force that hinders settling. The "two-phase" concept, on the other hand, is an attempt to take advantage of the di-phasic phenomenon of the anaerobic digestion process, by keeping the reactors separated physically and providing the optimum environmental conditions to stimulate and/or promote the hydrolysis-acidification and acetogenesis-methanogenesis in the first and second reactors respectively. In short, "Phase" should be used for processes when different reactions occur in different reactors and "Stage" should be applied for the same reaction/process occurring in the two consecutive reactors. It is also appropriate to avoid the use of the word "Steps", since it is usually used to describe various types of reactions ie. mechanisms of chemical reaction.

To determine whether a two-phase (UASB-UASB) process does occur, 3-dimensional plots of effluent profiles obtained along the height of both A-UASB and M-

UASB under different running conditions, were made. As shown in Figure 5.8 (a), it is clear

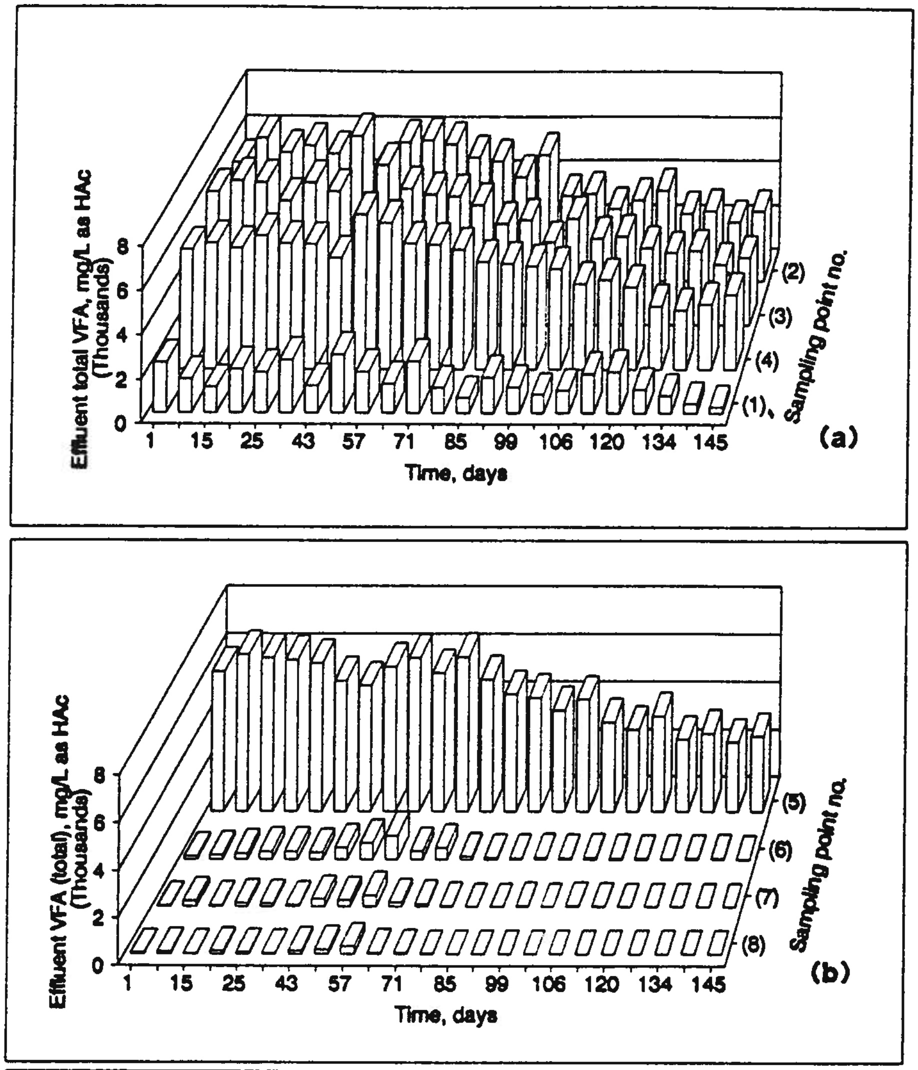
that hydrolysis-acidification predominates in the A-UASB; the average low concentration of influent soluble COD increases gradually from the bottom up to the top of the reactor under all tested running conditions during 145 days of the Sequence 2 experiment. In contrast, the average high COD concentration of the effluent from A-UASB, fed at the bottom of M-UASB, decreases rapidly as it enters the sludge bed and blanket, before leaving the system at the top of the reactor (as shown in Figure 5.8 (b)). This means that acetogenesis-methanogenesis dominates in the M-UASB and most of the reactions occurs at the lower part of the reactor. This result also agrees with the work presented by Ghosh (1984). Figures 5.9 and 5.26 reconfirm a similar situation of 3-dimensional plots of effluent total VFA and COD (sol) profiles, indicating a feasibility of two-phase (UASB-UASB) process phenomenon during both "best known" operating condition and maximization and recovery period experiments,respectively. In addition, Figure 5.10 shows a significant difference of MLVSS concentration at the sludge bed and blanket levels, compared with those of settling and effluent levels. Influent MLVSS concentration increased significantly at the sludge bed and blanket levels and then remained almost constant at the effluent level of A-UASB. In contrast, these high effluent VSS concentrations of A-UASB decreased sharply after the sludge bed and blanket levels and remained almost unchanged in the effluent of M-UASB. All these results appear to indicate the feasibility and effectiveness of the two-phase anaerobic stabilization (UASB-UASB) process, in which most of the reactions occurred at the lower part (sludge bed



Experimental running conditions		Experimental Periods
SR	RR	Days
70/30	3/6	1-29
70/30	5/8	35-71
60/40	5/8	78-106
60/40	3/6	107-145

(c)

Figure 5.8 COD (soluble) Profiles Along the Reactor Height: Under different running conditions
(a) A-UASB; (b) M-UASB; (c) Running Conditions
Note: All sampling locations are illustrated in Fig.4.1



Experimental running conditions

SR	RR
70/30	3/6
70/30	5/8
60/40	5/8
60/40	3/6

Experimental Periods

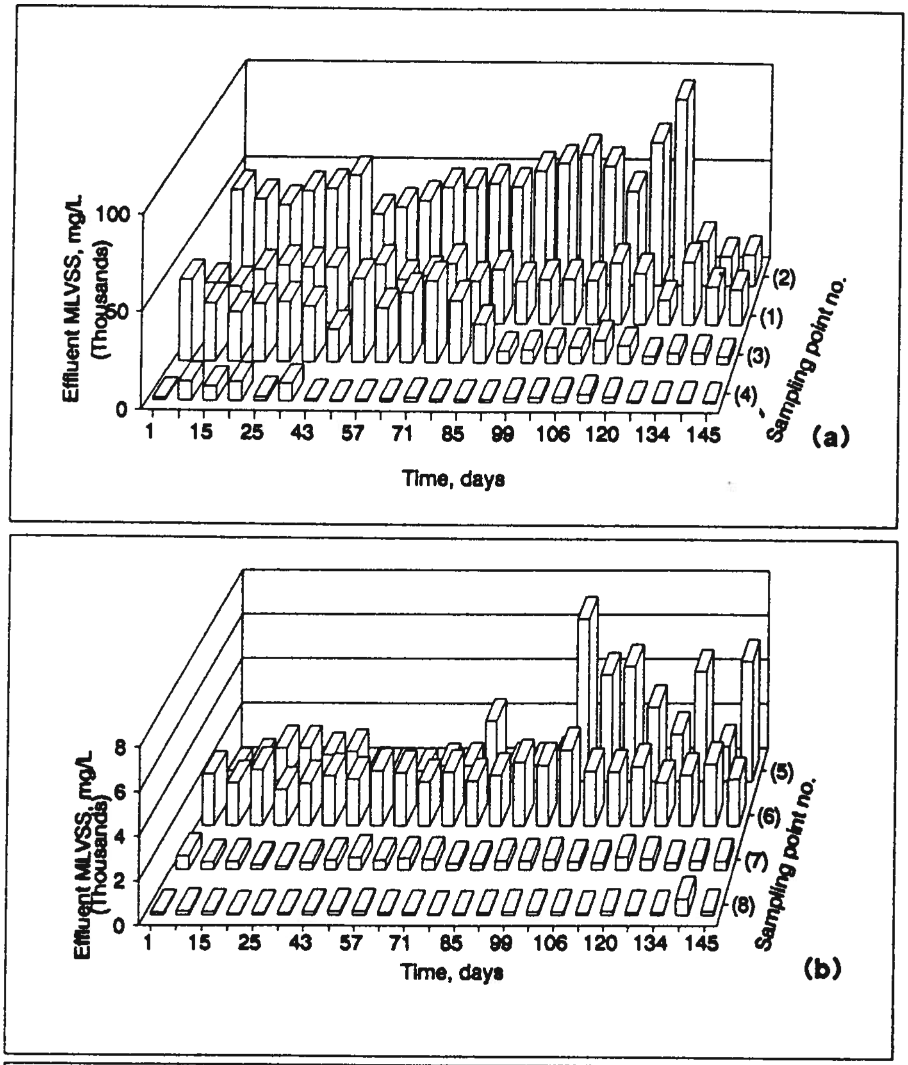
Days
1-29
35-71
78-106
107-145

(c)

Figure 5.9 Total VFA Profiles Along the Reactor Height: Under Different Running Conditions

(a) A-UASB; (b) M-UASB; (c) Running Conditions

Note: All sampling locations are illustrated in Fig.4.1



Experimental running conditions		Experimental Periods
SR	RR	Days
70/30	3/6	1-29
70/30	5/8	35-71
60/40	5/8	78-106
60/40	3/6	107-145

(c)

Figure 5.10 MLVSS Profiles Along the Reactor Height: Under Different Running Conditions

(a) A-UASB; (b) M-UASB; (c) Running Conditions

Note: All sampling locations are Illustrated in Fig.4.1

and blanket levels) of both A-UASB and M-UASB. Asinari (1981) and Harper (1986) reported a similar situation whereby the constant production of HPr and/or HBu acids in the first reactor was beneficial for the methanogenic reactor, since it enabled the development of a healthy population of obligate hydrogen producing acetogenic, (OHPA), bacteria and the associated hydrogen-oxidizing methanogens; this ensured the rapid assimilation of these acids in the second reactor.

5.2.1.4 Conclusions

With an application of a 2 by 2 factorial design experiment and Response Surface Method (RSM), the effect and interaction of SR and RR on the system responses and performance were calculated. An optimum "best known" running condition was located, with an interpretation of the effect and interaction of SR and RR on the response parameters at different sequences of the experiment. The results of this investigation can be summarized as follows:

(1) A steep ascent technique, one of the most promising RSM approaches, appears to be an effective measure in directing an appropriate step of the experimental design toward the optimum "best known" running condition, in cases where these conditions are fairly remote or unknown, (like those of the Sequence 1 experiment).

(2) The effect of SR on the effluent COD and PO_4-P was greater than that of RR and only the interaction of SR and RR on the effluent COD was significant in the

Sequence 1 experiments. However, there were no significant effects and interactions of SR and RR any of the response parameters in the Sequence 2 experiments, with the exception of SR on the effluent and removal efficiency of PO_4-P, and RR on the % CH_4 content (where a slight effect was detected).

(3) The optimum "best known" running condition was SR80/20 and RR5/8, with respect to PO_4-P removal efficiency, specific CH_4 gas productivity, and CH_4 gas production.

(4) The feasibility of two-phase separation of anaerobic digestion of sewage sludge was confirmed. Hydrolysis-acidification and acetogenesis-methanogenesis dominate in the A- and M- UASBs, respectively. In addition, it is quite probable that most of the reactions inside the M-UASB occurred at the lower part of the reactor (sludge bed and blanket).

5.2.2 Maximum Loading Capacity and Recovery Process

The conventional anaerobic digestion process has, until recently, been considered to be unpopular and not feasible for treatment of a high-strength organic waste (such as sewage sludge) under short retention times, since it is too sensitive to various extraneous factors and unable to retain a significant amount of viable sludge under high loading conditions. However, it is now possible and feasible to install well-functioning, full-scale anaerobic facilities operating at high loading rates. All modern "high rate" anaerobic processes are based on the principles of high viable biomass retention and sludge immobilization (ie. fixation). At least two mechanisms are involved here:(i) the formation of highly settleable sludge aggregates, combined with early gas separation and sludge settling; and (ii) attachment and entrapment of bacteria and sludge aggregates to a high density particulate carrier, or packing material, supplied to the reactor (Lettinga, 1983a). The UASB is considered to be one of the most successful and promising processes of the modern high-rate anaerobic digestion concept. It has long been recognized that the UASB process has superior flocculation and settling abilities, as well as being able to maintain a high solids retention time, under a high organic loading rate. Lettinga (1979b) suggested that high settleability and specific activity of the anaerobic sludge were the main prerequisites in achieving high loading rates. To accomplish this target, at least 3 conditions must be applied:(a) careful start-up of the process; (b) maintenance of favourable conditions for flocculation and growth; and (3) promotion of thickening.

Under these requirements, the system was loaded step-wisely, by keeping the best known running condition (SR80/20 and RR5/8) from the previous section as a starting point. The system loading rate was not stepped up until the system was operated as long as 2-3 system HRT and/or 80% removal efficiency was achieved. Prior to discussing the results of maximization and recovery period, the following terms and approaches used in this particular experiment, should be clearly defined:

(a) Maximum loading capacity - is the point where there was no system removal at all, with the influent and effluent COD concentrations being equal.

(b) Recovery process - is the approach to recover the system by reducing the organic loading rate, step-by-step, and analyzing the percentage of system recovery at each step of loading reduction after a complete system failure.

(c) Optimum operating condition - is the optimum point of SR and RR where the optimization of system COD removal efficiency and methane gas production were achieved.

The results of system maximization, process failure, recovery period, system recovery, and optimum operating conditions are discussed in the following sections.

5.2.2.1 Maximum Loading Capacity

As the organic loading rate increases step-by-step and finally overloads the system, it is important to monitor whether the system reaches the point of complete failure. Several factors have to be considered, including how to identify whether the system is close to the critical point; what parameters should be measured; what options are available; and how to control them. In general, feed stoppage, influent loading reduction, effluent recycle, and alkaline addition are recommended for recovering the system after a serious shock load and/or failure. A combination of step-loading reduction and recycle was selected as a practical and effective approach to this particular case.

(a) Process Failure

Although this two-phase UASB-UASB process is designed to provide optimum conditions to stimulate the growth of acidogens and methanogens in the A- and M-UASBs respectively, process failure can still occur, if the system is continuously and constantly overloaded. This can slowly turn the M-UASB into a single-stage digester, where both acidogens and methanogens compete for substrate utilization and growth. If overloading continues without any effective remedial actions taken, the system will eventually fail.

Better understanding of microbiological and biochemical reactions has lead to stability improvement of the anaerobic digestion process. It is now known that VFAs and hydrogen can be formed more rapidly than they are removed, under high loading rate and/or a sudden increase in organic loading (Zoetemeijer, 1982). Under this condition, acetogens (especially Obligate Hydrogen Producing Acetogens, OHPA), responsible for converting HPr and other higher VFAs into HAc, CO_2, and H_2, are inhibited if the hydrogen concentration exceeds 0.01 %. As a result, the excess of reduction equivalents is diverted into less favourable biochemical routes, resulting in accumulation of HPr or higher VFA products (Zoetemeijer, 1982). This observation can partly explain the feasibility of using the two-phase concept to stabilize influent substrate anaerobically. However, if system overloading still continues, high concentration of VFAs will destroy the M-UASB buffering capacity, resulting in a drop in the digester pH and discouraging the growth of methanogens. This situation combined with high loading and high recycle rates can lead to a washout of the methanogens from the system. If the HRT exceeds the maximum bacterial growth rate, cessation of CH_4 production and finally process failure may result.

Different approaches and methods have been proposed to predict whether the system has failed or not. Graef and Andrew (1974a and 1974b) suggested that cessation of CH_4 production rate, sudden increase in VFA concentration, a increase in % CO_2 content in dry gas, and a drop in pH, as indicators of process failure. Moreover, Bergman (1966) proposed that the ratio of VFA/alkalinity exceeding 0.3-0.4 was a signal for process failure.

As shown in Figure 5.11 and Figure 5.13-5.14, the system (M-UASB), during the maximization sequence, indicated some signs of failure as the loading rate increased, by shortening the HRT from 3.40 to 1.20 days; it failed completely at an HRT of less than 1.0 day (0.98), equivalent to a system hydraulic loading of 1.0 m^3/m^3-d. COD (sol.) and VFA removal efficiencies declined from 90 % down to less than 10 %, at the HRT of 1 day, with accumulation of PO_4-P inside the system (as shown in Figure 5.11). Figure 5.13 confirms this situation, whereby the total VFA concentration rose in the reactor at day 37, at a system hydraulic loading rate of 0.35 m^3/m^3-d. Initially, the concentration of both HAc and HPr increased rapidly to 930 mg/L and 340 mg/L at day 40; approximately 3-4 days later, the HAc disappeared and total VFA concentration rose to 1800 mg/L as HAc, by day 42. Also, the presence of HBu and other higher VFAs was noted, further increasing the concentration of total VFA up to 2815 mg/L as HAc at an HRT of 1 day (or process failure). It is interesting to note that there is an accumulation of HPr at an HRT of less than one day. Under the stress of a high organic loading rate, there may be a shift in the metabolic pathway to a less favourable one, inside the reactor. As the M-UASB was loaded up step-by-step, there was a shift in the ratio of VFA producers (acidogens and acetogens) and consumers (methanogens, SRB, and NRB) inside the reactor. This leads to the production of significant amounts of CO_2 and H_2. As a result, the partial pressure of H_2 inside the system increases up to certain level (higher than 10^{-4} atm) causing a shift in the metabolic pathway and accumulation of HPr, as shown in Figure 5.12. As also shown in Figure 5.13 (a), the effluent soluble COD and VFA concentrations increased gradually to day 51, with an increase in loading rate, after

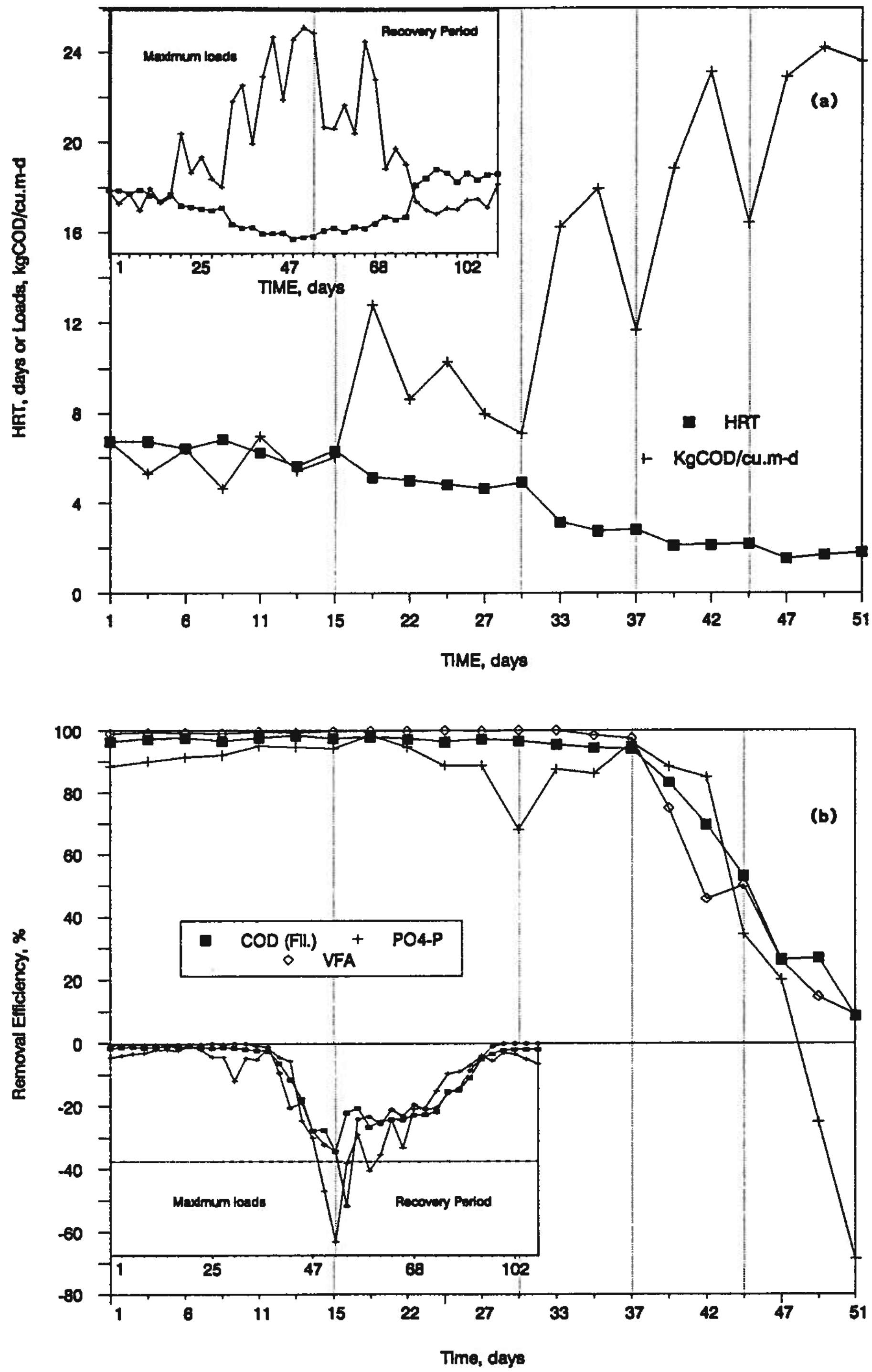


Figure 5.11 A Two-phase (UASB-UASB) Step-loading And M-UASB Removal Efficiency

During the system maximization

(a) HRT,Kg COD/cu.m-d; (b) Removal efficiency

(1) $C_6H_{12}O_6 + 2\ NAD^+ + 2\ ADP + 2\ P \longrightarrow 2\ CH_3COCOOH + 2\ NADH + 2\ ATP$
Pyruvic acid

(2) $2\ NADH \longrightarrow 2\ NAD^+ + 2\ H_2$

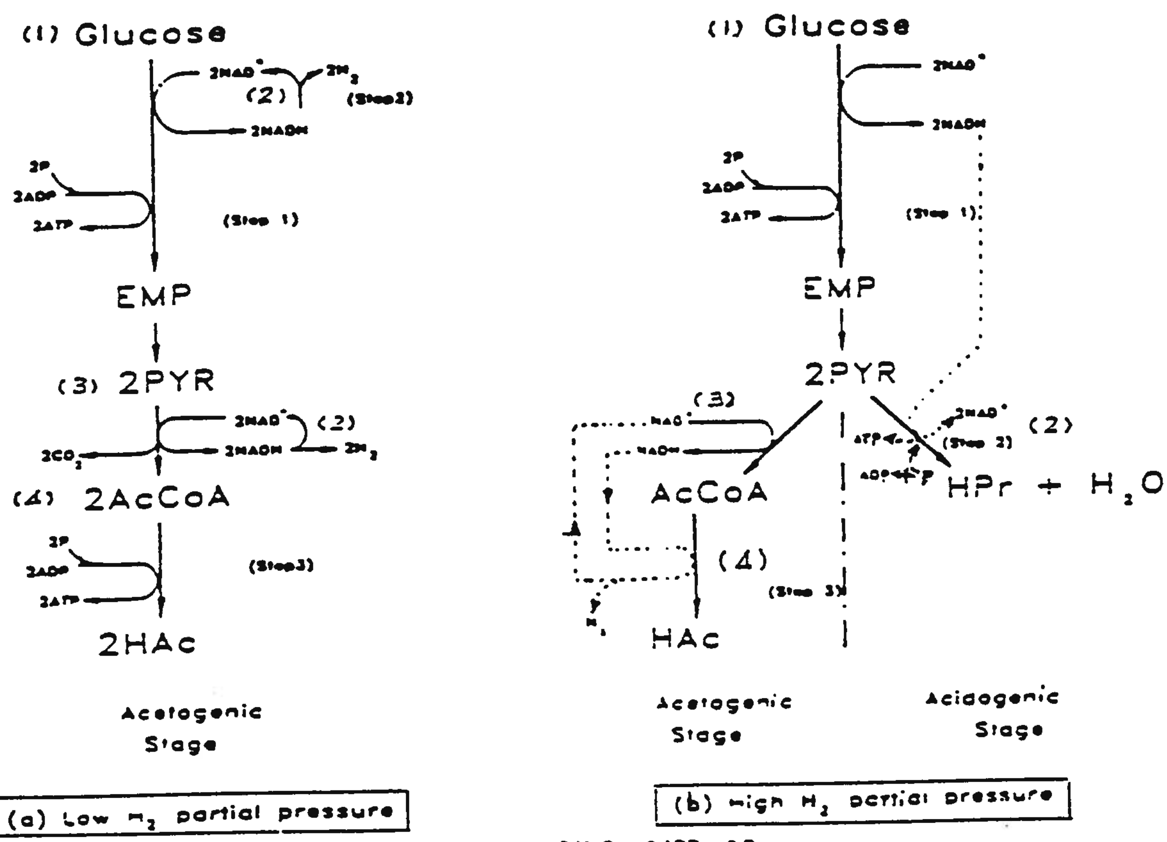
(3) $2\ CH_3COCOOH + 2\ NAD^+ \longrightarrow 2\ CH_3CoA + 2\ CO_2 + 2\ NADH$

(4) $2\ CH_3CoA + 2\ ADP + 2\ P \longrightarrow 2\ CH_3COOH + 2\ ATP$

(2) $CH_3COCOOH + 2\ NADH + ADP + P \longrightarrow CH_3CH_2COOH + 2\ NAD^+ + ATP + H_2O$

(3) $CH_3COCOOH + NAD^+ \longrightarrow CH_3CoA + CO_2 + NADH$

(4) $CH_3CoA + NADH \longrightarrow CH_3COOH + H_2 + NAD^+$



Overall: $C_6H_{12}O_6 + 2\ H_2O + 4\ ADP + 4\ P \longrightarrow 2\ CH_3COOH + 2\ CO_2 + 4\ H_2 + 4\ ATP$

$C_6H_{12}O_6 + 3\ ADP + 3\ P \longrightarrow CH_3CH_2COOH + CH_3COOH + CO_2 + H_2 + 3\ ATP$

Figure 5.12

Acidogenic phase of glucose fermentation under low and high H_2 partial pressures to form acetic acid, propionic acid, H_2 gas and CO_2. (Abbreviations: EMP – Embden-Meyerhof pathway; PYR – pyruvic acid; AcCoA – acetyl coenzyme A; HPr – propionic acid; HAc – acetic acid).

(Source: Modified after PALNS et.al, 1987)

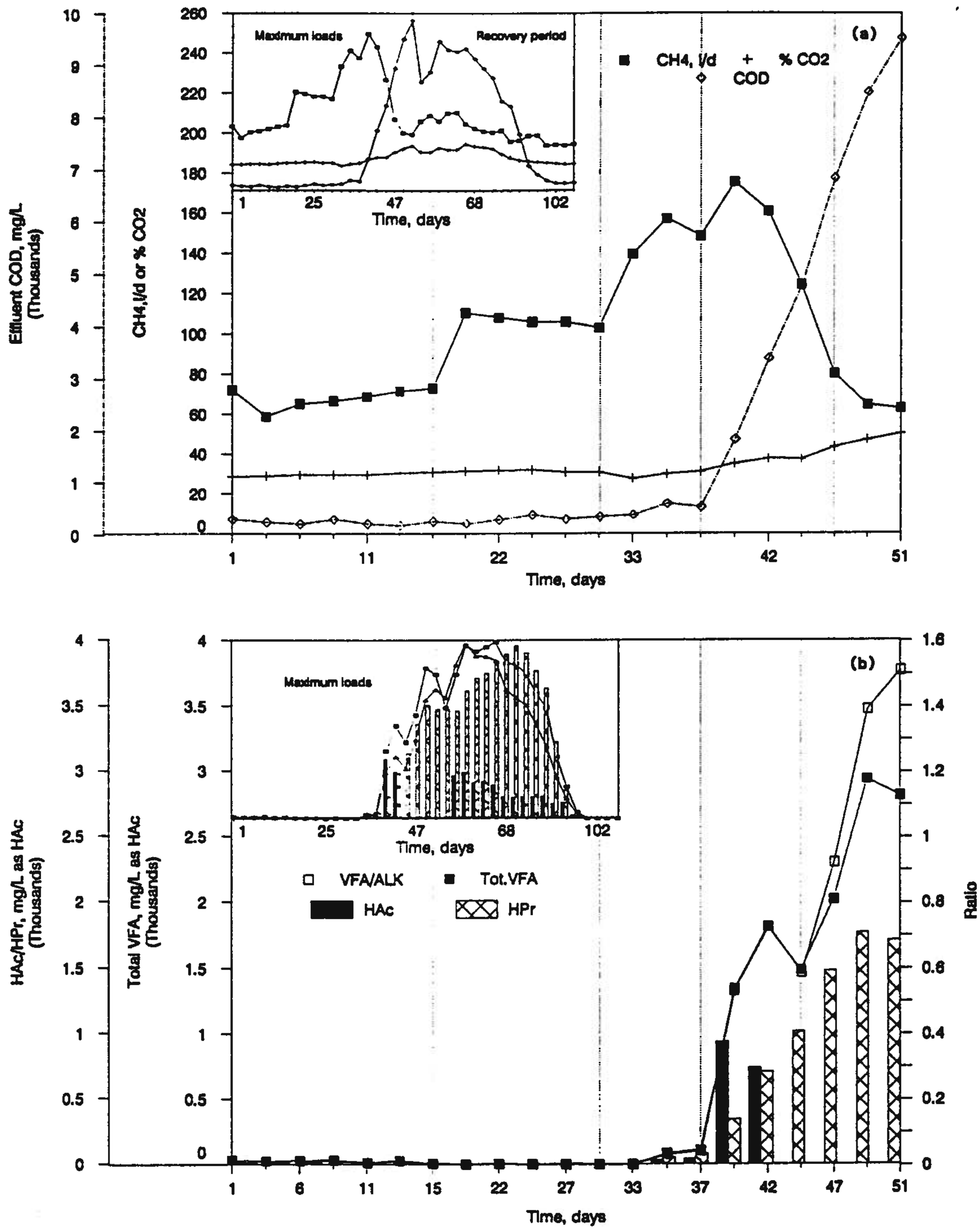


Figure 5.13 A M-UASB System Effluent Qualities:

During the process maximization

(a) CH4 production,%CO2,Eff.COD; (b) Total VFA,HAc/HPr,VFA/Alkalinity

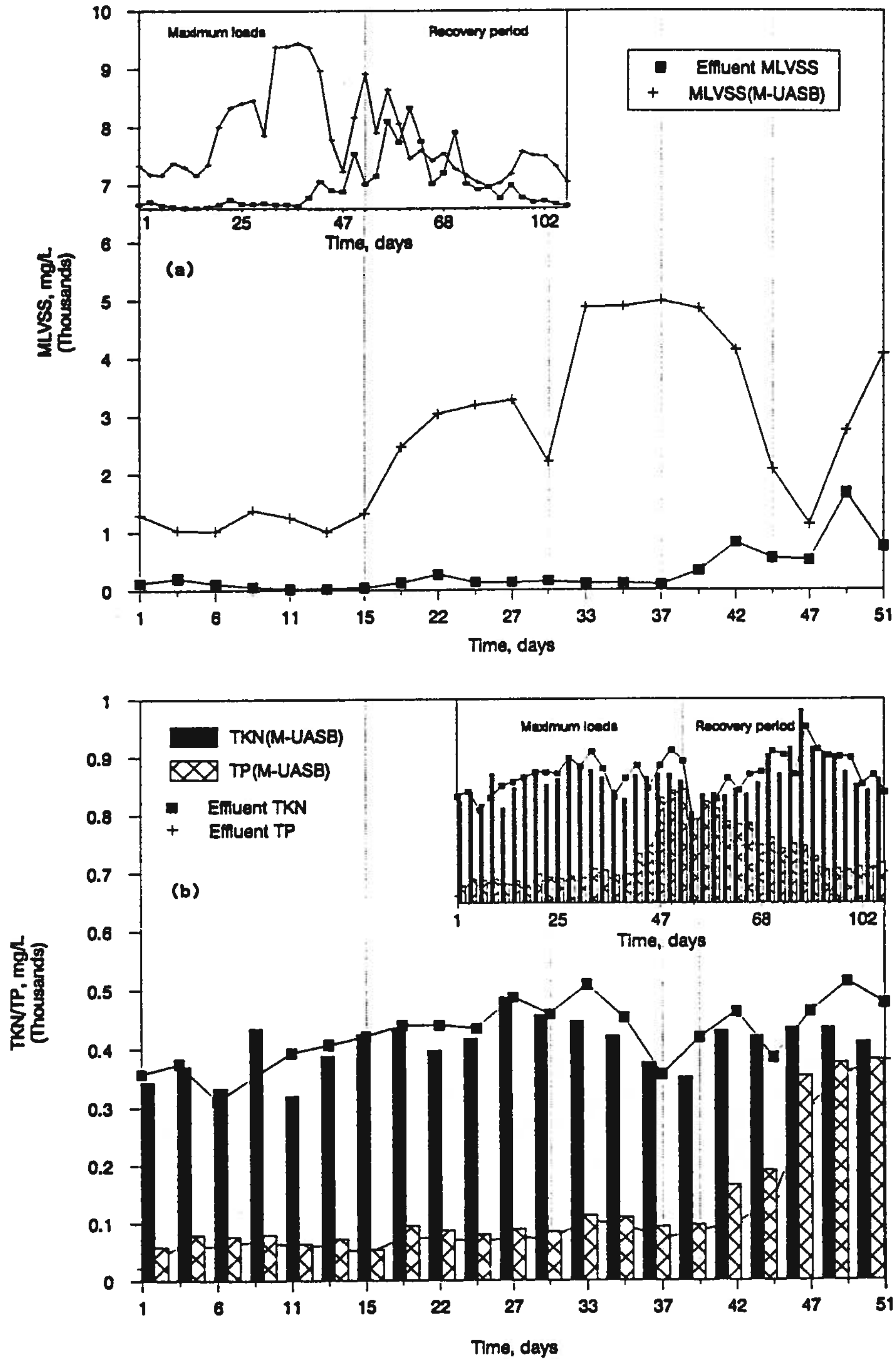


Figure 5.14 A M-UASB Nutrients and MLVSS:

During the System Maximization

(a) Effluent MLVSS,MLVSS(M-UASB); (b) TKN,TP shortening the HRT (M-UASB) to 1.20 days. The CO_2 content in the off gas increased from approximately 31.03 (day 37) to 51 % (day 51), as the loading rate increased, while CH_4 gas production increased almost linearly with a decrease in HRT (M-UASB) down to 1.55 days; however, beyond that, the CH_4 production rate decreased with a decrease in HRT. The VFA/alkalinity ratio also showed evidence of system failure at an HRT lower than 1.55 days. The ratio seems to increase linearly with a decreasing HRT and is above the critical level of 0.3-0.4 recommended by Bergman (1966).

The washout phenomenon (as shown in Figure 5.14), leading to system failure, corresponded to an increase in effluent VSS from the system. The concentration profile of MLVSS in the M-UASB, as shown in Figure 5.14, is similar to that of CH_4 gas production, illustrated in Figure 5.13. As shown, the system began to wash out the MLVSS and the concentration of MLVSS in the reactor declined sharply after reaching an HRT (M-UASB) of 1.55 days; however, the MLVSS concentration did recover slightly after about 4 days, at a hydraulic loading rate of 1.80 m^3/m^3-d (HRT of 1.0 day). This situation may have resulted from too high a loading rate creating an unsettled situation and severe turbulence in the lower part of the reactor, thus partly destroying the sludge bed. Because the samples were taken in the middle of the reactor (Sampling point no.6), it is possible that a higher concentration of MLVSS, resulting from this turbulence in this particular case, could occur.

It is interesting at this point to note that the main causes of process failure were the combination of hydraulic overloading, thus exceeding the growth rate of both acidogens and methanogens (washout phenomenon), and the destruction of the dynamic balance of acetogens and methanogens inside the M-UASB. The system demonstrated an increase in VFA concentration and % CO_2 content, but a decrease in % CH_4 content and production, as discussed earlier. This observation also confirmed that the failure was not caused by a toxic effect, since there was no sign of a decrease in VFA concentration corresponding to a decrease in % CH_4 content. In term of nutrient requirements during the process failure, only the concentration of TP inside the reactor and effluent increased significantly; TKN increased only slightly.

(b) Maximum Loading Rate

The system completely failed as the loading rate was increased and the HRT was shortened, in stepwise fashion. As shown in Figure 5.15, the soluble COD removal efficiency declined linearly, as the HRT decreased beyond 1.5 days. To predict the maximum loading rate precisely, a simple linear regression was applied, using the average values of each step loading rate, at pseudo steady-state conditions as follows:

$$Y = 129.281 - 3.214X \qquad (15)$$

where Y= % COD (soluble) removal efficiency

X = Influent flow rate, L/d

$r^2 = 0.88$

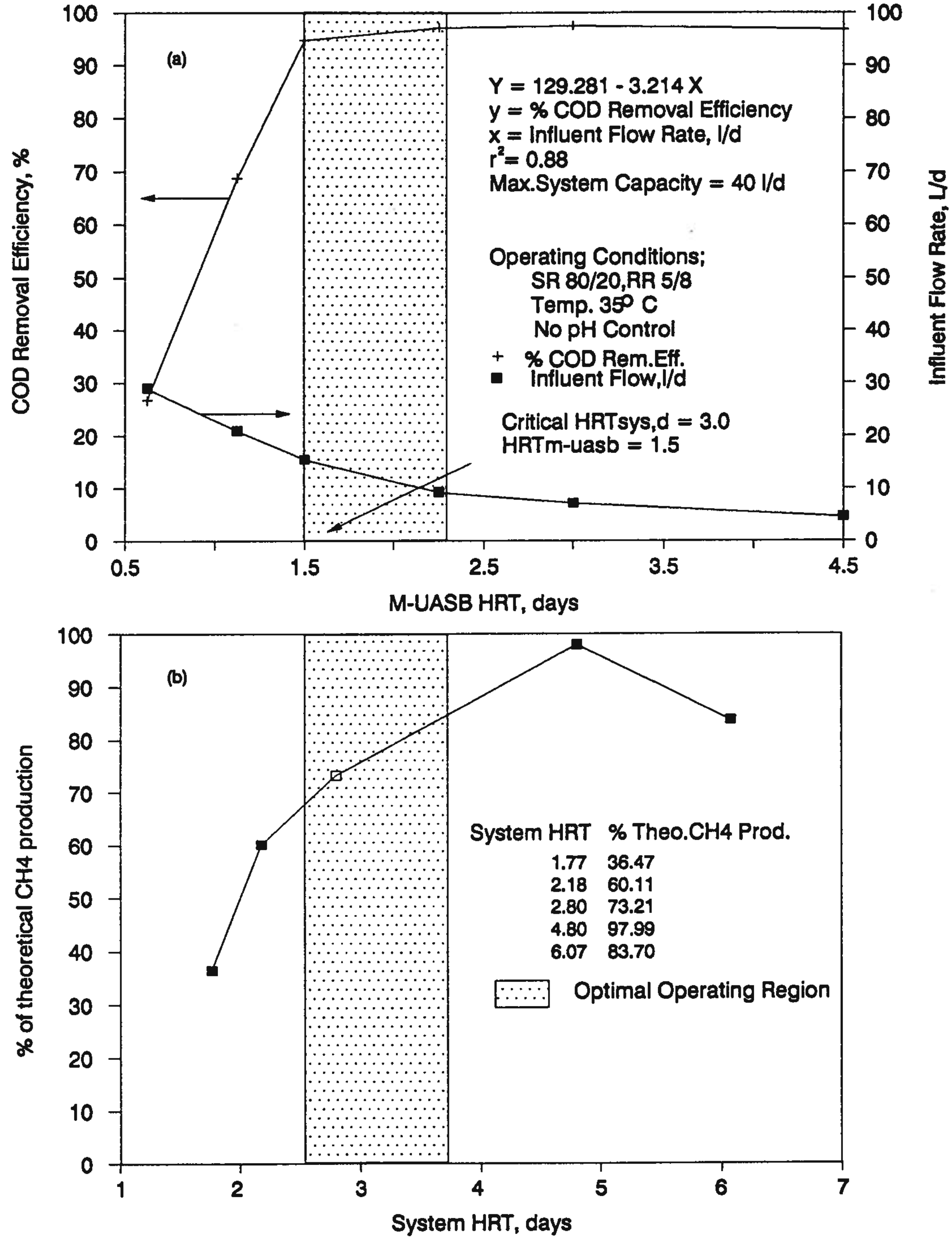


Figure 5.15 System Optimum Operating Region and Maximum Capacity:
(a) Optimal Operating Region;(b) Theoretical CH4 Production

Based on this simple model, the maximum loading rate (defined as no COD removal efficiency) as shown in Figure 5.15, was about 40 L/d; this was equivalent to a system hydraulic loading of 1.80 m^3/m^3-d, at a system HRT of 1.125 days (0.625 day for M-UASB). The CH_4 gas production at this point of complete failure was about 50 % of the theoretical value, which is a combination of CH_4 gas production from both A- and M-UASBs. Details of calculating the theoretical CH_4 gas production (based on the assumption that the influent substrate is 100 % glucose), are shown in Table D3.1 of Appendix D. At this "failure loading", the effluent COD (sol.) was in excess of 9540 mg/L, total VFAs were above 3,750 mg/L as HAc, the CO_2 content was more than 45 %, and the VFA/alkalinity ratio was over 1.55. Oleszkiewicz (1988) indicated that the "failure loading rate" for a biofilter using a UASB reactor to stabilize synthetic wastewater, was 20 kg COD/m^3-d, which is equivalent to 50 L/d at an HRT of 5.8 hrs. Moreover, Bergman (1966) pointed out that his system, being used to treat sewage sludge, failed at an HRT of 2.20 days, a pH of 4.60, and a HAc:HPr:HBu ratio of 2.0:2.5:1.0, with HPr over 9,000 mg/L. Although these results are not directly comparable, there is some similarity in the data bases from these UASB-UASB studies, with recognizable patterns and numerical indices in the same general range.

5.2.2.2 Recovery Process

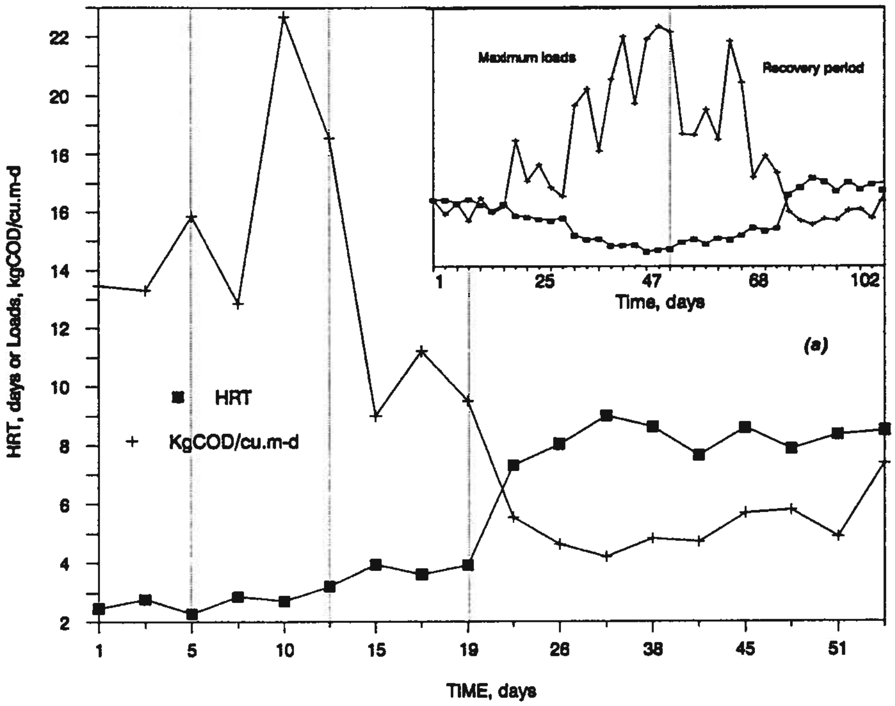
In anaerobic treatment processes, short term hydraulic overloading is a problem difficult to avoid and operational failure is frequently the outcome. An extended reactor recovery period is usually necessary. The problem of hydraulic overloading is aggravated where no recycle facility is available, to prevent the loss of the slow growing methanogens from the system. The following sections deal with the behaviour and response of this system after complete failure and the recovery to initial normality. Prior to a detailed discussion, however, some clarifications should be made.

The term "process failure" can be either temporary (ie. a sudden organic shock loading) or relatively prolonged (ie. a toxic shock load or hydraulic overloading - complete washout of the active biomass). Several studies have dealt with temporary failures, but rarely with a permanent one, especially that of hydraulic overloading. The following sections deal with system recovery back to the initial stage, using a combination of RR and step-down loading approaches.

(a) Recovery Period

The worst scenario in recovering a system after complete failure is the need to re-seed and re-acclimatize the system. However, this option is costly and not practical in terms of a full-scale operation: time-consuming processes and high-skilled manpower are required. A combination of step-down loading rate and RR is relatively simple and quite practical, compared with the option of reseeding and acclimatization (step-up loading). However, some questions still exist as to whether this approach is more effective than that of re-acclimatization, and what changes the system undergoes during the recovery process, compared with that of the initial normal stage.

As shown in Figure 5.16-5.18, the system appeared to begin recovering from the serious failure after 19 days of decreasing the hydraulic loading from 0.40 to 0.25 m^3/m^3-d; this was accomplished by prolonging the HRT (M-UASB) from 1.20 day up to 2.00 days. The system demonstrated COD and VFA removal efficiencies (M-UASB) of 43 and 45 % respectively, with 6,580 mg/L effluent COD, 47 % CO_2 content, 68 L/d of CH_4 gas production, and a VFA/alkalinity ratio of 1.40. Thereafter, the system seemed to recover linearly with time and recovered completely to the initial level of operation at approximately day 43, thereby showing 97 % VFA and 92 % soluble COD removal efficiencies. The effluent COD (soluble) was less than 1,000 (880) mg/L and the total VFA was 125 mg/L as HAc, with 32 % CO_2 content, 62 L/d of CH_4 gas production, and VFA/alkalinity ratio of less than 0.1 (0.05). The system then followed a "dimensional time frame", defined as the ratio of the recovery time to the HRT; this was equal to approximately 5.60 and 10 for the system and the M-UASB, respectively. This compared well to a ratio of 5-10 for an expanded bed anaerobic reactor (UASB with effluent recycle), operated at a high organic loading rate in non-steady state conditions reported elsewhere (Encina, 1987). By day 30, the active biomass (MLVSS) of the sludge blanket, in the middle of the reactor, recovered and reached a peak at day 40. This may have been the result of the system beginning to recover and producing small gas bubbles, thus creating flocculation at the sludge blanket level, (there was evidence of increasing CH_4 gas production at day 30, as illustrated in Figure 5.17 (a)). For the next 10 days (day 38-43), it is speculated that the granulation process played a major role in assisting substrate stabilization and system recovery; there was a sharp increase in COD and VFA



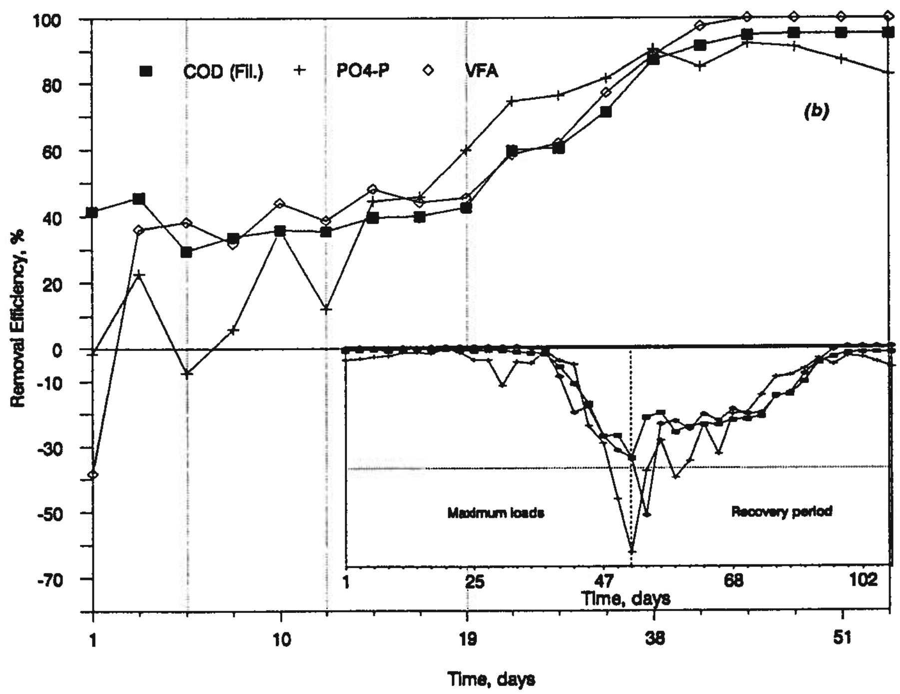


Figure 5.16 A Two-phase (UASB-UASB) Step-loading And M-UASB Removal Efficiency

During the system recovery
(a) HRT,Kg COD/cu.m-d; (b) Removal efficiency

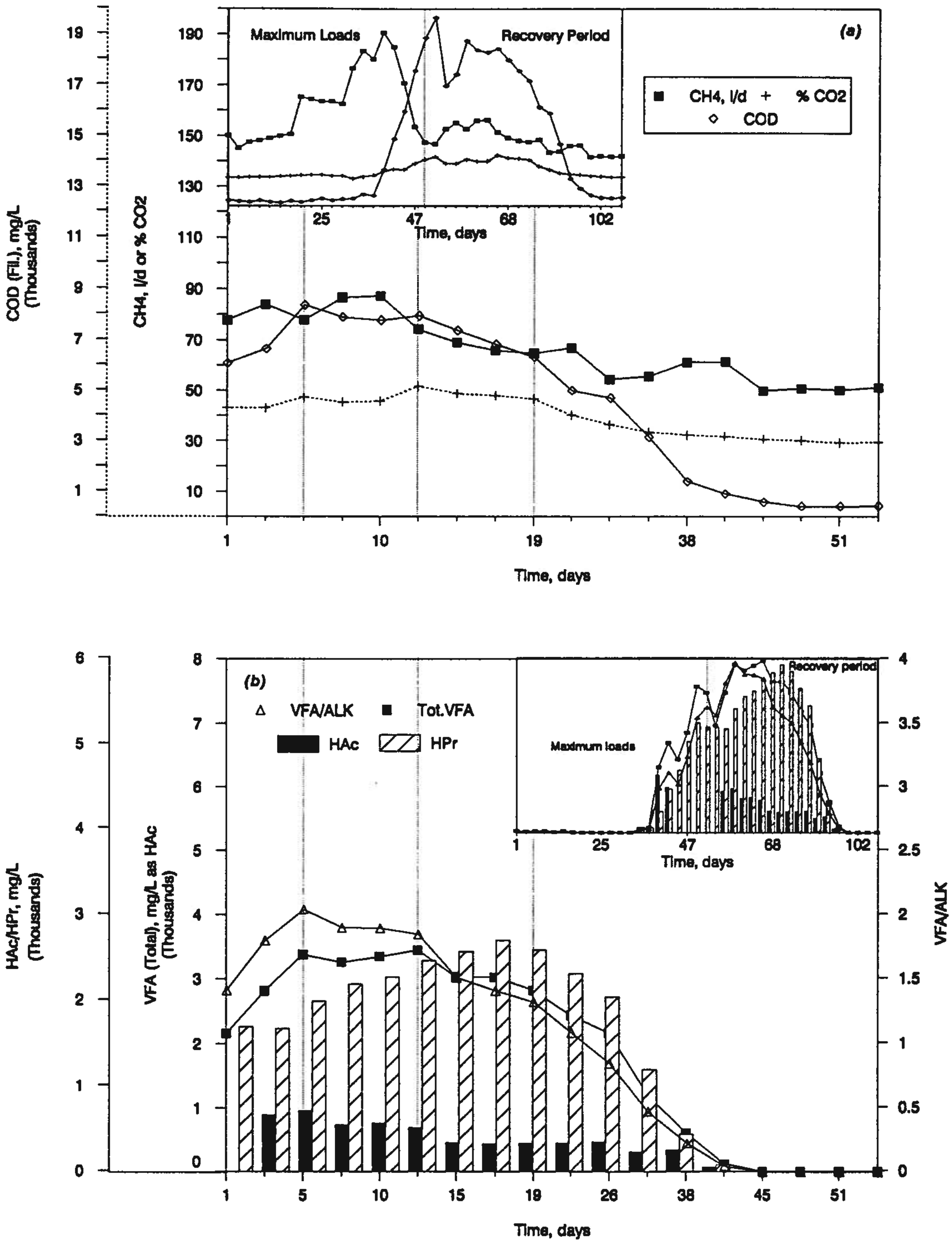


Figure 5.17 A M-UASB System Recovery Process:
(a) CH4 production,%CO2,Eff.COD; (b) Total VFA,HAc/HPr,VFA/Alkalinity

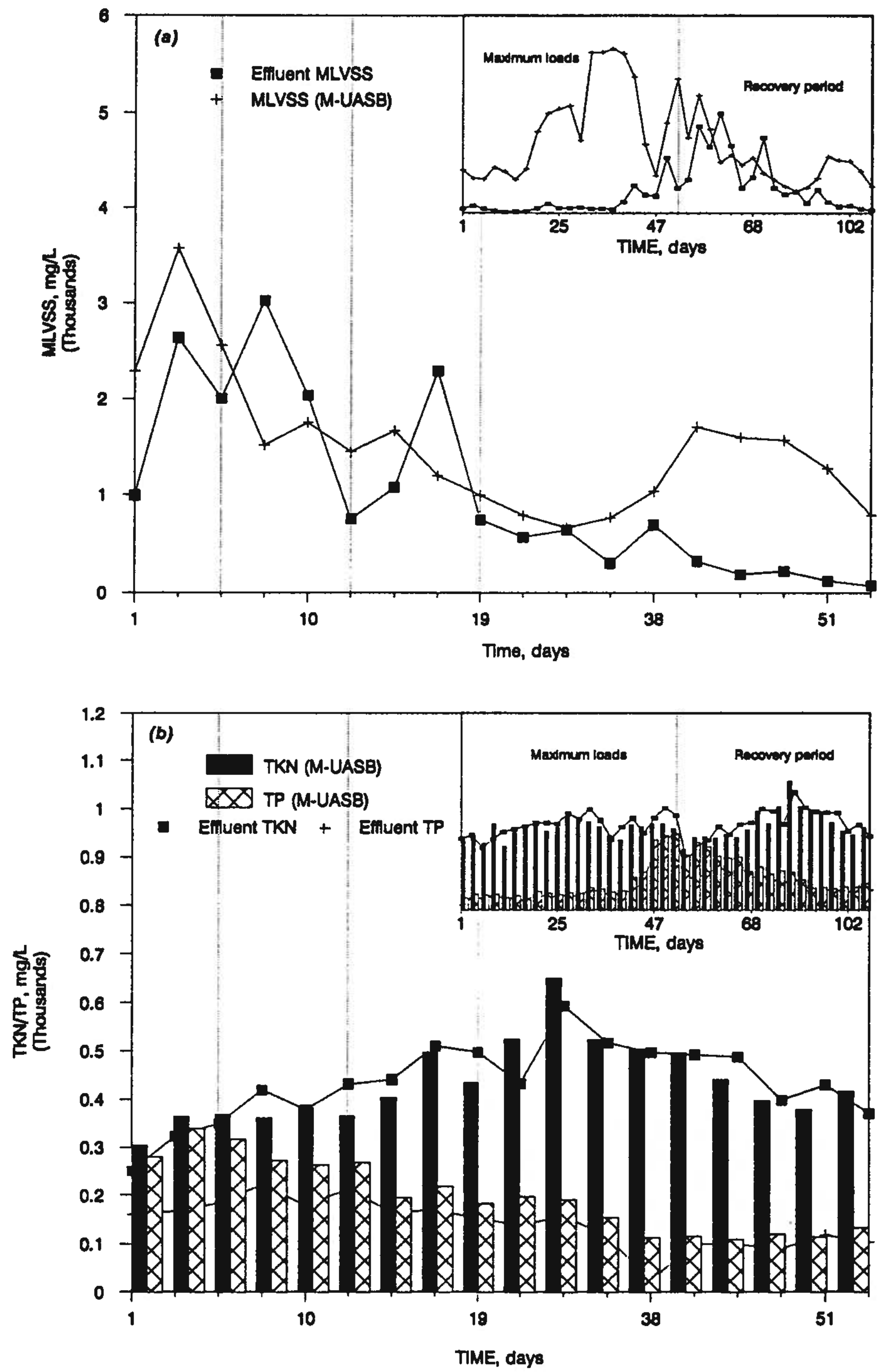


Figure 5.18 A System Nutrients and MLVSS:
During the recovery process
(a) Effluent MLVSS,MLVSS(M-UASB); (b) TKN,TP

removal efficiencies, approximately 91-97 %, a VFA/alkalinity ratio less than 0.5, and a sharp build up in biomass (MLVSS) in the sludge blanket, up to 1,700 mg/L. Nutrient requirements, measured as COD (total):TKN:TP inside the reactor at the sludge blanket level (sampling point no.6), was in the ratio of 36:4:1.

(b) System Recovery

Although the system returned to the initial level of operation by day 40, it is quite interesting to note that an accumulation of HPr and an increase in total VFA of the M-UASB occurred, as shown in Figure 17 (b); this is in agreement with results reported by Zoetemeijer et al, (1982). This might suggest that the system metabolic pathways shifted to a less favourable route; however, the pathways did shift back to more favourable ones after almost 20 days of loading reduction, as an increase in CH_4 gas production , % CH_4 content, and a linear reduction of Total VFA and HPr concentration were obtained. Rinzema (1988) indicated that a system using the UASB process, inoculated with granular sludge to stabilize VFA in the presence of H_2S concentration over 100 mg/L S, had a sharp drop of VFA removal efficiency, but recovered within 3-4 weeks.

To demonstrate how well the system recovered at each step of loading reduction, compared with the same loading rate during the maximization process, some modification and further analysis of the experimental results were made, as shown in Figure 5.19 and 5.20. COD (sol.) removal efficiency and CH_4 gas production were selected as main response parameters for this investigation, since superior supernatant quality and reasonable CH_4 gas production are the two main objectives of the anaerobic stabilization process. Figures 5.19 (c) and 5.19 (d) show the relationship between the actual running HRT and % soluble COD removal efficiency during the maximum loading and recovery period. Based on these relationships, COD removal efficiency at each discrete HRT starting from 1, 1.5, ... 4.5 days can be estimated during the maximization and recovery period. System recovery efficiency, defined as a percentage of COD removed during the recovery period over that of maximization at the same HRT, can then be calculated and graphed, as shown in Figures 5.19 (a) and 5.19 (b). Similarly, system recovery efficiency in terms of CH_4 gas production at each specific HRT during the maximization and recovery period can also be expressed, as shown in Figures 5.20 (a) - 5.20 (d).

Predictive models for this system recovery, with a high correlation (r^2=0.81-0.99), as shown in Figure 5.21, are formulated as follows:

$$Y = 25.37\ e^{0.29X} \qquad \text{(16)}$$

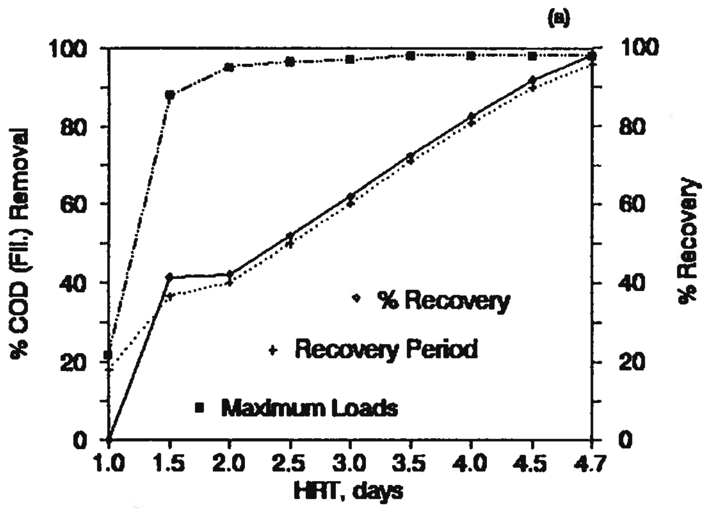
where Y = % COD (sol.) removal efficiency

X = HRT (M-UASB), days

For the CH_4 gas production, the predictive model is as follows:

$$Y1 = 9.25 + 64.01 \ln X1 \qquad \text{(20)}$$

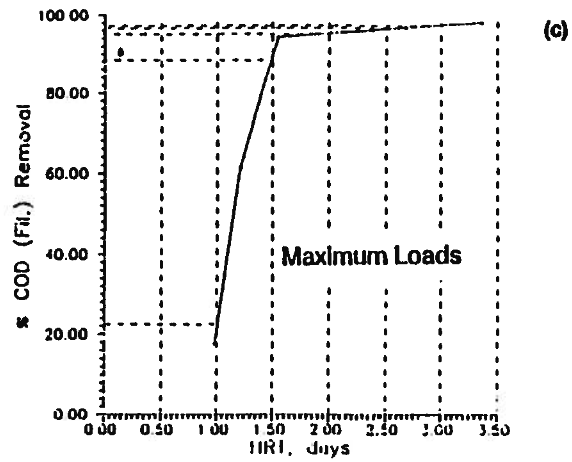
where Y1 = CH_4 gas production, L/d



(b)

HRT, days	% COD (Fil.) removal		
	Max.Loads	Recovery Period	% Recovery
1.0	22	18	0
1.5	88	37	41
2.0	95	40	42
2.5	97	50	52
3.0	97	60	62
3.5	98	71	72
4.0	98 *	81	83
4.5	98 *	90	92
4.7	98 *	96	98

Note:* Estimated values



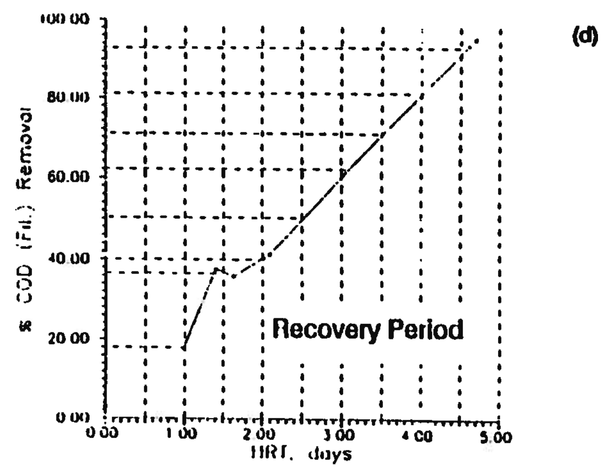
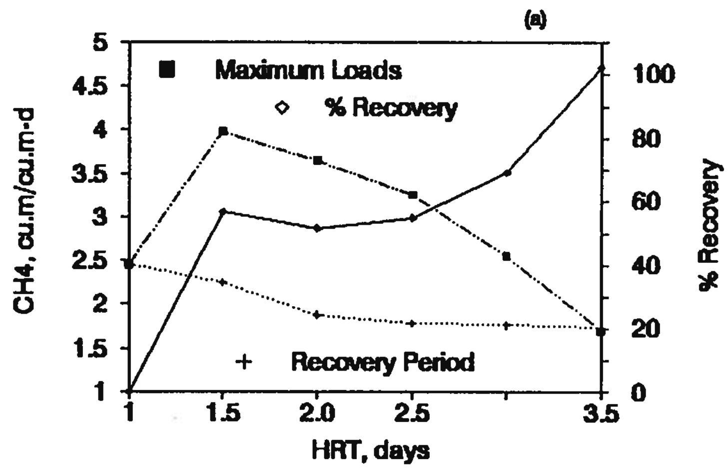
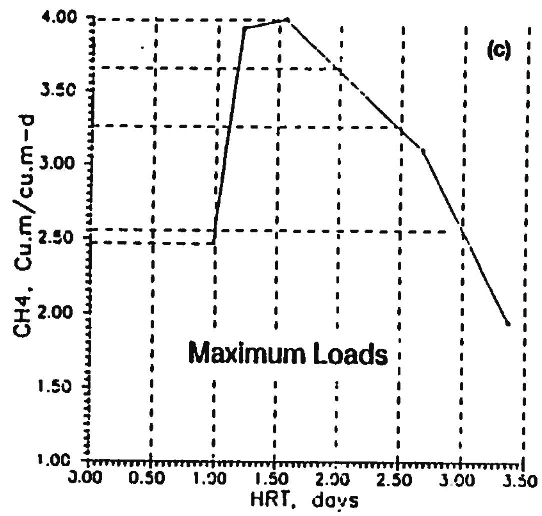


Figure 5.19 A M-UASB System Recovery at Pseudo Steady-state
With different running conditions
% COD (Fil.) removal



(b)

HRT, days	CH4, cu.m/cu.m-d		
	Max.Loads	Recovery Period	% Recovery
1	2.45	2.46	0
1.5	3.98	2.25	57
2.0	3.65	1.88	52
2.5	3.25	1.78	55
3.0	2.55	1.76	69
3.5	1.70	1.74	102



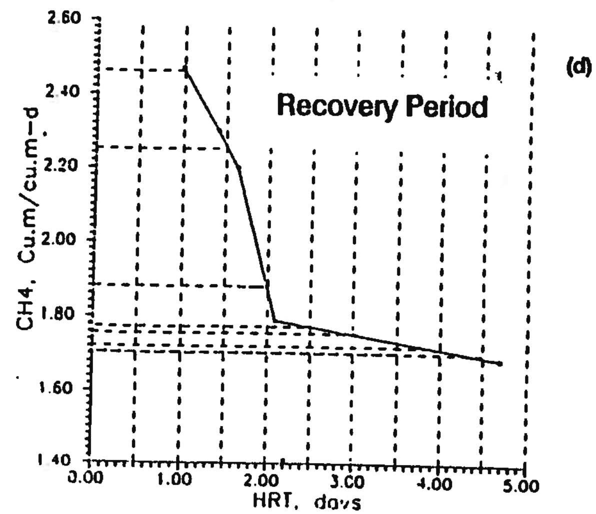
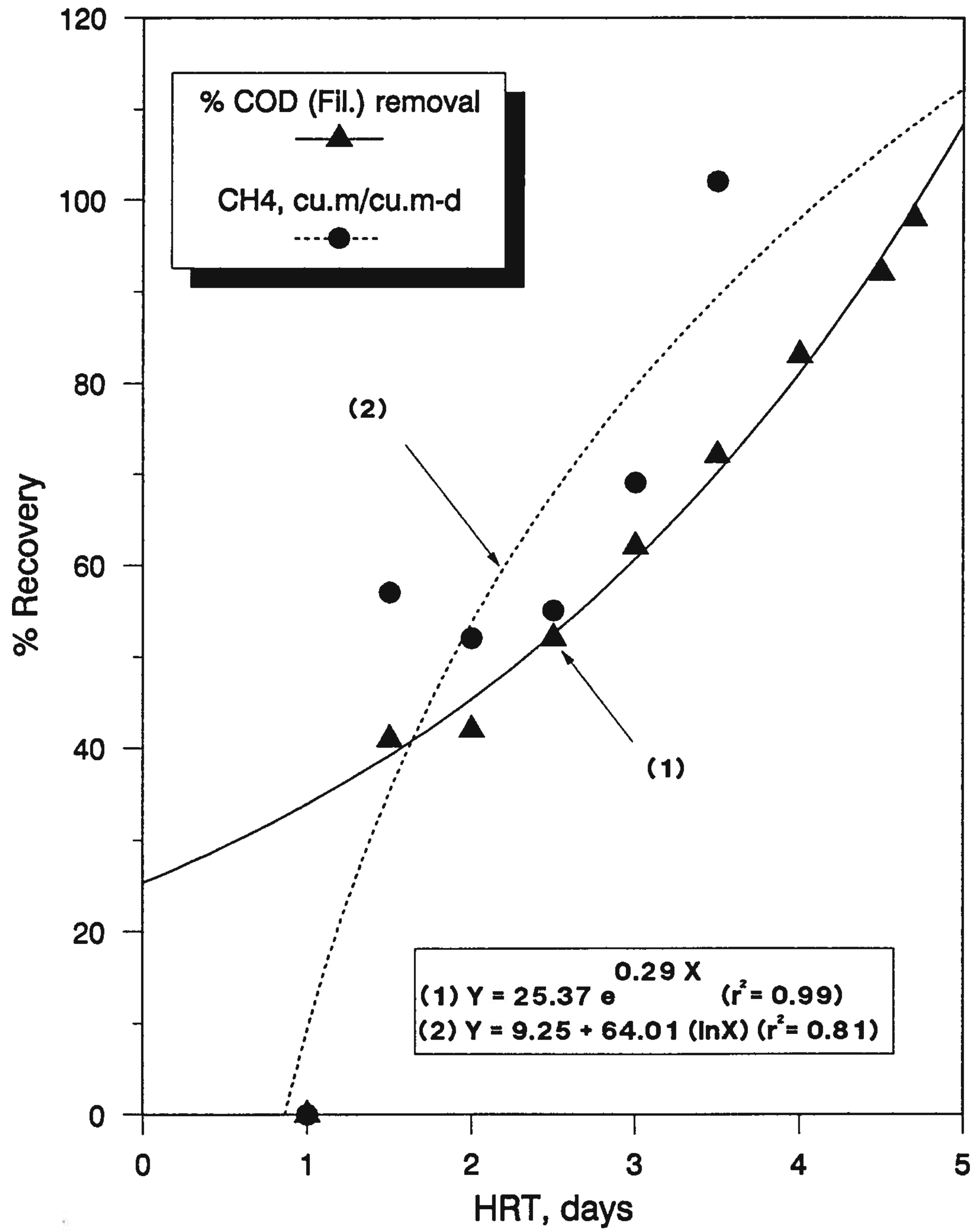


Figure 5.20 A M-UASB System Recovery at Pseudo Steady-state
With different running conditions
CH4, cu.m/cu.m-d

Figure 5.21 A Predicted M-UASB System Recovery Under Different Running Conditions



X1 = HRT (M-UASB), days

To meet the objectives of both pollution control and maximum CH_4 gas production, the optimum system HRT of 7.65 days and 4.25 days for the M-UASB (equivalent to 43 days of recovery period after complete system failure) were initiated in order to provide 92 and 100 % recovery of COD removal efficiency and CH_4 gas production, respectively. It is also interesting to point out that the breakthrough of system recovery is predicted at an $HRT_{M\text{-}UASB}$ of 1.5-1.7 days, resulting in more than 40 % recovery of both COD removal efficiency and CH_4 gas production, (as shown in Figure 5.21). The system then recovered back to the initial level at an HRT of 4.25 days. This observation leads to the conclusion that a two-step increase in HRT by 1.50 and 5.80 times that of the failure value $HRT_{M\text{-}UASB}$ of 0.625 days, is a most effective measure for complete recovery.

5.2.2.3 Basic Experimental Kinetics

Since the anaerobic stabilization process is considered to be bi-phasic in nature, thus requiring a balance between acid production and utilization, process stabilization and control may be possibly enhanced by physical separation of these two phases. Figure 5.8 confirmed the feasibility of the phase separation concept, as discussed earlier. Although the system achieved promising results, it would be interesting to know how the mixed culture of bacteria responded during both the maximization and recovery periods.

One way to achieve this is to predict the kinetic response governing the acid- and methane-phase reactors (A-UASB and M-UASB), under these situations. This prediction and estimation were based on the experimental data obtained at pseudo steady-state conditions, with a continuous step-loading rate during the maximization and recovery periods. It is important at this point to mention that this kinetic estimation is system dependent: process design and configuration, running conditions, feed characteristics, seed sludge and start-up procedure, and evaluation process. A comparison of these kinetic values with others must indeed take this dependency into account. The basic kinetic responses predicted here are expected to be higher than those cited in the literature, since synthetic substrate and continuous feeding (instead of batch feeding) were used, along with a prolonged period of acclimatization and experimental running of a well-adapted mixed culture of bacteria.

