OXYGEN TRANSFER IN A STIRRED TANK

by

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B.E., University of Shizuoka, 1966

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE

in the Department

of

CHEMICAL ENGINEERING

We accept this thesis as conforming to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

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ABSTRACT

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Microbiological leaching of sulfide minerals in fermenters is believed to have commercial potential. The oxygen transfer rate has been assumed to be one of the most important factors affecting the leach rate.

The mass-transfer rate at various solution pH's was studied by using an unsteady gassing out process. The sulfite-oxidation process was also studied in an attempt to explain the absorption mechanism.

A 7.5 inch I.D. methyl methacrylate tank with 4 baffles and a 4-inch diameter paddle type impeller were used. The impeller was driven by a motor mounted on a dynamometer which allowed measurement of the power used in agitation. All the experiments were carried out under highly turbulent conditions and covered the liquid temperature range 25° C to 40° C.

The results showed that pH had no effect on mass-transfer coefficient. The values of K_L^a increased as temperature increased. The relationship between K_L^a , power input and superficial gas velocity was found to be of the form:

 $K_{L}a = c(HP/V)^{X} (V_{S})^{Y}$

A comparison of the K_L observed in an unsteady gassing out process and that in a sulfite-oxidation process showed that the interfacial area/unit volume of liquid, a, is directly proportional to $(V_s)^{0.50}$ which coincides with Calderbank's result.

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ACKNOWLEDGEMENT

I wish to thank Professor Richard Branion of the Department of Chemical Engineering of the University of British Columbia, Dr. D. W. Duncan and Dr. C. C. Walden of the British Columbia Research Council for their guidance and helpful suggestions in carrying out this project.

I wish to thank the British Columbia Research Council for use of facilities and equipment and for financial assistance.

I wish also to thank Dr. J. S. Forsyth, the Head of the Department of Chemical Engineering of the University of British Columbia for lending the agitation equipment and for additional financial support.

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NOMENCLATURE

а	interfacial area per unit volume, ft^2/ft^3
b	stoichiometric coefficients for reacting substance B
c	concentration of liquid, g moles/1
Ci	concentration of component in gas-liquid interface, g moles/1
C*	concentration of component in liquid which would be in equilibrium with partial pressure of component in the gas phase, g moles/l
CB	concentration of reacting component in liquid, g moles/l
D _A	molecular diffusivity of component A, cm ² /hr
DB	molecular diffusivity of component B, cm ² /hr
DI	impeller diameter, ft
Dp	mean diameter of bubbles, cm
g	gravitational constant, cm/sec ²
Н	Henry's constant, g moles/l atm
Но	gas hold up, %
(HP/V)	power input, horsepower/1000 gallons of liquid
kl	reaction rate constant, $(conc)^{n-1}/(TIME)^n$
k _G	mass transfer coefficient for gas film, g moles/hr cm ² atm
kL	mass transfer coefficient for liquid, cm/hr
К _G	over-all mass-transfer coefficient based on gas-film control, g moles/hr cm ² atm
к _L	over-all mass-transfer coefficient based on liquid-film control, cm/hr
NA	mass-transfer rate, g moles/hr ft ²
NAl	mass-transfer rate of species A per unit area, g moles/hr ft 2
NB ¹	mass-transfer rate of species B per unit area, g moles/hr ft 2
N	agitation speed, rpm
Nsc	Schmidt number, dimensionless
P	partial pressure in gas phase, atm

Pi	partial pressure of component at gas-liquid interface, atm
P*	partial pressure of component which would be in equilibrium with concentration of liquid, atm
(Pg/V)	power input, erg/ml of liquid
Q	air flow rate, ft ³ /hr
t	time, hr
Т	absolute temperature, ^O K
Vs	superficial gas velocity, ft/hr
V _t	terminal superficial gas velocity, ft/hr
x	constant
X _L	liquid-film thickness, cm
У	constant
Z	constant
σ	surface tension, dyne/cm
ρ _c	continuous phase viscosity, g/cm ³
βd	dispersed phase viscosity, g/cm^3
ρ _L	density of liquid, g/cm ³
Δρ	density difference, g/cm ³
μc	continuous phase viscosity, centipoise
μĨ	dispersed phase viscosity, centipoise
ξ	reaction coefficient

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INTRODUCTION

The bacterium, Thiobacillus ferrooxidans, is unique among bacteria in that it can oxidize ferrous iron and reduced sulfur compounds utilizing the energy so derived for its life processes. When metallic sulfides are oxidized, the release of associated metals into solution may be of considerable economic value. Microbiological leaching of metallic sulfides is currently used commercially in the leaching of waste dumps or abandoned areas of mines. It has a potential use in the leaching of sulfide concentrates utilizing tank type fermenters. In such a system a pulp of finely ground sulfide mineral in water would be aerated and agitated in a suitable vessel in the presence of T. ferrooxidans and nutrients essential for growth. The bacteria would oxidize the sulfide to sulfate releasing the associated metal ions into solution. A better understanding of the various factors influencing bacterial growth and the microbiological dissociation of sulfides may aid in improving the efficiency of the biological leaching process and lead to its increased utilization.

Oxygen transfer has been assumed to be one of the most important rate controlling factors, because the oxygen demand in oxidizing sulfide to sulfate is large. Moreover, the respiratory enzymes can utilize only dissolved oxygen and oxygen is so insoluble that at any time only a small reservoir exists in solution (at 35°C for example, water in equilibrium with air contains about 7 ppm of oxygen). The microorganisms are continuously drawing upon this reservoir and the supply must be replenished at a rate adequate to satisfy the demand in every portion of the culture fluid. Otherwise, there will be local or temporary depletion of oxygen which may damage the respiring cells. The oxygen uptake rate for a resting cell suspension of <u>T. ferro-oxidans</u> can be as high as 22,000 microliters of oxygen per milligram of cell nitrogen per hour, when oxidizing ferrous iron (1). When oxidizing chalco-pyrite the oxygen uptake rate has been reported to be as high as 8,524 μ 1/mg N/hr for resting cell suspensions (2). However, when the organism was growing on chalcopyrite the maximum rate of oxygen utilization was 756 mg/1/hr (3).

Individual rate processes for the transfer of oxygen from the air to the respiratory enzyme system may be summarized as follows:

- Diffusional transfer from the air to the gas-liquid interface.
- (2) Diffusional transfer through the liquid film.
- (3) Diffusional or convective transfer through the liquid to the cells.
- (4) Diffusion through the film which surrounds the cell wall.
- (5) Diffusion across the cell wall to the cell membrane.
- (6) Chemical reaction with oxidizable substances through the mediation of the cell enzymes.

Each individual process must have a rate at least equal to the over-all rate; i.e., the over-all rate of the transfer can not exceed the lowest individual rate.

It has been assumed in most biological processes that the diffusional transfer of oxygen from the air to the liquid medium is a limiting factor in the rate of metabolism. Since the biological leaching of chalcopyrite is to be carried out at an optimum temperature of 35^oC and at pH values of 1.0 to 3.0, a knowledge of oxygen transfer rates under these conditions was required. Data at such pH values were not available prior to this study.

The object of this study was to attempt to obtain a correlation between over-all mass-transfer coefficient and the pH and temperature of the solution. At the same time the effects of various other parameters such as superficial velocity of the air and agitation speed were evaluated. This knowledge should allow one to predict the maximum leach rates possible if oxygen transfer is the rate limiting step in the microbiological oxidation of sulfides.

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SURVEY OF LITERATURE

A. Over-all Mass Transfer Coefficient

The rate of dissolution of oxygen is proportional to the depletion of dissolved oxygen in the liquid. The rate is also proportional to the interfacial area, and therefore, one may write for a unit volume of culture fluid

rate of absorption,
$$N_{A} = k_{G}a (P-P_{i}) = k_{L}a (C_{i}-C) -- (1)$$

 $N_{A} = K_{L}a (C^{*}-C) = K_{G}a (P-P^{*}) -- (2)$

The product of K_L and a can be found indirectly through a knowledge of C^* (by Henry's Law), and C (by measurement) and the rate of absorption N_A (by measurement). Since, in a steady state, the rate of absorption exactly equals the rate of demand

$$K_{\rm L}a = N_{\rm A}^{\prime}/(C^* - C)$$
 -- (3)

 K_L a provides an over-all measure of the gas absorbing capacity of any fermenter. It is in fact the only practical way to characterize the performance of laboratory or industrial devices.

B. Controlling Resistances

The proportionality constant K_L in equation (2) is the over-all mass transfer coefficient. Its reciprocal, $1/K_L$, an over-all resistance, is equal to the sum of the separate resistances residing in the gas film, the interface and the liquid film.

Chiang and Toor (4) and Scriven and Pigford (5) found in laminar liquid jet experiments that little interfacial resistance existed. Therefore the over-all resistance, as shown by equation (4)

$$1/K_{L}a = 1/k_{L}a + 1/H k_{C}a -- (4)$$

indicates that when k_{G}^{a} is large compared to k_{L}^{a} , the term $1/k_{G}^{a}$ is negligible compared to the term $1/k_{L}^{a}$ and the over-all transfer coefficient approximately equals the liquid phase coefficient. In such a case, it is said that the liquid phase constitutes the controlling resistance of the operation.

Experiments have shown that liquid film resistance was controlling for oxygen transfer in bubble aeration (6). Even under conditions of minimum mass-transfer rate in the gas film, Calderbank (7) showed that the mass-transfer coefficient of the gas film was at least 44 times higher than that of the liquid film.

C. Sulfite-Oxidation Process

Oxygen absorption rates can be determined practically in several ways, among which the sulfite oxidation process of Cooper <u>et al</u> (8) is used perhaps the most frequently for aeration rate studies. Basically, this method depends on the oxidation of sulfite to sulfate by oxygen in the presence of a catalyst according to equation (5).

$$SO_3^{\ddagger} + \frac{1}{2} O_2 \xrightarrow{Cu^{++}} SO_4^{\ddagger} \xrightarrow{--} (5)$$

Catalyst

The reaction is considered to be zero order with respect to both sulfite and sulfate concentrations and the reaction rate is considered to be sufficiently fast so that it is not the rate limiting step. In Cooper's procedure a sulfite solution is aerated for a measured time; a known excess of iodine is then added to react with the unoxidized sulfite and the unreacted iodine is titrated with sodium thiosulfate. By calculation, the amount of sulfite converted to sulfate may be determined; and hence, the amount of oxygen going into solution during the measured time interval can be calculated.

At any time the amount of unreacted, dissolved oxygen in the solution can be assumed to be zero because the chemical reaction rate is much faster than the rate of solution of oxygen. Therefore when C = 0, equation (3) becomes

$$\kappa_{\underline{E}} a = N_{\underline{A}} / C^* \qquad -- (6)$$

The saturation values (C^{*}) for oxygen in sulfite solutions can be calculated from the data of MacArthur (9). In very dilute solutions the values can be assumed to be the same as those in pure water. The rate of absorption (N_A) is determined experimentally and hence, values of K_L a are obtained.

Miyamoto (10, 11, 12, 13) has presented a comprehensive study of the sulfite-oxygen system. He found the absorption rate to be directly proportional to oxygen partial pressure and interfacial area. It increased with temperature, exhibiting an activation energy of approximately 12.5 kcal/mole.

Fuller and Crist (14) later made a very careful study of the reaction rate. The uncatalyzed reaction rate was found to be first-order with respect to sulfite. Westerterp <u>et al</u> (15) found that the copper-catalyzed sulfite-oxygen reaction was zero-order with respect to sulfite concentration and first-order with respect to the dissolved oxygen concentration.

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Phillips and Johnson (16) measured the effect of oxygen partial pressure on the rate of oxidation of copper- and cobalt-catalyzed sulfite solution in both sparged and unsparged cylinders. They found that in the sparged system the rate of oxidation varied directly with oxygen partial pressure. For the unsparged cylinder, at low turbulence levels, the rate of oxidation varied as the 1.5 power of the partial pressure of oxygen, and at high turbulence levels it varied directly, as for the sparged system. They derived one equation for low turbulence absorption where it was assumed that all of the oxygen-sulfite reaction occurred in the stagnant liquid film. This equation was second-order with respect to oxygen concentration and first-order with respect to sulfite concentration. A second equation was given for highly turbulent conditions in which it was assumed that the chemical reaction occurred in the bulk of the liquid. Under these conditions the transfer rate was independent of sulfite concentration and varied directly with oxygen partial pressure. The oxygen uptake rate determined under these highly turbulent conditions was considered to be the maximum rate at which oxygen could be transferred from the gas phase into a fermentation liquid.

Murphy <u>et al</u> (17) investigated aeration in tower-type fermenters in which air was introduced at the base of the fermenter through porous discs. They found that the rate of oxidation of copper-catalyzed sulfite solutions was strongly dependent on the total amount of sulfite and sulfate present, and not on the concentration of sulfite alone. For initial concentration of sulfite in the range 0.10 to 0.20 N the rate was highly dependent on the concentration. They attributed this to the dependence of bubble size on normality of the solution.

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Roxburgh (18) studied the effect of different catalysts on the oxidation of sodium sulfite solutions in several different types of equipment and showed radical differences in rates between copper-, cobalt-, nickel-, and iron-catalyzed systems. He also observed that the rate found for any single catalyst system depended to an appreciable extent on the pH of the sulfite solution.

Fuller and Crist (14) found that the rate of sulfite oxidation was independent of the pH between 8.2 and 8.8 but decreased in a complicated way between 3.2 and 5.9. This was accounted for by assuming that the rate was dependent on the sulfite ion concentration and the square root of the hydrogen ion concentration, but was independent of the acid sulfite ion concentration. They also found that the reaction system was very sensitive to both positive and negative catalysis. However, increased cupric ion concentration had no effect on the reaction rate at concentrations above 10^{-4} M.

Robinson and Engel (19) found that the copper-catalyzed sulfiteoxygen reaction rate was even slower than the uncatalyzed reaction rate. They recommended the use of a cobalt catalyst instead of a copper catalyst.

Carpani and Roxburg (20) found that the rate of oxidation of copper-catalyzed sulfite solutions decreased as agitation was increased in an unbaffled stirred jar in which oxygen could enter the liquid only through the horizontal air-liquid interface. This was contradictory to the results they found for oxygen transfer to water and sodium chloride solutions, where transfer rates increased with increasing agitation. Schultz and Gaden (21) had previously reported a similar phenomenon, and explained it on the basis of a chain mechanism for the oxidation of sulfite, with the requirement of an induction period for the concentration of intermediates to build up.

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Phillips (22), using three horizontal fermenters, rotating at peripheral velocities in excess of 100 cm/sec, found that the rate of oxygen transfer to catalyzed sodium sulfite solutions was similar to those for fermentations. However, at peripheral velocities below 100 cm/sec some unknown factors apparently affected the reaction kinetics and the resulting transfer rates were considerably higher than those observed for oxygen transfer to fermentations.

Carpani and Roxburgh, and Phillips were not dealing with the mass transfer from air bubbles to liquid but with transfer from air to flat liquid surfaces. Apparently, this kind of transfer was less affected than air bubble-liquid transfer by the properties of the liquid (23).