Because reactor kinetics governing the acid phase and methane phase are quite different, as a bi-phasic phenomenon, an estimation of the kinetics must be made accordingly. The rate-limiting step in the A-UASB reactor is the hydrolysis of particulate feed to soluble substrates, while methanogenesis is the predominant process in the M-UASB. The first-order hydrolysis constant (Kh) and percentage of particulate hydrolysis of the A-UASB, the yield coefficient (a), decay coefficient (b), maximum specific substrate utilization rate (K), and half-velocity coefficient (Ks) of the M-UASB were estimated, in order to provide a broad view of microbial response under different stresses.

The hydrolysis rate (Rh) follows an approximate first order reaction, with respect to the concentration of degradable particulate COD (Pavlostathis, 1986).

$$Rh = Kh*F \quad \text{.......................................} (17)$$

where Rh = hydrolysis rate

Kh = first-order hydrolysis constant

F = particulate COD concentration

A Mass balance around A-UASB at steady-state conditions yields:

$$Q(Fo-F)-V*Kh*F = 0 \quad \text{.......................................} (18)$$

where Q = Flow rate

Fo = Influent particulate COD concentration

V = Reactor volume

Dividing equation (22) by Q and rearranging yields:

$$\Theta = Fo/(\Delta F/\Theta) - 1/Kh \quad \text{.......................................} (18)$$

where Θ = HRT = V/Q, ΔF = Fo-F, and F*Kh = $\Delta F/\Theta$

By plotting Θ against $\Theta/\Delta F$, the intercept of this line is equal to 1/Kh, as illustrated in Figure 5.22 (c); the value of Kh is equal to 1.67 day^{-1} ($r^2 = 0.88$) during the maximization process, compared with 3.0 day^{-1} reported by Eastman (1981). Rajan (1989) also reported that the percentage of particulate hydrolysis was about 45 %, defined as the percentage of effluent soluble COD over total COD. However, in this evaluation, the difference between the effluent and influent soluble COD was used to calculate the percentage of particulate hydrolysis under different loading conditions, as shown in Figure 5.22 (d).

The relationship between the rate of microbial utilization of the substrate and the rate of bacterial growth can be expressed in terms of a mathematical model developed by Lawrence and McCarty (1970):

$$\delta S/\delta t = a\delta L/\delta t - bS \qquad (19)$$

where $\delta S/\delta t$ = net growth rate of microorganisms, mass/vol-time

a = growth yield coefficient, mass/mass

$\delta L/\delta t$ = substrate utilization rate, mass/vol-time

b = microorganisms decay coefficient, $time^{-1}$

S = microbial mass concentration, mass/vol.

Dividing equation (24) by S and rearranging yields:

$$(\delta L/\delta t)/S = a(\delta S/\delta t)/S - b \qquad (20)$$

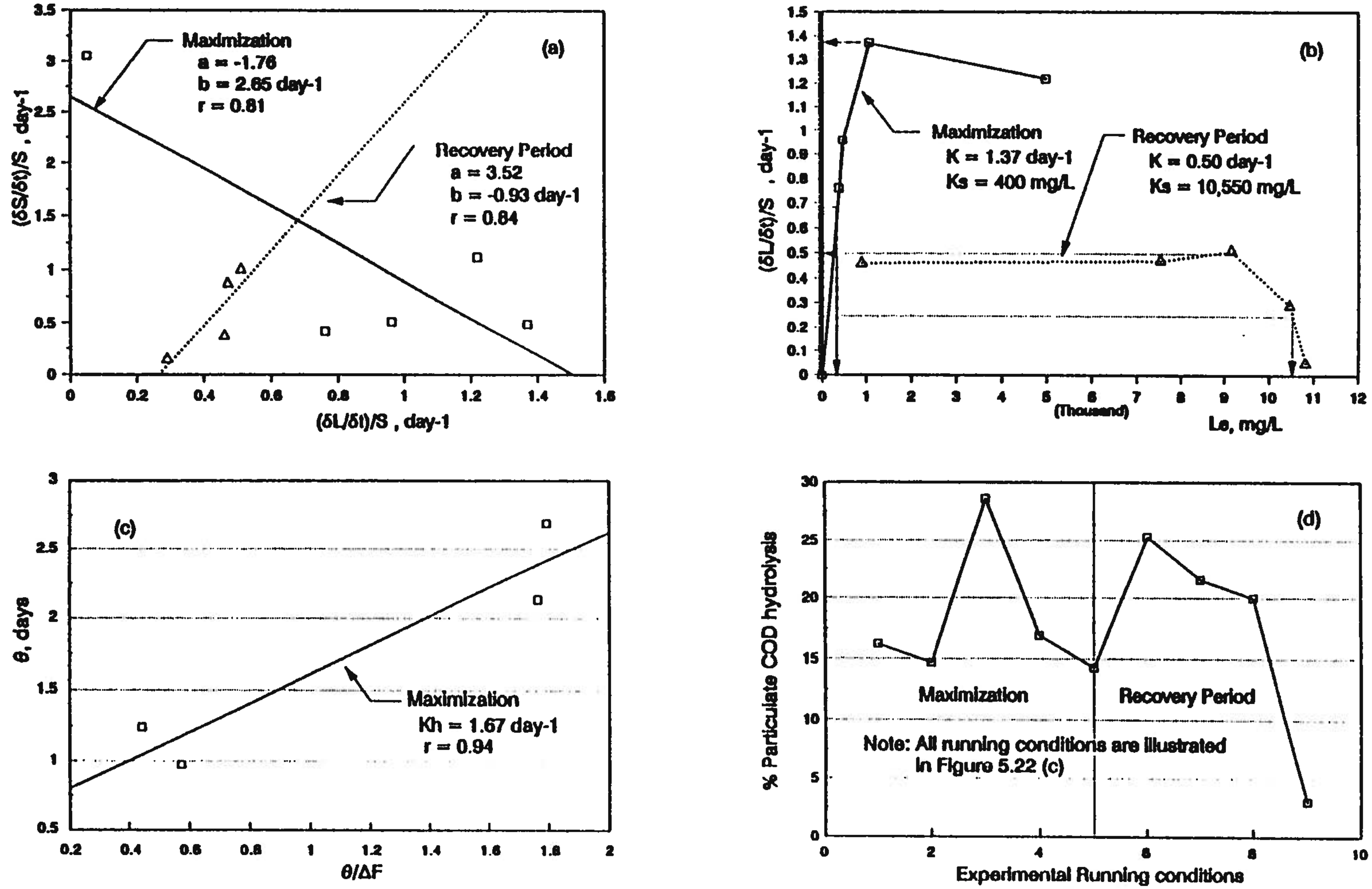


Figure 5.22 An Estimation of Experimental Kinetics
During maximization and recovery period
(a) a and b; (b) K and Ks; (c) Kh; (d) Particulate COD Hydrolysis

By plotting $(\delta L/\delta t)/S$ against $(\delta S/\delta t)/S$, a and b can be obtained as the slope and the intercept of the line, respectively, as shown in Figure 5.22 (a). The substrate utilization rate can also be related to substrate and microorganisms concentrations:

$$\delta L/\delta t = (kLeS)/(Ks + Le) \quad \text{...(21)}$$

where k = maximum rate of substrate utilization per unit weight of microorganisms, $time^{-1}$

Ks = half velocity coefficient, mass/vol, equal to substrate concentration when $\delta L/\delta t = (1/2)k$

Le = effluent substrate mass concentration, mass/vol.

L = influent substrate mass concentration, mass/vol.

Rearranging equation (26):

$$(\delta L/\delta t)/S = (kLe)/(Ks+Le) \quad \text{..(22)}$$

By applying the classic plot (Monod type) between $(\delta L/\delta t)/S$ against Le, the k and Ks values can be obtained, as shown in Figure 5.22 (b). In Table 5.4 and Figure 5.22 (a), the data show only a moderate correlation with the line (r^2 = 0.66-0.71) obtained by regression analysis, with "a" and "b" values particularly suspect. However, despite these shortcomings, one of the kinetic coefficients, in particular, does show some evidence of what may be happening inside the M-UASB during maximization and recovery periods. During maximization, as the loading rate increases step-by-step, the k value is about 1.4 day^{-1}, compared with 0.50 day^{-1} during the recovery period.

Table5.4 Statistical Constants and Kinetics During the Maximization and Recovery

Table 5.4 Statistical Constants and Kinetics During maximization and recovery period

Kinetics Coefficients and constants	A-UASB		M-UASB	
	Maximization	Recovery period	Maximization	Recovery period
n	4		5.00	4.00
r	0.95		0.80	0.85
Kh	1.70			
δx			0.75	1.70
a			(1.80)	3.50
b			2.65	(0.95)
K			1.40	0.50
Ks			400	10,550
%Par.COD Hydrolysis	14-29	3-26		

Note: n = number of data point

this tendency seems to reverse itself during the recovery period, as the loading rate is decreased step-by-step, (as shown in Figure 5.22 (b)). This result is in agreement with those reported by Chen (1978) where k was practically constant at low influent loadings but it increased rapidly at high loading rates. Unfortunately, none of the other coefficients lend themselves to definitive conclusions at this time and a more detailed "kinetic study" would be needed to advance any hypotheses further. Such an in-depth analysis could not be justified in this study.

5.2.2.4 Optimum Loading Capacity

Since this process is a two-phase UASB-UASB system, optimum loading capacity should be considered separately as A-UASB and M-UASB. However, if the system is considered as a whole, the optimum loading capacity of the M-UASB is really the system loading capacity, because the maximum space loading capacity of M-UASB is the rate-limiting step of the whole system. However, the optimum loading capacity of the M-UASB is not necessarily the optimum one for the A-UASB. In fact, the latter can handle a higher loading rate because the growth rate of acidogens is predominant and significantly greater than methanogens. To optimize the system loading capacity with respect to pollution control and CH_4 gas production, the following two particular cases are presented:

(a) Case 1: Overall System Loading Capacity

System loading capacity is dependent largely on system configuration and operational conditions. Differences in the configuration and operating conditions can affect the optimum system loading capacity. Figure 5.23 shows the optimum operating condition at 2 and 2.7 days HRTs for the M-UASB, resulting from two predictive models of COD removal efficiency and CH_4 gas production during the system maximization and recovery periods, respectively. These models are formulated based on the COD (sol.) removal efficiency and CH_4 gas production relative to the HRT of M-UASB as:

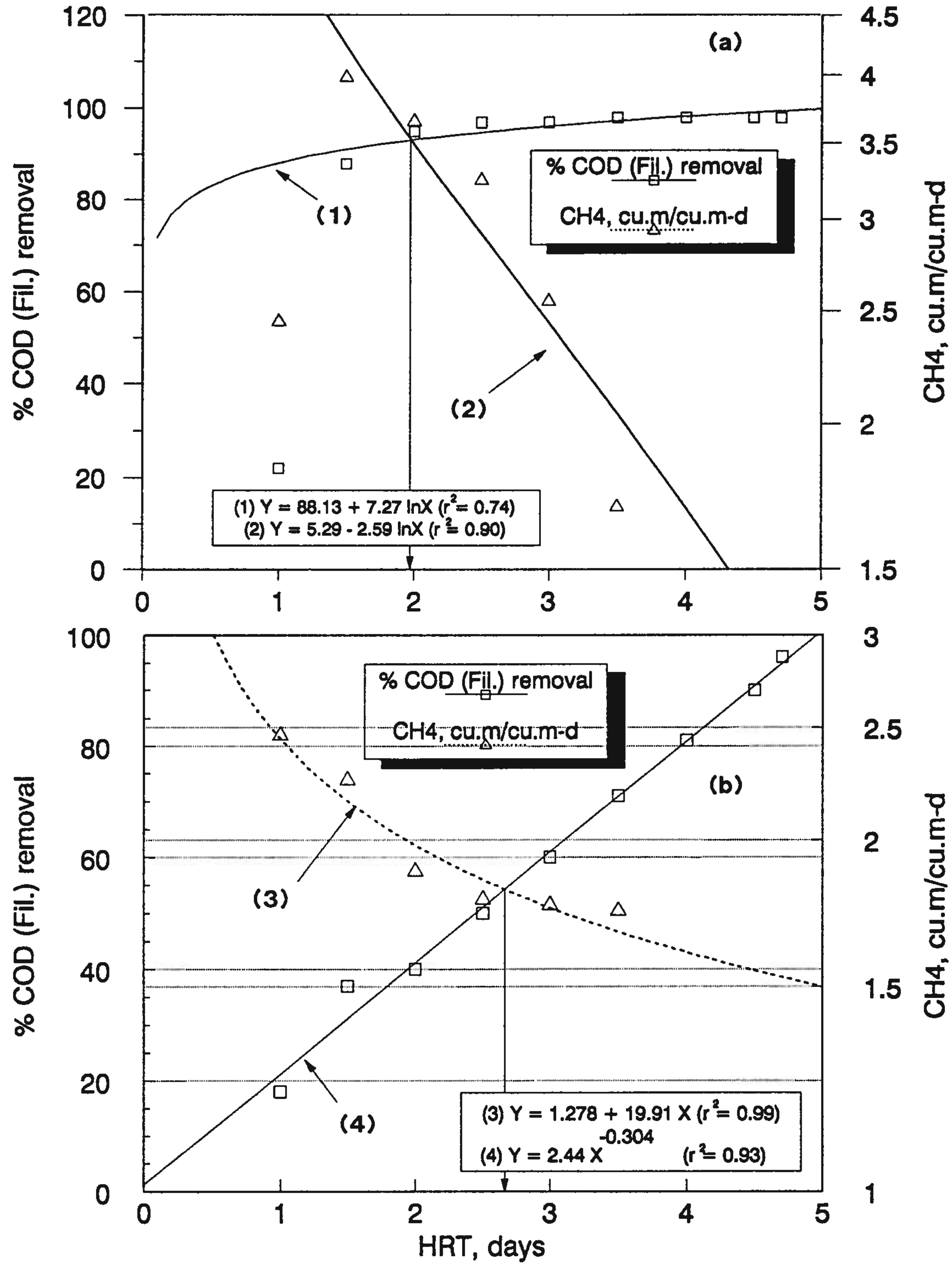


Figure 5.23 A Predicted Optimal Operating HRT
(a) Maximization Process;(b) Recovery Period

During the maximization process:

$$Y2 = 88.13 + 7.27 \ln X2 \quad (23)$$

where Y2 = % soluble COD removal efficiency

X2 = HRT (M-UASB), days

$r^2 = 0.74$

For CH_4 gas production, the predictive model is as follows:

$$Y3 = 5.29 - 2.59 \ln X3 \quad (24)$$

where Y3 = CH_4 gas production, L/d

X3 = HRT (M-UASB), days

$r^2 = 0.90$

During the recovery period:

$$Y4 = 2.44\, X4^{-0.304} \quad (25)$$

where Y4 = % soluble COD removal efficiency

X4 = HRT (M-UASB), days

$r^2 = 0.93$

For CH_4 gas production, the predictive model is as follows:

$$Y5 = 1.278 + 19.91\, X5 \quad (26)$$

where Y5 = CH_4 gas production, L/d

X5 = HRT (M-UASB), days

$r^2 = 0.99$

As shown in Figure 5.23, the overall optimum system operating condition is predicted at an HRT of 2.0 days, with 90 % COD (sol.) removal efficiency and 3.6 m^3/m^3-d of CH_4 gas production. This optimum HRT corresponds to the optimum point obtained from the CO_2 and VFA/alkalinity ratio data at HRTs from 1.5-2.25 days, as shown in Figure 5.13 and 5.14. Figure 5.15 indicates an optimum flow rate of 16.10 L/d, equivalent to an HRT of 1.55 days with 95 % COD removal efficiency and approximately 75-80 % of the theoretical CH_4 gas production. The optimum RR's are then calculated as 1.6 and 2.5. Ghosh (1984) suggested that HRTs of 0.9 - 1.5 and 4.0 - 5.0 days are optimum for A-and M-UASBs reactors respectively, and Chang et al. (1989) reported that an HRT of 2 days was the optimum for the A-UASB. Approximately 77% of the theoretical CH_4 gas production (0.48 m^3/kg VS added at standard temperature and pressure) was achieved through the use of a two-phase UASB-UASB process at HRTs of 5.5 and 5.9 days respectively (Ghosh, 1984). In principle, the minimum SRT for methanogens is in the range of 2.5-4.0 days (Eastman,1981; Andrews, 1965; Torpey, 1955; Bergman, 1966; and Anderson, 1978). US.EPA (1979), recommends that the optimum SRT is equal to the minimum SRT plus a safety factor of 2.5. Applying the EPA recommendation to this particular case, assuming that the minimum SRT (zero removal efficiency) is equivalent to the maximum HRT, the optimum HRT is then equal to approximately 1.6 days, corresponding to a maximum failure flow rate of 40.22 L/d, considerably higher than found in this study. (A summary of average responses and performance at each pseudo steady-state, under different running conditions, is shown in Table D1.1 of Appendix D).

Considering the optimum HRT obtained from this experimental research (1.5-2.25 days as mentioned earlier), the optimum HRTs cited in several publications, as well as the one calculated based on the US.EPA recommendation, it is reasonable and safe to suggest that the optimum operating HRT's for the M-UASB and the overall system, are 2.0 and 4.0 days respectively. This 2-day HRT is a slightly lower than the minimum range of 2.5-4.0 day SRT recommended for methanogens mentioned above; however, in this case, it is reasonable since the designed system is a two-phase one, providing the optimum environment to stimulate the growth of methanogens. It is also equipped with a recycle facility to increase the contact between microorganisms and substrate as well as to increase the system bufferring capacity. Moreover, it is interesting to note that this optimum HRT of 2 days, predicted from the experimental results during the maximization process, is shorter than that of 2.7 days HRT obtained at the recovery period, as shown in Figure 5.23. This may be the result of a shift in the microbial structure (a change in predominant bacterial communities and their microenvironment, and a difference in biochemical pathways) of the acetogenic and methanogenic bacterial community inside the M-UASB.

(b) Case 2: Optimum Loading Capacity of A- and M-UASBs

The optimum 2-day HRT of the M-UASB, recommended earlier in case (a), equivalent to a flow rate of about 16 L/d, is not necessarily the optimum one for the A-UASB, since the growth rate of acidogens is predominant in the A-UASB. From Figure 5.24 and Table D1.1 of Appendix D, it can be concluded that running condition no.4, at an A-UASB HRT of 1.0 (0.97) days and equivalent to a flow rate of 20 L/d, is the optimum loading capacity. This is in agreement with the optimum range of 0.9-1.5 day HRT for acidogenic reactors reported by Ghosh (1984). At this optimum running condition during the maximization period, the A-UASB generated the highest VFA/alkalinity ratio of 7.5 at day 40, with effluent COD (sol.) of 11,055 mg/L and total VFA production of 5,300 mg/L as HAc. The MLVSS concentration of the A-UASB also increased significantly up to 42,150 mg/L, but there was only a small change in the effluent TKN and TP concentrations, as shown in Figure D1.1 and D2.1 of Appendix D. It is interesting to note that the total VFA and the VFA/alkalinity ratio of the A-UASB increased significantly during the recovery period, as shown in Figure 5.24 (b). This may be the result of the ability of the A-UASB to tolerate shock-loads, and to stimulate the reactor's activity (Lettinga, 1979a). The optimum HRT ratios between A-and M-UASBs, and also between A-UASB and the overall system, are about 0.60 and 0.40 ,respectively (Details in Table D1.1 of Appendix D). Dinopoulou (1989) reported that the optimum volume of the acidogenic reactor was in the range of 12-25 % of the overall active

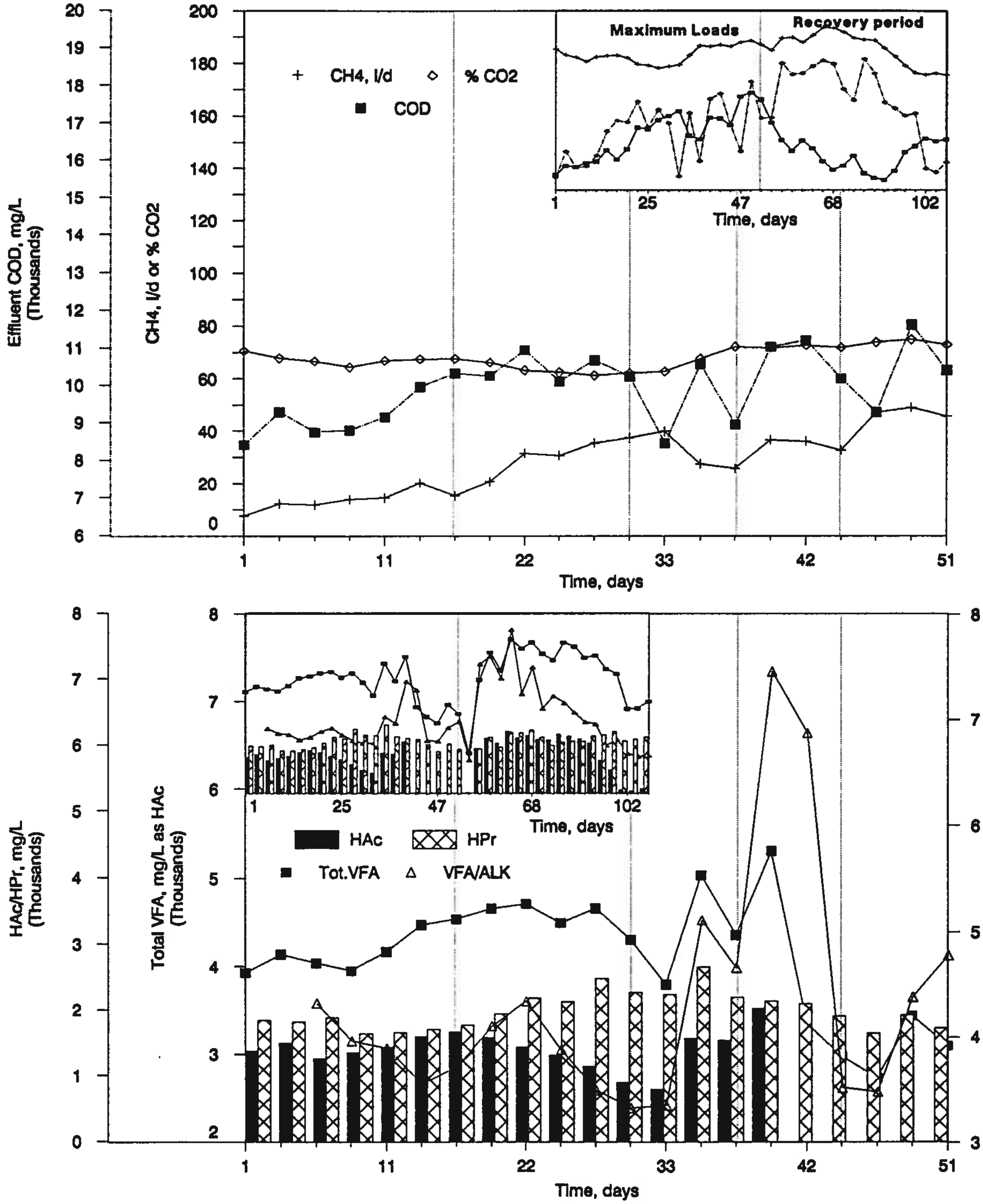


Figure 5.24 An A-UASB System Effluent Qualities:
During the process maximization
(a) CH4 production,%CO2,Eff.COD; (b) Total VFA,HAc/HPr,VFA/Alkalinity

volume in a study, using a two-phase anaerobic digestion system with CSTR acidogenic reactor and a methanogenic fluidized bed reactor to stabilize a synthetic wastewater. The difference in the HRTs ratios in this case may result from a longer hydrolysis rate of the particulate synthetic sludge taking place in the UASB-UASB process, compared with the shorter hydrolysis rate for the synthetic wastewater.

5.2.2.5 Conclusions

From both system performance and kinetic considerations, it appears that the UASB-UASB system can recover to its original performance by applying a step-down loading approach. Although the performance, in terms of % COD removal efficiency and % CH_4 content, recovered to the original values, the total CH_4 gas production was reduced and the optimum operating point between COD removal efficiency and gas production was moved a little further. This means that there was a total shift of the species ratio among the mixed culture of acetogens and methanogens inside the M-UASB after the recovery process. Based on the results of these studies, the following conclusions can be drawn:

(1) A combination of hydraulic and organic overloading of the M-UASB reactor was a major cause of process failure; this can result in MLVSS washout, increase in total VFA concentration, reduction of the system removal efficiency, and cessation of CH_4 gas production.

(2) A drop in pH and an increase in total VFA/alkalinity ratio, a reduction of CH_4 gas production, and an increase in the effluent total VFA, were also indicators of the process failure.

(3) The maximum hydraulic loading rates were 1.6 and 0.90 m^3/m^3-d, equivalent to HRTs of less than 1.125 and 0.625 days, for the M-UASB and the whole system, respectively. The CH_4 gas production was reduced to less than 50 % of the theoretical value, with effluent COD and total VFA of 9,540 mg/L and 3,750 mg/L as HAc, respectively.

(4) The M-UASB recovered exponentially with an increase in HRT (loading reduction) in term of COD removal efficiency, but logarithmically with respect to CH_4 gas production, as follows:

$$Y = 25.37\ e^{0.29X}$$

$$Y1 = 9.25 + 64.01 \ln X1$$

where Y = % soluble COD removal efficiency

X = HRT (M-UASB), days

$Y1$ = CH_4 gas production, L/d

$X1$ = HRT (M-UASB), days

The system did recover back to its initial stage of operation by applying a two-step increase of the $HRT_{M\text{-}UASB}$ at 1.5 and 5.8 times the failure HRT, with a dimensional time of 5.60 and 10 for the M-UASB and the overall system, respectively.

(5) The shockloads appeared to stimulate the A-UASB's activity during system recovery, but it appeared to have no effect at all on the M-UASB, when the system failed completely. The recovery approach, employing the step-loading reduction and the internal RR, seemed to have no significant beneficial effect, compared with the re-acclimatization in term of time requirement (both needed 4-5 weeks to complete the processes). However, it did provide some advantages in terms of ease of operation and a more practical approach for a potential full-scale operation.

(6) The hydrolysis rate governing the A-UASB was about 1.70 days. The specific velocity k during the maximization and recovery periods, was 1.40 and 0.50 day^{-1}, respectively. The corresponding substrate saturation coefficient (half velocity constant, Ks) was found to be 400 and 10,550 mg/L during the maximization and recovery period, respectively.

(7) The optimum HRT for the A-UASB was 1.0 (0.97) days, whereas, those for the M-UASB, with respect to COD removal efficiency and CH_4 gas production, during the maximization and recovery period, were 2.0 and 2.7 days, respectively. This seems to imply there was a restructuring of the bacterial community inside the M-UASB, during the recovery period. For design purposes, the optimum operating HRT's of 1 and 2 days, as well as the RR of 1.6 and 2.5 times the influent flow rate, are recommended for A- and M-UASBs, respectively, with a conservative organic loading rate of 19 kg COD(total)/m^3-d (equivalent to 0.55 m^3/m^3-d).

(8) The optimum $HRT_{A\text{-}UASB}/HRT_{M\text{-}UASB}$ ratio was about 0.60 and the $HRT_{A\text{-}UASB}/HRT_{system}$ was 0.40, as applied to the two-phase anaerobic digestion of sewage sludge (UASB-UASB).

5.2.3 Development of System Design Criteria

The main research goal was to evaluate the feasibility of the two-phase anaerobic digestion (UASB-UASB) concept, to stabilize a particulate substrate. The following sections, deal with the system effectiveness (or performance), system suitability (or loading capacity), and system feasibility, followed by a modification of design criteria and operation procedures. Finally, major system control parameters are evaluated and discussed.

5.2.3.1 Optimum System Performance and Feasibility

The optimum system HRT of 2.80 (1.24+1.55) days equates to a hydraulic loading rate of 0.40 m^3/m^3-d. The overall soluble and total COD removal efficiencies were 90.76 and 98 %, respectively, with 69 % CH_4 content and 179 L/d of CH_4 gas production (/equivalent to 73 % of the theoretical value). Average pseudo steady-state system performance and effluent quality, at the optimum running condition, are summarized in Table 5.5. It is interesting to point out that there was actually some PO_4-P (and/or TP) removal, but rarely NH_4-N (and/or TKN) removal as shown in Figure 5.14. This may be due to chemical reactions forming precipitating salts of Ca and/or Mg phosphate. However, there was a small change in NH_4-N (and/or TKN) concentration, since NH_4-N can be used as a release-and-apprehend ion to maintain the balance of buffer capacity

Table 5.5 Summary of Average Responses at the Optimal System Operating Condition Under Pseudo Steady-State Conditions

Average Responses Processes	Experimental Running Condition 2-phase (UASB-UASB)
Running Period, days	36
Sludge Feed Ratio (SR)	80/20
Recycle Ratio (RR)	2/3
Influent Flow, l/d	16.10
HRT, days	
A-UASB	1.25
M-UASB	1.55
System	2.80
Loading Rate	
cu.m/cu.m-d	0.35
KgCOD(sol.)/cu.m-d	2.15
Effluent Quality	
Solids, mg/L	
TS	2850
VS	1230
TSS	185
TVSS	110
COD , mg/L	
Total COD	680
COD(sol.)	550
Inorganics, mg/L	
NH4-N	300
TKN	400
TP	85
PO4-P	15
VFA , mg/L	
HAc	40
HPr	65
Iso - HBr	0
HBr	5
A - HVr	0
Iso - HVr	0
HVr	0
HHe	0
Total VFA mg/L as HAc	95

Table 5.5 Summary of Average Responses at the Optimal System Operating Condition Under Pseudo Steady-State Conditions (cont'd)

Average Responses Processes	Experimental Running Condition 2-phase (UASB-UASB)
Alkalinity, mg/L as CaCO3	
A-UASB	960
M-UASB	2520
Total VFA/Alk	
A-UASB	4.90
M-UASB	0.05
System Removal Efficiency	
Solids, %	
TSS	99.00
COD, %	
COD(sol.)	91.00
Total COD	98.00
Inorganics, %	
PO4-P	88.00
TP	39.00
Methane Gas	
Flow, l/d	
Total Gas	310.00
CH4 Gas	180.00
CH4 Productivity	
l/d	180.00
cu.m/cu.m-d	4.00
cu.m/cu.m-d@SC	3.50
cu.m/kgCOD(Total)added @SC	0.25
% of theoretical CH4 Production	73.00
% CH4 content	69.00

of the M-UASB, as well as a basic growth nutrient.

It is difficult to compare the performance of different processes, since each process has its own unique characteristics, configuration, and operating conditions. However, the optimum system performance and effluent quality can be used as guidelines to evaluate both effectiveness and suitability, possibly leading to an evaluation of system feasibility. As shown in Table 5.5, it is clear that the two-phase UASB-UASB concept, at an extremely low operating HRT (2.8 days), performs reasonably well with CH_4 gas production of about 73 % theoretical CH_4 value, effluent COD of 550 mg/L, and volatile acids of 95 mg/L.

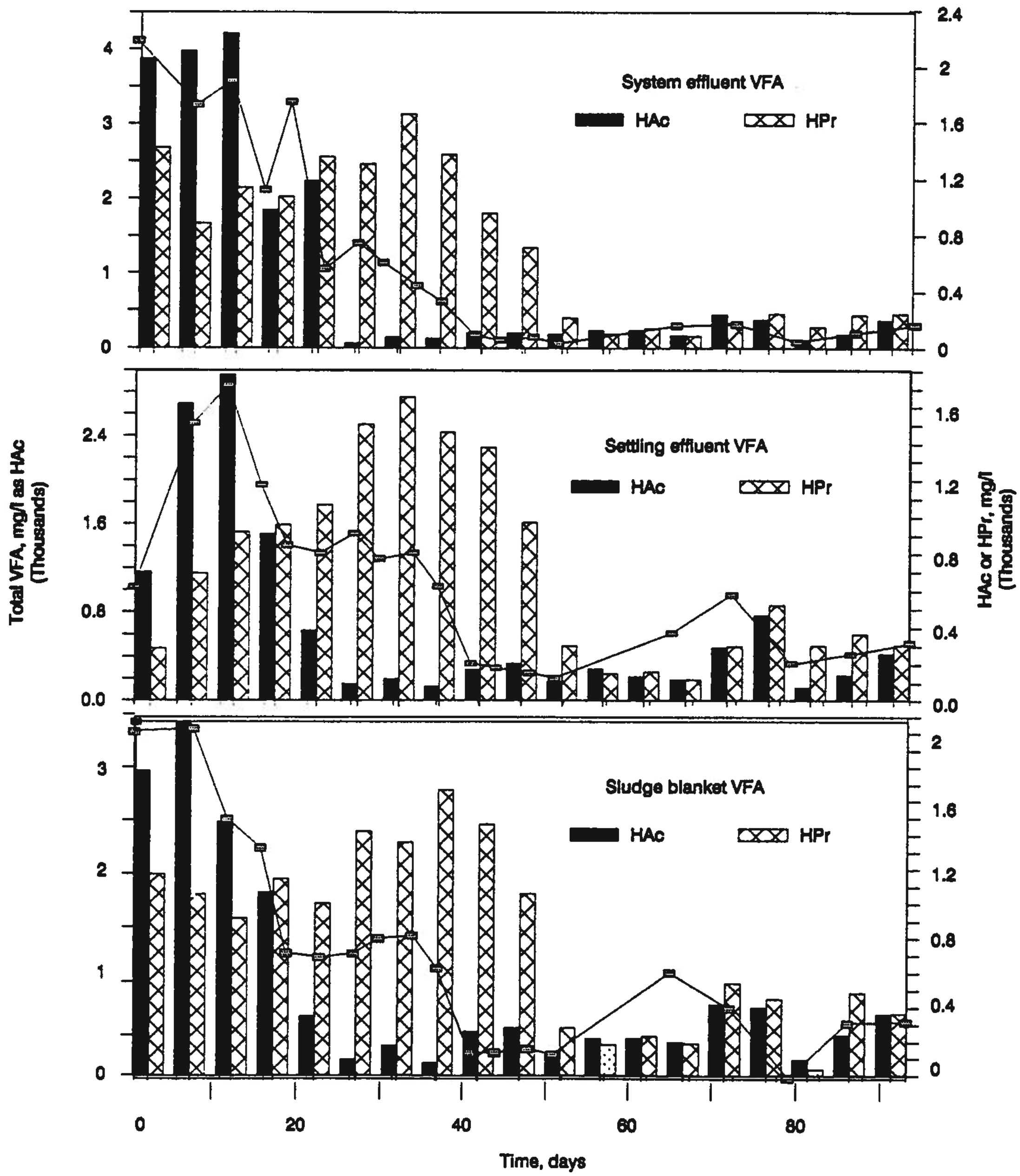
The internal RR appears to play a major role in controlling and maintaining the system performance by increasing the contact between microorganisms and substrates, reducing the effect of shock loading, and increasing the system buffering capacity. Combining influent loading rate control and appropriate RRs, it is thus possible to maintain a good system performance or to assist in recovering the system, in case of an interruption and/or failure.

5.2.3.2 Modification of Design Criteria and Operation

Development of anaerobic digestion system design has recently moved towards "high rate" digestion systems. Each system has its own merits, limitations, and potential, and depends largely on the local situation, characteristics of the wastes to be treated, and the performance and specific experience of each system designer in each type of system configuration. Although the two-phase anaerobic digestion concept works exceptionally well, compared with a single stage one, there is still no universal, two-phase digestion configuration that is optimum for all situations. The choice of the fermenter type depends largely on the physical, chemical and biological characteristics of the feed and the objective of treatment, ie., whether it is pollution control or maximization of CH_4 gas production. The design of the two-phase UASB-UASB process must ensure a uniform distribution of influent feed at the lower part of the reactor, a sufficient cross-section to prevent biomass entrainment, and an effective separation of gas, biomass, and liquid.

The keys to the successful anaerobic stabilization processes are to increase the contact between microorganisms and substrates as well as to increase the system bufferring capacity. Sludge recycling also plays a major role in these aspects, which subsequently improves the process performance and stability. Based on the results of this study, optimum design HRT's for A-and M-UASB's reactors are about 1 and 2 days, with RRs 2 and 3 times the influent flow rate, respectively. Most of the reactions seem to occur at the lower part of the reactors (sludge bed and blanket portion). As shown in Figure 5.25, there is no difference in the effluent VFA concentration profile from the bottom to the upper part of the M-UASB reactor. Possible reasons for this phenomenon may be due to high concentrations of active anaerobic sludge in the lower part of the reactor, the effective mixing created by the incoming flow rate, the upward escape of the produced gas, and the recycle of the effluent from the sludge blanket. All these factors

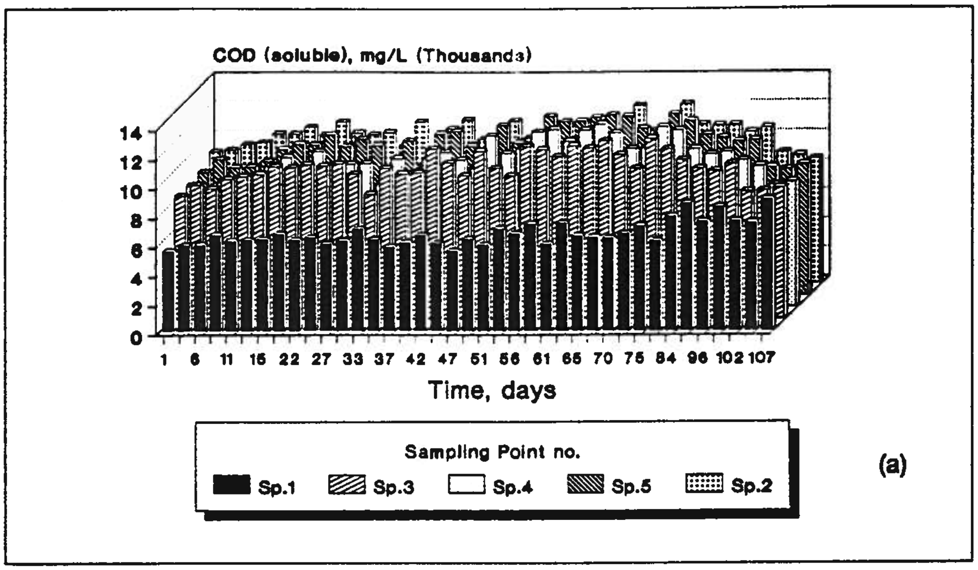
Figure 5.25 Comparison of Total VFA Along the Height of M-UASB:
During the Acclimatization Process

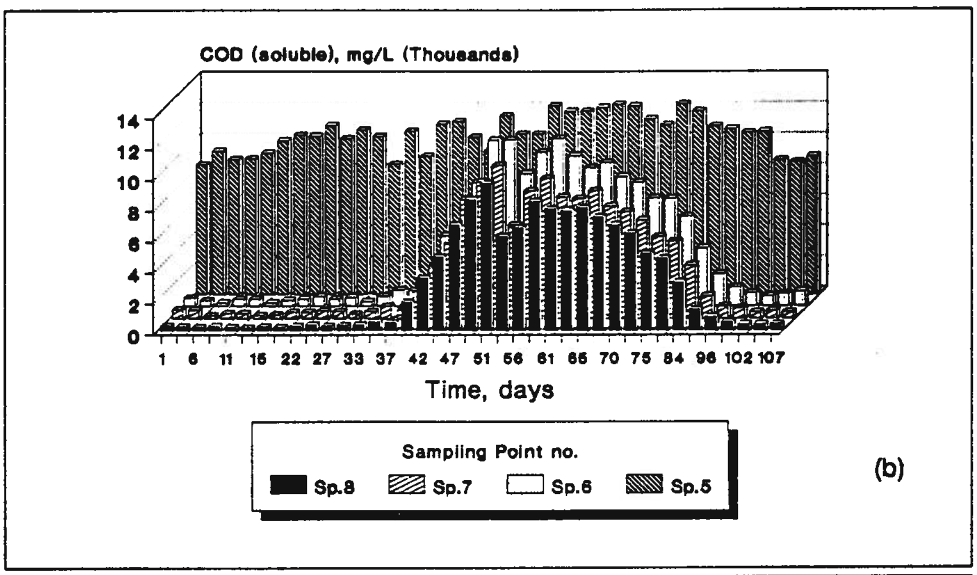


contribute to increase the removal efficiency at the lower part of the reactor.

Christensen (1984) found that COD removal occurred throughout the sludge bed and blanket of an UASB reactor. As shown in Figure 5.25 and 5.26, there was small change in effluent COD (sol.) profiles of both A-and M-UASBs, after the sludge blanket portion (sampling point no.3 and 6 as shown in Figure 4.2) during the acclimatization and maximization/recovery period. These results lead to the conclusion that the reactor height could have been reduced to 50 cms without any effects on the process performance. The ratio of reactor diameter to height could then be as low as 1:4 (12.5/50). However, for design purposes, this ratio should be closer to 1:8 to 1:10 (depending on safety factor chosen), to ensure that extra space is provided for temporary gas accumulation and for scum formation.

It is also important that peak hydraulic loading be taken into account for the design of digester volume. The design system hydraulic loading rate is conservatively set in the range of 0.55 m^3/m^3-d equivalent to 19 kg COD (total)/m^3-d, at 35 °C with an SR80/20 and RR1.6/2.5. Since most municipal wastewater treatment processes produce a sludge ratio (SR) of about 60/40 (by weight), the optimum ratio of this study (80/20) can be modified to compensate for the excess amount of waste activated sludge (WAS) produced. This can be done by either increasing the ratio of WAS portion or using the excess amount, which is full of nutrients (N and P), for soil conditioning and/or composting. A summary of recommended design criteria / start-up and acclimatization / and operation for the two-phase anaerobic digestion of sewage sludge (UASB-UASB) process is illustrated in Table 5.6.





Experimental running conditions | **Experimental Periods** (c)

System HRT, days		Days
5.65 - 6.84	Maximization	1 - 15
4.65 - 5.16		20 - 29
2.76 - 3.16		33 - 37
2.13 - 2.20		40 - 44
1.55 - 1.82		47 - 51
2.30 - 2.77	Recovery Period	54 - 58
2.71 - 3.21		61 - 65
3.63 - 3.95		68 - 72
7.32 - 9.00		75 - 107

Figure 5.26 COD (soluble) Profiles of a Two-phase UASB-UASB Process: During Maximization and Recovery Period
(a) A-UASB; (b) M-UASB; (c) Running Conditions
Note: All sampling locations are illustrated in Fig.4.2

Table 5.6 Recommended design criteria / start-up and acclimatization and operation of a two-phase anaerobic digestion of sewage sludge (UASB-UASB) process

Design criteria	Values	
Optimum HRT, days		
A-UASB	1.00	
M-UASB	2.00	
RR, Qr/Qin		
(Lower 1/3 of the reactor height)		
A-UASB	2.00	
M-UASB	3.00	
Reactor diameter/height ratio	1:10	
Gas collection aperture, m3/m2-d	0.70	
(Mid of the reactor height with 50 degree inclined wall)		
Organic Loading Rate,kgCOD(total)/m3-d	19.00	
Start-up and acclimatization		
System seeding ratio	1:1	
Start-up loading rate, kgCOD/kgVSS-d	0.10	
Step-up loading rate if:		
COD(sol.) removal efficiency, %	>80	
HRT, days	2-3	
pH control, 0.1 N, NaOH		
A-UASB	5.0-5.3	
M-UASB	7.0-7.3	
Temperature, o C	35.00	
SR	80/20	(a)
RR	4/7	(a)
System Operation		
Hydraulic loading rate, m3/m3-d	0.35	
pH values		
A-UASB	5.0-5.3	
M-UASB	7.0-7.3	
Temperature, o C	35.00	
SR	80/20	(a)
RR	2/3	(a)
Recovery Process		
2-step increasing HRT (where Q = Failure HRT)	1.5Q/5.8Q	(a)

Note: (a) = n1/n2,where n1 = A-UASB and n2 = M-UASB

To operate the system successfully and effectively, proper start-up and acclimatization are very important steps; also, close monitoring of several major control parameters is

absolutely necessary to maintain an acceptable performance. pH is one of the most sensitive and practical control parameters used to monitor the anaerobic stabilization process (as shown in Figure 5.27). A significant drop and rise in pH during the process failure and recovery period demonstrates the effectiveness of this control parameter. It is also interesting to point out that the pH values of A-and M-UASBs are practically constant at 5.0-5.3 and 7.0-7.3 respectively, indicating that both reactors are naturally buffered by themselves. This may result from a balance between the NH_4-ions, cations released from the fatty acid salts, and HCO_3-ions formed by CO_2, contributed partly by the recycling process in both reactors and helping to increase and stabilize the buffer capacity (Trudell, 1985).

Remedial actions should be quickly made if there are significant changes in system control parameters that are providing an overall picture of what happens inside the reactor under different circumstances. Hydraulic loading reduction and recycling facility are effective measures in recovering the system, by increasing the system buffering capacity and providing the methanogens a better opportunity to contact with substrates and survive under this stress conditions. pH adjustment with an alkaline addition is another promising measure to alleviate the problem. Therefore, a combination of these measures may be necessary if the system is severely damaged. All of these measures are designed to avoid a system washout, if at all possible.

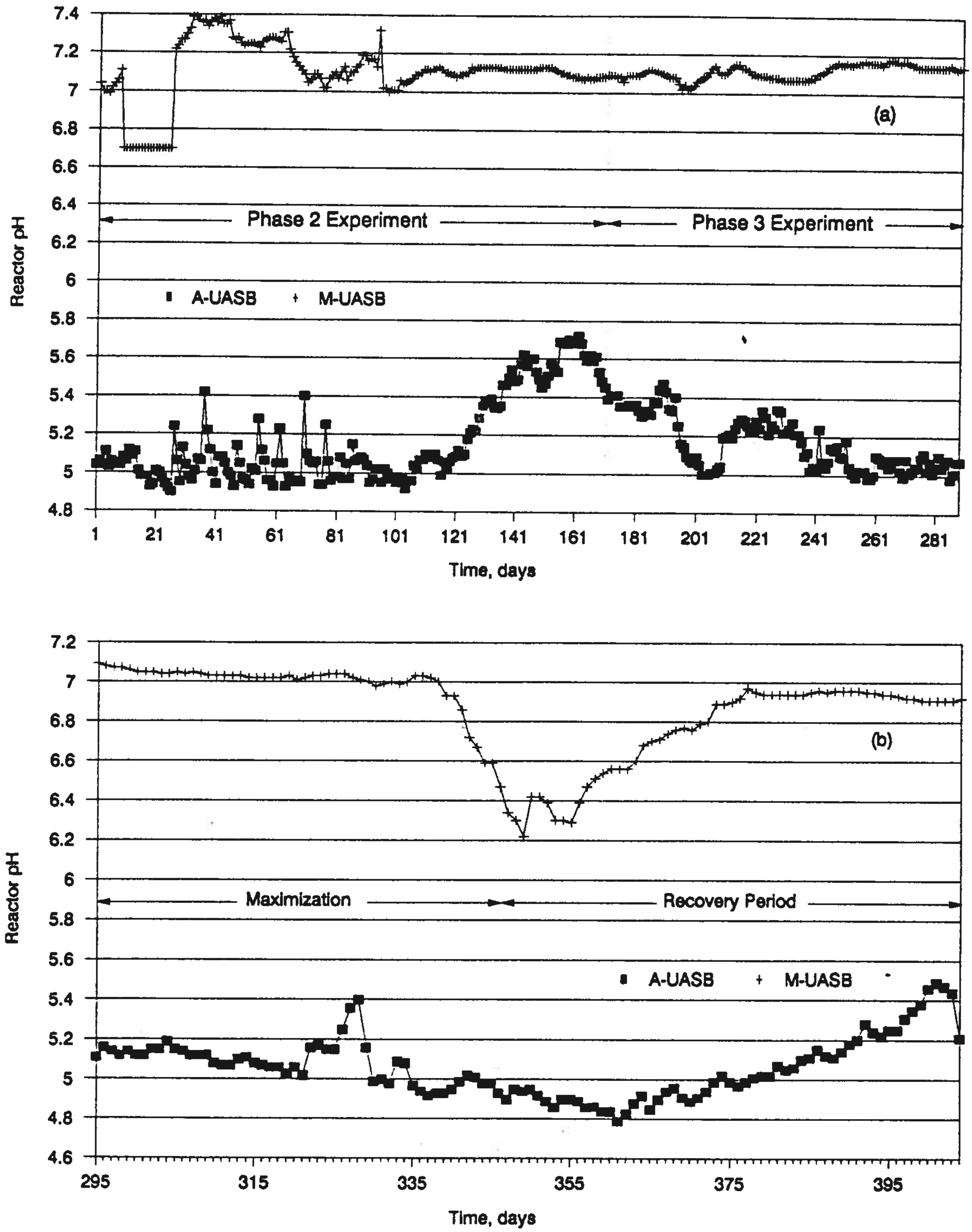


Figure 5.27 pH Variation in A-UASB and M-UASB:
(a) Sequence 2 and 3 Experiments; (b) Maximization and Recovery Period

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Modification and improvement of a process configuration, start-up and acclimatization, and system operation of a two-phase UASB-UASB process have been studied. The system appears to be feasible, effective, and suitable for stabilizing sewage sludge, with promising results. Based on the results of this research program, the following major conclusions can be made:

(1). A two-phase UASB-UASB process appears to be feasible and effective for stabilizing sewage sludge, with a high organic loading rate, while maintaining an acceptable level of supernatant quality and CH_4 gas production. The system also has a high potential to recover effectively after a serious failure, using a step-loading reduction and internal recirculation (RR) approach. The "Two-phase" concept has thus proven to be successful in treating sewage sludge. Hydrolysis and acidification predominate in the A-UASB, while acetogenesis and methanogenesis dominate in the M-UASB. Most of the reactions occur at the lower part of both reactors (Sludge blanket and bed).

(2). The most effective and practical approach to accelerate the acclimatization process is to provide a continuous, step-up organic loading rate, to match the bacterial growth.

The start-up loading rate recommended is 1.2 gCOD/L-d, with a seed sludge taken from an anaerobic digester for the M-UASB, and an acclimatized seed sludge for the A-UASB, at the ratio of 1:1 (by volume). The washout process occurred after two weeks of acclimatization at a sludge loading of 0.40 kg COD/kg VSS-d. The acclimatization process reached a pseudo steady-state within 4-5 weeks, with 91 and 100 % COD (sol.) and VFA removal efficiencies, respectively.

(3). Under specific control of temperature at 35 °C, an influent flow rate of 5-6 L/d, and a pH at 5.0-5.3 and 7.0-7.3 for the A-UASB and M-UASB respectively, the optimum "Best Known" running condition is at sludge ratio (SR) 80/20 and recycle ratio (RR) 5/8; this achieved more than 95 and 90 % COD (sol.) and PO_4-P removal efficiencies, with effluent COD (sol.) of 300 mg/L. In addition, this "Best Known" condition produced a high volume of CH_4 gas, about 1.55 m^3/m^3-d, equivalent to a specific CH_4 production of 0.32 m^3/kg COD (Total) added, at 72 % CH_4 content. Internal recirculation (RR) seems to be an important feature of the two-phase system; not only does it increase the contact between microorganisms and substrates, but also helps to recover the system from a serious failure and stabilizes, naturally, the buffering capacity in both A-and M-UASBs.

(4). A combination of hydraulic and organic overloading of the M-UASB was a major cause for process failure, as indicated by MLVSS washout, an increase in the total VFA concentration, a reduction in system removal efficiency, a cessation in CH_4 gas production, a drop in pH, and an increase in total VFA/alkalinity ratio.

(5). Maximum hydraulic loading rates found were 1.6 and 0.90 m^3/m^3-d, equivalent to HRTs of less than 1.125 and 0.625 days for the M-UASB and the system, respectively. The CH_4 gas production was reduced to less than 50 % of the theoretical value, with effluent COD and total VFA levels of 9,535 mg/L and 3,750 mg/L as HAc, respectively.

(6). The M-UASB recovered exponentially after failure, with an increase in HRT (loading reduction), in terms of COD removal efficiency, but logarithmically with respect to CH_4 gas production as follows:

$$Y = 25.37\ e^{0.29X}$$

$$Y1 = 9.25 + 64.01 \ln X1$$

where Y = % soluble COD removal efficiency

X = HRT (M-UASB), days

Y1 = CH_4 gas production, L/d

X1 = HRT (M-UASB), days

The system returned to its initial stage of operation by a two-step increase in the $HRT_{M\text{-}UASB}$, by 1.5 and 5.8 times that of the failure HRT value (with a dimensional time of 5.60 and 10 for the M-UASB and the overall system, respectively). Shock-loads seemed to stimulate the A-UASB's activity during the system recovery; however, there was no apparent effect on the M-UASB, after it has failed completely. The recovery approach, employing step-loading reduction and internal RR, appears to be comparable to re-acclimatization, in terms of time requirements (both need 4-5 weeks to complete the processes) for recovery. However, the recovery approach has some advantages, in terms of simplicity of operation and practicality, as applied to a full-scale plant.

(7). The optimum HRT for A-UASB was 1.0 (0.97) days, whereas the HRT for the M-UASB with respect to COD removal efficiency and CH_4 gas production during the maximization and recovery period was 2.0 and 2.7 days, respectively. This seems to imply a restructuring of bacterial community inside the M-UASB, during the recovery period. For design purposes, optimum operating HRTs of 1 and 2 days, as well as RR of 1.6 and 2.5 times the influent flow rate, are recommended for A-and M-UASB reactors, respectively.

(8) The optimum $HRT_{A\text{-}UASB}/HRT_{M\text{-}UASB}$ ratio was about 0.60 while the $HRT_{A\text{-}UASB}/HRT_{system}$ was 0.40, applied to the two-phase anaerobic digestion of sewage sludge (UASB-UASB). The reactor diameter to height ratio is recommended at 1:8 to 1:10, with a hydraulic loading rate of 0.55 m^3/m3-d (equivalent to 19 kg COD (total)/m^3-d at 35 °C and the SR80/20 and RR2/3).

6.2 RECOMMENDATIONS

Future research needs are recommended in the following areas:

(1). Rebuilding a bench-scale, two-phase UASB-UASB process according to the modified designed criteria, is highly recommended. Evaluation of system feasibility and effectiveness with actual sludge, operating at the optimum condition is also necessary.

(2). Organic shock loading and toxic spiking of the system should be investigated; this can provide additional information in understanding how the system responds under such circumstances and the degree of susceptibility.

(3). Investigating the temperature effects on the process performance by keeping the temperature of the A-UASB and M-UASB at 20 and 35 °C respectively, is an interesting area of further research. This may help reduce the cost of reactor heating.

(4). Recirculation of the wasted sludge from the A-UASB, as a whole or part, into the M-UASB is worth investigating; it may reduce the amount of sludge to be disposed of. However, it could also reduce the efficiency of the M-UASB.

(5). The effect of the internal RR and step-loading reduction on the optimum "best Known" running condition for system recovery from failure, should be re-evaluated by employing a 2 by 2 factorial design experiment.

(6). Treating the domestic wastewater directly by using this modified process configuration is highly recommended. The idea is to evaluate the feasibility and effectiveness of the system, as to whether or not it can temporarily serve as a main stream treatment facility, in case of a process interruption or failure. If successful, then a by-pass of the influent wastewater could then be temporarily re-directed through the two-phase system.

(7) Evaluating the effect of sludge recycling on the process performance. This may indicate whether there is any negative impact on system performance related to solids recycling or not.

REFERENCES

Anderson, G.K., Donnelly, T., (1978) "Anaerobic Contact Digestion for Treating High - Strength Soluble Wastes", In: Mattock, G.(ed.) New processes of waste water treatment and recovery, Ellis Horwood, Chichester, p.75.

Andrew, J.W., (1968) "A Mathematical Model for the Continuous Culture of Microorganisms Utilizing Inhibitory Substances", Biotech. Bioeng., 10, 707-723.

Andrew, J.F., and Pearson, E.A., (1965) " Kinetics and Characteristics of Volatile Acid Production in Anaerobic Fermentation Processes", Intl.Jour.Air and Water Poll. (G.B.), 9, 439.

Asinari Di San Margano, CM, (1981) "Volatile Fatty Acids, An Important State Parameter for the Control of the Reliability and the Productivities of Methane Anaerobic Digestions",Biomass, 1, 47-59

Bergman, R.D., (1966) "Anaerobic Sludge Digestion - MOP 16", J. WPCF, 38, 717-721.

Barrette, O.J., (1952) "Report on the Operation and Maintenance of the Waterly Sewage Treatment Plant-Cleveland, Ohio", Sewage and Industrial Wastes, 24, 1427.

Benefield, L.D.,and C.W. Randall, (1980) "Biological Process Design for Wastewater Process Treatment", Practice-Hall, Inc., N.J., 526pp.

Box, G.E.P., (1969) "Evolutionary Operation", John Wiley & Sons, Inc., N.Y., U.S.A.

Bruce, A., (1984) "Sewage Sludge Stabilization and Disinfection", Ellis Horwood Limited, Chichester, England.

Buijis, J.W., (1981) "Modelling and Scale-up of Anaerobic Conversion of Dissolved Fatty Acids", Advance in Biotechnology, I.M. Moo-Young and Robinson, C.W., Pergamon, N.Y., 529 pp.

Buijis, C., (1982) "Distribution and Behavoir of sludge in Upflow Reactor for Anaerobic Treatment of Wastewater", Biotech. Bioeng., 24, 1975.

Bull, M.A., (1984) "An Evaluation of Single- and Separate-Phase Anaerobic Ind. Waste Treatment in Fluidized Bed Reactor", Biotech. Bioeng., 26, 1054.

Cail, R.G., and et al., (1986) "The Development of Granulation in an Upflow Floc Digester and an UASB Treating Cane Juice Stillage" Biotechnology Letters, 7, 493-498.

Callender, I.J., et al., (1983) "Recent Advance in Anaerobic Digestion Technology", Process Biochem., 18 (4), 24-37.

Capri, M.G., (1975) "pH adjustment in Anaerobic Digestion", Wat.Res., 9, 307-313.

Chang, T.C., Wu, Y.C., and et.al, (1989) "Anaerobic Sludge Digestion Using Thermophilic Phase Separation", J.Chem.Tech.Biotechnol., 45, 335-337.

Chen, Y.R., Hashimoto, A.G., (1978) "Kinetics of Methane Fermentation", Biotechnology Bioengineering Symp., 8, 269-282.

Chiu-Yue, Lin, (1986) "Methanogenic Digestion Using Mixed Substrate of Acetic, Propionic, and Butyric Acids", Wat. Res., 20 (3), 385-394.

Choate, W.T., and et al., (1982) "Membrane-Enhanced Anaerobic Digesters" Proc. 37th Industrial Waste Confer., Purdue Univ., Indiana, 661-666.

Christensen, D.R., Gerick, J.A., (1984) "Design and Operation of an Upflow Anaerobic Sludge Blanket Reactor", WPCF, 56 (9), 1059-1062.

Chung, K.T., (1976) "Inhibitory Effects of H_2 on growth of Clostridium cellobioparum" Appl. envir. Microbiol., 31, 342-348.

Cohen, A., et al., (1979) "Influence of Phase Separation on the Anaerobic Digestion of Glucose-I: Maximum COD Turnover Rate during Continuous Operation", Wat. Res., 13, 571.

Cohen, A., et. al, (1983) "Two-Phase Digestion of Liquid and Solid wastes", Proc. 3rd Inter. Symp. on Anaero. Digest., Boston, USA, 123-138.

Colleran, E., and et al., (1983) "One and Two-Stage Anaerobic digestion of Agricultural Wastes" Proc. of the 3rd International Symposium on Anaerobic Digestion, Boston, USA.

Cortinovis, D., (1984) "Controlling Wastewater Treatment Processes", Ridge Line Press, California, U.S.A.

Datta, R.K., (1981) "Acidogenic Fermentation of Corn Stover" Biotech. Bioeng., 23, 61,

Dichtl, N.J., (1987) "Two Stage Sludge Stabilization" Wat. Sci. Technol., 19 (7), 1247-1250.

Dinopoulou, G, and Lester, J.N., (1989) "Optimization of a Two-phase Anaerobic Digestion System Treating a Complex Wastewater", Env.Tech.Lett, 10, 799-814.

Dolfing, J., 1986, "Granulation in UASB Reactor" Wat. Sci. Tech., 18 (12), 15-25.

Eastman, J.A., and Ferguson, J.F., (1981) "Solubilization of Particulate Organic Carbon during the Acid Phase of Anaerobic Digestion", J. WPCF, 53 (3), 352-365.

Encina, P.A.G., Polanco, F.F., (1987) "Behaviour of anaerobic expanded bed reactor in non-steady state conditions", Wat.Res. 21 (11), 1329-1334.

Fannin, K.F. et. al, (1981-1983) "Anaerobic Process", J. WPCF Literature Review Issue, 6, 53-55.

Fisher, A.J., (1934) "Digestor Overflow Liquor: Its Character and Effect on Plant Operation", Sewage Works, 6, 934.

Fongsatitkul, P., (1986) "A Preliminary Report: An Assessment of Wastewater Treatment System Practically Used in Thailand", CIDA Home Attachment Program.

Ghosh, S., and Henry, M.P., (1981) "Stabilization and Gasification of Soft Drink Manufacturing Waste by Conventional and Two-Phase Anaerobic Digestion" Proc. of the 36th Purdue Industrial Waste Conference, Lafayette, IN, 292.

Ghosh, S., and et al., (1983a) "Methane Production from Industrial Wastes by Two-Phase Anaerobic Digestion" Proc. of the 6th Symposium on Biomass and Wastes, Orlando, FL., USA.

Ghosh, S., and et al, (1983b) "Two-stage Upflow Anaerobic Digestion of Concentrated Sludge" Proc. of the 5th Smposium on Biotechnology for Fuels and Chemicals, Gatlinburg, TN.

Ghosh, S., (1984) "Advance Two-Phase Digestion of Sewage Sludge", Symp. on Energy from Biomass and Waste VIII, Lake Buena, Vista, Florida, USA, 3, 835-874 pp.

Ghosh, S., (1987) "Improved Sludge Gasification by Two-Phase Anaerobic Digestion" J.Envir. Eng. Div., 113 (6), 1265-1284.

Gloyna, E.F., (1982) "An Analysis of research Needs concerning the Treatment, Utilization, and Disposal of Wastewater treatment Plant Sludge", WPCF Highlights, 19 (7).

Graef, S.P. and Andrew, J.F., (1974a) "Stability and Control of Anaerobic Digestion", J. WPCF, 46, 666-683.

Graef, S.P., and Andrew, J.F., (1974b) "Mathematical Model and Control of Anaerobic Digestion" AIChE Symposium Series, 70, (136), 101-131.

Gujer, W., and Zehnder, A.J.B., (1983) "Pathway of Anaerobic Digestion", Wat. Sci.Tech., 25, 127.

Hamoda, M.F., and et al., (1984) "Effect of Settling on Performance of the Upflow Anaerobic Sludge Bed Reactors" Wat. Res., 12, 1561-1567.

Harper, S.R., and et al, (1986) "Biotechnology Report: Recent Developments in Hydrogen Management During Anaerobic Biological Wastewater Treatment", Biotech.Bioeng., 28 (4), 585-602.

Heertjes, P.M., (1978) "Dynamic of Liquid Flow in an Upflow Reactor used for Anaerobic Treatment of Wastewater", Biotech. Bioeng., 20, 1577.

Heertjes, P.M., (1982) "Fluid Flow in Upflow Reactor for Anaerobic Treatment of Beet Sugar Factory Wastewater", Biotech. Bioeng., 24, 443.

Hickey, R.F., Vanderwielen, J., and Swtzenbaum, M.S., (1987) "The Effects of Organic Toxicants on Methane Production and Hydrogen Gas levels during the Anaerobic Digestion of Waste Activated Sludge" Wat. Res., 21 (11), 1417-1427.

Hulsoff-Pol, L.W., de Zeeuw. W.J., et.al, (1983) "Granulation in UASB-reactors", Wat.Sci.Technol, 15, 291.

Hulsoff-Pol, L.W., et al, (1986) "New Technologies for Anaerobic Wastewater Treatment", Wat. Sci. Tech., 18, (12), 41-53.

Jame, R.W., (1976) "Sewage Sludge Treatment and Disposal", Noyes Data Corporation, New Jersey USA, 339 pp.

Jeris, J.S., and McCarty, P.L., (1965) "The Biochemistry of methane fermentation using C^{14} tracers" J. WPCF, 37, 178-192.

Kasper, H.F., and Wuhrmann, K., (1978) "Kinetic Parameters and Relative Turnover some Important Catabolic Reactions in Digesting sludge" Appl. envir. Microbiol 36, 1-7.

Keenan, J.D., (1976) "Multiple Staged Recovery from Solid Wastes" J. Environ. Sci. Health, A11 (8/9), 525.

Keleti, G., et al, (1974) "Handbook of Micromethods for the Biological Science", Van Nostrand Reinhold Inc., N.Y., USA.

Klapwijk, A., et al, (1981) "Denitrification of domestic wastewater in an upflow sludge blanket reactor without carrier material for the biomass" In:Cooper PF, Atkinson

B (eds) Fluidised bed treatment of water and wastewater. Ellis Horwood, Chichester, p.205.

Kugelman, I.J. and Jeris, J.S., (1981) "Sludge Treatment Anaerobic Digestion", Marcel. Dekker, Inc., N.Y., 591 pp.

Lawrence, A.W., and McCArty, P.L., (1970) " Kinetics of Methane Fermentation in Anaerobic Treatment", J.WPCF, 41, R1-R16

Lettinga, G., (1978) "The Prospects of Anaerobic Wastewater Treatment", 4th European Sewage and Refuse Symp., EAS, Munich., 226.

Lettinga, G., Van Der Gust, A. Th, (1979a) "Anaerobic Treatment of Methanolic Waste", Wat. Res., 13, 725.

Lettinga, G. Van Velsen, and et.al, (1979b) "Feasibility of the Upflow Anaerobic Sludge Blanket (UASB)-Process", Proc.Nat.Conf.on Environ.Eng., ASCE, San Francisco, USA, 35-45.

Lettinga, G. et al, (1980) "Use of Upflow Sludge Blanket (USB) Reactor Concept for Biological Wastewater Treatment, Especially for Anaerobic Treatment", Biotech. Bioeng., 22, 699-734.

Lettinga, G., Hobma, S.W., and et.al, (1983a) "Design, operation, and economy of anaerobic treatment", Wat. Sci. Tech., 15, 177-195.

Lettinga, G., Roersma, R., and Grin, P., (1983b) "Anaerobic Treatment of Raw Domestic Sewage at ambient temperature using a granular bed UASB Reactor" Biotech. Bioeng.,, 25, 1701-1723.

Lettinga, G., Hulshoff, Pol, et al, (1983c) "Upflow Sludge Blanket Process", Proc. 3rd Inter. Symp. on Anaerobic Digestion, Boston, USA, 139-158.

Lettinga, G., Hulshoff, Pol, et al, (1986) "Advanced Reactor Design, Operation and Economy", Wat. Sci. Tech., 18 (12), 99-108.

Maat, D.Z., and Harbets, L.H.A., (1987) "The Upflow Anaerobic Sludge Blanket Wastewater Treatment System: A Technology Review", Pulp&Paper Canada, 88 (11).

Mahoney, E.M., Varangu, L.K., Cairns, W.L., (1987) "The Effect of Calcium on Microbial Aggregation during UASB Reactor Start-Up " Wat. Sci. Tech., 19, 249-260.

Malina, J.F., (1980) "Anaerobic Waste Treatment", Lecture Note, Univ. of Texas (Austin).

Massey, M.C. and Pohland F.G., (1978) "Phase Separation of Anaerobic Stabilization by Kinetic Controls", J. WPCF, 50, 2204.

McCarty, P.L., (1971) "Energy and Kinetics of Anaerobic Treatment", Anaerobic Bio.Treat., Proc. Amer. Chem. Society, Advance in Chemistry Series, 105, 91-107.

Montgomery, C.D., (1984) "Design and Analysis of Experiments", John Wiley and Sons, 2nd Edition.

Mosey, F.E., (1983a) "Mathematical Modelling of Anaerobic Digestion Process: Regulatory Mechanisms for the Formation of Short-Chain Volatile Acids from Glucose" Water Sci. Technol., 15, 209-232.

Mosey, F.E., (1983b) "Kinetic Descriptions of Anaerobic Digestion", Proc. 3rd Inter. symp. on Anaerobic Digestion, Boston, USA, 37-52.

Normann, J., and Frostell, B., (1977) "Anaerobic Wastewater Treatment in a Two-Stage Reactor of a New Design" Proc. of the 32th Purdue Industrial Waste Conference, 387.

Oleszkiewicz, J.A., Thadani, V.J., (1988) "Effects of Biofilter Media on the Performance of Anaerobic Hybrid Reactors", Env.Tech.Lett, 9, 89-100.

Olthof, M., (1982) "Anaerobic Treatment of Industrial Wastewaters" Chemical Engineering, 89 (23), 121-126.

PALNS Sam-soon, et al, (1987) "Hypothesis for Pelletization in the Upflow Anaerobic Sludge Bed Reactor", Water SA Vol.13, No.2, 69-80.

Patel, G.B., Roth, L.A., and Sprott, G.D., (1979) "Factors Influencing Filament Length of Methanospirillum hungatii" J.Gen. Microbiol., 112, 411-415.

Pavlostathis, S.G., and Gossett, J.M., (1986) "A Kinetic Model for Anaerobic Digestion of Biological Sludge", Biotech. Bioeng., 28, 1519-1530.

Pavoni, J.L., Tenney, M.W., et al, (1972) "Bacterial Exocellular Polymers and Biological Flocculation", J.WPCF 44 (3), 415.

Perot, C., (1989) "Optimization of Sludge Anaerobic Digestion by Separation of Hydrolysis-Acidification and Methanogenesis" Envir. Technol. Letter., 10, 633-644.

Pipyn, P., and et al., (1979) "A Pilot-scale Anaerobic Upflow Reactor Treating Distillery Wastewaters", Biotechnol. Lett., 1, 495.

Pohland, F.G., and Ghosh, S., (1971) "Development in Anaerobic Treatment Processes", Biotech. Bioeng. Symp., 2, 85-106.

Pohland, F.G. and Ghosh, S., (1971a) "Development in Anaerobic Stabilization of Organic Waste - The Two-Phase Concept", Env.Letters, 1 (4).

Pohland, F.G. and Massey, M.L., (1975) "An Application of Process Kinetics for Phase Separation of the Anaerobic Stabilization Process", Progress in Wat. Tech., 7(1), 173-189.

Rajan, R.V., Lin Jih-Gaw, Ray , B.T., (1989) "Low-level chemical pretreatment for enhanced sludge solubilization ", J.WPCF, 61, 1678-1683.

Rijkens, B.A., (1981) "A Novel Two-Step Process for the Anaerobic Digestion of Solid Wastes" Proc. of the 5th Symposium on Energy from Biomass and Wastes, Orlando, FL, USA, 463-475.

Rinzema, A., Lettinga, G., (1988) "The Effect of Sulphide on the Anaerobic Degradation of Propionate", Env.Tech.Lett., 9, 83-88.

Ripley, L.E., and Boyle, W.C., (1983), "Anaerobic Digestion Models: Implication for the design engineer", Proc. 3rd Inter. Symp. on Anaerobic Digestion, Boston, USA, 451-463.

Scheifinger, C.C., Linehan, B., and Wolin, M.J., (1972) "H_2 production by Selenomonas ruminantium in the absence and presence of methanogenic bacteria" Appl. Microbiol., 29, 480-483.

Schwartz, L.J., (1982) "Anaerobic Digestion and Heat Pumps: Potential for Energy Recovery in a Waste Stream", Biotech. Bioeng. Symp., 11, 463.

Souza, M.E., (1986) "Criteria for the Utilization, Design and Operation of UASB Reactor" Wat. Sci. Tech.,, 18 (12), 55-69.

Stronach, L.J., et. al, (1986), in Industrial Wastewater Treatment", Springer-Verlag, eh, 183 pp

Tavery, M.A. et al, (1979) "Phase Separation Treatment: Surfactant-Foaming Problems; Solid-Liquid Separation", Water and Waste Engineering, 16 (2), 47.

Therkensen, H.H., (1979) "Thermopholic Digestion of a Strong Complex Substrate", J.

WPCF, 51, 1949-1964.

Torpey, W.N., (1955) "Loading to Failure of a Pilot High-Rate Digestor", Sew. and Ind. Wastes, 27, 121.

Trudell, M., Van der Berg, L., and et.al, (1985) "Anaerobic Treatment of High-Strength Acidic Organic Wastewaters Utilizing the Upflow Sludge Blanket Treatment Process", Water Poll.Res.Journal (CANADA), 20 (1), 25-41.

US.EPA, (1978), "Process Design Manual for Municipal Sludge Landfill", EPA 625/1-78-010.Tech. Transf.

US.EPA, (1979) "Process Design Manual for Sludge Treatment and Disposal", EPA 625/1-79-011, Tech. Transf.

Van Der Meer, R.R., (1983) "Mathematical Description of Anaerobic Treatment of Wastewater in Upflow reactor", Biotech. Bioeng., 25, 2531-2556.

Vesilind, P.A., (1980) "Treatment and Disposal of Wastewater Sludge", Ann Arbor Sci., Michigan, 323pp.

Wiegant, W.W., and et al., (1985) "Granulation of Biomass in Thermophilic Upflow Anaerobic Sludge Blanket Reactors Treating Acidified Wastewaters" Biotech. Bioeng., 28, 718-727.

Wu. Wei-min, et.al, (1985) "Properties of Granular Sludge in Upflow Anaerobic Sludge Blanket Reactor and its Formation", Proc. 4th Inter. Symp. on Anaerobic Digestion, Guangzhou, China.

Yan, Jing-Qing, (1991) "Anaerobic Digestion of Cheese Whey in An Upflow Anaerobic Sludge Blanket Reactor" Ph.d Thesis, Univ.of British Columbia, Canada.

Zeeuw. De Willem, (1980) "Acclimatization of Digested Sewage Sludge During Start-UP of An Upflow Anaerobic Sludge Blanket (UASB) Reactor", Proc. 35th Purdue. Ind. Waste Conference, 39- 47.

Ziekefoose, C., (1976) "Operations Manual-Anaerobic Sludge Digestion", EPA 430/g-76-001, US.EPA, Washington, D.C.,U.S.A.

Zoetemeijer, R.J., (1982) " Acidogenesis of Soluble Carbohydrate-Containing Wastewater, Ph.D Thesis, Univ. of Amsterdam, The Netherlands.

Zoetemeijer, R.J. et.al, (1982) "pH Influence on Acidogenic Dissimilation of Glucose in an Anaerobic Digestion", Wat. Res. 16, 303-311.

APPENDIX A

Synthetic Sludge Preparation and System Set-up

A1.1 : Summary of Research Problems/Remedial Actions/Scope and Approach Modifications

A2.1 : System Seeding and Loading Rate

A2.2 : Final Constituents of Primary and Secondary Synthetic Sludges and Chemical Analysis of Dog foods

A3.1 : Detailed Sizing of Acid- and Methane-Phase Reactors (UASB-UASB)

A3.2 : Spread-sheet for Sizing of the Acid- and Methane-Phase Reactors (UASB-UASB)

A4.1 : Development of A Small-Scale (1-Litre) Synthetic Sludge Preparation

A4.2 : Development of A Scale-Up (30-Litre) Synthetic Sludge Preparation

A5.1 : Monitoring the Characteristics of **Primary** Synthetic Sludge Prepared Throughout the Experiment

A5.2 : Monitoring the Characteristics of **Secondary** Synthetic Sludge Prepared Throughout the Experiment

Table A1.1 Summary of Research Problems/Remedial Actions/Scope and Approachs Modifications

Phase/duration	Research problems and conceptual ideas of the original proposal	Remedial actions and modifications of the research works *
1.Proposal preparation	Computer literature search on : sewage sludge; Two-phase anaerobic digestion; UASB Anaerobic digestion objectives : Pollution control Energy recovery Problem areas : Poor supernatant quality Low CH4 content and production Hydrolysis is rate limiting step Flow and feed is sensitive to UASB Effect of temperature and pH Approaches : HRT/RR/SR Mixing speed Susceptibility/recovery period Two-phase UASB-UASB Kinetics Specific control of pH/temp.	Agree with the approach Optimize both objectives in terms of : System removal efficiency CH4 content and production Control temp. @ 35 degree C and pH @ 5/7 for A- and M-UASBs Replicate - Build more UASB and run paralelly But, cost problems Optionally, comparison of actual CH4 production in terms of % theoretical CH4 production (> 0.4 - OK) Synthetic sludge - avoid toxics/unavailability Mixing Shaft - sealed with rubber/o-ring operate under water level Summarize problem areas/approach equipment req'd/cost estimation in the form of research proposal
2.Proposal Defense	Specific control of pH/temp. Optimal operating conditions : 2*2*2 factorial design : First step - FR/SR/mixing speed Second step - RR/wasting/mixing time Overall process performances : Rerun opt.running cond. Feed directly from Pri. and Sec. sludges Max.loading/recovery period Best known running cond. Recovery alternatives : Increase Sec.sludge ratio Stop feeding periodically Alkaline addition Combination - 2*2*2 factorial design	2-3 considerable parameters should be enough First step variables couldn't remain constant if applied to second step 77 % theoretical CH4 ??? (Dr. Oldham) Analytical method for sludge carbohydrate (Dr. K.Hall) Time constraint/no study on modelling Revision of experimental designs (See details later in exp. runs)

Note : * Discussion/agreement among researcher,supervisor,andCo-supervisor have been reached prior to any modifications to be taken

Phase/duration	Research problems and conceptual ideas of the original proposal	Remedial actions and modifications of the research works *
3. Experimental program 3.1 Synthetic sludge	Too high COD/VSS and TS	Blend dog food with water - 2 hrs/leave overnight warm @ 65-70 degree C - 1.5 hrs/mix 1hr Settle/drain portion of the solids out
	Too low N/P	Add urea/NaHPO4
3.2 System set up	Leak @ pH probe/reacters'covers	Double O-ring around the probes/more bolts Leak detection with foaming liquid/N2 gas
3.3 Acclimatization	Fermentation inside the blender Clogging inside the tube connecting the blender and A-UASB reacter	Move the blender to the cold room (4-5 degree C) Levelling the effluent line from the blender to the A-UASB 's inlet/replace all plastic tubes with the thicker ones used for food/beverage/ connect the soft tubes between the hard ones/ squeeze regularly
	No gas passing through the wet gas flow meters	Make U-tube @ the effluent line of both reacters/ Place sealant outside the O-ring between cover and reacters
	Sludge spillage	Simplify/shorten/reduce the tubing line and and connecters/replace cone-shape connecters with the straight ones and plastic clamps with the metal ones
	Running conditions : 35 degree C/pH 5/7 FR 10,SR 80/20, RR 4/7 Mix @ 20 rpm	Revise running conditions : Same as proposed, except FR 5-6 (Spillage/time delays)
3.4 Experimental runs 3.4.1 Opt.operating cond.	Same as those mentioned in 2.0	Considering comments/time constraints, Revision of the approach was as : Use Surface response method (SRM)/ 2*2 factorial design instead of 2*2*2 factorial design Pseudo-steady state : 2-3 HRT/5-10 % variation of all responses

Phase/duration	Research problems and conceptual ideas of the original proposal	Remedial actions and modifications of the research works *
		Phase 1 : Reference condition (Acclimatization) Runs SR RR FR 0 80/20 4/7 5-6 1 50/50 2/4 5-6 2 80/20 6/10 5-6 3 50/50 6/10 5-6 4 80/20 2/4 5-6 Phase 2 : "Best known" condition Runs SR RR FR 0 80/20 4/7 5-6 1 70/30 3/6 5-6 2 90/10 5/8 5-6 3 70/30 5/8 5-6 4 90/10 3/6 5-6 Phase 3 : Additional runs Runs SR RR FR 1 60/40 3/6 5-6 2 60/40 5/8 5-6 3 80/20 5/8 5-6
	No replicate for each run to calculate effect/interaction of SR and RR	Calculate effect/interaction based on replicate with time/replicate @ center pt. (acclimatization) Compare S.E. @ center pt. with those @ each running condition
	No significant change in the major response parameters of each running condition	Check MLVSS @ each running condition
3.4.2 Max.loading/ Recovery period	Same as those mentioned in 2.0	Limitation of Sludge preparation/time constraints Approach was revised as : Max.loads,HRT-d 9 6.5 4.5 3.0 2.25 1.5 1.13 Recovery,HRT-d 2.25 3.0 4.5 9.0 MGLH - alkaline addition ????

Table A2.1 System Seeding and Loading Rate

Volume of seed sludge required for acid-phase reactor:
= 0.5*20 litre
= 10 litre + 10 litre tap water

Volume of seed sludge required for methane-phase reactor:
= 0.5*25 litre
= 12.5 litre + 12.5 litre tapwater

Recommended start-up loading:
1.2 gCOD/l/d [0.1 gCOD/gVSS/d @ 58-hr HRT] and/or
5.0 KgCOD/cu.m-d [0.1-0.2 KgCOD/KgTS/d]

Check loading rate:

If pri.sl : sec.sl = 80 : 20
Then, mixed liquid sludge concentration:
C1V1 +C2V2 = CV
C[VSS] = [[0.8V*17293]+[0.2*11772]]/V
= 16,189 Mg/l

Similarly, C[TS] = [[0.8*33369]+[0.2*19973]]/V
= 30,890 Mg/l

C[COD] = [[0.8*32872]+[0.2*25467]]/V
= 31391 Mg/l

Sludge loading rate = [[COD/VSS]*FLOW]/V
= 0.1gCOD/gVSS/d

= [[31391/16189]/45]*flow
Then, Flow = 2.32 l/d OK

Volumetric loading rate:
= [[31391/[45*1000]]*flow
= 1.2 gCOD/l/d
Then, Flow = 1.72 l/d OK

Table A2.2 Final Constituents of Primary and Secondary Synthetic Sludges and Chemical Analysis of Dog Foods

(a)

Constituents	Synthetic Sludges (%)	
	Primary	Secondary
Dog Food	86.50	93.00
Soap	3.00	0.25
Oil	3.00	2.00
$CaCO_3$	2.00	
$NaHPO_4 \cdot 7H_2O$	1.50	3.25
Paper	2.00	
$MgCO_3$	2.00	
Urea		1.50

(b)

Constituents	Analysis (%)
"No Name" Special Dinner for Dogs	
Proteins	22 (min)
Fat	7 (min)
Carbohydrate	54 (min)
Fibre	5 (max)
Moisture	12 (max)

Table A3.1 Detailed Sizing of Acid- and Methane- Phase Reacters
(A-UASB AND M-UASB)

(1). Design Criteria
- 1.1) System Surface Loading Rate (Sys-SLR) = 1-1.5 m3/m2.hr
- 1.2) Settler Surface Loading Rate Less Than 0.7 m3/m2.hr
- 1.3) Gas Collection Aperture (GCA) Less Than 2.0 m3/m2.hr
- 1.4) 50 o Inclined Walls
- 1.5) Designed HRT : 2 hrs. - 9 days
- 1.6) Active Sludge Blanket/Bed (ASB) and Settler Ratio = 7:3
- 1.7) Proper Baffle Arrangement Beneath Gas Collecter

(2). Reactor Volume

Sys-SLR = 1.0-1.5 m3/m2.hr (1.0 m3/m2.hr)
Dia. of required area = 12.5 cms.
Area required = (22/7)*d2/4
= 0.0123 m2
Max. Flow (Q) = Area * SLR
= 0.0123 m2 * 1 m3/m2.hr
= 0.0123 m3/hr w 295 l/d
Critical HRT = 2 hrs:
Reacter Vol. = HRT*Q
= 2 hrs.*0.0123 m3/hrs
= 0.0246 m3 ~ 25 litre
Min Flow = ((0.0246 m3)/(9 days))*(1000 l/m3)
= 2.73 l/d

(3). Reacter Height (RH)

Approx., RH = Vol/Area req'd
= (0.0246 m3)/(0.0123 m2)
= 1.99 w 2.00 m
Settler Vol. = 0.3*25.00
= 7.5 litre ~ 0.0075 m3
Doubling settler's diameter = 12.5*2 =25.00 cm.
Area req'd = 0.0491 m2
Settler H = (0.0075 m3)/(0.0491 m2)
= 15.27 cm ~ 15 cm
Connect V = 5 litre
ASV = 25-7.5-5.0 = 12.5 litre
ASH = (0.0125 m3)/(0.0123 m2 ~ 1.00 m

(4).Gas Collection Apparatus

GCA = 2.00 m3/m2.hr
Area Req'd = Flow/GCA
= (0.0123 m3/hr)/(2.00 m3/m2/hr)
= 0.0062 m2
Dia.of GCA = ((0.0062 m2)*((4)/(22/7))1/2
= 0.0885 m. w 8.85 cm

(5). Additional Settler Arrangement

Doubling the settler 's diameter (12.5 cm.* 2 w 25 cm) to slow down the liquid velocity passing through the effluent weir.

CHECK : Set-SLR s 0.7 m3/m2.hr
Settler area = (22/7)(d2/4)
= (22/7)*((0.25)2/4))
Actual SLR = (0.0064 m3/hr)/((22/7)*((0.25 m)2/4))
= 0.25 m3/m2.hr OK

To help settle solids back to the ASB, a proper baffle arrangment beneath the gas collecter and 50o inclined wall @ the connection between settler and ASB including the gas collecter were created.

Table A3.2 Detailed Sizing of A- and M-UASB Reactors

[1]. Design Criteria

1.1 System Surface Loading Rate (Sys-SLR) = 1.0-1.5 m3/m2.hr
1.2 Settler Surface Loading Rate (Set-SLR) < or = 0.7 m3/m2.hr
1.3 Gas Collection Apparatus (GCA) < or = 2.0 m3/m2.hr
1.4 50 o Inclined Walls
1.5 Designed HRT = 2 hrs - 9 days
1.6 Active Sludge Blanket/Bed (ASB) and Settler Ratio = 7:3
1.7 Proper Baffle Arrangement Beneath GCA

[2]. Reactor Volume [RV]									[3]. Reactor Height [RH]						[4].Gas Collection Apparatus			
Dia.	SLR	Area req'	Max. flow	Crit. HRT	React. vol.	Min. flow	ApprS. vol.	Set. dia.	Area req'	Set- High	Conn. vol.	Act.Sl. vol.	Act.Sl High	Total RH	GCA	Area req'	GCA Dia.	Check SLR
cm.	m3/m2.hr	m2	L/d	hrs.	lit.	L/d	m3	cm	m2	cm	lit	ASV,m3	ASH,m	m	m3/m2.hr	m2	cm	0.7m3/m2h
10.00	1	0.0079	189	2	16	1.75	0.0047	20	0.0314	15	2.13	0.0089	1.13	1.34	2	0.0039	7.07	0.25
10.50	1	0.0087	208	2	17	1.93	0.0052	21	0.0347	15	2.13	0.0100	1.15	1.36	2	0.0043	7.42	0.25
11.00	1	0.0095	228	2	19	2.11	0.0057	22	0.0380	15	2.13	0.0112	1.18	1.39	2	0.0048	7.78	0.25
11.50	1	0.0104	249	2	21	2.31	0.0062	23	0.0416	15	2.13	0.0124	1.19	1.40	2	0.0052	8.13	0.25
12.00	1	0.0113	272	2	23	2.51	0.0068	24	0.0453	15	2.13	0.0137	1.21	1.42	2	0.0057	8.49	0.25
12.50	1	0.0123	295	2	25	2.73	0.0074	25	0.0491	15	2.13	0.0151	1.23	1.44	2	0.0061	8.84	0.25
13.00	1	0.0133	319	2	27	2.95	0.0080	26	0.0531	15	2.13	0.0165	1.24	1.45	2	0.0066	9.19	0.25
14.00	1	0.0154	370	2	31	3.42	0.0092	28	0.0616	15	2.13	0.0194	1.26	1.47	2	0.0077	9.90	0.25

Table A4.1 Development of a Small scale (1–litre) Synthetic Sludge Preparation Between October 23 to November 10, 1987

Characteristics, %TS

Primary Synthetic Sludge

Experimental Runs	COD/VS	STD	STD	TS	STD	STD	VS	STD	STD	TP	STD	STD	PROT.	STD	STD	TOC	TKN	STD	STD	CARB	STD	STD
{1}	3.00	1.2	1.6	3.82	3	7	92	64	93	0.83	0.35	1.2	20.63	20	30		3.3	1.5	4	15.00	17	26
{2}	1.42	1.2	1.6	2.90	3	7	93	64	93	0.79	0.35	1.2	20.82	20	30	29.6	3.3	1.5	4	15.80	17	26
{av}	2.21	1.2	1.6	3.36	3	7	93	64	93	0.81	0.35	1.2	20.73	20	30	29.6	3.3	1.5	4	15.40	17	26

Secondary Synthetic Sludge

Experimental Runs	COD/VS	STD	C/N	STD	STD	TS	STD	STD	VS	STD	STD	TKN	STD	STD	TP	STD	STD	ROT.	STD	STD	CARB	TOC	STD	STD
{1}	2.90	2.17		3.5	14.6	4.1	1	2	92.2	59	88	3.60	2.4	6.7	0.90	1.3	1.6	22.50	32	41	12.50		17	44
{2}	2.43	2.17	8.0	3.5	14.6	2.4	1	2	91.6	59	88	3.73	2.4	6.7	1.06	1.3	1.6	23.30	32	41	26.67	38.3	17	44
{3}[1]	2.35	2.17	18.1	3.5	14.6	2.1	1	2	89.7	59	88	3.59	2.4	6.7	1.60	1.3	1.6	22.50	32	41	27.90	65.0	17	44
[2]	3.10	2.17	14.7	3.5	14.6	1.7	1	2	87.6	59	88	3.90	2.4	6.7	1.50	1.3	1.6	24.70	32	41	19.89	57.3	17	44
[3]	3.75	2.17	13.5	3.5	14.6	1.8	1	2	88.0	59	88	4.10	2.4	6.7	1.80	1.3	1.6	25.60	32	41	26.64	55.5	17	44
[4]	2.75	2.17	14.8	3.5	14.6	2.0	1	2	89.3	59	88	3.70	2.4	6.7	1.40	1.3	1.6	23.30	32	41	20.31	54.7	17	44
[5]	2.41	2.17	15.9	3.5	14.6	2.4	1	2	87.9	59	88	3.78	2.4	6.7	1.50	1.3	1.6	23.65	32	41	27.10	60.3	17	44
[6]	3.10	2.17	15.2	3.5	14.6	2.3	1	2	89.5	59	88	3.98	2.4	6.7	1.59	1.3	1.6	24.90	32	41	20.90	60.8	17	44
[7]	2.84	2.17	15.1	3.5	14.6	2.4	1	2	90.0	59	88	4.00	2.4	6.7	1.65	1.3	1.6	25.00	32	41	32.10	60.2	17	44
[8[	2.36	2.17	13.8	3.5	14.6	2.8	1	2	90.7	59	88	3.80	2.4	6.7	1.49	1.3	1.6	23.80	32	41	21.10	52.7	17	44
[9]	2.67	2.17	15.8	3.5	14.6	3.3	1	2	90.5	59	88	3.89	2.4	6.7	1.42	1.3	1.6	24.36	32	41	24.60	61.3	17	44
[10]	2.90	2.17	18.6	3.5	14.6	3.0	1	2	89.5	59	88	3.66	2.4	6.7	1.43	1.3	1.6	22.89	32	41	22.20	68.0	17	44
[11]	2.61	2.17	18.4	3.5	14.6	2.8	1	2	90.0	59	88	3.64	2.4	6.7	1.45	1.3	1.6	22.78	32	41	17.00	67.0	17	44
[12]	2.61	2.17	19.6	3.5	14.6	3.2	1	2	91.0	59	88	3.75	2.4	6.7	1.33	1.3	1.6	23.41	32	41	20.80	73.7	17	44
[av]	2.79	2.17	16.1	3.5	14.6	2.5	1	2	89.5	59	88	3.82	2.4	6.7	1.51	1.3	1.6	23.91	32	41	23.38	61.4	17	44
{4}(1)												4.53	2.4	6.7	1.71	1.3	1.6							
(2)												4.72	2.4	6.7	1.43	1.3	1.6							
(3)												7.96	2.4	6.7	1.39	1.3	1.6							
(4)												10.55	2.4	6.7	1.06	1.3	1.6							
(av)												6.94	2.4	6.7	1.40	1.3	1.6							

Note:

{1} = OCT 23, 1987
{2} = NOV 2, 1987
{3} = NOV 10, 1987
{4} = DEC 15, 1987

12 Combination Options of Feed solids (%T)S, Settling time (ST), Warming time, (WT)

[1] = 5% WT.
[2] = 5% WT.
[3] = 5% WT.
[4] = 5% WT.
[5] = 6%T R WT.
[6] = 6%T R WT.
[7] = 6%T R WT.
[8] = 6%T R WT.
[9[= 7%T WT.
[10] = 7%T WT.
[11] = 7%T WT.
[12] = 7%T WT.

STD = Typical normal ranges of actual primary sludge characteristics

Table A4.2 Development of a Scale-Up (30-litre) Synthetic Sludge Preparation Between November 17 to December 30, 1987

Primary Synthetic Sludge

Experimental Runs	Characteristics, %TS																							
	COD/VS	STD	STD	TS	STD	STD	VS	STD	STD	TKN	STD	STD	TP	STD	STD	PROT	STD	STD	CARBO	STD	STD	TOC
{1}	2.27	1.2	1.6	2.3	3	7	88.8	64	93	3.1	1.5	4	0.98	0.3	1.2	19.2	20	30	35.7	17	26	42.7
	2.46	1.2	1.6	2.1	3	7	88.1	64	93	3.1	1.5	4	0.94	0.3	1.2	19.5	20	30	28.6	17	26	34.4
	2.51	1.2	1.6	1.9	3	7	87.2	64	93	3.1	1.5	4	0.94	0.3	1.2	19.5	20	30	27.2	17	26	27.9
[av]	2.41	1.2	1.6	2.1	3	7	88.0	64	93	3.1	1.5	4	0.95	0.3	1.2	19.4	20	30	30.5	17	26	35.0
	2.30	1.2	1.6	2.1	3	7	87.7	64	93	2.9	1.5	4	0.93	0.3	1.2	17.5	20	30	21.5	17	26	35.6
	2.21	1.2	1.6	2.3	3	7	88.9	64	93	2.8	1.5	4	0.89	0.3	1.2	17.7	20	30	17.7	17	26	29.6
{2}	2.29	1.2	1.6	2.3	3	7	87.8	64	93	2.9	1.5	4	0.83	0.3	1.2	18.1	20	30	17.8	17	26	49.2
	1.94	1.2	1.6	2.9	3	7	89.7	64	93	3.1	1.5	4	0.81	0.3	1.2	19.3	20	30	17.7	17	26	28.3
[av]	2.19	1.2	1.6	2.4	3	7	88.5	64	93	2.9	1.5	4	0.87	0.3	1.2	18.2	20	30	18.7	17	26	35.7
	1.54	1.2	1.6	3.0	3	7	90.3	64	93	3.5	1.5	4	0.92	0.3	1.2	21.8	20	30	23.1	17	26	31.5
	1.69	1.2	1.6	2.6	3	7	89.2	64	93	3.6	1.5	4	0.89	0.3	1.2	22.3	20	30	22.0	17	26	32.2
{3}	1.30	1.2	1.6	2.4	3	7	88.8	64	93	3.6	1.5	4	0.94	0.3	1.2	22.3	20	30	13.5	17	26	52.0
	1.83	1.2	1.6	2.2	3	7	88.5	64	93	3.5	1.5	4	0.91	0.3	1.2	22.1	20	30	23.1	17	26	49.8
[av]	1.59	1.2	1.6	2.5	3	7	89.2	64	93	3.6	1.5	4	0.92	0.3	1.2	22.1	20	30	20.4	17	26	41.4
	1.58	1.2	1.6	3.2	3	7	90.9	64	93	3.9	1.5	4	1.05	0.3	1.2	25.5	20	30				
	1.89	1.2	1.6	3.6	3	7	91.0	64	93	3.9	1.5	4	1.05	0.3	1.2	25.5	20	30				
{4}	2.09	1.2	1.6	3.3	3	7	91.0	64	93	3.9	1.5	4	1.08	0.3	1.2	25.4	20	30				
	2.07	1.2	1.6	3.3	3	7	90.8	64	93	4.1	1.5	4	1.07	0.3	1.2	25.9	20	30				
[av]	1.91	1.2	1.6	3.4	3	7	90.9	64	93	3.9	1.5	4	1.06	0.3	1.2	25.6	20	30				

Note: {1} = NOV 17,1987 {2} = NOV 25,1987 {3} = DEC 1, 1987 {4} = DEC 30,1987
STD = Typical normal ranges of actual primary sludge characteristics

Table A4.2 Development of a Scale-Up (30-litre) Synthetic Sludge Preparation Between November 17 to December 30, 1987 (cont'd)

Secondary Synthetic Sludge

Exp. Runs	Characteristics, %TS																						
	COD/VSS	STD	TS	STD	STD	VS	STD	STD	TKN	STD	STD	TP	STD	STD	PROT.	STD	STD	CARBO.	TOC	STD	STD	C/N	STD	STD
{1}	2.65	2.2	1.7	1.0	2	87.4	59	88	3.2	2.4	6.7	1.7	1.3	1.6	19.8	32	41	22.9	30.1	17	44	9.4	3.5	14.6
	2.50	2.2	1.7	1.0	2	87.1	59	88	3.0	2.4	6.7	1.6	1.3	1.6	18.4	32	41	30.3	32.5	17	44	11.0	3.5	14.6
	3.07	2.2	1.9	1.0	2	87.5	59	88	3.1	2.4	6.7	1.5	1.3	1.6	19.0	32	41	32.0	47.6	17	44	15.6	3.5	14.6
	2.38	2.2	1.8	1.0	2	87.9	59	88	3.1	2.4	6.7	1.5	1.3	1.6	19.0	32	41	25.9	42.8	17	44	14.0	3.5	14.6
[av]	2.65	2.2	1.8	1.0	2	87.5	59	88	3.1	2.4	6.7	1.6	1.3	1.6	19.1	32	41	27.8	38.3	17	44	12.5	3.5	14.6
	2.32	2.2	2.3	1.0	2	89.1	59	88	3.7	2.4	6.7	1.5	1.3	1.6	23.0	32	41	19.8	45.4	17	44	12.4	3.5	14.6
	1.92	2.2	2.4	1.0	2	89.5	59	88	3.7	2.4	6.7	1.4	1.3	1.6	22.3	32	41	18.0	32.4	17	44	8.9	3.5	14.6
{2}	2.19	2.2	2.2	1.0	2	89.4	59	88	3.6	2.4	6.7	1.5	1.3	1.6	22.5	32	41	18.7	34.3	17	44	9.5	3.5	14.6
	2.26	2.2	2.2	1.0	2	88.8	59	88	3.4	2.4	6.7	1.4	1.3	1.6	22.2	32	41	24.1	36.5	17	44	10.7	3.5	14.6
[av]	2.17	2.2	2.3	1.0	2	89.2	59	88	3.6	2.4	6.7	1.4	1.3	1.6	22.5	32	41	20.2	37.2	17	44	10.4	3.5	14.6
	2.03	2.2	2.1	1.0	2	88.1	59	88	5.6	2.4	6.7	1.3	1.3	1.6	35.1	32	41	30.4	34.0	17	44	6.1	3.5	14.6
	2.19	2.2	2.0	1.0	2	88.2	59	88	5.8	2.4	6.7	1.6	1.3	1.6	36.4	32	41	25.5	32.7	17	44	5.6	3.5	14.6
{3}	2.20	2.2	1.9	1.0	2	88.8	59	88	6.4	2.4	6.7	1.8	1.3	1.6	40.0	32	41	25.0	34.1	17	44	5.3	3.5	14.6
	2.21	2.2	2.0	1.0	2	88.5	59	88	5.5	2.4	6.7	1.3	1.3	1.6	34.7	32	41	25.1	33.0	17	44	6.0	3.5	14.6
[av]	2.16	2.2	2.0	1.0	2	88.4	59	88	5.8	2.4	6.7	1.5	1.3	1.6	36.6	32	41	26.5	33.4	17	44	5.7	3.5	14.6

Note: {1} = NOV 25, 1987 {2} = DEC 1, 1987 {3} = DEC 23, 1987
STD = Typical normal ranges of actual primary sludge characteristics

Table A5.1 Summary of Data Monitoring on the Primary Synthetic Sludges Used Throughout the Experimental Program Between April 13, 1988 to December 21, 1989

Date	Days	COD, mg/L Total	COD, mg/L Sol.	VSS mg/L	COD/ VSS	STD	STD	TS	STD	STD	VS	STD	STD	TKN	STD	STD	TP	STD	STD	PROT.	STD	STD
					Characteristics, %TS																	
04/13/88	1	37505	7084	24550	1.53	1.2	1.6	2.10	3.00	7.00	89.15	64	93	3.85	1.5	4.00	0.91	0.35	1.20	24.06	20	30
05/10/88	28	37959	4549	24320	1.56	1.2	1.6	3.30	3.00	7.00	91.94	64	93	3.52	1.5	4.00	0.80	0.35	1.20	22.00	20	30
05/31/88	49	43662	5191	25480	1.71	1.2	1.6	3.26	3.00	7.00	92.68	64	93	4.06	1.5	4.00	0.87	0.35	1.20	25.37	20	30
07/12/88	91	27907	5349	20460	1.36	1.2	1.6	2.16	3.00	7.00	87.79	64	93	3.85	1.5	4.00	0.86	0.35	1.20	24.06	20	30
08/16/88	126	23952	5509	16880	1.42	1.2	1.6	2.84	3.00	7.00	88.60	64	93	3.24	1.5	4.00	0.99	0.35	1.20	20.25	20	30
09/30/88	171	30515	7340	24800	1.23	1.2	1.6	3.41	3.00	7.00	89.25	64	93	3.57	1.5	4.00	0.92	0.35	1.20	22.31	20	30
11/01/88	203	23810	6587	17960	1.33	1.2	1.6	3.64	3.00	7.00	89.12	64	93	3.59	1.5	4.00	0.65	0.35	1.20	22.44	20	30
12/09/88	241	30400	5440	21280	1.43	1.2	1.6	2.67	3.00	7.00	88.99	64	93	3.52	1.5	4.00	0.92	0.35	1.20	22.00	20	30
02/14/89	308	25984	4724	23586	1.10	1.2	1.6	2.56	3.00	7.00	87.65	64	93	4.06	1.5	4.00	1.09	0.35	1.20	25.37	20	30
03/14/89	336	48898	5371	25950	1.88	1.2	1.6	2.66	3.00	7.00	86.84	64	93	3.95	1.5	4.00	0.93	0.35	1.20	24.69	20	30
04/18/89	371	39437	5956	23850	1.65	1.2	1.6	3.55	3.00	7.00	84.25	64	93	3.43	1.5	4.00	0.99	0.35	1.20	21.44	20	30
05/30/89	413	22612	6706	17230	1.31	1.2	1.6	2.47	3.00	7.00	87.21	64	93	3.26	1.5	4.00	0.80	0.35	1.20	20.38	20	30
07/04/89	448	27219	4930	15060	1.81	1.2	1.6	2.47	3.00	7.00	89.70	64	93	4.23	1.5	4.00	1.13	0.35	1.20	26.44	20	30
08/01/89	476	22963	5147	21810	1.05	1.2	1.6	3.75	3.00	7.00	89.96	64	93	3.90	1.5	4.00	0.90	0.35	1.20	24.38	20	30
08/22/89	497	24492	4525	20950	1.17	1.2	1.6	3.07	3.00	7.00	88.15	64	93	4.23	1.5	4.00	0.97	0.35	1.20	26.44	20	30
10/03/89	539	26016	5041	15090	1.72	1.2	1.6	2.28	3.00	7.00	86.26	64	93	5.42	1.5	4.00	0.99	0.35	1.20	33.88	20	30
10/25/89	561	28545	6373	23020	1.24	1.2	1.6	3.03	3.00	7.00	87.04	64	93	3.52	1.5	4.00	0.99	0.35	1.20	22.00	20	30
11/21/89	588	35785	5567	18780	1.91	1.2	1.6	2.65	3.00	7.00	89.19	64	93	3.65	1.5	4.00	0.91	0.35	1.20	22.81	20	30
12/21/89	618	26423	5854	17850	1.48	1.2	1.6	2.50	3.00	7.00	86.01	64	93	3.68	1.5	4.00	0.89	0.35	1.20	23.00	20	30
Average		30741	5644	20995	1.47	1.2	1.6	2.86	3.00	7.00	88.41	64	93	3.82	1.5	4.00	0.92	0.35	1.20	23.86	20	30

STD = Typical normal ranges of actual primary sludge characteristics

Table A5.1 Summary of Data Monitoring on the Primary Synthetic Sludges Used Throughout the Experimental Program Between April 13, 1988 to December 21, 1989

Day	Days						VFA, mg/L					Tot.VFA
		NH4-N	PO4-P	HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	mg/L HAc
04/13/88	1	23	115	51	35		31					101
05/10/88	28	18	134	51	43		90					147
05/31/88	49	23	80	46	45						34	100
07/12/88	91	9	95	85	9	112		25				183
08/16/88	126	45	90	82	9		111					165
09/30/88	171	34	127	110	119		58			45		273
11/01/88	203	32	138	98	45		85					192
12/09/88	241	14	75	120	45		75					208
02/14/89	308	38	171	162	82		12					237
03/14/89	336	16	106	75	21		16					103
04/18/89	371	33	114	97	98		31			19		209
05/30/89	413	35	120	53	91		29			30		164
07/04/89	448	38	129	45	107					77	82	219
08/01/89	476	26	123	48	110					57	57	200
08/22/89	497	11	134	56	32		45					113
10/03/89	539	15	64	36	67		24					107
10/25/89	561	14	122	63	57		48			19		153
11/21/89	588	7	166	59	56		27					123
12/21/89	618	10	139	45	55		18					102
Average		23	118	73	59	112	47	25		41	58	163

Table A5.2 Summary of Data Monitored on the Secondary Synthetic Sludges Used Throughout the Experimental Program Between April 13, 1988 to December 21, 1989

Date	Days	COD, mg/L Total	COD, mg/L Sol.	VSS mg/L	COD/VSS	STD	TS	STD	STD	VS	STD	STD	TKN	STD	STD	TP	STD	STD	PROT	STD	STD	Sol.N	C/N	STD	STD
							Characteristics, %TS																		
04/13/88	1	47505	7084	16300	2.91	2.17	2.17	1.00	2.00	89.74	59	88	4.95	2.40	6.70	1.36	1.30	1.60	31	32	41	785	9.02	4	15
05/10/88	28	41632	7008	18800	2.21	2.17	2.23	1.00	2.00	86.84	59	88	5.09	2.40	6.70	1.51	1.30	1.60	32	32	41	801	8.75	4	15
05/31/88	49	26541	7123	15780	1.68	2.17	2.38	1.00	2.00	93.86	59	88	5.61	2.40	6.70	1.41	1.30	1.60	35	32	41	546	13.05	4	15
07/12/88	91	25581	6357	11085	2.31	2.17	2.16	1.00	2.00	87.79	59	88	4.95	2.40	6.70	1.32	1.30	1.60	31	32	41	685	9.28	4	15
08/16/88	126	30515	7340	15010	2.03	2.17	2.53	1.00	2.00	89.32	59	88	4.80	2.40	6.70	0.89	1.30	1.60	30	32	41	658	11.16	4	15
09/30/88	171	28016	6190	15780	1.78	2.17	2.54	1.00	2.00	88.98	59	88	4.94	2.40	6.70	0.86	1.30	1.60	31	32	41	756	8.19	4	15
11/01/88	203	27200	6080	13870	1.96	2.17	2.55	1.00	2.00	86.25	59	88	4.57	2.40	6.70	1.43	1.30	1.60	29	32	41	764	7.96	4	15
12/09/88	241	29622	7008	16160	1.83	2.17	2.48	1.00	2.00	92.74	59	88	4.90	2.40	6.70	1.50	1.30	1.60	31	32	41	741	9.46	4	15
02/14/89	308	36768	6970	15760	2.33	2.17	2.23	1.00	2.00	89.99	59	88	4.11	2.40	6.70	1.11	1.30	1.60	26	32	41	757	9.21	4	15
03/14/89	336	25651	6092	15560	1.65	2.17	2.23	1.00	2.00	88.54	59	88	3.59	2.40	6.70	0.95	1.30	1.60	22	32	41	501	12.16	4	15
04/18/89	371	29779	7324	14160	2.10	2.17	2.46	1.00	2.00	81.88	59	88	4.50	2.40	6.70	1.23	1.30	1.60	28	32	41	716	10.23	4	15
05/30/89	413	38207	7407	15060	2.54	2.17	1.85	1.00	2.00	86.05	59	88	4.06	2.40	6.70	1.36	1.30	1.60	25	32	41	731	10.13	4	15
07/04/89	448	43738	6839	22410	1.95	2.17	3.11	1.00	2.00	87.49	59	88	6.74	2.40	6.70	1.54	1.30	1.60	42	32	41	696	9.83	4	15
08/01/89	476	25185	5074	13690	1.84	2.17	1.94	1.00	2.00	86.53	59	88	6.00	2.40	6.70	1.36	1.30	1.60	38	32	41	630	8.05	4	15
08/22/89	497	26639	6827	15810	1.68	2.17	2.56	1.00	2.00	88.68	59	88	4.26	2.40	6.70	0.97	1.30	1.60	27	32	41	801	8.52	4	15
10/03/89	539	23967	6281	11500	2.08	2.17	2.00	1.00	2.00	87.39	59	88	5.47	2.40	6.70	1.21	1.30	1.60	34	32	41	808	7.77	4	15
10/25/89	561	28512	6289	14710	1.94	2.17	2.73	1.00	2.00	89.03	59	88	5.18	2.40	6.70	0.83	1.30	1.60	32	32	41	598	10.52	4	15
11/21/89	588	28231	7316	16160	1.75	2.17	2.56	1.00	2.00	87.20	59	88	5.27	2.40	6.70	1.32	1.30	1.60	33	32	41	658	11.12	4	15
12/21/89	618	26016	7236	16030	1.62	2.17	2.56	1.00	2.00	88.77	59	88	5.12	2.40	6.70	1.12	1.30	1.60	32	32	41	785	9.22	4	15
Average		31016	6729	15454	2.01	2.17	2.38	1.00	2.00	88.27	59	88	4.95	2.40	6.70	1.23	1.3	1.6	31	32	41	706	9.66	4	15

STD = Typical normal ranges of actual primary sludge characteristics

Table A5.2 Summary of Monitoring Data on the Secondary Synthetic Sludges Used Throughout the Experimental Program Between April 13, 1988 to December 21, 1989

Date	Days	NH4-N	PO4-P	HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	Tot.VFA mg/L HAc
04/13/88	1	23	115	55	45		43					121
05/10/88	28	18	134	41			65			37		107
05/31/88	49	23	80	52							41	73
07/12/88	91	9	95	29			101					98
08/16/88	126	45	90	106	87		128			15		273
09/30/88	171	34	127	180	81		10					252
11/01/88	203	32	138	145	54		8					194
12/09/88	241	14	75	134	56		9			12		193
02/14/89	308	38	171	146	103		30					250
03/14/89	336	16	106	41			109					115
04/18/89	371	33	114	22								22
05/30/89	413	35	120	25	14							36
07/04/89	448	38	129				17					12
08/01/89	476	26	123				16					11
08/22/89	497	11	134								97	50
10/03/89	539	15	64	23			3					25
10/25/89	561	14	122	35	11		5					47
11/21/89	588	7	166				47					32
12/21/89	618	10	139	45			81					100
Average		23	118	72	56		45			21	69	106

APPENDIX B

Acclimatization Process

Table B1.1 : Average System Effluent Quality and Removal Efficiency at Pseudo Steady-state Under Different Alternatives During the Acclimatization

Table B2.1-B2.8 : Response Data of the Sampling Point Numbered 1 to 8 Under Different Running Conditions During the Acclimatization.

Figure B1.1 : Effluent Qualities of the M-UASB (COD, MLVSS, PO_4-P, TKN/TP) Under Different Running Conditions During the Acclimatization

Figure B2.1 : System Gas Production and Loading Rate Under Different Running Condition During the Acclimatization

Note : All sampling locations are illustrated in Figure 4.2
Acclimatization Alternatives:

(a) Seeding both A-UASB and M-UASB with sludge from the Lion's Gate anaerobic sludge digester and using a step-loading approach;
(b) Seeding both A-UASB and M-UASB with acclimatized synthetic seed sludge and using a constant-loading approach;
(c) Seeding the A-UASB with acclimatized synthetic seed sludge, but the M-UASB with sludge from the Lion's Gate anaerobic sludge digester, using a step-loading approach.

Table B1.1 Average System effluent Quality and Removal Efficiency At Pseudo Steady-State Under Different Alternatives During the Acclimatization

Running conditions	[a]	[b]	[c]
Running time, days	48	22	50
Loading rate			
L/D	3.65	3.79	5.18
A-UASB			
Cu.m/cu.m-d	0.18	0.19	0.26
KgCOD/cu.m-d (Sol.COD)	1.00	1.14	1.75
KgCOD/cu.m-d (Tot COD)	5.50	7.69	9.04
KgVS/cu.m-d	5.59	6.66	7.33
M-UASB			
Cu.m/cu.m-d	0.15	0.15	0.21
KgCOD/cu.m-d (Sol.COD)	1.56	1.41	2.19
KgCOD/cu.m-d (Tot.COD)	1.75	1.64	2.59
KgVS/cu.m-d	0.38	0.60	0.97
SYSTEM			
Cu.m/cu.m-d	0.08	0.08	0.12
KgCOD/cu.m-d (Sol.COD)	0.45	0.51	0.78
KgCOD/cu.m-d (Tot.COD)	2.44	3.42	4.02
KgVS/cu.m-d	2.48	2.96	3.26
Gas content, %			
A-UASB			
CO2	73.40	65.94	64.87
N2	2.95	1.70	1.82
CH4	23.64	32.36	33.32
M-UASB			
CO2	30.20	16.79	27.26
N2	0.81	1.18	0.40
CH4	69.00	82.04	72.34
Gas productivity			
A-UASB			
Total gas, l/d	10.90	21.70	17.13
CH4 gas, l/d	2.58	7.03	5.71
M-UASB			
Total gas, l/d	45.83	30.84	74.41
CH4 gas, l/d	31.62	25.43	53.81
SYSTEM			
Total gas, l/d	56.73	52.54	91.54
CH4 gas, l/d	34.20	32.46	59.52

Table B1.1 Average System effluent Quality and Removal Efficiency At Pseudo Steady-State Under Different Alternatives During the Acclimatization (cont'd)

Running conditions	[a]	[b]	[c]
Running time, days	48	22	50
Gas productivity (CH4 gas)			
A-UASB			
Cu.m/cu.m-d	0.13	0.37	0.29
Cu.m/cu.m-d @ SC	0.12	0.33	0.25
M-UASB			
Cu.m/cu.m-d	1.26	1.01	2.15
Cu.m/cu.m-d @ SC	1.12	0.90	1.91
SYSTEM			
Cu.m/cu.m-d	0.76	0.72	1.32
Cu.m/cu.m-d @ SC	0.67	0.64	1.17
Specific gas production (CH4)			
A-UASB			
Cu.m/KgVS added	0.02	0.06	0.04
Cu.m/KgVS destroyed	0.03	0.07	0.05
Cu.m/KgVS added @ SC	0.02	0.05	0.03
Cu.m/KgVS destroyed @ SC	0.02	0.06	0.04
Cu.m/KgCOD added	0.13	0.33	0.16
Cu.m/KgCOD removed	-0.14	-1.19	-0.34
Cu.m/KgCOD added @ SC	0.12	0.29	0.15
Cu.m/KgCOD removed @ SC	-0.12	-1.05	-0.30
M-UASB			
Cu.m/KgVS added	3.88	1.88	2.42
Cu.m/KgVS destroyed	4.95	3.94	3.29
Cu.m/KgVS added @ SC	3.44	1.66	2.14
Cu.m/KgVS destroyed @ SC	4.39	3.49	2.92
Cu.m/KgCOD added	0.81	0.73	1.02
Cu.m/KgCOD removed	0.87	0.80	1.10
Cu.m/KgCOD added @ SC	0.72	0.64	0.91
Cu.m/KgCOD removed @ SC	0.77	0.71	0.97
SYSTEM			
Cu.m/KgVS added	0.32	0.25	0.41
Cu.m/KgVS destroyed	0.36	0.26	0.42
Cu.m/KgVS added @ SC	0.29	0.22	0.36
Cu.m/KgVS destroyed @ SC	0.32	0.23	0.38
Cu.m/KgCOD added	1.71	1.39	1.72
Cu.m/KgCOD removed	1.98	1.62	1.90
Cu.m/KgCOD added @ SC	1.51	1.23	1.52
Cu.m/KgCOD removed @ SC	1.75	1.44	1.68

Table B1.1 Average System Effluent Quality and Removal Efficiency At Pseudo Steady-State Under Different Alternatives During the Acclimatization (cont'd)

Running conditions	[a]	[b]	[c]
Running time, days	48	22	50
System effluent			
Solids			
TS, mg/L	4903	5327	3262
VS, mg/L	2740	1897	1101
TSS, mg/L	837	165	277
TVSS, mg/L	527	105	141
TS, %	0.49	0.53	0.33
VS, % dry solids	54.88	38.51	33.59
TSS, %	0.09	0.02	0.03
TVSS, % dry solids	62.94	62.97	50.40
COD, mg/L			
Total COD	1692	975	820
Sol.COD	758	861	648
Inorganics, mg/L			
NH4-N	290	271	386
TKN	303	296	423
TP	74	79	73
PO4-P	14	23	9
VFA, mg/L			
HAc	112	116	45
HPr	105	207	231
Iso-HBr	0	0	14
HBr	0	0	0
A - HVr	0	0	0
HVr	0	0	0
Iso-HVr	0	0	0
HHe	0	0	0
Total VFA, mg/L as HAc (M-UASB)	197	284	235
Total VFA, mg/L as HAc (A-UASB)	5164	4494	5667
System removal efficiency			
COD Removal, %			
Total COD	94	98	98
Sol. COD	86	87	91
TSS Removal, %	97	99	99
Total VFA Removal, % (M-UASB	96	94	96
TP Removal, %	54	55	64
PO4-P Removal, %	89	84	95

Note : [a] Seeding both A-UASB and M-UASB with sludge from the Lion's Gate anaerobic sludge digester and using a step-loading approach

[b] Seeding both A-UASB and M-UASB with acclimatized synthetic seed sludge using a constant-loading approach

[c] Seeding A-UASB with acclimatized synthetic seed sludge, but M-UASB with sludge from the Lion's Gate anaerobic sludge digester, using a step-loading approach

Table B2.1 Response Data of the Sampling Point Numbered 1 Under Different Acclimatization Alternatives

Acclim.	Date	Days	Solids, mg/L				Solids, % or %TS				COD, mg/L	
Alter.			TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	Total	soluble
(1)	03/28/88	1	30660	27170	29640	27030	3.06	88.62	2.96	91.19	56161	5534
	04/04/88	8	52300	47240	52610	48460	5.23	90.33	5.26	92.11	62400	5720
	04/08/88	12	28470	25480	24090	22360	2.85	89.50	2.41	92.82	78920	6074
	04/12/88	16	35620	31920	18450	17120	3.56	89.59	1.85	92.80	33336	6000
	04/15/88	19	32480	28930	21220	19690	3.25	89.07	2.12	92.79	50742	5245
	04/19/88	23	45390	40930	27630	25560	4.54	90.17	2.76	92.51	51524	5639
	04/23/88	27	31320	28540	22290	22530	3.13	91.12	2.23	92.10	96604	5084
	04/26/88	30	49960	45160	32740	30170	4.99	90.39	3.27	92.15	59514	5304
	04/30/88	34	47600	42610	30420	28190	4.76	89.52	3.04	92.67	35482	5967
	05/03/88	37	42200	37830	28980	27180	4.22	89.64	2.89	93.79	24998	5000
	05/07/88	41	33250	29940	20190	19150	3.32	90.00	2.02	94.85	30204	4980
	05/10/88	44	26300	23220	35410	32540	2.63	88.29	3.54	91.89	33197	5697
	05/14/88	48	31070	27680	24730	22930	3.11	89.09	2.47	92.72	24747	5477
	05/17/88	51	45500	40790	29710	27770	4.55	89.65	2.97	93.47	32193	5312
(2)	05/31/88	1	33450	30660	22520	22020	3.35	91.66	2.25	97.78	32727	7960
	06/07/88	8	40940	36710	33650	31110	4.09	89.67	3.36	92.42	55936	7203
	06/14/88	15	40100	37140	34120	33380	4.01	92.62	3.41	97.83	45545	8198
	06/21/88	22	41900	38700	33190	31531	4.19	92.36	3.32	95.00	49600	5760
	06/28/88	29	33510	30680	25240	24225	3.35	91.55	2.52	95.98	29268	5285
(3)	11/15/88	1	26415	22465	22030	19520	2.64	85.05	2.20	88.61	29249	5138
	11/18/88	4	29250	25465	28150	25110	2.93	87.06	2.82	89.20	44444	5079
	11/22/88	8	23720	20460	21340	19660	2.37	86.26	2.13	92.13	54475	5681
	11/25/88	11	29180	25580	28970	26400	2.92	87.66	2.90	91.13	32258	5403
	11/29/88	15	32180	29190	25360	24380	3.22	90.71	2.54	96.14	32800	6000
	12/02/88	18	29160	26360	29690	28240	2.92	90.40	2.97	95.12	33198	5344
	12/06/88	22	36865	33470	35660	34020	3.69	90.79	3.57	95.40	26721	5182
	12/09/88	25	37665	34595	32650	31240	3.77	91.85	3.27	95.68	45669	6535
	12/13/88	29	35800	32680	34040	32900	3.58	91.28	3.40	96.65	30709	5196
	12/16/88	32	32045	28760	24130	22920	3.20	89.75	2.41	94.99	33006	7073
	12/20/88	36	29340	26255	22180	21090	2.93	89.49	2.22	95.09	36292	5996
	12/23/88	39	33335	30370	28970	27580	3.33	91.11	2.90	95.20	33735	6345
	12/27/88	43	35260	32005	30830	29340	3.53	90.77	3.08	95.17	50400	6880
	12/30/88	46	38020	34810	25480	24450	3.80	91.56	2.55	95.96	36508	7619
	01/03/89	50	32515	29610	26710	25190	3.25	91.07	2.67	94.31	40396	6970
	01/06/89	53	25580	22840	28850	27210	2.56	89.29	2.89	94.32	28685	5976
(4)			34290	30563	29950	27747	3.43	89.01	2.99	92.69	30046	5495
(5)			38503	35507	30850	29712	3.85	92.18	3.08	96.27	41471	6414
(6)			32038	29087	27013	25617	3.20	90.64	2.70	94.86	35196	6855

Table B2.1 Response Data of the Sampling Point Numbered 1 Under Different Acclimatization Alternatives (cont'd)

Accl. Alter.	Date	Day	Inorganics, mg/L NH4-N	TKN	TKN, %TS	TP, %TS	TP	PO4-P	VFA, mg/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHc	Tot. VFA mg/L HAc
(1)	03/28/88	1	26.40	147	3.78	100	2.00	130	520	38							551
	04/04/88	8	37.50	250	1.52	170	1.80	99	401	26		39					449
	04/08/88	12	45.86	386	2.07	148	1.76	127	425	31		101			224		651
	04/12/88	16	30.56	450	1.59	142	2.03	196	324	42		116			184		545
	04/15/88	19	28.76	166	3.66	152	0.90	124	127	33		52					189
	04/19/88	23	28.76	196	3.93	158	1.18	128	228	113		157					427
	04/23/88	27	29.87	297	3.25	206	0.75	121	282	163		123		73			541
	04/26/88	30	40.64	242	3.15	152	0.96	133	535	404		218		390			1241
	04/30/88	34	37.77	249	4.16	183	0.91	135	440	293	172				325		986
	05/03/88	37	18.07	318	3.65	159	1.06	124	307	193		116		243			686
	05/07/88	41	23.00	239	3.69	157	0.97	119	357	271		132		272			827
	05/10/88	44	23.00	266	3.58	166	1.13	122	317	248		125	250				750
	05/14/88	48	21.00	257	3.01	142	0.82	122	236	211		100		254	30		642
	05/17/88	51	28.00	243	3.00	170	0.74	142	479	477		124			352		1157
(2)	05/31/88	1	86.00	326	4.86	278	1.89	268	707	607		77			297		1426
	06/07/88	8	44.00	312	4.05	184	1.02	167	842	137			36		242		1117
	06/14/88	15	29.00	262	4.55	190	0.88	157	979	133			69		462		1399
	06/21/88	22	24.00	304	4.14	168	0.81	136	546	49				240			727
	06/28/88	29	22.00	280	4.27	169	0.81	124	556	136		119		251			895
(3)	11/15/88	1	13.15	263	3.20	181	1.64	141	753	702		116			98		1459
	11/18/88	4	28.34	286	3.41	137	2.02	106	463	377		62			70		852
	11/22/88	8	74.00	329	4.94	201	1.70	149	890	796		158			54		1675
	11/25/88	11	72.00	339	5.07	201	1.75	162	1198	1112		199			27		2251
	11/29/88	15	95.00	422	4.85	205	1.86	149	975	840		148			30		1775
	12/02/88	18	43.00	342	4.07	153	1.35	132	582	424					45		952
	12/06/88	22	30.00	350	4.35	159	1.36	143	504	640		157					1130
	12/09/88	25	26.00	343	3.95	233	0.93	178	755	1077		273					1814
	12/13/88	29	9.00	302	4.13	174	0.92	141	559	893		153					1387
	12/16/88	32	18.00	362	4.20	172	1.05	118	508	788		115					1225
	12/20/88	36	18.00	345	4.18	154	1.22	130	376	498		63			14		831
	12/23/88	39	57.22	338	4.04	192	0.96	141	549	664		42		239	48		1285
	12/27/88	43	57.22	304	4.50	172	0.97	160	869	1419		106			238		2232
	12/30/88	46	72.60	419	4.61	216	1.03	171	882	1415		16		200	90		2211
	01/03/89	50	18.00	345	4.14	187	1.02	160	1028	1620		106			204		2534
	01/06/89	53	30.00	394	5.10	213	1.07	220	788	1295		59			182		1985
(4)			24.00	255	3.20	159	0.90	129	344	312		116	250	254	191		850
(5)			25.00	282	4.32	176	0.83	139	694	106		119	69	246	462		1007
(6)			40.20	386	4.62	205	1.04	184	899	1443		60		200	159		2243

Note:(4),(5),and (6) are average responses at pseudo steady-state (6-14 to 6-28, 1988; 5-10 to 5-17, 1988; 12-30 to 01-06, 1989) for alter. 1, 2, and 3 respectively

Table B2.2 Response Data of Sampling Point No.2 Under Different Acclimatization Alternatives

Acclim. Alter.	Date	Days	Solids, mg/L TSS	TVSS	[%]	%TS]	, mg/L Total	Sol.	NH4-N	TKN	Inorganics, mg/L TKN [%TS]	TP	TP [%TS]	PO4-P
(1)	03/28/88	1	46670	43880	4.67	94.02	100606	11071	277	398	1.19	190	2.76	202
	04/04/88	8	37640	35320	3.76	93.84	77600	9920	288	150	3.32	110	2.32	184
	04/08/88	12	41400	38910	4.14	93.98	88012	9380	250	545	1.74	162	0.87	183
	04/12/88	16	40700	38650	4.07	94.96	69172	10834	270	446	1.71	154	0.91	202
	04/15/88	19	41250	38560	4.12	93.48	78884	10362	242	242	5.97	172	0.67	209
	04/19/88	23	41470	39210	4.15	93.94	67792	10169	235	212	5.45	168	0.63	187
	04/23/88	27	46690	43990	4.67	94.22	76677	10345	275	282	5.97	183	0.57	205
	04/26/88	30	58540	55170	5.85	94.24	113776	9676	216	275	5.52	183	0.58	179
	04/30/88	34	54530	51700	5.45	94.81	116122	10161	276	348	5.75	193	0.82	186
	05/03/88	37	54150	51360	5.42	94.85	105638	9193	259	366	6.07	183	0.93	183
	05/07/88	41	52500	49790	5.25	94.84	89795	9388	304	336	6.21	191	0.59	190
	05/10/88	44	50660	47960	5.07	94.67	108608	10451	280	363	5.84	213	0.55	183
	05/14/88	48	50990	48440	5.10	94.99	95335	10832	253	339	5.89	207	0.60	193
	05/17/88	51	50990	48600	5.10	95.31	120724	9416	245	329	5.81	192	0.60	195
(2)	05/31/88	1	45330	42990	4.53	94.84	89293	8768	455	368	6.82	202	0.82	195
	06/07/88	8	55030	51280	5.50	93.19	80080	9537	327	396	6.15	214	0.85	207
	06/14/88	15	51280	48810	5.13	95.18	105743	8673	292	350	6.12	182	1.05	178
	06/21/88	22	53790	50132	5.38	93.20	111200	8800	224	268	6.24	174	0.81	171
	06/28/88	29	53600	51390	5.36	95.88	127525	7480	89	108	7.54	195	0.94	71
(3)	11/15/88	1	56560	54130	5.66	95.70	74310	10751	299	368	6.57	204	0.84	203
	11/18/88	4	60880	57990	6.09	95.25	98413	9762	266	353	5.89	192	0.81	182
	11/22/88	8	50100	48160	5.01	96.13	71595	10350	297	388	7.45	195	0.66	190
	11/25/88	11	55730	53500	5.57	96.00	108065	10484	284	470	8.11	234	0.68	200
	11/29/88	15	52950	50510	5.30	95.39	105600	9600	293	417	7.85	199	0.76	182
	12/02/88	18	40190	38300	4.02	95.30	85020	8907	287	342	6.50	173	0.82	166
	12/06/88	22	59840	57370	5.98	95.87	86640	9474	230	278	6.27	165	0.81	166
	12/09/88	25	50720	48480	5.07	95.58	96063	10315	193	302	6.08	201	0.81	178
	12/13/88	29	38590	36600	3.86	94.84	63780	8268	133	224	5.07	144	0.67	141
	12/16/88	32	51420	49260	5.14	95.80	117092	10295	216	299	5.8	205	0.69	187
	12/20/88	36	49930	48050	4.99	96.23	107298	11124	260	354	5.95	205	0.74	183
	12/23/88	39	48640	46730	4.86	96.07	62651	10683	268	330	5.62	198	0.68	190
	12/27/88	43	64220	61890	6.42	96.37	80800	11120	287	356	6.21	192	0.78	190
	12/30/88	46	45960	44110	4.60	95.97	84921	10159	319	428	5.64	199	0.81	179
	01/03/89	50	49020	46930	4.90	95.74	90297	10455	287	336	5.98	176	0.98	183
	01/06/89	53	42990	41230	4.30	95.91	64542	9721	293	394	5.84	191	0.72	182
(4)			50880	48333	5.09	94.99	108222	10233	259	344	5.85	204	0.58	190
(5)			52890	50111	5.29	94.75	114823	8318	202	242	6.63	184	0.93	140
(6)			45990	44090	4.60	95.87	79920	10112	300	386	5.82	189	0.84	181

Table B2.2 Response Data of Sampling Point No.2 Under Different Acclimatization Alternatives

Accl. Alter.	Date	Days	VFA, mg/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	Tot.VFA mg/L HAc
(1)	03/28/88	1	2506	1765	40	1490					4980
	04/04/88	8	2246	1740	36	1521			782		5178
	04/08/88	12	1544	1185	25	1173			582		3664
	04/12/88	16	1810	1587	31	1426			724		4516
	04/15/88	19	1459	1471	24	1226			601		3858
	04/19/88	23	1511	1606	28	1276			661		4091
	04/23/88	27	2128	2364	37	1204	18	39	694	88	5378
	04/26/88	30	2080	2498	31	1131	16	35	632	3	5301
	04/30/88	34	1751	2034	42	1189	26	52	696	4	4697
	05/03/88	37	1648	1824	32	1154	18	38	622	4	4336
	05/07/88	41	1663	1998	43	1220	26	55	698	4	4604
	05/10/88	44	1710	1793	36	1173	20	44	665	4	4418
	05/14/88	48	1982	2089	40	1316	23	52	792	5	5113
	05/17/88	51	1754	1798	36	1266	22	47	749	5	4583
(2)	05/31/88	1	1382	1565	49	929	31	66	747	106	3869
	06/07/88	8	1313	1742	49	1043	30	61	947	695	4440
	06/14/88	15	1049	1601	49	1051	29	56	860	212	3763
	06/21/88	22	1682	1690	27	990	17	37	765	153	4307
	06/28/88	29	802	794		380		18	279	48	1904
(3)	11/15/88	1	2125	2182	45	1027	19	59	590	110	5075
	11/18/88	4	2065	2023	41	987	18	55	574	99	4838
	11/22/88	8	2058	1853	49	1022	24	57	647	95	4768
	11/25/88	11	2204	1958	47	1015	20	54	587		4904
	11/29/88	15	2261	2060	53	864	22	58	546	82	4967
	12/02/88	18	2142	2058	52	879	24	58	580	92	4882
	12/06/88	22	2334	2025	27	1011			503		4980
	12/09/88	25	2395	2070		962			481		5012
	12/13/88	29	1825	1724		756			432		3992
	12/16/88	32	2321	2304		931			506		5122
	12/20/88	36	2420	2468	26	1080	69	135	845	84	5836
	12/23/88	39	2281	2295	30	1032	59	129	776	80	5474
	12/27/88	43	2643	2547	31	1107	49		770	96	6015
	12/30/88	46	2321	2236	36	938		99	730	82	5328
	01/03/89	50	2535	2664	34	871		94	702	69	5816
	01/06/89	53	2201	2431	34	854	18	100	663	69	5273
(4)			1815	1893	37	1252	22	48	735	4	4705
(5)			1178	1362	38	807	23	37	635	138	3325
(6)			2352	2444	35	888	18	98	698	73	5472

Note:(4),(5),and (6) are average responses at pseudo steady-state (6-14 to 6-28, 1988; 5-10 to 5-17, 19 12-30 to 01-06, 1989) for alternatives 1, 2, and 3 respectively.

Table B2.3 Response Data of Sampling Point No.3 Under Different Acclimatization Alternatives

Acclim. Alter.	Date	Days	Solids, mg/L TS	VS	TSS	TVSS	Solids, % or %TS [%]	[%TS]	[%]	[%TS]	COD, mg/L Tot.	sol.	NH4-N	TKN	TKN [%TS]	Inorganics, mg/L TP	TP [%TS]	PO4-P
(1)	03/28/88	1	7320	4870	2240	2030	0.73	66.53	0.22	90.63	15152	9758	249	430	5.78	200	1.86	187
	04/04/88	8	6610	4500	1800	1590	0.66	68.08	0.18	88.33	14720	12975	283	155	4.52	160	2.07	177
	04/08/88	12	7330	5150	2800	2550	0.73	70.26	0.28	91.07	16611	9875	257	424	6.17	142	2.09	188
	04/12/88	16	6420	4500	2310	2070	0.64	70.09	0.23	89.61	16835	10418	232	436	5.65	160	2.08	200
	04/15/88	19	7860	5670	2720	2580	0.79	72.14	0.27	94.85	23623	10788	240	236	5.15	180	3.10	207
	04/19/88	23	7690	5410	2920	2550	0.77	70.35	0.29	87.33	17965	10254	223	232	4.67	166	2.45	203
	04/23/88	27	8360	5980	3080	2740	0.84	71.53	0.31	88.96	17121	9291	235	286	4.96	165	2.02	185
	04/26/88	30	10520	8090	7480	6690	1.05	76.90	0.75	89.44	32254	10000	213	264	5.08	183	1.29	179
	04/30/88	34	9960	7350	4610	4180	0.99	73.80	0.46	90.67	39254	10644	230	282	5.14	194	1.82	193
	05/03/88	37	10000	7410	4190	3880	1.00	74.10	0.42	92.69	21773	9999	235	348	5.00	193	1.94	190
	05/07/88	41	8280	5930	3030	2840	0.82	72.50	0.30	93.73	12517	9633	255	306	4.89	197	2.44	188
	05/10/88	44	8730	6290	3680	3290	0.87	72.05	0.37	89.40	19262	9713	245	292	4.72	185	2.25	169
	05/14/88	48	9480	6890	4180	3800	0.95	72.68	0.42	90.90	18797	11724	243	329	4.70	207	2.36	190
	05/17/88	51	9930	7430	4990	4510	0.99	74.82	0.50	90.38	22535	9577	241	308	4.97	197	2.13	197
(2)	05/31/88	1	8440	6960	4690	4510	0.84	82.46	0.47	96.16	15111	7475	428					174
	06/07/88	8	8270	5440	4130	3100	0.83	65.78	0.41	75.06	15855	6962	386					198
	06/14/88	15	6640	4980	2060	1960	0.66	75.00	0.21	90.30	13386	9228	342	388	4.49	204	3.17	199
	06/21/88	22	12893	10627	6500	5993	1.28	82.42	0.65	92.20	24640	8880	264	308	5.69	192	1.46	178
	06/28/88	29	9330	6875	3970	3720	0.93	73.69	0.40	93.70	19187	9024	234	249	5.03	169	2.48	176
(3)	11/15/88	1	21600	18070	15405	14485	2.16	83.66	1.54	94.03	32411	10751	327	368	4.61	204	1.63	205
	11/18/88	4	63130	58235	59650	56750	6.31	92.25	5.97	95.14	109524	10794	325	365	6.21	206	0.75	200
	11/22/88	8	35770	32250	31800	30210	3.58	90.16	3.18	95.00	57588	8794	330	431	7.16	214	0.71	203
	11/25/88	11	48930	44690	40000	38440	4.89	91.33	4.00	96.10	73387	10645	321	397	8.42	205	1.15	202
	11/29/88	15	42380	38420	46580	44290	4.24	90.66	4.66	95.08	92000	9920	312	431	7.56	212	0.98	190
	12/02/88	18	40700	37190	40710	38940	4.07	91.38	4.07	95.65	81781	9636	304	346	6.16	185	0.82	179
	12/06/88	22	40510	36400	28410	27110	4.05	89.85	2.84	95.42	55061	9393	252	350	6.53	207	0.89	168
	12/09/88	25	37570	34010	34640	32950	3.76	90.52	3.46	95.12	77165	9606	233	310	6.80	193	0.81	176
	12/13/88	29	39390	35530	36410	34200	3.94	90.20	3.64	93.93	83465	9528	215	277	5.63	182	0.69	164
	12/16/88	32	41010	36930	30460	29070	4.10	90.05	3.05	95.44	58939	10452	245	291	5.96	191	0.69	185
	12/20/88	36	39580	36000	34720	33440	3.96	90.96	3.47	96.31	59172	11203	285	324	6.21	191	0.76	190
	12/23/88	39	45720	42150	33700	32400	4.57	92.19	3.37	96.14	61847	13173	280	338	6.11	200	0.78	186
	12/27/88	43	42530	38790	38060	36610	4.25	91.21	3.81	96.19	65600	10800	319	382	6.21	202	0.76	186
	12/30/88	46	39040	34840	34690	33290	3.90	89.24	3.47	95.96	63492	10794	331	391	6.36	199	0.97	190
	01/03/89	50	35170	31830	38120	36570	3.52	90.50	3.81	95.93	66535	10218	299	391	5.08	204	0.83	183
	01/06/89	53	41030	37370	41690	39890	4.10	91.08	4.17	95.68	37450	10996	330	479	6.29	247	0.90	205
(4)			9380	6870	4283	3867	0.94	73.18	0.43	90.23	20198	10338	243	310	4.80	196	2.25	185
(5)			9621	7494	4177	3891	0.96	77.04	0.42	92.07	19071	9044	280	315	5.07	188	2.37	184
(6)			38413	34680	38167	36583	3.84	90.27	3.82	95.86	55826	10669	320	420	5.91	217	0.90	193

Table B2.3 Response Data of the Sampling Point Numbered 3 Under Different Acclimatization Alternatives (cont'd)

Accl. Alter.	Date	Days	VFA, mg/L HAc	HPr	Iso-HBr	HBr	A-HVr	iso-HVr	HVr	HHe	Tot.VFA mg/L HAc
(1)	03/28/88	1	1668	1179	29	936					3282
	04/04/88	8	2090	1644	34	1429			74		4464
	04/08/88	12	1349	1017	22	1053			512		3208
	04/12/88	16	1286	1155	20	1124			547		3324
	04/15/88	19	1540	1579	23	1334			669		4139
	04/19/88	23	1571	1634	24	1333			674		4218
	04/23/88	27	1920	2169	28	1090	11	26	625	93	4878
	04/26/88	30	1799	2157	26	953	11	30	533	75	4592
	04/30/88	34	1956	2364	30	1212	15	42	629	3	5125
	05/03/88	37	1822	2079	30	1190	16	42	630	3	4746
	05/07/88	41	1959	2116	35	1360	20	51	739	4	5104
	05/10/88	44	1766	1824	33	1207	18	48	664	4	4522
	05/14/88	48	2110	2243	39	1459	22	55	850	5	5498
	05/17/88	51	1963	2037	36	1340	21	54	782	5	5060
(2)	05/31/88	1	1459	1410	40	855	25	55	677	93	3706
	06/07/88	8	1074	1300	38	746	23	45	641	14	3087
	06/14/88	15	1040	1800	54	1162	33	64	985	247	4093
	06/21/88	22	1430	1775	35	1030	21	46	854	176	4228
	06/28/88	29	1887	2043	27	1016	17	40	771	144	4816
(3)	11/15/88	1	2130	2345	52	1087		66	639	126	5288
	11/18/88	4	2183	2213	49	1056	18	65	621	113	5203
	11/22/88	8	2424	2365	54	1236	26	73	690	121	5748
	11/25/88	11	2454	2285	61	1172	30	73	711	107	5682
	11/29/88	15	2376	2104	57	1000	27	67	617	101	5273
	12/02/88	18	2269	2006	48	889	22	55	545		4900
	12/06/88	22	2309	2121		941			505		4967
	12/09/88	25	2256	2091		884			474		4833
	12/13/88	29	2290	2281		897			516		5055
	12/16/88	32	2496	2520	34	954			556		5540
	12/20/88	36	2349	2445	30	1004	69	140	816	70	5676
	12/23/88	39	2229	2248	22	991	56	131	764		5302
	12/27/88	43	2335	2311	30	966	61	133	744	83	5483
	12/30/88	46	2414	2336	36	988		101	769	89	5564
	01/03/89	50	2305	2429	32	774		95	636	64	5287
	01/06/89	53	2480	2767	39	951	21	109	726	70	5938
(4)			1946	2035	36	1335	20	52	765	5	5026
(5)			1452	1873	39	1069	24	50	870	189	4379
(6)			2400	2511	36	904	21	102	710	74	5596

Note:(4),(5),and (6) are average responses at pseudo steady-state (6–14 to 6–28, 1988; 5–10 to 5–17, 1988; 12–30 to 01–06, 1989) for alternatives 1, 2, and 3 respectively.