The kinetics and mechanism of the oxidation of sulfite have been extensively studied and mechanisms have been proposed by several authors, the most noteworthy being Laidler (24), who postulated a free radical ion intermediate. Nevertheless, many questions concerning this reaction remain unanswered. The sulfite-oxidation process has also been found not suitable for comparison of the over-all mass-transfer rate at low pH values, because as shown by Fuller and Crist (14), the rate of the sulfite-oxygen reaction was so slow at low pH values that it became the rate limiting step.

However, the dependence of the reaction rate of the copper-catalyzed sulfite-oxygen reaction on the unreacted sulfite concentration was studied as part of this thesis. The data were compared with those obtained by an unsteady gassing out process. An attempt was made to explain the absorption mechanism in the sulfite-oxidation process.

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D. Unsteady Gassing Out Process

A gassing out process appeared to be the only way of measuring K_La in a liquid medium at low pH. Under these conditions of low pH dissolved oxygen can be determined either by the Modified Winkler Method Appendix (I) or by the use of an oxygen analyser. Saturation values can be determined at any pH. Data from International Critical tables (25) showed that when air was brought into contact with 0.5 N sulfuric acid, the saturation oxygen concentration was 7.05 ppm at 25°C, the value in pure water under the same condition is 7.50 ppm.

The mass transfer coefficient can be calculated from the integral form of the rate equation either graphically or numerically,

$$\frac{dC}{dt} = K_{L}a \quad (C^* - C) \qquad -- (7)$$

on integration

$$K_{La} = \frac{1}{(t_2 - t_1)} \qquad \ln \frac{(C^* - C_1)}{(C^* - C_2)} \qquad -- (8)$$

E. <u>Mass Transfer with Chemical Reaction (Sulfite-Oxidation Process) and</u> without Chemical Reaction (Unsteady Gassing Out Process)

Theoretical equations for simultaneous diffusion and chemical reaction in the liquid phase have been derived. The first attempt was made by Hatta (26). He applied Lewis and Whitman's two film theory (27) to the absorption of carbon dioxide in alkali solution. Derivations based on the unsteady-state theories of Higbie and Danckwerts have been given in many papers (28). From a physical point of view, the unsteady-state theories are probably more correct, but all these models give qualitatively the same results as the film theory (29). Because of this and the simplicity of the film theory, we shall deal with it exclusively.

The film theory assumes that the resistance to diffusion is concentrated in both the gas and liquid films which are adjacent to the gas-liquid interface, that the concentration profile is independent of time, i.e., at steady state, and that instantaneous equilibrium between P_i and C_i is established as soon as the gas contacts the liquid (Figure 1). Figure 1 shows the concentration profiles in the two films.

(1) Infinitely Fast Reaction

When the reaction is infinitely fast according to the equation,

A (gas phase) + b B (liquid phase) \longrightarrow product -- (9)

A will dissolve and react immediately with B at the phase boundary. The product will begin to diffuse toward the main body of liquid. The concentration profiles for this case would be as shown in Figure 2.

In a unit contact area, the diffusion rate of A and B in the liquid phase can be expressed as:

$$N_{A}^{1} = \frac{D_{A}}{fx_{L}} (C_{i} - 0)$$
 -- (10)

$$N_B^{1} = \frac{D_B}{(1-f)x_L}$$
 $(C_B^{-} 0) = \frac{SD_A}{(1-f)x_L}$ $C_B^{-} - (11)$

where S = $D_{\rm B}/D_{\rm A}$ and f is as shown in Figure 2.

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(C AND P) WITHIN THE EFFECTIVE FILMS CHANGE LINEARLY WITH DISTANCE FROM THE INTERPHASE

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FIG 2. SKETCH OF GRADIENTS IN DOUBLE FILM WITH IRREVERSIBLE INSTANTANEOUS REACTION FOLLOWING ABSORPTION At steady state $N_B^1 = N_A^1 b$, therefore by combining equation (10) and (11), solving for f and substituting in equation (10),

$$N_{A}^{1} = \frac{D_{A}}{x_{L}} C_{i} \left(1 + \frac{S}{b} \frac{C_{B}}{C_{i}} \right) = K_{L} C_{i} \left(1 + \frac{S}{b} \frac{C_{B}}{C_{i}} \right) - (12)$$

Since $C_i = H P_i$, equation (12) can be rearranged as:

$$N_{A}^{1} = \frac{P_{A} + S C_{B}^{\prime}/b.H}{1/k_{G} + 1/Hk_{L}} = \frac{C^{*} + S C_{B}^{\prime}/b}{H/k_{G} + 1/k_{L}} -- (13)$$

where $C^* = HP_A$

when there is no chemical reaction

$$N_A^1 = k_L C_i$$

The reaction coefficient

 $\xi = \frac{\frac{N_A}{1} \text{ with reaction}}{N_A \text{ without reaction}} = 1 + qS -- (14)$

$$\hat{w}$$
here, q = C_B/b C_i

The derivation of equation (13) follows that of Hatta (26), who was interested in the batch absorption of CO_2 by KOH solutions.

(2) Irreversible-Pseudo-First-Order-Slow-Reaction

If the reaction is a pseudo-first-order reaction and the reactant in the liquid is insoluble in the gas, i.e., the zone of reaction is in the liquid film, the diffusion rate = reaction rate (30). Therefore,

$$D = \frac{d^2 C_A}{dx^2} = k_1 C_A -- (15)$$

The boundary conditions are:

$$x = o$$
 $C_A = C_i$
 $x = x_L$ $C_A = C_L$ -- (16)

Solution of (15) and (16) gives:

$$N_{A} \left| x=o = -D \right| \frac{dC_{A}}{dx} \left| x = o = \frac{DC_{i}}{x_{L}} \left(\frac{b_{1} \cosh b_{1} - b_{1}F}{\sinh b_{L}} \right) - (17)$$

$$(N_{A}) \text{ no reaction} = -D \left| \frac{dC_{A}}{dx} \right| x=o \text{ no reaction} = \frac{DC_{i}}{x_{L}} (1-F) - (18)$$

$$\frac{1}{\sqrt{1-2}}$$

where $b_1 = \sqrt{k_1 x_L^2/D}$, $\Gamma = C_L/C_i$

In the special case where the concentration of A in the main body of liquid is low, equation (17) may be written

$$N_{A} | x=0 = \frac{bD (C_{i} - C_{L})}{x_{L}} -- (19)$$
where $b = \frac{b_{1}}{tanh b_{1}} > 1.0$

$$(K_{L}) \text{ reaction} = \frac{N_{A}|x=0}{(C_{i} - C_{L})} = b \frac{D}{x_{L}} -- (20)$$

(K_L) no reaction =
$$\frac{D}{x_L}$$
 -- (21)

The reaction coefficient

$$\xi = \frac{(K_L) \text{ reaction}}{(K_L) \text{ no reaction}} = \frac{b_1}{\tanh b_1} > 1.0 \qquad -- (22)$$

The ratio of mass-transfer coefficients is always greater than 1.0. It depends on the reaction rate constant, film thickness and diffusivity. If $b_1 > 5$, ξ nearly equals b_1 , and it equals b. Therefore the absorption rate becomes

$$N_{A} = \sqrt{k_{1}D} C_{i} \qquad -- (23)$$

With a very fast reaction the absorption rate will be a constant, which is independent of the film thickness. It should be pointed out that the magnitudes of $k_{\rm G}$, $k_{\rm L}$, H, C_i, C^{*} in the above equations are different to those for purely physical absorption, because the properties should be adjusted to allow for the presence of salts. But with very dilute solutions, we can assume that all the values are the same in both situations.

F. Factors Affecting the Values of Mass-Transfer Coefficients

(1) Effect of Liquid Temperature on K a

Robinson and Engel (19) made a series of runs over the liquid temperature range 65[°] to 105[°] F, with a single-stage cycled apparatus and found that the temperature dependence of the over-all mass-transfer coefficient was not significantly greater than the normal experimental scatter.

O'Connor (31) studied the effect of temperature on the value of K a and found the following relationship to exist:

$$\frac{K_{L}a(t_{1})}{K_{L}a(t_{2})} = \sqrt{\frac{T_{1}\mu_{2}}{T_{2}\mu_{1}}}$$
(24)

This equation was derived on the basis of oxygen transfer during bubble aeration of an activated-sludge process for the biological treatment of waste.

Yoshida (32) found that in oxygen-water contactors, the effect of temperature on K_L^a was slight. At 20[°] and 40[°] C values of K_L^a coincided over the entire experimental range of agitator speeds 100 to 600 rpm, indicating that at those two temperatures the effect of temperature on K_L^a and on the interfacial area, a, offset each other. The values of K_L^a at 7[°] C were found to be about 25% lower than at 20[°] C for the same agitator speed.

As far as fermentation is concerned only a narrow range of temperature is of any interest. Thus the present experiments covered a liquid temperature range from 25[°] C to 40[°] C.

(2) Effect of Liquid Depth on K a

Yoshida (32) used oxygen-water contactors and found that the effect of the ratio of liquid depth to tank diameter on K_L a was negligible for ratios less than 1.0, but it becomes appreciable for values above unity, e.g., at 1.4, values of K_L a are reduced about 30% from those at unity. An empirical factor (f_c) was presented in graphical form by Cooper <u>et al</u> (8) to correct for the case in which the ratio of liquid height to vessel diameter, H_L/D_r , deviates from 1.0.

$$K_L a = f_c (K_L a)_{H_L} / D_t = 1.0$$
 -- (25)
e.g., when $H_L / D_t = 2.0$

Bewtra and Nicholas (33) performed aeration tests in a 4-foot deep aeration tank and found a linear relationship between percent oxygen absorbed from the inlet air stream and depth. The oxygen absorption efficiency increased as the water depth increased. To evaluate the contribution of surface aeration and transfer during formation, they extended their plot of absorption efficiency versus depth to zero depth and considered the intercept on the vertical axis as the contribution of oxygen transfer occurring during bubble formation and at the surface. They assumed that gas transfer occurring at bubble formation and the surface was independent of depth. Aiba et al (34) made the same assumption when they extended a plot of K_La versus depth to zero depth in order to evaluate the contribution of transfer during bubble formation and at the surface.

Radford (35) found that in a 7.5-inch I.D. lucite column the overall transfer coefficient, $K_{L}a$, was essentially independent of water depth from 1 to 7 feet at an air flow rate of 2300 ml/min. There was only a slight variation in $K_{L}a$ with depth at a flow rate of 1150 ml/min.

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Obviously, the oxygen absorption efficiency will be increased as the water depth is increased, because of the longer retention time of air bubbles in the water at greater depths. On the other hand, the effect of liquid depth on the values of K_L a does not appear straightforward. Yoshida's (32) and Cooper's (8) results contradict each other. This present work does not resolve this conflict because liquid depth was maintained at a constant level. Since the true oxygen transfer rate from the air bubbles to the liquid must be calculated by subtracting the amount of oxygen transfer by surface aeration from the total aeration rate, the magnitude of surface aeration should be studied.

According to equation (3)

$$K_{L}a = N_{A}/(C^{*} - C)$$
 -- (3)

where C^* is the concentration of oxygen in the liquid that would be in equilibrium with the partial pressure of oxygen in the air. However, there is some debate over what value of $(C^* - C)$ should be used. Cooper <u>et al</u> (8) have assumed C = 0 and have based the concentration driving force on C^* in equilibrium with the inlet gas stream. But when the liquid medium is perfectly mixed, the proper driving force would be based on C^* of the outlet gas stream. If liquid depth in the tank is comparably high, a logarithmic mean driving force based on C^* at the gas inlet and C^* at the gas outlet should be used.

(3) Effect of Gas Superficial Velocity and Power Input

To correlate the mass_transfer coefficients in agitated vessels to the pertinent operating variables, equations of the following form are often encountered:

$$K_{L}^{a} \alpha (HP/V)^{x} (V_{s})^{y} -- (26)$$

or

$$K_{L}^{a} \alpha (N)^{z} (V_{s}^{v})^{y}$$
 -- (27)

The relationship between K_L and power input at constant gas flow rate obtained by Cooper (8) for a vaned-disc impeller was:

$$K_{L}a \propto (HP/V)^{0.95} (V_{s})^{0.67}$$
 -- (28)

whereas Augenstein and Wong (36) showed that the following relationship existed:

$$K_{L}^{a} \alpha (HP/V)^{0.85} (V_{s})^{0.2}$$
 for (HP/V) < 40.0 -- (29)

However, when the agitator power was increased above 40 HP/1000 gallons the dependence of K_{I} a on power input was found to be drastically reduced. Thus

$$K_{L}^{a} \alpha (HP/V)^{0.57} (V_{s})^{0.2}$$
 for $(HP/V) > 40.0$ -- (30)

the latter authors postulated that for power inputs greater than 40 HP/1000 gallons the increase in the over-all mass-transfer coefficient was due to a combination of a decrease in the average bubble size and possibly an increase in the $K_{\rm L}$ arising from an increase in the velocity of the bubbles.

The same authors showed that for gas flow rates equivalent to a superficial gas velocity of 39.6 ft/hr, the mass-transfer coefficient was proportional only to the 0.2 power of the gas velocity. A further increase in the gas flow had no effect on the mass transfer coefficient. These findings were in general agreement with the results reported by Westerterp $\underline{et} \ \underline{al} \ (15).$

It has been recommended (37) that equation 28 be applied under the following conditions (V_s < 90 m/hr) for one set of impellers and (V_s < 150 m/hr) for two sets of impellers, provided:

$$(HP/V) > 0.1 HP/m^3$$
 and $H_L/D_t = 1.0$

For a paddle impeller

$$K_{L}^{a} \alpha (HP/V)^{0.53} (V_{s})^{0.67} -- (31)$$

provided:

$$V_s < 21.0 \text{ m/hr}, \text{HP/V} > 0.06 \text{HP/m}^3, \text{H}_L/D_t = 1.0$$

Using the light-transmission technique, Calderbank (7,38) found the mean diameter for dispersions of gas bubbles in solutions of electrolytes to be:

$$D_{\rm P} = 2.25 \qquad \frac{\sigma}{({\rm Pg/V})^{0.4} \rho_{\rm c}^{0.2}} \qquad H_{\rm o}^{0.40} \qquad \frac{(\mu_{\rm d})^{0.25}}{(\mu_{\rm c})} \qquad -- (32)$$

For dispersions of gas bubbles in aqueous solutions of alcohols he found:

$$D_{\rm P} = 1.90 \quad \frac{\sigma^{0.6}}{({\rm Pg/V})^{0.4} \rho_{\rm c}^{0.2}} \quad H_{\rm o}^{0.65} \quad \left(\frac{\mu_{\rm d}}{\mu_{\rm c}}\right)^{0.25} \quad -- (33)$$

The bubble sizes in pure liquids were greater than in electrolytes. Calderbank explained this could be attributed to the greater ease of bubble coalescence in the pure liquids. He concluded that the bubbles close to the tip of the impeller were not the mean values for the whole tank contents and proposed the equation:

a = 1.44
$$\frac{(Pg/V)^{0.4} \rho_c^{0.2}}{\sigma^{0.6}} \left(\frac{V_s}{V_t}\right)^{0.5}$$
 -- (34)

He also found two correlations for liquid-phase mass-transfer coefficients for the different sizes of the bubbles. For average bubble diameter greater than about 2.5 mm:

$$k_{\rm L} (N_{\rm sc})^{0.5} = 0.42 \left(\frac{\Delta \rho \ \mu \ g}{\rho_{\rm c}^2} \right)^{1/3}$$
 -- (35)

For average bubble diameter less than 2.5 mm:

$$k_{\rm L} (N_{\rm sc})^{2/3} = 0.31 \left(\frac{\Delta \rho \, \mu_{\rm c} \, g}{\rho_{\rm c}^2} \right)^{1/3}$$
 -- (36)

¢

Both equations show that k_{L} is independent of bubble size and rising velocity and depends only on the physical properties of the system. The presence of organic substances, solid particles, cells, etc., may affect the values of $K_{\rm L}a$ but they will not be examined as part of this thesis.