Table B2.4 Response Data of Sampling Point Numbered 4 Under Different Acclimatization Alternatives

Acclim.	Date	Days	Solids, mg/L				COD, mg/L			Inorganics, mg/L		
Alter.			TSS	TVSS	[%]	[%TS]	Total	Soluble	NH4-N	TKN	TP	PO4-P
(1)	03/28/88	1	1200	1050	0.12	87.50	11353	8848	273	379	160	200
	04/04/88	8	860	740	0.09	86.05	11040	9040	298	280	70	193
	04/08/88	12	1120	980	0.11	87.50	11940	9793	265	440	144	197
	04/12/88	16	980	840	0.09	85.57	12834	10928	247	454	126	209
	04/15/88	19	970	890	0.09	91.75	12238	10020	220	240	162	200
	04/19/88	23	900	810	0.09	90.00	12287	9999	230	220	156	199
	04/23/88	27	1310	1040	0.13	79.39	11968	9615	243	340	206	201
	04/26/88	30	1020	820	0.10	80.39	12591	9838	245	304	208	203
	04/30/88	34	1240	1090	0.12	87.90	13064	11209	250	318	207	205
	05/03/88	37	1330	1240	0.13	93.23	12902	10322	239	378	189	190
	05/07/88	41	1050	910	0.11	86.67	12653	8735	250	299	194	190
	05/10/88	44	950	750	0.10	78.95	12664	9959	267	306	188	178
	05/14/88	48	1400	1340	0.14	95.71	13753	9939	248	315	201	186
	05/17/88	51	1340	1130	0.13	84.33	13119	9829	243	305	196	187
(2)	05/31/88	1	3260	3150	0.33	96.67	12000	6101	370	428	146	141
	06/07/88	8	1880	940	0.19	50.00	10825	8410	407	415	202	198
	06/14/88	15	600	550	0.06	55.00	10891	8356	329	412	212	192
	06/21/88	22	630	505	0.06	80.20	9920	7840	257	284	274	178
	06/28/88	29	815	705	0.08	86.50	10650	8943	247	295	195	192
(3)	11/15/88	1	1100	875	0.11	79.55	12095	10672	345	421	202	203
	11/18/88	4	1103	883	0.11	80.05	11587	10714	325	380	208	200
	11/22/88	8	1024	966	0.10	94.34	12840	10895	322	417	203	205
	11/25/88	11	970	940	0.10	96.91	12661	10968	321	422	232	213
	11/29/88	15	894	846	0.09	94.63	11680	10080	345	489	236	192
	12/02/88	18	955	893	0.10	93.51	11012	9555	317	354	185	186
	12/06/88	22	938	888	0.09	94.67	10850	9069	265	290	157	173
	12/09/88	25	1283	1190	0.13	92.75	11575	8898	240	302	178	164
	12/13/88	29	1218	1138	0.12	93.43	11181	8583	210	236	152	160
	12/16/88	32	1150	1066	0.12	92.70	11081	9823	231	287	185	178
	12/20/88	36	1903	1803	0.19	94.75	13728	10729	299	358	207	190
	12/23/88	39	2300	2183	0.23	94.91	13655	10120	293	343	200	190
	12/27/88	43	1878	1768	0.19	94.14	13040	10000	312	334	191	190
	12/30/88	46	1463	1388	0.15	94.87	11984	8730	344	428	206	183
	01/03/89	50	1393	1285	0.14	92.25	10931	9227	402	350	196	183
	01/06/89	53	1403	1300	0.14	92.66	12510	10518	320	444	213	194
(4)			1230	1073	0.12	86.33	13179	9909	253	309	195	184
(5)			682	587	0.07	73.90	10487	8380	278	330	227	187
(6)			1420	1324	0.14	93.26	11808	9492	355	407	205	187

Table B2.4 Response Data of the Sampling Point Numbered 4 Under Different Acclimatization Alternatives

Acclim. Alter.	Date	Days	VFA, mg/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	Tot.VFA mg/L HAc
(1)	03/28/88	1	767	327	22	189					1176
	04/04/88	8	1859	1456	31	1265			660		4311
	04/08/88	12	2149	1667	37	1624			840		5127
	04/12/88	16	1607	1450	28	1381			690		4149
	04/15/88	19	1411	1434	21	1229			601		3780
	04/19/88	23	1649	1785	28	1420			724		4509
	04/23/88	27	1905	2162	29	1131	12	28	610	3	4832
	04/26/88	30	2044	2453	30	1069	14	32	582	3	5153
	04/30/88	34	1999	2444	32	1230	17	42	651	3	5260
	05/03/88	37	1676	2005	30	1154	16	36	624	3	4509
	05/07/88	41	1596	1973	34	1213	19	42	697	4	4493
	05/10/88	44	1717	1912	35	1241	20	44	708	4	4593
	05/14/88	48	1795	2199	40	1391	23	51	845	5	5097
	05/17/88	51	1620	1887	34	1196	12	48	723	5	4452
(2)	05/31/88	1	1035	1118	38	628	25	51	500	266	2872
	06/07/88	8	1049	1536	49	871	30	59	768	188	3523
	06/14/88	15	818	1721	56	1014	34	66	959	264	3702
	06/21/88	22	1107	1654	37	818	22	45	816	184	3646
	06/28/88	29	1681	2179	31	1011	18	43	845	162	4775
(3)	11/15/88	1	1938	2247	53	952	24	77	550	110	4885
	11/18/88	4	2095	2243	49	1040	23	69	590	111	5115
	11/22/88	8	1985	2102	57	1080	29	68	689	95	4976
	11/25/88	11	2339	2358	64	1226	31	74	760	108	5695
	11/29/88	15	1976	2011	57	970	28	65	638	102	4790
	12/02/88	18	2040	1719	41	853	18	45	501		4375
	12/06/88	22	1993	2139	31	891			554		4682
	12/09/88	25	1961	2047	30	835			507		4509
	12/13/88	29	1730	2003		695			454		4095
	12/16/88	32	2223	875					561		3262
	12/20/88	36	2221	2614	37	971	74	140	830	89	5688
	12/23/88	39	1980	2361	33	926	59	129	780	77	5157
	12/27/88	43	2010	2433	37	873	71		758	85	5135
	12/30/88	46	2120	2448	39	905		104	786	92	5320
	01/03/89	50	1958	2447	39	706		98	646	83	4931
	01/06/89	53	2100	2721	40	814	23	110	693	71	5411
(4)			1711	1999	37	1276	18	48	759	4	4714
(5)			1202	1851	41	948	25	51	873	203	4041
(6)			2059	2539	39	808	23	104	708	82	5220

Note:(4),(5),and (6) are average responses at pseudo steady-state (6-14 to 6-28, 1988; 5-10 to 5-17, 1988; 12-30 to 01-06, 1989) for alternatives 1, 2, and 3 respectively.

Table B2.5 Response Data of Sampling Point No.5 Under Different Acclimatization Alternatives

Acclim. Alter.	Date	Days	Solids, mg/L				Solids, % or %TS				COD, mg/L		Inorganics, mg/L			
			TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	Total	sol.	NH4-N	TKN	TP	PO4-P
(1)	03/28/88	1	5590	3300	520	480	0.56	59.03	0.05	80.00	11879	10586	277	380	201	160
	04/04/88	8	4780	2670	820	690	0.48	55.86	0.08	84.15	10480	10537	290	440	175	170
	04/08/88	12	5110	3140	500	480	0.51	61.45	0.05	96.00	11528	9462	268	436	190	134
	04/12/88	16	4920	3000	720	590	0.49	60.98	0.07	81.94	11668	11168	275	492	227	160
	04/15/88	19	5670	2700	590	540	0.57	47.62	0.06	91.53	10873	5074	267	282	209	149
	04/19/88	23	4740	3940	650	450	0.47	83.12	0.07	69.23	11270	10169	232	351	203	192
	04/23/88	27	5650	3570	890	710	0.57	63.18	0.09	79.78	12455	9696	245	282	232	201
	04/26/88	30	5150	3100	670	490	0.52	60.19	0.07	73.13	11781	10405	243	340	232	205
	04/30/88	34	5190	2930	560	440	0.52	56.45	0.06	78.57	12015	11209	285	307	140	201
	05/03/88	37	5270	3150	550	420	0.53	59.77	0.06	76.36	11854	10403	252	404	202	202
	05/07/88	41	5170	3050	510	380	0.52	58.99	0.05	74.51	11592	9796	267	316	200	199
	05/10/88	44	5410	3020	460	330	0.54	35.82	0.05	71.74	11517	10861	280	333	206	186
	05/14/88	48	5720	3380	680	570	0.57	59.09	0.07	83.82	12536	10832	245	325	208	193
	05/17/88	51	3430	1390	690	590	0.34	40.52	0.07	85.51	11992	10463	281	291	186	199
(2)	05/31/88	1	1970	1940	1660	1420	0.20	98.48	0.17	82.54	7232	5051	319	385	196	111
	06/07/88	8	5240	2740	1380	490	0.52	52.29	0.14	35.51	9376	8732	394	396	210	200
	06/14/88	15	4420	2830	120	42	0.44	64.03	0.01	35.20	10653	9307	337	412	208	208
	06/21/88	22	6125	4205	520	394	0.61	68.65	0.05	75.80	10240	8720	269	304	194	178
	06/28/88	29	7115	4240	890	790	0.71	59.59	0.09	88.76	11463	9837	264	299	199	188
(3)	11/15/88	1	7430	4537	1033	780	0.74	61.06	0.10	75.51	12964	11779	365	443	217	213
	11/18/88	4	6787	3927	900	576	0.68	57.86	0.09	64.00	12222	10952	335	395	202	195
	11/22/88	8	7208	4520	520	496	0.72	62.71	0.05	95.38	11751	10584	319	441	212	198
	11/25/88	11	6310	3646	463	435	0.63	57.78	0.05	93.95	11048	11048	317	455	230	210
	11/29/88	15	7173	4373	1213	1153	0.72	60.96	0.12	95.05	12160	9600	321	422	199	187
	12/02/88	18	4483	2303	557	493	0.45	51.37	0.06	88.51	10283	9717	313	322	171	179
	12/06/88	22	6985	4415	538	483	0.70	63.21	0.05	89.78	10688	9312	274	314	177	168
	12/09/88	25	6483	3653	553	508	0.65	56.35	0.06	91.86	10394	10079	245	302	186	176
	12/13/88	29	7357	4500	698	643	0.74	61.17	0.07	92.12	11181	9606	215	261	174	171
	12/16/88	32	6737	4067	600	563	0.67	60.37	0.06	93.83	11709	10138	240	287	187	180
	12/20/88	36	7700	5233	1003	943	0.77	67.96	0.10	94.02	13333	11361	304	370	211	194
	12/23/88	39	7640	5107	1503	1405	0.76	66.85	0.15	93.48	13494	10843	651	412	222	198
	12/27/88	43	7737	5180	1038	968	0.77	66.95	0.10	93.26	12960	10960	331	390	202	190
	12/30/88	46	6863	4290	600	553	0.69	62.51	0.06	92.17	11984	10635	351	442	199	186
	01/03/89	50	6460	3930	683	618	0.65	60.84	0.07	90.48	11089	9663	351	354	163	179
	01/06/89	53	8177	5615	1574	1463	0.82	68.67	0.16	92.95	14104	11394	343	474	222	201
(4)		48	4853	2597	610	497	0.48	45.14	0.06	80.36	12015	10719	269	316	200	193
(5)		22	5887	3758	510	409	0.59	64.09	0.05	66.59	10785	9288	290	338	200	191
(6)		50	7167	4612	952	878	0.72	64.00	0.10	91.87	12392	10564	348	423	195	189

Table B2.5 Response Data of Sampling Point No.5 Under Different Acclimatization Alternatives

Accl. Alter.	Date	Days	VFA , mg/L HAc	HPr	Iso-HBr	HBr	A - HVr	Iso-HVr	HVr	HHe	Tot.VFA mg/L HAc
(1)	03/28/88	1	1051	512	28	346					1721
	04/04/88	8	2059	1602	34	1371			696		4725
	04/08/88	12	1837	1407	31	1433			724		4402
	04/12/88	16	2067	1833	33	1706			871		5251
	04/15/88	19	1423	1291	31	1270			656		3743
	04/19/88	23	1560	1626	24	1323			660		4185
	04/23/88	27	1932	2151	28	1110	12	25	629	92	4891
	04/26/88	30	2076	2461	30	1072	14	32	593	77	5238
	04/30/88	34	2046	2420	31	1226	16	37	642	3	5275
	05/03/88	37	1894	2193	32	1247	17	39	663	3	4968
	05/07/88	41	1777	1856	32	1190	18	39	644	3	4529
	05/10/88	44	1961	2032	38	1372	21	48	755	4	5057
	05/14/88	48	2073	2191	39	1414	22	49	817	4	5364
	05/17/88	51	1970	2049	37	1336	22	48	780	5	5070
(2)	05/31/88	1	864	911	32	531	21	44	399	55	2288
	06/07/88	8	1125	1404	42	805	25	50	692	151	3370
	06/14/88	15	935	1771	54	1136	32	65	960	241	3929
	06/21/88	22	1380	1823	37	1065	22	47	874	179	4257
	06/28/88	29	2037	2262	32	1135	19	46	862	162	5296
(3)	11/15/88	1	2069	2402	68	1112	32	91	643	130	5339
	11/18/88	4	2068	2295	59	1093	28	81	625	111	5203
	11/22/88	8	2094	2210	53	1132	25	74	637	111	5184
	11/25/88	11	2256	2331	65	1191	29	77	724	105	5545
	11/29/88	15	2101	1966	57	964	27	65	622	91	4858
	12/02/88	18	2205	2066	52	933	24	60	571	84	4980
	12/06/88	22	2210	2133	38	958			531		4931
	12/09/88	25	2339	2219	36	966			540		5139
	12/13/88	29	2247	2243		893			512		4976
	12/16/88	32	2322	2404		916			544		5216
	12/20/88	36	2536	2693	38	1092	76	146	862	82	6170
	12/23/88	39	2231	2572	49	1074	75	154	855	92	5767
	12/27/88	43	2418	2490	39	1046	56	133	798	92	5805
	12/30/88	46	2323	2324	40	966		105	754	87	5444
	01/03/89	50	2186	2513	51	880		114	729	83	5397
	01/06/89	53	2508	2920	48	995	29	120	760	78	6162
(4)		48	2001	2091	38	1374	22	48	784	4	5164
(5)		22	1451	1952	41	1112	24	53	899	194	4494
(6)		50	2339	2586	46	947	29	113	748	83	5667

Note:(4),(5),and (6) are average responses at pseudo steady-state (6-14 to 6-28, 1988; 5-10 to 5-17, 1988; 12-30 to 01-06, 1989) for alternatives 1, 2, and 3 respectively.

Table B2.6 Response Data of Sampling Point No.6 Under Different Acclimatization Alternatives

Acclim. Alter.	Date	Days	Solids, mg/L TS	VS	TSS	TVSS	[%]	[%TS]	Solids, mg/L [%]	[%TS]	COD, mg/L Total	Soluble	NH4-N	TKN	Inorganics, mg/L TKN [%TS]	TP	TP [%TS]	PO4-P
(1)	03/28/88	1	4570	2660	600	470	0.46	58.21	0.06	78.33	4242	3919	277	279	5.79	113	1.02	32
	04/04/88	8	8060	5000	1930	1400	0.81	62.03	0.19	72.54	7760	7231	283	267	3.89	119	1.03	65
	04/08/88	12	7420	4230	1750	1270	0.74	57.01	0.18	72.57	7479	5661	229	282	3.96	156	0.91	80
	04/12/88	16	6490	3740	930	660	0.65	57.63	0.09	70.97	10751	4917	235	296	4.11	150	0.91	96
	04/15/88	19	6570	3930	1160	750	0.66	59.82	0.12	64.66	5586	3880	255	257	2.85	134	1.21	59
	04/19/88	23	6340	3780	1860	1280	0.63	59.62	0.19	68.82	5423	2881	228	257	2.83	127	1.86	52
	04/23/88	27	6350	3610	2190	1570	0.64	56.85	0.22	71.69	5234	2880	270	286	2.74	205	1.95	36
	04/26/88	30	6020	3170	1720	1200	0.60	52.66	0.17	69.77	5061	2146	278	286	3.32	138	1.98	35
	04/30/88	34	7620	4610	3440	2520	0.76	60.50	0.34	73.26	7177	3145	241	307	2.47	211	2.98	53
	05/03/88	37	6910	4030	2880	2170	0.69	58.32	0.29	75.35	5725	2339	270	258	2.85	129	2.67	43
	05/07/88	41	7860	4770	4250	3130	0.79	60.69	0.43	73.65	5796	898	265	279	3.62	117	2.61	30
	05/10/88	44	8130	4790	5130	3710	0.81	58.92	0.51	72.32	6762	1106	282	303	3.51	129	2.76	10
	05/14/88	48	9470	5900	6370	4650	0.95	62.30	0.64	72.99	6349	895	279	284	3.88	28	2.68	23
	05/17/88	51	10710	6750	7860	5750	1.07	63.02	0.79	73.15	9819	925	286	291	4.06	50	2.44	9
(2)	05/31/88	1	5390	3850	1920	1650	0.54	71.43	0.19	85.94	4000	3192	277					29
	06/07/88	8	4340	2040	1310	330	0.43	47.00	0.13	25.19	2616	1891	285					47
	06/14/88	15	3570	1850	1090	328	0.36	51.82	0.11	30.10	1703	1069	299	312	1.78	80	3.55	42
	06/21/88	22	5830	3680	1190	605	0.58	63.12	0.12	50.80	2800	1600	292	316	1.54	92	2.00	37
	06/28/88	29	5795	2920	2140	1265	0.58	50.39	0.21	59.11	2927	1138	249	253	2.19	66	4.55	14
(3)	11/15/88	1	3885	2140	830	477	0.39	55.08	0.08	57.47	4901	4427	428	567	3.44	125	4.32	24
	11/18/88	4	5240	2940	997	587	0.52	56.11	0.10	58.88	6190	4762	418	470	2.06	131	3.11	29
	11/22/88	8	5185	3110	1067	770	0.52	59.98	0.11	72.16	5759	4358	393	489	2.74	138	3.08	47
	11/25/88	11	5900	3425	2480	1810	0.59	58.05	0.25	72.98	5241	2823	402	504	3.00.	120	2.82	22
	11/29/88	15	6370	3620	3110	2170	0.64	56.83	0.31	69.77	5600	2640	373	489	2.85	118	3.12	27
	12/02/88	18	9325	5630	3690	2290	0.93	60.38	0.37	62.06	4696	1053	378	350	2.63	31	3.16	14
	12/06/88	22	5963	2937	3200	1990	0.60	49.25	0.32	62.19	3644	891	365	342	2.91	90	5.02	27
	12/09/88	25	7100	3610	4180	2370	0.71	50.85	0.42	56.70	4331	866	326	363	3.02	102	4.87	6
	12/13/88	29	6805	3130	3790	2250	0.68	46.00	0.38	59.37	3858	787	296	326	3.28	146	6.43	29
	12/16/88	32	5550	2625	2630	1740	0.56	47.30	0.26	66.16	2986	943	280	303	2.52	132	6.06	43
	12/20/88	36	6250	3480	2840	2050	0.63	55.68	0.28	72.18	5128	2367	324	324	2.97	130	4.00	77
	12/23/88	39	6105	3410	2940	2030	0.61	55.86	0.29	69.05	5301	2651	357	369	2.99	129	3.45	5
	12/27/88	43	6955	3910	3460	2480	0.70	56.22	0.35	71.68	6160	2320	376	338	3.30	108	3.79	15
	12/30/88	46	6765	3720	3110	2240	0.68	54.99	0.31	72.03	5159	873	408	391	3.53	100	3.57	44
	01/03/89	50	6430	3505	3820	2540	0.64	54.51	0.38	66.49	4673	1505	414	437	3.54	104	4.42	25
	01/06/89	53	6085	3375	3690	2580	0.61	55.46	0.37	69.92	4143	558	366	479	4.35	41	5.62	8
(4)			9437	5813	6453	4703	0.94	61.41	0.65	72.82	7643	975	282	293	3.82	69	2.63	14
(5)			5065	2817	1473	733	0.51	55.11	0.15	46.67	2477	1269	280	294	1.84	79	3.37	31
(6)			6427	3533	3540	2453	0.64	54.99	0.35	69.48	4658	979	396	436	3.81	82	4.54	26

Table B2.6 Response Data of Sampling Point No.6 Under Different Acclimatization Alternatives (cont'd)

Accl. Alter.	Date	Days	VFA, mg/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	Tot.VFA mg/L HAc
(1)	03/28/88	1	1780	1172	25	1029					3449
	04/04/88	8	2062	1053	55	496			315		3477
	04/08/88	12	1479	912	44	329			222		2603
	04/12/88	16	1065	1144	55	241			225		2327
	04/15/88	19	345	1003	39	80			125		1313
	04/19/88	23	92	1424	41						1275
	04/23/88	27	172	1359	32	10	14				1311
	04/26/88	30	69	1664	32	6	15				1453
	04/30/88	34	255	1466	25	11	24				1482
	05/03/88	37	277	1058	21	9	24				1170
	05/07/88	41	131	277							356
	05/10/88	44	216	178							360
	05/14/88	48	216	227							400
	05/17/88	51	193	186							344
(2)	05/31/88	1	415	540	32	155	18	25	188	27	1130
	06/07/88	8	398	447			12	17	27		793
	06/14/88	15	89	35							117
	06/21/88	22	236	484			16	5	17		651
	06/28/88	29	359	361					17		662
(3)	11/15/88	1	619	611	44	276	18	31	241		1503
	11/18/88	4	886	962	56	259	28	56	335		2127
	11/22/88	8		1236	60	73	30	67	190		1262
	11/25/88	11	407	978	56		30	63	34		1313
	11/29/88	15	252	584	57	964	12	55	14		1469
	12/02/88	18	122	146					11		247
	12/06/88	22		198							161
	12/09/88	25		133							108
	12/13/88	29		266							216
	12/16/88	32	104	155							230
	12/20/88	36	96	1143	19		59	117	81		1187
	12/23/88	39	101	1396	19			16	34		1275
	12/27/88	43	95	1301	13		48		137		1268
	12/30/88	46	92	819	12			23	100		837
	01/03/89	50	201	437	10	29			174		684
	01/06/89	53	63	123	2						164
(4)			208	197							368
(5)			228	293			16	5	17		477
(6)			119	460	8	29		23	137		562

Note:(4),(5),and (6) are average responses at pseudo steady-state (6-14 to 6-28, 1988; 5-10 to 5-17, 1988; 12-30 to 01-06, 1989) for alternatives 1, 2, and 3 respectively.

Table B2.7 Response Data of Sampling Point No.7 Under Different Acclimatization Alternatives

Acclim. Alter.	Date	Days	Solids, mg/L				COD, mg/L		Inorganics, mg/L			
			TSS	VSS	[%]	[%TS]	Total	Sol.	NH4-N	TKN	TP	O4-P
(1)	03/28/88	1	900	690	0.09	76.67	4404	2788	277	286	113	25
	04/04/88	8	920	610	0.92	66.30	6080	5520	290	320	116	56
	04/08/88	12	530	360	0.05	67.92	4752	5578	242	240	252	66
	04/12/88	16	730	520	0.07	71.23	5834	5000	235	312	400	59
	04/15/88	19	840	610	0.08	72.62	4562	4136	245	156	150	45
	04/19/88	23	850	570	0.09	67.06	4152	3305	245	156	150	47
	04/23/88	27	1000	670	0.10	67.00	3773	3205	270	278	138	38
	04/26/88	30	770	460	0.08	59.74	3765	3036	272	286	138	44
	04/30/88	34	1070	810	0.11	75.70	4435	3064	303	319	139	47
	05/03/88	37	750	630	0.08	84.00	3226	2258	278	292	146	44
	05/07/88	41	1240	1220	0.12	98.39	2041	816	275	296	129	30
	05/10/88	44	870	540	0.09	62.07	1926	1004	294	313	132	22
	05/14/88	48	1120	850	0.11	75.89	2150	832	279	298	76	32
	05/17/88	51	940	370	0.09	69.15	1730	724	284	284	46	13
(2)	05/31/88	1	3120	2590	0.31	83.01	4566	2222	290	349	54	36
	06/07/88	8	1530	390	0.15	25.49	2616	1891	288	329	76	45
	06/14/88	15	500	160	0.05	32.00	1386	990	282	332	88	33
	06/21/88	22	650	406	0.07	62.50	2000	1120	287	316	90	33
	06/28/88	29	595	350	0.06	58.82	1707	1138	237	261	70	28
(3)	11/15/88	1	893	568	0.09	63.61	5296	4190	451	575	116	34
	11/18/88	4	745	370	0.07	49.66	4286	3492	464	477	118	24
	11/22/88	8	205	190	0.02	92.68	3658	3580	438	567	133	49
	11/25/88	11	478	323	0.05	67.57	2823	2339	402	523	124	38
	11/29/88	15	860	523	0.09	60.81	2960	1920	392	494	105	15
	12/02/88	18	677	417	0.07	61.60	1619	971	387	410	66	14
	12/06/88	22	780	483	0.08	61.92	1377	729	365	362	90	22
	12/09/88	25	930	560	0.09	60.22	1575	1024	326	339	84	12
	12/13/88	29	875	475	0.09	54.29	1181	1024	300	326	126	20
	12/16/88	32	857	490	0.09	57.18	1375	668	275	287	112	23
	12/20/88	36	810	500	0.08	61.73	2288	1775	294	329	120	27
	12/23/88	39	740	440	0.07	59.46	2691	1285	338	338	117	26
	12/27/88	43	1080	720	0.11	66.67	2760	2160	312	377	112	9
	12/30/88	46	690	530	0.07	76.81	1151	754	376	377	97	5
	01/03/89	50	785	490	0.08	62.42	1228	950	338	359	176	9
	01/06/89	53	370	207	0.04	55.95	916	398	171	459	75	4
(4)			977	587	0.10	69	1935	853	286	298	85	22
(5)			582	305	0.06	51	1698	1083	269	303	83	31
(6)			615	409	0.06	65	1098	701	295	398	116	6

Table B2.7 Response Data of Sampling Point No.7 Under Different Acclimatization Alternatives (cont'd)

Acclim. Alter.	Date	Days	VFA, mg/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	Tot.VFA mg/L HAc
(1)	03/28/88	1	698	284		154					1033
	04/04/88	8	1615	692	38	305			170		2510
	04/08/88	12	1775	914	47	284			186		2851
	04/12/88	16	904	955	46	208			171		1952
	04/15/88	19	381	1063	42	83			135		1408
	04/19/88	23	90	1502	44						1338
	04/23/88	27	118	1652	39	28	18				1513
	04/26/88	30	76	1459	29	5	11				1288
	04/30/88	34	169	1379	23	39	20				1341
	05/03/88	37	204	969	19	35	19				1038
	05/07/88	41	103	297		7					349
	05/10/88	44	174	146		25					309
	05/14/88	48	130	156		10					263
	05/17/88	51	115	114		10					214
(2)	05/31/88	1	287	295		55	11	12	69		618
	06/07/88	8	464	518	21	30	19	19	33		961
	06/14/88	15	72	298		27			23		346
	06/21/88	22	136	362							430
	06/28/88	29	254	302		26			22		530
(3)	11/15/88	1	587	290	34	126	12	25	139		1035
	11/18/88	4	820	572	46	105	18	41	160		1516
	11/22/88	8	996	769	54		27	48	60		1736
	11/25/88	11	560	700	54		19	57	14		1217
	11/29/88	15	585	533		120			20		1111
	12/02/88	18	186	56					10		237
	12/06/88	22		60							49
	12/09/88	25		68							55
	12/13/88	29	104	189		28					276
	12/16/88	32	78	48							117
	12/20/88	36	44	853	13		87		52		826
	12/23/88	39	134	1259	16	35			52		1220
	12/27/88	43	85	824	7	26			42		800
	12/30/88	46	56	650	7				38		610
	01/03/89	50	118	219	4	18			143		395
	01/06/89	53	53	46							90
(4)			140	139		15					262
(5)			154	321		27			23		435
(6)			76	305	6	18			91		365

Note: (4), (5), and (6) are average responses at pseudo steady-state (6-14 to 6-28, 1988; 5-10 to 5-17, 1988; 12-30 to 01-06, 19 for alternatives 1, 2, and 3 respectively.

Table B2.8 Response Data of Sampling Point No.8 Under Different Acclimatization Alternatives (cont'd)

Accl. Alter.	Date	Days	VFA, mg/L HAc	HPr	Iso-HBr	HBr	-HVr	Iso-HBr	HVr	HHe	Tot.VFA mg/L HAc
(1)	03/28/88	1	2051	1417	29	1249					4071
	04/04/88	8	2108	883	50	366		231	231		3243
	04/08/88	12	2229	1135	61	330		235	235		3554
	04/12/88	16	977	1072	52	208		193	193		2137
	04/15/88	19	1182	1353	25	1013		499	499		3280
	04/19/88	23	33	1304	39						1117
	04/23/88	27	75	1659	40		16				1457
	04/26/88	30	66	1371	26		8				1200
	04/30/88	34	105	955	15	8	12				902
	05/03/88	37	107	713		3	12				694
	05/07/88	41	97	214							270
	05/10/88	44	122	96							200
	05/14/88	48	124	136							234
	05/17/88	51	90	83							157
(2)	05/31/88	1	235	174				6		11	382
	06/07/88	8	200	244							398
	06/14/88	15	57	146							175
	06/21/88	22	95	235							286
	06/28/88	29	195	240							390
(3)	11/15/88	1	412	68	26	25		15	69		542
	11/18/88	4	635	188	38	29	12	30	60		875
	11/22/88	8	834	689	51		21	50	43		1465
	11/25/88	11	423	613	53	24	17	55	13		990
	11/29/88	15	308	666			14	48	15		865
	12/02/88	18	142	211					10		319
	12/06/88	22	0	0	0	0	0	0	0	0	0
	12/09/88	25	0	0	0	0	0	0	0	0	0
	12/13/88	29	0	0	0	0	0	0	0	0	0
	12/16/88	32	0	0	0	0	0	0	0	0	0
	12/20/88	36	44	895	13			92	53		810
	12/23/88	39	57	1207	6		25		115		1122
	12/27/88	43	59	1045	15				79		963
	12/30/88	46	48	571	14						521
	01/03/89	50	50	99							130
	01/06/89	53	36	23							55
(4)		48	112	105							197
(5)		22	116	207							284
(6)		50	45	231	14						235

Note:(4),(5),and (6) are average responses at pseudo steady-state (6–14 to 6–28, 1988; 5–10 to 5–17, 1988; 12–30 to 01–06, 1989) for alternatives 1, 2, and 3 respectively.

Table B2.8 Response Data of Sampling Point No.8 Under Different Acclimatization Alternatives

Acclim. Alter.	Date	Days	Solids, mg/L TS	VS	TSS	TVSS	Solids, % or %TS [%]	[%TS]	[%]	[%TS]	COD, mg/L Total	Sol.	NH4-N	TKN	Inorganics, mg/L TP	PO4-P
(1)	03/28/88	1	3580	2280	660	360	0.36	63.69	0.07	54.55	2727	2869	258	398	190	58
	04/04/88	8	5220	2640	400	230	0.52	50.57	0.04	57.50	5360	4960	280	271	106	58
	04/08/88	12	6350	3420	260	190	0.64	53.86	0.03	73.08	5578	5351	229	236	150	66
	04/12/88	16	6100	3650	430	290	0.61	59.84	0.04	67.44	5084	4917	237	294	154	70
	04/15/88	19	6060	3510	670	410	0.60	57.92	0.07	61.19	4307	2537	235	232	160	45
	04/19/88	23	5020	2870	530	380	0.50	57.17	0.05	71.69	3983	3008	235	150	152	38
	04/23/88	27	5520	2960	1090	740	0.55	53.62	0.11	67.89	3854	2860	264	297	130	24
	04/26/88	30	6030	3420	2130	1540	0.60	56.72	0.21	72.30	5061	2530	264	275	130	32
	04/30/88	34	4670	2290	2053	1604	0.46	49.03	0.06	72.73	3225	2419	272	289	124	43
	05/03/88	37	7600	4460	3770	2870	0.76	58.68	0.38	76.13	6048	1774	265	229	114	35
	05/07/88	41	4830	2740	1740	1360	0.48	56.73	0.17	78.16	2367	735	287	309	104	22
	05/10/88	44	4610	2290	780	490	0.46	49.67	0.08	62.82	1762	799	294	326	117	16
	05/14/88	48	3840	2010	860	540	0.38	52.34	0.09	62.79	1744	791	284	298	54	19
	05/17/88	51	6260	3920	870	550	0.63	62.62	0.09	63.22	1569	684	291	286	50	8
(2)	05/31/88	1	4130	3220	1300	1290	0.41	77.97	0.13	99.23	2707	1515	306	356	50	36
	06/07/88	8	4010	1850	1280	300	0.40	46.13	0.13	23.44	2052	1268	282	318	70	36
	06/14/88	15	2790	1230	120	60	0.28	44.09	0.01	50.00	911	851	274	296	72	28
	06/21/88	22	3980	1612	260	169	0.40	40.50	0.03	65.00	1120	920	284	312	90	23
	06/28/88	29	9210	2850	115	85	0.92	30.94	0.01	73.91	894	813	254	280	76	17
(3)	11/15/88	1	3260	1870	1010	580	0.33	57.36	0.10	57.43	3953	2688	471	612	100	47
	11/18/88	4	3225	1655	720	320	0.32	51.32	0.07	44.44	3095	2540	438	518	104	34
	11/22/88	8	3442	1916	322	170	0.34	55.67	0.03	52.80	3502	2412	438	553	122	42
	11/25/88	11	3915	2095	340	190	0.39	53.51	0.03	55.88	2419	2258	392	533	118	12
	11/29/88	15	3596	1783	470	270	0.36	49.58	0.05	57.45	2320	1920	364	485	92	27
	12/02/88	18	3167	1300	263	138	0.32	41.05	0.03	52.47	1053	891	374	370	55	12
	12/06/88	22	3243	1263	393	197	0.32	38.95	0.04	50.13	574	486	357	378	88	12
	12/09/88	25	3345	1335	373	188	0.33	39.91	0.04	50.40	866	709	322	351	84	12
	12/13/88	29	3355	1160	437	200	0.34	34.58	0.04	45.77	709	551	296	335	116	14
	12/16/88	32	3403	1037	317	157	0.34	30.47	0.03	49.53	707	589	280	287	103	14
	12/20/88	36	3777	1490	427	210	0.38	39.45	0.04	49.18	1933	1854	304	462	146	26
	12/23/88	39	3909	1657	380	193	0.39	42.39	0.04	50.79	2289	1847	274	330	102	5
	12/27/88	43	3917	1717	350	113	0.39	43.83	0.04	32.29	2040	2040	351	338	80	5
	12/30/88	46	3507	1300	257	177	0.35	37.07	0.03	68.87	1309	1032	370	400	76	15
	01/03/89	50	3260	1070	370	177	0.33	32.82	0.04	47.84	713	554	395	391	70	5
	01/06/89	53	3020	933	203	70	0.30	30.89	0.02	34.48	438	359	394	479	73	7
(4)			4903	2740	837	527	0.49	54.88	0.09	62.94	1692	758	290	303	74	14
(5)			5327	1897	165	105	0.53	38.51	0.02	62.97	975	861	271	296	79	23
(6)			3262	1101	277	141	0.33	33.59	0.03	50.40	820	648	386	423	73	9

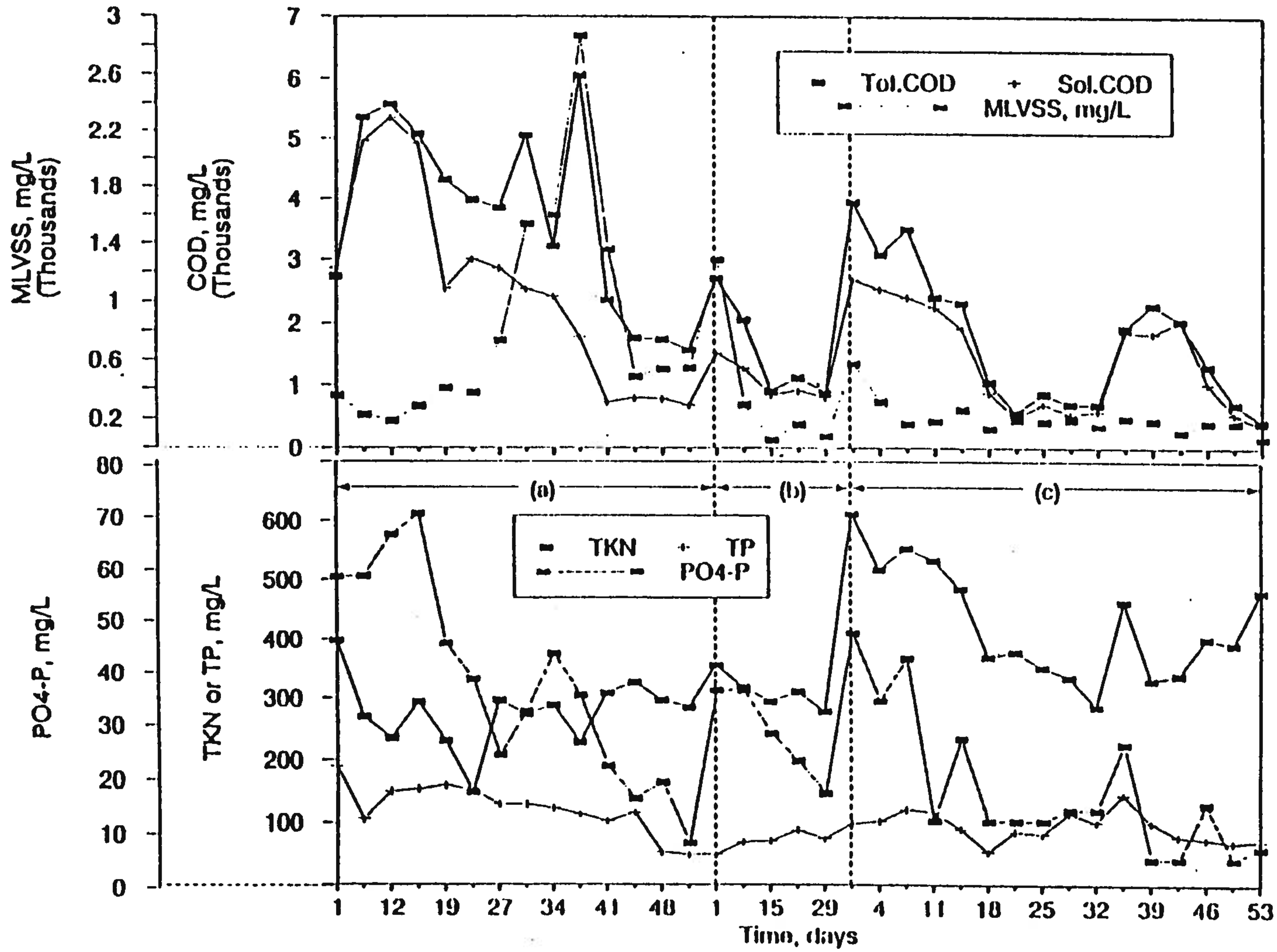


Figure B1.1 Effluent Quality of the M-UASB:

During the acclimatization under different running conditions:
(a) A-UASB and M-UASB seeded with Lion Gate sludge; (b) M-UASB seeded with acclimatized sludge;
(c) M-UASB seeded with Lion Gate sludge

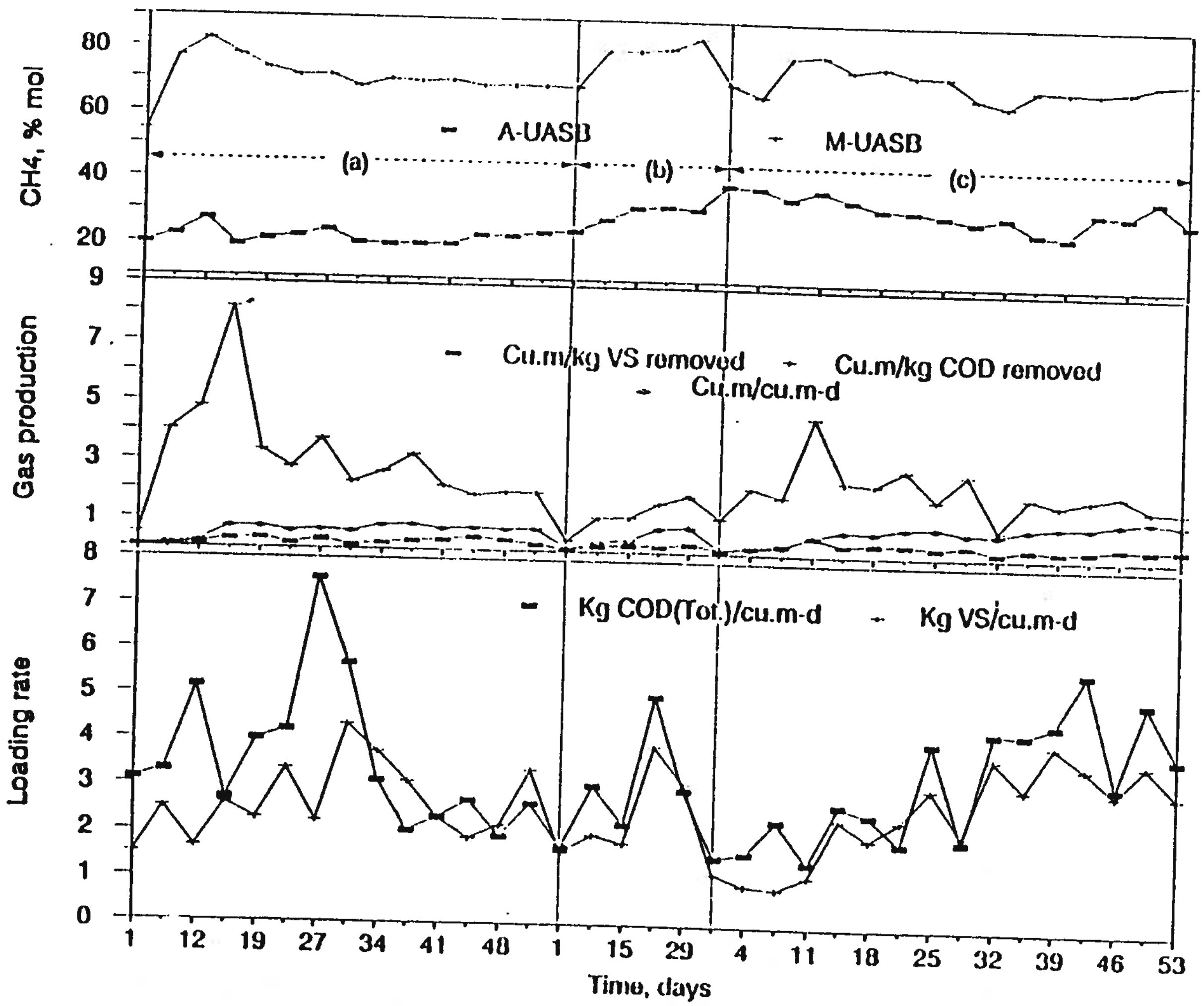


Figure B2.1 System Gas Production and Loading Rate
During acclimatization under different running conditions:
(a) A-UASB and M-UASB seeded with Lion Gate sludge; (b) M-UASB seeded with acclimatized sludge; (c) M-UASB seeded with Lion Gate sludge

APPENDIX C

Optimum "best known" Operating Condition

Table C1.1-C1.8 : Response Data of the Sampling Point Numbered 1 to 8 Under Different Running Conditions During the Sequence 1, 2, and 3 Experiments.

Table C2.1 : Calculation of the effects (SR and RR), Interaction, Phase means, Change in means, on the Response Parameters during the Acclimatization (Sequence 1, 2, and 3 Experiments).

Table C3.1 : pH of A-and M-UASBs During the Sequence 2 and 3 Experiments as well as the Maximization and Recovery Period

Table C3.2 : NaOH (0.1 N) Addition During the Sequence 1 Experiment

Note : All sampling locations are illustrated in Figure 4.2

TABLE C1.1 RESPONSE DATA (SAMPLING POINT NUMBERED 1) UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER.RUN NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE TS	VS	TSS	TVSS	[%]	[%TS]	[%]	%TS]	COD, MG/L TOTAL	SOL.	INORGANICS, MG/L or ELSE NH4-	TKN	[%TS]	TP	[%TS]	PO4-P
[1].F5,SR80/20,	1	07/12/88	48533	44427	45500	43300	4.85	91.54	4.55	95.16	75864	5149	18	276	4.06	171	1.06	169
RR2/4	8	07/19/88	43980	40455	38250	36420	4.40	91.98	3.83	95.22	87230	4951	20	245	3.75	158	0.91	110
	11	07/22/88	50255	46380	48180	46080	5.03	92.29	4.82	95.64	47195	4487	18	267	4.04	165	0.88	136
[2].F5,SR80/20,	15	07/26/88	46760	43040	42510	40760	4.68	92.04	4.25	95.88	43461	8450	18	258	4.62	185	1.21	168
RR6/10	22	08/02/88	33655	29360	27260	25060	3.37	87.24	2.73	91.93	31727	7430	50	270	4.27	167	1.15	134
[07/30/88]	29	08/09/88	41095	36550	31520	28670	4.11	88.94	3.15	90.96	44488	8645	52	296	4.27	136	1.31	112
	32	08/12/88	27915	24930	22180	21090	2.79	89.31	2.22	95.09	62800	7800	50	282	4.56	168	1.24	140
	36	08/16/88	36000	32970	27270	26320	3.60	91.58	2.73	96.52	51098	6786	30	227	3.96	151	0.89	128
	39	08/19/88	32810	30065	26580	25700	3.28	91.63	2.66	96.69	41352	7157	23	269	4.08	155	0.99	131
	43	08/23/88	34620	31595	25724	24978	3.46	91.26	2.57	97.10	45759	6233	18	292	4.23	175	0.97	136
	46	08/26/88	35050	32125	28130	27490	3.51	91.65	2.81	97.72	38509	6501	32	277	4.08	175	0.85	147
[3].F5,SR50/50,	49	08/29/88	28119	25625	33620	32800	2.81	91.13	3.36	97.56	46217	8793	42	281	4.36	186	0.89	173
RR6/10	53	09/02/88	28475	25835	18960	18770	2.85	90.73	1.90	99.00	38763	7256	39	378	4.69	218	0.63	189
[08/31/88]	57	09/06/88	17080	15447	16310	16080	1.71	90.44	1.63	98.59	30266	7689	31	429	4.53	222	0.94	191
	60	09/09/88	35340	32135	27790	26680	3.53	90.93	2.78	96.01	42149	7107	41	464	4.78	231	1.44	180
	65	09/14/88	49545	45210	34140	32680	4.95	91.25	3.41	95.72	47737	7654	21	472	4.31	214	1.26	178
	68	09/17/88	37825	34755	29570	28610	3.78	91.88	2.96	96.75	34426	8115	50	477	4.43	244	1.23	193
	71	09/20/88	30430	27230	20580	19930	3.04	89.48	2.06	96.84	38367	6449	42	443	4.32	204	1.10	169
	74	09/23/88	29295	26275	28350	26990	2.93	89.69	2.84	95.20	40650	5935	59	485	3.45	192	1.12	161
	78	09/27/88	42045	38420	34390	33240	4.20	91.38	3.44	96.66	52209	6827	68	462	3.62	245	0.86	189
	81	09/30/88	45025	40755	51830	49050	4.50	90.52	5.18	94.64	47619	6270	39	480	3.33	220	0.83	177
[4].F5,SR50/50,	85	10/04/88	32600	29020	26400	25190	3.26	89.02	2.64	95.42	33939	6426	34	473	3.74	194	1.08	163
RR2/4	95	10/14/88	32495	29330	24250	23130	3.25	90.26	2.43	95.38	41107	6324	23	494	4.52	230	1.50	181
[10/03/88]	99	10/18/88	28400	25165	19930	18980	2.84	88.61	1.99	95.23	38400	6250	28	501	5.29	217	1.69	178
	102	10/21/88	28745	25640	33960	31970	2.87	89.20	3.40	94.14	37600	6320	14	521	4.69	212	1.56	166
[5].F5,SR70/30,	1	01/17/89	25685	22560	21470	20120	2.57	87.83	2.15	93.71	35777	7801	53	434	5.04	225	1.81	182
RR3/6	8	01/24/89	27190	23960	19800	18460	2.72	88.12	1.98	93.23	37324	6761	54	622	6.12	252	2.59	247
[14/01/88]	15	01/31/89	33770	30680	28300	27160	3.38	90.85	2.83	95.97	35331	5931	41	458	4.70	174	1.26	154
	22	02/07/89	36065	32735	31090	29570	3.61	90.77	3.11	95.11	40217	6087	77	416	4.43	197	1.28	158
	25	02/10/89	37400	33715	30240	28560	3.74	90.15	3.02	94.44	62602	6179	56	467	4.57	202	1.27	165
	29	02/14/89	36525	33140	29920	28630	3.65	90.73	2.99	95.69	25806	6532	82	409	3.79	217	0.96	182

TABLE C1.1 RESPONSE DATA (SAMPLING POINT NUMBERED 1) UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENT

EXPER.RUN	DAY	DATE	SOLIDS, MG/L or ELSE								COD, MG/L		INORGANICS, MG/L or ELSE					
NUMBERS			TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	TOTAL	SOL.	NH4-N	TKN	%TS]	TP	%TS]	PO4-P
[6].F5,SR70/30,	43	01/14/00	26025	23245	20450	19400	2.60	89.32	2.05	94.87	37081	6469	57	444	4.95	174	1.33	149
RR5/8	50	01/21/00	40265	36585	31140	30050	3.02	90.48	3.11	96.50	50909	7354	67	478	4.85	257	1.48	198
[02/20/89]	57	01/28/00	30185	27310	23350	22500	4.03	90.86	2.34	96.36	51429	7184	44	413	4.77	197	1.48	159
	64	02/04/00	26420	23995	25400	24450	3.02	90.48	2.54	96.26	43373	6667	26	440	4.61	199	1.18	167
	71	02/11/00	36275	33310	32890	31040	2.64	90.82	3.29	94.38	37333	6578	25	385	3.54	200	0.92	185
[7].F5,SR60/40,	78	02/18/00	22470	19720	23260	21940	3.63	91.83	2.33	94.33	40984	6967	25	477	4.38	202	1.40	175
RR5/8	85	02/25/00	32405	29210	29010	27740	2.25	87.76	2.90	95.62	38134	7789	21	423	4.24	233	1.30	218
[03/29/89]	92	03/03/00	26305	23365	22550	21810	3.24	90.14	2.26	96.72	29779	7082	25	496	3.87	218	1.32	195
	99	03/10/00	28240	25440	23840	22970	2.63	88.82	2.38	96.35	30891	8951	10	561	4.92	233	1.72	182
	102	03/13/00	25695	22905	24350	23230	2.82	90.08	2.44	95.40	37833	6918	12	406	4.25	183	1.19	173
	106	03/17/00	32880	30278	23760	22340	2.57	89.14	2.38	94.02	50493	8126	21	417	4.94	209	1.20	182
[8].F5,SR60/40,	113	03/24/00	37165	33760	33290	31470	3.29	92.09	3.33	94.53	36078	7216	19	501	5.72	251	1.47	210
RR3/6	120	03/31/00	31010	28100	27410	26230	3.72	90.84	2.74	95.70	50693	7446	28	507	5.12	226	0.87	194
[05/09/89]	130	04/10/00	20045	17545	13390	12890	3.10	90.62	1.34	96.27	40864	7151	20	542	5.14	227	1.23	185
	134	04/14/00	34135	31385	33230	32020	2.00	87.53	3.32	96.36	39766	7641	24	523	3.59	235	0.95	175
	137	04/17/00	28130	25465	20040	19410	3.41	91.94	2.00	96.86	30888	7490	15	445	5.30	179	1.08	180
	141	04/21/00	28050	25275	18610	18070	2.81	90.53	1.86	97.10	36223	7245	10	510	5.05	218	3.22	167
[9].F5,SR80/20,	1	06/13/89	29755	26895	21470	20920	2.81	90.11	2.15	97.44	36361	6679	17	365	5.44	164	0.98	146
RR5/8	8	06/20/89	31610	28565	18270	17820	2.98	90.39	1.83	97.54	46473	7137	12	316	5.24	150	1.05	141
[06/10/89]	15	06/27/89	29000	25945	22770	21420	3.16	90.37	2.28	94.07	60729	7935	10	414	5.38	209	0.98	164
[10].F5,SR80/20	22	07/04/89	32250	28795	38230	36550	2.90	89.47	3.82	95.61	31014	6759	8	353	5.09	195	0.76	161
RR5/8	29	07/11/89	39730	36180	33740	32190	3.23	89.29	3.37	95.41	59082	7425	27	366	5.12	200	1.04	163
[07/02/89]	36	07/18/89	31935	28810	28170	26660	3.97	91.06	2.82	94.64	50980	6902	43	345	3.99	192	0.81	160
Reacclimatizatio	43	07/25/89	25555	22830	25090	24110	3.19	90.21	2.51	96.09	56000	6080	45	330	4.77	167	0.96	132
	46	07/28/89	25875	22895	24150	22970	2.56	89.34	2.42	95.11	37037	5778	23	278	4.24	152	0.86	130
	50	08/01/89	29765	26670	28050	26330	2.59	88.48	2.81	93.87	38235	4926	29	217	5.11	110	1.13	101
	53	08/04/89	27540	24565	31490	29480	2.98	89.60	3.15	93.62	39085	5073	39	265	4.94	147	1.21	121

TABLE C1.1 RESPONSE DATA (SAMPLING POINT NUMBERED 1) UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENT

EXPER.RUN	DAY	DATE	SOLIDS, MG/L or ELSE								COD, MG/L		INORGANICS, MG/L or ELSE					
NUMBERS			TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	TOTAL	SOL.	NH4-	TKN	%TS]	TP	%TS]	PO4-P
[11].F5,SR90/10,	57	08/08/89	38015	34745	33450	31890	2.75	89.20	3.35	95.34	50224	5650	39	241	5.83	156	0.75	131
RR5/8	64	08/15/89	30460	26955	25430	23790	3.80	91.40	2.54	93.55	32340	5447	33	337	4.88	296	1.07	121
[08/05/89]	71	08/22/89	46800	41945	39560	37220	3.05	88.49	3.96	94.08	48361	5656	24	343	4.73	290	0.78	103
	78	08/29/89	39910	36240	37820	35950	4.68	89.63	3.78	95.06	24899	5944	34	547	4.24	226	1.04	123
	81	09/01/89	34845	31530	32710	30870	3.99	90.80	3.27	94.37	46400	6800	24	521	3.88	237	0.94	160
	85	09/05/89	32710	29305	34620	33080	3.48	90.49	3.46	95.55	48413	6270	24	276	4.36	151	0.94	123
[12].F5,SR90/10,	92	09/12/89	30195	27045	24550	23430	3.27	89.59	2.46	95.44	35020	5992	18	255	4.55	141	1.04	138
RR3/6	99	09/19/89	35215	32030	36350	34810	3.02	89.57	3.64	95.76	59345	6705	24	283	4.37	177	0.85	165
[09/06/89]	106	09/26/89	32320	29175	31330	29870	3.52	90.96	3.13	95.34	42485	5691	54	262	4.46	137	1.00	142
	109	09/29/89	30295	27385	29520	28130	3.23	90.27	2.95	95.29	51534	5971	50	281	4.06	164	0.66	142
	113	10/03/89	34265	31352	32240	31560	3.03	90.39	3.22	97.89	31398	6504	39	278	3.52	177	0.74	156
	116	10/06/89	32090	28070	33720	31020	3.43	91.50	3.37	91.99	41322	6033	24	278	4.32	151	1.23	135
NOTE: 1, 2,.......,12 ARE AVERAGE RESPONSES AT PSEUDO-STEADY STATE FOR EXPERIMENTAL RUNNING CONDITIONS NUMBERED 1 TO 12 RESPEC																		
	1		46998	43292	42980	41087	4.70	92.11	4.30	95.58	59295	5963	19	257	4.14	169	1.00	138
	2		32596	29782	29158	28423	3.26	91.35	2.92	97.46	43495	7176	31	283	4.22	179	0.90	152
	3		38788	35150	38190	36427	3.88	90.53	3.82	95.50	46826	6344	55	476	3.47	219	0.94	176
	4		29880	26712	26047	24693	2.99	89.36	2.60	94.92	39036	6298	22	505	4.83	220	1.58	175
	5		36663	33197	30417	28920	3.67	90.55	3.04	95.08	42875	6266	72	431.	4.26	205	1.17	168
	6		31348	28653	29145	27745	2.83	90.65	2.91	95.32	40353	6623	26	413	4.08	200	1.05	176
	7		31913	28981	27133	25680	2.89	90.44	2.71	94.65	41468	7420	17	441	4.97	214	1.16	180
	8		28090	25370	19325	18740	3.11	91.23	1.93	96.98	33556	7368	13	478	5.18	199	2.15	174
	9		30305	27255	20520	19620	3.07	90.38	2.05	95.80	53601	7536	11	365	5.31	180	1.31	207
	10		27727	24710	27897	26260	2.71	89.14	2.79	94.20	38119	5259	30	253	4.76	136	1.52	189
	11		35822	32358	35050	33300	4.05	90.31	3.51	94.99	39904	6338	27	448	4.16	205	1.46	178
	12		32217	28936	31827	30237	3.23	90.72	3.18	95.06	41418	6169	38	279	3.97	164	0.88	144

TABLE C1.1 RESPONSE DATA (SAMPLING POINT NUMBERED 1) UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER.RUN NUMBERS	DAY	DATE	VFA , MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
[1].F5,SR80/20,	1	07/12/88	426	143		89					603
RR2/4	8	07/19/88	512	294		117					830
	11	07/22/88	580	371		117					961
[2].F5,SR80/20,	15	07/26/88	1318	2175		285					3276
RR6/10	22	08/02/88	594	472		227		1776			2176
[07/30/88]	29	08/09/88	297	23		155		988			1003
	32	08/12/88	579	30		272		169			888
	36	08/16/88	551	53		141	176				794
	39	08/19/88	621	86		81		160			840
	43	08/23/88	561	261		60	233	146			1036
	46	08/26/88	612	321		73	209				1045
[3].F5,SR50/50,	49	08/29/88	841	556		137	339				1585
RR6/10	53	09/02/88	728	495		97	337				1394
[08/31/88]	57	09/06/88	709	288		124	318				1214
	60	09/09/88	448	151		114	190		17		770
	65	09/14/88	388	101		88	36				551
	68	09/17/88	551	225		160	253		34		1011
	71	09/20/88	261	98		5		33	14		372
	74	09/23/88	222	101					12		311
	78	09/27/88	622	391		31		48	22		1001
	81	09/30/88	350	213		20		67	15		585
[4].F5,SR50/50,	85	10/04/88	248	145				25	12		387
RR2/4	95	10/14/88	483	383		51		55	24		875
[10/03/88]	99	10/18/88	368	228		32		34	9		600
	102	10/21/88	340	200		31			17		533
[5].F5,SR70/30,	1	01/17/89	854	1527		166			127		2280
RR3/6	8	01/24/89	579	918		153			194		1542
[14/01/88]	15	01/31/89	510	777		62			9.5		1188
	22	02/07/89	866	1275		83			44		1982
	25	02/10/89	736	1304		61			30		1853
	29	02/14/89	997	1607		126			49		2415
[6].F5,SR70/30,	43	02/28/89	551	808		47					1238
RR5/8	50	03/07/89	1122	1732		112			45		2629
[02/20/89]	57	03/14/89	761	1253		75			80		1875
	64	03/21/89	568	905		65			13		1354
	71	03/28/89	1059	1470		132			39		2364
[7].F5,SR60/40,	78	04/04/89	455	776		67			49		1159
RR5/8	85	04/11/89	349	375		54			22		703
[03/29/89]	92	04/18/89	631	1135		76			41		1627
	99	04/25/89	436	853		67			50		1203
	102	04/28/89	350	555		50			41		858
	106	05/02/89	416	674		58			48		1030

TABLE C1.1 RESPONSE DATA (SAMPLING POINT NUMBERED 1) UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER.RUN NUMBERS	DAY	DATE	VFA, MG/L HAc	HPr	Iso-HBr	HBr	-HVr	Iso-HVr	HVr	HHe	TOT.VFA g/L HAc
[8].F5,SR60/40,	113	05/09/89	634	1272		113			62		1779
RR3/6	120	05/16/89	650	1356		120			85		1881
[05/09/89]	130	05/26/89	463	624		72			83		1067
	134	05/30/89	480	332		46			69		821
	137	06/02/89	289	159		50					452
	141	06/06/89	240	83							307
[9].F5,SR80/20,	1	06/13/89	444	394		187					891
RR5/8	8	06/20/89	403	528		224					984
[06/10/89]	15	06/27/89	749	1393		391			102		2205
[10].F5,SR80/20,	22	07/04/89	740	1563		326			99		2288
RR5/8	29	07/11/89	683	1432		234			81		2051
[07/02/89]	36	07/18/89	792	1681		273			118		2411
Reacclimatization	43	07/25/89	721	1385		183			217		2096
	46	07/28/89	632	1341		180			87		1893
	50	08/01/89	559	1144		155			86		1643
	53	08/04/89	566	1211		165			93		1715
[11].F5,SR90/10,	57	08/08/89	650	1332		193			112		1927
RR5/8	64	08/15/89	567	1116		261			85		1700
[08/05/89]	71	08/22/89	493	998		278			516		1795
	78	08/29/89	572	1280		333			110		1902
	81	09/01/89	759	1505		358			48		2252
	85	09/05/89	547	972		216			74		1526
[12].F5,SR90/10,	92	09/12/89	588	1224		254			56		1787
RR3/6	99	09/19/89	766	1449		291			74		2183
[09/06/89]	106	09/26/89	533	914		182			36		1419
	109	09/29/89	497	896		178			37		1367
	113	10/03/89	712	1290		241			61		1958
	116	10/06/89	508	787		144			29		1261
NOTE: 1, 2,.......,12 ARE AVERAGE RESPONSES AT PSEUDO-STEADY STATE (EXPERIMENTAL RUNNING CONDITIONS NO.1 TO 12 RESPECTIVELY)											
	1		803	947		173					1689
	2		671	379		90	260	146			1222
	3		398	235		26		58	16		632
	4		397	270		38		45	17		669
	5		866	1395		90			41		2083
	6		814	1188		99			26		1859
	7		757	1123		100			44		1761
	8		265	121		50					380
	9		490	755		65			32		1165
	10		534	994		72			46		1415
	11		393	704		59			46		1030
	12		572	991		188			42		1529

TABLE C1.2 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 2 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER.RUN NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE				COD, MG/L					INORGANICS, MG/L		
			TSS	TVSS	[%]	[%TS]	Total	Sol.	NH4-N	TKN	[%TS]	TP	[%TS]	PO4-P
[1].F5,SR80/20,	1	07/12/88	60290	58360	6.03	96.80	127525	10931	280	272	7.06	199	0.75	193
RR2/4	8	07/19/88	63550	61140	6.36	96.21	172888	8880	172	223	6.07	168	0.78	163
	11	07/22/88	49120	47450	4.91	96.60	72727	9207	208	260	6.10	175	0.93	169
[2].F5,SR80/20,	15	07/26/88	69990	67550	7.00	96.51	121529	10865	231	302	5.49	185	0.71	182
RR6/10	22	08/02/88	62360	57490	6.24	92.19	131325	9679	266	358	5.57	187	0.76	171
[07/30/88]	29	08/09/88	59560	57410	5.96	96.39	109842	8701	239	368	6.06	182	0.67	166
	32	08/12/88	67430	65280	6.74	96.81	122800	10040	234	292	6.00	179	0.59	178
	36	08/16/88	58010	56140	5.80	96.78	118962	9261	257	295	5.78	185	0.78	180
	39	08/19/88	64460	62360	6.45	96.74	112127	9463	232	269	5.60	166	0.87	172
	43	08/23/88	61830	59900	6.18	96.88	119132	9389	236	312	6.33	183	0.73	175
	46	08/26/88	50030	48590	5.00	97.12	92340	9648	246	296	6.23	173	0.74	187
[3].F5,SR50/50,	49	08/29/88	67100	65260	6.71	97.26	96155	11329	256	324	6.22	202	0.79	192
RR6/10	53	09/02/88	60580	58960	6.06	97.33	113814	11216	353	350	5.98	210	0.89	268
[08/31/88]	57	09/06/88	66750	64920	6.68	97.26	109611	10061	403	437	5.80	222	0.82	224
	60	09/09/88	59720	58200	5.97	97.45	98347	10826	370	448	5.79	243	0.85	227
	65	09/14/88	56410	55060	5.64	97.61	120988	9218	366	437	5.77	226	0.76	216
	68	09/17/88	54010	52530	5.40	97.26	100000	9836	363	450	5.66	248	0.76	236
	71	09/20/88	47780	46590	4.78	97.51	96326	9714	358	427	5.85	230	0.87	219
	74	09/23/88	55470	53830	5.55	97.04	104878	9675	382	444	6.52	235	0.67	225
	78	09/27/88	47620	46180	4.76	96.98	102008	10924	430	507	5.93	265	0.52	239
	81	09/30/88	56660	55020	5.67	97.11	107143	11032	417	480	6.09	249	0.65	247
[4].F5,SR50/50,	85	10/04/88	74640	72180	7.46	96.70	147071	10667	367	437	5.84	240	0.64	238
RR2/4	95	10/14/88	59150	57330	5.92	96.92	154150	10751	401	505	6.63	253	0.77	242
[10/03/88]	99	10/18/88	60600	58070	6.06	95.83	121600	9840	393	478	6.39	242	0.78	235
	102	10/21/88	49760	48320	4.98	97.11	96000	9600	376	502	6.01	258	0.07	235
[5].F5,SR70/30,	1	01/17/89	50460	48270	5.05	95.66	93255	10440	320	504	5.88	220	0.99	189
RR3/6	8	01/24/89	45370	43600	4.54	96.10	83803	11831	448	580	5.64	285	1.09	243
[14/01/88]	15	01/31/89	41950	40520	4.20	96.59	63092	10726	363	514	6.44	252	1.00	219
	22	02/07/89	49780	47800	4.98	96.02	103261	10978	304	455	6.14	208	0.89	201
	25	02/10/89	51480	49180	5.15	95.53	60163	11301	320	418	6.08	220	0.95	215
	29	02/14/89	58590	56050	5.86	95.66	98387	11452	362	440	5.78	217	0.75	208

TABLE C1.2 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 2 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER.RUN	DAY	DATE	SOLIDS, MG/L or ELSE				COD, MG/L					INORGANICS, MG/L		
NUMBERS			TSS	TVSS	[%]	[%TS]	Total	Sol.	NH4-N	TKN	[%TS]	TP	[%TS]	PO4-P
[6].F5,SR70/30,	14	01/14/00	38000	36280	3.80	95.47	36292	9625	306	427	5.85	191	1.20	184
RR5/8	21	01/21/00	41570	39960	4.16	96.13	67879	11313	362	478	5.88	229	0.94	216
[02/20/89]	28	01/28/00	44980	43530	4.50	96.78	63673	12653	351	440	5.50	223	1.01	199
	35	02/04/00	52210	50340	5.22	96.42	84337	11165	364	451	5.29	219	0.69	208
	42	02/11/00	52390	50440	5.24	96.28	69010	10602	386	481	5.44	233	0.74	217
[7].F5,SR60/40,	49	02/18/00	54290	52230	5.43	96.21	94202	11639	444	459	4.76	214	0.69	231
RR5/8	56	02/25/00	52310	50560	5.23	96.65	79513	10142	478	492	5.97	231	0.82	237
[03/29/89]	63	03/03/00	61000	58790	6.10	96.38	107847	10865	434	403	5.28	190	0.93	233
	70	03/10/00	65370	62680	6.54	95.88	87129	10614	463	469	4.91	209	0.82	233
	73	03/13/00	70330	67730	7.03	96.30	97018	10656	513	432	5.71	228	1.00	240
	77	03/17/00	64740	61750	6.47	95.38	116765	10256	504	462	6.57	243	0.95	231
[8].F5,SR60/40,	113	05/09/89	51400	48670	5.14	94.69	69804	9804	517	657	6.98	278	1.14	240
RR3/6	120	05/16/89	78950	73810	7.90	93.49	123564	10297	531	589	7.04	249	1.01	245
[05/09/89]	130	05/26/89	97800	96250	9.78	98.42	23567	8173	511	542	6.53	223	1.95	227
	134	05/30/89	25140	23190	2.51	92.24	39766	7875	469	510	3.31	233	1.56	227
	137	06/02/89	16420	15140	1.64	92.20	43240	8031	465	520	5.92	238	1.50	237
	141	06/06/89	16460	16090	1.65	97.75	17726	8324	469	477	6.38	222	1.39	242
[9].F5,SR80/20,	1	06/13/89	36450	34490	3.65	94.62	50085	8349	398	418	7.35	205	1.28	198
RR5/8	8	06/20/89	18640	17790	1.86	95.44	47303	9461	379	424	6.09	209	1.11	208
[06/10/89]	15	06/27/89	52080	48980	5.21	94.05	77733	9717	411	503	7.28	234	1.09	221
[10].F5,SR80/20,	22	07/04/89	54490	50910	5.45	93.43	50895	6362	550	658	6.15	222	0.89	212
RR5/8	29	07/11/89	37000	33240	3.70	89.84	57485	10299	381	526	6.09	224	1.25	203
[07/02/89]	36	07/18/89	51020	47860	5.10	93.81	105098	10745	335	477	5.55	218	0.81	193
Reacclimatization	43	07/25/89	54530	51610	5.45	94.65	89600	9200	313	422	6.45	181	1.03	170
	46	07/28/89	63200	59200	6.32	93.67	121482	8741	334	461	6.46	201	1.01	166
	50	08/01/89	67020	62310	6.70	92.97	87500	9044	302	417	5.95	176	1.01	164
	53	08/04/89	55410	51550	5.54	93.03	78170	8233	286	357	6.65	166	1.07	158

TABLE C1.2 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 2 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER.RUN	DAY	DATE	SOLIDS, MG/L or ELSE				COD, MG/L					INORGANICS, MG/L		
NUMBERS			TSS	TVSS	[%]	[%TS]	Total	Sol.	NH4-N	TKN	[%TS]	TP	[%TS]	PO4-P
[11].F5,SR90/10,	57	08/08/89	63650	59240	6.37	93.07	89886	8610	235	329	6.52	169	1.50	158
RR5/8	64	08/15/89	63040	59050	6.30	93.67	74043	8170	260	308	6.23	145	1.50	124
[08/05/89]	71	08/22/89	58850	55710	5.89	94.66	73770	10738	250	162	6.73	189	0.99	160
	78	08/29/89	74000	70150	7.40	94.80	94779	9639	270	553	6.04	179	1.79	162
	81	09/01/89	81410	77640	8.14	95.37	176000	13200	301	521	5.95	237	0.93	203
	85	09/05/89	65780	62600	6.58	95.17	166667	11032	283	390	4.94	208	0.80	191
[12].F5,SR90/10,	92	09/12/89	74950	71450	7.50	95.33	122178	10117	300	380	6.04	193	1.11	131
RR3/6	99	09/19/89	72380	69420	7.24	95.91	168786	11946	300	379	5.25	201	0.82	207
[09/06/89]	106	09/26/89	60450	57920	6.05	95.81	113026	9539	268	340	4.31	166	1.06	174
	109	09/29/89	71100	68030	7.11	95.68	143149	9898	357	356	5.50	187	0.84	183
	113	10/03/89	77030	73860	7.70	95.88	95122	10569	268	337	6.00	198	0.85	192
	116	10/06/89	78780	75220	7.88	95.48	134711	10909	270	332	5.08	186	0.69	197

TABLE C1.2 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 2 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER.RUN NUMBERS	DAY	DATE	VFA, MG/L								TOT. VFA
			HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	mg/L HAc
[1].F5,SR80/20,	1	07/12/88	2214	2282	30	1090	19	44	750		5306
RR2/4	8	07/19/88	1920	1787	22	879	14	32	616	115	4432
	11	07/22/88	1984	1945	28	885	20	41	650	121	4664
[2].F5,SR80/20,	15	07/26/88	2507	2859	31	953	23	48	734	121	6032
RR6/10	22	08/02/88	1892	1918	32	981		151	738		4661
[07/30/88]	29	08/09/88	1948	1858	29	1104		107	613	121	4713
	32	08/12/88	2216	1949	30	1324		23	523	139	5113
	36	08/16/88	2127	1685	35	1389	15	80	518	163	4909
	39	08/19/88	2095	1694	30	1292	1	68	480	148	4769
	43	08/23/88	1937	1662	31	1034	12	55	476	129	4397
	46	08/26/88	1870	1698	32	1025	14	36	488	131	4352
[3].F5,SR50/50,	49	08/29/88	2308	2278	37	1276	15	43	693	160	5575
RR6/10	53	09/02/88	1977	1965	38	1105	18	76	638	150	4858
[08/31/88]	57	09/06/88	2093	1947	35	1110	21	74	619	153	4951
	60	09/09/88	2117	2078	33	1199	13	42	634	151	5125
	65	09/14/88	2008	2065	39	1101	67		589	123	4909
	68	09/17/88	1934	1908	30	1145	15	57	561	124	4719
	71	09/20/88	1908	1911	28	909	17	23	518	84	4468
	74	09/23/88	2001	1961	26	976	16	23	530		4609
	78	09/27/88	2385	2313	32	1083	20	30	619	99	5465
	81	09/30/88	2241	2254	32	1074	21	29	571	93	5236
[4].F5,SR50/50,	85	10/04/88	2122	2311	28	1075	17	26	569	87	5153
RR2/4	95	10/14/88	2239	2369	30	1021	20	28	577	92	5292
[10/03/88]	99	10/18/88	2272	2049	28	872	18	26	520	101	4931
	102	10/21/88	2878	1867	25	764	15	23	477	108	5289
[5].F5,SR70/30,	1	01/17/89	2353	2324	35	869	15	92	705	84	5375
RR3/6	8	01/24/89	2843	2882	36	1069	15	95	760	90	6491
[14/01/88]	15	01/31/89	2708	2518	32	975	8.2	32	585	67	5839
	22	02/07/89	2765	2735	30	946	8.5	78	773		6154
	25	02/10/89	2546	2648	27	915	8	75	695		5793
	29	02/14/89	2938	2958	36	1001	12	56	862		6590
[6].F5,SR70/30,	43	02/28/89	2315	2115	29	962	10	48	720		5163
RR5/8	50	03/07/89	2824	2963	42	928	15	45	656	77	6349
[02/20/89]	57	03/14/89	2702	2984	38	1175	14	52	679	80	6428
	64	03/21/89	2742	2863	42	1047	17	54	619	83	6255
	71	03/28/89	2363	2809	37	846	16	77	639		5673
[7].F5,SR60/40,	78	04/04/89	2271	2592	41	968	23	49	603	55	5486
RR5/8	85	04/11/89	1800	2552	37	681	22	47	565	50	4758
[03/29/89]	92	04/18/89	2227	3042	42	888	23	49	618	57	5763
	99	04/25/89	1220	2180	40	740	22	46	520	46	3889
	102	04/28/89	1036	2492	47	731	27	54	572	36	3990
	106	05/02/89	614	2306	46	604	29	53	497	44	3290

TABLE C1.2 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 2 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER.RUN NUMBERS	DAY	DATE	VFA, MG/L								TOT.VFA mg/L HAc
			HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	
[8].F5,SR60/40,	113	05/09/89	408	2685	59	774	39	68	747	62	3687
RR3/6	120	05/16/89	650	2891	74	713	51	84	831	86	4143
[05/09/89]	130	05/26/89	359	2274	64	532	40	69	670	57	3097
	134	05/30/89	493	2018	50	738	31	55	809	74	3231
	137	06/02/89	406	1735		649	24	48	639	50	2699
	141	06/06/89	399	2148	55	788	32	64	698	58	3212
[9].F5,SR80/20,	1	06/13/89	567	1841	43	734	21	49	581	54	3000
RR5/8	8	06/20/89	580	2073	49	889	31	91	742	59	3439
[06/10/89]	15	06/27/89	765	2306	49	824	34	94	766	67	3790
[10].F5,SR80/20,	22	07/04/89	791	1370		413	52	165	628		2680
RR5/8	29	07/11/89	1472	2109		650	27	77	656	53	4100
[07/02/89]	36	07/18/89	1708	2195		722	23	70	614	52	4423
Reacclimatization	43	07/25/89	943	2143		601	25	72	606	59	3534
	46	07/28/89	750	2080		544	24	67	540	51	3205
	50	08/01/89	870	2398	46	622	34	81	596	51	3714
	53	08/04/89	877	2098		574	30	73	496	41	3343
[11].F5,SR90/10,	57	08/08/89	1087	2261		586	27	68	525	39	3705
RR5/8	64	08/15/89	1013	1858		600	24	63	525	52	3315
[08/05/89]	71	08/22/89	1674	2187		873	26	68	631	76	4508
	78	08/29/89	1480	2085		785	23	61	575	69	4129
	81	09/01/89	2591	2684	38	1234	24	56	781	81	6183
	85	09/05/89	2024	2399	41	941	27	58	727	95	5165
[12].F5,SR90/10,	92	09/12/89	1654	2096	36	752	24	51	638	71	4347
RR3/6	99	09/19/89	2264	2651	40	961	25	57	800	87	5660
[09/06/89]	106	09/26/89	1692	2158	37	789	24	51	667	66	4476
	109	09/29/89	1691	2187	37	812	24	52	707	69	4539
	113	10/03/89	1975	2291	32	905	21	46	692	62	4950
	116	10/06/89	1858	2411	39	938	25	55	731	71	4993

TABLE C1.3 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 3 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER. RUNS NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE								COD, MG/L		INORGANICS, MG/L or ELSE					
			TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	OTAL	SOL.	H4-N	TKN	[%TS]	TP	[%TS]	PO4-P
[1].F5,SR80/20,	1	07/12/88	13127	10240	5480	5240	1.31	78.01	0.55	95.62	22178	11406	244	314	4.99	211	1.94	211
RR2/4	8	07/19/88	14765	11695	5560	5225	1.48	79.21	0.56	93.97	22947	10688	236	285	4.75	202	1.92	199
	11	07/22/88	13385	10435	6750	6475	1.34	77.96	0.68	95.93	23830	10290	263	318	5.40	199	1.73	193
[2].F5,SR80/20,	15	07/26/88	10795	8160	3925	3780	1.08	75.59	0.39	96.31	21569	10543	261	294	4.42	183	2.18	182
RR6/10	22	08/02/88	11360	8520	11780	5325	1.14	75.00	1.18	45.20	22731	11044	329	385	4.76	196	1.96	191
[07/30/88]	29	08/09/88	44675	41290	39645	38265	4.47	92.42	3.96	96.52	68701	9409	267	311	6.10	177	0.62	178
	32	08/12/88	44160	40490	34920	33930	4.42	91.69	3.49	97.16	66600	9000	222	282	6.14	174	0.67	166
	36	08/16/88	49920	46225	40930	39680	4.99	92.60	4.09	96.95	75235	8782	244	263	6.07	166	0.96	173
	39	08/19/88	43925	40565	41280	39950	4.39	92.35	4.13	96.78	84692	9463	253	290	5.81	187	0.88	179
	43	08/23/88	47645	44415	41056	39586	4.76	93.22	4.11	96.42	85602	9073	256	343	6.41	200	0.64	170
	46	08/26/88	61405	57760	56210	54670	6.14	94.06	5.62	97.26	82609	9979	263	320	6.08	186	0.57	190
[3].F5,SR50/50,	49	08/29/88	48960	45010	43450	42310	4.90	91.93	4.35	97.38	71575	10184	254	620	6.18	458	0.66	244
RR6/10	53	09/02/88	48015	44385	42130	41020	4.80	92.44	4.21	97.37	75763	11794	382	402	5.95	231	0.63	217
[08/31/88]	57	09/06/88	34857	25450	45240	44210	3.49	73.01	4.52	97.72	67894	10552	403	456	6.02	231	0.64	231
	60	09/09/88	51030	47695	44230	43110	5.10	93.46	4.42	97.47	100826	10165	409	425	5.97	224	0.67	220
	65	09/14/88	34755	31725	30510	29730	3.48	91.28	3.05	97.44	55967	9877	361	429	6.07	216	0.73	216
	68	09/17/88	25815	22985	21250	20690	2.58	89.04	2.13	97.36	45082	9672	442	442	6.07	231	0.87	227
	71	09/20/88	18145	15475	12000	11650	1.81	85.29	1.20	97.08	25306	10204	396	459	6.12	235	1.19	229
	74	09/23/88	17435	14890	10720	10380	1.74	85.40	1.07	96.83	27642	9837	425	457	6.14	237	1.25	246
	78	09/27/88	31955	28780	26160	25320	3.20	90.06	2.62	96.79	64257	11004	444	495	6.21	261	0.81	213
	81	09/30/88	45485	41915	39830	38500	4.55	92.15	3.98	96.66	72222	11190	437	480	5.76	251	1.36	247
[4].F5,SR50/50,	85	10/04/88	45650	41745	42080	40660	4.57	91.45	4.21	96.63	67071	11636	397	444	5.39	240	0.66	238
RR2/4	95	10/14/88	44995	41640	39690	38460	4.50	92.54	3.97	96.90	95652	10435	406	505	6.89	259	0.86	244
[10/03/88]	99	10/18/88	53140	49680	54680	53200	5.31	93.49	5.47	97.29	86400	10400	431	450	6.27	230	0.74	242
	102	10/21/88	49585	46065	47100	45600	4.96	92.90	4.71	96.82	90400	10640	438	521	6.74	258	0.74	240
[5].F5,SR70/30,	1	01/17/89	54340	49440	43750	41940	5.43	90.98	4.38	95.86	91495	11144	343	439	4.81	218	0.83	198
RR3/6	8	01/24/89	34380	34380	31260	30130	3.44	100.00	3.13	96.39	75352	11690	448	590	6.22	263	1.25	238
[14/01/88]	15	01/31/89	33780	30490	26200	25450	3.38	90.26	2.62	97.14	50473	11230	426	590	6.28	265	1.09	228
	22	02/07/89	40600	36690	31140	29780	4.06	90.37	3.11	95.63	59783	11304	346	440	5.67	217	0.92	208
	25	02/10/89	33860	29230	32410	30760	3.39	86.33	3.24	94.91	58537	11707	367	471	6.39	245	1.13	215
	29	02/14/89	41450	36690	29900	28540	4.15	88.52	2.99	95.45	54032	10887	378	377	6.01	196	0.88	201

TABLE C1.3 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 3 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER. RUNS	DAY	DATE	SOLIDS, MG/L or ELSE								COD, MG/L		INORGANICS, MG/L or ELSE					
NUMBERS			TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	OTAL	SOL.	H4-N	TKN	[%TS]	TP	[%TS]	PO4-P
[6].F5,SR70/30,	43	02/28/89	24110	20740	17750	16850	2.41	86.02	1.78	94.93	38185	9389	306	398	5.01	193	0.89	181
RR5/8	50	03/07/89	40650	37120	44510	42880	4.07	91.32	4.45	96.34	81212	11475	392	495	6.07	227	1.05	211
[02/20/89]	57	03/14/89	33470	30260	28780	27820	3.35	90.41	2.88	96.66	57959	12245	382	447	5.71	223	1.61	204
	64	03/21/89	41770	38160	37040	35840	4.18	91.36	3.70	96.76	55422	10924	391	451	6.23	219	1.04	204
	71	03/28/89	45100	42040	43370	41780	4.51	93.22	4.34	96.33	84323	11394	424	488	5.09	235	0.83	210
[7].F5,SR60/40,	78	04/04/89	39250	35910	33260	32180	3.93	91.49	3.33	96.75	71311	11148	473	521	5.24	252	0.82	228
RR5/8	85	04/11/89	27550	24610	20580	19780	2.76	89.33	2.06	96.11	48682	10467	483	488	5.98	240	0.98	247
[03/29/89]	92	04/18/89	10410	8120	6190	6020	1.04	78.00	0.62	97.25	21328	10946	483	519	6.41	236	2.44	243
	99	04/25/89	10710	8530	7100	6870	1.07	79.65	0.71	96.76	11089	11327	488	500	5.85	226	2.22	238
	102	04/28/89	12380	9870	8640	8360	1.24	79.73	0.86	96.76	25050	11054	504	492	5.43	257	2.14	240
	106	05/02/89	14680	11920	8860	8350	1.47	81.20	0.89	94.24	29191	9625	485	432	7.34	228	1.89	221
[8].F5,SR60/40,	113	05/09/89	21760	18450	13140	12110	2.18	84.79	1.31	92.16	28627	9804	512	589	7.05	266	2.04	247
RR3/6	120	05/16/89	11900	9480	9470	8890	1.19	79.66	0.95	93.88	22178	8951	522	558	6.70	251	2.12	245
[05/09/89]	130	05/26/89	5700	3870	3910	3590	0.57	67.89	0.39	91.82	12181	7701	469	542	6.46	235	3.86	219
	134	05/30/89	8920	6970	6090	5490	0.89	78.14	0.61	90.15	12866	8343	469	498	3.21	233	2.54	227
	137	06/02/89	8360	6260	6060	5540	0.84	74.88	0.61	91.42	13514	8108	460	445	5.47	220	3.28	234
	141	06/06/89	6910	5140	3700	3570	0.69	74.38	0.37	96.49	16185	8709	460	429	5.48	218	7.32	237
[9].F5,SR80/20,	1	06/13/89	9030	6920	5820	5680	0.90	76.63	0.58	97.59	19355	8653	388	381	5.89	199	2.43	200
RR5/8	8	06/20/89	10360	8350	5840	5690	1.04	80.60	0.58	97.43	21162	8963	369	349	5.55	183	1.82	198
[06/10/89]	15	06/27/89	12650	9560	6810	5890	1.27	75.57	0.68	86.49	20648	9717	415	475	6.86	230	2.36	200
[10].F5,SR80/20,	22	07/04/89	5670	3600	2760	2350	0.57	63.49	0.28	85.14	8748	3897	491	544	4,53	138	2.98	147
RR5/8	29	07/11/89	6650	4150	3480	2650	0.67	62.41	0.35	76.15	14531	9261	401	489	8.08	216	2.51	193
[07/02/89]	36	07/18/89	7320	5160	3740	3110	0.73	70.49	0.37	83.16	17098	11137	386	456	5.24	216	2.41	198
Reacclimatization	43	07/25/89	9830	7530	4260	4190	0.98	76.60	0.43	98.36	17600	9200	381	426	4.60	190	2.80	170
	46	07/28/89	9550	6960	4840	4420	0.96	72.88	0.48	91.32	15259	8519	339	391	6.06	179	2.13	164
	50	08/01/89	9050	6830	5110	4660	0.91	75.47	0.51	91.19	16618	7721	329	308	5.77	145	2.12	155
	53	08/04/89	9900	7410	5570	4570	0.99	74.85	0.56	82.05	16133	7900	314	345	6.44	166	2.16	153

TABLE C1.3 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 3 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER. RUNS NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE								COD, MG/L		INORGANICS, MG/L or ELSE					
			TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	OTAL	SOL.	H4-N	TKN	[%TS]	TP	[%TS]	PO4-P
[11].F5,SR90/10,	57	08/08/89	7250	4860	3470	3130	0.73	67.03	0.35	90.20	12915	7444	314	325	5.31	168	2.65	153
RR5/8	64	08/15/89	10370	7220	5970	5410	1.04	69.62	0.60	90.62	15830	7915	229	279	4.80	233	3.33	119
[08/05/89]	71	08/22/89	9850	7160	4430	3980	0.99	72.69	0.44	89.84	20656	8770	240	349	6.27	277	2.01	132
	78	08/29/89	11690	8820	5990	5310	1.17	75.45	0.60	88.65	19598	8996	281	547	5.83	237	3.58	155
	81	09/01/89	9810	7480	3540	3090	0.98	76.25	0.35	87.29	20160	10880	291	501	4.16	233	2.40	185
	85	09/05/89	9340	6610	5760	5240	0.93	70.77	0.58	90.97	18413	11190	311	343	5.27	210	2.30	198
[12].F5,SR90/10,	92	09/12/89	11375	8525	5420	5200	1.14	74.95	0.54	95.94	18055	10817	316	375	5.24	203	1.97	189
RR3/6	99	09/19/89	12330	9520	5890	5600	1.23	77.21	0.59	95.08	20809	10559	311	340	5.54	185	1.94	200
[09/06/89]	106	09/26/89	35790	32450	31120	29730	3.58	90.67	3.11	95.53	53707	9780	321	323	5.14	162	0.87	190
	109	09/29/89	12740	10430	7420	7030	1.27	81.87	0.74	94.74	24376	9652	304	334	4.60	175	1.32	185
	113	10/03/89	48000	40560	6810	6410	4.80	84.50	0.68	94.13	23740	10163	286	337	5.33	193	1.57	187
	116	10/06/89	14560	11000	8050	7670	1.46	75.55	0.81	95.28	24793	10579	293	369	6.22	205	1.55	197

TABLE C1.3 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 3 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	VFA, MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
[1].F5,SR80/20,	1	07/12/88	2303	2436	34	1123	21	56	812	74	5628
RR2/4	8	07/19/88	2234	2380	34	1106	24	51	814	124	5528
	11	07/22/88	2137	2357	38	1004	25	57	819	145	5364
[2].F5,SR80/20,	15	07/26/88	2175	2560	37	954	28	56	743	136	5483
RR6/10	22	08/02/88	1941	2096	35	905		160	762		4824
[07/30/88]	29	08/09/88	2015	1916	32	1148		98	575	128	4835
	32	08/12/88	2044	1876	31	1191	11	121	608	116	4894
	36	08/16/88	1844	1527	30	1254	6	109	480	140	4380
	39	08/19/88	2112	1775	33	1359	12	81	520	159	4943
	43	08/23/88	1925	1738	34	1046	13	58	479	135	4464
	46	08/26/88	2130	2011	40	1134	18	51	562	145	5007
[3].F5,SR50/50,	49	08/29/88	2189	2201	36	1200	14	56	719	149	5358
RR6/10	53	09/02/88	2297	2263	45	1262	20	61	713	177	5582
[08/31/88]	57	09/06/88	2137	2038	39	1109	43	100	631	158	5109
	60	09/09/88	2028	2030	35	1120	14	58	618	140	4940
	65	09/14/88	1836	1888	36	994	42		479	114	4435
	68	09/17/88	1954	1940	35	1091	38		511	123	4681
	71	09/20/88	2005	1972	32	922	18	25	537	79	4636
	74	09/23/88	2131	2111	32	998	19	26	569	92	4954
	78	09/27/88	2299	2262	34	1027	21	30	581	95	5277
	81	09/30/88	2306	2262	33	1051	21	31	589	91	5303
[4].F5,SR50/50,	85	10/04/88	2417	2630	34	1155	21	32	649	104	5827
RR2/4	95	10/14/88	2184	2345	34	970	22	31	545	90	5168
[10/03/88]	99	10/18/88	2737	2594	39	1095	25	36	702	129	6129
	102	10/21/88	2319	2005	31	819	20	29	524	121	4924
[5].F5,SR70/30,	1	01/17/89	2649	2627	45	952	22	113	768	90	6037
RR3/6	8	01/24/89	2854	2945	43	1050	13	106	769	93	6558
[14/01/88]	15	01/31/89	2918	2765	41	1015	13	91	845		6438
	22	02/07/89	2695	2700	35	905	11	83	77		5626
	25	02/10/89	2848	3007	33	1031	10	54	674		6446
	29	02/14/89	2726	2763	36	926	13	55	679		6062
[6].F5,SR70/30,	43	02/28/89	2138	2002	28	876	10	36	554	69	4766
RR5/8	50	03/07/89	3242	3345	51	1069	19	65	812	94	7293
[02/20/89]	57	03/14/89	2630	2872	41	1112	16	55	654	77	6211
	64	03/21/89	2616	2743	42	985	18	56	585	77	5968
	71	03/28/89	2452	2911	45	898	20	63	577	64	5877
[7].F5,SR60/40,	78	04/04/89	2262	2631	43	950	25	52	564	54	5477
RR5/8	85	04/11/89	1601	2549	41	735	26	52	573	62	4612
[03/29/89]	92	04/18/89	1881	2501	37	741	20	42	505	41	4794
	99	04/25/89	1287	2028	36	660	20	41	510		3742
	102	04/28/89	1388	2944	52	870	29	61	642	44	4857
	106	05/02/89	747	2726	51	735	30	59	617	47	3933

TABLE C1.3 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 3 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	VFA, MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
[8].F5,SR60/40,	113	05/09/89	453	2946	62	852	40	71	796	66	4032
RR3/6	120	05/16/89	585	2429	52	614	34	58	680	70	3499
[05/09/89]	130	05/26/89	498	2261	49	584	29	52	729	52	3266
	134	05/30/89	454	2153	50	786	31	56	842	73	3354
	137	06/02/89	365	1788		684	24	50	660	53	2740
	141	06/06/89	418	2030	48	781	25	55	644	54	3083
[9].F5,SR80/20,	1	06/13/89	463	1681		722	19	46	547	51	2705
RR5/8	8	06/20/89	615	2160	46	978	31	92	803	66	3643
[06/10/89]	15	06/27/89	620	2334	47	929	33	96	827	68	3775
[10].F5,SR80/20,	22	07/04/89	555	694		215		4	276		1429
RR5/8	29	07/11/89	1705	2131		711	25	73	615	34	4355
[07/02/89]	36	07/18/89	1619	2066		686	24	73	609	46	4201
Reacclimatization	43	07/25/89	874	2230		668	29	82	686	66	3641
	46	07/28/89	528	2164		603	27	76	628	61	3155
	50	08/01/89	568	2085		556	30	75	533	45	3036
	53	08/04/89	643	2094		601	32	76	539	46	3155
[11].F5,SR90/10,	57	08/08/89	721	2076		552	29	71	508	41	3159
RR5/8	64	08/15/89	1028	1873		625	24	62	569	54	3386
[08/05/89]	71	08/22/89	1289	1848		689	19	54	502	56	3624
	78	08/29/89	836	1258		443	16	45	380	41	2439
	81	09/01/89	1821	2212	36	859	24	50	598	63	4653
	85	09/05/89	2069	2625	42	1001	27	60	741	80	5437
[12].F5,SR90/10,	92	09/12/89	1888	2455	43	876	28	60	754	81	5042
RR3/6	99	09/19/89	1979	2480	41	851	26	58	730	77	5117
[09/06/89]	106	09/26/89	1765	2350	42	849	27	58	733	74	4797
	109	09/29/89	1660	2239	39	799	25	54	681	61	4525
	113	10/03/89	1871	2322	38	873	24	54	738	71	4892
	116	10/06/89	1786	2545	48	940	31	67	780	74	5078

TABLE C1.4 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 4 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE				COD, MG/L		INORGANICS, MG/L			
			TSS	TVSS	[%]	[%TS]	Total	Sol.	H4-N	TKN	TP	PO4-P
[1].F5,SR80/20,	1	07/12/88	940	880	0.09	93.62	11406	9109	248	307	195	193
RR2/4	8	07/19/88	1025	970	0.10	94.63	12574	9430	242	289	187	184
	11	07/22/88	882	818	0.09	92.74	11451	9981	261	304	197	211
[2].F5,SR80/20,	15	07/26/88	617	600	0.06	97.24	17706	10543	270	306	191	197
RR6/10	22	08/02/88	1503	1360	0.15	90.49	13775	10562	347	429	200	197
[07/30/88]	29	08/09/88	1390	1323	0.14	95.18	13031	8858	304	358	179	175
	32	08/12/88,	1563	1510	0.16	96.61	13720	9800	259	311	183	183
	36	08/16/88	1560	1487	0.16	95.32	12455	9182	284	316	181	187
	39	08/19/88	1650	1580	0.17	95.76	12883	9463	286	310	179	189
	43	08/23/88	1567	1527	0.16	97.45	12623	8994	286	327	183	184
	46	08/26/88	1417	1383	0.14	97.60	13126	9317	275	347	194	190
[3].F5,SR50/50,	49	08/29/88	1453	1447	0.15	99.59	13538	10020	265	324	190	232
RR6/10	53	09/02/88	1560	1529	0.16	98.01	14351	11216	353	421	226	126
[08/31/88]	57	09/06/88	1757	1723	0.18	98.06	14151	9571	420	476	229	217
	60	09/09/88	1830	1757	0.18	96.01	14628	9917	385	479	243	225
	65	09/14/88	1127	1123	0.11	99.65	12346	9630	409	468	231	211
	68	09/17/88	710	689	0.07	97.04	11639	9836	400	438	231	236
	71	09/20/88	547	516	0.05	94.33	11999	9959	400	443	234	231
	74	09/23/88	603	570	0.06	94.53	11301	9756	411	465	233	222
	78	09/27/88	992	912	0.10	91.94	12851	10442	430	507	257	234
	81	09/30/88	1459	1383	0.15	94.79	14048	10317	422	484	255	247
[4].F5,SR50/50,	85	10/04/88	1920	1826	0.19	95.10	15353	11071	397	491	249	242
RR2/4	95	10/14/88	1584	1504	0.16	94.95	13281	10119	431	490	242	249
[10/03/88]	99	10/18/88	1492	1432	0.15	95.98	12960	9680	435	470	234	239
	102	10/21/88	1474	1416	0.15	96.07	12749	9820	397	490	296	369
[5].F5,SR70/30,	1	01/17/89	1405	1348	0.14	95.94	12493	10029	339	389	182	189
RR3/6	8	01/24/89	10250	9820	1.03	95.80	28169	10704	421	552	246	216
[14/01/88]	15	01/31/89	7655	7365	0.77	96.21	11861	9968	453	576	248	223
	22	02/07/89	10380	9805	1.04	94.46	28043	10326	399	471	215	215
	25	02/10/89	2600	2330	0.26	89.62	14959	10813	383	413	215	208
	29	02/14/89	9410	8915	0.94	94.74	25806	11048	383	422	220	215

TABLE C1.4 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 4 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE '	SOLIDS, MG/L or ELSE				COD, MG/L		INORGANICS, MG/L			
			TSS	TVSS	[%]	[%TS]	Total	Sol.	NH4-N	TKN	TP	PO4-P
[6].F5,SR70/30,	14	01/14/00	1070	980	0.11	91.59	23353	9467	342	436	206	186
RR5/8	21	01/21/00	855	850	0.09	99.42	12444	11152	392	491	229	211
[02/20/89]	28	01/28/00	1105	1100	0.11	99.55	14204	12327	382	447	205	204
	35	02/04/00	1510	1470	0.15	97.35	14056	11004	431	485	225	213
	42	02/11/00	2255	2095	0.23	92.90	15289	10562	454	496	231	224
[7].F5,SR60/40,	49	02/18/00	1665	1540	0.17	92.49	15246	11230	478	470	221	245
RR5/8	56	02/25/00	1505	1430	0.15	95.02	13631	10548	502	531	249	249
[03/29/89]	63	03/03/00	1515	1445	0.15	95.38	13843	10865	473	511	236	243
	70	03/10/00	2495	2330	0.25	93.39	14178	10614	513	554	242	240
	73	03/13/00	2765	2610	0.28	94.39	15905	11133	504	573	241	240
	77	03/17/00	3165	2885	0.32	91.15	15148	9941	518	529	227	235
[8].F5,SR60/40,	113	05/09/89	4465	4075	0.45	91.27	16627	10275	549	652	282	247
RR3/6	120	05/16/89	2980	2760	0.30	92.62	15129	9030	531	553	241	238
[05/09/89]	130	05/26/89	1375	1230	0.14	89.45	9430	7308	479	560	206	217
	134	05/30/89	1125	980	0.11	87.11	9669	8109	479	479	219	227
	137	06/02/89	1205	1080	0.12	89.63	9498	7954	488	515	234	239
	141	06/06/89	820	790	0.08	96.34	9788	8478	460	628	296	242
[9].F5,SR80/20,	1	06/13/89	995	746	0.10	74.97	10702	8577	417	332	203	174
RR5/8	8	06/20/89	1145	802	0.11	70.04	11120	8797	388	332	200	174
[06/10/89]	15	06/27/89	1660	1070	0.17	64.46	11093	9393	415	516	221	111
[10].F5,SR80/20,	22	07/04/89	990	775	0.10	78.28	6362	3658	496	646	142	142
RR5/8	29	07/11/89	2215	1710	0.22	77.20	11098	8942	422	460	196	191
[07/02/89]	36	07/18/89	1175	845	0.12	71.91	12078	9961	396	460	209	191
Reacclimatization	43	07/25/89	1340	1225	0.13	91.42	11520	8400	371	374	161	159
	46	07/28/89	1565	1375	0.16	87.86	10963	8741	360	461	203	168
	50	08/01/89	1210	1085	0.12	89.67	9853	7721	371	439	190	161
	53	08/04/89	1340	1215	0.13	90.67	9979	7734	342	369	171	158

TABLE C1.4 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 4 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE				COD, MG/L		INORGANICS, MG/L			
			TSS	TVSS	[%]	[%TS]	Total	Sol.	NH4-N	TKN	TP	PO4-P
[11].F5,SR90/10,	57	08/08/89	1055	925	0.11	87.68	12018	7085	302	341	171	155
RR5/8	64	08/15/89	1020	905	0.10	88.73	9021	7915	263	460	144	134
[08/05/89]	71	08/22/89	1325	1155	0.13	87.17	10820	8450	260	285	131	141
	78	08/29/89	1100	910	0.11	82.73	10281	8835	311	462	205	160
	81	09/01/89	855	740	0.09	86.55	12800	10480	311	481	222	180
	85	09/05/89	1340	1135	0.13	84.70	12381	10873	322	375	210	196
[12].F5,SR90/10,	92	09/12/89	910	855	0.09	93.96	12607	10039	333	385	200	189
RR3/6	99	09/19/89	780	715	0.08	91.67	12023	10019	333	362	197	196
[09/06/89]	106	09/26/89	1295	1205	0.13	93.05	11703	9379	304	405	179	181
	109	09/29/89	1090	1050	0.11	96.33	11452	9816	425	498	198	190
	113	10/03/89	1285	1155	0.13	89.88	11544	9431	339	337	189	187
	116	10/06/89	1340	1325	0.13	98.88	13554	10000	323	405	208	197

TABLE C1.4 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 4 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	VFA, MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
[1].F5,SR80/20, RR2/4	1	07/12/88	1779	2177	33	878	21	51	720	106	4686
	8	07/19/88	1613	2071	34	945	24	.50	737	119	4498
	11	07/22/88	1833	2335	38	994	27	57	830	143	5041
[2].F5,SR80/20, RR6/10 [07/30/88]	15	07/26/88	1908	2644	43	1003	31	64	824	143	5380
	22	08/02/88	1933	2417	43	982	18	108	595	118	5077
	29	08/09/88	1674	1972	42	1116	18	140	732		4586
	32	08/12/88	1934	2072	36	1235	13	84	566	127	4936
	36	08/16/88	1845	1991	43	1492	19	92	579	179	5004
	39	08/19/88	1837	1834	37	1331	16	58	498	159	4675
	43	08/23/88	1698	1792	39	1038	20	90	535	146	4340
	46	08/26/88	1678	1888	38	1038	17	59	554	143	4387
[3].F5,SR50/50, RR6/10 [08/31/88]	49	08/29/88	1857	2159	39	1042	17	59	648	150	4848
	53	09/02/88	1871	2238	46	1108	77		748	174	5048
	57	09/06/88	1793	2091	44	951	58		599	16	4562
	60	09/09/88	1805	2157	38	999	17	76	665	147	4783
	65	09/14/88	1759	2121	42	937	32	56	469	125	4539
	68	09/17/88	1874	1943	35	1041	18	89	562	122	4640
	71	09/20/88	1917	2025	31	913	19	26	553		4554
	74	09/23/88	2021	2127	30	987	20	27	591	99	4866
	78	09/27/88	1960	2250	34	968	22	30	589	99	4896
	81	09/30/88	1913	2173	32	931	21	29	571	93	4745
[4].F5,SR50/50, RR2/4 [10/03/88]	85	10/04/88	2036	2481	34	1031	21	32	631	104	5230
	95	10/14/88	1801	2363	36	821	24	34	472	83	4656
	99	10/18/88	1922	2101	32	800	22	29	524	97	4581
	102	10/21/88	1147	1751	37	301	25	32	368	53	3075
[5].F5,SR70/30, RR3/6 [14/01/88]	1	01/17/89	2211	2622	47	804	19	109	641	74	5408
	8	01/24/89	2352	2781	48	822	16	107	662	89	5708
	15	01/31/89	2286	2629	42	780	14	86	705		5452
	22	02/07/89	2460	3033	45	848	16	93	743		6029
	25	02/10/89	2354	2745	34	869	10	80	730		5678
	29	02/14/89	2254	2825	40	832	15	84	780		5656
[6].F5,SR70/30, RR5/8 [02/20/89]	43	02/28/89	2302	2132	30	887	11	24	553	66	5036
	50	03/07/89	3112	3189	49	1097	19	54	786	98	7035
	57	03/14/89	2900	3047	43	1120	17	58	705	87	6667
	64	03/21/89	2491	2708	44	884	19	47	509	73	5695
	71	03/28/89	2322	2851	45	873	22	62	539	62	5658
[7].F5,SR60/40, RR5/8 [03/29/89]	78	04/04/89	2172	2692	43	933	25	51	602	51	5445
	85	04/11/89	1695	2672	43	772	27	53	642	61	4873
	92	04/18/89	1757	2579	40	770	22	46	555	47	4791
	99	04/25/89	1502	2619	48	849	28	56	602	52	4668
	102	04/28/89	1232	2818	51	831	28	59	613	46	4554
	106	05/02/89	718	2677	50	725	30	59	602	58	3853

TABLE C1.4 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 4 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	VFA, MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
[8].F5,SR60/40,	113	05/09/89	427	2993	65	809	42	73	810	73	4032
RR3/6	120	05/16/89	569	2699	61	600	39	67	707	88	3732
[05/09/89]	130	05/26/89	329	2164	48	474	28	52	601	42	2862
	134	05/30/89	330	1822	43	586	28	46	626	56	2677
	137	06/02/89	340	2002	49	673	30	58	695	53	2944
	141	06/06/89	416	2334	58	792	35	69	699	58	3390
[9].F5,SR80/20,	1	06/13/89	537	2076	54	749	32	66	605	51	3208
RR5/8	8	06/20/89	526	1978	46	787	34	93	685	53	3203
[06/10/89]	15	06/27/89	555	2321	50	842	36	98	763	66	3607
[10].F5,SR80/20,	22	07/04/89	479	685		184	8	63	366		1417
RR5/8	29	07/11/89	1542	2041		641	26	72	578	30	4047
[07/02/89]	36	07/18/89	1532	2151		664	26	73	618	47	4175
Reacclimatization	43	07/25/89	701	1988		542	27	75	551	53	3094
	46	07/28/89	506	2343		589	30	80	629	59	3273
	50	08/01/89	522	2253	43	538	33	79	520	44	3139
	53	08/04/89	557	2103		545	32	76	500	40	3012
[11].F5,SR90/10,	57	08/08/89	634	2013		494	29	70	468	35	2955
RR5/8	64	08/15/89	981	1990		608	28	68	566	55	3427
[08/05/89]	71	08/22/89	1434	2248		755	28	70	582	61	4203
	78	08/29/89	1406	2347		767	31	75	608	72	4289
	81	09/01/89	1869	2429	40	896	27	56	640	69	4938
	85	09/05/89	1963	2590	42	973	27	59	733	75	5276
[12].F5,SR90/10,	92	09/12/89	1679	2364	42	795	28	59	728	80	4687
RR3/6	99	09/19/89	1784	2455	42	785	28	59	698	78	4841
[09/06/89]	106	09/26/89	1504	2244	41	743	27	57	656	67	4328
	109	09/29/89	1613	2342	42	787	27	58	735	70	4596
	113	10/03/89	1730	2327	40	814	25	55	683	69	4684
	116	10/06/89	1590	2381	45	860	30	63	737	70	4662

TABLE C1.5 RESPONSE DATA OF THE SAMPLING POINT NO.5 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER. RUNS NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE								COD, MG/L		INORGANICS, MG/L or ELSE			
			TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	TOTAL	SOL.	NH4-N	TKN	TP	PO4-P
[1].F5,SR80/20,	1	07/12/88	7358	4693	580	535	0.74	63.78	0.06	92.24	12673	11089	270	318	209	208
RR2/4	8	07/19/88	8374	5494	540	520	0.84	65.61	0.05	96.30	12416	10295	238	293	190	184
	11	07/22/88	7333	4558	537	480	0.73	62.16	0.05	89.39	11683	10058	274	318	187	184
[2].F5,SR80/20,	15	07/26/88	7310	4700	437	420	0.73	64.30	0.04	96.11	12072	11509	283	338	207	194
RR6/10	22	08/02/88	6404	3824	753	660	0.64	59.71	0.08	87.65	13293	10884	310	385	187	191
[07/30/88]	29	08/09/88	9912	7208	4067	3910	0.99	72.72	0.41	96.14	19576	9409	282	344	185	183
	32	08/12/88	7012	4432	433	411	0.70	63.21	0.04	94.92	11880	9000	237	315	179	166
	36	08/16/88	8438	5828	497	483	0.84	69.07	0.05	97.18	11657	9820	331	326	192	190
	39	08/19/88	6360	4123	863	847	0.64	64.83	0.09	98.15	12565	10020	290	399	217	196
	43	08/23/88	6880	4613	580	558	0.69	67.05	0.06	96.21	12623	9152	275	320	179	177
	46	08/26/88	6470	4090	1580	633	0.65	63.21	0.16	40.06	13043	9979	273	398	196	192
[3].F5,SR50/50,	49	08/29/88	8230	5640	2177	2160	0.82	68.53	0.22	99.22	16074	10593	275	363	210	190
RR6/10	53	09/02/88	7813	5157	2193	2143	0.78	66.01	0.22	97.72	16165	12041	382	385	231	217
[08/31/88]	57	09/06/88	9585	5970	1523	1513	0.96	62.28	0.15	99.34	15215	10879	441	492	241	238
	60	09/09/88	7850	5410	3327	3260	0.79	68.92	0.33	97.99	18926	10992	409	487	247	232
	65	09/14/88	4700	2517	1818	504	0.47	53.55	0.18	27.72	15870	10123	380	460	231	225
	68	09/17/88	4620	2400	400	393	0.46	51.95	0.04	98.25	11230	9918	429	458	237	231
	71	09/20/88	4670	2337	298	288	0.47	50.04	0.03	96.64	11265	10286	396	463	245	234
	74	09/23/88	4487	2160	312	266	0.45	48.14	0.03	85.26	10976	9837	415	498	255	234
	78	09/27/88	4947	2450	414	362	0.49	49.52	0.04	87.44	12129	10923	444	507	261	244
	81	09/30/88	4927	2430	474	436	0.49	49.32	0.05	91.98	12143	11270	468	512	260	256
[4].F5,SR50/50,	85	10/04/88	7110	4263	1508	1426	0.71	59.96	0.15	94.56	15758	11394	412	420	227	240
RR2/4	95	10/14/88	5017	2637	592	560	0.50	52.56	0.06	94.59	10356	10514	435	517	259	251
[10/03/88]	99	10/18/88	6500	4090	1822	1752	0.65	62.92	0.18	96.16	16560	10400	435	533	255	246
	102	10/21/88	5517	2707	3586	3452	0.55	49.07	0.36	96.26	15320	11210	397	421	314	369
[5].F5,SR70/30,	1	01/17/89	7433	4467	477	463	0.74	60.10	0.05	97.06	11554	10792	325	429	209	191
RR3/6	8	01/24/89	7080	4153	900	879	0.71	58.66	0.09	97.67	13732	11831	430	547	261	197
[14/01/88]	15	01/31/89	6040	3500	1470	1465	0.60	57.95	0.15	99.66	14385	11483	443	637	285	240
	22	02/07/89	7057	4053	1565	1473	0.71	57.43	0.16	94.12	14022	11196	357	482	219	208
	25	02/10/89	7407	4667	1363	1173	0.74	63.01	0.14	86.06	14228	12114	388	462	237	215
	29	02/14/89	8463	4923	1385	1325	0.85	58.17	0.14	95.67	14113	11855	420	444	217	215

TABLE C1.5 RESPONSE DATA OF THE SAMPLING POINT NO.5 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER. RUNS	DAY	DATE	SOLIDS, MG/L or ELSE								COD, MG/L		INORGANICS, MG/L or ELSE			
NUMBERS			TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	TOTAL	SOL.	H4-N	TKN	TP	PO4-P
[6].F5,SR70/30,	43	02/28/89	4963	2717	685	530	0.50	54.75	0.07	77.37	11124	10178	372	419	204	198
RR5/8	50	03/07/89	6513	3870	530	510	0.65	59.42	0.05	96.23	12040	11071	413	406	206	208
[02/20/89]	57	03/14/89	6997	3893	505	485	0.70	55.64	0.05	96.04	12816	12000	391	447	223	204
	64	03/21/89	6240	3957	740	700	0.62	63.41	0.07	94.59	12691	11647	426	496	233	218
	71	03/28/89	5917	3773	805	730	0.59	63.77	0.08	90.68	12121	11572	459	477	227	228
[7].F5,SR60/40,	78	04/04/89	7253	4810	2825	2705	0.73	66.32	0.28	95.75	18279	12049	502	562	254	238
RR5/8	85	04/11/89	4873	2627	800	736	0.49	53.91	0.08	92.00	12738	10467	507	531	255	249
[03/29/89]	92	04/18/89	5400	3227	735	730	0.54	59.76	0.07	99.32	11590	10865	478	334	174	246
	99	04/25/89	5953	3760	1010	985	0.60	63.16	0.10	97.52	12515	10772	513	396	185	243
	102	04/28/89	10750	8420	7635	7330	1.08	78.33	0.76	96.01	26243	10974	508	455	239	243
	106	05/02/89	8553	6327	5090	4785	0.86	73.97	0.51	94.01	19566	9625	485	440	230	233
[8].F5,SR60/40,	113	05/09/89	9553	7153	5585	5180	0.96	74.88	0.56	92.75	19922	10275	587	657	284	250
RR3/6	120	05/16/89	8353	5429	3645	3316	0.84	64.99	0.36	90.97	18563	9347	526	610	263	238
[05/09/89]	130	05/26/89	5427	3403	2310	2115	0.54	62.70	0.23	91.56	11002	7623	479	472	212	219
	134	05/30/89	8750	6600	5515	4930	0.88	75.43	0.55	89.39	10292	8109	497	560	212	229
	137	06/02/89	5420	3440	1745	1560	0.54	63.47	0.17	89.40	18224	8880	488	477	239	226
	141	06/06/89	9727	7453	5830	5415	0.97	76.62	0.58	92.88	20193	8786	479	504	249	234
[9].F5,SR80/20,	1	06/13/89	6210	4037	6235	5799	0.62	65.01	0.62	93.01	26565	9108	407	408	203	210
RR5/8	8	06/20/89	7645	5122	6870	6550	0.76	67.00	0.69	95.34	24730	10041	498	434	205	229
[06/10/89]	15	06/27/89	5185	3578	5897	3774	0.52	69.01	0.59	64.00	36032	9879	505	548	236	200
[10].F5,SR80/20,	22	07/04/89	4675	2770	1510	1102	0.47	59.25	0.15	72.98	6044	3658	496	516	128	137
RR5/8	29	07/11/89	5415	3005	1780	1375	0.54	55.49	0.18	77.25	10060	9501	427	485	211	193
[07/02/89]	36	07/18/89	5750	3250	1400	1030	0.58	56.52	0.14	73.57	11608	10353	370	444	211	196
Reacclimatization	43	07/25/89	8005	5645	3480	3320	0.80	70.52	0.35	95.40	16160	9200	376	465	205	172
	46	07/28/89	7680	5460	3427	3093	0.77	71.09	0.34	90.25	14667	8741	350	444	198	166
	50	08/01/89	7135	4830	3610	2770	0.71	67.69	0.36	76.73	13676	7721	350	409	179	159
	53	08/04/89	8230	5920	4610	3960	0.82	71.93	0.46	85.90	16466	7734	359	377	171	158

TABLE C1.5 RESPONSE DATA OF THE SAMPLING POINT NO.5 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER. RUNS NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	COD, MG/L TOTAL	SOL.	INORGANICS, MG/L or ELSE H4-N	TKN	TP	PO4-P
[11].F5,SR90/10,	57	08/08/89	7400	4945	3210	2900	0.74	66.82	0.32	90.34	15067	7534	330	345	171	155
RR5/8	64	08/15/89	8655	6035	4450	4030	0.87	69.73	0.45	90.56	14806	7660	229	238	144	121
[08/05/89]	71	08/22/89	12270	9335	7370	6590	1.23	76.08	0.74	89.42	26885	8934	250	372	296	101
	78	08/29/89	9855	7200	4630	4100	0.99	73.06	0.46	88.55	17992	8594	311	475	211	160
	81	09/01/89	7810	5195	7170	4560	0.78	66.52	0.72	63.60	16000	10960	373	455	214	180
	85	09/05/89	10495	7640	2690	2300	1.05	72.80	0.27	85.50	18730	11032	342	406	220	198
[12].F5,SR90/10,	92	09/12/89	9597	6870	5390	4935	0.96	71.58	0.54	91.56	20233	10195	328	385	196	189
RR3/6	99	09/19/89	7485	4975	2070	1940	0.75	66.47	0.21	93.72	14489	9557	328	375	189	191
[09/06/89]	106	09/26/89	7120	4925	2100	1950	0.71	69.17	0.21	92.86	12986	9379	339	392	183	192
	109	09/29/89	7085	4870	2840	2580	0.71	68.74	0.28	90.85	13742	9407	339	453	198	194
	113	10/03/89	5830	4695	7490	6891	0.58	80.53	0.75	92.00	17886	10488	411	482	205	208
	116	10/06/89	11270	8135	5090	4760	1.13	72.18	0.51	93.52	22810	10496	422	496	226	206
NOTE: 1, 2,..,12 ARE AVERAGE RESPONSES AT PSEUDO-STEADY STATE FOR EXPERIMENTAL RUNNING CONDITIONS NUMBERED 1 TO 12 RESPEC																
	1		7672	4917	505	473	0.77	64.02	0.05	93.93	12057	10621	265	316	195	187
	2		7193	4781	1446	1117	0.72	66.26	0.14	78.50	13913	9908	274	360	195	186
	3		4787	2347	400	355	0.48	48.99	0.04	88.23	11749	10677	442	506	259	245
	4		5678	3145	2000	1921	0.57	54.85	0.20	95.67	14079	10708	422	490	276	289
	5		7642	4548	1438	1324	0.76	59.54	0.14	91.95	14121	11722	388	463	224	213
	6		6079	3865	773	715	0.61	63.59	0.08	92.64	12406	11610	443	487	230	223
	7		9619	7300	6103	5765	0.96	75.73	0.61	94.25	21910	10291	527	517	251	242
	8		7574	5447	3788	3488	0.76	70.05	0.38	91.14	19209	8833	484	491	ERR	244
	9		6415	4350	6384	5162	0.64	68.00	0.64	79.67	30381	9960	502	491	221	215
	10		7682	5403	3882	3274	0.77	70.24	0.39	84.30	14936	8065	353	410	183	161
	11		9387	6678	4830	3653	0.94	70.79	0.48	79.22	17574	10195	342	445	215	179
	12		8062	5900	5140	4744	0.81	73.82	0.51	92.12	18146	10130	391	477	210	203

TABLE C1.5 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 5 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	VFA, MG/L								TOT.VFA
			HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	mg/L HAc
[1].F5,SR80/20,	1	07/12/88	2203	2440	38	1118	25	57	773	139	5544
RR2/4	8	07/19/88	2016	2232	34	1044	24	51	757	132	5118
	11	07/22/88	1926	2314	41	973	31	62	771	141	5075
[2].F5,SR80/20,	15	07/26/88	2086	2519	41	961	31	61	761	130	5381
RR6/10	22	08/02/88	2177	2439	42	1049		70	572	121	5339
[07/30/88]	29	08/09/88	2036	1949	36	1177	11	122	607	140	4951
	32	08/12/88	2013	1916	33	1162	12	82	525	118	4806
	36	08/16/88	2081	1797	38	1472	13	87	540	171	5032
	39	08/19/88	2102	1908	41	1407	18	88	533	161	5095
	43	08/23/88	1907	1841	40	1092	17	101	632	148	4689
	46	08/26/88	1932	1942	40	1075	16	80	599	143	4750
[3].F5,SR50/50,	49	08/29/88	2089	2261	43	1194	20	83	739	152	5340
RR6/10	53	09/02/88	2174	2272	49	1209	61	91	750	171	5493
[08/31/88]	57	09/06/88	2043	2128	45	1102	23	78	687	162	5098
	60	09/09/88	1946	2179	43	1096	21	75	761		4993
	65	09/14/88	1905	1937	37	1001	18	71	488	120	4585
	68	09/17/88	2015	1901	36	1083	61		549	124	4742
	71	09/20/88	2043	2027	32	926	19	26	546	89	4733
	74	09/23/88	2152	2107	30	965	19	26	553	93	4939
	78	09/27/88	2351	2349	34	1058	22	31	608	93	5437
	81	09/30/88	2376	2366	35	1087	22	32	613	99	5503
[4].F5,SR50/50,	85	10/04/88	2415	2612	35	1142	22	34	653	101	5805
RR2/4	95	10/14/88	2073	2371	38	961	26	35	559	94	5090
[10/03/88]	99	10/18/88	2165	2177	32	918	21	30	542	101	4979
	102	10/21/88	1218	1742	37	302	25	33	380	52	3146
[5].F5,SR70/30,	1	01/17/89	2591	2593	41	939	19	104	734	85	5910
RR3/6	8	01/24/89	2917	2945	45	1027	14	106	780	94	6614
[14/01/88]	15	01/31/89	2920	2838	42	986	14	89	845		6480
	22	02/07/89	2812	2950	43	1007	16	63	747		6406
	25	02/10/89	2985	3249	39	110	13	86	834		6270
	29	02/14/89	2633	2833	45	96	18	74	717	60	5533
[6].F5,SR70/30,	43	02/28/89	2433	2237	33	937	12	37	608	66	5329
RR5/8	50	03/07/89	2732	2775	45	910	17	47	663	81	6103
[02/20/89]	57	03/14/89	2968	3146	45	1154	17	65	79	92	6479
	64	03/21/89	2550	2792	47	903	21	49	519	73	5846
	71	03/28/89	2743	3227	56	998	26	58	592	75	6515
[7].F5,SR60/40,	78	04/04/89	2221	2758	46	955	27	55	612	53	5575
RR5/8	85	04/11/89	1780	2655	44	785	27	55	654	65	4964
[03/29/89]	92	04/18/89	1822	2545	39	766	21	45	536	45	4812
	99	04/25/89	1425	2393	44	770	25	50	507	43	4285
	102	04/28/89	1330	2893	53	850	29	60	632	44	4738
	106	05/02/89	658	2680	53	714	33	61	608	51	3793

TABLE C1.5 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 5 UNDER DIFFERENT RUNNING DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	VFA , MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
[8].F5,SR60/40,	113	05/09/89	348	2575	56	729	37	63	698	58	3470
RR3/6	120	05/16/89	602	2859	66	723	44	74	812	84	4049
[05/09/89]	130	05/26/89	359	2236	49	571	29	54	682	54	3073
	134	05/30/89	398	2175	54	776	34	58	851	75	3321
	137	06/02/89	329	1942	50	714	30	59	748	60	2948
	141	06/06/89	406	2148	55	785	32	65	675	57	3204
[9].F5,SR80/20,	1	06/13/89	537	2227	57	888	31	67	710	61	3494
RR5/8	8	06/20/89	481	2592	80	827	50	101	759	68	3771
[06/10/89]	15	06/27/89	546	2526	69	874	42	91	739	70	3786
[10].F5,SR80/20,	22	07/04/89	472	606		185		4	264		1247
RR5/8	29	07/11/89	1677	2106		695	24	69	578	31	4269
[07/02/89]	36	07/18/89	1903	2438		807	28	78	713	54	4940
Reacclimatization	43	07/25/89	893	2397	43	716	30	82	722	69	3880
	46	07/28/89	521	2338		655	29	79	675	65	3357
	50	08/01/89	546	2400	48	623	37	87	610	52	3408
	53	08/04/89	529	2244	51	603	40	88	566	46	3226
[11].F5,SR90/10,	57	08/08/89	711	2278	43	600	33	77	564	46	3417
RR5/8	64	08/15/89	990	1954		632	26	66	590	56	3435
[08/05/89]	71	08/22/89	1276	2028		723	25	65	555	60	3824
	78	08/29/89	1380	2338	45	772	33	80	651	77	4322
	81	09/01/89	1969	2638	47	978	32	66	709	79	5322
	85	09/05/89	1988	2717	48	995	32	68	763	83	5453
[12].F5,SR90/10,	92	09/12/89	1688	2395	46	807	30	64	724	77	4732
RR3/6	99	09/19/89	1597	2376	48	735	32	67	682	73	4555
[09/06/89]	106	09/26/89	1453	2406	52	755	35	71	727	71	4481
	109	09/29/89	1622	2335	45	806	29	62	723	69	4610
	113	10/03/89	1646	2524	80	829	55	112	743	71	4884
	116	10/06/89	1595	2552	73	861	51	104	757	73	4875
NOTE: 1, 2,.......,12 ARE AVERAGE RESPONSES AT PSEUDO-STEADY STATE (EXPERIMENTAL RUNNING CONDITIONS NO. 1 TO 12 RESPECTIVELY)											
	1		2009	2355	39	993	29	58	763	134	5191
	2		1976	2015	41	1120	18	88	657		4926
	3		2293	2274	33	1037	21	30	591	95	5293
	4		1819	2097	36	727	24	33	494	82	4405
	5		2810	3011	42	404	16	74	766	60	6070
	6		2647	3010	52	951	24	54	556	74	6180
	7		2482	2993	51	977	27	57	602	64	4001
	8		368	2045	53	750	31	62	712	59	3076
	9		1801	2600	42	776	24	50	595	55	3779
	10		1624	2469	42	768	23	48	522	44	3331
	11		1378	2643	49	810	27	55	570	44	5032
	12		1621	2470	66	832	45	93	741	71	4790

TABLE C1.6 RESPONSE DATA OF SAMPLING POINT NO.6 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE								COD, MG/L		INORGANICS, MG/L or ELSE					
			TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	TOT.	SOL.	NH4-N	TKN	[%TS]	TP	[%TS]	PO4-P
[1].F5,SR80/20,	1	07/12/88	7840	4593	895	495	0.78	58.58	0.09	55.31	3089	2693	261	276	0.71	52	2.25	24
RR2/4	8	07/19/88	10295	6735	705	395	1.03	65.42	0.07	56.03	4165	3222	274	293	0.53	70	2.16	35
	11	07/22/88	9130	5865	1815	925	0.91	64.24	0.18	50.96	4255	3017	278	289	0.93	55	3.38	20
[2].F5,SR80/20,	15	07/26/88	7275	4475	610	340	0.73	61.51	0.06	55.74	3219	2897	298	306	0.74	65	3.15	7
RR6/10	22	08/02/88	8370	4150	1420	615	0.84	49.58	0.14	43.31	5582	4137	310	389	0.94	85	3.09	53
[07/30/88]	29	08/09/88	11230	7580	925	495	1.12	67.50	0.09	53.51	6339	6260	376	363	0.84	76	2.85	23
	32	08/12/88	11465	6880	2723	1223	1.15	60.01	0.27	44.91	7160	5320	376	363	1.05	117	5.13	102
	36	08/16/88	14660	9295	2990	1290	1.47	63.40	0.30	43.14	6228	4711	331	321	0.93	90	5.21	34
	39	08/19/88	9965	5895	2737	1147	1.00	59.16	0.27	41.91	6203	4294	351	389	1.37	141	6.62	42
	43	08/23/88	9210	5975	3015	1242	0.92	64.88	0.30	41.19	4497	3313	369	363	1.62	132	9.40	137
	46	08/26/88	9380	5205	3413	1380	0.94	55.49	0.34	40.43	5590	3188	365	394	1.23	134	8.46	84
[3].F5,SR50/50,	49	08/29/88	10795	5780	5190	1897	1.08	53.54	0.52	36.55	5767	3640	365	406	1.56	155	7.30	85
RR6/10	53	09/02/88	9235	4595	4467	1647	0.92	49.76	0.45	36.87	4784	2887	399	411	1.66	164	10.63	57
[08/31/88]	57	09/06/88	6635	2715	3347	1240	0.66	40.92	0.33	37.05	3681	1963	420	421	1.62	149	10.22	110
	60	09/09/88	7810	2550	4730	1700	0.78	32.65	0.47	35.94	3388	1736	399	425	1.40	209	10.03	29
	65	09/14/88	8155	2550	3170	1123	0.82	31.27	0.32	35.43	3539	1975	361	402	2.19	332	11.22	157
	68	09/17/88	6470	2340	2974	1167	0.65	36.17	0.30	39.24	4508	2459	404	426	3.41	231	11.58	176
	71	09/20/88	3520	1160	657	400	0.35	32.95	0.07	60.88	4245	3592	388	431	2.84	224	10.29	210
	74	09/23/88	4360	1730	1467	727	0.44	39.68	0.15	49.56	5054	4246	406	465	2.87	248	6.38	232
	78	09/27/88	4545	1705	1720	827	0.45	37.51	0.17	48.08	6827	5462	439	466	2.88	197	6.27	201
	81	09/30/88	5075	1985	1893	887	0.51	39.11	0.19	46.86	6825	5635	468	487	3.84	236	7.39	233
[4].F5,SR50/50,	85	10/04/88	4730	1990	530	347	0.47	42.07	0.05	65.47	6788	6060	432	444	3.46	295	7.89	301
RR2/4	95	10/14/88	4990	2260	533	420	0.50	45.29	0.05	78.80	7352	6640	384	399	4.63	360	6.90	345
[10/03/88]	99	10/18/88	6390	3275	1486	1163	0.64	51.25	0.15	78.26	7760	6240	406	498	5.51	417	7.09	403
	102	10/21/88	5445	2925	640	580	0.54	53.72	0.06	90.63	7200	5840	397	490	4.46	260	6.57	355
[5].F5,SR70/30,	1	01/17/89	5795	3170	2960	2320	0.58	54.70	0.30	78.38	3812	411	380	489	4.58	91	3.37	8
RR3/6	8	01/24/89	6240	3085	2560	1910	0.62	49.44	0.26	74.61	3803	352	421	444	4.62	72	3.16	4
[14/01/88]	15	01/31/89	6070	3070	3600	2500	0.61	50.58	0.36	69.44	4543	1136	497	632	5.11	118	4.81	28
	22	02/07/89	5530	2735	2370	1600	0.55	49.46	0.24	67.51	3370	543	425	422	4.74	220	4.25	8
	25	02/10/89	6360	2985	2970	1900	0.64	46.93	0.30	63.97	4228	813	473	494	5.47	49	4.57	11
	29	02/14/89	6255	3155	3190	2230	0.63	50.44	0.32	69.91	3790	887	473	444	4.73	112	5.80	20

TABLE C1.6 RESPONSE DATA OF SAMPLING POINT NO.6 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE								COD, MG/L		INORGANICS, MG/L or ELSE					
			TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	TOT.	SOL	NH4-N	TKN	[%TS]	TP	[%TS]	PO4-P
[6].F5,SR70/30,	43	02/28/89	5270	2940	2800	2070	0.53	55.79	0.28	73.93	4103	710	387	482	4.95	151	4.51	2.64
RR5/8	50	03/07/89	5490	3035	2920	2460	0.55	55.28	0.29	84.25	4687	1131	433	432	4.78	147	3.47	13.76
[02/20/89]	57	03/14/89	6525	3765	3010	2380	0.65	57.70	0.30	79.07	5469	1633	448	447	4.68	115	4.04	6.14
	64	03/21/89	5550	3160	2660	1990	0.56	56.94	0.27	74.81	3213	803	444	443	4.99	111	3.81	9.21
	71	03/28/89	5720	3390	3320	2410	0.57	59.27	0.33	72.59	4380	1026	429	414	4.58	115	4.34	6
[7].F5,SR60/40,	78	04/04/89	4475	2455	2720	2010	0.45	54.86	0.27	73.90	3443	656	493	510	5.52	98	4.25	92
RR5/8	85	04/11/89	5055	2820	2980	2250	0.51	55.79	0.30	75.50	3732	487	517	507	6.18	97	4.36	20
[03/29/89]	92	04/18/89	5655	3455	3610	2860	0.57	61.10	0.36	79.22	3622	322	522	488	5.04	84	4.35	26
	99	04/25/89	5850	3450	3690	2720	0.59	58.97	0.37	73.71	4990	1663	559	473	5.14	97	5.12	44
	102	04/28/89	5755	3685	4330	3400	0.58	64.03	0.43	78.52	5010	477	541	432	5.38	93	5.27	23
	106	05/02/89	5770	3260	3310	2450	0.58	56.50	0.33	74.02	5207	473	522	417	6.79	90	6.13	59
[8].F5,SR60/40,	113	05/09/89	5385	3150	3420	2420	0.54	58.50	0.34	70.76	3843	353	587	610	5.90	151	6.34	40
RR3/6	120	05/16/89	5330	2895	3650	2660	0.53	54.32	0.37	72.88	3732	317	587	662	6.69	149	6.26	109
[05/09/89]	130	05/26/89	4345	2270	2920	1940	0.43	52.24	0.29	66.44	2358	236	511	479	5.80	93	7.13	69
	134	05/30/89	4865	2830	3570	2270	0.49	58.17	0.36	63.59	3977	546	460	529	4.10	196	6.71	198
	137	06/02/89	5520	3270	4190	2780	0.55	59.24	0.42	66.35	3166	421	511	493	5.78	107	6.88	61
	141	06/06/89	4945	2830	2740	2070	0.49	57.23	0.27	75.55	3622	385	529	451	5.72	125	2.61	110
[9].F5,SR80/20,	1	06/13/89	6165	3825	3890	2950	0.62	62.04	0.39	75.84	5844	380	560	483	6.16	135	6.87	42
RR5/8	8	06/20/89	5345	3200	2460	2010	0.53	59.87	0.25	81.71	3485	415	531	499	5.99	104	5.39	18
[06/10/89]	15	06/27/89	4215	2080	2490	1390	0.42	49.35	0.25	55.82	2267	162	491	524	4.66	103	7.66	18
[10].F5,SR80/20	22	07/04/89	2635	1005	1600	980	0.26	38.14	0.16	61.25	1034	318	447	467	3.65	87	4.89	28
RR5/8	29	07/11/89	3480	1490	1270	560	0.35	42.82	0.13	44.09	1836	399	498	534	3.48	92	6.50	24
[07/02/89]	36	07/18/89	4905	2740	3000	1980	0.49	55.86	0.30	66.00	3294	392	473	514	3.55	79	3.35	28
Reacclimatizatio	43	07/25/89	4060	2035	1710	1460	0.41	50.12	0.17	85.38	2160	320	450	448	5.56	70	4.54	6
	46	07/28/89	3975	2025	1590	1170	0.40	50.94	0.16	73.58	1926	370	423	391	4.71	99	4.75	8
	50	08/01/89	3735	1385	1470	1000	0.37	37.08	0.15	68.03	1912	368	429	426	5.24	84	5.22	36
	53	08/04/89	3395	1195	1370	880	0.34	35.20	0.14	64.23	1414	249	398	397	5.89	39	6.07	15

TABLE C1.6 RESPONSE DATA OF SAMPLING POINT NO.6 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	COD, MG/L TOT.	SOL	INORGANICS, MG/L or ELSE NH4-N	TKN	[%TS]	TP	[%TS]	PO4-P
[11].F5,SR90/10,	57	08/08/89	4030	1110	1750	1210	0.40	27.54	0.18	69.14	1794	359	381	357	5.49	80	6.45	8
RR5/8	64	08/15/89	3870	980	1870	1240	0.39	25.32	0.19	66.31	1787	340	342	407	4.70	81	6.46	34
[08/05/89]	71	08/22/89	3535	1645	1500	860	0.35	46.53	0.15	57.33	1639	328	322	331	5.81	273	5.72	4
	78	08/29/89	4285	2050	1930	1190	0.43	47.84	0.19	61.66	2249	522	393	527	5.04	90	6.40	6
	81	09/01/89	3920	2120	2150	1530	0.39	54.08	0.22	71.16	2160	400	381	527	3.83	196	2.93	6
	85	09/05/89	4320	2155	1510	1010	0.43	49.88	0.15	66.89	3016	476	404	417	3.36	61	3.10	18
[12].F5,SR90/10,	92	09/12/89	4255	1880	1550	1130	0.43	44.18	0.16	72.90	2033	467	383	422	3.25	54	2.79	15
RR3/6	99	09/19/89	3190	1365	970	520	0.32	42.79	0.10	53.61	1079	308	394	449	3.41	59	6.92	18
[09/06/89]	106	09/26/89	3530	1575	1180	790	0.35	44.62	0.12	66.95	1443	240	411	423	3.33	57	5.20	4
	109	09/29/89	3410	1715	1680	1042	0.34	50.29	0.17	62.02	1636	409	411	431	3.31	58	4.85	9
	113	10/03/89	4055	2020	1710	1080	0.41	49.82	0.17	63.16	1789	407	411	419	4.11	12	7.68	22
	116	10/06/89	4195	1945	1260	880	0.42	46.36	0.13	69.84	1488	331	428	405	3.02	47	5.24	5

TABLE C1.6 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 6 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	VFA, MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
[1].F5,SR80/20,	1	07/12/88	654	779	25	38	18	14	156		1439
RR2/4	8	07/19/88	846	1028	39	43	40	30	87		1828
	11	07/22/88	792	1021	39	22	34	25	49		1725
[2].F5,SR80/20,	15	07/26/88	629	799	37	15	23		28		1342
RR6/10	22	08/02/88	1464	905	50	167	733	531	804		3562
[07/30/88]	29	08/09/88	2382	836	78	323	638	492	760		4445
	32	08/12/88	2497	882	79	290	127	249	479		3967
	36	08/16/88	2170	757	71	214	109	223	351		3380
	39	08/19/88	1845	752	67	183	91	219	395		3040
	43	08/23/88	1290	629	63	93	65	214	342		2272
	46	08/26/88	1414	585	64	106	31	122	295		2268
[3].F5,SR50/50,	49	08/29/88	1324	690	63	126	78	197	344		2376
RR6/10	53	09/02/88	966	418	54	50	21	140	267		1628
[08/31/88]	57	09/06/88	498	347	32	30	10	76	122		944
	60	09/09/88	368	330	20	60		116	274		920
	65	09/14/88	241	365	18	82	13	33	210		756
	68	09/17/88	370	469	29	153	36		237	30	1050
	71	09/20/88	274	602	29	145	26	24	232		1047
	74	09/23/88	435	1188	39	80	31	33	305		1696
	78	09/27/88	226	1637	42	271	32	38	376	53	2056
	81	09/30/88	126	1836	51	242	38	47	409	59	2136
[4].F5,SR50/50,	85	10/04/88	311	1745	44	330	31	39	390	58	2281
RR2/4	95	10/14/88	423	1840	39	392	28	34	385	51	2498
[10/03/88]	99	10/18/88	452	1844	40	355	27	35	386	59	2510
	102	10/21/88	480	1647	39	310	24	49	452	56	2391
[5].F5,SR70/30,	1	01/17/89	72	61							121
RR3/6	8	01/24/89	116	84	3						186
[14/01/88]	15	01/31/89	148	122		9					253
	22	02/07/89	216	118	5	5					318
	25	02/10/89	218	125	5	7					328
	29	02/14/89	187	113	6						283
[6].F5,SR70/30,	43	02/28/89	393	102	6	1					480
RR5/8	50	03/07/89	562	124	8	8					674
[02/20/89]	57	03/14/89	818	193	13	12		5			994
	64	03/21/89	287	64	3						341
	71	03/28/89	352	149	8	24					495
[7].F5,SR60/40,	78	04/04/89	102	34							130
RR5/8	85	04/11/89	55	19							70
[03/29/89]	92	04/18/89	44	15							56
	99	04/25/89	58	28							81
	102	04/28/89	39	19							54
	106	05/02/89	41	43		6					80

TABLE C1.6 RESPONSE DATA OF THE SAMPLING POINT NUMBERED 6 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	VFA , MG/L								TOT.VFA mg/L HAc
			HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	
[8].F5,SR60/40,	113	05/09/89	33	23							52
RR3/6	120	05/16/89	29	21							46
[05/09/89]	130	05/26/89	22	17							36
	134	05/30/89	39								39
	137	06/02/89									56
	141	06/06/89									0
[9].F5,SR80/20,	1	06/13/89									0
RR5/8	8	06/20/89									0
[06/10/89]	15	06/27/89									0
[10].F5,SR80/20,	22	07/04/89									0
RR5/8	29	07/11/89									0
[07/02/89]	36	07/18/89									0
Reacclimatization	43	07/25/89									0
	46	07/28/89									0
	50	08/01/89									0
	53	08/04/89									0
[11].F5,SR90/10,	57	08/08/89									0
RR5/8	64	08/15/89									0
[08/05/89]	71	08/22/89									0
	78	08/29/89									0
	81	09/01/89	37	24							56
	85	09/05/89	44	44		6			9		89
[12].F5,SR90/10,	92	09/12/89	34	21							51
RR3/6	99	09/19/89	29	19		2					46
[09/06/89]	106	09/26/89	30	20							46
	109	09/29/89	34	28		4					59
	113	10/03/89	52	40		6					89
	116	10/06/89	44	35		3					74

TABLE C1.7 RESPONSE DATA OF THE SAMPLING POINT NO.7 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER. RUNS NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE TSS	TVSS	[%]	[%TS]	COD, MG/L Total	Sol.	INORGANICS, MG/L NH4-N	TKN	TP	PO4-P
[1].F5,SR80/20,	1	07/12/88	605	365	0.06	60.33	2772	2297	255	261	50	19
RR2/4	8	07/19/88	500	320	0.05	64.00	3694	3065	259	285	70	47
	11	07/22/88	638	352	0.06	55.17	3327	3095	274	282	51	22
[2].F5,SR80/20,	15	07/26/88	527	320	0.05	60.72	3058	2495	287	302	65	19
RR6/10	22	08/02/88	500	267	0.05	53.40	4378	4217	366	381	82	39
[07/30/88]	29	08/09/88	660	373	0.07	56.52	6260	5157	354	358	79	44
	32	08/12/88	437	290	0.04	66.36	5971	5320	376	387	125	44
	36	08/16/88	610	350	0.06	57.38	4950	4471	346	347	111	69
	39	08/19/88	680	377	0.07	55.44	4771	4374	366	373	138	91
	43	08/23/88	1040	527	0.10	50.67	3945	3314	376	394	144	136
	46	08/26/88	770	437	0.08	56.75	3685	3188	348	402	204	69
[3].F5,SR50/50,	49	08/29/88	1043	503	0.10	48.23	4049	3558	365	429	161	136
RR6/10	53	09/02/88	783	413	0.08	52.75	3452	2804	369	406	128	136
[08/31/88]	57	09/06/88	1020	467	0.10	45.78	2209	1718	420	441	155	114
	60	09/09/88	793	393	0.08	49.56	1983	1488	409	456	167	30
	65	09/14/88	1153	603	0.12	52.30	2222	1564	390	418	324	308
	68	09/17/88	560	400	0.06	71.43	2705	1885	392	410	224	186
	71	09/20/88	316	256	0.03	81.01	3674	3347	392	407	213	217
	74	09/23/88	306	226	0.03	73.86	4472	3984	382	440	239	220
	78	09/27/88	332	232	0.03	69.88	5863	7068	406	491	233	208
	81	09/30/88	257	185	0.03	71.98	5794	5476	457	491	246	242
[4].F5,SR50/50,	85	10/04/88	364	292	0.04	80.22	6303	5980	427	466	299	299
RR2/4	95	10/14/88	462	406	0.05	87.88	6798	6403	372	446	379	349
[10/03/88]	99	10/18/88	324	316	0.03	97.53	6480	6080	384	395	379	346
	102	10/21/88	300	278	0.03	92.67	12400	9600	430	502	262	244
[5].F5,SR70/30,	1	01/17/89	840	660	0.08	78.57	938	352	380	474	82	17
RR3/6	8	01/24/89	600	370	0.06	61.67	845	704	421	529	76	11
[14/01/88]	15	01/31/89	560	415	0.06	74.11	1136	568	511	693	107	13
	22	02/07/89	475	265	0.05	55.79	1033	435	473	490	84	15
	25	02/10/89	500	190	0.05	38.00	1016	813	462	413	34	6
	29	02/14/89	510	340	0.05	66.67	847	403	478	471	73	11