G. Effect of Aeration Rate on Power Consumption

The power consumption for an impeller operating at various speeds in a liquid can be predicted from published power number versus Reynold's number plots (39). However, similar plots are not available for gassed systems, since aeration causes changes in the liquid properties, (density and viscosity) in a manner which is not easily characterized.

Ohyama and Endoh (40) have correlated Pg/Po, with aeration number $Q/(ND_T^3)$ where:

$$\frac{Q}{(ND_{I}^{3})} = \frac{Q/D_{I}^{2}}{(ND_{I})} = \frac{Velocity \text{ of air through sectional area of tank}}{Tip velocity of impeller}$$
(Dimensionless)

The resulting curves were independent of physical properties of the liquids, but were dependent on the types of impellers and the geometrical ratio of the agitated vessels. Calderbank (38) and Moo-Young (41) used flat-blade impellers in aerated mixing vessels and found that the curves of Pg/Po vs. $Q/(ND_I^3)$ were independent of the properties of the liquids used.

Aiba (42) reached the opposite conclusion since his curves of Pg/Po vs. $Q/(ND_I^3)$ were dependent on the viscosity of the liquid for both Newtonian and non-Newtonian liquids.

EXPERIMENTAL DETAILS

I. APPARATUS

A. General

The apparatus consisted of a reactor, an impeller, an agitator with dynamometer, a nozzle, three saturators, a heating coil, a water bath, an oxygen analyser with electrode, a recorder, a mercury manometer, thermocouples, a thermometer, a variable flow meter, a needle valve, a temperature regulator, a relay, a tachometer, a liquid nitrogen cylinder and normal titration equipment.

B. Detail

(1) Reactor

The reactor was a cylindrical tank made of methyl methacrylate polymer, $7\frac{1}{2}$ inches I.D. and 24 inches high with an open top. Four baffles, each one-tenth of the tank diameter and extending the full depth of the tank, were symmetrically attached to the internal wall. A steel rule was attached to the tank wall as shown in Figure 3.

(2) Impeller

The stainless steel impeller had six straight, flat-blades, 4 inches in diameter, of the paddle type. It was located one impeller diameter above the bottom of the tank (Figure 3).

(3) Agitator with Dynamometer

A quarter horsepower BENCO model ELB experimental agitator with dynamometer accessory was used. Fastened to the motor, which rested on a nearly frictionless ball-bearing, was a rod that was attached to a spring balance. The displacement of the spring, due to the action of the rotating shaft could then be measured. The motor had an output speed of 0 to 1100 rpm.



(4) Nozzle

A stainless steel nozzle, having 18, 0.0260 in. I.D. holes (Figure 4), was mounted 1 inch below the impeller.

(5) Saturators

Three 1 & pyrex Erlenmeyer flasks filled with water were connected in series as an air saturator.

(6) Heating Coil

Air was preheated to the desired temperature by passing through an externally heated coil made of 3/8" O.D. copper tubing.

(7) Water Bath

The reactor, saturators and heating coil were kept in a 3' x 2' x $2\frac{1}{2}$ ' galvanized iron water bath. A one KW heater activated by a mercury thermoregulator, maintained the desired temperature (+ 0.5° C). An agitator driven by a 1/20 horsepower motor was used to circulate the water.

(8) Oxygen Analyzer with Electrode

A Beckman 39065 polarographic oxygen electrode was mounted through on the side of the reactor, two inches from the bottom (Figure 3). It was placed at an angle of nearly 15 degrees from the horizontal, in order to prevent any air bubbles from contacting the sensing membrane. A thermistor is built into this electrode to compensate for variations in diffusion rate through the teflon membrane, due to temperature changes. According to the manufacturer this temperature compensation reduced errors to less than \pm 5% of the reading over the 15[°] C range. The accuracy of the electrode at constant temperature was 1% full scale.


A Beckman Model 777 Laboratory Oxygen Analyser was connected to the electrode to determine the dissolved oxygen concentration. It showed a linearity of 0.5% full scale at constant temperature and could be operated over the temperature range 0° C to 90° C.

(9) Recorder

The output of the oxygen analyser was recorded on a Sargent Model SRL Recorder.

(10) Manometer

A mercury manometer was used to indicate the pressure at the air inlet.

(11) Thermocouples and Potentiometer

All temperature measurements were made with pre-calibrated copperconstantan thermocouples and a Leeds and Northrup Co. No. 8657-C Double Range Potentiometer. The calibration curve for the thermocouples is shown in Appendix II.

(12) Variable flow meter

A size number 5, RGI spherical float flow meter was used. The calibration curve for air at standard conditions is shown in Appendix III.

(13) Thermoregulator and Relay

A Canlab-Magnetic Control Thermoregulator No. 81-635/2 was used. The temperature range was 0 to 50° C, with subdivisions of 1° C. The relay was a mercury plunger type 81-573/110, having a load rating of 3300 watts.

(14) Needle Valve

A high pressure gas needle valve was used to control the air flow rate accurately.

(15) Tachometer

A Jones Motroda Co. Model 4800, 3 dial, multiple range hand tachometer with stop button was used. A peripheral wheel normally used for measuring surface speeds was used for measuring the shaft speeds.

(16) Liquid Nitrogen

Canadian Liquid Air "L" grade nitrogen was used.

II PROCEDURES

A. Unsteady Gassing Out Process

Water was added to the reactor to a depth of 2 tank diameters (15 inches), and was heated by the surrounding water bath to the desired temperature, within the range 25° C to 40° C. The pH of the solution was adjusted with c.p. grade concentrated sulfuric acid or 18 Normal sodium hydroxide solution. The range covered was pH 1.0 to 12.5.

Most of the tests were run in tap water. A few, however, were made in distilled water. Five agitation speeds (285, 380, 570, 760, and 950 rpm) were chosen. These were equivalent to ungassed Reynolds' numbers of 44,000, 67,000, 100,000, 130,000 and 170,000 in pure water at 70°F (21.1°C) respectively. The usually accepted Reynolds' number for the transition to turbulence in mixing tanks is around 1,000.

Prior to each test the dissolved oxygen was removed to a final concentration of approximately 0.5 ppm by the desorptive effect of rising nitrogen bubbles (43). The solution was then agitated for at least 5 minutes to remove any nitrogen bubbles in the solution.

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Air preheated to the desired temperature during passage through the copper coil immersed in the water bath and saturated with water was injected through the nozzle (Figure 5). Unsaturated air was used in some of the tests in order to check the effect of saturation on the mass-transfer coefficient.

Dissolved oxygen was determined with the Beckman Oxygen Analyser. It was calibrated at the saturation value before each run. The signals from the anlyser were amplified and continuously recorded by the Sargent Recorder with respect to time. During the aeration interval, the agitator power consumption, the air flow rate, gas hold up, and the temperature of the solution were measured several times. Normally they were constant for a given run.

The over-all mass-transfer coefficients were calculated numerically according to equation (8) using an I.B.M. 7044 computer. The correlation work was also carried out with the same computer. The programs for these calculations are shown in Appendix IV and Appendix V.

The magnitude of aeration through the liquid surface should be measured. This should be done by measuring the oxygen accumulation when the air bubbles had the oxygen composition which was equivalent to the oxygen concentration in the solution. It was difficult to control the composition of the air bubbles so that this condition could be achieved, hence, we measured the oxygen accumulation while the air flow was turned off. It is realized that the exact values of surface aeration could not be obtained by using this method.

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B. Sulfite-Oxidation Process

The apparatus used in the unsteady gassing out process was used in the sulfite-oxidation process. Distilled water was placed in the tank and the agitator was started. Approximately 1000 grams of c.p. grade sodium sulfite anhydrous powder were added to make the solution approximately 1.2 Normal with respect to the sulfite ion. After the sulfite powder had completely dissolved, predissolved c.p. cupric sulfate was added to give a Cu⁺⁺ concentration of 10^{-3} M. The air was then turned on and a timer was started. The oxidation reaction was allowed to continue for 3 - 100 minutes, depending on the rate of oxidation. The oxidative reaction was exothermic especially at high agitation speeds. The addition of a cooling coil could possibly change the flow pattern in the reactor, so air without preheating was used. The temperature remained within + 1° C of the desired value.

The rate of oxygen absorption was followed by the determination of the sulfite-ion concentration before and after each run. A 4.0 ml sample was taken directly from the reactor with a 10 ml syringe and was run immediately into an excess of freshly pipetted standard iodine solution (14). The tip of the syringe was held as closely as possible to the iodine standard solution surface, to prevent air oxidation of the samplefduring transfer. After at least a 10 minute wait, designed to ensure complete oxidation of sulfite to sulfate, the unreacted iodine was back-titrated with standard sodium thiosulfate solution to a starch indicator end point (44).

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The over-all mass-transfer coefficients K_L a were calculated according to equation (6) where:

$$K_{L}^{a} = NA/(C^{*})$$
 -- (6)

The logarithmic mean value of C^{*} was used.

III RESULTS AND DISCUSSION

A. Saturation Oxygen Concentrations

The modified Winkler Method (Appendix I) was used to measure the oxygen concentration of water in equilibrium with water-saturated air. However, this method could not be applied at low pH levels. Saturation values for 0.12 N sulfuric acid solutions were measured with a Beckman Oxygen Analyser. The values are compared in Table I with the experimental values calculated according to Eckenfelder's equation (45). It was concluded that pH had no effect on saturation values (C^{*}) and so the calculated values were used in K_r a calculations.

B. Effect of Unsaturated Air on K a

Unsaturated air was used to check the effect of saturation on K_L^a at 30° C (Figure 6) and 35° C (Figure 7). The K_L^a values were plotted versus superficial gas velocities for two shaft speeds (950 rpm and 285 rpm) on log-log paper. The data are in Appendix VII. At both temperatures K_L^a values for unsaturated air were found to fall on the same line as those for saturated air. This shows that the diffusional transfer of water vapor to the gas phase had an insignificant effect on K_L^a over the entire experimental range of gas flow rates (5.0 1/min to 52.4 1/min, at 1 atm., 21° C).

TABLE I

Saturation Oxygen Concentration of Water and Acid Solution

at Various Temperatures (ppm)

	25 [°] C	30 [°] C	35 ⁰ C	40 [°] C
Calculated Value (Eckenfelder eq (45))	8.11	7.53	7.04	6.60
Distilled Water (by Winkler Method)	8.10	7.50	7.03	6.60
0.1 N Sulfuric Acid (by Oxygen Analyser)	8.04	7.48	7.00	6.59





Hence, in later studies the air was used without making sure it was saturated. The same result was obtained by Chiang and Toor (4) in laminar liquid jet experiments.

C. Effect of Tap Water vs. Distilled Water on K_ta

The effect of tap water versus distilled water on K_L^a was examined at 35[°] C. When values of K_L^a were plotted against superficial gas velocities, using shaft speed as a parameter (Figure 8), the values of K_L^a for tap water were found to lie on the same line as those for distilled water. The data are shown in Appendix VII. Consequently tap water was used in all subsequent experiments.

D. Effect of Oxygen Concentration on K_a

To obtain a typical time versus oxygen concentration curve, such as is shown in Figure 9, the oxygen analyser was calibrated initially at the saturation value for the given conditions. Then the air was turned off, and the nitrogen turned on to strip the dissolved oxygen from the solution. After the nitrogen was shut off, the oxygen concentration continued to decrease slowly because of the time required for the nitrogen bubbles to escape from the reactor. When air was introduced into the reactor at the desired flow rate, the dissolved oxygen concentration increased with time (Figure 9). Table II presents the K_L a values calculated from Figure 9 according to equation (8). The relatively constant values of K_L a indicate that K_L a is almost independent of the oxygen concentration over the range studied. The experimental data are presented in Appendix VII.





TABLE II

Sample Calculation of ${\rm K}_{\rm L}{\rm a}$ Based on Fig. 9

Temperature = 40° C Saturation Oxygen Concentration C^{*} = 6.60 Shaft Speed = 570 rpm Superficial Velocity = 127 cm/min

TIME (Min)	0.0	0.1	0.2	0.3	• 0.4		
Oxygen Concentration (ppm)	1.78	3.40	4.55	5.27	5.75		
Driving Force C* - C (ppm)	4.82	3.20	2.05	1.33	0.85		
K _L a (Min) ⁻¹	4.12 4.17 4.34 4.49						

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E. Correlation of K_L^{La} with Operating Variables

.21

One way to examine the rate of mass transfer in agitated vessels is to compare the overall mass-transfer coefficient, $K_{L}a$, to the impeller power input and superficial gas velocity. However, there is considerable variation between the results obtained by various investigators with regard to the correlation of $K_{L}a$ and the operating variables (8, 21, 32, 37, 38).

In this study the K_La values were determined by the gassing out technique at pH 1.0, 2.0 and 5.7 (natural pH of tap water) and at solution temperatures of 25, 30, 35 and 40°C. In addition at 35°C, values were determined at pH 1.5, 4.5, 7.0, 10.0, 11.0 and 12.5. The raw data are in Appendix VII. Figure 10 obtained at 35°C is typical of the results and shows that pH has no effect on K_Ta values.

The data were then rearranged in the form $(HP/V)^{a} \cdot (V_{s})^{b}$ using a least squares curve fitting method. The computer program is shown in Appendix V. The K_La values obtained at various pH's were plotted against $(HP/V)^{a}(V_{s})^{b}$ for the temperatures 25, 30, 35 and 40°C (Figures 11-14). The "a" and "b" values calculated at different temperatures are as follows: $(K_{L}a)_{25°C} = (7.5 \pm 0.06) (HP/V)^{0 \cdot 32} \pm 0.02 (V_{s})^{0.46} \pm 0.04 --(37)$ $(K_{L}a)_{30°C} = (9.3 \pm 0.03) (HP/V)^{0.33} \pm 0.02 (V_{s})^{0.46} \pm 0.03 ---(38)$ $(K_{L}a)_{35°C} = (8.6 \pm 0.05) (HP/V)^{0.39} \pm 0.01 (V_{s})^{0.46} \pm 0.02 --(39)$ $(K_{L}a)_{40°C} = (8.8 \pm 0.04) (HP/V)^{0.40} \pm 0.01 (V_{s})^{0.50} \pm 0.02 --(40)$

These confidence limite are for the 95% level. The computer program for these calculations is shown in Appendix 5-5.

In view of these confidence limits, one could say that the exponent on the gas superficial velocity is 0.5. Since according to











OF LIQUID HP/V, AND SUPERFICIAL GAS VELOCITY Vs.

Calderbank (38), the value of K_L is independent of bubble size and rising velocity, but depends only on the physical properties of the system, any increase in K_La must be contributed only by an increase in interfacial area of the gas bubbles per unit volume of the liquid, a, hence,

$$\alpha (V_s)^{0.5}$$

â

which agrees with Calderbank's result (38). According to his light transmission experiments, the value of .a in a stirred vessel varies with V_s in the same way. It should be noted that precise comparison with other workers' results is made difficult by differences in the geometry of the studied tank systems.

The value of K_La increases with increasing temperature which is contrary to the conclusions reported by Robinson and Engel (19) and Yoshida <u>et al</u> (32). However, O'Connor suggests that according to equation (24), the ratio of K_La at different temperatures is dependent on the temperature and the viscosity of the liquid, for example, the ratio of K_La at 40°C to that at 25°C for pure water is:

$$\frac{(K_{L}a)_{40} \circ c}{(K_{L}a)_{25} \circ c} = \sqrt{\frac{T_{40} \circ c}{T_{25} \circ c}} \frac{\mu_{25} \circ c}{\mu_{40} \circ c}$$
$$= \sqrt{\frac{313 \times 0.8937}{298 \times 0.6560}}$$

= 1.20

The ratio is a constant for a given pair of temperatures. However, in my study the ratio of $K_{L}a$ is dependent on the power input. The ratio is not a constant for a given pair of temperatures.

$$\frac{(K_La)_{40} \circ C}{(K_La)_{25} \circ C} = 1.2 (HP/V)^{0.08}$$

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F. Sulfite-Oxygen Reaction Mechanism

The data obtained from the sulfite-oxidation experiments are shown in Appendix VII and plotted in Figures 15 to 18. The resulting straight lines in these plots indicate that the copper-catalyzed sulfiteoxidation reaction is zero order with respect to sulfite concentration in all cases (shaft speeds of 280, 570 and 950 rpm, and sulfite concentrations ranging from 0.06 to 1.30 N). Hence, the diffusion rate of sulfite ions is not the rate limiting step. Therefore, this is not the case of infinitely fast reaction. This agrees with the results of Cooper (8) and Westerterp (15).

G. Sulfite-Oxygen Absorption Mechanism

According to the data presented in Figure 19 - 21, the relationship between K_La and superficial gas velocity V_s , as determined by the sulfite-oxidation process is:

 $K_{La} \propto (V_{s})^{0 \times 50}$

The K_L a values determined by the sulfite-oxidation process and by purely physical absorption are compared at different agitation speeds, in Figures 19 to 21. The data are given in Appendices VII-C and VIII.

According to Figures 19 to 21 the average ratios of K_La for the sulfite-oxidation process to K_La for pure water are: 9.0 at an agitation speed of 950 rpm, 5.0 at an agitation speed of 570 rpm, 2.5 at an agitation speed of 275 rpm. This was plotted on a logarithmic paper and shown in Figure 22. The resulting straight line has a slope of nearly 1.0. The more experiments are needed to confirm this.

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1.4 Vs = 38.01_ft./hr. Vs=71.21 ft/hr. Vs=148.4 ft/hr. CONCENTRATION © 0 Vs=241.2 ft/hr. Vs=351.5 ft/hr. 50 SULFITE 0.6 0.4 80 60 70 50 20 30 40 10 0 TIME min) FIG 15. TIME-CONCENTRATION CURVE FOR COPPER CATALYZED SULFITE-OXYGEN REACTION AT 35 °C (285 RPM)







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There is little agreement among those investigators (21,22) who have tried to compare K_L a values from sulfite-oxidation experiments with those obtained from real fermentations. As based on film theory, K_L a in a reaction system is dependent on film thickness, diffusivity and reaction rate constant. The fermentation broths generally differ greatly from sulfite solutions in physical and chemical properties. Physical properties, such as ionic strength, surface tension, and viscosity may affect the value of 'a' as well as K_L . The differences in these physical properties between fermentation broths and sulfite solutions can be minimized by using a very dilute solution, but this has no effect on chemical properties.

Since reaction rate constants vary from one reaction system to another, different K_L 's from different reaction systems are expected. Hence, if the reaction rate constants are different, the comparison of K_L between the two different systems is of little value. Furthermore, there are great differences between the diffusional processes involved in these two systems. In sulfite solution, oxygen passes from the gas through the interface into the liquid film. Oxygen utilization takes place in this film. In a suspension of microorganisms, the site of oxygen utilization is intimately associated with discrete cell units which are physically localized and relatively remote from the interface. So the best way of comparing the performance of different fermentation equipment is to use an actual fermentation system.

H. Oxygen Supply

In order to supply the maximum oxygen uptake rate of 756 mg/l/hr (3) required by T. ferrooxidans when oxidizing chalcopyrite, the value of

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 K_{L}^{a} should be greater than 756/(7.0-0) hr⁻¹ or 108 hr⁻¹ at 35^o C (in this case, the oxygen concentration in the fermentation tank is assumed to be zero). This value of K_{t}^{a} for the case of pure physical absorption, is:

$$(K_{L}a)_{35}o_{C} = 8.6 (HP/V)^{0.39} (V_{s})^{0.48}$$

Therefore $(HP/V)^{0.39}(V_s)^{0.48}$ should be greater than 108/8.6 or 12.5. This is easily achieved, for example, when HP/V = 10 horsepower/1000 gallons of liquid, and $V_s = 100$ ft/hr, the value of K_L a will be 190 hr⁻¹, which is much greater than 108 hr⁻¹.

If oxygen supply is the rate limiting factor in bacterial growth during biological leaching of chalcopyrite, then, the physical properties of the biological suspension may limit the rate of oxygen absorption.

I. Power Requirements in a Gassed System

Plots of Pg/Po versus $Q/(ND_I^3)$ based on the present data (Appendix VII) are shown in Figures 23 - 24. The results are not as simple as those shown by Ohyama (40), Moo-Young (41) and Aiba (42). The resulting curves are not only dependent on the shaft speed from 285 rpm to 950 rpm (Figure 22), but also dependent on the temperature of the liquid from 25° C to 40° C (Figure 23). Only at the highest shaft speed of 950 rpm does the effect of temperature seem insignificant. Further study of the power requirements in a gassed system would be of interest.





IV CONCLUSION

(1) The values of $K_{L}a$ were unaffected by solution pH over the range 1.0 to 12.5. The use of unsaturated air or tap water also had no effect on $K_{I}A$.

(2) The values of K_L^a obtained by the unsteady gassing out process were correlated as a form of C \cdot (HP/V)^a \cdot (V_S)^b, at 35^oC for example:

 $(K_{La})_{350C} = 8.6 (HP/V)^{0.39} (V_s)^{0.48}$

The value increased with increasing temperature of the solution.

(3) The copper-catalyzed sulfite-oxidation reaction was found to be zero order with respect to unreacted sulfite concentration. The values of $K_{L}a$ from this technique were found to be proportional to $(V_S)^{0.50}$. When combined with the data obtained by the unsteady gassing out process, it was concluded that the interfacial area of the bubbles per unit volume of liquid 'a' was proportional to $(V_S)^{0.50}$.

(4) The oxygen demand of <u>T. ferrooxidans</u> oxidizing chalcopyrite would appear to be easily satisfied but further study on the rate of oxygen absorption during the biological fermentation is necessary to confirm this.

(5) Plots of Pg/Po versus $Q/(ND_I^3)$ were not as straightforward as shown by other investigators. The resulting curves were dependent on the temperature of the liquid as well as the shaft speed of the impeller.

V RECOMMENDATIONS FOR FURTHER STUDY

There are many problems to be solved both in the theory of oxygen transfer and in the application of the theory to tanks containing thousands of gallons of bacterial suspension.

If the rate of oxygen transfer is a rate limiting step in the rate of metabolism, a further study including the effects of ore particles, cell bodies and other nútrients on oxygen transfer rate is necessary.

Instead of using chemical systems, use of biological systems to study this type of mass transfer problem has certain advantages. Although the chemical systems are less sensitive to changes in physical and chemical properties the direct application of the data from chemical systems to the biological systems is extremely difficult. With biological systems, realistic values for the mass transfer rates can be obtained, even if the reaction and absorption mechanisms are unknown. The biological system is the most reliable method for evaluating the performance of fermentors.

The coefficient K_L^a is known to be dependent on the power input and superficial gas velocity. In most cases high superficial gas velocities are desired because it is more economical to increase the superficial gas velocity than to increase the agitator power imput. However, a minimum power input is necessary in order to assure the suspension and even distribution of ore particles and cell bodies. This is a very important factor when considering the economic value of a biological leaching process.

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ALSTERBERG (AZIDE) MODIFICATION OF WINKLER METHOD (46)

A. Reagents

(1) Manganous Sulfate Solution

Dissolve 480 g MnSO₄ \cdot 4 H₂O, 400 g MnSO₄ \cdot 2 H₂O, or 364 g MnSO₄ \cdot H₂O in distilled water, filter, and dilute to 1 liter. When uncertainty exists regarding the water of crystallization, a solution of equivalent strength may be obtained by adjusting the specific gravity of the solution to a value of 1.270 at 20°C. The manganous sulfate solution should liberate not more than a trace of iodine when added to an acidified solution of potassium iodide.

(2) Alkali-Iodide-Azide Reagent

Dissolve 500 g NaOH (or 700 g KOH) and 135 g NaI (or 150 g KI) in distilled water and dilute to 1 liter. To this solution add 10 g NaN3 dissolved in 40 ml distilled water. Potassium and sodium salts may be used interchangeably. This reagent should not give a color with starch solution when dilute and acidified.

(3) Sulfuric Acid, Concentrated

The strength of this acid is about 36 N. Hence, 1 ml is equivalent to about 3 ml of the alkali-iodide-azide reagent.

(4) Starch Solution

Prepare an emulsion of 5 - 6 g potato, arrowroot, or soluble starch in a mortar or beaker with a small quantity of distilled water. Pour this emulsion into 1 liter of boiling water, allow to boil a few minutes, and let settle overnight. Use the clear supernatant. This solution may be preserved with 1.25 g

salicylic acid per liter or by the addition of a few drops of toluene.

(5) Standard Sodium Thiosulfate Solution, 0.025 N Harleco Volumetric Concentrate Ampul was used. Hartman-Leddon Co. production.

B. Procedure

To the sample, as collected in a 250- to 300-ml bottle, add 2 ml (1) $MnSO_4$ solution followed by 2 ml alkali-iodide-azide reagent, well below the surface of the liquid; stopper with care to exclude air bubbles and mix by inverting the bottle several times. When the precipitate settles, leaving a clear supernatant above the managanese hydroxide floc, shake again. When settling has produced at least 100 ml clear supernatant, carefully remove the stopper and immediately add 2.0 ml concentrated H₂SO₄ by allowing the acid to run down the neck of the bottle, restopper, and mix by gentle inversion until dissolution is complete. The iodine should be uniformly distributed throughout the bottle before decanting the amount needed for titration. This should correspond to 200 ml of the original sample after correction for the loss of sample by displacement with the reagents has been made. Thus, when a total of 4 ml (2 ml each) of the manganous sulfate and alkali-iodide-azide reagents is added to a 300-ml bottle, the volume taken for titration should be

$$200 \text{ x} \frac{300}{300 - 4} = 203 \text{ m1}$$

(2) Titrate with 0.025 N thiosulfate to a pale straw color. Add 1 - 2 ml freshly prepared starch solution and continue the titration to the first disappearance of the blue color. If the end point is overrun, the sample may be back-titrated with 0.025 N biniodate, which is added dropwise, or by an additional measured volume of sample. Correction for the amount of biniodate or sample should be made. Subsequent recolorations due to the catalytic effect of nitrite or to traces of ferric salts which have not been complexed with fluoride should be disregarded.





COMPUTER PROGRAM FOR CALCULATION OF UNSTEADY GASSING OUT PROCESS

C	T(N)TIME IN MIN	· · · · · · · · · · · · · · · · · · ·
C	CT(N)OXYGEN CONCENTRATION IN PPM	- ^م ورد ا
	REAL KLA	
	DIMENSION T(100), CT(100)	
C.		*
[C	READ OF NUMBER OF CARDS, TEMPERATURE, AIR VELOCITY,	
C	AIR INLET PRESSURE, POWER REQUIREMENTS,	
) <u>`</u> C	HOLD UP IN INCH, AND SHAFT SPEED	
100	READ 10, N, TEMP, GASVEL, HEAD, PTORQ, HOLDUP, R	PM
10	FORMAT(I2,6F10.0)	
C		• •
С	SATURATION OXYGEN CONCENTRATION	
	CS=14.16-0.3943*TEMP+0.007714*TEMP**2	
ŀ	1 -0.0000646*TEMP**3	
	READ 20, $(T(I), CT(I), I=1, N)$	
20	FORMAT(2F10.0)	
C		
C	RECALCULATION OF AIR VOLUME ACCORDING TO APP 2	
	FACT=(29.921+HEAD)/29.921	·
	IF(GASVEL.EQ.5.0) GASVEL=4.60*FACT	:
 	IF(GASVEL.EQ.10.0) GASVEL=8.30*FACT	
į .	IF(GASVEL.EQ.20.0) GASVEL=16.10*FACT	
1	IF(GASVEL.EQ.30.0) GASVEL=24.00*FACT	•
	IF(GASVEL.EQ.40.0) GASVEL=32.80*FACT	
C		1
C	SUPERFICIAL VELOCITY IN CM/MIN	
[SUPVEL=GASVEL*1000./((7.5*2.54/2.)**2*3.1416)	
	PRINT 60, TEMP, CS, GASVEL, SUPVEL, RPM	· .
60	FORMAT(1X, 5F20.8)	· .
	PRINT 55, T(1), CT(1)	1
55	FORMAT(10X,F20.8,10X,F20.8)	
	SUM=0.0	
	DD 30 I=2,N	
С		
C	CALCULATION OF KLA ACCORDING TO EQUATION	
	KLA=1.0/(T(I)-T(I-1))*	
	1 $ALOG((CS-CT(I-1))/(CS-CT(I)))$	
}	SUM=SUM+KLA	+
30	PRINT 50, T(I), CT(I), KLA	
50	FORMAT(// 10X,F20.8, 10X, F20.8, 20X, F20.8)	ć
	AVKLA=SUM/FLOAT(N-1)	54
ł	PRINT 70, AVKLA	
70	FORMAT(8X,12H AVERAGE KLA, F20.8)	;
	GO TO 100	
200	STOP	
	END	
;\$EN	TRY	•
		 .