TABLE C1.7 RESPONSE DATA OF THE SAMPLING POINT NO.7 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER. RUNS NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE				COD, MG/L		INORGANICS, MG/L			
			TSS	TVSS	[%]	[%TS]	Total	Sol,	NH4-N	TKN	TP	PO4-P
[6].F5,SR70/30,	43	02/28/89	760	465	0.08	61.18	1065	828	408	411	67	4
RR5/8	50	03/07/89	845	585	0.08	69.23	1374	687	423	512	153	8
[02/20/89]	57	03/14/89	570	470	0.06	82.46	1673	1020	444	462	99	2
	64	03/21/89	775	545	0.08	70.32	1365	482	444	455	85	9
	71	03/28/89	745	510	0.07	68.46	1147	412	366	403	78	10
[7].F5,SR60/40,	78	04/04/89	510	310	0.05	60.78	820	369	449	440	76	83
RR5/8	85	04/11/89	535	330	0.05	61.68	730	365	507	517	86	18
[03/29/89]	92	04/18/89	585	420	0.06	71.79	724	201	496	512	46	15
	99	04/25/89	665	440	0.07	66.17	792	673	528	558	93	40
	102	04/28/89	620	490	0.06	79.03	1909	318	417	532	72	22
	106	05/02/89	690	390	0.07	56.52	1972	828	440	559	82	61
[8].F5,SR60/40,	113	05/09/89	620	355	0.06	57.26	902	314	568	558	95	38
RR3/6	120	05/16/89	855	600	0.09	70.18	1188	317	615	693	191	103
[05/09/89]	130	05/26/89	735	510	0.07	69.39	1022	314	552	542	133	79
	134	05/30/89	620	350	0.06	56.45	858	390	474	542	131	126
	137	06/02/89	736	425	0.07	57.74	734	232	397	506	65	68
	141	06/06/89	600	450	0.06	75.00	1040	462	472	520	175	105
[9].F5,SR80/20,	1	06/13/89	820	565	0.08	68.90	1139	417	531	550	135	54
RR5/8	8	06/20/89	990	805	0.10	81.31	1162	747	510	517	98	33
[06/10/89]	15	06/27/89	930	490	0.09	52.69	891	243	496	524	83	30
[10].F5,SR80/20,	22	07/04/89	675	265	0.07	39.26	994	358	460	479	95	25
RR5/8	29	07/11/89	985	545	0.10	55.33	998	479	503	567	90	25
[07/02/89]	36	07/18/89	880	405	0.09	46.02	902	431	478	493	66	37
Reacclimatization	43	07/25/89	585	495	0.06	84.62	840	280	439	448	50	10
	46	07/28/89	525	365	0.05	69.52	741	370	321	444	48	12
	50	08/01/89	670	350	0.07	52.24	882	294	387	418	66	37
	53	08/04/89	520	335	0.05	64.42	748	291	392	409	44	16

TABLE C1.7 RESPONSE DATA OF THE SAMPLING POINT NO.7 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER. RUNS NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE				COD, MG/L		INORGANICS, MG/L			
			TSS	TVSS	[%]	[%TS]	Total	Sol,	NH4-N	TKN	TP	PO4-P
[11].F5,SR90/10,	57	08/08/89	630	335	0.06	53.17	807	404	364	365	72	9
RR5/8	64	08/15/89	695	445	0.07	64.03	814	298	359	365	95	45
[08/05/89]	71	08/22/89	615	305	0.06	49.59	820	369	352	402	111	2
	78	08/29/89	535	265	0.05	49.53	683	240	381	547	133	5
	81	09/01/89	510	270	0.05	52.94	680	320	393	547	133	3
	85	09/05/89	500	250	0.05	50.00	794	397	414	424	20	27
[12].F5,SR90/10,	92	09/12/89	595	430	0.06	72.27	856	350	399	390	46	23
RR3/6	99	09/19/89	600	380	0.06	63.33	771	308	438	483	24	23
[09/06/89]	106	09/26/89	730	505	0.07	69.18	962	281	393	427	57	4
	109	09/29/89	505	375	0.05	74.26	777	409	446	496	48	6
	113	10/03/89	590	350	0.06	59.32	813	407	446	455	52	22
	116	10/06/89	380	255	0.04	67.11	661	289	446	514	49	9

TABLE C1.7 RESPONSE DATA OF THE SAMPLING POINT NO.7 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	VFA, MG/L HAc	HPr	Iso-HBr	HBr	-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
[1].F5,SR80/20,	1	07/12/88	563	676	22	22	21		28		1170
RR2/4	8	07/19/88	787	973	36	42	37	27	81		1714
	11	07/22/88	800	1015	40	36	33	26	53		1741
[2].F5,SR80/20,	15	07/26/88	586	777	37	10	21	14	18		1279
RR6/10	22	08/02/88	1363	816	48	151	664	476	704		3245
[07/30/88]	29	08/09/88	2279	748	75	293	592	452	691		4157
	32	08/12/88	2484	803	78	269	124	240	453		3852
	36	08/16/88	2169	701	71	183	252	289	333		3425
	39	08/19/88	1967	751	71	187	411	352	460		3471
	43	08/23/88	1389	618	64	93	52	167	312		2309
	46	08/26/88	1386	480	59	70	45	169	298		2164
[3].F5,SR50/50,	49	08/29/88	1394	601	61	98	49	163	305		2294
RR6/10	53	09/02/88	999	331	49	32	82		1		1371
[08/31/88]	57	09/06/88	528	292	29	44	62		24		865
	60	09/09/88	339	221	17	20		47			571
	65	09/14/88	289	306	16	73	19	32	170		728
	68	09/17/88	294	331	26	101	30	99	240		866
	71	09/20/88	333	666	32	180	30	29	267	39	1229
	74	09/23/88	413	1062	37	49	31	32	281	35	1553
	78	09/27/88	162	1555	42	239	33	38	362	51	1895
	81	09/30/88	149	1706	48	244	35	43	380	57	2030
[4].F5,SR50/50,	85	10/04/88	330	1807	46	324	33	41	402	51	2354
RR2/4	95	10/14/88	381	1804	39	359	26	33	376	55	2399
[10/03/88]	99	10/18/88	446	1671	36	327	25	31	358	53	2319
	102	10/21/88	2552	2038	30	718	19	28	500	108	5092
[5].F5,SR70/30,	1	01/17/89	47	23							66
RR3/6	8	01/24/89	121	105		23			73		265
[14/01/88]	15	01/31/89	60	22							78
	22	02/07/89	131	45							167
	25	02/10/89	116	38							147
	29	02/14/89	75	22							93
[6].F5,SR70/30,	43	02/28/89	244	88		28			5		337
RR5/8	50	03/07/89	271	25							291
[02/20/89]	57	03/14/89	428	64	5						483
	64	03/21/89	178	24							197
	71	03/28/89	113	29							137
[7].F5,SR60/40,	78	04/04/89	47								47
RR5/8	85	04/11/89	20								20
[03/29/89]	92	04/18/89	21								21
	99	04/25/89	30	16							43
	102	04/28/89	20								20
	106	05/02/89	21	24							40

TABLE C1.7 RESPONSE DATA OF THE SAMPLING POINT NO.7 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	VFA , MG/L								TOT.VFA
			HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	mg/L HAc
[8].F5,SR60/40,	113	05/09/89	17	15							29
RR3/6	120	05/16/89		14							11
[05/09/89]	130	05/26/89									0
	134	05/30/89	19								19
	137	06/02/89									0
	141	06/06/89									0
[9].F5,SR80/20,	1	06/13/89									0
RR5/8	8	06/20/89		96					281		243
[06/10/89]	15	06/27/89									0
[10].F5,SR80/20,	22	07/04/89									0
RR5/8	29	07/11/89									0
[07/02/89]	36	07/18/89									0
Reacclimatization	43	07/25/89									0
	46	07/28/89									0
	50	08/01/89									0
	53	08/04/89									0
[11].F5,SR90/10,	57	08/08/89									0
RR5/8	64	08/15/89									0
[08/05/89]	71	08/22/89									0
	78	08/29/89									0
	81	09/01/89	19	13							30
	85	09/05/89	23	20		3					41
[12].F5,SR90/10,	92	09/12/89	19	13		2				9	36
RR3/6	99	09/19/89	20	12							30
[09/06/89]	106	09/26/89	20	13		2					32
	109	09/29/89	22	17		3					38
	113	10/03/89	28	18							43
	116	10/06/89	32	26		4					56

TABLE C1.8 RESPONSE DATA OF THE SAMPLING POINT NO.8 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER. RUNS	DAY	DATE	SOLIDS, MG/L or ELSE								COD, MG/L		INORGANICS, MG/L or ELSE			
NUMBERS			TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	TOTAL	SOL.	NH4-N	TKN	TP	PO4-P
[1].F5,SR80/20,	1	07/12/88	6415	3420	320	185	0.64	53.31	0.03	57.81	2297	2178	263	295	50	22
RR2/4	8	07/19/88	7968	4670	350	230	0.80	58.61	0.04	65.71	3300	3065	259	278	58	28
	11	07/22/88	7238	4148	260	147	0.72	57.31	0.03	56.54	2785	2824	268	307	48	25
[2].F5,SR80/20,	15	07/26/88	6224	3272	193	153	0.62	52.57	0.02	79.27	2254	2374	289	322	67	10
RR6/10	22	08/02/88	6404	2580	223	103	0.64	40.29	0.02	46.19	3896	3916	355	366	72	37
[07/30/88]	29	08/09/88	9556	6111	183	120	0.96	63.95	0.02	65.57	4843	5689	361	377	72	33
	32	08/12/88	8765	5368	200	160	0.88	61.24	0.02	80.00	5480	5140	369	363	85	57
	36	08/16/88	10532	6797	423	260	1.05	64.54	0.04	61.47	4471	4152	336	331	81	37
	39	08/19/88	7387	4477	357	200	0.74	60.61	0.04	56.02	4135	3817	334	368	111	72
	43	08/23/88	7127	4787	770	420	0.71	67.17	0.08	54.55	3313	3116	358	367	116	116
	46	08/26/88	6423	3990	320	207	0.64	62.12	0.03	64.69	3354	3043	348	398	120	92
[3].F5,SR50/50,	49	08/29/88	5950	3817	650	370	0.60	64.15	0.07	56.92	3476	3006	365	390	136	64
RR6/10	53	09/02/88	5143	3130	273	210	0.51	60.86	0.03	76.92	2804	2309	374	385	131	38
[08/31/88]	57	09/06/88	5335	2045	630	317	0.53	38.33	0.06	50.32	1636	1391	391	398	124	86
	60	09/09/88	3240	1197	307	170	0.32	36.94	0.03	55.37	1901	1405	385	429	123	19
	65	09/14/88	3900	1063	727	437	0.39	27.26	0.07	60.11	1481	1235	385	433	241	136
	68	09/17/88	3610	1133	200	197	0.36	31.39	0.02	98.50	2377	1885	421	438	244	223
	71	09/20/88	3223	987	155	130	0.32	30.62	0.02	83.87	3592	3429	404	431	232	223
	74	09/23/88	3333	1280	190	152	0.33	38.40	0.02	80.00	4228	3943	396	436	244	237
	78	09/27/88	3323	1150	195	169	0.33	34.61	0.02	86.67	5622	5422	444	437	229	232
	81	09/30/88	3777	1467	176	150	0.38	38.84	0.02	85.23	5555	5238	437	434	222	231
[4].F5,SR50/50,	85	10/04/88	4650	2007	292	228	0.47	43.16	0.03	78.08	6384	5899	412	444	306	303
RR2/4	95	10/14/88	5417	2547	286	272	0.54	47.02	0.03	95.10	6640	6090	380	458	379	370
[10/03/88]	99	10/18/88	5393	2683	324	300	0.54	49.75	0.03	92.59	6240	6160	401	434	455	410
	102	10/21/88	5517	2607	237	217	0.55	47.25	0.02	91.56	6570	5850	434	506	258	240
[5].F5,SR70/30,	1	01/17/89	3067	947	170	97	0.31	30.88	0.02	57.06	352	293	366	394	57	20
RR3/6	8	01/24/89	3473	953	293	160	0.35	27.44	0.03	54.61	282	528	403	547	83	7
[14/01/88]	15	01/31/89	2800	640	216	126	0.28	22.86	0.02	58.33	631	568	511	622	96	11
	22	02/07/89	2913	767	230	43	0.29	26.33	0.02	18.70	489	489	425	404	77	6
	25	02/10/89	3370	1040	213	73	0.34	30.86	0.02	34.27	569	488	462	516	75	10
	29	02/14/89	3110	907	193	80	0.31	29.16	0.02	41.45	403	403	473	471	70	11

TABLE C1.8 RESPONSE DATA OF THE SAMPLING POINT NO.8 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER. RUNS NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	COD, MG/L TOTAL	SOL.	INORGANICS, MG/L or ELSE NH4-N	TKN	TP	PO4-P
[6].F5,SR70/30,	43	02/28/89	2553	643	303	137	0.26	25.19	0.03	45.21	394	394	362	394	31	3
RR5/8	50	03/07/89	2953	1060	263	150	0.30	35.90	0.03	57.03	606	525	372	457	35	6
[02/20/89]	57	03/14/89	3110	947	240	167	0.31	30.45	0.02	69.58	980	816	395	428	37	3
	64	03/21/89	4875	1995	170	93	0.49	40.92	0.02	54.71	482	361	439	451	85	9
	71	03/28/89	2317	867	240	107	0.23	37.42	0.02	44.58	331	291	361	388	63	2
[7].F5,SR60/40,	78	04/04/89	2027	603	160	60	0.20	29.75	0.02	37.50	656	328	449	444	67	67
RR5/8	85	04/11/89	2247	593	190	73	0.22	26.39	0.02	38.42	406	365	517	461	75	10
[03/29/89]	92	04/18/89	2340	837	207	113	0.23	35.77	0.02	54.59	362	161	493	477	82	19
	99	04/25/89	2210	880	153	120	0.22	39.82	0.02	78.43	396	594	533	457	73	37
	102	04/28/89	2383	897	187	120	0.24	37.64	0.02	64.17	477	318	532	417	77	8
	106	05/02/89	2300	783	285	115	0.23	34.04	0.03	40.35	394	394	513	440	72	50
[8].F5,SR60/40,	113	05/09/89	2385	765	217	73	0.24	32.08	0.02	33.64	392	353	531	620	78	45
RR3/6	120	05/16/89	2113	667	357	150	0.21	31.57	0.04	42.02	515	317	591	558	120	102
[05/09/89]	130	05/26/89	1910	547	217	103	0.19	28.64	0.02	47.47	432	314	515	548	110	66
	134	05/30/89	2165	765	277	110	0.22	35.33	0.03	39.71	542	429	479	555	171	167
	137	06/02/89	3005	1475	1200	713	0.30	49.08	0.12	59.42	386	309	515	461	57	58
	141	06/06/89	2267	873	263	150	0.23	38.51	0.03	57.03	501	385	515	504	113	89
[9].F5,SR80/20,	1	06/13/89	2293	857	200	153	0.23	37.37	0.02	76.50	493	304	555	477	123	41
RR5/8	8	06/20/89	2393	970	190	153	0.24	40.53	0.02	80.53	539	373	531	461	88	18
[06/10/89]	15	06/27/89	2823	1133	423	157	0.28	40.13	0.04	37.12	405	243	491	516	93	21
[10].F5,SR80/20,	22	07/04/89	2193	647	363	137	0.22	29.50	0.04	37.74	437	398	460	467	83	30
RR5/8	29	07/11/89	2253	663	387	120	0.23	29.43	0.04	31.01	519	399	478	563	75	7
[07/02/89]	36	07/18/89	2657	943	580	260	0.27	35.49	0.06	44.83	745	431	483	510	58	15
Reacclimatization	43	07/25/89	2300	690	143	133	0.23	30.00	0.01	93.01	440	240	434	526	55	6
	46	07/28/89	2758	1013	220	90	0.28	36.73	0.02	40.91	222	333	439	400	55	11
	50	08/01/89	2700	590	393	207	0.27	21.85	0.04	52.67	515	294	392	383	24	24
	53	08/04/89	2337	267	277	133	0.23	11.42	0.03	48.01	457	291	398	377	18	18

TABLE C1.8 RESPONSE DATA OF THE SAMPLING POINT NO.8 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3

EXPER. RUNS NUMBERS	DAY	DATE	SOLIDS, MG/L or ELSE								COD, MG/L		INORGANICS, MG/L or ELSE			
			TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	TOTAL	SOL.	NH4-N	TKN	TP	PO4-P
[11].F5,SR90/10,	57	08/08/89	2307	185	350	113	0.23	8.02	0.04	32.29	448	314	375	365	76	7
RR5/8	64	08/15/89	2423	145	363	140	0.24	5.98	0.04	38.57	426	213	336	448	14	14
[08/05/89]	71	08/22/89	2436	700	260	57	0.24	28.74	0.03	21.92	328	287	363	238	97	4
	78	08/29/89	2587	807	467	124	0.26	31.19	0.05	26.55	442	241	373	553	109	8
	81	09/01/89	2640	1033	313	160	0.26	39.13	0.03	51.12	320	320	414	560	171	8
	85	09/05/89	2743	943	247	83	0.27	34.38	0.02	33.60	516	278	381	390	20	18
[12].F5,SR90/10,	92	09/12/89	2423	657	140	60	0.24	27.12	0.01	42.86	389	272	421	427	48	7
RR3/6	99	09/19/89	2687	1010	207	110	0.27	37.59	0.02	53.14	347	270	427	440	47	13
[09/06/89]	106	09/26/89	2470	990	183	127	0.25	40.08	0.02	69.40	441	281	411	423	49	5
	109	09/29/89	2517	1110	180	103	0.25	44.10	0.02	57.22	368	368	446	435	42	5
	113	10/03/89	3395	1105	233	100	0.34	32.55	0.02	42.92	407	285	411	401	19	20
	116	10/06/89	2847	1053	123	60	0.28	36.99	0.01	48.78	496	248	422	423	21	9

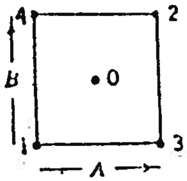
TABLE C1.8 RESPONSE DATA OF THE SAMPLING POINT NO.8 UNDER DIFFERENT RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	VFA, MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
[1].F5,SR80/20,	1	07/12/88	586	673	23	14	20		18		1179
RR2/4	8	07/19/88	756	887	28	34	55	34	25	104	1638
	11	07/22/88	716	881	37	12	30	20	19		1504
[2].F5,SR80/20,	15	07/26/88	572	734	36	26	17		23		1233
RR6/10	22	08/02/88	1366	779	47	139	703	499	737		3265
[07/30/88]	29	08/09/88	2272	701	76	259	628	470	692		4122
	32	08/12/88	2447	743	79	225	556	437	567		4174
	36	08/16/88	2129	645	71	159	101	227	383		3227
	39	08/19/88	1721	607	64	119	89	218	362		2731
	43	08/23/88	1334	576	62	98	34	111	244		2139
	46	08/26/88	1315	399	54	52	23	100	241		1925
[3].F5,SR50/50,	49	08/29/88	1345	528	61	78	30	137	203		2086
RR6/10	53	09/02/88	909	256	45	23	13	156			1262
[08/31/88]	57	09/06/88	447	172	24	10	91				663
	60	09/09/88	349	208	15	46	29	37	23		612
	65	09/14/88	231	72	10	11	26				319
	68	09/17/88	402	221	28	83	25	46	252		847
	71	09/20/88	326	556	33	150	31	29	253	37	1105
	74	09/23/88	380	951	33	38	29	29	252	28	1396
	78	09/27/88	189	1661	44	263	33	40	371	54	2034
	81	09/30/88	103	1640	47	211	35	42	366	52	1896
[4].F5,SR50/50,	85	10/04/88	261	1661	44	301	32	39	386	56	2141
RR2/4	95	10/14/88	378	1824	39	382	26	34	380	57	2432
[10/03/88]	99	10/18/88	415	1833	41	353	28	36	386	59	2465
	102	10/21/88	2932	2143	31	799	20	28	511	114	5623
[5].F5,SR70/30,	1	01/17/89	26	18							41
RR3/6	8	01/24/89	50	48		7			28		110
[14/01/88]	15	01/31/89	32.5								33
	22	02/07/89	91	34							119
	25	02/10/89	75	15							87
	29	02/14/89	35								35
[6].F5,SR70/30,	43	02/28/89	124	32							150
RR5/8	50	03/07/89	180	13							191
[02/20/89]	57	03/14/89	303	30	4						330
	64	03/21/89	53								53
	71	03/28/89	46								46
[7].F5,SR60/40,	78	04/04/89	17								17
RR5/8	85	04/11/89	0								0
[03/29/89]	92	04/18/89	0								0
	99	04/25/89	0								0
	102	04/28/89	0								0
	106	05/02/89	0								0

TABLE C1.8 RESPONSE DATA OF THE SAMPLING POINT NO.8 UNDER DIFFERENT RUNNING COND..
RUNNING CONDITIONS DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER. RUNS NUMBERS	DAY	DATE	VFA , MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
[8].F5,SR60/40,	113	05/09/89	0								0
RR3/6	120	05/16/89	0								0
[05/09/89]	130	05/26/89	0								0
	134	05/30/89	0								0
	137	06/02/89	0								0
	141	06/06/89	0								0
[9].F5,SR80/20,	1	06/13/89	0								0
RR5/8	8	06/20/89	0								0
[06/10/89]	15	06/27/89	0								0
[10].F5,SR80/20,	22	07/04/89	0								0
RR5/8	29	07/11/89	0								0
[07/02/89]	36	07/18/89	0								0
Reacclimatization	43	07/25/89	0								0
	46	07/28/89	0								0
	50	08/01/89	0								0
	53	08/04/89	0								0
[11].F5,SR90/10,	57	08/08/89	0								0
RR5/8	64	08/15/89	0								0
[08/05/89]	71	08/22/89	0								0
	78	08/29/89	0								0
	81	09/01/89	15	10							23
	85	09/05/89	13	11							22
[12].F5,SR90/10,	92	09/12/89	10								10
RR3/6	99	09/19/89	10								10
[09/06/89]	106	09/26/89	0								0
	109	09/29/89	12	11		2					22
	113	10/03/89	13	12							23
	116	10/06/89	16								16
NOTE: 1, 2,.,12 ARE AVERAGE RESPONSES AT PSEUDO-STEADY STATE (EXPERIMENTAL RUNNING CONDITIONS NUMBERED 1 TO 12 RESPECTIVELY)											
	1		681	834	34	24	34	27	22	104	1459
	2		1331	501	59	76	29	116	229		2050
	3		224	1417	41	171	32	37	330	45	1776
	4		1242	1933	37	511	25	33	426	77	3507
	5		67	25							80
	6		50								50
	7		0								0
	8		0								0
	9		0								0
	10		0								0
	11		9	11							15
	12		14	12		2					20

C2.1 : Calculation of the effects (SR and RR), Interaction, Phase means, Change in means, on the Response Parameters during the Acclimatization (Sequence 1 and 2 Experiments).



2^2 *Factorial with added reference condition*

CYCLE n = **1**

Response **: FIL.COD (mg/L)**

Project **UASB— UASB**
Phase **I**
Date

Calculation of Averages						Calculation of Standard Deviation		
Operating conditions	(0)	(1)	(2)	(3)	(4)	Prior estimate of σ	=	**2,325**
(i) Previous cycle sum						Previous sum s	=	
(ii) Previous cycle average						Previous average s	=	
(iii) New observations	**851**	**4,848**	**3,043**	**6,160**	**1,054**	New s = range $\times f_{5,n}$	=	
(iv) Differences (ii) less (iii)						Range	=	
(v) New sums	**851**	**4,848**	**3,043**	**6,160**	**1,054**	New sum s	=	
(vi) New averages: $\bar{y}_i$	**851**	**4,848**	**3,043**	**6,160**	**1,054**	New average $s = \frac{\text{new sum } s}{n-1}$	=	

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **3,191**

(A) **RR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **1,651**

(B) **SR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **-3,456**

(AB) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **339**

Change in mean effect = phase mean $- \bar{y}_0$ = **2,340**

Calculation of 2 S.E. Limits

For new average s: $\pm \frac{2}{\sqrt{n}} s$ = **±4,650**

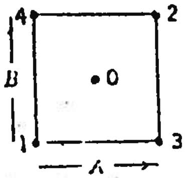
For new effects: $\pm \frac{2}{\sqrt{n}} s$ = **±4,650**

For change in mean: $\pm \frac{1.79}{\sqrt{n}} s$ = **±4,162**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 2$

Response: **FIL.COD (mg/L)**

Project **UASB – UASD**
Phase **I**
Date

Calculation of Averages						Calculation of Standard Deviation		
Operating conditions	(0)	(1)	(2)	(3)	(4)	Prior estimate of σ	=	2,325
(i) Previous cycle sum	851	4,848	3,043	6,160	1,054	Previous sum s	=	
(ii) Previous cycle average	851	4,848	3,043	6,160	1,054	Previous average s	=	
(iii) New observations	920	5,238	3,088	5,720	1,095	New s = range $\times f_{5,n}$	=	249
(iv) Differences (ii) less (iii)	− 69	390	45	− 440	41	Range	=	830
(v) New sums	1,771	10,086	6,131	11,880	2,149	New sum s	=	249
(vi) New averages: $\bar{y}_i$	886	5,043	3,066	5,940	1,075	New average $s = \dfrac{\text{new sum } s}{n-1}$	=	249

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **3,202**

(*A*) **RR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **1,440**

(*B*) **SR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **− 3,421**

(*AB*) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **547**

Change in mean effect = phase mean $- \bar{y}_0 =$ **2,316**

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 351**

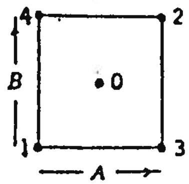
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 351**

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = **± 314**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n =$ 3

Response : FIL.COD (mg/L)

Project UASB – UASB
Phase I
Date

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum	1,771	10,086	6,131	11,880	2,149
(ii) Previous cycle average	886	5,043	3,066	5,940	1,057
(iii) New observations	813	5,040	3,006	6,080	1,136
(iv) Differences (ii) less (iii)	73	3	60	-140	-79
(v) New sums	1,699	10,083	6,072	12,020	2,193
(vi) New averages: $\bar{y}_i$	850	5,042	3,036	6,010	1,097

Calculation of Standard Deviation

Prior estimate of σ	=	2325
Previous sum s	=	249
Previous average s	=	249
New s = range $\times f_{5,n}$	=	74.55
Range	=	213
New sum s	=	324
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	162

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 3,207

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = 1,454

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = -3,460

(AB) Interaction on (SR•RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = 486

Change in mean effect = phase mean $- \bar{y}_0 =$ 2,357

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 186

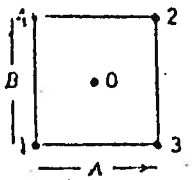
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 186

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = ± 167

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 1$

Response FIL.COD (mg/L)

Project UASB– UASB
Phase II
Date

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average					
(iii) New observations	1,032	429	361	594	489
(iv) Differences (ii) less (iii)					
(v) New sums					
(vi) New averages: $\bar{y}_i$	1,032	429	361	594	489

Calculation of Standard Deviation

Prior estimate of σ = 266

Previous sum s =

Previous average s =

New s = range $\times f_{5,n}$ =

Range =

New sum s =

New average $s = \dfrac{\text{new sum } s}{n-1}$ =

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 581

(*A*) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = -283

(*B*) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = - 86.5

(*AB*) Interaction on (SR*RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = -147

Change in mean effect = phase mean $- \bar{y}_0 =$ -451

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 532

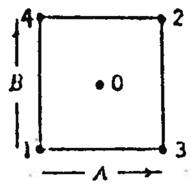
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 532

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = ± 476

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 2$

Response: FIL. COD (mg/L)

Project UASB— UASD
Phase II
Date

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum	1,032	429	361	594	489
(ii) Previous cycle average	1,032	429	361	594	489
(iii) New observations	554	309	291	318	488
(iv) Differences (ii) less (iii)	478	120	70	276	1
(v) New sums	1,586	738	652	912	977
(vi) New averages: $\bar{y}_i$	793	369	326	456	489

Calculation of Standard Deviation

Prior estimate of σ	=	266
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	143
Range	=	477
New sum s	=	143
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	143

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) = 487$

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4) = -38$

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3) = -5$

(AB) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4) = -125$

Change in mean effect = phase mean $- \bar{y}_0 = -306$

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s = \pm 202$

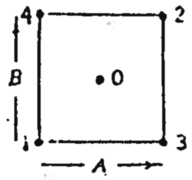
For new effects: $\pm \dfrac{2}{\sqrt{n}} s = \pm 202$

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s = \pm 180$

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.90	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n =$ 3

Response : FIL.COD (mg/L)

Project UASB—UASB
Phase II
Date

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum	1,586	738	652	912	977
(ii) Previous cycle average	793	369	326	456	489
(iii) New observations	359	385	326	394	403
(iv) Differences (ii) less (iii)	434	- 16	0	62	86
(v) New sums	1,152	754	652	850	892
(vi) New averages: $\bar{y}_i$	576	377	326	425	446

Calculation of Standard Deviation

Prior estimate of σ	=	266
Previous sum s	=	143
Previous average s	=	143
New s = range $\times f_{5,n}$	=	158
Range	=	450
New sum s	=	301
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	151

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 430

(*A*) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = - 36

(*B*) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = - 15

(*AB*) **Interaction on (SR•RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = - 84

Change in mean effect = phase mean $- \bar{y}_0 =$ -146

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s = \pm 173$

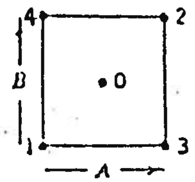
For new effects: $\pm \dfrac{2}{\sqrt{n}} s = \pm 173$

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s = \pm 155$

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 1$

Response: TREATMENT EFFICIENCY(%)-FIL.COD

Project UASB—UASB
Phase I
Date

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average					
(iii) New observations	89.62	32.76	53.19	- 5.48	85.40
(iv) Differences (ii) less (iii)					
(v) New sums					
(vi) New averages: $\bar{y}_j$	89.62	32.76	53.19	- 5.48	85.40

Calculation of Standard Deviation

Prior estimate of σ = 39.38

Previous sum s =
Previous average s =
New s = range $\times f_{5,n}$ =

Range =
New sum s =

New average $s = \dfrac{\text{new sum } s}{n-1}$ =

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 51.09

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = -35.23

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = 55.66

(AB) Interaction on (SR*RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = 3.01

Change in mean effect = phase mean $- \bar{y}_0$ = -38.53

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = ±78.76

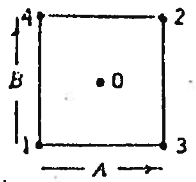
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = ±78.76

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = ±70.49

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n =$ **2**

Response: **TREATMENT EFFICIENCY(%)-FIL.COD**

Project **UASB— UASB**
Phase **I**
Date

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	**89.62**	**32.76**	**53.19**	**-5.48**	**85.40**
(iii) New observations	**84.03**	**16.46**	**61.87**	**8.19**	**88.66**
(iv) Differences (ii) less (iii)	**5.59**	**16.30**	**- 8.68**	**-3.19**	**-3.26**
(v) New sums	**173.65**	**49.22**	**115.06**	**2.71**	**174.06**
(vi) New averages: $\bar{y}_i$	**86.83**	**24.61**	**57.53**	**1.36**	**87.03**

Calculation of Standard Deviation

Prior estimate of σ	=	**39.38**
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	**7.49**
Range	=	**24.98**
New sum s	=	**7.49**
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	**7.49**

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **51.47**

(A) **RR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **-26.38**

(B) **SR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **59.30**

(AB) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **- 3.13**

Change in mean effect = phase mean $- \bar{y}_0 =$ **-35.36**

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 10.56**

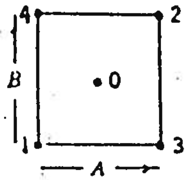
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 10.56**

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = **± 9.44**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 Factorial with added reference condition

CYCLE $n =$ 3

Response : TREATMENT EFFICIENCY(%)-FIL.COD

Project UASB – UASB
Phase I
Date

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	86.83	24.61	57.53	1.36	87.03
(iii) New observations	84.62	28.14	65.81	5.30	88.03
(iv) Differences (ii) less (iii)	2.21	- 3.53	- 8.28	-3.94	-1.00
(v) New sums	171.45	52.75	123.34	6.66	175.06
(vi) New averages: $\bar{y}_i$	85.73	26.38	61.67	3.33	87.53

Calculation of Standard Deviation

Prior estimate of σ	=	
Previous sum s	=	
Previous average s	=	7.49
New s = range $\times f_{5,n}$	=	3.67
Range	=	10.49
New sum s	=	11.16
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	5.58

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 52.93

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = - 24.46

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = 59.75

(AB) Interaction on (SR•RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = - 1.40

Change in mean effect = phase mean $- \bar{y}_0$ = - 30.56

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 6.42

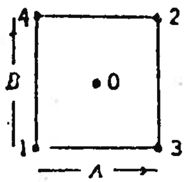
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 6.42

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = ± 5.75

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 1$

Response: TREATMENT EFFICIENCY(%)-FIL.COD

Project UASB— UASD
Phase II
Date

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average					
(iii) New observations	86.45	94.39	94.59	93.36	91.97
(iv) Differences (ii) less (iii)					
(v) New sums					
(vi) New averages: $\bar{y}_i$	86.45	94.39	94.59	93.36	91.97

Calculation of Standard Deviation

Prior estimate of σ	=	3.35
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	
Range	=	
New sum s	=	
New average $s = \frac{\text{new sum } s}{n-1}$	=	

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 92.15

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = 0.80

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = -0.60

(AB) Interaction on (SR•RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = 183

Change in mean effect = phase mean $- \bar{y}_0 =$ 5.7

Calculation of 2 S.E. Limits

For new average s: $\pm \frac{2}{\sqrt{n}} s$ = ± 6.70

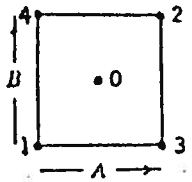
For new effects: $\pm \frac{2}{\sqrt{n}} s$ = ± 6.70

For change in mean: $\pm \frac{1.79}{\sqrt{n}} s$ = ± 6.00

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n =$ 2

Response :TREATMENT EFFICIENCY(%)-FIL.COD

Project UASB— UASB
Phase II
Date

Calculation of Averages						Calculation of Standard Deviation		
Operating conditions	(0)	(1)	(2)	(3)	(4)	Prior estimate of σ	=	3.35
(i) Previous cycle sum						Previous sum s	=	
(ii) Previous cycle average	86.45	94.39	94.59	93.36	91.97	Previous average s	=	
(iii) New observations	92.05	95.87	95.58	95.40	92.10	New s = range $\times f_{5,n}$	=	1.98
(iv) Differences (ii) less (iii)	- 5.60	- 1.48	- 0.99	- 2.04	- 0.13	Range	=	6.59
(v) New sums	178.50	190.26	190.17	188.76	184.07	New sum s	=	1.98
(vi) New averages: $\bar{y}_i$	89.25	95.13	95.09	94.38	92.04	New average $s = \dfrac{\text{new sum } s}{n-1}$	=	1.98

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 93.18

(A) **RR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = 1.15

(B) **SR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = -1.19

(AB) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = 1.90

Change in mean effect = phase mean $- \bar{y}_0 =$ 3.93

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 2.79

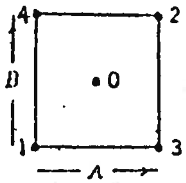
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 2.79

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = ± 2.49

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n =$ 3

Response: <u>TREATMENT EFFICIENCY(%)-FIL.COD</u>

Project <u>UASB — UASD</u>
Phase <u>II</u>
Date ______

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	89.25	95.13	95.09	94.38	92.04
(iii) New observations	93.44	94.69	95.09	95.15	93.83
(iv) Differences (ii) less (iii)	- 4.19	0.44	0.00	-0.77	-1.79
(v) New sums	182.69	189.82	190.18	189.53	185.87
(vi) New averages: $\bar{y}_i$	91.35	94.91	95.09	94.77	92.94

Calculation of Standard Deviation

Prior estimate of σ	=	
Previous sum s	=	
Previous average s	=	1.98
New s = range $\times f_{5,n}$	=	1.62
Range	=	4.63
New sum s	=	3.60
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	1.80

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 93.81

(A) <u>RR</u> effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4) =$ 1.01

(B) <u>SR</u> effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3) =$ - 0.83

(AB) <u>Interaction on (SR*RR)</u> effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4) =$ 1.15

Change in mean effect = phase mean $- \bar{y}_0 =$ 2.46

Calculation of 2 S.E. Limits

For new average s: $\pm \frac{2}{\sqrt{n}} s =$ ± 2.07

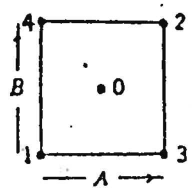
For new effects: $\pm \frac{2}{\sqrt{n}} s =$ ± 2.07

For change in mean: $\pm \frac{1.79}{\sqrt{n}} s =$ ± 1.85

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 1$

Response GAS PRODUCTION(CH_4)

Project UASB— UASB
Phase I
Date

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average					
(iii) New observations	1.35	1.05	1.75	0.63	1.46
(iv) Differences (ii) less (iii)					
(v) New sums					
(vi) New averages: $\bar{y}_i$	1.35	1.05	1.75	0.63	1.46

Calculation of Standard Deviation

Prior estimate of σ	=	0.43
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{s,n}$	=	
Range	=	
New sum s	=	
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **1.25**

(*A*) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **-0.07**

(*B*) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **0.77**

(*AB*) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **0.36**

Change in mean effect = phase mean $- \bar{y}_0$ = **0.10**

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 0.86**

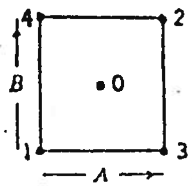
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 0.86**

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = **± 0.77**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{s,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n =$ 2

Response: GAS PRODUCTION (CH_4)

Project UASB— UASB
Phase 1
Date

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	1.35	1.05	1.75	0.63	1.46
(iii) New observations	1.69	3.16	1.47	2.19	0.82
(iv) Differences (ii) less (iii)	-0.34	-2.11	0.28	-1.56	0.64
(v) New sums	3.04	4.21	3.22	2.82	2.28
(vi) New averages: $\bar{y}_j$	1.52	2.11	1.61	1.41	1.14

Calculation of Standard Deviation

Prior estimate of σ	=	0.43
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	0.83
Range	=	2.75
New sum s	=	0.83
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	0.83

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 1.56

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = -0.12

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = -0.39

(AB) Interaction on (SR•RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = 0.59

Change in mean effect = phase mean $- \bar{y}_0 =$ 0.04

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 1.17

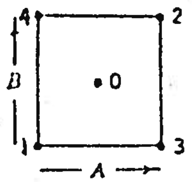
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 1.17

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = ± 1.04

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n =$ 3

Response **: GAS PRODUCTION (CH_4)**

Project **UASB—UASB**
Phase **I**
Date

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	1.52	2.11	1.61	1.41	1.14
(iii) New observations	1.90	1.33	2.14	3.49	1.01
(iv) Differences (ii) less (iii)	-0.38	0.78	-0.53	-2.08	0.13
(v) New sums	3.42	3.44	3.75	4.90	2.15
(vi) New averages: $\bar{y}_i$	1.71	1.72	1.88	2.45	1.08

Calculation of Standard Deviation

Prior estimate of σ	=	
Previous sum s	=	
Previous average s	=	0.83
New s = range $\times f_{5,n}$	=	1.00
Range	=	2.86
New sum s	=	1.83
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	0.92

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **1.77**

(A) **RR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **0.77**

(B) **SR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **-0.61**

(AB) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **0.04**

Change in mean effect = phase mean $- \bar{y}_0 =$ **0.06**

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = ± **1.05**

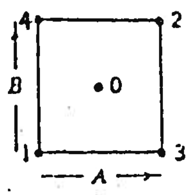
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = ± **1.05**

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = ± **0.95**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n =$ 1

Response: GAS PRODUCTION(CH_4)

Project UASB—UASB
Phase II
Date

Calculation of Averages					
Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum (ii) Previous cycle average (iii) New observations	2.23	1.81	1.58	2.92	1.79
(iv) Differences (ii) less (iii) (v) New sums					
(vi) New averages: $\bar{y}_i$	2.23	1.81	1.58	2.92	1.79

Calculation of Standard Deviation

Prior estimate of σ = 0.53

Previous sum s =

Previous average s =

New s = range $\times f_{5,n}$ =

Range =

New sum s =

New average $s = \dfrac{\text{new sum } s}{n-1}$ =

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 2.07

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = 0.45

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = -0.68

(AB) Interaction on (SR•RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = -0.66

Change in mean effect = phase mean $- \bar{y}_0 =$ -0.16

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s = \pm$ 1.06

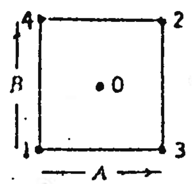
For new effects: $\pm \dfrac{2}{\sqrt{n}} s = \pm$ 1.06

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s = \pm$ 0.95

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.90	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n =$ 2

Response GAS PRODUCTION(CH_4)

Project UASB— UASB
Phase II
Date

Calculation of Averages					
Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	2.23	1.81	1.59	2.92	1.79
(iii) New observations	1.74	1.52	1.74	2.17	2.19
(iv) Differences (ii) less (iii)	0.49	0.29	-0.15	0.75	-0.40
(v) New sums	4.00	3.33	3.33	5.09	3.98
(vi) New averages: $\bar{y}_i$	2.00	1.67	1.67	2.55	1.99

Calculation of Standard Deviation		
Prior estimate of σ	=	
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	0.35
Range	=	1.15
New sum s	=	0.35
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	0.35

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 1.98

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = 1.83

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = -0.28

(AB) **Interaction on** (SR•RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = -0.60

Change in mean effect = phase mean $- \bar{y}_0 =$ -0.02

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 0.49

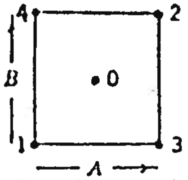
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 0.49

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = ± 0.44

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 3$

Response : GAS PRODUCTION (CH_4)

Project UASB—UASB
Phase II
Date

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	2.00	1.67	1.67	2.55	1.99
(iii) New observations	1.67	1.81	1.66	2.51	1.87
(iv) Differences (ii) less (iii)	0.33	-0.14	0.01	0.04	0.12
(v) New sums	3.67	3.48	3.33	5.06	3.86
(vi) New averages: $\bar{y}_i$	1.84	1.74	1.67	2.53	1.93

Calculation of Standard Deviation

Prior estimate of σ	=	
Previous sum s	=	
Previous average s	=	0.35
New s = range $\times f_{5,n}$	=	0.16
Range	=	0.47
New sum s	=	0.51
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	0.26

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **1.94**

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **0.27**

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **-0.34**

(AB) Interaction on (SR•RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **-0.53**

Change in mean effect = phase mean $- \bar{y}_0 =$ **0.10**

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = **±0.29**

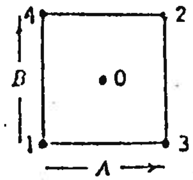
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = **±0.29**

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = **±0.27**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n =$ **1**

Response **: CH_4 CONTENT (%)**

Project **UASB— UASB**
Phase **I**
Date

Calculation of Averages					
Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average					
(iii) New observations	**87.24**	**52.30**	**70.53**	**55.15**	**83.12**
(iv) Differences (ii) less (iii)					
(v) New sums					
(vi) New averages: $\bar{y}_i$	**87.24**	**52.30**	**70.53**	**55.15**	**83.12**

Calculation of Standard Deviation		
Prior estimate of σ	=	**15.83**
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	
Range	=	
New sum s	=	
New average $s = \frac{\text{new sum } s}{n-1}$	=	

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **69.67**

(A) **RR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **- 4.87**

(B) **SR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **23.10**

(AB) **Interaction on (SR•RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **- 7.72**

Change in mean effect = phase mean $- \bar{y}_0 =$ **-17.57**

Calculation of 2 S.E. Limits

For new average s: $\pm \frac{2}{\sqrt{n}} s$ = **± 31.66**

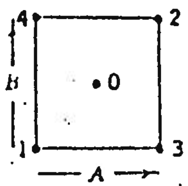
For new effects: $\pm \frac{2}{\sqrt{n}} s$ = **± 31.66**

For change in mean: $\pm \frac{1.79}{\sqrt{n}} s$ = **± 28.34**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n =$ 2

Response: CH_4 CONTENT (%)

Project UASB – UASB
Phase I
Date

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	87.24	52.30	70.53	55.15	83.12
(iii) New observations	80.38	56.20	66.61	53.15	79.64
(iv) Differences (ii) less (iii)	6.86	- 3.90	3.92	2.00	3.48
(v) New sums	167.62	108.50	137.14	108.30	162.76
(vi) New averages: $\bar{y}_i$	83.81	54.25	68.57	54.15	81.38

Calculation of Standard Deviation S=14.22

Prior estimate of σ	=	
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	3.23
Range	=	10.76
New sum s	=	3.23
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	3.23

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 68.43

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = - 6.46

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = 20.78

(AB) Interaction on (SR•RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = - 6.36

Change in mean effect = phase mean $- \bar{y}_0 =$ -15.38

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 4.55

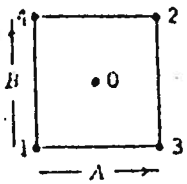
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 4.55

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = ± 4.03

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 3$

Response : CH_4 CONTENT (%)

Project UASB– UASB
Phase I
Date

Calculation of Averages					
Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	83.81	54.25	68.57	54.15	81.38
(iii) New observations	84.58	54.57	67.27	50.30	80.06
(iv) Differences (ii) less (iii)	- 0.77	- 0.32	1.30	3.85	1.32
(v) New sums	168.39	108.82	135.84	104.45	161.44
(vi) New averages: $\bar{y}_i$	84.20	54.41	67.92	52.23	80.72

Calculation of Standard Deviation	S=14.64
Prior estimate of σ =	
Previous sum s =	
Previous average s =	3.23
New s = range $\times f_{5,n}$ =	1.62
Range =	4.62
New sum s =	4.85
New average $s = \frac{\text{new sum } s}{n-1}$ =	2.43

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 67.90

(A) **RR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = - 7.49

(B) **SR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = 5.31

(AB) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = -5.31

Change in mean effect = phase mean $- \bar{y}_0 =$ -16.30

Calculation of 2 S.E. Limits

For new average s: $\pm \frac{2}{\sqrt{n}} s$ = ± 2.79

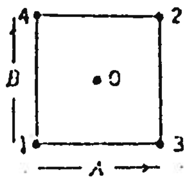
For new effects: $\pm \frac{2}{\sqrt{n}} s$ = ± 2.79

For change in mean: $\pm \frac{1.79}{\sqrt{n}} s$ = ± 2.50

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 1$

Response: **CH_4 CONTENT (%)**

Project **UASB— UASD**
Phase **II**
Date

Calculation of Averages					
Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum (ii) Previous cycle average (iii) New observations	**70.59**	**74.03**	**69.93**	**72.15**	**74.00**
(iv) Differences (ii) less (iii) (v) New sums					
(vi) New averages: $\bar{y}_i$	**70.59**	**74.03**	**69.93**	**72.15**	**74.00**

Calculation of Standard Deviation **S= 1.89**	
Prior estimate of σ	=
Previous sum s	=
Previous average s	=
New s = range $\times f_{5,n}$	=
Range	=
New sum s	=
New average $s = \dfrac{\text{new sum } s}{n-1}$	=

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **72.14**

(A) **RR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **- 2.98**

(B) **SR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **- 1.13**

(AB) **Interaction on (SR•RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **- 1.10**

Change in mean effect = phase mean $- \bar{y}_0 =$ **1.55**

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 3.78**

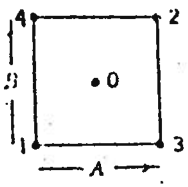
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 3.78**

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = **± 3.38**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.90	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 Factorial with added reference condition

CYCLE $n = 2$

Response : CH_4 CONTENT (%)

Project UASB — UASB
Phase II
Date

Calculation of Averages					
Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	70.59	74.03	69.93	72.15	74.00
(iii) New observations	73.01	73.72	70.03	72.30	73.99
(iv) Differences (ii) less (iii)	- 2.42	0.31	- 0.10	- 0.15	0.01
(v) New sums	143.60	147.75	139.96	144.45	147.99
(vi) New averages: $\bar{y}_i$	71.80	73.88	69.98	72.23	73.99

Calculation of Standard Deviation		S= 1.67
Prior estimate of σ	=	
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	0.77
Range	=	2.57
New sum s	=	0.77
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	0.77

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 72.37

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = - 2.86

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = - 1.10

(AB) Interaction on (SR•RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = - 1.21

Change in mean effect = phase mean $- \bar{y}_0 =$ 0.58

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 1.09

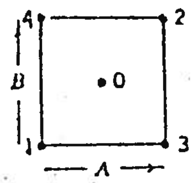
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 1.09

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = ± 0.97

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 3$

Response : CH_4 CONTENT (%)

Project UASB— UASB
Phase II
Date

Calculation of Averages					
Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	71.80	73.88	69.98	72.23	73.99
(iii) New observations	73.43	73.01	69.98	72.10	75.77
(iv) Differences (ii) less (iii)	- 1.63	0.87	0.00	0.13	- 1.78
(v) New sums	145.23	146.89	139.96	144.33	149.76
(vi) New averages: $\bar{y}_i$	72.62	73.45	69.98	72.17	74.88

Calculation of Standard Deviation		S= 1.80
Prior estimate of σ	=	
Previous sum s	=	
Previous average s	=	0.77
New s = range $\times f_{5,n}$	=	0.93
Range	=	2.65
New sum s	=	1.70
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	0.85

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **72.62**

(A) **RR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **- 3.09**

(B) **SR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **- 3.38**

(AB) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **- 1.81**

Change in mean effect = phase mean $- \bar{y}_0 =$ **0.00**

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 0.98**

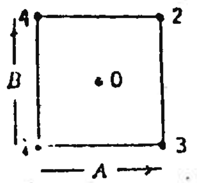
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 0.98**

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = **± 0.88**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 1$

Response: PO_4-P (mg/L)

Project UASB– UASB
Phase I
Date

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average					
(iii) New observations	23	232	116	410	28
(iv) Differences (ii) less (iii)					
(v) New sums					
(vi) New averages: $\bar{y}_i$	23	232	116	410	28

Calculation of Standard Deviation

Prior estimate of σ	=	162.63
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{S,n}$	=	
Range	=	
New sum s	=	
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **161.80**

(*A*) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **237.50**

(*B*) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **-249.00**

(*AB*) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **- 45.00**

Change in mean effect = phase mean $- \bar{y}_0 =$ **138.80**

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 325.26**

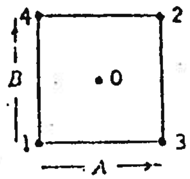
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 325.26**

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = **± 291.11**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{S,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE n = 2

Response : PO_4-P (mg/L)

Project UASB—UASB
Phase I
Date

Calculation of Averages					
Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	23	232	116	410	28
(iii) New observations	17	231	92	240	25
(iv) Differences (ii) less (iii)	6	1	24	170	3
(v) New sums	40	463	208	650	53
(vi) New averages: $\bar{y}_i$	20	232	104	325	27

Calculation of Standard Deviation		
Prior estimate of σ	=	162.63
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	51.30
Range	=	171.00
New sum s	=	51.30
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	51.30

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 141.60

(*A*) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = 85.00

(*B*) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = -213.00

(*AB*) Interaction on (SR•RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = - 8.00

Change in mean effect = phase mean $- \bar{y}_0 =$ 121.60

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 72.33

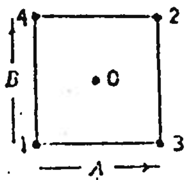
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 72.33

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = ± 64.64

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n =$ **1**

Response: **PO_4-P (mg/L)**

Project **UASB– UASB**
Phase **II**
Date ______

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum (ii) Previous cycle average (iii) New observations	**5**	**167**	**9**	**37**	**6**
(iv) Differences (ii) less (iii) (v) New sums					
(vi) New averages: $\bar{y}_i$	**5**	**167**	**9**	**37**	**6**

Calculation of Standard Deviation

Prior estimate of σ	=	**69.58**
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	
Range	=	
New sum s	=	
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **44.80**

(A) **RR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **-63.50**

(B) **SR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **-94.50**

(AB) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **66.50**

Change in mean effect = phase mean $- \bar{y}_0 =$ **39.80**

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 139.16**

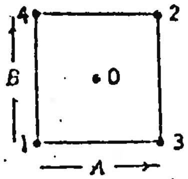
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 139.16**

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = **± 124.55**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	[illegible]	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 2$

Response : PO_4-P (mg/L)

Project UASB – UASB
Phase II
Date

Calculation of Averages					
Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	5	167	9	37	6
(iii) New observations	7	89	2	50	11
(iv) Differences (ii) less (iii)	-2	78	7	-13	- 5
(v) New sums	12	256	11	87	17
(vi) New averages: $\bar{y}_i$	6	128	6	44	9

Calculation of Standard Deviation		
Prior estimate of σ	=	52.49
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	27.30
Range	=	91.00
New sum s	=	27.30
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	27.30

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **38.60**

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **-43.50**

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **-78.50**

(AB) Interaction on (SR•RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **40.50**

Change in mean effect = phase mean $- \bar{y}_0 =$ **32.60**

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 38.49**

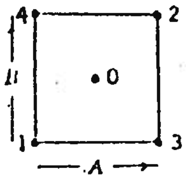
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 38.49**

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = **± 34.40**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 1$

Project: UASB—UASB
Phase: I
Date:

Response: TREATMENT EFFICIENCY(%)-PO_4-P

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average					
(iii) New observations	83.09	6.53	33.71	-109.68	63.29
(iv) Differences (ii) less (iii)					
(v) New sums					
(vi) New averages: $\bar{y}_i$	83.09	6.53	33.71	-109.68	63.29

Calculation of Standard Deviation

Prior estimate of σ = 75.72

Previous sum s =
Previous average s =
New s = range $\times f_{5,n}$ =

Range =
New sum s =
New average $s = \dfrac{\text{new sum } s}{n-1}$ =

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 15.39

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = - 72.90

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = 101.84

(AB) Interaction on (SR•RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = 43.32

Change in mean effect = phase mean $- \bar{y}_0 =$ -67.70

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 151.44

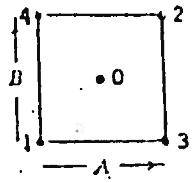
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 151.44

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = ± 135.54

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 2$

Response: TREATMENT EFFICIENCY(%)-PO_4-P

Project: UASB—UASB
Phase: I
Date:

Calculation of Averages

Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	83.09	6.53	33.71	-109.68	63.29
(iii) New observations	86.09	-0.91	31.43	- 21.70	70.91
(iv) Differences (ii) less (iii)	- 3.00	7.44	2.28	- 43.99	- 7.62
(v) New sums	169.18	5.62	65.14	-131.38	134.20
(vi) New averages: $\bar{y}_i$	84.59	2.81	32.57	- 65.69	67.10

Calculation of Standard Deviation

Prior estimate of σ	=	59.36
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	15.43
Range	=	51.43
New sum s	=	15.43
New average $s = \frac{\text{new sum } s}{n-1}$	=	15.43

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 24.28

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = -51.52

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = 81.28

(AB) Interaction on (SR*RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = 16.99

Change in mean effect = phase mean $- \bar{y}_0$ = -60.31

Calculation of 2 S.E. Limits

For new average s: $\pm \frac{2}{\sqrt{n}} s$ = ± 21.76

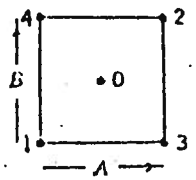
For new effects: $\pm \frac{2}{\sqrt{n}} s$ = ± 21.76

For change in mean: $\pm \frac{1.79}{\sqrt{n}} s$ = ± 19.44

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 1$

Response : TREATMENT EFFICIENCY(%)-PO_4-P

Project UASB— UASB
Phase II
Date

Calculation of Averages					
Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average					
(iii) New observations	**91.23**	**67.78**	**94.61**	**79.67**	**96.20**
(iv) Differences (ii) less (iii)					
(v) New sums					
(vi) New averages: $\bar{y}_i$	**91.23**	**67.78**	**94.61**	**79.67**	**96.20**

Calculation of Standard Deviation		
Prior estimate of σ	=	**12.02**
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	
Range	=	
New sum s	=	
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	

Calculation of Effects

Phase mean	$= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4)$	=	**85.90**
(A) RR effect	$= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$	=	**5.15**
(B) SR effect	$= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$	=	**21.68**
(AB) **Interaction on (SR•RR)** effect	$= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$	=	**- 6.74**
Change in mean effect	= phase mean $- \bar{y}_0$	=	**- 5.33**

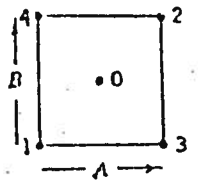
Calculation of 2 S.E. Limits

For new average s:	$\pm \frac{2}{\sqrt{n}} s$	=	**± 24.04**
For new effects:	$\pm \frac{2}{\sqrt{n}} s$	=	**± 24.04**
For change in mean:	$\pm \frac{1.79}{\sqrt{n}} s$	=	**± 21.52**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.90	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery, 1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 2$

Response **: TREATMENT EFFICIENCY(%)-PO_4-P**

Project **UASB— UASB**
Phase **II**
Date

Calculation of Averages					
Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	91.23	67.78	94.61	79.67	96.20
(iii) New observations	96.82	46.71	98.92	72.53	93.96
(iv) Differences (ii) less (iii)	- 5.59	21.07	- 4.31	7.14	2.24
(v) New sums	188.05	114.49	193.53	152.20	190.16
(vi) New averages: $\bar{y}_i$	94.03	57.25	96.77	76.10	95.00

Calculation of Standard Deviation		
Prior estimate of σ	=	12.02
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	7.99
Range	=	26.66
New sum s	=	7.99
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	7.99

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **83.83**

(A) **RR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **10.31**

(B) **SR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **29.21**

(AB) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **- 8.54**

Change in mean effect = phase mean $- \bar{y}_0$ = **-10.20**

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 11.27**

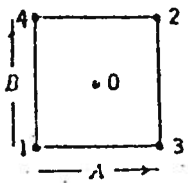
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = **± 11.27**

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = **± 10.07**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 1$

Response **: VFA(mg/L) AS HAc**

Project **UASB— UASB**
Phase **I**
Date

Calculation of Averages					
Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average					
(iii) New observations	**175**	**2,034**	**2,138**	**2,432**	**1,638**
(iv) Differences (ii) less (iii)					
(v) New sums					
(vi) New averages: $\bar{y}_i$	**175**	**2,034**	**2,138**	**2,432**	**1.638**

Calculation of Standard Deviation

Prior estimate of σ = **889.85**
Previous sum s =
Previous average s =
New s = range $\times f_{5,n}$ =
Range =
New sum s =
New average $s = \dfrac{\text{new sum } s}{n-1}$ =

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **1,683**

(A) **RR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **449**

(B) **SR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **- 345**

(AB) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **51**

Change in mean effect = phase mean $- \bar{y}_0$ = **1,508**

Calculation of 2 S.E. Limits

For new average s: $\pm \frac{2}{\sqrt{n}} s$ = **± 1779.70**

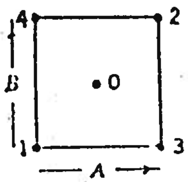
For new effects: $\pm \frac{2}{\sqrt{n}} s$ = **± 1779.70**

For change in mean: $\pm \frac{1.79}{\sqrt{n}} s$ = **± 1592.83**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 2$

Response : VFA(mg/L) AS HAc

Project UASB— UASB
Phase I
Date

Calculation of Averages					
Operating conditions	(0)	(1)	(2)	(3)	(4)
(i) Previous cycle sum					
(ii) Previous cycle average	175	2,034	2,138	2,432	1,638
(iii) New observations	286	1,896	1,924	5,623	1,504
(iv) Differences (ii) less (iii)	- 111	138	214	- 3,191	134
(v) New sums	461	3,930	4,062	8,055	3,142
(vi) New averages: $\bar{y}_i$	231	1,965	2,031	4,028	1,571

Calculation of Standard Deviation		
Prior estimate of σ	=	889.85
Previous sum s	=	
Previous average s	=	
New s = range $\times f_{5,n}$	=	1,022
Range	=	3,405
New sum s	=	1,022
New average $s = \dfrac{\text{new sum } s}{n-1}$	=	1,022

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ 1,965

(A) RR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = 1,262

(B) SR effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = -1,196

(AB) Interaction on (SR*RR) effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = - 802

Change in mean effect = phase mean $- \bar{y}_0 =$ 1,734

Calculation of 2 S.E. Limits

For new average s: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 1,441

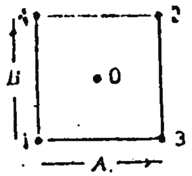
For new effects: $\pm \dfrac{2}{\sqrt{n}} s$ = ± 1,441

For change in mean: $\pm \dfrac{1.79}{\sqrt{n}} s$ = ± 1,288

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 1$

Response **: VFA(mg/L) AS HAc**

Project **UASB – UASB**
Phase **II**
Date

Calculation of Averages						Calculation of Standard Deviation		
Operating conditions	(0)	(1)	(2)	(3)	(4)	Prior estimate of σ	=	**219**
(i) Previous cycle sum (ii) Previous cycle average (iii) New observations	**521**	**0**	**53**	**0**	**119**	Previous sum s = Previous average s = New s = range $\times f_{5,n}$ =		
(iv) Differences (ii) less (iii) (v) New sums (vi) New averages: $\bar{y}_i$	**521**	**0**	**53**	**0**	**119**	Range = New sum s = New average $s = \frac{\text{new sum } s}{n-1}$ =		

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **138.60**

(A) **RR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **- 33.00**

(B) **SR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **86.00**

(AB) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **- 33.00**

Change in mean effect = phase mean $- \bar{y}_0 =$ **-382.40**

Calculation of 2 S.E. Limits

For new average s: $\pm \frac{2}{\sqrt{n}} s$ = **± 438**

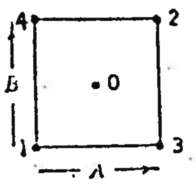
For new effects: $\pm \frac{2}{\sqrt{n}} s$ = **± 438**

For change in mean: $\pm \frac{1.79}{\sqrt{n}} s$ = **± 392**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	[illegible]	[illegible]	0.76	0.71	0.67	[illegible]
$1.79/\sqrt{n}$	1.79	1.26	1.03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Source: Reference (Montgomery,1984)



2^2 *Factorial with added reference condition*

CYCLE $n = 2$

Response **: VFA(mg/L) AS HAc**

Project **UASB— UASB**
Phase **II**
Date

Calculation of Averages						Calculation of Standard Deviation		
Operating conditions	(0)	(1)	(2)	(3)	(4)	Prior estimate of σ	=	
(i) Previous cycle sum						Previous sum s	=	
(ii) Previous cycle average	**521**	**0**	**53**	**0**	**119**	Previous average s	=	
(iii) New observations	**55**	**0**	**46**	**0**	**35**	New s = range $\times f_{5,n}$	=	**139.80**
(iv) Differences (ii) less (iii)	**466**	**0**	**7**	**0**	**84**	Range	=	**466.00**
(v) New sums	**576**	**0**	**99**	**0**	**154**	New sum s	=	**139.80**
(vi) New averages: $\bar{y}_i$	**288**	**0**	**50**	**0**	**77**	New average $s = \frac{\text{new sum } s}{n-1}$	=	**139.80**

Calculation of Effects

Phase mean $= \frac{1}{5}(\bar{y}_0 + \bar{y}_1 + \bar{y}_2 + \bar{y}_3 + \bar{y}_4) =$ **83.00**

(A) **RR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_3 - \bar{y}_1 - \bar{y}_4)$ = **- 13.50**

(B) **SR** effect $= \frac{1}{2}(\bar{y}_2 + \bar{y}_4 - \bar{y}_1 - \bar{y}_3)$ = **63.50**

(AB) **Interaction on (SR*RR)** effect $= \frac{1}{2}(\bar{y}_1 + \bar{y}_2 - \bar{y}_3 - \bar{y}_4)$ = **- 13.50**

Change in mean effect = phase mean $- \bar{y}_0 =$ **-205.00**

Calculation of 2 S.E. Limits

For new average s: $\pm \frac{2}{\sqrt{n}} s = \pm$ **197**

For new effects: $\pm \frac{2}{\sqrt{n}} s = \pm$ **197**

For change in mean: $\pm \frac{1.79}{\sqrt{n}} s = \pm$ **176**

Table of Multiplying Factors

n	1	2	3	4	5	6	7	8	9	10
$f_{5,n}$		0.30	0.35	0.37	0.38	0.39	0.40	0.40	0.40	0.41
$1/n$	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11	0.10
$1/(n-1)$		1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.12	0.11
$2/\sqrt{n}$	2.00	1.41	1.15	1.00	0.89	0.82	0.76	0.71	0.67	0.63
$1.79/\sqrt{n}$	1.79	1.26	1.03	0.89	0.80	0.73	0.68	0.63	0.60	0.57

Source: Reference (Montgomery,1984)

Table C3.1 pH of A–UASB and M–UASB during the Phase 2 and 3 experiments including maximization and recovery period

Days	pH (UASB)		Days	pH (UASB)		Days	pH (UASB)		Days	pH (UASB)		Days	pH (UASB)	
	A–	M–		A–	M–		A–	M–		A–	M–		A–	M–
1	5.04	7.04	41	4.94	7.39	81	4.98	7.10	121	5.09	7.09	161	5.70	7.08
2	5.06	7.00	42	5.08	7.35	82	5.08	7.13	122	5.12	7.09	162	5.72	7.07
3	5.04	7.00	43	5.08	7.35	83	4.97	7.06	123	5.09	7.10	163	5.68	7.07
4	5.11	6.99	44	5.05	7.37	84	5.05	7.10	124	5.10	7.10	164	5.62	7.08
5	5.03	7.02	45	5.00	7.28	85	4.97	7.10	125	5.18	7.13	165	5.59	7.07
6	5.06	7.04	46	4.98	7.27	86	5.15	7.13	126	5.21	7.12	166	5.62	7.07
7	5.04	7.06	47	4.93	7.28	87	5.06	7.14	127	5.23	7.13	167	5.59	7.08
8	5.05	7.11	48	5.14	7.25	88	5.07	7.19	128	5.22	7.13	168	5.61	7.08
9	5.04	6.70	49	5.05	7.24	89	5.08	7.19	129	5.29	7.13	169	5.53	7.08
10	5.08	6.70	50	4.97	7.25	90	5.07	7.16	130	5.35	7.13	170	5.48	7.08
11	5.06	6.70	51	4.96	7.25	91	5.04	7.17	131	5.38	7.13	171	5.45	7.09
12	5.12	6.70	52	4.94	7.25	92	4.95	7.17	132	5.37	7.13	172	5.39	7.09
13	5.09	6.70	53	5.02	7.24	93	4.97	7.13	133	5.39	7.13	173	5.41	7.09
14	5.11	6.70	54	5.01	7.23	34	5.02	7.32	134	5.34	7.13	174	5.41	7.08
15	5.01	6.70	55	5.28	7.26	95	5.02	7.02	135	5.34	7.13	175	5.41	7.08
16	4.98	6.70	56	5.12	7.27	96	4.95	7.02	136	5.35	7.12	176	5.35	7.06
17	4.98	6.70	57	5.06	7.28	97	5.02	7.00	137	5.46	7.12	177	5.35	7.09
18	4.98	6.70	58	4.96	7.28	98	5.00	7.01	138	5.46	7.12	178	5.35	7.09
19	4.93	6.70	59	4.96	7.28	99	4.97	7.01	139	5.50	7.12	179	5.36	7.09
20	4.94	6.70	60	4.93	7.27	100	4.98	7.01	140	5.54	7.12	180	5.35	7.09
21	5.01	6.70	61	5.05	7.26	101	4.95	7.06	141	5.48	7.12	181	5.36	7.09
22	5.00	6.70	62	5.23	7.31	102	4.96	7.04	142	5.49	7.12	182	5.33	7.10
23	4.97	6.70	63	5.05	7.31	103	4.98	7.05	143	5.57	7.12	183	5.30	7.11
24	4.94	6.70	64	4.93	7.22	104	4.92	7.06	144	5.62	7.12	184	5.33	7.12
25	4.92	6.70	65	4.98	7.18	105	4.96	7.07	145	5.56	7.12	185	5.32	7.12
26	4.90	7.22	66	4.95	7.15	106	4.96	7.09	146	5.60	7.12	186	5.31	7.11
27	5.24	7.24	67	4.96	7.13	107	5.04	7.09	147	5.60	7.12	187	5.37	7.11
28	5.06	7.27	68	4.96	7.11	108	5.02	7.10	148	5.53	7.13	188	5.37	7.10
29	4.95	7.27	69	4.95	7.09	109	5.07	7.12	149	5.49	7.13	189	5.44	7.10
30	5.13	7.30	70	5.40	7.05	110	5.07	7.12	150	5.45	7.13	190	5.47	7.09
31	5.04	7.33	71	5.10	7.06	111	5.10	7.11	151	5.47	7.13	191	5.43	7.08
32	4.98	7.39	72	5.06	7.09	112	5.10	7.12	152	5.51	7.13	192	5.34	7.08
33	4.96	7.39	73	5.05	7.09	113	5.08	7.12	153	5.57	7.12	193	5.33	7.08
34	5.01	7.37	74	5.06	7.07	114	5.10	7.13	154	5.54	7.11	194	5.40	7.05
35	5.07	7.36	75	4.94	7.02	115	5.07	7.12	155	5.53	7.10	195	5.25	7.02
36	5.06	7.37	76	4.94	7.02	116	4.99	7.10	156	5.69	7.10	196	5.16	7.04
37	5.42	7.34	77	5.25	7.07	117	5.06	7.10	157	5.68	7.09	197	5.14	7.02
38	5.22	7.37	78	5.06	7.08	118	5.02	7.09	158	5.68	7.09	198	5.09	7.03
39	5.12	7.38	79	4.96	7.10	119	5.06	7.09	159	5.70	7.08	199	5.07	7.04
40	5.00	7.36	80	4.98	7.07	120	5.08	7.08	160	5.68	7.08	200	5.06	7.06

Note: (1) The Phase 1 and 2 Experiments Start @ day 1 and 170 respectively; whereas, the Maximization and Recovery Period St @ day 295 and 364, respectively; and (2) A– and M– represent A–UASB and M–UASB, respectively

Table C3.1 pH of A-UASB and M-UASB during the Phase 2 and 3 experiments including maximization and recovery period (cont'd)

Days	pH (UASB)		Days	pH (UASB)		Days	pH (UASB)		Days	pH (UASB)		Days	pH (UASB)		Days	pH (UASB)	
	A–	M–		A–	M–		A–	M–		A–	M–		A–	M–		A–	M–
201	5.09	7.07	241	5.02	7.10	281	5.04	7.14	321	5.02	7.02	361	4.79	6.56	401	5.49	6.91
202	5.05	7.08	242	5.24	7.11	282	5.10	7.14	322	5.16	7.03	362	4.83	6.56	402	5.47	6.91
203	5.00	7.09	243	5.07	7.12	283	5.04	7.14	323	5.17	7.03	363	4.88	6.60	403	5.44	6.91
204	5.00	7.11	244	5.04	7.14	284	5.06	7.14	324	5.15	7.04	364	4.92	6.68	404	5.21	6.92
205	5.00	7.13	245	5.07	7.14	285	5.08	7.15	325	5.15	7.04	365	4.85	6.70			
206	5.01	7.14	246	5.14	7.15	286	4.98	7.14	326	5.25	7.04	366	4.90	6.71			
207	5.01	7.11	247	5.13	7.16	287	5.01	7.13	327	5.36	7.02	367	4.94	6.74			
208	5.03	7.10	248	5.15	7.15	288	5.07	7.14	328	5.40	7.01	368	4.96	6.76			
209	5.04	7.10	249	5.10	7.15	289	5.07	7.14	329	5.16	7.00	369	4.91	6.77			
210	5.19	7.11	250	5.09	7.16	290	5.11	7.14	330	4.99	6.98	370	4.89	6.76			
211	5.20	7.13	251	5.18	7.15	291	5.13	7.14	331	5.00	6.99	371	4.91	6.79			
212	5.21	7.14	252	5.04	7.15	292	5.16	7.14	332	4.98	7.00	372	4.94	6.80			
213	5.19	7.15	253	5.01	7.16	293	5.05	7.12	333	5.09	6.99	373	4.99	6.89			
214	5.24	7.15	254	4.99	7.16	294	5.09	7.10	334	5.08	7.00	374	5.02	6.89			
215	5.27	7.13	255	5.02	7.16	295	5.11	7.09	335	4.97	7.03	375	4.99	6.90			
216	5.29	7.13	256	5.02	7.17	296	5.16	7.08	336	4.94	7.03	376	4.97	6.92			
217	5.28	7.12	257	5.02	7.16	297	5.14	7.07	337	4.92	7.02	377	4.99	6.97			
218	5.25	7.10	258	4.98	7.16	298	5.12	7.07	338	4.93	7.00	378	5.01	6.95			
219	5.23	7.10	259	4.98	7.16	299	5.14	7.06	339	4.93	6.93	379	5.02	6.94			
220	5.23	7.09	260	5.00	7.16	300	5.12	7.05	340	4.95	6.93	380	5.02	6.94			
221	5.28	7.09	261	5.10	7.16	301	5.12	7.05	341	4.99	6.86	381	5.07	6.94			
222	5.24	7.09	262	5.09	7.15	302	5.15	7.05	342	5.02	6.72	382	5.05	6.94			
223	5.33	7.09	263	5.06	7.17	303	5.15	7.04	343	5.01	6.67	383	5.06	6.94			
224	5.30	7.08	264	5.08	7.17	304	5.19	7.04	344	4.98	6.59	384	5.10	6.94			
225	5.21	7.08	265	5.04	7.18	305	5.15	7.05	345	4.98	6.59	385	5.11	6.95			
226	5.26	7.08	266	5.05	7.17	306	5.14	7.04	346	4.93	6.47	386	5.15	6.96			
227	5.24	7.08	267	5.08	7.17	307	5.12	7.05	347	4.90	6.34	387	5.12	6.95			
228	5.34	7.07	268	5.08	7.16	308	5.12	7.04	348	4.95	6.30	388	5.11	6.96			
229	5.33	7.07	269	5.02	7.17	309	5.12	7.03	349	4.94	6.22	389	5.14	6.96			
230	5.22	7.07	270	4.99	7.17	310	5.08	7.03	350	4.95	6.42	390	5.18	6.96			
231	5.22	7.07	271	5.08	7.16	311	5.07	7.03	351	4.92	6.42	391	5.20	6.96			
232	5.24	7.07	272	5.01	7.15	312	5.07	7.03	352	4.89	6.39	392	5.28	6.95			
233	5.27	7.07	273	5.02	7.15	313	5.10	7.03	353	4.86	6.30	393	5.24	6.95			
234	5.21	7.07	274	5.04	7.14	314	5.11	-7.02	354	4.90	6.30	394	5.22	6.94			
235	5.21	7.07	275	5.04	7.14	315	5.08	7.02	355	4.90	6.29	395	5.25	6.94			
236	5.17	7.07	276	5.09	7.14	316	5.07	7.02	356	4.89	6.39	396	5.25	6.93			
237	5.10	7.07	277	5.11	7.14	317	5.06	7.02	357	4.86	6.47	397	5.31	6.92			
238	5.12	7.08	278	5.02	7.14	318	5.06	7.02	358	4.86	6.51	398	5.35	6.92			
239	5.02	7.08	279	5.07	7.14	319	5.03	7.03	359	4.84	6.54	399	5.38	6.91			
240	5.04	7.10	280	5.01	7.14	320	5.06	7.01	360	4.84	6.56	400	5.46	6.91			

Note: (1) The Phase 1 and 2 Experiments Start @ day 1 and 170 respectively; whereas, the Maximization and Recovery Period Start @ day 295 and 364, respectively; and (2) A– and M– represent A–UASB and M–UASB, respectively

Table C3.2 Alkaline (0.1 N, NaOH) Addition During the Phase 1 Experiment

Running Conditions	Date	Days	NaOH Use, ml/d		Running Conditions	Date	Days	NaOH Use, ml/d	
			A-UASB	M-UASB				A-UASB	M-UASB
[1].F5,SR80/20,	07/09/88	1	400	760	[2].F5,SR80/20,	07/30/88	22	63	981
RR2/4	07/10/88	2	0	1178	RR6/10	07/31/88	23	0	1094
	07/11/88	3	882	725	[07/30/88]	08/01/88	24	0	1252
	07/12/88	4	0	1100		08/02/88	25	0	760
	07/13/88	5	1100	600		08/03/88	26	0	1254
	07/14/88	6	0	1350		08/04/88	27	0	1176
	07/15/88	7	0	659		08/05/88	28	0	744
	07/16/88	8	0	653		08/06/88	29	0	1286
	07/17/88	9	209	751		08/07/88	30	0	320
	07/18/88	10	900	400		08/08/88	31	0	1700
	07/19/88	11	1768	1389		08/09/88	32	0	877
	07/20/88	12	0	1120		08/10/88	33	1114	691
	07/21/88	13	61	613		08/11/88	34	0	853
	07/22/88	14	0	667		08/12/88	35	0	688
	07/23/88	15	0	353		08/13/88	36	0	772
	07/24/88	16	0	469		08/14/88	37	0	1237
	07/25/88	17	0	400		08/15/88	38	0	372
	07/26/88	18	497	331		08/16/88	39	0	200
	07/27/88	19	0	533		08/17/88	40	0	200
	07/28/88	20	0	660		08/18/88	41	0	360
	07/29/88	21	0	864		08/19/88	42	0	326
						08/20/88	43	0	0

Table C3.2 Alkaline (0.1 N, NaOH) Addition During the Phase 1 Experiment (cont'd)

Running Conditions	Date	Days	NaOH Use, ml/d		Running Conditions	Date	Days	NaOH Use, ml/d	
			A-UASB	M-UASB				A-UASB	M-UASB
[3].F5,SR50/50,	08/31/88	54	0	0	[4].F5,SR50/50,	10/03/88	87	0	1136
RR6/10	09/01/88	55	0	0	RR2/4	10/04/88	88	40	460
[08/31/88]	09/02/88	56	0	0	[10/03/88]	10/05/88	89	20	2312
	09/03/88	57	41	776		10/06/88	90	0	0
	09/04/88	58	0	1266		10/07/88	91	0	3527
	09/05/88	59	0	392		10/08/88	92	0	1700
	09/06/88	60	0	740		10/09/88	93	0	1020
	09/07/88	61	0	584		10/10/88	94	0	1795
	09/08/88	62	0	647		10/11/88	95	0	2480
	09/09/88	63	0	1054		10/12/88	96	0	1716
	09/10/88	64	0	704		10/13/88	97	0	157
	09/11/88	65	0	595		10/14/88	98	0	0
	09/12/88	66	0	469		10/15/88	99	0	2508
	09/13/88	67	0	1186		10/16/88	100	43	1451
	09/14/88	68	0	1091		10/17/88	101	0	940
	09/15/88	69	0	1164		10/18/88	102	0	1760
	09/16/88	70	0	1097		10/19/88	103	0	1740
	09/17/88	71	0	1273		10/20/88	104	0	1200
	09/18/88	72	0	823		10/21/88	105	0	1318
	09/19/88	73	0	900		10/22/88	106	0	1043

APPENDIX D
Maximum Loading Capacity and Recovery Process

Table D1.1 : Summary of Average System Performance and Removal Efficiency at Pseudo Steady-state During the Maximization and Recovery Period.