COMPUTER PROGRAM FOR CURVE FITTING

C Y(I) = C* A**A*B*B C JIMENSION Y(3,3), V(3) REAL PH,TEMP,RPM,POW,HOLD,KLA,SUPVEL 2000 DD 10 I=1.3 V(I)=0.0 10 0 (I,J)=0.0 1000 READ 20, PH,TEMP,RPM,POW,HOLD,KLA,SUPVEL RPM=RPM*1.9/0.5 IF(PH.EQ.0.0) GO TO 900 20 FORMAT(7F10.0) C POWER INPUT HORSEPOWER C HP=5.0*POW*RPM/63025.0 C VOLIME OF LOQUID IN (CM)**3, (FT)**3, U.S. GALLON C	: <u>C</u>	LEAST SOUMARE ELTTING	The second second	
C DIMENSION Y(3,3), V(3) REAL PH,TEMP,RPM,POW,HOLD,KLA,SUPVEL 2000 D0 10 J=1,3 10 Y(1,j)=0.0 1000 READ 20, PH,TEMP,RPM,POW,HOLD,KLA,SUPVEL RPM=RPM*1.9/0.5 IF(PH.EQ.0.0) GC TO 900 20 FORMAT(7F10.0) C POWER INPUT HORSEPOWER C HP=5.0*POW*RPM/63025.0 C VOLIME OF LOQUID IN (CM)**3, (FT)**3, U.S. GALLON C VCM=(7.5*2.54/2.0)**2*3.1416*15.0*2.54 VFT=VCM/28316.0 VGAL=VFT*7.481 C C C HP/1000.0 GALLON OF LIQUID C AA=HP/VGAL*1000.0 C SUPERFICIAL GAS VELOCITY FT/HR C BB=SUPVEL/30.48*60.0 C YY=ALOG10(KLA) AA=ALOG10(KLA) AA=ALOG10(KLA) AA=AA*AA AAB=AA*BB AAA=AA*AA AAB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(1,2)=Y(1,2)+AA	c	Y(I) = C* A**A*B***B		
DIMENSION Y(3,3), V(3) REAL PH,TEMP,RPM,POW,HOLD,KLA,SUPVEL 2000 DD 10.1=1.3 V(11-0.0 DO 10 J=1,3 10 Y(1,J)=0.0 1000 READ 20, PH,TEMP,RPM,POW,HOLD,KLA,SUPVEL RPM=RPM*1.9/0.5 IF(PH.EQ.0.0) GO TO 900 20 FORMAT(7F10.0) C POWER INPUT HORSEPOWER C HP=5.0*POW*RPM/63025.0 C VOLIME OF LOQUID IN (CM)**3, (FT)**3, U.S. GALLON C VCM=(7.5*2.54/2.0)**2*3.1416*15.0*2.54 VFT=VCM/28316.0 VGAL=VFT*7.481 C MP/1000.0 GALLON OF LIQUID C AA=HP/VGAL*1000.0 C SUPERFICIAL GAS VELOCITY FT/HR C BB=SUPVEL/30.48*60.0 C C HANGE THE UNIT OF KLA 1/HR C KLA=KLA*60.0 YY=ALOGIO(KLA) AA=APA#A AABB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(1,2)=Y(1,2)+AA	С.	ان این می دود. منطق بر مدینا مسلم کی مربق میکند و محکوم این از میکند از محکوم این از میکند.		•
<pre>KEAL PH, TEMP, KPM, PUW, HULD, KLA, SUPVEL 2000_D10_I=1,3 V(I)=0.0 D0_10_J=1,3 V(I)=0.0 1000 READ 20, PH, TEMP, RPM, POW, HOLD, KLA, SUPVEL RPM=RPM#1.9/0.5 IF(PH.E0.0.0) GD T0 900 20 FORMAT(7F10.0) C POWER INPUT HORSEPOWER C HP=5.0*POW*RPM/63025.0 C VOLIME OF LOQUID IN (CM)**3, (FT)**3, U.S. GALLON C VCM=(7.5*2.54/2.0)**2*3.1416*15.0*2.54 VFT=VCM/28316.0 VGAL=VFT*7.481 C C C HP/1000.0 GALLON OF LIQUID C AA=HP/VGAL*1000.0 C C BB=SUPVEL/30.48*60.0 C C CHANGE THE UNIT OF KLA 1/HR C KLA=KLA*60.0 YT=ALOG10(KLA) AA=AA*AA AABB=AA*AB AAAB=AA*AA AABB=AA*AB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(1,2)+AA Y(3,1)=Y(1,2)+AA Y(3,1)=Y(1,2)+AA Y(3,1)=Y(1,2)+AA Y(3,1)=Y(1,2)+AA </pre>		DIMENSION $Y(3,3)$, $V(3)$	A. 01101151	
COUNDUTETS V(I)=0.0 D010J=1,3 10 Y(I,J)=0.0 1000 READ 20, PH,TEMP,RPM,POW,HOLD,KLA,SUPVEL RPM=RPM*1.9/0.5 IF(PH.EQ.0.0) GO TO 900 20 FORMAT(7F10.0) C PDWER INPUT HORSEPOWER C HP=5.0*POW*RPM/63025.0 C VCM=(7.5*2.54/2.0)**2*3.1416*15.0*2.54 VFT=VCM/28316.0 VGAL=VFT*7.481 C C C C C C C VGAL=VFT*7.481 C C C C C BB=SUPVEL/30.48*60.0 C C C C C C C C C C C C C C C C C C C	200	REAL PH, IEMP, RPM, PUW, HULD, KL	A, SUPVEL	
<pre>V(1)-0.0 D) 10 J=1,3 10 Y(1,J)=0.0 1000 READ 20, PH,TEMP,RPM,POW,HOLD,KLA,SUPVEL RPM=RPM41.9/0.5 IF(PH.EQ.0.0) GD TO 900 20 FORMAT(7F10.0) C POWER INPUT HORSEPOWER</pre>	200	$\frac{10 10 10 1=1,3}{10 10 0}$		
10 Y(1, J)=0.0 1000 READ 20, PH,TEMP,RPM,POW,HOLD,KLA,SUPVÉL RPM=RPM*1.9/0.5 IF(PH.EQ.0.0) GO TO 900 20 FORMAT(7F10.0) C POWER INPUT HORSEPOWER C HP=5.0*POW*RPM/63025.0 C VOLIME OF LOQUID IN (CM)**3, (FT)**3, U.Š. GALLON C VCM=(7.5*2.54/2.0)**2*3.1416*15.0*2.54 VFT=VCM/28316.0 VGAL=VFT*7.481 C C C HP/1000.0 GALLON OF LIQUID C AA=HP/VGAL*1000.0 C BB=SUPVEL/30.48*60.0 C CHANGE THE UNIT OF KLA 1/HR C KLA=KLA*60.0 YY=ALOG10(KLA) AA=AACG10(AA) BBBB=BB*BB AAAA=AA*AA AAB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(3,1)=Y(2,1)+AA Y(3,1)=Y(1,1)+BB Y(1,2)=Y(1,2)+AA	ļ	V(1) = 0 + 0		Sector Prod
1000 READ 20, PH,TEMP,RPM,POW,HOLD,KLA,SÜPVEL RPM=RPM#1.9/0.5 IF(PH.EQ.0.0) GO TO 900 20 FORMAT(7F10.0) C POWER INPUT_HORSEPOWER_ C HP=5.0*POW*RPM/63025.0 C VOLIME OF LOQUID IN (CM)**3, (FT)**3, U.S. GALLON C VCM=(7.5*2.54/2.0)**2*3.1416*15.0*2.54 VFT=VCM/28316.0 VGAL=VFT*7.481 C C HP/1000.0 GALLON OF LIQUID C	10	$Y(1 \cdot 1) = 0 \cdot 0$		
<pre>RPM=RPM#1.9/0.5 IF(PH.EQ.0.0) GO TO 900 20 FORMAT(7F10.0) C POWER INPUT HORSEPOWER C HP=5.0*POW*RPM/63025.0 C VOLIME OF LOQUID IN (CM)**3, (FT)**3, U.S. GALLON C VCM=(7.5*2.54/2.0)**2*3.1416*15.0*2.54 VFT=VCM/28316.0 VGAL=VFT*7.481 C C C HP/1000.0 GALLON OF LIQUID C AA=HP/VGAL*1000.0 C SUPERFICIAL GAS VELOCITY FT/HR C BB=SUPVEL/30.48*60.0 C C CHANGE THE UNIT OF KLA 1/HR C KLA=KLA*60.0 YY=ALOG10(KLA) AA=ALOG10(KLA) AA=ALOG10(KLA) AA=ALOG10(KLA) AA=ALOG10(KLA) AA=ALOG10(KLA) AA=AA=AA*AA AAAB=AA*AB AAAA=AA*AA AABB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(1,2)=Y(1,2)+AA</pre>	100	0 READ 20, PH, TEMP, RPM, POW, HOL	D,KLA,SUPVEL	
IF(PH.EQ.0.0) GO TO 900 20 FORMAT(7F10.0) C POWER INPUT HORSEPOWER C HP=5.0*POW*RPM/63025.0 C VOLIME OF LOQUID IN (CM)**3, (FT)**3, U.S. GALLON C VCM=(7.5*2.54/2.0)**2*3.1416*15.0*2.54 VFT=VCM/28316.0 VGAL=VFT*7.481 C C HP/1000.0 GALLON OF LIQUID C AA=HP/VGAL*1000.0 C SUPERFICIAL GAS VELOCITY FT/HR C BB=SUPVEL/30.48*60.0 C CHANGE THE UNIT OF KLA 1/HR C KLA=KLA*60.0 YY=ALOG10(KLA) AA=ALOG10(KLA) AA=ALAG10(AA) BB=ALOG10(BB) BBBB=BB*BB AAA=AA*AA AABB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(1,2)=Y(1,2)+AA		RPM=RPM*1.9/0.5	• • • • • • •	·
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<pre>HP=3.0+POW*RPM/03023.0 C VOLIME OF LOQUID IN (CM)**3, (FT)**3, U.S. GALLON VCM=(7.5*2.54/2.0)**2*3.1416*15.0*2.54 VFT=VCM/28316.0 VGAL=VFT*7.481 C C C AA=HP/VGAL*1000.0 C C AA=HP/VGAL*1000.0 C C SUPERFICIAL GAS VELOCITY FT/HR C BB=SUPVEL/30.48*60.0 C C CHANGE THE UNIT OF KLA 1/HR C KLA=KLA*60.0 YY=ALOGIO(KLA) AA=ALOGIO(KLA) BB=BAEBB BBB=BB*BB AAA=AA*AA AABB=AA*AB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(1,2)=Y(1,2)+AA</pre>	C		•	
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VFT=VCM/28316.0 VGAL=VFT*7.481 C C C HP/1000.0 GALLON OF LIQUID C AA=HP/VGAL*1000.0 C C SUPERFICIAL GAS VELOCITY FT/HR C BB=SUPVEL/30.48*60.0 C C CHANGE THE UNIT OF KLA 1/HR C C KLA=KLA*60.0 YY=ALOGI0(KLA) AA=ALOGI0(KLA) BB=ALOGI0(BB) BBB=BB*BB AAAA=AA*AA AABB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(1,2)=Y(1,2)+AA		VCM=(7.5*2.54/2.0)**2*3.1416	*15.0*2.54	··· ··· · · · · · · · · · · · · · · ·
VGAL=VFT*7.481 C C HP/1000.0 GALLON OF LIQUID C AA=HP/VGAL*1000.0 C SUPERFICIAL GAS VELOCITY FT/HR C BB=SUPVEL/30.48*60.0 C C CHANGE THE UNIT OF KLA 1/HR C KLA=KLA*60.0 YY=ALOG10(KLA) AA=ALOG10(KLA) BB=ALOG10(KLA) BB=BB*BB AAA=AA*AA AAB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AA		VFT=VCM/28316.0	•	
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C HP/1000.0 GALLON OF LIQUID AA=HP/VGAL*1000.0 C SUPERFICIAL GAS VELOCITY FT/HR C BB=SUPVEL/30.48*60.0 C CHANGE THE UNIT OF KLA 1/HR C KLA=KLA*60.0 YY=ALOG10(KLA) AA=ALOG10(AA) BB=ALOG10(BB) BBBB=BB*BB AAA=AA*AA AABB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AA	<u>C</u>			
C HP/1000.0 GALLON OF LIGOTO C AA=HP/VGAL*1000.0 C SUPERFICIAL GAS VELOCITY FT/HR C BB=SUPVEL/30.48*60.0 C CHANGE THE UNIT OF KLA: 1/HR C KLA=KLA*60.0: YY=ALOGIO(KLA) AA=ALOGIO(KLA) BB=ALOGIO(BB) BBB=BB*BB AAA=AA*AA AABB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AA	C			
AA=HP/VGAL*1000.0 C C SUPERFICIAL GAS VELOCITY FT/HR C BB=SUPVEL/30.48*60.0 C C CHANGE THE UNIT OF KLA: 1/HR C KLA=KLA*60.0 YY=ALOG10(KLA) AA=ALOG10(KLA) BB=ALOG10(BB) BBBB=BB*BB AAAA=AA*AA AABB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AA	C	HP/ICOU.O GALLON OF LIQUID		÷ .
C C SUPERFICIAL GAS VELOCITY FT/HR C BB=SUPVEL/30.48*60.0 C C C CHANGE THE UNIT OF KLA 1/HR C KLA=KLA*60.0 YY=ALOGIO(KLA) AA=ALOGIO(KLA) BB=ALOGIO(BB) BBBB=BB*BB AAAA=AA*AA AABB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AA	0	$\Delta \Delta = HP / VG \Delta I \approx 1000 \circ 0$		······································
C SUPERFICIAL GAS VELOCITY FT/HR C BB=SUPVEL/30.48*60.0 C C CHANGE THE UNIT OF KLA 1/HR C KLA=KLA*60.0 YY=ALOGIO(KLA) AA=ALOGIO(AA) BB=ALOGIO(BB) BBBB=BB*BB AAAA=AA*AA AABB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AA	С			
C BB=SUPVEL/30.48*60.0 C C CHANGE THE UNIT DF KLA 1/HR C YY=ALOG10(KLA) AA=ALOG10(KLA) BB=ALOG10(BB) BBB=BB*BB AAA=AA*AA AABB=AA*AB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(1,2)=Y(1,2)+AA	C	SUPERFICIAL GAS VELOCITY FT/HR		
BB=SUPVEL/30.48*60.0 C C C C CHANGE THE UNIT OF KLA. 1/HR C $KLA=KLA*60.0$ YY=ALOG10(KLA) AA=ALOG10(AA) BB=ALOG10(BB) BBBB=BB*BB AAA=AA*AA AABB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AA	C		•	
C C CHANGE THE UNIT OF KLA $1/HR$ C KLA=KLA*60.0 YY=ALOG10(KLA) AA=ALOG10(AA) BB=ALOG10(BB) BBBB=BB*BB AAAA=AA*AA AABB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AA		BB=SUPVEL/30.48*60.0		
C CHANGE THE UNIT OF KLA 17HR C YY=ALOG10(KLA) AA=ALOG10(AA) BB=ALOG10(BB) BBBB=BB*BB AAAA=AA*AA AABB=AA*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AA	C.		ana ini manana any piri si sarahisi	ана с 25 Алинисти Алинисти Алинисти
$ \begin{array}{c} KLA = KLA * 60.0 \\ YY = ALOG10(KLA) \\ AA = ALOG10(AA) \\ BB = ALOG10(BB) \\ BBBB = BB * BB \\ AAAA = AA * AA \\ AABB = AA * BB \\ Y(1,1) = Y(1,1) + 1.0 \\ Y(2,1) = Y(2,1) + AA \\ Y(3,1) = Y(3,1) + BB \\ Y(1,2) = Y(1,2) + AA \end{array} $	C	CHANGE THE UNIT OF KLA 1/HR		
$\begin{array}{c} KLA = KLA + BO \cdot O \\ YY = ALOG1O(KLA) \\ AA = ALOG1O(AA) \\ BB = ALOG1O(BB) \\ BBBB = BB * BB \\ AAAA = AA * AA \\ AABB = AA * AA \\ AABB = AA * BB \\ Y(1, 1) = Y(1, 1) + 1 \cdot O \\ Y(2, 1) = Y(2, 1) + AA \\ Y(3, 1) = Y(3, 1) + BB \\ Y(1, 2) = Y(1, 2) + AA \end{array}$	L	KI A-KI A#60 0	•	
AA = ALOGIO(AA) BB = ALOGIO(BB) BBBB = BB * BB AAAA = AA * AA AABB = AA * BB Y(1,1) = Y(1,1) + 1.0 Y(2,1) = Y(2,1) + AA Y(3,1) = Y(3,1) + BB Y(1,2) = Y(1,2) + AA		$\frac{\mathbf{KLA} - \mathbf{KLA} + \mathbf{OU} \cdot \mathbf{U}}{\mathbf{VV} = \mathbf{ALOCIO}(\mathbf{KLA})$		<u> </u>
$BB = ALOG10(BB)$ $BBBB = BB * BB$ $AAAA = AA * AA$ $AABB = AA * BB$ $Y(1,1) = Y(1,1) + 1 \cdot 0$ $Y(2,1) = Y(2,1) + AA$ $Y(3,1) = Y(3,1) + BB$ $Y(1,2) = Y(1,2) + AA$		$\Delta \Delta = \Delta I \cap G \cap (\Delta \Delta)$		
BBBB=BB*BBAAAA=AA*AAAABB=AA*BBY(1,1)=Y(1,1)+1.0Y(2,1)=Y(2,1)+AAY(3,1)=Y(3,1)+BBY(1,2)=Y(1,2)+AA		BB=ALOG1O(BB)	· · · · · · · · · · · · · · · · · · ·	
$\begin{array}{c} AAAA=AA*AA\\ AABB=AA*BB\\ Y(1,1)=Y(1,1)+1.0\\ Y(2,1)=Y(2,1)+AA\\ Y(3,1)=Y(3,1)+BB\\ Y(1,2)=Y(1,2)+AA\end{array}$		BBBB=BB*BB		
$\begin{array}{c} AABB=AA*BB \\ Y(1,1)=Y(1,1)+1.0 \\ Y(2,1)=Y(2,1)+AA \\ Y(3,1)=Y(3,1)+BB \\ Y(1,2)=Y(1,2)+AA \end{array}$		ΑΑΑΑ=ΑΑ * ΑΑ		
Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AA		AABB=AA*BB		
Y $(2,1) = Y(2,1) + AA$ Y $(3,1) = Y(3,1) + BB$ Y $(1,2) = Y(1,2) + AA$		Y(1,1) = Y(1,1) + 1.0	,	
Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AA	'	Y(2,1) = Y(2,1) + AA		
	·	Y(3,1)=Y(3,1)+BB	· · · · · · · · · · · · · · · · · · ·	· · · · · · · · · · · · · · · · · · ·
V12 21-V12 21+AAAA		Y (1 y Z) = Y (1 y Z) + A A V (2 - 2) - V (2 - 2) + A A A	JAC.	
IIICICI-IICICITAAAA		1 1 C 9 C 1 - 1 1 C 9 C 1 T A A A A	A martin bush	

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	$Y(3_{1}2)$	=Y(3,2)	+AABB			·		
	V(2,2)	-3 (1,3) -V(2,3)	+DD +∧∧qq '		•	•.		• •
;	V(2,2)	-1(2+3)	+RRRR	•				2 5.4. 32
	V(1) = V	(1)+YY			:			1.2 S. 1.
· .	V(2) = V	(2) + Y Y *	ΔΔ ·	•				7 12
	V(3) = V	(3) + YY *	BB	•				Entre :
	GO TO	1000	•.	· .				
900	PRINT	85, ((Y	(I,J),Ĵ	=1,3)	•V(I),I=	1,3)		
85	FORMAT	(1X, 4E)	20.8)	•				
······	CALL S	<u>OLTN (Y</u>	, V , 3 , 3 ,	DET)				
н. К	C=10.0	**V(l)				•		
	A=V(2)				- - -			
··· ·	B=V(3)					\ 		کار در دور ور محمد محمد در در
	PRINT	80, C,A	• B			·		
80	FURMAI	11X, 5H	ι= ,	F20:8	, 5 X, 2日	A=, 1	-20.8,	5X, 2HB=
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117	END					:4		
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C C DIMENSION Y(3,3), V(3) REAL PH,TEMP,RPM,POW,HOLD,KLA,SUPVEL 2000 D0 10 I=1,3 V(I)=0.0 D0 10 J=1,3 10 Y(I,J)=0.0 1000 READ 20, PH,TEMP,RPM,POW,HOLD,KLA,SUPVEL RPM=RPM*1.9/0.5 PHOLD=HOLD/15.0*100.0 20 FORMAT(7F10.0) C C POWER INPUT HORSEPOWER C HP=5.0*POW*RPM/63025.0 C C C HP/1000.0 GALLON OF LIQUID C C VOLIME OF LOQUID IN (CM)**3, (FT)**3, U.S. GALLON C AREA=(7.5*2.54/2.0)**2*3.1416 VCM=(7.5*2.54/2.0)**2*3.1416*15.0*2.54 VFT=VCM/28316.0 VGAL=VFT*7.481 C AA=HP/VGAL*1000.0 BB=SUPVEL/30.48*60.0 KLA=KLA*60.0 IF(TEMP.EQ.25.0) GO TO 52 IF (TEMP.EQ. 30.0) GO TO 53 IF (TEMP.EQ. 35.0) GO TO 54 A=0.4011 B=0.4974	
C DIMENSION Y(3,3), V(3) REAL PH,TEMP,RPM,POW,HOLD,KLA,SUPVEL 2000 D0 10 J=1,3 10 Y(I,J)=0.0 1000 READ 20, PH,TEMP,RPM,POW,HDLD,KLA,SUPVEL RPM=RPM*1.9/0.5 PHOLD=HOLD/15.0*100.0 20 FORMAT(7F10.0) C C POWER INPUT HORSEPOWER C HP=5.0*POW*RPM/63025.0 C C HP/1000.0 GALLON OF LIQUID C C VOLIME OF LOQUID IN (CM)**3, (FT)**3, U.S. GALLON C AREA=(7.5*2.54/2.0)**2*3.1416 VCM=(7.5*2.54/2.0)**2*3.1416*15.0*2.54 VFT=VCM/28316.0 VGAL=VFT*7.481 C AA=HP/VGAL*1000.0 BB=SUPVEL/30.48*60.0 KLA=KLA*60.0 IF(TEMP.EQ.25.0) GO TO 52 IF (TEMP.EQ.30.0) GO TO 53 IF (TEMP.EQ. 35.0) GO TO 54 A=0.4011 B=0.4974	
DIMENSION Y(3,3), V(3) REAL PH,TEMP,RPM,POW,HOLD,KLA,SUPVEL 2000 D0 10 I=1,3 V(1)=0.0 D0 10 J=1,3 10 Y(1,J)=0.0 1000 READ 20, PH,TEMP,RPM,POW,HOLD,KLA,SUPVEL RPM=RPM*1.9/0.5 PHOLD=HOLD/15.0*100.0 20 FORMAT(7F10.0) C POWER INPUT HORSEPOWER C HP=5.0*POW*RPM/63025.0 C HP/1000.0 GALLON OF LIQUID C VOLIME OF LOQUID IN (CM)**3, (FT)**3, U.S. GALLON C AREA=(7.5*2.54/2.0)**2*3.1416 VCM=(7.5*2.54/2.0)**2*3.1416*15.0*2.54 VFT=VCM/28316.0 VGAL=VFT*7.481 C AA=HP/VGAL*1000.0 BB=SUPVEL/30.48*60.0 KLA=KLA*60.0 IF(TEMP.EQ.25.0) GO TO 52 IF (TEMP.EQ.35.0) GO TO 53 IF (TEMP.EQ.35.0) GO TO 54 A=0.4011 B=0.4974	
REAL PH, TEMP, RPM, POW, HOLD, KLA, SUPVEL 2000 DO 10 I=1,3 V(I)=0.0 DO 10 J=1,3 10 Y(I,J)=0.0 1000 READ 20, PH, TEMP, RPM, POW, HOLD, KLA, SUPVEL RPM=RPM*1.9/0.5 PHOLD=HOLD/15.0*100.0 20 FORMAT(7F10.0) C C POWER INPUT HORSEPOWER C HP=5.0*POW*RPM/63025.0 C C C VOLIME OF LOQUID IN (CM)**3, (FT)**3, U.S. GALLON C AREA=(7.5*2.54/2.0)**2*3.1416 VCM=(7.5*2.54/2.0)**2*3.1416*15.0*2.54 VFT=VCM/28316.0 VGAL=VFT*7.481 C AA=HP/VGAL*1000.0 BB=SUPVEL/30.48*60.0 KLA=KLA*60.0 IF(TEMP.EQ.25.0) GO TO 52 IF (TEMP.EQ.35.0) GO TO 53 IF (TEMP.EQ.35.0) GO TO 54 A=0.4011 B=0.4974	
2000 D0 10 I=1,3 V(I)=0.0 D0 10 J=1,3 10 Y(I,J)=0.0 1000 READ 20, PH,TEMP,RPM,POW,H0LD,KLA,SUPVEL RPM=RPM*1.9/0.5 PHOLD=H0LD/15.0*100.0 20 FORMAT(7F10.0) C POWER INPUT HORSEPOWER C HP=5.0*POW*RPM/63025.0 C C C C VOLIME OF LOQUID IN (CM)**3, (FT)**3, U.S. GALLON C AREA=(7.5*2.54/2.0)**2*3.1416 VCM=(7.5*2.54/2.0)**2*3.1416*15.0*2.54 VFT=VCM/28316.0 VGAL=VFT*7.481 C AA=HP/VGAL*1000.0 BB=SUPVEL/30.48*60.0 KLA=KLA*60.0 IF(TEMP.EQ.25.0) GO TO 52 IF (TEMP.EQ.35.0) GO TO 53 IF (TEMP.EQ.35.0) GO TO 54 A=0.4011 B=0.4974	
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AA=HP7VGAL+1000.0 BB=SUPVEL/30.48*60.0 KLA=KLA*60.0 IF(TEMP.EQ.25.0) GO TO 52 IF (TEMP.EQ. 30.0) GO TO 53 IF (TEMP.EQ. 35.0) GO TO 54 A=0.4011 B=0.4974	
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IF (TEMP.EQ. 35.0) GO TO 54 A=0.4011 B=0.4974	
A=0.4011 B=0.4974	
B=0.4974	
GO TO 51	
52 A=0.3199	
B=0.4621	
GO TO 51	
53 A=0.3286	
B=0.4562	
GO TO 51	
54 A=0 3872	
$D = V \bullet 4 1 1 1$	
BBB=BB <u>*</u> *B	

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FORTRAN SOURCE LIST

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SOURCE STATEMENT

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\$IBFTC DATA

+101	SUBROUTINE DAT (X, AV, PROD, NREAD, NROW, NVAR	,XMIN,XMAX)	
	DIMENSION X(70), AV(70), PROD(70, 70), XMIN(7	0), XMAX(70)	
	DO 5 K=1,NROW		
	READ $(5,4)$ $(X(I),I=1,NREAD)$		
4	FORMAT (3F10.0)		
	X(1) = ALOG(X(1))	,	
	X(2) = ALOG(X(2))		
	X(3) = ALOG(X(3))		
С	X=VARIABLES		
С	TRANSFORMATIONS ENTERED HERE		
	IF (K.NE.1) GO TO 3		
С	FIND MINIMUM AND MAXIMUM VALUES		
	DO 2 I=1,NVAR		
	XMIN(I) = X(I)		
2	XMAX(I) = X(I)	,	
3	DO 1 I=1, NVAR		
	IF $(X(I) \cdot LT \cdot XMIN(I)) \times MIN(I) = X(I)$		
	IF $(X(I) \cdot GT \cdot XMAX(I)) \cdot XMAX(I) = X(I)$		
1	CONTINUE	· ·	
С	CALCULATE SUMS (AV) AND PRODUCTS (PROD)		
	DO 5 I=1,NVAR		
•	AV(I) = AV(I) + X(I)		
	DO 6 J=I,NVAR		
	PROD(I,J) = PROD(I,J) + X(I) + X(J)		
6	$\frac{PROD(J,I) = PROD(I,J)}{PROD(I,J)}$		
5	CONTINUE		
	RETURN		
	END .		

SES FOR ABOVE ASSEMBLY

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COMPUTER PROGRAM OF SULFITE OXIDATION PROCESS

С	T(N)TIME	
C	CCI(N)ML IODINE STANDARD SOLUTION	
C	CCNA(N)ML SODIUM THIOSULEATE SOLUTION	2 . 2
C C		··· .
	DIMENSION $T(100)$ CCI(100) CCNA(100) V(2.2)	1123
	DIMENSION $((100))((1(100))((100)))$	V(3)
<u> </u>		·
	DO 15 I=1,3	:
ł	V(I)=0.	1
	DO 15 J=1,3	
15	Y(I, J) = 0.	
C		
C	READ OF MISAMPLE, TEMPERATURE, SHAFT SPEED, AIRV	FINCITY.
C	AIR PRESSURE. POWER REQUIREMENT	
: 111	READ 10. SAMP. TEMP. RDM. GASVEL. HEAD. POW.	N
111	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	
1.0	$\frac{1}{100} \frac{1}{100} \frac{1}$	
10		-
1	READ 20, $(1(1), CCI(1), CCNA(1), I=1, N)$	
20	FORMAT(3F10.0)	
C		
l C	SATURATION OXYGEN CONCENTRATION AT 35 C	
	CS=7.0394	
C		
lic	RECALCULATION OF AIR VELOCITY ACCORDING TO APP 2	
8	EACT=(29,921+HEAD)/29,921	
<u></u>	$\frac{1}{1} \frac{1}{1} \frac{1}$	
	$\frac{1}{1} \left(\frac{1}{10} + \frac{1}{10} $	1
ί.	IF(GASVEL .EQ.IU.U)GASVEL=8.30*FACT	
	IF(GASVEL .EQ.20.0) GASVEL=16.10*FAC	-
j	IF(GASVEL .EQ.30.0)GASVEL=24.00*FACT	,
	IF(GASVEL .EQ.40.0) GASVEL=32.80*FACT	
	IF(GASVEL .EQ.O.O) GASVEL=0.0	1
C		
C	TANK CROSSECTIONAL AREA	
C	TANK VOLUME IN CM**3	
Ċ	TANK VOLUME IN GALLON	41
C		
C	DECALCULATION OF SHAFT SPEED (DDM)	1. Jun 1
	RECALCULATION OF SHAFT SPEED (KPM)	
	PUWER INPUT HURSEPUWER/IUUUGALLUN	
L	SUPERFICIAL VELOCITY IN FL / HR	3 + 12 A
1	ARE=(7.5*2.54/2.0)**2*3.1416	
.	VOL=ARE*15.0*2.54	
1	VGAL=VOL/28316.0*7.481	
1	SUPVEL=GASVEL*1000./ARF	
1	RPM=RPM*1.9/0.5	• • • • · • • • • • • • • • • • • • • •
4	$HP = 5 \cdot 0 \times P \cap W \times R P M / 6 3 \cap 25 \cdot 0$	
i	$AA = HD / VCAL \pm 1.000 \text{ o}$	
t		
: 		