Table D2.1-D2.8 : Response Data of the Sampling Point Numbered 1 to 8 Under Different Running Conditions During the During the Maximization and Recovery Period.

Table D2.9 : Average Response Data of the Sampling Point Numbered 1 through 8 at Pseudo Steady-state Under Different Running Conditions During the During the Maximization and Recovery Period.

Table D3.1 : Calculation of the Theoretical CH_4 Production

Table D4.1 : A-and M-UASBs System Recovery at Pseudo Steady-state Under Different Running Conditions (CH_4, m^3/m^3-d)

Table D4.2 : A-and M-UASBs System Recovery at Pseudo Steady-state Under Different Running Conditions (COD (sol.) Removal Efficiency, %)

Table D5.1 : Response Data of Gas Composition, Production, and Loading Rate (A- and M-UASBs) During the Acclimatization Process.

Table D5.2 : Response Data of Gas Composition, Production, and Loading Rate (A- and M-UASBs) During Sequence 1, 2, and 3 Experiments.

Table D5.3 : Response Data of Gas Composition, Production, and Loading Rate (A-UASB) During the Maximization and Recovery Period.

Table D5.4 : Response Data of Gas Composition, Production, and Loading Rate (M-UASB) During the Maximization and Recovery Period.

Figure D1.1 : An A-UASB Step-loading and Removal Efficiency (COD,PO_4-P) Under Different Running Conditions During the Maximization and Recovery Period.

Figure D2.1 : An A-UASB System Nutrients and MLVSS Under Different Running Conditions During the Maximization and Recovery Period.

Note : All sampling locations are illustrated in Figure 4.2
All experimental running conditions numbered 1 through 9 are shown in Figure 5.26 (c).
D1.1 : Summary of Average System Performance and Removal Efficiency at Pseudo Steady-state During the Maximization and Recovery Period.

Table D1.1 Summary of Average System Performance and Removal Efficiency at Pseudo Steady-state During the Maximization and Recovery Period

Average Responses	Experimental Running Conditions								
	1	2	3	4	5	6	7	8	9
Running Period, days	13	27	36	43	50	57	64	71	106
Influent Flow, l/d	7.43	9.37	16.10	20.69	25.49	17.89	15.30	11.95	5.34
HRT, days									
A-UASB	2.69	2.13	1.24	0.97	0.78	1.12	1.31	1.67	3.75
M-UASB	3.36	2.67	1.55	1.21	0.98	1.40	1.63	2.09	4.69
System	6.06	4.80	2.80	2.17	1.77	2.52	2.94	3.77	8.43
	Loading Rate								
cu.m/cu.m-d	0.17	0.21	0.36	0.46	0.57	0.40	0.34	0.27	0.12
KgCOD(sol.)/cu.m-d	1.02	1.28	2.14	2.89	3.46	2.78	2.37	1.72	0.97
	Effluent Quality								
Solids, mg/L									
TS	2397	2828	2854	5712	9365	8389	6820	6240	2163
VS	962	1125	1232	3492	5920	5474	4133	3829	790
TSS	201	184	185	1169	1572	3030	1769	1813	157
TVSS	31	145	108	685	1209	2322	1397	1520	73
COD , mg/L									
Total COD	318	469	677	5147	11200	11077	9483	8562	682
COD(sol.)	207	331	554	4089	9015	7507	7862	6573	424
Inorganics, mg/L									
NH4-N	377	394	301	362	332	261	302	387	345
TKN	407	460	404	424	496	337	406	505	371
TP	57	71	84	121	370	176	196	161	103
PO4-P	11	34	15	71	296	193	169	99	34
VFA , mg/L									
HAc	11	0	40	731	0	695	550	335	0
HPr	9	0	67	858	1738	1837	2365	2641	0
Iso - HBr	0	0	0	77	53	53	68	84	0
HBr	6	5	5	135	1421	678	477	78	0
A - HVr	0	0	0	149	34	26	31	44	0
Iso - HVr	0	0	0	178	55	52	66	89	0
HVr	0	0	0	428	637	597	735	355	0
HHe	0	0	0	0	70	48	134	97	0
Total VFA mg/L as HAc	19	1	96	1648	2877	3096	3396	2922	0
Alkalinity, mg/L as CaCO3									
A-UASB	1188	1267	963	669	719	557	700	882	1438
M-UASB	2621	2659	2519	2513	1988	1607	1813	2132	2225
Total VFA/Alk									
A-UASB	3.63	3.42	4.84	6.26	4.23	9.91	8.71	5.63	2.38
M-UASB	0.01	0.01	0.06	0.51	0.71	2.17	1.83	1.35	0.01

Table D1.1 Summary of Average System Performance and Removal Efficiency at Pseudo Steady-state During the Maximization and Recovery Period (cont'd)

Average Responses	Experimental Running Conditions								
	1	2	3	4	5	6	7	8	9
	System Removal Efficiency								
Solids, %									
TSS	99.24	99.33	99.09	96.01	66.99	90.15	95.23	93.26	99.21
COD, %									
COD(sol.)	96.66	94.64	90.76	34.43	-48.19	-7.30	-13.99	-1.41	94.88
Total COD	99.15	98.81	98.29	87.37	73.50	69.83	84.35	78.12	98.71
Inorganics, %									
PO4-P	92.34	73.16	87.71	45.11	-130.89	-37.41	-26.46	22.35	80.88
TP	68.29	57.63	39.21	18.14	-151.89	-19.81	-35.96	-5.16	37.76
	Methane Gas								
Flow, l/d									
Total Gas	153.38	244.51	311.00	359.33	311.89	248.55	249.41	193.58	135.63
CH4 Gas	87.76	139.50	179.40	177.01	110.94	103.58	98.81	80.48	75.97
CH4 Productivity									
l/d	87.76	139.50	179.40	177.01	110.94	103.58	98.81	80.48	75.97
cu.m/cu.m-d	1.95	3.10	3.99	3.93	2.47	2.30	2.20	1.79	1.69
cu.m/cu.m-d@SC	1.73	2.75	3.53	3.49	2.19	2.04	1.95	1.59	1.50
% of theo.CH4 Prod.	83.70	97.99	73.21	60.11	36.47	59.92	32.80	58.68	74.41
Specific CH4 Gas Prod.									
cu.m/kgCODadded	1.91	2.42	1.86	1.35	0.71	0.85	0.93	1.04	1.76
cu.m/kgCODrem.	1.97	2.56	2.05	4.57	-1.59	3367	-10.25	4.57	1.85
cu.m/kgCODadded @S	1.69	2.15	1.65	1.20	0.63	0.75	0.83	0.92	1.56
cu.m/kgCODrem.@SC	1.75	2.27	1.82	4.05	-1.41	2984	-9.08	4.05	1.64
% CH4 content	69.67	68.61	69.29	62.69	50.66	54.26	51.31	51.88	69.82

Note: Experimental running conditions (1...9) @ 35 degree C, pHs 5.0-5.3
and 7.0-7.3 for A- and M-UASBs under different HRTs mentioned aboved
All CODs used in calculation of spec.CH4 gas production are soluble COD

TABLE D2.1 RESPONSE DATA OF SAMPLING POINT No.1 UNDER DIFFERENT RUNNING DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP. No.	DAY	DATE	SOLIDS, MG/L TS	VS	TSS	TVSS	SOLIDS, % or %TS [%]	[%TS]	[%]	[%TS]	COD, MG/L TOTAL	SOL.
1	1	10/13/89	18165	15500	14060	13560	1.82	85.33	1.41	96.44	45455	5455
	4	10/16/89	23635	20750	20300	19390	2.36	87.79	2.03	95.52	35802	5844
	6	10/18/89	22160	19305	22070	21670	2.22	87.12	2.21	98.19	40909	5868
	8	10/20/89	27565	24565	21870	20930	2.76	89.12	2.19	95.70	31687	6584
	11	10/23/89	26740	23655	26920	25370	2.67	88.46	2.69	94.24	43354	6135
	13	10/25/89	30600	27345	27870	25980	3.06	89.36	2.79	93.22	30608	6205
	15	10/27/89	31345	28030	25070	23080	3.13	89.42	2.51	92.06	38333	6250
2	20	11/01/89	31235	27765	27400	25760	3.12	88.89	2.74	94.01	66013	6597
	22	11/03/89	39410	35735	21695	20185	3.94	90.67	2.17	93.04	43354	6217
	25	11/06/89	35900	32380	29360	28110	3.59	90.19	2.94	95.74	49796	6367
	27	11/08/89	33340	27810	26070	24440	3.33	83.41	2.61	93.75	37161	5929
	29	11/10/89	28910	25265	28080	26060	2.89	87.39	2.81	92.81	34999	6167
3	33	11/14/89	34155	30710	29050	28070	3.42	89.91	2.91	96.63	51452	6971
	35	11/16/89	27725	24785	22440	21400	2.77	89.40	2.24	95.37	49583	6250
	37	11/18/89	23490	20345	18220	16660	2.35	86.61	1.82	91.44	33131	5737
4	40	11/21/89	28080	24865	17840	16670	2.81	88.55	1.78	93.44	40159	6044
	42	11/23/89	30075	26970	33100	31220	3.01	89.68	3.31	94.32	49802	6561
	44	11/25/89	26685	23505	25260	23550	2.67	88.08	2.53	93.23	36104	6024
5	47	11/28/89	33395	29470	26240	24920	3.34	88.25	2.62	94.97	35388	5487
	49	11/30/89	35090	31600	35230	33100	3.51	90.05	3.52	93.95	41649	6305
	51	12/02/89	27795	24600	32030	29650	2.78	88.51	3.20	92.57	42828	5899
6	54	12/05/89	31900	28300	26040	24550	3.19	88.71	2.60	94.28	33265	6982
	56	12/07/89	33475	29695	32480	30350	3.35	88.71	3.25	93.44	36961	6653
	58	12/09/89	28525	24880	28940	26860	2.85	87.22	2.89	92.81	36475	7295
7	61	12/12/89	35075	31405	33970	32040	3.51	89.54	3.40	94.32	36961	5941
	63	12/14/89	42970	38725	39320	36800	4.30	90.12	3.93	93.59	61538	7368
	65	12/16/89	31140	27805	31120	29140	3.11	89.29	3.11	93.64	59635	6491
8	68	12/19/89	27130	23885	20980	19720	2.71	88.04	2.10	93.99	35628	6397
	70	12/21/89	25970	22820	25950	24020	2.60	87.87	2.60	92.56	40650	6341
	72	12/23/89	33720	30100	30500	28380	3.37	89.26	3.05	93.05	37247	6640
9	75	12/26/89	37650	33805	33020	31510	3.77	89.79	3.30	95.43	40644	7163
	79	12/30/89	26560	23555	25130	23430	2.66	88.69	2.51	93.24	37247	6154
	84	01/04/90	29220	26105	24980	23950	2.92	89.34	2.50	95.88	37827	7807
	91	01/11/90	28260	25245	24900	23720	2.83	89.33	2.49	95.26	41616	8727
	96	01/16/90	30390	27365	31980	30440	3.04	90.05	3.20	95.18	36072	7455
	98	01/18/90	33845	30800	33720	32030	3.38	91.00	3.37	94.99	48907	8429
	102	01/22/90	30970	28020	32070	30580	3.10	90.47	3.21	95.35	45679	7490
	104	01/24/90	34860	31560	27740	26590	3.49	90.53	2.77	95.85	40974	7383
	107	01/27/90	38010	34940	33700	32150	3.80	91.92	3.37	95.40	62903	8952

TABLE D2.1 RESPONSE DATA OF SAMPLING POINT No.1 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP. No.	DAY	DATE	INORGANICS , MG/L						VFA , MG/L						TOT.VFA
			NH4-N	TKN	%TS	TP	%TS	PO4-P	HAc	HPr	HBr	Iso-HVr	HVr	HHe	mg/l HAc
1	1	10/13/89	24	299	5.26	129	0.84	119	448	401	108		62		883
	4	10/16/89	18	320	4.81	132	1.11	117	357	246	130		76		690
	6	10/18/89	18	345	5.32	156	1.22	131	354	256	155		88		719
	8	10/20/89	30	316	5.35	175	1.06	149	579	533	416		73		1338
	11	10/23/89	24	364	4.01	185	1.10	140	380	343	235		33		838
	13	10/25/89	18	378	4.33	171	0.90	140	398	363	235				853
	15	10/27/89	18	398	4.51	181	1.14	138	237	417	232		3		735
2	20	11/01/89	16	381	4.17	195	1.05	142	408	775	349				1274
	22	11/03/89	11	390	3.18	176	0.80	127	321	764	293				1140
	25	11/06/89	11	338	3.96	172	0.85	145	510	1099	365				1650
	27	11/08/89	11	421	3.11	161	0.65	121	126	427	144				570
	29	11/10/89	16	416	5.02	173	1.13	125	391	963	292				1371
3	33	11/14/89	2	345	4.43	165	0.91	145	586	1337	363				1918
	35	11/16/89	2	372	3.95	149	0.82	118	451	1060	312				1523
	37	11/18/89	10	352	3.76	126	1.05	118	193	338	110				542
4	40	11/21/89	8	352	2.67	130	0.66	114	171	225	107	28			443
	42	11/23/89	2	371	4.04	149	1.01	123	398	676	272				1132
	44	11/25/89	2	358	3.81	147	0.69	131	424	725	271				1197
5	47	11/28/89	3	376	3.90	149	0.73	135	253	556	269				887
	49	11/30/89	8	394	4.28	159	0.99	135	356	456	204	24	2		880
	51	12/02/89	8	343	3.23	137	0.85	123	285	621	192		3		921
6	54	12/05/89	3	426	4.12	158	0.97	135	385	485	312	44	24		1031
	56	12/07/89	5	335	3.87	139	0.75	139	403	400	287				923
	58	12/09/89	3	354	3.65	154	0.63	141	374	453	365				990
7	61	12/12/89	8	371	4.35	150	1.14	124	289	69	88		117		474
	63	12/14/89	11	330	2.48	137	1.19	136	343	91	164		203		648
	65	12/16/89	2	375	2.36	150	1.32	132	358	80	256				597
8	68	12/19/89	4	359	3.61	143	1.02	130	288	89	265				541
	70	12/21/89	1	404	3.80	157	0.99	132	345	106	333				658
	72	12/23/89	5	372	4.25	149	1.11	120	318	105	253				576
9	75	12/26/89	5	440	3.90	231	0.99	173	399	169	508				882
	79	12/30/89	9	335	3.71	152	0.91	106	346	186	278				686
	84	01/04/90	5	313	4.62	201	0.94	147	622	384	609		189		1460
	91	01/11/90	23	350	4.36	194	0.88	143	653	492	591		109		1519
	96	01/16/90	23	317	4.11	152	0.86	131	522	415	458				1171
	98	01/18/90	30	304	4.68	196	0.89	137	672	652	664		178		1758
	102	01/22/90	19	347	5.04	179	0.87	144	581	535	459				1328
	104	01/24/90	19	316	4.01	160	0.86	137	523	464	377		137		1237
	107	01/27/90	27	394	4.00	203	0.87	164	714	819	677		176		1943

TABLE D2.2 RESPONSE DATA OF SAMPLING POINT NO.2 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP.	DAY	DATE	SOLIDS , MG/L					SOLIDS , % OR %T			COD , MG/L			
NOs.			TS	VS	TSS	TVSS	[%]	%TS]	[%]	%TS]	OTAL	SOL.	H4-N	PO4-P
1	1	10/13/89	9570	7200	5310	5060	0.96	75.24	0.53	95.29	18017	8430	270	167
	4	10/16/89	11350	8730	7220	6930	1.14	76.92	0.72	95.98.	20741	9218	270	172
	6	10/18/89	11820	9060	5870	5450	1.18	76.65	0.59	92.84	17851	8926	293	186
	8	10/20/89	11080	8720	8170	7550	1.11	78.70	0.82	92.41	23045	9547	323	203
	11	10/23/89	12720	10110	8580	7830	1.27	79.48	0.86	91.26	24540	9734	276	210
	13	10/25/89	12250	9800	8790	8010	1.23	80.00	0.88	91.13	23648	9895	375	206
	15	10/27/89	14010	11190	9400	8590	1.40	79.87	0.94	91.38	22667	10417	293	212
2	20	11/01/89	17960	15030	12410	11570	1.80	83.69	1.24	93.23	32067	10355	299	200
	22	11/03/89	36370	32630	35450	33390	3.64	89.72	3.55	94.19	30561	10552	268	212
	25	11/06/89	13370	11140	9970	9690	1.34	83.32	1.00	97.19	28571	10449	286	206
	27	11/08/89	21046	18803	12670	12160	2.10	89.34	1.27	95.97	31733	10605	293	198
	29	11/10/89	10630	8080	6960	6550	1.06	76.01	0.70	94.11	20833	9917	256	188
3	33	11/14/89	13900	11450	8310	7900	1.39	82.37	0.83	95.07	20747	8548	180	157
	35	11/16/89	10750	8460	6540	6240	1.08	78.70	0.65	95.41	17917	10333	192	153
	37	11/18/89	15250	12600	10090	9640	1.53	82.62	1.01	95.54	27879	9939	242	159
4	40	11/21/89	44640	41460	44030	42150	4.46	92.88	4.40	95.73	76740	10020	162	163
	42	11/23/89	71360	67000	67180	64350	7.14	93.89	6.72	95.79	125692	11621	180	184
	44	11/25/89	66340	62510	71010	68200	6.63	94.23	7.10	96.04	110040	10683	162	184
5	47	11/28/89	78300	73310	74480	71580	7.83	93.63	7.45	96.11	116103	9781	147	195
	49	11/30/89	70860	66530	69980	66840	7.09	93.89	7.00	95.51	103918	11464	130	159
	51	12/02/89	77990	73390	75220	71730	7.80	94.10	7.52	95.36	143838	10263	113	189
6	54	12/05/89	58400	54280	52950	50560	5.84	92.95	5.30	95.49	67351	9774	153	172
	56	12/07/89	67220	62730	63550	60710	6.72	93.32	6.36	95.53	123203	11745	170	218
	58	12/09/89	67210	62530	59560	56680	6.72	93.04	5.96	95.16	93443	11557	289	203
7	61	12/12/89	61180	56970	57530	55440	6.12	93.12	5.75	96.37	112526	11088	175	214
	63	12/14/89	68680	63950	69540	66840	6.87	93.11	6.95	96.12	106883	11822	163	220
	65	12/16/89	65860	61450	67120	64430	6.59	93.30	6.71	95.99	130629	11684	145	216
8	68	12/19/89	62760	58350	59780	57590	6.28	92.97	5.98	96.34	97166	12146	211	218
	70	12/21/89	74440	69390	58560	56460	7.44	93.22	5.86	96.41	91870	11220	235	212
	72	12/23/89	68540	64410	68810	66260	6.85	93.97	6.88	96.29	104453	10283	163	180
9	75	12/26/89	72300	67750	78410	75490	7.23	93.71	7.84	96.28	117505	12314	270	247
	79	12/30/89	15740	12760	10530	9950	1.57	81.07	1.05	94.49	39406	11579	304	224
	84	01/04/90	10380	7930	5570	5380	1.04	76.40	0.56	96.59	27632	10865	259	201
	91	01/11/90	60720	56860	17990	17270	6.07	93.64	1.80	96.00	120404	10263	270	199
	96	01/16/90	37550	34030	24840	23710	3.76	90.63	2.48	95.45	54509	10100	277	185
	98	01/18/90	12310	10040	8370	7800	1.23	81.56	0.84	93.19	27038	10577	197	183
	102	01/22/90	9980	7850	6140	5590	1.00	78.66	0.61	91.04	16872	8724	243	174
	104	01/24/90	7620	5550	4150	3830	0.76	72.83	0.42	92.29	16227	8763	248	171
	107	01/27/90	6430	4890	3650	3420	0.64	76.05	0.37	93.70	26210	8952	288	188

TABLE D2.2 RESPONSE DATA OF SAMPLING POINT NO.2 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP. NOs.	DAY	DATE	INORGANICS , MG/L TKN	%TS	TP	%TS	VFA , MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
1	1	10/13/89	316	8.55	168	2.15	1397	1842	35	785	23	50	664	68	3918
	4	10/16/89	275	7.54	179	2.10	1526	1838	36	939	23	50	680	75	4163
	6	10/18/89	333	7.28	180	2.02	1509	1781	37	1052	24	53	697	84	4194
	8	10/20/89	354	7.19	204	1.79	1471	1704	40	1155	27	57	680	96	4166
	11	10/23/89	398	5.57	216	1.39	1575	1713	46	1355	30	63	656	100	4411
	13	10/25/89	446	5.55	242	1.53	1620	1705	47	1424	30	65	631	99	4484
	15	10/27/89	367	6.35	226	1.68	1725	1780	43	1471	24	45	458	76	4550
2	20	11/01/89	354	5.60	220	1.35	1631	1927	45	1556	24	70	523	72	4685
	22	11/03/89	390	6.53	241	1.13	1626	2143	49	1673	26	110	716		5039
	25	11/06/89	373	6.29	204	1.45	1360	2174	48	1545	26	66	491	65	4585
	27	11/08/89	425	7.74	230	1.71	1202	2399	50	1567	29	74	511	78	4651
	29	11/10/89	415	6.00	225	1.80	846	2139	47	1423	27	66	467	68	3947
3	33	11/14/89	310	4.43	171	0.91	886	2334	35	1099	20	88	643		3993
	35	11/16/89	323	5.44	183	1.51	1633	2693	31	1153	10	85	751		5121
	37	11/18/89	337	5.47	179	1.21	1801	2571	33	943	13	96	778		5073
4	40	11/21/89	325	6.01	192	0.83		1895	30	1363	9	93	756		2991
	42	11/23/89	326	4.96	210	0.74	2129	2145	34	1628	12	94	808		5539
	44	11/25/89	331	6.22	201	0.86	1998	1936	34	1559	12	48	544	50	5035
5	47	11/28/89	233	5.74	191	0.57		1777	31	1675	9	89	690		3068
	49	11/30/89	394	5.33	203	0.59		1926	35	2041	9	35	570	52	3365
	51	12/02/89	242	5.28	195	0.55		1596	28	1715		26	578		2838
6	54	12/05/89	266	5.35	167	0.87			32	1567	10	30	594		1463
	56	12/07/89	293	5.89	211	0.93	1997	2001	29	1569		34	546	70	5086
	58	12/09/89	312	6.21	212	1.80	1857	1907	25	1478		33	535	49	4787
7	61	12/12/89	285	6.61	205	2.71	691	1771	45	982		45	571	42	3211
	63	12/14/89	302	8.64	230	0.84	2322	2316	30	1758		38	573	40	5799
	65	12/16/89	285	6.96	217	0.73	2137	2319	29	1668		35	520	30	5516
8	68	12/19/89	351	7.00	224	0.67	2159	2388	42	1698		53	521	31	5635
	70	12/21/89	385	6.62	235	0.74	2055	2132	46	1669		55	482	37	5288
	72	12/23/89	265	6.54	181	0.77	1698	1525	33	1426		36	345	8	4158
9	75	12/26/89	447	6.04	275	0.80	2149	1845	58	2114	20	59	505	25	5482
	79	12/30/89	440	5.37	243	1.59	2142	1941	70	1848	26	69	491	52	5395
	84	01/04/90	363	5.63	209	3.34	2057	1942	61	1484	28	65	538	59	5087
	91	01/11/90	375	6.61	204	0.62	1987	2280	61	1505	28	69	783	63	5454
	96	01/16/90	342	6.74	182	0.75	1193	2139	59	1397	26	66	833	58	4494
	98	01/18/90	342	7.02	188	1.21	916	2389	66	1579	28	69	954	68	4628
	102	01/22/90	359	6.42	181	1.89	161	2026	62	1261	31	62	817	30	3257
	104	01/24/90	347	6.02	181	2.34	109	2047	63	1195	32	64	888	55	3234
	107	01/27/90	398	5.87	198	2.69	209	2235	67	1363	35	70	1026	60	3692

TABLE D2.3 RESPONSE DATA OF THE SAMPLING POINT No.3 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP.	DAY	DATE	SOLIDS , MG/L					SOLIDS , % OR %TS			COD , MG/L			
NOs.			TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	TOTAL	SOL.	H4-N	PO4-P
1	1	10/13/89	9570	7200	5310	5060	0.96	75.24	0.53	95.29	18017	8430	270	167
	4	10/16/89	11350	8730	7220	6930	1.14	76.92	0.72	95.98	20741	9218	270	172
	6	10/18/89	11820	9060	5870	5450	1.18	76.65	0.59	92.84	17851	8926	293	186
	8	10/20/89	11080	8720	8170	7550	1.11	78.70	0.82	92.41	23045	9547	323	203
	11	10/23/89	12720	10110	8580	7830	1.27	79.48	0.86	91.26	24540	9734	276	210
	13	10/25/89	12250	9800	8790	8010	1.23	80.00	0.88	91.13	23648	9895	375	206
	15	10/27/89	14010	11190	9400	8590	1.40	79.87	0.94	91.38	22667	10417	293	212
2	20	11/01/89	17960	15030	12410	11570	1.80	83.69	1.24	93.23	32067	10355	299	200
	22	11/03/89	36370	32630	35450	33390	3.64	89.72	3.55	94.19	30561	10552	268	212
	25	11/06/89	13370	11140	9970	9690	1.34	83.32	1.00	97.19	28571	10449	286	206
	27	11/08/89	21046	18803	12670	12160	2.10	89.34	1.27	95.97	31733	10605	293	198
	29	11/10/89	10630	8080	6960	6550	1.06	76.01	0.70	94.11	20833	9917	256	188
3	33	11/14/89	13900	11450	8310	7900	1.39	82.37	0.83	95.07	20747	8548	180	157
	35	11/16/89	10750	8460	6540	6240	1.08	78.70	0.65	95.41	17917	10333	192	153
	37	11/18/89	15250	12600	10090	9640	1.53	82.62	1.01	95.54	27879	9939	242	159
4	40	11/21/89	44640	41460	44030	42150	4.46	92.88	4.40	95.73	76740	10020	162	163
	42	11/23/89	71360	67000	67180	64350	7.14	93.89	6.72	95.79	125692	11621	180	184
	44	11/25/89	66340	62510	71010	68200	6.63	94.23	7.10	96.04	110040	10683	162	184
5	47	11/28/89	78300	73310	74480	71580	7.83	93.63	7.45	96.11	116103	9781	147	195
	49	11/30/89	70860	66530	69980	66840	7.09	93.89	7.00	95.51	103918	11464	130	159
	51	12/02/89	77990	73390	75220	71730	7.80	94.10	7.52	95.36	143838	10263	113	189
6	54	12/05/89	58400	54280	52950	50560	5.84	92.95	5.30	95.49	67351	9774	153	172
	56	12/07/89	67220	62730	63550	60710	6.72	93.32	6.36	95.53	123203	11745	170	218
	58	12/09/89	67210	62530	59560	56680	6.72	93.04	5.96	95.16	93443	11557	289	203
7	61	12/12/89	61180	56970	57530	55440	6.12	93.12	5.75	96.37	112526	11088	175	214
	63	12/14/89	68680	63950	69540	66840	6.87	93.11	6.95	96.12	106883	11822	163	220
	65	12/16/89	65860	61450	67120	64430	6.59	93.30	6.71	95.99	130629	11684	145	216
8	68	12/19/89	62760	58350	59780	57590	6.28	92.97	5.98	96.34	97166	12146	211	218
	70	12/21/89	74440	69390	58560	56460	7.44	93.22	5.86	96.41	91870	11220	235	212
	72	12/23/89	68540	64410	68810	66260	6.85	93.97	6.88	96.29	104453	10283	163	180
9	75	12/26/89	72300	67750	78410	75490	7.23	93.71	7.84	96.28	117505	12314	270	247
	79	12/30/89	15740	12760	10530	9950	1.57	81.07	1.05	94.49	39406	11579	304	224
	84	01/04/90	10380	7930	5570	5380	1.04	76.40	0.56	96.59	27632	10865	259	201
	91	01/11/90	60720	56860	17990	17270	6.07	93.64	1.80	96.00	120404	10263	270	199
	96	01/16/90	37550	34030	24840	23710	3.76	90.63	2.48	95.45	54509	10100	277	185
	98	01/18/90	12310	10040	8370	7800	1.23	81.56	0.84	93.19	27038	10577	197	183
	102	01/22/90	9980	7850	6140	5590	1.00	78.66	0.61	91.04	16872	8724	243	174
	104	01/24/90	7620	5550	4150	3830	0.76	72.83	0.42	92.29	16227	8763	248	171
	107	01/27/90	6430	4890	3650	3420	0.64	76.05	0.37	93.70	26210	8952	288	188

TABLE D2.3 RESPONSE DATA OF THE SAMPLING POINT No.3 UNDER DIFFERENT RUNNING COND DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP. NOs.	DAY	DATE	INORGANICS, MG/L TKN	%TS	TP	%TS	VFA, MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
1	1	10/13/89	316	8.55	168	2.15	1397	1842	35	785	23	50	664	68	3918
	4	10/16/89	275	7.54	179	2.10	1526	1838	36	939	23	50	680	75	4163
	6	10/18/89	333	7.28	180	2.02	1509	1781	37	1052	24	53	697	84	4194
	8	10/20/89	354	7.19	204	1.79	1471	1704	40	1155	27	57	680	96	4166
	11	10/23/89	398	5.57	216	1.39	1575	1713	46	1355	30	63	656	100	4411
	13	10/25/89	446	5.55	242	1.53	1620	1705	47	1424	30	65	631	99	4484
	15	10/27/89	367	6.35	226	1.68	1725	1780	43	1471	24	45	458	76	4550
2	20	11/01/89	354	5.60	220	1.35	1631	1927	45	1556	24	70	523	72	4685
	22	11/03/89	390	6.53	241	1.13	1626	2143	49	1673	26	110	716		5039
	25	11/06/89	373	6.29	204	1.45	1360	2174	48	1545	26	66	491	65	4585
	27	11/08/89	425	7.74	230	1.71	1202	2399	50	1567	29	74	511	78	4651
	29	11/10/89	415	6.00	225	1.80	846	2139	47	1423	27	66	467	68	3947
3	33	11/14/89	310	4.43	171	0.91	886	2334	35	1099	20	88	643		3993
	35	11/16/89	323	5.44	183	1.51	1633	2693	31	1153	10	85	751		5121
	37	11/18/89	337	5.47	179	1.21	1801	2571	33	943	13	96	778		5073
4	40	11/21/89	325	6.01	192	0.83		1895	30	1363	9	93	756		2991
	42	11/23/89	326	4.96	210	0.74	2129	2145	34	1628	12	94	808		5539
	44	11/25/89	331	6.22	201	0.86	1998	1936	34	1559	12	48	544	50	5035
5	47	11/28/89	233	5.74	191	0.57		1777	31	1675	9	89	690		3068
	49	11/30/89	394	5.33	203	0.59		1926	35	2041	9	35	570	52	3365
	51	12/02/89	242	5.28	195	0.55		1596	28	1715		26	578		2838
6	54	12/05/89	265	5.35	167	0.87			32	1567	10	30	594		1463
	56	12/07/89	293	5.89	211	0.93	1997	2001	29	1569		34	546	70	5086
	58	12/09/89	312	6.21	212	1.80	1857	1907	25	1478		33	535	49	4787
7	61	12/12/89	285	6.61	205	2.71	691	1771	45	982		45	571	42	3211
	63	12/14/89	302	8.64	230	0.84	2322	2316	30	1758		38	573	40	5799
	65	12/16/89	285	6.96	217	0.73	2137	2319	29	1668		35	520	30	5516
8	68	12/19/89	351	7.00	224	0.67	2159	2388	42	1698		53	521	31	5635
	70	12/21/89	385	6.62	235	0.74	2055	2132	46	1669		55	482	37	5288
	72	12/23/89	265	6.54	181	0.77	1698	1525	33	1426		36	345	8	4158
9	75	12/26/89	447	6.04	275	0.80	2149	1845	58	2114	20	59	505	25	5482
	79	12/30/89	440	5.37	243	1.59	2142	1941	70	1848	26	69	491	52	5395
	84	01/04/90	363	5.63	209	3.34	2057	1942	61	1484	28	65	538	59	5087
	91	01/11/90	375	6.61	204	0.62	1987	2280	61	1505	28	69	783	63	5454
	96	01/16/90	342	6.74	182	0.75	1193	2139	59	1397	26	66	833	58	4494
	98	01/18/90	342	7.02	188	1.21	916	2389	66	1579	28	69	954	68	4628
	102	01/22/90	359	6.42	181	1.89	161	2026	62	1261	31	62	817	30	3257
	104	01/24/90	347	6.02	181	2.34	109	2047	63	1195	32	64	888	55	3234
	107	01/27/90	398	5.87	198	2.69	209	2235	67	1363	35	70	1026	60	3692

TABLE D2.4 RESPONSE DATA OF SAMPLING POINT NO.4 UNDER DIFFERENT RUNNING COND DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP. NOs.	DAY	DATE	SOLIDS, MG/L OR ELSE TSS	TVSS	[%]	[%TS]	COD, MG/L TOTAL	SOL.	NH4-N	PO4-P
1	1	10/13/89	1100	1090	0.11	99.09	10579	8347	311	168
	4	10/16/89	1340	1325	0.13	98.88	20741	7901	282	165
	6	10/18/89	1085	985	0.11	90.78	10744	8595	299	170
	8	10/20/89	1415	1295	0.14	91.52	11687	8889	329	194
	11	10/23/89	1960	1665	0.20	84.95	13415	9080	317	212
	13	10/25/89	2265	1980	0.23	87.42	13417	9644	276	212
	15	10/27/89	2500	2215	0.25	88.60	14333	10250	305	223
2	20	11/01/89	3230	3045	0.32	94.27	16543	9102	274	194
	22	11/03/89	4890	4600	0.49	94.07	17669	10634	311	218
	25	11/06/89	4720	4515	0.47	95.66	16980	9796	311	218
	27	11/08/89	5560	5365	0.56	96.49	19040	9770	286	198
	29	11/10/89	4580	4300	0.46	93.89	16999	9833	280	192
3	33	11/14/89	3025	2865	0.30	94.71	13444	8465	229	174
	35	11/16/89	1735	1615	0.17	93.08	13000	10167	199	145
	37	11/18/89	1430	1325	0.14	92.66	12283	9131	229	163
4	40	11/21/89	3930	3700	0.39	94.15	16382	10179	186	174
	42	11/23/89	4185	3970	0.42	94.86	17233	10593	192	192
	44	11/25/89	5480	5155	0.55	94.07	18956	10040	180	186
5	47	11/28/89	35840	34060	3.58	95.03	35785	9542	147	199
	49	11/30/89	13190	12665	1.32	96.02	38652	11711	135	209
	51	12/02/89	18790	17930	1.88	95.42	41212	10505	135	199
6	54	12/05/89	4960	4770	0.50	96.17	17522	10842	289	189
	56	12/07/89	39350	26210	3.94	66.61	17248	11992	181	218
	58	12/09/89	3050	2800	0.31	91.80	16393	12131	181	212
7	61	12/12/89	4540	4350	0.45	95.81	19986	11335	193	220
	63	12/14/89	4880	4670	0.49	95.70	17814	12065	181	228
	65	12/16/89	5820	5500	0.58	94.50	23259	12495	157	226
8	68	12/19/89	4525	4390	0.45	97.02	25641	11903	223	231
	70	12/21/89	4200	4060	0.42	96.67	18157	10813	242	212
	72	12/23/89	3470	3350	0.35	96.54	18354	10850	181	197
9	75	12/26/89	3600	3530	0.36	98.06	18243	12314	281	247
	79	12/30/89	2770	2610	0.28	94.22	15924	12065	349	240
	84	01/04/90	2120	1970	0.21	92.92	15292	10785	293	199
	91	01/11/90	2080	1890	0.21	90.87	13737	10424	315	208
	96	01/16/90	2420	2200	0.24	90.91	13894	10581	317	201
	98	01/18/90	2230	1970	0.22	88.34	15109	10020	271	186
	102	01/22/90	3220	2920	0.32	90.68	15638	9630	265	176
	104	01/24/90	2820	2670	0.28	94.68	13523	8357	265	186
	107	01/27/90	2610	2400	0.26	91.95	14247	8548	205	203

TABLE D2.4 RESPONSE DATA OF SAMPLING POINT NO.4 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP. NOs.	DAY	DATE	INORGANICS , MG/L		VFA , MG/L								TOT.VFA
			TKN	TP	HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	mg/L HAc
1	1	10/13/89	328	174	1282	1983	40	760	26	55	649	71	3901
	4	10/16/89	320	178	1372	1780	36	849	14	50	664	73	3885
	6	10/18/89	320	184	1407	1752	37	1015	25	52	695	84	4042
	8	10/20/89	367	197	1368	1683	40	1108	27	56	678	94	4012
	11	10/23/89	417	222	1380	1700	46	1178	31	63	618	98	4062
	13	10/25/89	407	214	1507	1710	48	1318	31	66	644	101	4313
	15	10/27/89	407	230	1639	1810	45	1409	26	63	542	81	4511
2	20	11/01/89	367	224	1444	1852	44	1362	25	60	453	70	4257
	22	11/03/89	434	261	1510	2123	49	1527	27	64	503	71	4692
	25	11/06/89	439	236	1307	2292	52	1473	28	67	468	73	4574
	27	11/08/89	461	226	1062	2312	49	1366	28	65	455	75	4263
	29	11/10/89	452	228	833	2345	52	1388	30	68	462	69	4081
3	33	11/14/89	403	216	777	2321	40	938	25	92	594		3744
	35	11/16/89	345	194	1521	2682	32	1079	15	84	660		4900
	37	11/18/89	345	173	1496	2307	30	824	12	82	715		4425
4	40	11/21/89	306	209	1812	2046	34	1291	12	87	736		4866
	42	11/23/89	286	192		2148	37	1534	16	87	815		3353
	44	11/25/89	322	193	1796	1893	36	1412	17	87	724		4805
5	47	11/28/89	279	222		1887	34	1549	11	33	455	59	2933
	49	11/30/89	293	236		1666	29	1757		39	515	46	2918
	51	12/02/89	302	218		1758	33	1822	8	40	589	51	3091
6	54	12/05/89	281	171		1785	34	1560	11	29	561	56	2917
	56	12/07/89	319	222	2080	2198	32	1670		40	604	50	5427
	58	12/09/89	323	209	2098	2259	32	1727		39	632	44	5546
7	61	12/12/89	367	242	2006	2098	34	1554		43	596	44	5188
	63	12/14/89	318	217	2239	2412	35	1755		42	623	46	5830
	65	12/16/89	338	238	2207	2457	32	1768		40	565	34	5800
8	68	12/19/89	354	237	2036	2488	45	1598		56	572	51	5569
	70	12/21/89	347	201	1865	2197	47	1529		55	511	45	5077
	72	12/23/89	372	229	1868	1860	44	1593		47	442	30	4795
9	75	12/26/89	236	258	2098	2011	63	2012	25	64	547	111	5575
	79	12/30/89	489	269	2087	2017	74	1888	29	72	521	54	5454
	84	01/04/90	370	211	2015	2028	66	1528	29	68	554	57	5159
	91	01/11/90	405	209	1710	2184	62	1436	29	70	753	64	5036
	96	01/16/90	388	196	1183	1187	66	1495	30	72	902	66	3834
	98	01/18/90	375	194	760	2219	63	1441	27	63	884	56	4187
	102	01/22/90	375	179	148	2160	69	1264	33	65	870	44	3400
	104	01/24/90	379	183	100	2075	65	1126	33	64	901	21	3192
	107	01/27/90	311	206	189	2155	65	1207	34	66	978	56	3467

TABLE D2.5 RESPONSE DATA OF SAMPLING POINT NO.5 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP.	DAY	DATE	SOLIDS , MG/L				SOLIDS , % OR %T				COD, MG/L			
NOs.			TS	VS	TSS	TVSS	[%]	%TS	[%]	%TS	OTAL	SOL.	H4-N	PO4-P
1	1	10/13/89	7625	5185	2290	2210	0.76	68.00	0.23	96.51	12397	8430	293	167
	4	10/16/89	5775	3625	2300	2190	0.58	62.77	0.23	95.22	11029	9300	282	153
	6	10/18/89	7330	5015	2750	2500	0.73	68.42	0.28	90.91	14215	8760	305	177
	8	10/20/89	7100	4730	2400	2100	0.71	66.62	0.24	87.50	14979	8807	428	191
	11	10/23/89	15125	12275	9730	8900	1.51	81.16	0.97	91.47	26830	9162	299	199
	13	10/25/89	8135	5790	3530	2900	0.81	71.17	0.35	82.15	16268	9979	288	210
	15	10/27/89	12965	10330	8180	7470	1.30	79.68	0.82	91.32	24167	10333	323	193
2	20	11/01/89	13615	10930	7280	6710	1.36	80.28	0.73	92.17	24885	10271	299	202
	22	11/03/89	13340	10600	7680	7190	1.33	79.46	0.77	93.62	26102	10961	317	212
	25	11/06/89	13840	11300	8470	8220	1.38	81.65	0.85	97.05	28408	10122	274	198
	27	11/08/89	8295	7075	9700	9135	0.83	85.29	0.97	94.18	31619	10689	311	186
	29	11/10/89	8545	7325	7851	7256	0.85	85.72	0.79	92.42	25648	10250	256	188
3	33	11/14/89	7175	5040	2570	2410	0.72	70.24	0.26	93.77	13942	8465	205	161
	35	11/16/89	7015	4810	2110	2020	0.70	68.57	0.21	95.73	13667	10583	205	166
	37	11/18/89	7085	4785	2150	2090	0.71	67.54	0.22	97.21	12768	8970	211	155
4	40	11/21/89	14310	11635	9080	8080	1.43	81.31	0.91	88.99	28151	11054	223	172
	42	11/23/89	10770	8365	5990	5660	1.08	77.67	0.60	94.49	20237	11225	186	186
	44	11/25/89	17085	14290	11640	11110	1.71	83.64	1.16	95.45	31968	10201	162	174
5	47	11/28/89	16545	13455	9650	9180	1.65	81.32	0.97	95.13	29105	9304	130	185
	49	11/30/89	18745	15760	12750	12170	1.87	84.08	1.28	95.45	32330	11629	198	207
	51	12/02/89	24715	21590	19090	18180	2.47	87.36	1.91	95.23	36633	10424	118	197
6	54	12/05/89	8185	5880	2770	2620	0.82	71.84	0.28	94.58	17248	10431	153	178
	56	12/07/89	9730	7115	3160	3000	0.97	73.12	0.32	94.94	19165	12238	170	224
	58	12/09/89	10915	8155	4990	4710	1.09	74.71	0.50	94.39	21038	11885	181	197
7	61	12/12/89	12610	9775	6280	5970	1.26	77.52	0.63	95.06	26831	11910	193	220
	63	12/14/89	13415	10380	7280	6930	1.34	77.38	0.73	95.19	23212	12146	145	220
	65	12/16/89	14045	11155	8880	8450	1.40	79.42	0.89	95.16	25963	12333	145	224
8	68	12/19/89	10855	8095	5570	5390	1.09	74.57	0.56	96.77	19433	12227	248	231
	70	12/21/89	10855	8120	5630	5380	1.09	74.80	0.56	95.56	20325	11382	235	216
	72	12/23/89	8505	6930	10720	10190	0.85	81.48	1.07	95.06	26721	11012	199	199
9	75	12/26/89	10520	7665	5030	4820	1.05	72.86	0.50	95.83	19048	12394	276	240
	79	12/30/89	13010	10420	7270	6830	1.30	80.09	0.73	93.95	22942	11903	372	233
	84	01/04/90	5830	3660	1740	1570	0.58	62.78	0.17	90.23	14219	10946	298	205
	91	01/11/90	7105	4610	2000	1800	0.71	64.88	0.20	90.00	15084	10747	287	205
	96	01/16/90	6085	4035	3720	3400	0.61	66.31	0.37	91.40	12558	10501	299	182
	98	01/18/90	9185	6805	4090	3660	0.92	74.09	0.41	89.49	17495	10577	294	188
	102	01/22/90	8685	6570	5380	4860	0.87	75.65	0.54	90.33	16735	8724	254	169
	104	01/24/90	12530	10050	9340	8620	1.25	80.21	0.93	92.29	22177	8600	271	186
	107	01/27/90	10680	8380	5970	5450	1.07	78.46	0.60	91.29	18011	8952	305	198

TABLE D2.5 RESPONSE DATA OF SAMPLING POINT NO.5 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP. NOs.	DAY	DATE	INORGANICS, MG/L TKN	TP	VFA, MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
1	1	10/13/89	328	170	1388	1855	40	782	26	56	674	71	3934
	4	10/16/89	290	199	1509	1833	38	930	24	53	682	76	4141
	6	10/18/89	354	175	1275	1896	47	1004	32	64	702	86	4043
	8	10/20/89	358	194	1360	1651	42	1089	29	59	653	90	3952
	11	10/23/89	403	210	1443	1669	47	1273	32	65	628	94	4171
	13	10/25/89	403	210	1603	1714	49	1417	32	67	633	99	4474
	15	10/27/89	331	214	1677	1779	45	1442	27	68	532	74	4540
2	20	11/01/89	398	239	1596	1949	48	1539	27	66	523	73	4658
	22	11/03/89	403	232	1445	2189	57	1594	33	55	534		4711
	25	11/06/89	395	224	1324	2133	49	1513	27	66	487	68	4495
	27	11/08/89	421	217	1144	2493	59	1576	35	59	481	81	4660
	29	11/10/89	415	226	910	2277	50	1514	25	106	689		4305
3	33	11/14/89	323	183	802	2243	37	1050	22	90	628		3797
	35	11/16/89	367	196	1577	2664	34	1141	15	86	741		5033
	37	11/18/89	313	164	1539	2205	28	806	11	81	690		4355
4	40	11/21/89	415	201	2029	2147	41	1425	18	95	795		5303
	42	11/23/89	335	214	0	2100	35	1604	12	86	792		3344
	44	11/25/89	331	201	0	1915	35	1553	13	33	499	41	2977
5	47	11/28/89	246	187	0	1645	29	1564	9	27	489		2729
	49	11/30/89	316	212	0	1930	44	1936	19	96	778		3440
	51	12/02/89	269	208	0	1731	32	1874	8	29	628		3094
6	54	12/05/89	274	171	0	0	30	1550	8	77	740		1563
	56	12/07/89	312	222	1756	1743		1397			483		4406
	58	12/09/89	327	209	2141	2191	30	1701		38	596		5471
7	61	12/12/89	310	221	1948	1816	29	1449		37	511	39	4771
	63	12/14/89	314	221	2409	2370	33	1819		41	589	46	5988
	65	12/16/89	334	238	2167	2357	31	1708		37	536	38	5620
8	68	12/19/89	432	246	2259	2469	50	1726		62	555	44	5858
	70	12/21/89	391	227	2098	2195	47	1691		55	500	44	5412
	72	12/23/89	353	229	2091	1881	45	1781		49	446	37	5171
9	75	12/26/89	405	249	2289	1992	63	2232		64	538	50	5849
	79	12/30/89	482	251	2238	2044	83	1930	37	86	539	56	5686
	84	01/04/90	363	215	2129	2026	66	1523	28	69	538	54	5257
	91	01/11/90	329	225	1960	2221	63	1468	30	73	760	64	5345
	96	01/16/90	363	179	1272	2279	66	1502	32	75	908	66	4820
	98	01/18/90	367	194	914	2403	70	1571	29	73	952	66	4635
	102	01/22/90	355	179	152	2041	64	1255	30	64	820	57	3273
	104	01/24/90	371	188	103	2109	68	1199	35	73	899	55	3298
	107	01/27/90	418	201	184	2190	71	1285	37	76	977	56	3554

TABLE D2.6 RESPONSE DATA OF SAMPLING POINT NO.6 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP. NOs.	DAY	DATE	SOLIDS , MG/L				SOLIDS , % OR %T				COD , MG/L			
			TS	VS	TSS	TVSS	[%]	%TS	[%]	%TS	TOTAL	SOL.	NH4-N	PO4-P
1	1	10/13/89	4685	2465	2010	1300	0.47	52.61	0.20	64.68	2562	579	358	24
	4	10/16/89	3915	1850	1560	1040	0.39	47.25	0.16	66.67	1646	412	375	21
	6	10/18/89	4130	1895	1710	1020	0.41	45.88	0.17	59.65	1736	248	358	5
	8	10/20/89	8700	2090	2220	1380	0.87	24.02	0.22	62.16	2305	494	368	9
	11	10/23/89	3965	1970	2360	1250	0.40	49.68	0.24	52.97	2209	491	364	15
	13	10/25/89	4170	2015	2090	1010	0.42	48.32	0.21	48.33	2096	252	375	23
	15	10/27/89	4240	2205	2390	1330	0.42	52.00	0.24	55.65	2333	417	364	35
2	20	11/01/89	6240	3565	3740	2470	0.62	57.13	0.37	66.04	4426	501	377	15
	22	11/03/89	6355	3575	4660	3040	0.64	56.25	0.47	65.24	5317	654	317	4
	25	11/06/89	6495	3785	4730	3180	0.65	58.28	0.47	67.23	4816	490	396	13
	27	11/08/89	6865	3930	4820	3270	0.69	57.25	0.48	67.84	5929	585	402	33
	29	11/10/89	5915	3225	3280	2210	0.59	54.52	0.33	67.38	3417	333	384	75
3	33	11/14/89	8305	4900	7090	4880	0.83	59.00	0.71	68.83	7552	664	272	43
	35	11/16/89	8940	5300	7430	4890	0.89	59.28	0.74	65.81	8500	1083	279	15
	37	11/18/89	10435	6420	7350	4990	1.04	61.52	0.74	67.89	8566	1051	303	23
4	40	11/21/89	9505	6100	7000	4850	0.95	64.18	0.70	69.29	10417	1909	297	25
	42	11/23/89	9405	5885	6220	4150	0.94	62.57	0.62	66.72	9091	4585	346	62
	44	11/25/89	7805	4990	2890	2080	0.78	63.93	0.29	71.97	8835	5382	322	166
5	47	11/28/89	7925	4995	1370	1130	0.79	63.03	0.14	82.48	10099	8032	318	336
	49	11/30/89	10040	6625	3540	2750	1.00	65.99	0.35	77.68	15050	10804	278	369
	51	12/02/89	12655	8910	4960	4070	1.27	70.41	0.50	82.06	17131	10828	249	354
6	54	12/05/89	8665	5780	2840	2290	0.87	66.71	0.28	80.63	11992	8624	192	293
	56	12/07/89	9910	6725	4990	3580	0.99	67.86	0.50	71.74	13799	10021	221	312
	58	12/09/89	8740	5590	3320	2560	0.87	63.96	0.33	77.11	13852	10902	238	316
7	61	12/12/89	7515	4665	1860	1520	0.75	62.08	0.19	81.72	11910	9774	278	285
	63	12/14/89	8010	4980	2350	1760	0.80	62.17	0.24	74.89	11093	8988	278	258
	65	12/16/89	7030	4105	1640	1450	0.70	58.39	0.16	88.41	11521	9331	235	276
8	68	12/19/89	6575	4070	1950	1670	0.66	61.90	0.20	85.64	10121	8421	332	218
	70	12/21/89	6380	3750	1330	1200	0.64	58.78	0.13	90.23	9675	8049	296	199
	72	12/23/89	5060	2880	1070	1000	0.51	56.92	0.11	93.46	8664	7045	344	164
9	75	12/26/89	5130	2910	900	790	0.51	56.73	0.09	87.78	8370	7002	389	99
	79	12/30/89	4990	2865	950	660	0.50	57.41	0.10	69.47	7287	5830	503	22
	84	01/04/90	4570	2680	1130	770	0.46	58.64	0.11	68.14	4909	3783	486	34
	91	01/11/90	4105	2270	1950	1040	0.41	55.30	0.20	53.33	3556	2101	457	15
	96	01/16/90	4725	2605	3010	1710	0.47	55.13	0.30	56.81	4168	1260	396	41
	98	01/18/90	4725	2490	2785	1600	0.47	52.70	0.28	57.45	3658	875	442	24
	102	01/22/90	4620	2100	2920	1570	0.46	45.45	0.29	53.77	3292	658	356	37
	104	01/24/90	4200	1815	2390	1270	0.42	43.21	0.24	53.14	2596	811	351	32
	107	01/27/90	4305	1990	1420	790	0.43	46.23	0.14	55.63	3790	968	345	49

TABLE D2.6 RESPONSE DATA OF SAMPLING POINT NO.6 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP. NOs.	DAY	DATE	INORGANICS , MG/L TKN	%TS	TP	%TS	VFA , MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
1	1	10/13/89	345	3.90	59	3.63	145	87	7	12	12		11		242
	4	10/16/89	371	3.01	80	6.08	67	40		8					105
	6	10/18/89	333	3.60	76	6.27	78	51		10			8		131
	8	10/20/89	434	3.90	80	6.41	68	40		7					105
	11	10/23/89	320	4.33	64	7.85	64	38		9					101
	13	10/25/89	388	4.31	73	6.15	62	33		8					94
	15	10/27/89	425	5.10	54	6.83	33	30		7					62
2	20	11/01/89	434	3.94	96	6.03	51	55		7					100
	22	11/03/89	398	4.40	87	7.21	54	65		9					113
	25	11/06/89	417	5.22	81	7.34	55	66		9					115
	27	11/08/89	487	4.57	90	6.32	39	46		8					82
	29	11/10/89	456	4.88	85	7.62				6					4
3	33	11/14/89	447	4.58	114	5.83	45	67		6					103
	35	11/16/89	421	4.74	110	5.90	89	136		13					208
	37	11/18/89	376	5.07	94	5.94	159	194		12	5				327
4	40	11/21/89	352	4.82	98	5.20	440	347	31	44	33	17	72		844
	42	11/23/89	430	5.11	166	6.39	1110	986	71	219	105	53	223		2331
	44	11/25/89	421	3.54	191	3.56		1107	74	278	116	94	434		1516
5	47	11/28/89	435	2.78	354	3.91		1508	51	882	64	55	469	67	2239
	49	11/30/89	435	3.07	376	3.38		1745	51	1457	39	55	596	64	2882
	51	12/02/89	412	3.22	382	3.20		1807	48	1780	23	53	636	64	3163
6	54	12/05/89	304	3.25	280	2.86			40	1234	15	31	523	56	1232
	56	12/07/89	365	3.56	340	3.02	1177	1931	41	1357		44	578	66	4096
	58	12/09/89	369	3.21	318	3.12	1220	2218	47	1494		49	659	47	4510
7	61	12/12/89	363	4.88	273	1.17	2197	2068	32	1646		39	568	54	5403
	63	12/14/89	383	5.32	264	1.28	864	2164	1132	1132	20	54	685	144	4683
	65	12/16/89	367	4.71	269	1.17	772	2452	54	1084		55	718	138	4062
8	68	12/19/89	404	3.02	195	3.73	601	2599	72	576	35	77	697	138	3697
	70	12/21/89	498	3.00	219	3.87	635	2655	79	484	38	86	628	132	3682
	72	12/23/89	435	3.72	183	4.56	692	2326	78	404	39	84	483	104	3317
9	75	12/26/89	524	2.92	197	3.92	723	1989	75	393	40	78	406	98	3014
	79	12/30/89	651	2.78	191	4.53	543	2185	87	115	50	86	153		2622
	84	01/04/90	524	2.44	154	4.48	352	1519		41	31		56		1663
	91	01/11/90	505	2.17	113	5.41	515	656				21	38		1082
	96	01/16/90	497	3.40	115	6.68	222	294							460
	98	01/18/90	442	3.18	109	6.32	94	124							195
	102	01/22/90	398	2.87	120	7.37	59	77							121
	104	01/24/90	379	3.03	114	7.79	55	72							113
	107	01/27/90	418	3.07	133	7.58	55	72							113

TABLE D2.7 RESPONSE DATA OF SAMPLING POINT NO.7 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP. NOs.	DAY	DATE	SOLIDS , MG/L OR ELSE TSS	TVSS	[%]	[%TS]	COD , MG/L TOTAL	SOL.	NH4-N	PO4-P
1	1	10/13/89	610	380	0.06	62.30	785	579	399	9
	4	10/16/89	425	295	0.04	69.41	576	535	387	19
	6	10/18/89	395	200	0.04	50.63	413	207	375	6
	8	10/20/89	310	175	0.03	56.45	576	329	358	8
	11	10/23/89	600	240	0.06	40.00	573	327	405	10
	13	10/25/89	520	185	0.05	35.58	461	210	387	18
	15	10/27/89	315	120	0.03	38.10	625	250	370	26
2	20	11/01/89	630	370	0.06	58.73	752	418	390	22
	22	11/03/89	425	310	0.04	72.94	695	409	390	28
	25	11/06/89	465	405	0.05	87.10	776	490	402	23
	27	11/08/89	425	325	0.04	76.47	752	459	408	26
	29	11/10/89	560	425	0.06	75.89	750	292	396	72
3	33	11/14/89	660	420	0.07	63.64	1037	456	322	39
	35	11/16/89	710	510	0.07	71.83	1250	792	297	50
	37	11/18/89	635	390	0.06	61.42	1212	687	297	20
4	40	11/21/89	1850	1225	0.19	66.22	3459	1789	323	22
	42	11/23/89	1625	1090	0.16	67.08	4585	3439	334	46
	44	11/25/89	1350	935	0.14	69.26	6225	4899	371	128
5	47	11/28/89	1520	1045	0.15	68.75	8151	7714	341	224
	49	11/30/89	1800	1380	0.18	76.67	9650	8866	341	348
	51	12/02/89	1380	1090	0.14	78.99	11879	9939	306	356
6	54	12/05/89	1135	880	0.11	77.53	8624	6078	232	223
	56	12/07/89	2105	1970	0.21	93.59	10267	8296	249	254
	58	12/09/89	1165	965	0.12	82.83	11066	9098	255	250
7	61	12/12/89	1705	1405	0.17	82.40	9117	7885	332	200
	63	12/14/89	1315	1100	0.13	83.65	8259	7773	308	170
	65	12/16/89	1495	1280	0.15	85.62	9412	8276	308	216
8	68	12/19/89	1460	1360	0.15	93.15	7935	7287	368	101
	70	12/21/89	990	935	0.10	94.44	8049	6911	423	128
	72	12/23/89	1170	940	0.12	80.34	7368	6397	332	97
9	75	12/26/89	680	610	0.07	89.71	6197	5312	412	36
	79	12/30/89	700	570	0.07	81.43	5425	5020	543	57
	84	01/04/90	800	520	0.08	65.00	4427	3461	469	68
	91	01/11/90	780	485	0.08	62.18	2182	1455	497	22
	96	01/16/90	745	425	0.07	57.05	1603	802	453	43
	98	01/18/90	730	425	0.07	58.22	1272	676	402	39
	102	01/22/90	840	445	0.08	52.98	1235	411	374	46
	104	01/24/90	665	375	0.07	56.39	974	487	356	46
	107	01/27/90	395	235	0.04	59.49	726	424	362	54

TABLE D2.7 RESPONSE DATA OF SAMPLING POINT NO.7 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP. NOs.	DAY	DATE	INORGANICS, MG/L TKN	TP	VFA, MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
1	1	10/13/89	409	62	65	66		22			20		145
	4	10/16/89	405	74	35	22		6					57
	6	10/18/89	379	78	38	26		8					65
	8	10/20/89	446	73	29	19		7					49
	11	10/23/89	427	77	25	14		3					38
	13	10/25/89	398	66	29	16		5					45
	15	10/27/89	376	36	11			5					14
2	20	11/01/89	421	81	22	25		5					46
	22	11/03/89	434	69	21			6					25
	25	11/06/89	461	79	21	27		6					47
	27	11/08/89	496	81	16			7					21
	29	11/10/89	487	83	0								0
3	33	11/14/89	487	100	23	46		8					66
	35	11/16/89	461	110	67	87		6					142
	37	11/18/89	388	68	66	111		9					162
4	40	11/21/89	411	105	383	327	32	35	33	16	69		763
	42	11/23/89	371	28		702	64	113	123	165	372		1078
	44	11/25/89	453	170		1032	83	178	168	177	494		1508
5	47	11/28/89	477	287		1391	48	740	55	48	426	62	2008
	49	11/30/89	486	384			61	1062	58	59	606	71	1228
	51	12/02/89	454	370			60	1469	36	58	725	74	1563
6	54	12/05/89	297	214			51	987	26	39	523	55	1082
	56	12/07/89	365	259	921	1840	48	1009		47	558	49	3515
	58	12/09/89	381	256	837	1843	45	1005		47	571	46	3435
7	61	12/12/89	428	217	535	2150	65	593	26	63	690	139	3257
	63	12/14/89	359	184	550	2118	64	552	27	63	679	129	3206
	65	12/16/89	396	211	506	2408	63	555		63	747	134	3426
8	68	12/19/89	368	198	341	2482	70	178	33	72	583	122	2990
	70	12/21/89	523	173	348	2639	81	135	39	84	458	108	3033
	72	12/23/89	498	163	391	2349	76	143	39	79	293	95	2736
9	75	12/26/89	475	148	328	2205	80	65	44	83	177		2394
	79	12/30/89	601	159	394	2166	86	37	49	81	96		2367
	84	01/04/90	538	152	297	1368			27		38		1444
	91	01/11/90	555	49	298	501							704
	96	01/16/90	493	103	74	107							161
	98	01/18/90	455	100	44	44						3	81
	102	01/22/90	438	116	16								16
	104	01/24/90	426	123	15	27							37
	107	01/27/90	422	123									0

TABLE D2.8 RESPONSE DATA OF SAMPLING POINT NO.8 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP.	DAY	DATE	SOLIDS , MG/L				SOLIDS , % OR %T				COD , MG/L			
NOs.			TS	VS	TSS	VSS	[%]	%TS	[%]	%TS	TOT.	OL.	NH4-N	PO4-P
1	1	10/13/89	2590	1137	163	123	0.26	43.90	0.02	75.46	289	289	387	19
	4	10/16/89	2527	907	375	210	0.25	35.89	0.04	56.00	247	247	381	15
	6	10/18/89	2187	747	197	113	0.22	34.16	0.02	57.36	207	207	364	15
	8	10/20/89	2357	773	123	60	0.24	32.80	0.01	48.78	329	288	428	15
	11	10/23/89	2377	1030	197	20	0.24	43.33	0.02	10.15	368	204	387	10
	13	10/25/89	2363	860	180	30	0.24	36.39	0.02	16.67	252	168	381	11
	15	10/27/89	2450	997	227	43	0.25	40.69	0.02	18.94	333	250	364	11
2	20	11/01/89	2487	1080	197	130	0.25	43.43	0.02	65.99	459	209	365	3
	22	11/03/89	2827	1267	387	273	0.28	44.82	0.04	70.54	695	286	341	11
	25	11/06/89	2217	893	150	137	0.22	40.28	0.02	91.33	449	367	371	22
	27	11/08/89	3555	1300	203	137	0.36	36.57	0.02	67.49	501	292	408	21
	29	11/10/89	2713	1183	200	160	0.27	43.60	0.02	80.00	458	333	402	60
3	33	11/14/89	2350	910	290	120	0.24	38.72	0.03	41.38	539	373	340	20
	35	11/16/89	2667	1173	203	118	0.27	43.98	0.02	58.13	667	583	322	23
	37	11/18/89	3040	1290	167	97	0.30	42.43	0.02	58.08	687	525	279	6
4	40	11/21/89	3537	1823	597	333	0.35	51.54	0.06	55.78	2147	1829	352	20
	42	11/23/89	5147	3047	1360	820	0.51	59.20	0.14	60.29	4269	3399	377	28
	44	11/25/89	6277	3937	977	550	0.63	62.72	0.10	56.29	6024	4779	346	114
5	47	11/28/89	7227	4610	667	510	0.72	63.79	0.07	76.46	7594	6839	352	148
	49	11/30/89	9700	6040	2263	1673	0.97	62.27	0.23	73.93	10520	8495	369	259
	51	12/02/89	9030	5800	880	745	0.90	64.23	0.09	84.66	11879	9535	295	332
6	54	12/05/89	6120	3933	1260	1000	0.61	64.26	0.13	79.37	8131	6078	221	181
	56	12/07/89	8470	5780	3290	2640	0.85	68.24	0.33	80.24	11006	6653	255	173
	58	12/09/89	8307	5167	2770	2003	0.83	62.20	0.28	72.31	11148	8361	267	212
7	61	12/12/89	9253	6010	4137	3027	0.93	64.95	0.41	73.17	11663	7885	320	207
	63	12/14/89	7603	4733	2725	2040	0.76	62.25	0.27	74.86	9798	7773	320	141
	65	12/16/89	6037	3533	813	753	0.60	58.52	0.08	92.62	9168	7951	284	197
8	68	12/19/89	6373	4013	1265	1080	0.64	62.97	0.13	85.38	8502	7368	356	128
	70	12/21/89	7217	4520	2775	2295	0.72	62.63	0.28	82.70	9837	6829	411	117
	72	12/23/89	5263	3137	850	745	0.53	59.60	0.09	87.65	7287	6316	362	80
9	75	12/26/89	4930	2910	740	567	0.49	59.03	0.07	76.62	6117	4990	395	61
	79	12/30/89	4983	3007	790	640	0.50	60.35	0.08	81.01	6478	4696	537	55
	84	01/04/90	3057	1587	577	300	0.31	51.91	0.06	51.99	3702	3139	463	38
	91	01/11/90	4023	2163	1090	697	0.40	53.77	0.11	63.94	2586	1374	474	20
	96	01/16/90	2500	1103	573	320	0.25	44.12	0.06	55.85	1122	882	408	27
	98	01/18/90	2587	1187	390	183	0.26	45.88	0.04	46.92	835	557	396	15
	102	01/22/90	1970	580	500	217	0.20	29.44	0.05	43.40	658	412	356	15
	104	01/24/90	1830	580	310	120	0.18	31.69	0.03	38.71	609	406	356	24
	107	01/27/90	2163	790	157	73	0.22	36.52	0.02	46.50	682	424	345	34