	SUPVEL'=BB	· .
	9 PRINT 30, RPM, SUPVEL, AA	; .
· 30	FORMAT(1X, 3F20.8)	
1 C		
	CONCENTRATION OF CULETTE IN THE CONTINUE TO THE	
i C	CONCENTRATION OF SULFITE IN THE SULUTION AT I(I)	1. (j.)
	ANORM1 = (CCI(1) - CCNA(1)) *0.2/SAMP	•
	NN=N-1	
•	SUM=0_0	5 64
• •		
10-10		
L.		
ζC	CONCENTRATION OF SULFITE IN THE SOLUTION AT T(2)	
1.1	ANORM2 = (CCI(I+1)) - CCNA(I+1)) * 0.2/SAMP	
	DT = T(I+1) - T(I)	
Ċ		
· ~ ` `	SATUDATION GANCEN CONCENTRATION	
L.	SATURATION DATGEN CONCENTRATION	
	CSIN=7.0394	
С		
۰C	OXYGEN ABSORBED LITERS/MIN	÷ .
\rightarrow	DXYABS = (ANDRM1 - ANDRM2)/2 + *22 + 4*10 + 86/DT	
i c		· 1
ຸບ ດ		
5 U	AIR INLET LITERSYMIN	•
	AIRIN=SUPVEL*ARE/(30.48)**2/60.*28.32*273./308.	1
∳C		
Ϊ£ –	OXYGEN INLET LITERS/MIN	
	$\Box X Y I N = \Delta I P I N \neq 0$ 21	
1	UKTIN-AININ-U•21	,
C		
C	CUMPOSITION OF DXYGEN IN DUTLET PERCENT	
÷ .	OUTLET=(OXYIN-OXYABS)/(AIRIN-OXYABS)	
C		
IC	OXYGEN CONCEN. IN FOUL, WITH OUTLET AIR	
<u> </u>		<u> </u>
C		
L		
C	LUG MEAN VALUE OF SATURATION OXYGEN CONCEN.	
	CS=(CSIN-CSOUT)/2.303/ALOG(CSIN/CSOUT)	
	KLA=(ANORM1-ANORM2)*16.0*1000.0 /DT/CS	; ;
i	KI A=KI A*60.	
ļ		
IEA.	$= \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0$	1
150	FUKMAI(IX,2F2U.8)	:
40	CONTINUE	,
Ì	AVKLA=SUM/FLOAT(NN)	-
	PRINT 60, AVKLA	,
60	EDRMAT (//1X-E20 8//)	
		,
C		
1	KLA=AVKLA*60.0	
1	YY = ALOG1O(KLA)	
1 :	$\Delta \Delta = \Delta I \cap G I \cap (\Delta \Delta)$	
1		
اني		• • • • • • • • • • • • • • • • • • • •

ι

AABB=	AA*BB		<u></u>	<u></u>			
ΑΑΑΑ=	= A A * A A						•
BBBB=	-BB*BB	11.1		x			
Y(1,1	.)=Y(1,	1)+1.0	•	,			
Y(3.1	.)=1(2; .)=Y(3;	1)+BB					;
Y(1,2	')=Y(1;)-V(2;	2)+AA	٨				. 1
Y(3.2	2)=1(2) 2)=Y(3。	2)+AAR	A R				
Y(1,3	3)=Y(1,	3)+BB					Υ, Υ.
Y(2,3	3)=Y(2,	3)+AABI	В				* · · · · · · · · · · · · · · · · · · ·
Y(3,3	s)=Y(3,	3)+BBBI	В		•		
. V(1)=	:V(1)+Y	ΥΥ • • • • •					1
V(2)=	·V (2)+Y •V/2)+V	′Y*AA ∕V*00		-			!
	· V (5 / T))]]]	1-00				•	
CALL	SOL TN (Y.V.3.	3.DET)				\$
C=10.	0**V(1)					
A = V (2)	2)						
B = V(3)	5)				,		in the second
PRINT	<u>80</u> , C	; ,A, B					
FURMA STOD	(1X)	3-20.8)	•			
END				·			
Y							
						•	2. T
	•						
<u>-</u>							
		*				, f	
							s. Sa A
						۰ 	
						•	
						:	
						· .	· · · · ·
							<u>,</u> •
	AABB AAAA BBBB Y(1,1 Y(2,1 Y(2,2 Y(3,2 Y(1,3 Y(2,2 Y(1,3 Y(2,3 Y(1,3 Y(2,3 Y(1,3 Y(2,3 Y(1,3 Y(2,3) Y(1,3 Y(2,3) Y(1,3 Y(2,3) Y(1,3 Y(2,3) Y(1,3 Y(2,3) Y(1,3 Y(2,3) Y(1,3) Y(2,3) Y(1,3) Y(2,3) Y(1,3) Y(2,3) Y(1,3) Y(2,3) Y(1,3) Y(2,3) Y(1,3) Y(1,2) Y(1,3) Y(1,2) Y(1,3) Y(1,2) Y(1,3) Y(1,3) Y(1,2) Y(1,3	AABB=AA*BB AAAA=AA*AA BBBB=BB*BB Y(1,1)=Y(1, Y(2,1)=Y(2, Y(3,1)=Y(3, Y(1,2)=Y(1, Y(2,2)=Y(2, Y(3,2)=Y(3, Y(1,3)=Y(1, Y(2,3)=Y(1, Y(2,3)=Y(2, Y(3,3)=Y(3, V(1)=V(1)+Y V(2)=V(2)+Y V(3)=V(3)+Y GO TO 111 CALL SOLTN(C=10.0**V(1) A=V(2) B=V(3) PRINT 80, C FORMAT(1X, STOP END	AABB=AA*BB AAAA=AA*AA BBBB=BB*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AA Y(2,2)=Y(2,2)+AAA Y(3,2)=Y(3,2)+AAB Y(1,3)=Y(1,3)+BB Y(2,3)=Y(2,3)+ABB Y(1)=V(1)+YY V(2)=V(2)+YY*AA V(3)=V(3)+YY*BB GO TO 111 CALL SOLTN(Y,V,3, C=10.0**V(1) A=V(2) B=V(3) PRINT 80, C ,A, B FORMAT(1X, 3F20.8 STOP END	AABB=AA*BB AAAA=AA*AA BBBB=BB*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AA Y(2,2)=Y(2,2)+AAAA Y(3,2)=Y(3,2)+AABB Y(1,3)=Y(1,3)+BB Y(2,3)=Y(2,3)+AABB Y(3,3)=Y(3,3)+BBBB V(1)=V(1)+YY V(2)=V(2)+YY*AA V(3)=V(3)+YY*BB GO TO 111 CALL SOLTN(Y,V,3,3,DET) C=10.0**V(1) A=V(2) B=V(3) PRINT 80, C,A, B FORMAT(1X, 3F20.8) STOP END	AABB=AA*BB AAAA=AA*AA BBBB=BB*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(2,2)+AAAA Y(3,2)=Y(3,2)+AABB Y(1,3)=Y(1,3)+BB Y(2,3)=Y(2,3)+AABB Y(2,3)=Y(2,3)+BBBB V(1)=V(1)+YY V(2)=V(2)+YY*AA V(3)=V(3)+YY*BB GO TO 111 CALL SOLTN(Y,V,3,3,DET) C=10.0**V(1) A=V(2) B=V(3) PRINT 80, C ,A, B FORMAT(1X, 3F20.8) STOP END	AABS=AA#BB AAAA=AA#AA BBBB=BB#BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AAAA Y(3,2)=Y(2,2)+AAABB Y(1,3)=Y(1,3)+BB Y(1,3)=Y(2,3)+AABB Y(2,3)=Y(2,3)+AABB Y(1)=V(1)+YY V(2)=V(2)+YY*AA V(3)=V(3)+YY*BB GO TO 111 CALL SOLTN(Y,V,3,3,DET) C=10.0**V(1) A=V(2) B=V(3) PRINT 80, C ,A, B FORMAT(1X, 3F20.8) STOP END	AABB=AA*BB AAAA=AA*AA BBB=BB*BB Y(1,1)=Y(1,1)+1.0 Y(2,1)=Y(2,1)+AA Y(3,1)=Y(3,1)+BB Y(1,2)=Y(1,2)+AAB Y(2,2)=Y(2,2)+AABB Y(1,3)=Y(1,3)+BB Y(2,3)=Y(2,3)+AABB Y(2,3)=Y(2,3)+BBBB V(1)=V(1)+YY V(2)=V(2)+YY*AA V(3)=V(3)+YY*BB GO TO 111 CALL SOLTN(Y,V,3,3,DET) C=10.0**V(1) A=V(2) B=V(3) PRINT 80, C ,A, B FORMAT(1X, 3F20.8) STOP END

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6-3

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UNSTEADY GASSING OUT PROCESS

(A) Temperature 25°C

pH value 1.0

 $K_{L}a = c(HP/V)a (Vs)^{b}$

Agitation Speed rpm	Power Input HP/1000 Gals.	Superficial Velocity ft/hr	K _L a hr ⁻¹	(HP) ^a (Vs) ^b	P/Po	$Q/ND_I^3 \times 10^2$
285	1 182	0.000	0.300	0,000	1.000	0.000
285	1.024	35,610	35,340	5,252	0.867	0.345
285	0.709	67.618	49,440	6,280	0.600	0.655
285	0.630	141.398	60.540	8,504	0.533	1.370
285	0.552	262.697	70.320	10.849	0.467	2.545
285	0.552	362.815	78.120	12,595	0.467	3.576
380	3.152	0.000	0.480	0.000	1.000	0.000
380	2.837	36.024	53.160	7.314	0.900	0.262
380	2.102	67.618	78.720	8.889	0.667	0.491
380	1.576	141.398	92.280	11.401	0.500	1.027
380	1.471	233.622	95.220	14.064	0.467	1.697
380	1.366	358.071	120.180	16.731	0.433	2.604
570	11.033	0.000	1.080	0.000	1.000	0.000
570	10.245	35.886	86.280	11.010	0.929	0.174
570	8.826	67.618	126.600	14.068	0.800	0.328
570	5,989	141.398	149.520	17.474	0.543	0.685
570	5.359	235.000	163.740	21:326	0.486	1.139
570	5.044	359.016	178.800	25.441	0.457	1.740
760	25.218	0.000	1.080	0.000	1.000	0.000
760	25.218	35.748	111.780	14.661	1.000	0.132
760	21.015	67.618	162.000	18.567	0.833	0.246
760	14.711	140.925	180.660	23.258	0.583	0.516
760	13.030	230.846	198.420	28.103	0.517	0.840
760	12.609	353.346	206.400	33.856	0.500	1.284
950 ·	52.538	0.000	2.400	0.000	1.000	0.000
950	49.912	35.886	105.180	18.272	0.950	0.104
950	42.031	67.382	201.240	23.139	0.800	0.196
950	28.896	141.398	226.440	28.910	0.550	0.410
950	26.269	235.000	233.700	35.461	0.500	0.684
950	24.168	359.016	230.460	41.997	0.460	1.044

7-1

c = 7.46

a = 0.32

Temperature 25 [°] C	c = 7.46
pH Value 2.0	a = 0.32
$K_{Ia} = c(HP/V)^{a} (V_{s})^{b}$	b = 0.46

Agitation Speed rpm	Power Input HP/1000 Gals.	Superficial Velocity	$K_r a hr^{-1}$	(HP)a (Vs) ^b	P/Po	Q/ND ³
· ·		ft/hr	Li			x 10 ²
285	1 1 9 9	0,000	0 000	0.000	1 000	0,000
285	1 102	37 618	32 040	5 506	1.000	0.000
285	0 788	71 / 57	52.040	5.500	0.933	0.305
285	0.700	146 969	67 020	8 990	0.007	1 424
285	0.709	243.996	78,180	11, 363	0.000	2 364
285	0.630	368.504	92.820	13.239	0.533	3.576
380	3.152	0.000	0.300	0.000	1.000	0.000
380	3.047	37.874	53.280°	7.659	0.967	0.275
380	2.102	71.398	86.100	9.115	0.607	0.518
380	1.681	150.689	105.600	11.986	0.533	1.094
380	1.576	246.083	120.420	14.728	0.500	1.788
380	1.576	372.283	137.400	17.833	0.500	2.705
570	11.821	0.000	0.840	0.000	1.000	0.000
570	11.033	37.874	89.340	11.559	0.933	0.184
570	9.457	71.437	138.660	14.752	0.800	0.639
570	6.305	149.744	167.340	18.241	0.533	0.725
570	5.51/	24/.461	186.480	22.044	0.46/	1.199
570	5.201	3/4.1/3	203.460	26.188	0.440	1.812
760	27.320	0.000	1.860	0.000	1.000	0.000
760	25.218	37.087	138.480	14.912	0.923	0.132
760	22.066	71.220	211.560	19.317	0.808	0.258
760	14.711	150.217	238.560	23.955	0.538	0.546
760	13.660	247.461	246.600	29.463	0.500	0.900
760	12.609	372.283	262.980	34.683	.0.462	1.356
950	49.912	0.000	2.040	0.000	1.000	0.000
950	47.285	37.480	131.340	18.323	0.947	0.109
950	39.404	71.220	175.320	23.254	0.789	0.208
950	28.896	150.217	208.860	29.729	0.579	0.437
950	26.269	246.083	220.680	36.224	0.526	0.715
950	24.956	377.953	239.640	43.450	0.500	1.098

Temperature 25°C	c = 7.46
pH Value 5.7	a = 0.32
$K_{La} = c(HP/V)^{a} (Vs)^{b}$	c = 0.46

Speed rpm	HP/1000 Gals.	Superficial Velocity ft/hr	K _L a hr ⁻¹	(HP) ^G (Vs) ^b	P/Po	Q/ND_{I}^{3} x 10 ²
			·····			
285	1.182	0.000	0.000	0 000	1 000	0 000
285	0.946	36.024	31,440	5.147	0.800	0.349
285	0.709	67.382	45.540	6.270	0.600	0.653
285	0.630	142,776	61,500	8.542	0.533	1.382
285	0.552	236.378	69.840	10.332	0.467	2,292
285	0.552	360.925	78.420	12.564	0.467	3.492
	0.150				1 000	
380	3.152	0.000	0.000	0.000	1.000	0.000
380	3.047	36.024	46.020	7.483	0.907	0.262
380	2.102	67.382	/8.360	8.8/5	0.667	0.490
380	1.5/6	142.776	102.840	11.452	0.500	1.038
380	1.576	236.378	120.000	14.456	0.500	1.716
380	1.4/1	360,925	131.760	17.195	0.467	2.628
570	11.033	0.000	0.000	0.000	1.000	0.000
570	11.033	35.886	64.200	11.274	1.000	0.174
570	9.457	67.382	115.260	14.359	0.857	0.324
570	6.305	142.323	158.280	17.817	0.571	0.684
570	5.517	232.087	192.120	21.401	0.500	1.128
570	5.517	359.016	194.220	26.180	0.500	1.739
760	27, 320	0,000	0.000	0.000	1,000	0.000
760	25,218	35,079	81,660	14.534	0.923	0.127
760	21.015	67.382	136.320	18 537	0.769	0.245
760	14.711	141.398	195.000	23,294	0.538	0.514
760	13,660	230.846	232.800	28,531	0.500	0.839
760	12.609	364.705	241.440	34.354	0.462	1.320
050	17.005	0.000	0.000	0.000	1 000	0.000
950	4/.285	0.000	0.000	0.000	1.000	0.000
950	4/.285	32.010	90.480	1/.895	0.94/	0.103
950	39.404	0/.382	120.300	22.666	0.833	0.196
950	28.896	141.850	215.580	28.952	0.611	0.412
950	24.956	234.311	2/3.540	34.83/	0.528	0.680
950	22.329	303./60	310.800	41.196	0.4/2	1.05/