TABLE D2.8 RESPONSE DATA OF SAMPLING POINT NO.8 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP. NOs.	DAY	DATE	INORGANICS, MG/L TKN	TP	VFA, MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
1	1	10/13/89	358	23	21	13		3					34
	4	10/16/89	375	61	14	11		4					26
	6	10/18/89	311	59	16	13		4					29
	8	10/20/89	354	68	18	15		6					34
	11	10/23/89	393	62	12	5							16
	13	10/25/89	407	60	15	13		7					30
	15	10/27/89	421	48	6			5					9
2	20	11/01/89	439	75				5					3
	22	11/03/89	439	73				7					5
	25	11/06/89	434	68	0								0
	27	11/08/89	487	74				5					3
	29	11/10/89	458	72	0								0
3	33	11/14/89	509	104	0								0
	35	11/16/89	452	96	35	55		5					83
	37	11/18/89	356	72	45	78							108
4	40	11/21/89	419	87	930	341	33	36	34	17	68		1324
	42	11/23/89	462	99	731	703	70	102	130	175	366		1813
	44	11/25/89	385	143		1012	84	167	167	180	489		1483
5	47	11/28/89	463	305		1478	65	551	95	62	461	69	2018
	49	11/30/89	514	360		1768	50	1515	35	55	594	70	2939
	51	12/02/89	477	380		1708	56	1327	33	54	679	70	2815
6	54	12/05/89	251	160		1698	48	592	26	36	527		2160
	56	12/07/89	323	167	673	1678	51	573		52	517	43	2816
	58	12/09/89	350	184	717	1995	55	782	26	51	676	52	3375
7	61	12/12/89	420	223	555	2189	67	530	29	62	686	127	3260
	63	12/14/89	379	178	574	2270	70	492	32	66	720	132	3347
	65	12/16/89	432	213	525	2459	66	461	30	65	750	136	3446
8	68	12/19/89	441	164	346	2566	73	132	37	76	569	118	3029
	70	12/21/89	511	169	329	2697	82	94	43	88	435	106	3024
	72	12/23/89	498	153	340	2584	85	62	45	90	274	87	2821
9	75	12/26/89	433	138	339	2313	84	43	89	148			2440
	79	12/30/89	594	157	352	2039	78		47	71	68		2168
	84	01/04/90	517	114	231	1197							1202
	91	01/11/90	497	24	255	440							612
	96	01/16/90	493	100	59	80							124
	98	01/18/90	488	98									0
	102	01/22/90	398	90									0
	104	01/24/90	430	118									0
	107	01/27/90	371	103									0

TABLE D2.9 AVERAGE RESPONSE DATA OF SAMPLING POINT NO.1, 2, 3, and 6 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP.	DAY	SOLIDS , MG/L				SOLIDS , % or %TS				OD , MG/L		
NOs.		TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	TOTAL	SOL.	NH4-N
					SAMPLING POINT NUMBERED 1							
1	13	29562	26343	26620	24810	2.96	89.08	2.66	93.17	37432	6197	20
2	27	32717	28485	27837	26203	3.27	87.00	2.78	94.10	40652	6154	13
3	36	25608	22565	20330	19030	2.56	88.00	2.03	93.40	41357	5994	6
4	43	28380	25238	29180	27385	2.84	88.88	2.92	93.78	42953	6293	2
5	50	31443	28100	33630	31375	3.14	89.28	3.36	93.26	42239	6102	8
6	57	31000	27288	30710	28605	3.10	87.96	3.07	93.13	36718	6974	4
7	64	37055	33265	35220	32970	3.71	89.71	3.52	93.61	60587	6930	7
8	71	29845	26460	28225	26200	2.98	88.57	2.82	92.81	38949	6491	3
9	106	36435	33250	30720	29370	3.64	91.23	3.07	95.63	51939	8168	23
					SAMPLING POINT NUMBERED 2							
1	13	12993	10367	8923	8143	1.30	79.78	0.89	91.26	23618	10015	315
2	27	15015	12674	9867	9467	1.50	82.89	0.99	95.76	27046	10324	278
3	36	13000	10530	8315	7940	1.30	80.66	0.83	95.48	22898	10136	217
4	43	68850	64755	69095	66275	6.89	94.06	6.91	95.92	117866	11152	171
5	50	74425	69960	72600	69285	7.44	94.00	7.26	95.44	123878	10864	122
6	57	67215	62630	61555	58695	6.72	93.18	6.16	95.35	108323	11651	230
7	64	67270	62700	68330	65635	6.73	93.21	6.83	96.05	118756	11753	154
8	71	71490	66900	63685	61360	7.15	93.60	6.37	96.35	98162	10752	199
9	106	7025	5220	3900	3625	0.70	74.44	0.39	92.99	21219	8858	268
					SAMPLING POINT NUMBERED 3							
1	13	12993	10367	8923	8143	1.30	79.78	0.89	91.26	23618	10015	315
2	27	15015	12674	9867	9467	1.50	82.89	0.99	95.76	27046	10324	278
3	36	13000	10530	8315	7940	1.30	80.66	0.83	95.48	22898	10136	217
4	43	68850	64755	69095	66275	6.89	94.06	6.91	95.92	117866	11152	171
5	50	74425	69960	72600	69285	7.44	94.00	7.26	95.44	123878	10864	122
6	57	67215	62630	61555	58695	6.72	93.18	6.16	95.35	108323	11651	230
7	64	67270	62700	68330	65635	6.73	93.21	6.83	96.05	118756	11753	154
8	71	71490	66900	63685	61360	7.15	93.60	6.37	96.35	98162	10752	199
9	106	7025	5220	3900	3625	0.70	74.44	0.39	92.99	21219	8858	268
					SAMPLING POINT NUMBERED 6							
1	13	4125	2063	2280	1197	0.41	50.00	0.23	52.31	2213	387	368
2	27	6425	3647	4277	2887	0.64	56.68	0.43	67.48	4721	469	394
3	36	9688	5860	7390	4940	0.97	60.40	0.74	66.85	8533	1067	291
4	43	8605	5438	4555	3115	0.86	63.25	0.46	69.35	8963	4984	334
5	50	11348	7768	4250	3410	1.13	68.20	0.43	79.87	16091	10816	264
6	57	9325	6158	4155	3070	0.93	65.91	0.42	74.43	13826	10462	230
7	64	7520	4543	1995	1605	0.75	60.28	0.20	81.65	11307	9160	257
8	71	5720	3315	1200	1100	0.57	57.85	0.12	91.84	9170	7547	320
9	106	4253	1903	1905	1030	0.43	44.72	0.19	54.39	3193	890	348

TABLE D2.9 AVERAGE RESPONSE DATA OF SAMPLING POINT NO.1, 2, 3, and 6 UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD (CONT'D)

EXP. NO.	DAY	INORGANICS, MG/L TKN	%TS	TP	%TS	PO4-P	VFA, MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/l HAc
							SAMPLING POINT NUMBERED 1								
1	13	380	4.28	179	1.05	139	338	374	0	234	0	0	18	0	808
2	27	392	4.03	169	0.88	130	342	830	0	267	0	0	0	0	1197
3	36	362	3.86	138	0.94	118	322	699	0	211	0	0	0	0	1033
4	43	365	3.93	148	0.85	127	411	701	0	272	0	0	0	0	1164
5	50	369	3.76	148	0.92	129	321	539	0	198	0	24	3	0	901
6	57	345	3.76	147	0.69	140	389	427	0	326	0	0	0	0	957
7	64	353	2.42	144	1.26	134	351	86	0	210	0	0	203	0	623
8	71	388	4.03	153	1.05	126	332	106	0	293	0	0	0	0	617
9	106	355	4.01	182	0.87	151	619	642	0	527	0	0	157	0	1590
							SAMPLING POINT NUMBERED 2								
1	13	404	5.82	228	1.53	209	1640	1733	45	1417	28	58	582	92	4482
2	27	404	6.68	220	1.65	197	1136	2237	48	1512	27	69	490	70	4395
3	36	330	5.46	181	1.36	156	1717	2632	32	1048	12	91	765	0	5097
4	43	329	5.59	206	0.80	184	2064	2041	34	1594	12	71	676	50	5287
5	50	318	5.31	199	0.57	174	0	1761	32	1878	9	31	574	52	3101
6	57	303	6.05	212	1.37	211	1927	1954	27	1524	0	34	541	60	4937
7	64	294	7.80	224	0.79	218	2230	2318	30	1713	0	37	547	35	5658
8	71	325	6.58	208	0.76	196	1877	1829	40	1548	0	46	414	23	4723
9	106	373	5.95	190	2.52	180	159	2141	65	1279	34	67	957	58	3463
							SAMPLING POINT NUMBERED 3								
1	13	404	5.82	228	1.53	209	1640	1733	45	1417	28	58	582	92	4482
2	27	404	6.68	220	1.65	197	1136	2237	48	1512	27	69	490	70	4395
3	36	330	5.46	181	1.36	156	1717	2632	32	1048	12	91	765	0	5097
4	43	329	5.59	206	0.80	184	2064	2041	34	1594	12	71	676	50	5287
5	50	318	5.31	199	0.57	174	0	1761	32	1878	9	31	574	52	3101
6	57	303	6.05	212	1.37	211	1927	1954	27	1524	0	34	541	60	4937
7	64	294	7.80	224	0.79	218	2230	2318	30	1713	0	37	547	35	5658
8	71	325	6.58	208	0.76	196	1877	1829	40	1548	0	46	414	23	4723
9	106	373	5.95	190	2.52	180	159	2141	65	1279	34	67	957	58	3463
							SAMPLING POINT NUMBERED 6								
1	13	378	4.58	64	6.94	24	53	34	0	8	0	0	0	0	86
2	27	453	4.89	85	7.09	40	47	56	0	8	0	0	0	0	67
3	36	399	4.91	102	5.92	19	124	165	0	13	5	0	0	0	268
4	43	426	4.33	179	4.98	114	1110	1047	73	249	111	74	329	0	1924
5	50	424	3.15	379	3.29	362	0	1776	50	1619	31	54	616	64	3023
6	57	367	3.39	329	3.07	314	1199	2075	44	1426	0	47	619	57	4303
7	64	375	5.02	267	1.23	267	818	2308	593	1108	20	55	702	141	4373
8	71	467	3.36	201	4.22	182	664	2491	79	444	39	85	556	118	3500
9	106	399	3.05	124	7.69	41	55	72	0	0	0	0	0	0	113

TABLE D2.9 AVERAGE RESPONSE DATA OF SAMPLING POINT NOs.5 AND 8 AT PSEUDO STEADY-STATE UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD (cont'd)

EXP.	DAY	SOLIDS , MG/L				SOLIDS , % OR %TS				COD , MG/L		INORGANICS , MG/L			
NOs.		TS	VS	TSS	TVSS	[%]	[%TS]	[%]	[%TS]	TOTAL	SOL.	NH4-N	TKN	TP	PO4-P
SAMPLING POINT NUMBERED 5															
1	13	12075	9465	7147	6423	1.21	77.34	0.71	88.31	22422	9825	303	379	211	201
2	27	10227	8567	8674	8204	1.02	84.22	0.87	94.55	28558	10354	280	410	222	191
3	36	7050	4798	2130	2055	0.71	68.05	0.21	96.47	13218	9777	208	340	180	161
4	43	13928	11328	8815	8385	1.39	80.66	0.88	94.97	26103	10713	174	333	208	180
5	50	21730	18675	15920	15175	2.17	85.72	1.59	95.34	34482	11027	158	293	210	202
6	57	10323	7635	4075	3855	1.03	73.92	0.41	94.66	20102	12062	176	320	216	211
7	64	13730	10768	8080	7690	1.37	78.40	0.81	95.17	24588	12240	145	324	230	222
8	71	9680	7525	8175	7785	0.97	78.14	0.82	95.31	23523	11197	217	372	228	208
9	106	11605	9215	7655	7035	1.16	79.34	0.77	91.79	20094	8776	288	395	195	192
SAMPLING POINT NUMBERED 8															
1	13	2397	962	201	31	0.24	40.14	0.02	15.25	318	207	377	407	57	11
2	27	2828	1125	184	145	0.28	40.15	0.02	79.61	469	331	394	460	71	34
3	36	2854	1232	185	108	0.29	43.21	0.02	58.11	677	554	301	404	84	15
4	43	5712	3492	1169	685	0.57	60.96	0.12	58.29	5147	4089	362	424	121	71
5	50	9365	5920	1572	1209	0.94	63.25	0.16	79.29	11200	9015	332	496	370	296
6	57	8389	5474	3030	2322	0.84	65.22	0.30	76.28	11077	7507	261	337	176	193
7	64	6820	4133	1769	1397	0.68	60.39	0.18	83.74	9483	7862	302	406	196	169
8	71	6240	3829	1813	1520	0.62	61.12	0.18	85.17	8562	6573	387	505	161	99
9	106	2163	790	157	73	0.22	36.52	0.02	46.50	682	424	345	371	103	34

TABLE D2.9 AVERAGE RESPONSE DATA OF SAMPLING POINT NOs.5 AND 8 AT PSEUDO STEADY-STATE UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD (cont'd)

EXP. NOs.	DAY	VFA, MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
				SAMPLING POINT NUMBERED 5						
1	13	1574	1721	47	1377	30	67	598	89	4395
2	27	1126	2301	53	1534	29	77	552	75	4487
3	36	1558	2435	31	974	13	84	716	0	4694
4	43	0	2008	35	1579	13	60	646	41	3160
5	50	0	1831	38	1905	14	63	703	0	3267
6	57	1949	1967	30	1549	0	38	540	0	4938
7	64	2288	2364	32	1764	0	39	563	42	5804
8	71	2095	2038	46	1736	0	52	473	41	5292
9	106	144	2150	70	1242	36	75	938	56	3426
				SAMPLING POINT NUMBERED 8						
1	13	11	9	0	6	0	0	0	0	19
2	27	0	0	0	5	0	0	0	0	1
3	36	40	67	0	5	0	0	0	0	96
4	43	731	858	77	135	149	178	428	0	1648
5	50	0	1738	53	1421	34	55	637	70	2877
6	57	695	1837	53	678	26	52	597	48	3096
7	64	550	2365	68	477	31	66	735	134	3396
8	71	335	2641	84	78	44	89	355	97	2922
9	106	0	0	0	0	0	0	0	0	0

TABLE D2.9 AVERAGE RESPONSE DATA OF THE SAMPLING POINT NOs.4 AND 7 AT PSEUDO STEADY-STATE UNDER DIFFERENT RUNNING CONDITIONS DURING THE MAXIMIZATION AND RECOVERY PERIOD (cont'd)

EXP. NOS.	DAY	SOLIDS, MG/L OR ELSE TSS	TVSS	[%]	%TS	COD, MG/L TOT.	SOL.	INORGANICS, MG/L NH4-N	TKN	TP	PO4-P	VFA, MG/L HAc	HPr	Iso-HBr	HBr	A-HVr	Iso-HVr	HVr	HHe	TOT.VFA mg/L HAc
SAMPLING POINT NUMBERED 4																				
1	13	2242	1953	0.22	86.99	13722	9658	299	410	222	216	1509	1740	46	1302	29	64	601	93	4295
2	27	4953	4727	0.50	95.35	17673	9800	292	451	230	203	1067	2316	51	1409	29	67	462	72	4306
3	36	1583	1470	0.16	92.87	12642	9649	214	345	184	154	1509	2495	31	952	14	83	688	0	4662
4	43	4833	4563	0.48	94.47	18095	10317	186	304	193	189	1796	2021	37	1473	17	87	770	0	4079
5	50	15990	15298	1.60	95.72	39932	11108	135	298	227	204	0	1712	31	1790	8	40	552	49	3005
6	57	21200	14505	2.12	79.21	16821	12062	181	321	216	215	2089	2229	32	1699	0	40	618	47	5487
7	64	5350	5085	0.54	95.10	20537	12280	169	328	228	227	2223	2435	34	1762	0	41	594	40	5815
8	71	3835	3705	0.38	96.60	18256	10832	212	360	215	205	1867	2029	46	1561	0	51	477	38	4936
9	106	2715	2535	0.27	93.32	13885	8453	235	345	195	195	145	2115	65	1167	34	65	940	39	3330
SAMPLING POINT NUMBERED 7																				
1	13	478	182	0.05	37.89	553	262	387	400	60	18	22	15	0	4	0	0	0	0	33
2	27	483	385	0.05	79.82	759	414	402	481	81	40	12	27	0	7	0	0	0	0	23
3	36	673	450	0.07	66.62	1231	740	297	425	89	35	67	99	0	8	0	0	0	0	152
4	43	1488	1013	0.15	68.17	5405	4169	353	412	99	87	0	867	74	146	146	171	433	0	1293
5	50	1590	1235	0.16	77.83	10765	9403	324	470	377	352	0	0	61	1266	47	59	666	73	1395
6	57	1635	1468	0.16	88.21	10667	8697	252	373	258	252	879	1842	47	1007	0	47	565	48	3475
7	64	1405	1190	0.14	84.63	8836	8025	308	378	198	193	528	2263	64	554	27	63	713	132	3316
8	71	1080	938	0.11	87.39	7709	6654	378	511	168	113	370	2494	79	139	39	82	376	102	2884
9	106	530	305	0.05	57.94	850	456	359	424	123	50	15	27	0	0	0	0	0	0	18

Table D3.1 Calculation of the CH_4 Production

1.According to Symons & Buswell (J.Amer.Chem.Soc. 55:2028)

$$C_nH_aO_b + [n\text{-}a/4\text{-}b/2]H_2O \longrightarrow [n/2+a/8\text{-}b/4]CH_4 + [n/2\text{-}a/8+b/4]CO_2$$

ie. $C_6H_{12}O_6 \longrightarrow 3CO_2 + 3CH_4$

$3CH_4 + 6O_2 \longrightarrow 3CO_2 + 6H_2O$

48 192

$$\frac{\text{kg } CH_4}{\text{kg COD}} = \frac{48/180}{192/180} = 0.25$$

V_{CH_4} = (0.25)(1000 g/kg)(1 mol/16g)(22.4 l/1 mol)(cu.m/1000 l)

= 0.35 cu.m CH_4 @ Std. cond. (P=760 mmHg,t= 0 C

In the other words, V_{CH_4} cu.m/kg COD removed = 0.35

Similarly, Ramalho, 1983 "Intro. to Wastewater Treatment Process"

CH_4 produced/gmCOD removed = 0.35 l/gm.COD removed

Or, = 0.35 l/gm * 454g/lb * cu.ft/28.32 l = 5.61 cu.ft CH_4/lb COD

2.According to Lawrence & McCarthy

G = 5.61 [8.34 Qf (Sf-Se) - 1.42 Xv]

Where G = cu.ft CH_4 @ Std.Cond.

8.34 Qf (Sf-Se) = Total COD removal, lb/d

Qf = MGD,Sf & Se = mg/l COD

1.42 Xv = lb/d COD removal, which is converted to biomass

and Xv = lb/d biomass yields

Or, Xv = Y(Sf-Se)Qf -KdXvV (Ramalho, p.237)

Where Y(Sf-Se)Qf = lb/d MLVSS produced

KdXvV = lb/d MLVSS loss Endogeneous respiration

Y = 0.06 mgVSS/mgBOD, Kd = 0.03 (1/day) - Metcalf & Eddy, p. 459

If average molecular formular for biomass is $C_5H_7NO_2$

$C_5H_7NO_2 + 5O_2 \longrightarrow 5CO_2 + NH_3 + 2H_2O$

113 5*32 = 160

, 160/113 = 1.42 lbO_2 / lb biomass produced

3.Total CH_4 gas @ T,P

Total CH_4,cu.ft @ T, P = G * (760/P) * (T/273)

Where P = mm Hg, T = 273 + C

Table D4.1 A M–UASB System Recovery at Pseudo Steady–state Condition
Under Different Running Conditions
(CH4, m3/m3–d)

HRT, days	CH4, cu.m/cu.m–d		
	Max.Loads	Recovery Period	% Recovery
1.0	2.45	2.46	0
1.5	3.98	2.25	57
2.0	3.65	1.88	52
2.5	3.25	1.78	55
3.0	2.55	1.76	69
3.5	1.70	1.74	102

Table D4.2 A M–UASB System Recovery at Pseudo Steady–state Condition
Under Different Running Conditions
(COD (Fil.) removal, %)

HRT, days	COD (Fil.) removal, %		
	Max.Loads	Recovery Period	% Recovery
1.0	22	18	0
1.5	88	37	41
2.0	95	40	42
2.5	97	50	52
3.0	97	60	62
3.5	98	71	72
4.0	98	81	83
4.5	98	90	92
4.7	98	96	98

TABLE D5.1 RESPONSE DATA OF GAS COMPOSITION/PRODUCTION/LOADING RATE DURING THE ACCLIMATIZATION PROCESS

ACCL.	DAY	DATE	FLOW,	KgCOD	CH4 GAS PRODUCTION			SPECIFIC CH4 PRODUCTION			
ALTER.			L/D	ADDED/DAY	L/D	M3/M3-D	M3/M3-D@SC	M3/KgCOD(ADD)	M3/KgCOD(REM.)	M3/KgCOD(ADD@SC)	M3/KgCOD(REM.@SC)
1	1	03/28/88	2.5	0.014	3.17	0.07	0.06	0.23	0.48	0.20	0.42
	8	04/04/88	2.38	0.014	7.28	0.16	0.14	0.54	4.03	0.47	3.57
	12	04/08/88	2.95	0.018	10.23	0.23	0.20	0.57	4.79	0.51	4.25
	16	04/12/88	3.67	0.022	32.44	0.72	0.64	1.47	8.16	1.31	7.24
	19	04/15/88	3.55	0.019	32.27	0.72	0.64	1.73	3.36	1.54	2.98
	23	04/19/88	3.68	0.021	27.09	0.60	0.53	1.31	2.80	1.16	2.48
	27	04/23/88	3.53	0.018	29.43	0.65	0.58	1.64	3.75	1.45	3.32
	30	04/26/88	4.31	0.023	27.67	0.61	0.55	1.21	2.31	1.07	2.05
	34	04/30/88	3.95	0.024	37.55	0.83	0.74	1.59	2.68	1.41	2.37
	37	05/03/88	3.68	0.018	38.68	0.86	0.76	2.10	3.26	1.86	2.89
	41	05/07/88	3.48	0.017	32.71	0.73	0.64	1.89	2.21	1.67	1.96
	44	05/10/88	3.68	0.021	34.55	0.77	0.68	1.65	1.92	1.46	1.70
	48	05/14/88	3.55	0.019	33.42	0.74	0.66	1.72	2.01	1.52	1.78
	51	05/17/88	3.72	0.020	34.64	0.77	0.68	1.75	2.01	1.55	1.78
2	1	05/31/88	2.39	0.019	5.93	0.13	0.12	0.31	0.38	0.28	0.34
	8	06/07/88	2.45	0.018	17.08	0.38	0.34	0.97	1.17	0.86	1.04
	15	06/14/88	2.21	0.018	19.41	0.43	0.38	1.07	1.20	0.95	1.06
	22	06/21/88	4.56	0.026	37.64	0.84	0.74	1.43	1.71	1.27	1.51
	29	06/28/88	4.59	0.024	40.33	0.90	0.79	1.66	1.96	1.47	1.74
3	1	11/15/88	2.39	0.012	7.08	0.16	0.14	0.58	1.21	0.51	1.07
	4	11/18/88	1.66	0.008	9.59	0.21	0.19	1.14	2.28	1.01	2.02
	8	11/22/88	1.94	0.011	12.64	0.28	0.25	1.15	1.99	1.02	1.77
	11	11/25/88	2.04	0.011	30.17	0.67	0.59	2.74	4.70	2.43	4.17
	15	11/29/88	3.72	0.022	38.45	0.85	0.76	1.72	2.53	1.53	2.25
	18	12/02/88	3.4	0.018	37.31	0.83	0.73	2.05	2.46	1.82	2.18
	22	12/06/88	3.22	0.017	45.14	1.00	0.89	2.71	2.99	2.40	2.65
	25	12/09/88	4.02	0.026	46.24	1.03	0.91	1.76	1.97	1.56	1.75
	29	12/13/88	2.89	0.015	38.34	0.85	0.76	2.55	2.86	2.26	2.53
	32	12/16/88	5.88	0.042	37.49	0.83	0.74	0.90	0.98	0.80	0.87
	36	12/20/88	5.34	0.032	46.53	1.03	0.92	1.45	2.10	1.29	1.86
	39	12/23/88	6.02	0.038	50.65	1.13	1.00	1.33	1.87	1.18	1.66
	43	12/27/88	5.06	0.035	50.74	1.13	1.00	1.46	2.07	1.29	1.84
	46	12/30/88	3.94	0.030	58.30	1.30	1.15	1.94	2.25	1.72	1.99
	50	01/03/89	5.61	0.039	62.71	1.39	1.24	1.60	1.74	1.42	1.54
	53	01/06/89	5.99	0.036	57.55	1.28	1.13	1.61	1.71	1.42	1.52

TABLE D5.1 RESPONSE DATA OF GAS COMPOSITION/PRODUCTION/LOADING RATE DURING THE ACCLIMATIZATION PROCESS (cont'd)

ACCL. ALTER.	DAY	DATE	FLOW, L/D GAS	CH4	M3/M3-D	LOADING RATE KgCOD(SOL)/M3-D	KgCOD/M3-D(TOT)	KgVS/M3-D	GAS COMPOSITION, MOLE % (A- AND M-UASBs, RESPECTIVELY) CO2	N2	CH4	O2	CO2	N2	CH4	O2
1	1	03/28/88	10.80	3.17	0.06	0.31	3.12	1.51	55.47	21.18	20.00	3.35	19.26	25.98	54.35	0.41
	8	04/04/88	14.58	7.28	0.05	0.30	3.30	2.50	62.38	13.62	22.70	1.30	12.59	10.49	76.92	
	12	04/08/88	18.34	10.23	0.07	0.40	5.17	1.67	69.35	3.16	27.49		13.79	3.45	82.76	
	16	04/12/88	51.12	32.44	0.08	0.49	2.72	2.60	70.21	9.81	19.59	0.39	21.26	1.07	77.67	
	19	04/15/88	52.07	32.27	0.08	0.41	4.00	2.28	75.43	2.98	21.60		25.72	0.78	73.50	
	23	04/19/88	44.40	27.09	0.08	0.46	4.21	3.35	73.70	3.65	22.64		27.78	0.89	71.33	
	27	04/23/88	50.90	29.43	0.08	0.40	7.58	2.24	71.64	3.84	24.50		27.38	1.00	71.62	
	30	04/26/88	47.50	27.67	0.10	0.51	5.70	4.33	73.49	5.30	20.66	0.54	28.55	0.63	68.28	
	34	04/30/88	61.11	37.55	0.09	0.52	3.11	3.74	76.54	3.12	20.34		28.80	0.75	70.45	
	37	05/03/88	62.35	38.68	0.08	0.41	2.04	3.09	76.59	2.94	20.49		29.37	0.64	69.97	
	41	05/07/88	53.00	32.71	0.08	0.39	2.34	2.32	77.38	2.36	20.64	0.29	28.20	1.40	70.40	0.29
	44	05/10/88	57.75	34.55	0.08	0.47	2.71	1.90	73.19	3.43	23.38		30.52	0.60	68.88	
	48	05/14/88	55.02	33.42	0.08	0.43	1.95	2.18	74.22	2.51	23.25		30.27	0.66	69.08	
	51	05/17/88	57.43	34.64	0.08	0.44	2.66	3.37	72.80	2.92	24.28		29.82	1.17	69.03	
2	1	05/31/88	13.43	5.93	0.05	0.42	1.74	1.63	71.92	3.14	24.94		30.48	0.69	68.83	
	8	06/07/88	31.37	17.08	0.05	0.39	3.05	2.00	69.56	1.83	28.61		18.23	1.40	80.38	
	15	06/14/88	33.25	19.41	0.05	0.40	2.24	1.82	66.30	1.30	32.40		18.23	1.40	80.38	
	22	06/21/88	62.70	37.64	0.10	0.58	5.03	3.92	65.53	1.75	32.72		17.68	1.16	81.17	
	29	06/28/88	61.68	40.33	0.10	0.54	2.99	3.13	65.99	2.05	31.96		14.45	0.98	84.58	
3	1	11/15/88	13.70	7.08	0.05	0.27	1.55	1.19	58.03	2.37	39.60		29.82		70.18	
	4	11/18/88	17.64	9.59	0.04	0.19	1.64	0.94	57.86	3.38	38.74		20.94	12.23	66.83	
	8	11/22/88	20.84	12.64	0.04	0.24	2.35	0.88	61.64	2.50	35.86		18.86	1.85	79.28	
	11	11/25/88	43.34	30.17	0.05	0.24	1.46	1.16	59.47	2.17	38.35		19.25	0.69	80.08	
	15	11/29/88	58.92	38.45	0.08	0.50	2.71	2.41	61.94	2.47	35.61		24.07	0.51	75.43	
	18	12/02/88	56.49	37.31	0.08	0.40	2.51	1.99	64.58	2.26	33.15		22.92	0.46	76.62	
	22	12/06/88	68.89	45.14	0.07	0.37	1.91	2.39	64.20	2.99	32.80		25.17	0.65	74.18	
	25	12/09/88	72.55	46.24	0.09	0.58	4.08	3.09	66.84	1.81	31.37		25.59	0.46	73.94	
	29	12/13/88	63.05	38.34	0.06	0.33	1.97	2.10	68.16	2.13	29.71		32.08	0.46	67.45	
	32	12/16/88	67.24	37.49	0.13	0.92	4.31	3.76	65.63	3.01	31.35		34.13	0.56	65.31	
	36	12/20/88	77.20	46.53	0.12	0.71	4.31	3.12	70.11	3.16	26.73		29.08	0.50	70.42	
	39	12/23/88	86.48	50.65	0.13	0.85	4.51	4.06	67.39	6.93	25.67		29.44	0.48	70.07	
	43	12/27/88	81.10	50.74	0.11	0.77	5.67	3.60	66.35	3.56	33.09		29.67	0.48	69.87	
	46	12/30/88	90.85	58.30	0.09	0.67	3.20	3.05	64.98	2.73	32.31		28.90	0.51	70.59	
	50	01/03/89	94.53	62.71	0.12	0.87	5.04	3.69	61.50	1.26	37.24		26.65	0.32	73.01	
	53	01/06/89	89.24	57.55	0.13	0.80	3.82	3.04	68.13	1.46	30.40		26.22	0.36	73.43	

TABLE D5.2 RESPONSE DATA OF GAS COMPOSITION/PRODUCTION/LOADING RATE (A-ANDM-UASBs) DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER.RUN NUMBERS	DAY	DATE	INF.FLOW, L/D	FLOW,L/D GAS SYSTEM	FLOW,L/D CH4	LOADING RATE M3/M3-D	LOADING RATE KgCOD/M3-D (SOLUBLE)	CH4 PRODUCTIVITY L/D	CH4 PRODUCTIVITY M3/M3-D	CH4 PRODUCTIVITY M3/M3-D @SC/D	SPECIFIC CH4 PRODUCTION M3/KgCODADD (SOLUBLE)	SPECIFIC CH4 PRODUCTION M3/KgCODADD (SOLUBLE)@SC
1	1	07/12/88	6.02	62.65	35.58	0.13	0.69	35.58	0.79	0.70	1.15	1.02
	8	07/19/88	5.03	51.17	31.48	0.11	0.55	31.48	0.70	0.62	1.26	1.12
	11	07/22/88	4.70	53.34	35.52	0.10	0.47	35.52	0.79	0.70	1.68	1.49
2	15	07/26/88	4.44	54.20	35.95	0.10	0.83	35.95	0.80	0.71	0.96	0.85
	22	08/02/88	4.69	39.90	23.81	0.10	0.77	23.81	0.53	0.47	0.68	0.61
	29	08/09/88	5.59	37.46	21.30	0.12	1.07	21.30	0.47	0.42	0.44	0.39
	32	08/12/88	5.15	46.33	28.57	0.11	0.89	28.57	0.63	0.56	0.71	0.63
	36	08/16/88	6.43	58.90	36.48	0.14	0.97	36.48	0.81	0.72	0.84	0.74
	39	08/19/88	6.17	72.81	43.66	0.14	0.98	43.66	0.97	0.86	0.99	0.88
	43	08/23/88	5.09	76.25	44.80	0.11	0.71	44.80	1.00	0.88	1.41	1.25
	46	08/26/88	7.08	74.64	42.83	0.16	1.02	42.83	0.95	0.84	0.93	0.82
3	49	08/29/88	6.11	90.24	48.96	0.14	1.19	48.96	1.09	0.96	0.91	0.81
	53	09/02/88	5.12	96.34	59.83	0.11	0.83	59.83	1.33	1.18	1.61	1.43
	57	09/06/88	5.22	97.85	58.12	0.12	0.89	58.12	1.29	1.14	1.45	1.28
	60	09/09/88	5.46	92.66	52.41	0.12	0.86	52.41	1.16	1.03	1.35	1.20
	65	09/14/88	4.47	52.25	26.36	0.10	0.76	26.36	0.59	0.52	0.77	0.68
	68	09/17/88	4.77	45.30	19.17	0.11	0.86	19.17	0.43	0.38	0.50	0.44
	71	09/20/88	5.57	40.44	15.71	0.12	0.80	15.71	0.35	0.31	0.44	0.39
	74	09/23/88	4.83	39.56	14.42	0.11	0.64	14.42	0.32	0.28	0.50	0.45
	78	09/27/88	4.07	31.66	12.87	0.09	0.62	12.87	0.29	0.25	0.46	0.41
	81	09/30/88	4.20	33.86	13.72	0.09	0.59	13.72	0.30	0.27	0.52	0.46
4	85	10/04/88	5.22	42.35	14.96	0.12	0.75	14.96	0.33	0.29	0.45	0.40
	95	10/14/88	4.83	26.16	8.28	0.11	0.68	8.28	0.18	0.16	0.27	0.24
	99	10/18/88	6.00	25.40	7.77	0.13	0.83	7.77	0.17	0.15	0.21	0.18
	102	10/21/88	5.15	22.69	6.50	0.11	0.72	6.50	0.14	0.13	0.20	0.18
5	1	01/17/89	4.15	76.04	49.17	0.09	0.72	49.17	1.09	0.97	1.52	1.35
	8	01/24/89	5.59	84.66	52.31	0.12	0.84	52.31	1.16	1.03	1.38	1.23
	15	01/31/89	6.56	94.78	59.85	0.15	0.86	59.85	1.33	1.18	1.54	1.36
	22	02/07/89	5.96	96.10	59.80	0.13	0.81	59.80	1.33	1.18	1.65	1.46
	25	02/10/89	4.86	94.09	60.40	0.11	0.67	60.40	1.34	1.19	2.01	1.78
	29	02/14/89	4.59	77.44	52.82	0.10	0.67	52.82	1.17	1.04	1.76	1.56
6	43	02/28/89	3.90	82.89	49.60	0.09	0.56	49.60	1.10	0.98	1.97	1.74
	50	03/07/89	3.94	76.50	45.77	0.09	0.64	45.77	1.02	0.90	1.58	1.40
	57	03/14/89	4.09	92.94	58.49	0.09	0.65	58.49	1.30	1.15	1.99	1.76

TABLE D5.2 RESPONSE DATA OF GAS COMPOSITION/PRODUCTION/LOADING RATE (A-ANDM-UASBs) DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER.RUN NUMBERS	DAY	DATE	INF.FLOW, L/D	FLOW,L/D GAS SYSTEM	CH4	LOADING RATE M3/M3-D	LOADING RATE KgCOD/M3-D (SOLUBLE)	CH4 PRODUCTIVITY L/D	CH4 PRODUCTIVITY M3/M3-D	CH4 PRODUCTIVITY M3/M3-D @SC/D	SPECIFIC CH4 PRODUCTION M3/KgCODADD (SOLUBLE)	SPECIFIC CH4 PRODUCTION M3/KgCODADD (SOLUBLE)@SC
	64	03/21/89	5.11	89.15	57.03	0.11	0.76	57.03	1.27	1.12	1.67	1.48
	71	03/28/89	5.45	93.18	59.78	0.12	0.80	59.78	1.33	1.18	1.67	1.48
7	78	04/04/89	4.57	71.90	43.87	0.10	0.71	43.87	0.97	0.86	1.38	1.22
	85	04/11/89	4.43	69.95	43.33	0.10	0.77	43.33	0.96	0.85	1.26	1.11
	92	04/18/89	3.84	86.30	52.97	0.09	0.60	52.97	1.18	1.04	1.95	1.73
	99	04/25/89	2.75	104.71	61.12	0.06	0.55	61.12	1.36	1.20	2.48	2.20
	102	04/28/89	4.47	110.96	63.86	0.10	0.69	63.86	1.42	1.26	2.07	1.83
	106	05/02/89	3.13	104.00	60.54	0.07	0.57	60.54	1.35	1.19	2.38	2.11
8	113	05/09/89	3.99	114.07	65.73	0.09	0.64	65.73	1.46	1.29	2.28	2.02
	120	05/16/89	4.76	108.76	64.43	0.11	0.79	64.43	1.43	1.27	1.82	1.61
	130	05/26/89	6.40	98.67	51.00	0.14	1.02	51.00	1.13	1.00	1.11	0.99
	134	05/30/89	4.57	105.96	59.35	0.10	0.78	59.35	1.32	1.17	1.70	1.51
	137	06/02/89	5.76	121.68	67.83	0.13	0.96	67.83	1.51	1.34	1.57	1.39
	141	06/06/89	5.40	129.74	74.67	0.12	0.87	74.67	1.66	1.47	1.91	1.69
9	148	06/13/89	5.41	127.20	71.65	0.12	0.80	71.65	1.59	1.41	1.98	1.76
	155	06/20/89	4.82	114.20	63.54	0.11	0.76	63.54	1.41	1.25	1.85	1.64
	162	06/27/89	3.40	126.12	75.14	0.08	0.60	75.14	1.67	1.48	2.79	2.47
10	169	07/04/89	4.59	29.96	17.01	0.10	0.69	17.01	0.38	0.34	0.55	0.49
	176	07/11/89	3.72	66.81	39.57	0.08	0.61	39.57	0.88	0.78	1.43	1.27
	183	07/18/89	3.53	54.46	35.63	0.08	0.54	35.63	0.79	0.70	1.46	1.30
	190	07/25/89	4.24	98.84	60.83	0.09	0.57	60.83	1.35	1.20	2.36	2.09
	193	07/28/89	5.42	90.01	54.90	0.12	0.70	54.90	1.22	1.08	1.75	1.55
	197	08/01/89	4.57	99.16	54.49	0.10	0.50	54.49	1.21	1.07	2.42	2.15
	200	08/04/89	5.03	71.36	40.19	0.11	0.57	40.19	0.89	0.79	1.58	1.40
11	204	08/08/89	3.51	75.31	44.23	0.08	0.44	44.23	0.98	0.87	2.23	1.98
	211	08/15/89	4.87	79.25	49.92	0.11	0.59	49.92	1.11	0.98	1.88	1.67
	218	08/22/89	3.33	70.00	42.08	0.07	0.42	42.08	0.94	0.83	2.23	1.98
	225	08/29/89	3.29	76.16	47.51	0.07	0.43	47.51	1.06	0.94	2.43	2.15
	228	09/01/89	5.08	92.91	58.29	0.11	0.77	58.29	1.30	1.15	1.69	1.50
	232	09/05/89	4.20	85.94	55.66	0.09	0.59	55.66	1.24	1.10	2.11	1.87
12	239	09/12/89	5.93	77.03	47.54	0.13	0.79	47.54	1.06	0.94	1.34	1.19
	246	09/19/89	4.77	75.70	47.51	0.11	0.71	47.51	1.06	0.94	1.49	1.32
	253	09/26/89	4.33	69.10	40.29	0.10	0.55	40.29	0.90	0.79	1.64	1.45
	256	09/29/89	3.95	74.45	44.13	0.09	0.52	44.13	0.98	0.87	1.87	1.66
	260	10/03/89	4.45	92.93	53.38	0.10	0.64	53.38	1.19	1.05	1.84	1.63
	263	10/06/89	4.74	80.29	49.16	0.11	0.64	49.16	1.09	0.97	1.72	1.52

TABLE D5.2 RESPONSE DATA OF GAS COMPOSITION/PRODUCTION/LOADING RATE (A-ANDM-UASBs) DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER.RUN NUMBERS	DAY	DATE	CH4 PRODUCTION PHASE			GAS COMPOSITION, MOLE %						
						A-UASB				M-UASB		
			A-UASB	M-UASB	SYST.	C02	N2	CH4	O2	C02	N2	CH4
1	1	07/12/88	8.26	27.32	35.58	66.25	5.64	26.86	1.25	10.15	3.46	85.63
	8	07/19/88	6.43	25.04	31.48	69.33	1.85	28.82		12.27	0.92	86.81
	11	07/22/88	7.70	27.82	35.52	61.41	2.70	35.50	0.39	10.82	1.27	87.93
2	15	07/26/88	6.64	29.30	35.95	59.82	4.44	35.06	0.68	16.10	0.75	83.13
	22	08/02/88	5.19	18.62	23.81	65.48	3.17	31.34		19.08	1.17	79.75
	29	08/09/88	5.55	15.76	21.30	68.31	2.40	29.29		13.68	1.24	85.08
	32	08/12/88	4.72	23.85	28.57	68.66	2.17	29.19		19.87	1.06	79.07
	36	08/16/88	6.21	30.27	36.48	67.32	2.09	30.59		20.01	1.38	78.41
	39	08/19/88	5.78	37.88	43.66	69.82	1.78	28.42		26.40	1.39	72.21
	43	08/23/88	5.52	39.28	44.80	66.15	4.68	28.31	0.87	30.23	0.54	69.21
	46	08/26/88	6.95	35.89	42.83	68.35	2.42	29.24		28.88	0.57	70.53
3	49	08/29/88	5.69	43.27	48.96	68.45	8.82	22.16	0.55	32.35	0.61	67.02
	53	09/02/88	6.56	53.27	59.83	67.75	1.86	30.37		28.29	0.44	71.27
	57	09/06/88	7.41	50.71	58.12	67.66	1.61	30.75		31.25	0.00	68.76
	60	09/09/88	7.12	45.29	52.41	67.84	1.40	30.76		34.85	0.00	65.15
	65	09/14/88	3.29	23.07	26.36	72.87	2.74	24.40		38.48	1.99	59.53
	68	09/17/88	3.79	15.38	19.17	75.53	1.67	22.79		45.29	1.02	53.68
	71	09/20/88	3.57	12.13	15.71	76.66	1.73	21.60		48.00	1.23	50.77
	74	09/23/88	4.24	10.17	14.42	76.77	1.33	21.90		47.50	2.09	50.41
	78	09/27/88	3.36	9.51	12.87	75.65	1.71	22.66		42.08	1.47	56.45
	81	09/30/88	3.15	10.57	13.72	76.92	2.15	20.93		42.20	1.60	56.20
4	85	10/04/88	4.00	10.96	14.96	80.78	1.04	18.17		44.16	1.99	53.85
	95	10/14/88	4.68	3.60	8.28	74.12	2.09	23.79		40.53	3.94	55.53
	99	10/18/88	5.84	1.93	7.77	69.12	4.23	26.65		39.65	5.20	55.15
	102	10/21/88	5.63	0.86	6.50	69.00	4.24	26.78		39.02	8.55	52.42
5	1	01/17/89	3.33	45.85	49.17	70.44	2.54	27.02		27.54	0.50	71.94
	8	01/24/89	5.25	47.06	52.31	74.65	1.40	23.96		24.61	0.40	74.99
	15	01/31/89	6.68	39.57	46.25	66.83	2.28	30.91		24.82	0.37	74.81
	22	02/07/89	6.82	52.98	59.80	70.78	1.37	27.83		25.62	0.38	74.00
	25	02/10/89	6.73	53.67	60.40	65.32	3.44	31.24		25.74	0.27	73.99
	29	02/14/89	3.98	48.84	52.82	64.45	4.85	30.68		23.90	0.35	75.77
6	43	02/28/89	3.93	45.67	49.60	73.01	2.80	24.19		31.00	0.47	68.52
	50	03/07/89	3.02	47.62	50.63	70.45	5.40	24.13		27.99	1.31	70.70
	57	03/14/89	3.71	54.79	58.49	75.59	0.99	23.41		28.97		71.05

TABLE D5.2 RESPONSE DATA OF GAS COMPOSITION/PRODUCTION/LOADING RATE (A-ANDM-UASBs) DURING PHASE 1, 2, AND 3 EXPERIMENTS

EXPER.RUN NUMBERS	DAY	DATE	CH4 PRODUCTION PHASE			GAS COMPOSITION, MOLE % A-UASB			M-UASB			
			A-UASB	M-UASB	SYST.	C02	N2	CH4	O2	C02	N2	CH4
	64	03/21/89	4.95	46.91	51.85	64.03	5.06	30.91		28.80		71.20
	71	03/28/89	4.80	54.99	59.78	65.06	2.23	32.71		29.96		70.03
7	78	04/04/89	5.37	38.50	43.87	66.13	3.21	30.64		29.19		70.81
	85	04/11/89	7.84	35.92	43.76	61.48	0.94	37.58		28.03		71.98
	92	04/18/89	7.84	45.13	52.97	65.55	0.62	33.81		28.50		71.50
	99	04/25/89	14.07	52.87	66.94	63.54		36.46		27.84		72.15
	102	04/28/89	20.16	43.71	63.86	60.09		39.91		27.72		72.30
	106	05/02/89	20.09	40.45	60.54	58.04		41.95		27.90		72.10
8	113	05/09/89	20.45	45.28	65.73	59.38		40.62		28.94		71.06
	120	05/16/89	15.80	46.85	62.65	58.42	2.35	39.23		27.75		72.24
	130	05/26/89	17.48	33.56	51.03	58.46	8.36	33.18		26.08	0.96	72.95
	134	05/30/89	19.93	39.43	59.35	56.35	5.84	37.81		25.97		74.03
	137	06/02/89	23.55	39.40	62.96	55.40	5.67	38.93		26.28		73.72
	141	06/06/89	25.84	41.27	67.11	55.41	5.11	39.48		26.95		73.04
9	148	06/13/89	22.93	48.72	71.65	60.62	0.97	38.41		27.82		72.18
	155	06/20/89	22.03	41.51	63.54	60.76		39.24		28.49		71.51
	162	06/27/89	19.34	55.80	75.14	60.78		39.22		26.78	0.56	72.65
10	169	07/04/89	2.53	14.48	17.01	74.75		25.25		26.34	1.02	72.64
	176	07/11/89	8.05	31.52	39.57	64.12	2.01	33.87		25.95	0.84	73.22
	183	07/18/89	2.74	32.88	35.63	65.82	2.14	32.03		27.65	0.70	71.65
	190	07/25/89	15.73	45.10	60.83	57.59		42.41		26.97		73.03
	193	07/28/89	13.37	41.53	54.90	59.02		40.97		27.62		72.38
	197	08/01/89	19.44	35.06	54.49	60.76		39.24		27.93	1.43	70.64
	200	08/04/89	13.25	26.94	40.19	61.20		38.81		27.62		72.39
11	204	08/08/89	14.31	29.92	44.23	57.79		42.23		27.75		72.23
	211	08/15/89	10.98	38.94	49.92	58.96	0.75	40.29		25.12		74.88
	218	08/22/89	8.58	33.50	42.08	61.68	1.02	37.29		26.12	2.60	71.28
	225	08/29/89	9.56	37.96	47.51	60.23	1.12	38.65		25.34	0.86	73.80
	228	09/01/89	9.08	49.21	58.29	63.96	1.22	34.82		25.51	0.85	73.64
	232	09/05/89	7.25	48.41	55.66	62.78	1.43	35.78		25.58	0.70	73.72
12	239	09/12/89	7.99	39.55	47.54	64.64	1.26	34.10		26.22		73.78
	246	09/19/89	9.03	38.48	47.51	58.97	1.52	39.53		26.28	0.89	72.81
	253	09/26/89	8.57	31.73	40.29	63.46	2.95	33.59		26.06	1.17	72.77
	256	09/29/89	9.82	34.31	44.13	62.59	0.94	36.48		26.13	4.67	72.19
	260	10/03/89	12.56	40.81	53.38	64.27	1.81	33.94		25.94	1.03	73.00
	263	10/06/89	16.70	32.46	49.16	51.85	1.65	46.51		25.80	1.08	73.14

TABLE D5.3 RESPONSE DATA OF GAS PRODUCTION/COMPOSITION/LOADING RATE (A-UASB) DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXPER. NOs.	DAY	DATE	SPECIFIC GAS PRODUCTION [CH4] M3/KgCOD(SOL) ADDED	M3/KgCOD(SOL) ADDED @ SC	COMPOSITIONS, % C02	N2	CH4
1	1	10/13/89	0.21	0.19	70.52		29.49
	4	10/16/89	0.32	0.28	67.75	2.36	29.89
	6	10/18/89	0.29	0.25	66.55	2.48	30.97
	8	10/20/89	0.32	0.28	64.33	2.28	33.49
	11	10/23/89	0.33	0.29	66.83	0.84	32.30
	13	10/25/89	0.41	0.36	67.36		32.64
	15	10/27/89	0.35	0.31	67.67		32.35
2	20	11/01/89	0.36	0.32	66.26	0.84	32.90
	22	11/03/89	0.56	0.50	63.15	0.87	35.99
	25	11/06/89	0.52	0.46	62.39	0.83	36.76
	27	11/08/89	0.62	0.55	61.17	0.64	38.20
	29	11/10/89	0.66	0.59	61.99		38.01
3	33	11/14/89	0.40	0.36	62.72	0.33	36.95
	35	11/16/89	0.27	0.24	67.59	0.89	31.52
	37	11/18/89	0.28	0.25	72.30	0.41	27.39
4	40	11/21/89	0.29	0.25	71.87	1.77	26.36
	42	11/23/89	0.26	0.23	72.76	2.01	25.22
	44	11/25/89	0.27	0.24	71.88	0.97	27.16
5	47	11/28/89	0.29	0.26	74.01	0.62	25.35
	49	11/30/89	0.30	0.26	75.02	1.00	23.98
	51	12/02/89	0.31	0.28	72.91		27.09
6	54	12/05/89	0.27	0.24	69.97	1.17	28.86
	56	12/07/89	0.23	0.21	76.21	0.39	23.40
	58	12/09/89	0.14	0.12	76.47	1.52	22.02
7	61	12/12/89	0.27	0.24	73.98	0.67	25.35
	63	12/14/89	0.17	0.15	77.74	1.92	20.36
	65	12/16/89	0.16	0.14	81.49	0.16	18.35
8	68	12/19/89	0.14	0.13	81.25	0.22	18.53
	70	12/21/89	0.16	0.14	79.12	0.31	20.57
	72	12/23/89	0.23	0.20	76.40		23.61
9	75	12/26/89	0.19	0.17	75.48	1.70	22.82
	79	12/30/89	0.18	0.16	75.14	1.35	23.49
	84	01/04/90	0.13	0.12	71.13	1.95	26.93
	91	01/11/90	0.22	0.19	67.16	1.45	31.39
	96	01/16/90	0.44	0.39	62.45	1.18	36.13
	98	01/18/90	0.51	0.45	59.09	1.80	39.11
	102	01/22/90	0.61	0.54	58.24	2.20	39.56
	104	01/24/90	0.63	0.55	58.87	1.50	39.62
	107	01/27/90	0.54	0.48	58.18	1.17	40.65

TABLE D5.3 RESPONSE DATA OF GAS PRODUCTION/COMPOSITION/LOADING RATE (A-UASB) DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP. NOs.	DAY	DATE	INF. FLOW L/D	FLOW (SYSTEM GAS L/D	CH4 L/D	LOADING RATE M3/M3-D	gCOD(SOL) M3-DAY	HRT, DAYS	CH4 PRODUCTIVITY L/D	M3/M3-D	3/M3-D@SC
1	1	10/13/89	6.67	25.96	7.66	0.15	0.81	3.00	7.66	0.17	0.15
	4	10/16/89	6.66	41.14	12.30	0.15	0.86	3.00	12.30	0.27	0.24
	6	10/18/89	7.00	38.00	11.77	0.16	0.91	2.86	11.77	0.26	0.23
	8	10/20/89	6.58	41.24	13.81	0.15	0.96	3.04	13.81	0.31	0.27
	11	10/23/89	7.22	44.63	14.42	0.16	0.98	2.77	14.42	0.32	0.28
	13	10/25/89	7.97	61.71	20.14	0.18	1.10	2.51	20.14	0.45	0.40
	15	10/27/89	7.10	47.57	15.39	0.16	0.99	2.82	15.39	0.34	0.30
2	20	11/01/89	8.73	63.00	20.73	0.19	1.28	2.29	20.73	0.46	0.41
	22	11/03/89	8.96	87.44	31.47	0.20	1.24	2.23	31.47	0.70	0.62
	25	11/06/89	9.32	83.60	30.73	0.21	1.32	2.15	30.73	0.68	0.61
	27	11/08/89	9.67	92.50	35.34	0.21	1.27	2.07	35.34	0.79	0.70
	29	11/10/89	9.13	98.02	37.26	0.20	1.25	2.19	37.26	0.83	0.73
3	33	11/14/89	14.23	107.58	39.75	0.32	2.20	1.41	39.75	0.88	0.78
	35	11/16/89	16.29	87.00	27.42	0.36	2.26	1.23	27.42	0.61	0.54
	37	11/18/89	15.90	93.96	25.74	0.35	2.03	1.26	25.74	0.57	0.51
4	40	11/21/89	21.12	138.61	36.54	0.47	2.84	0.95	36.54	0.81	0.72
	42	11/23/89	20.90	143.00	36.06	0.46	3.05	0.96	36.06	0.80	0.71
	44	11/25/89	20.48	120.44	32.71	0.46	2.74	0.98	32.71	0.73	0.64
5	47	11/28/89	29.13	185.54	47.03	0.65	3.55	0.69	47.03	1.05	0.93
	49	11/30/89	26.18	204.29	48.99	0.58	3.67	0.76	48.99	1.09	0.96
	51	12/02/89	24.80	168.09	45.54	0.55	3.25	0.81	45.54	1.01	0.90
6	54	12/05/89	18.22	118.16	34.10	0.40	2.83	1.10	34.10	0.76	0.67
	56	12/07/89	16.22	108.25	25.33	0.36	2.40	1.23	25.33	0.56	0.50
	58	12/09/89	19.56	90.59	19.95	0.43	3.17	1.02	19.95	0.44	0.39
7	61	12/12/89	15.65	98.65	25.01	0.35	2.07	1.28	25.01	0.56	0.49
	63	12/14/89	16.60	103.84	21.14	0.37	2.72	1.20	21.14	0.47	0.42
	65	12/16/89	14.00	79.98	14.68	0.31	2.02	1.43	14.68	0.33	0.29
8	68	12/19/89	11.38	55.77	10.33	0.25	1.62	1.76	10.33	0.23	0.20
	70	12/21/89	12.41	60.73	12.49	0.28	1.75	1.61	12.49	0.28	0.25
	72	12/23/89	11.48	73.67	17.39	0.26	1.69	1.74	17.39	0.39	0.34
9	75	12/26/89	6.15	37.36	8.53	0.14	0.98	3.25	8.53	0.19	0.17
	79	12/30/89	5.60	26.46	6.22	0.12	0.77	3.57	6.22	0.14	0.12
	84	01/04/90	5.00	19.15	5.16	0.11	0.87	4.00	5.16	0.11	0.10
	91	01/11/90	5.22	31.30	9.83	0.12	1.01	3.83	9.83	0.22	0.19
	96	01/16/90	5.88	53.39	19.29	0.13	0.97	3.40	19.29	0.43	0.38
	98	01/18/90	5.24	57.31	22.41	0.12	0.98	3.82	22.41	0.50	0.44
	102	01/22/90	5.72	66.25	26.21	0.13	0.95	3.50	26.21	0.58	0.52
	104	01/24/90	5.38	62.69	24.84	0.12	0.88	3.72	24.84	0.55	0.49
	107	01/27/90	5.29	63.45	25.79	0.12	1.05	3.78	25.79	0.57	0.51

TABLE D5.4 RESPONSE DATA OF GAS PRODUCTION/COMPOSITION/LOADING RATE (M-UASB) DURING THE MAXIMIZATION AND RECOVERY PERIOD

EXP. NOs.	DAY	DATE	INF. FLOW L/D	FLOW, L/D GAS SYSTEM	CH4	LOADING RATE M3/M3-D	KgCOD(SOL) M3-DAY	CH4 PRODUCTIVITY L/D	M3/M3-D	M3/M3-D @ SC
1	1	10/13/89	6.67	101.20	72.07	0.15	1.25	72.07	1.60	1.42
	4	10/16/89	6.66	82.78	58.84	0.15	1.38	58.84	1.31	1.16
	6	10/18/89	7.00	92.50	65.24	0.16	1.36	65.24	1.45	1.29
	8	10/20/89	6.58	94.71	66.69	0.15	1.29	66.69	1.48	1.31
	11	10/23/89	7.22	98.52	68.82	0.16	1.47	68.82	1.53	1.36
	13	10/25/89	7.97	102.53	71.49	0.18	1.77	71.49	1.59	1.41
	15	10/27/89	7.10	105.17	73.01	0.16	1.63	73.01	1.62	1.44
2	20	11/01/89	8.73	160.85	110.65	0.19	1.99	110.65	2.46	2.18
	22	11/03/89	8.96	158.21	108.26	0.20	2.18	108.26	2.41	2.13
	25	11/06/89	9.32	155.30	106.02	0.21	2.10	106.02	2.36	2.09
	27	11/08/89	9.67	155.17	106.03	0.21	2.30	106.03	2.36	2.09
	29	11/10/89	9.13	148.94	103.13	0.20	2.08	103.13	2.29	2.03
3	33	11/14/89	14.23	196.07	139.54	0.32	2.68	139.54	3.10	2.75
	35	11/16/89	16.29	223.60	157.03	0.36	3.83	157.03	3.49	3.09
	37	11/18/89	15.90	217.43	148.61	0.35	3.17	148.61	3.30	2.93
4	40	11/21/89	21.12	269.60	175.59	0.47	5.19	175.59	3.90	3.46
	42	11/23/89	20.90	257.45	160.78	0.46	5.21	160.78	3.57	3.17
	44	11/25/89	20.48	197.77	124.46	0.46	4.64	124.46	2.77	2.45
5	47	11/28/89	29.13	145.89	80.17	0.65	6.02	80.17	1.78	1.58
	49	11/30/89	26.18	125.82	64.62	0.58	6.77	64.62	1.44	1.27
	51	12/02/89	24.80	125.58	62.73	0.55	5.74	62.73	1.39	1.24
6	54	12/05/89	18.22	139.15	77.85	0.40	4.22	77.85	1.73	1.53
	56	12/07/89	16.22	150.50	83.96	0.36	4.41	83.96	1.87	1.65
	58	12/09/89	19.56	147.76	77.91	0.43	5.17	77.91	1.73	1.53
7	61	12/12/89	15.65	159.00	86.72	0.35	4.14	86.72	1.93	1.71
	63	12/14/89	16.60	160.70	87.32	0.37	4.48	87.32	1.94	1.72
	65	12/16/89	14.00	154.29	74.48	0.31	3.84	74.48	1.66	1.47
8	68	12/19/89	11.38	135.13	69.20	0.25	3.09	69.20	1.54	1.36
	70	12/21/89	12.41	129.26	66.17	0.28	3.14	66.17	1.47	1.30
	72	12/23/89	11.48	123.50	64.91	0.26	2.81	64.91	1.44	1.28
9	75	12/26/89	6.15	112.08	66.99	0.14	1.69	66.99	1.49	1.32
	79	12/30/89	5.60	86.96	54.55	0.12	1.48	54.55	1.21	1.07
	84	01/04/90	5.00	84.75	55.67	0.11	1.22	55.67	1.24	1.10
	91	01/11/90	5.22	91.83	61.26	0.12	1.25	61.26	1.36	1.21
	96	01/16/90	5.88	91.35	61.48	0.13	1.37	61.48	1.37	1.21
	98	01/18/90	5.24	72.54	49.91	0.12	1.23	49.91	1.11	0.98
	102	01/22/90	5.72	73.50	50.81	0.13	1.11	50.81	1.13	1.00
	104	01/24/90	5.38	71.76	50.15	0.12	1.03	50.15	1.11	0.99
	107	01/27/90	5.29	73.36	51.17	0.12	1.05	51.17	1.14	1.01

TABLE D5.4 RESPONSE DATA OF GAS PRODUCTION/COMPOSITION/LOADING RATE (M-UASB) DURING THE MAXIMIZATION AND RECOVERY PERIOD (cont'd)

EXP. NOs.	DAY	DATE	SPECIFIC GAS PRODUCTION [CH4] M3/KgCOD(SOL) ADDED	M3/KgCOD(SOL) ADDED @ SC	GAS ANALYSIS COMPOSITIONS, % C02	N2	CH4
1	1	10/13/89	1.28	1.14	28.78		71.22
	4	10/16/89	0.95	0.84	28.92		71.08
	6	10/18/89	1.06	0.94	29.46		70.53
	8	10/20/89	1.15	1.02	29.59		70.42
	11	10/23/89	1.04	0.92	29.37	0.77	69.85
	13	10/25/89	0.90	0.80	30.27		69.73
	15	10/27/89	1.00	0.88	30.56		69.42
2	20	11/01/89	1.23	1.09	31.21		68.79
	22	11/03/89	1.10	0.98	31.55		68.43
	25	11/06/89	1.12	1.00	31.70		68.27
	27	11/08/89	1.03	0.91	30.52	1.12	68.33
	29	11/10/89	1.10	0.98	30.74		69.24
3	33	11/14/89	1.16	1.03	27.57	1.27	71.17
	35	11/16/89	0.91	0.81	29.75		70.23
	37	11/18/89	1.04	0.92	31.03	0.65	68.35
4	40	11/21/89	0.75	0.67	34.87		65.13
	42	11/23/89	0.69	0.61	37.53		62.45
	44	11/25/89	0.60	0.53	37.07		62.93
5	47	11/28/89	0.30	0.26	43.10	1.96	54.95
	49	11/30/89	0.21	0.19	46.92	1.72	51.36
	51	12/02/89	0.24	0.22	50.05		49.95
6	54	12/05/89	0.41	0.36	43.05	0.98	55.95
	56	12/07/89	0.42	0.37	43.10	1.08	55.79
	58	12/09/89	0.34	0.30	47.28		52.73
7	61	12/12/89	0.47	0.41	45.43		54.54
	63	12/14/89	0.43	0.38	45.69		54.34
	65	12/16/89	0.43	0.38	51.73		48.27
8	68	12/19/89	0.50	0.44	48.79		51.21
	70	12/21/89	0.47	0.42	48.04	0.77	51.19
	72	12/23/89	0.51	0.46	46.74	0.70	52.56
9	75	12/26/89	0.88	0.78	40.22		59.77
	79	12/30/89	0.82	0.73	36.52	0.75	62.73
	84	01/04/90	1.02	0.90	33.43	0.88	65.69
	91	01/11/90	1.09	0.97	32.34	0.95	66.71
	96	01/16/90	1.00	0.88	31.66	1.04	67.30
	98	01/18/90	0.90	0.80	30.70	0.50	68.80
	102	01/22/90	1.02	0.90	30.11	0.76	69.13
	104	01/24/90	1.08	0.96	29.32	0.78	69.88
	107	01/27/90	1.08	0.96	29.43	0.81	69.75

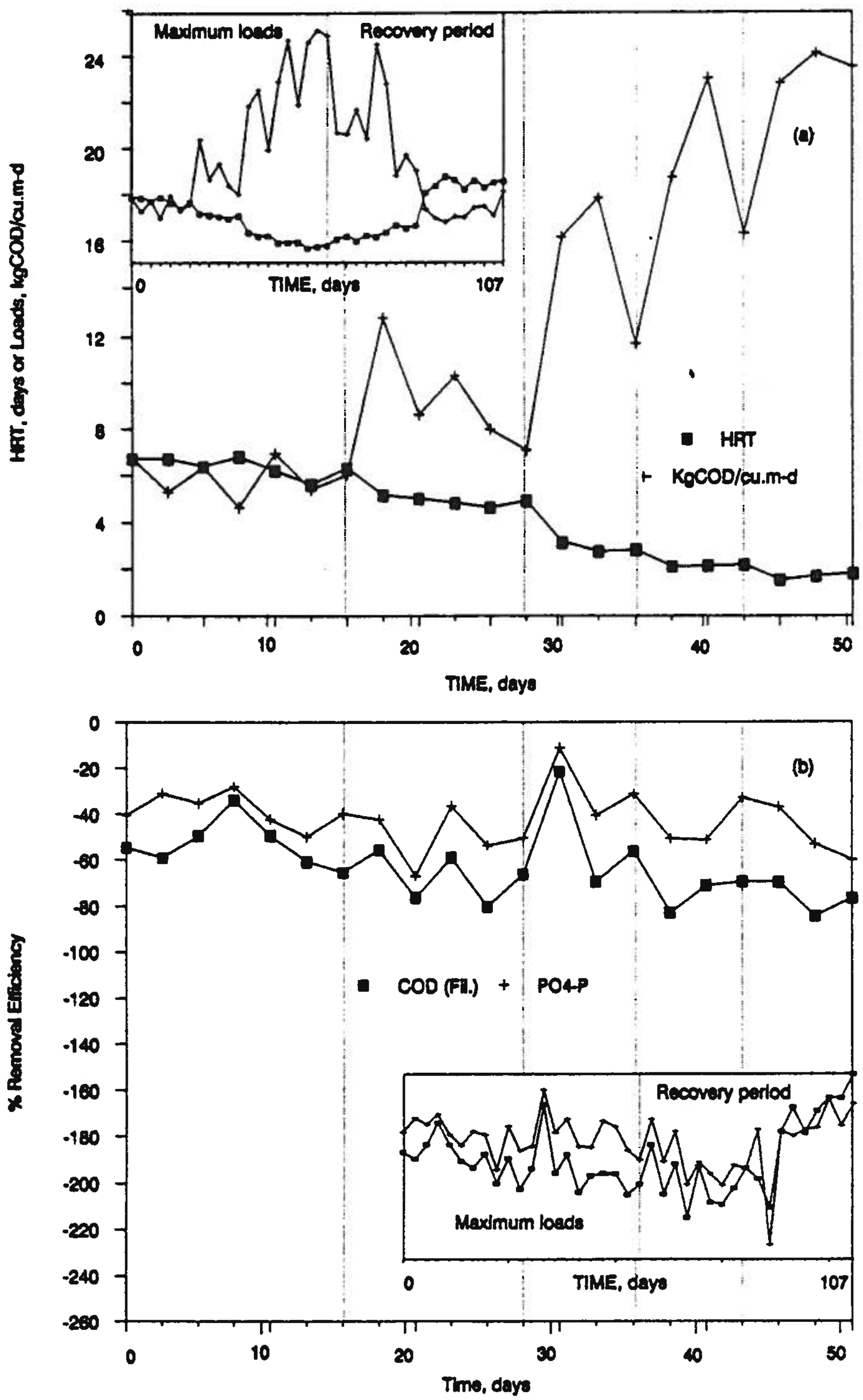


Figure D1.1 An A-UASB Step-loading and Removal Efficiency:

During the system maximization

(a) HRT,Kg COD/cu.m-d; (b) Removal efficiency

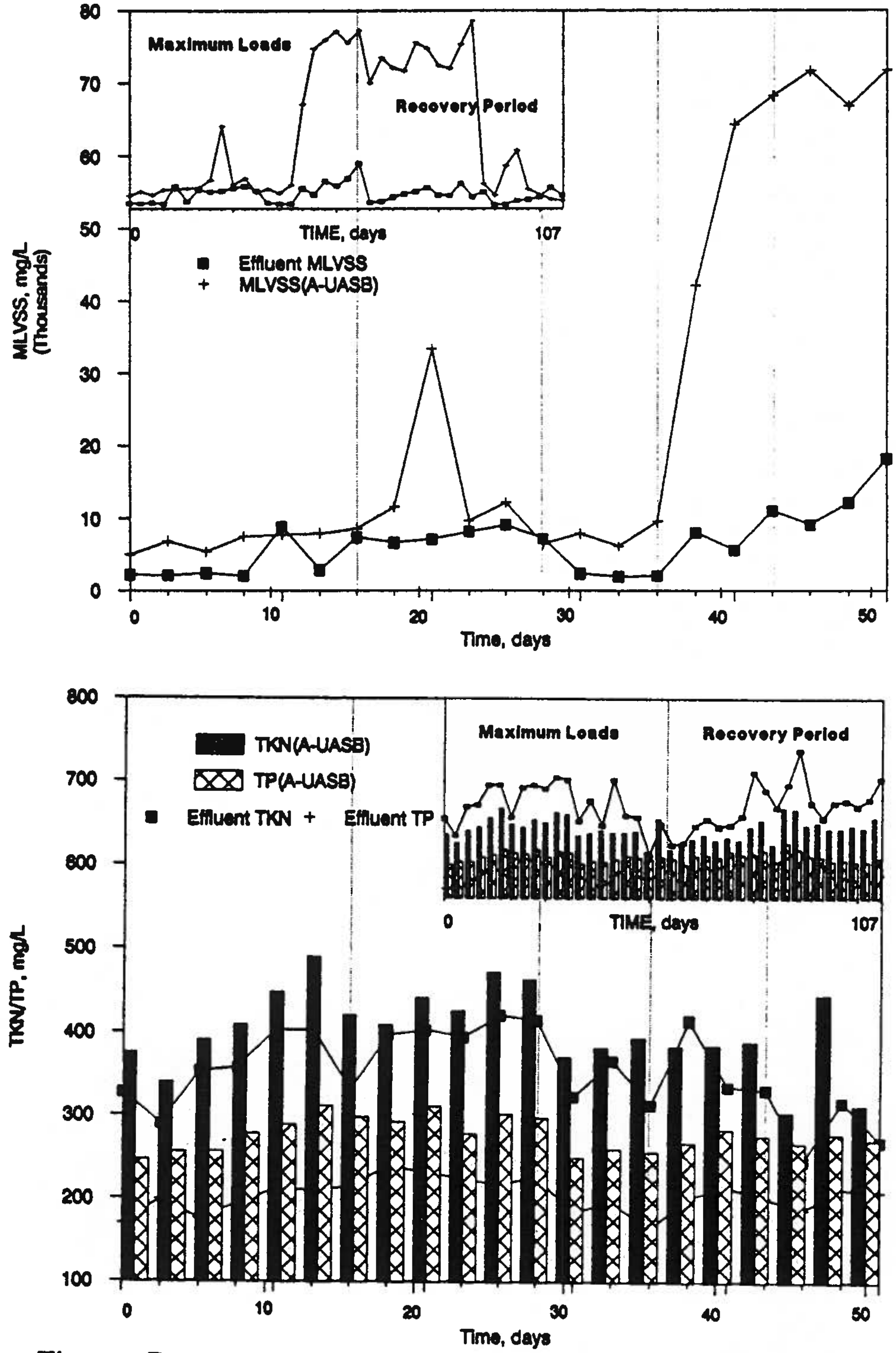


Figure D2.1 An A-UASB System Nutrients and MLVSS:

During the process maximization

(a) Effluent MLVSS,MLVSS(A-UASB); (b) TKN,TP