7-3

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(B) Temperature $30^{\circ}C$ c = 9.27 pH Value 1.0 a = 0.33 $K_{L}a = c(HP/V)^{a}(vs)^{b}$ b = 0.46

Agitation Speed rpm	Power Input HP/1000 Gals.	Superficial Velocity	K _T ahr ⁻¹	(HP) ^a (Vs) ^b	P/Po	Q/ND ³ I
	· · · · · · · · · · · · · · · · · · ·	ft/hr				x 10 ²
285	1,182	0.000	1.740	0,000	1,000	0.000
285	1.103	36.024	36,060	5,298	0.933	0.348
285	0.788	67.382	51,600	6.312 ⁻	0.667	0.653
285	0.630	236.378	77.580	10.399	0.533	2.292
285	0.630	360.925	94.860	12.614	0.533	3.492
380	3.152	0.000	0.060	0.000	1.000	0.000
380	2.627	36.024	60.420	7.046	0.827	0.262
380	2.102	67.618	85.680	8.727	0.688	0.492
380	1.576	141.850	105.540	11.133	0.503	1.031
380	1.576	233.622	122.640	13.978	0.503	1.692
380	1.576	360.925	142.980	17.046	0.503	2.622
570	10.245	0.000	0.540	0.000	1.000	0.000
570	10.245 ′	35.886	97.200	11.000	1.000	0.173
570	8.669	67.382	141.840	13.880	0.846	0.326
570	6.305	142.323	177.060	17.583	0.615	0.690
570	5.517	232.224	193.020	21.040	0.538	1.124
570	5.517	359.016	211.560	25.666	0.538	1.740
760	25.218	0.000	0.300	0.000	1.000	0.000
760	25.218	35.079	121.140	14.637	1.000	0.127
760	19.965	67.382	183.480	18.258	0.792	0.245
760	13.660	141.398	217.200	22.602	0.542	0.514
760	13,660	230.846	250.560	28.266	0.542	0.839
760	12,609	364.705	265.320	33.919	0.500	1.320
950	49.912	0.000	2.640	0.000	1.000	0.000
950	47.285	35.610	175.440	18.119	0.947	0.103
950	39.404	67.382	244.560	22.828	0.789	0.196
950	28.896	141.850	292.260	28.953	0.579	0.408
950	25.218	234.311	303.960	34.810	0.505	0.682
950	23.642	363.760	318.720	41.652	0.474	1.057

Temperature 30°C	c = 9.27
pH Value 2.0	a = 0.33
$K_{L}a = c(HP/V)a (V_{s})b$	b = 0.46

Agitation Speed rpm	Power Input HP/1000 Gals.	Superficial Velocity ft/hr	K _L a hr ⁻¹	(HP) ^a (Vs) ^b	P/Po	Q/ND_1^3 x 10 ²
205		0.000	0 (00	0 000	1 000	0 000
285	1.570	0.000	0.420	0.000	1.000	0.000
285	1.5/6	3/.618	37.920	6.0/6	1.000	0.365
285	1.340	/1.220	55.380	7.707	0.850	0.690
285	0.946	149.744	69.960	9.648	0.600	1.452
285	0.630	244.843	88.920	10.568	0.400	2.376
285	0.552	373.228	104.460	12.259	0.350	3.612
380	4.203	0.000	0.600	0.000	1.000	0.000
380	3,993	37.736	58,500	8.259	0.953	0.275
380	3.362	71.220	94.140	10.428	0.800	0.517
380	2.837	148,819	110,160	13,803	0.677	1.081
380	2,732	246.083	142,680	17,149	0.650	1.788
380	2.627	373.228	158.880	20.472	0.626	2.712
570 "	11.821	0.000	1.200	0.000	1.000	0.000
570	11.821	37.480	102.660	11.761	1.000	0.181
570	9.142	71.220	154.680	14.486	0.773	0.344
570	6.777	150.689	182.280	18.481	0.573	0.730
570	6.305	245.394	197.580	22.544	0.533	1.189
570	5.832	371.319	215.760	26.544	0.493	1.799 [.]
760	26 260	0 000	1 960	0 000	1 000	0 000
760	20.209	0.000	100 (10	15 111	1.000	0.000
760	22.218	37.018	139.010		0.960	0.13/
760	23.11/	/1.220	201.540	19.649	0.880	0.259
760	12.702	150.217	239.340	24.353	0.600	0.546
760	14./11	246.772	263.400	29.857	0.560	0.896
760	12.609	370.374	274.980	34.159	0.480	1.344
950	52.538	0.000	3.420	0.000	1.000	0.000
950	49.912	37.480	167.760	18.880	0.950	0.109
950	42.031	71.220	246.540	23.915	0.800	0.208
950	28.896	150.217	282.900	29.720	0.550	0.437
950	26.269	247.461	306.720	36.170	0.500	0.720
950	23.642	369.429	315.840	41.947	0.450	1.074

Temperature 30°C	c =	9.27
pH Value 5.7	a =	0.33
$K_{L}a = c(HP/V)^{a}(Vs)^{b}$	b =	0.46

Agitation Speed rpm	Power Iñput HP/1000 gals.	Superficial Velocity ft/hr	K _L a hr ⁻¹	(HP) ^a (Vs) ^b	P/Po	Q/ND <mark>3</mark> x 102
285 285 285	1.024 0.867 0.709	32.972 59.724 117.697	37.740 60.660 74.340	4.966 6.164 7.864	1.000 0.846 0.692	0.000* 0.578* 1.140*
285 285 285	0.630 0.630 1.103	178.917 252.087 37.736	85.440 101.880 35.280	9.159 10.709 5.412	0.615 0.615 1.000	1.728* 2.448* 0.000
285 285 285 285 285	0.867 0.709 0.709 0.709	71.220 150.217 246.083 371.319	58.440 73.860 84.540 103.260	6.680 8.790 11.010 13.283	0.786 0.643 0.643 0.643	0.690 1.452 2.388 3.598
380 380 380 380 380	2.732 2.207 1.681 1.576 1.576	37.874 71.220 151.142 246.772 375 118	59.700 92.280 114.900 142.020	7.302 9.080 11.705 14.332	1.000 0.808 0.615 0.577	0.275 0.517 1.098 1.788 2.725
570 570 570 570 570 570	11.003 9.457 6.620 5.989 5.517	37.736 71.220 150.689 248.150 376.063	109.520 172.620 201.780 236.280 263.760	11.533 14.648 18.339 22.280 26.215	1.000 0.857 0.600 0.543 0.500	0.182 0.345 0.730 1.200 1.824
760 760 760 760 760	25.218 22.066 15.762 13.660 12.609	37.480 70.965 150.217 247.461 376.063	145.380 227.760 284.940 316.800 349.740	15.086 19.319 24.353 29.176 34.397	1.000 0.875 0.625 0.542 0.500	0.136 0.258 0.546 0.899 1.368
950 950 950 950 950 950	49.912 47.285 42.031 28.896 26.269	0:000 32.697 59.232 117.224 178.917	3.540 175.200 265.320 307.920 349.680	0.000 17.427 21.986 26.541 31.195	1.000 0.947 0.842 0.579 0.526	0.000* 0.095* 0.172* 0.341* 0.520*
950 950 950 950 950 950	24.956 47.285 42.031 28.896 26.269 24.956	251.969 37.618 71.220 150.689 248.150 373.228	403.140 165.540 268.620 332.640 373.740 410.100	35.860 18.578 23.915 29.763 36.216 42.899	0.500 0.947 0.889 0.611 0.556 0.528	0.732* 0.109 0.208 0.438 0.721 1.085

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* unsaturated air

APPENDIX VII 7-7

(C)	Temperature 35 ⁰ C	с =	8.58
	pH Value 1.0	a =	0.39
	$K_{L}a = c(HP/V)^{a}(Vs)^{b}$	b =	0.48

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Agitation Speed rpm	Power Input HP/1000 gals.	Superficial Velocity	K,ahr ⁻¹	(HP) ^a (Vs) ^b	P/Po	Q/ND_{I}^{3}
		ft/hr	L			x 10 ²
285	1.024	37.618	40.440	5,710	1.000	0.365
285	0.788	71,220	62,760	6.997	0.769	0.688
285	0.709	149.744	81 120	9,581	0.692	1,452
285	0.709	246.083	97,140	12,147	0.692	2.376
285	0.709	371.319	115.440	14.784	0.692	3.612
380	2.627	37.480	62.400	8.208	1.000	0.274
380	1.891	70.965	94.740	9.804	0.720	0.516
380	1.576	150.217	117.660	13.072	0.600	1.092
380	1.471	246.772	151.320	16.133	0.560	1.788
380	1.366	376.063	183.840	19.171	0.520	2.692
570	10.718	37.618	115.500	14.172	1.000	0.182
570	8.669	70.965	182.760	17.678	0.809	0.343
570	6.305	150.217	232,560	22.359	0.588	0.727
570	5.674	247.461	277.740	27.245	0.529	1.200
570	5.359	376.063	298.140	32.546	0.500	1.824
760	25.218	37.480	169.740	19,704	1.000	0.136
760	21.015	70.965	270.540	24.907	0.833	0.258
760	14.711	149.744	315.960	30.994	0.583	0.544
760	13.450	246,772	355.680	38.005	0.533	0.896
760	12.609	376.063	360.780	45.330	0.500	1.368
950	47.285	37.205	202.020	25.045	1.000	0.108
950	42.031	70.728	314.340	32.523	0.889	0.205
950	28.896	150.217	388.080	40.314	0.611	0.437
950	26.269	247.461	442.020	49.316	0.556	0.720
950	23.642	376.063	459.840	57,822	0.500	1.093

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Temperature 35 [°] C	с :	=	8.58
pH value 1.5	a =	-	0.39
$K_{La} = c(HP/V)^{a}(vs)^{b}$	Ъ =	=	0.48

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Agitation Speed rpm	Power Input HP/1000 gals.	Superficial Velocity ft/hr	$K_{L}a hr^{-1}$	(HP) ^a (Vs) ^b	P/Po	Q/ND ₁ x 10 ²
205	1 102	27 618	/1 000	E 07(1 000	0.005
205	0 788	70 065	41.000	2.070	1.000	0.303
205	0.700	150 690	04.320	0.905	0.714	0.000
285	0.709	2/9 959	101 990	9.010	0.643	1.404
285	0.709	376.063	124,920	14.874	0.643	2.412
		3,01003	1211/1/20	11.071	01015	,51040
380	3.152	37.618	72.300	8.823	1.000	0.274
380	2.312	71.220	106.560	10.615	0.733	0.516
380	1.786	150.217	144.420	13.721	0.567	1.092
380	1.681	246.772	166.440	16.989	0.533	1.793
380	1.576	376.063	192.840	20.263	0.500	3.279
570	10 245	37 205	118 200	13 853	1 000	0 180
570	9 457	70 965	104 040	18 283	0 023	0.100
570	6.305	150 217	235 440	22 359	0.525	0.343
570	5,674	248.150	281,100	27 281	0.554	1 200
570	5.359	376.063	325.020	32.546	0.523	1.824
760	05 010	07 (10	17/ 0/0	10 700	1 000	
760	25.218	37.618	1/4.240	19.738	1.000	0.13/
760	21.015	/0./28	265.080	24.868	0.833	0.25/
760	14./11	150.217	318.960	31.040	0.583	0.546
760	13.450	248.150	356.220	38.106	0.533	0.901
760	12.609	376.063	393.480	45.330	0.500	1.368
950	49.912	36.949	208.860	25.491	1.000	0.107
950	42.031	70.728	316.860	32.523	0.842	0.205
950	28.896	150.217	397.980	40.314	0.579	0.437
950	24.956	246.772	435.840	48.282	0.500	0.718
950	23.642	376.063	453.480	57.822	0.474	1.093
			··· ··· ··· ··· ··· ····	• .		

Temperature 35 [°] C	c =	8.58
pH value 2.0	a =	0.39
$K_{I,a} = c(HP/V)^{a}(Vs)^{b}$	b =	0.48

Agitation Speed rpm	Power Input HP/1000 gals.	Superficial Velocity ft/hr	K _L a hr ⁻¹	(HP) ^a (Vs) ^b	P/Po	Q/ND_1^3 x 10^2
285 285 285 285 285 285 285	1.182 1.024 0.788 0.709 0.709 0.630	0.000 37.618 70.965 149.744 244.705 368.484	0.420 39.060 61.620 78.180 100.740 105.160	0.000 5.710 6.985 9.581 12.114 14.074	1.000 0.867 0.667 0.600 0.600 0.533	0.000 0.365 0.688 1.452 2.376 3.576
380 380 380 380 380 380	2.837 2.102 1.576 1.576 1.471	37.618 71.220 149.291 247.461 370.374	$\begin{array}{c} 0.720 \\ 64.440 \\ 94.800 \\ 122.760 \\ 140.280 \\ 174.000 \end{array}$	0.000 8.471 10.230 13.033 16.592 19.586	1.000 0.931 0.689 0.517 0.517 0.483	0.000 0.274 0.517 1.085 1.798 2.688
570 570 570 570 570 570	10.245 9.457 6.305 5.674 5.359	37.205 70.965 150.689 247.461 373.228	$114.960 \\ 170.760 \\ 200.760 \\ 220.440 \\ 243.360$	13.853 18.283 22.392 27.245 32.429	0.929 0.857 0.571 0.514 0.486	0.180 0.343 0.730 1.200 1.812
760 760 760 760 760 760	25.218 26.269 23.117 14.711 13.660 12.609	0.000 37.343 70.728 148.819 246.772 373.228	2.460 152.940 220.380 250.620 274.020 303.540	0.000 19.983 25.803 30.902 38.234 45.167	1.000 1.000 0.917 0.583 0.542 0.500	0.000 0.136 0.257 0.649 0.896 1.356
950 950 950 950 950 950 950	52.538 49.912 42.031 28.896 26.269 23.642	0.000 37.343 70.728 150.217 247.461 373.228	4.620 178.680 266.640 298.320 326.220 331.740	0.000 25.620 32.523 40.314 49.316 57.614	1.000 0.950 0.800 0.550 0.500 0.450	0.000 0.109 0.205 0.537 0.719 1.085

7–9

Temperature 35 ⁰ C	c =	8.58
pH value 4.5	a =	0.39
$K_{L}a = c(HP/V)a(Vs)^{b}$	b =	0.48

Agitation Speed rpm	Power Input HP/1000 gals.	Superficial Velocity ft/hr	K _L a hr ⁻¹	(HP) ^a (Vs) ^b	P/Po	Q/ND_{I}^{3} × 10 ²
205	1 00/	28 012	/1 //0	F 700	1 000	0.160
205	1.024	30.012	41.400	5.730	1.000	0.300
285	0.709	/1.093	01.920	0.739	0.092	0.095
285	0.630	102.992	//./00	9.248	0.615	1.490
285	0.630	240.000	98.940	1/ 011	0.615	2.412
285	0.630	376.063	102.720	14.211	0.615	3.048
380	2.627	38.012	60.720	8.263	1.000	0.272
380	1.891	71.693	91.740	9.852	0.720	0.516
380	1.576	152.067	119.400	13.148	0.600	1.092
380	1.471	250,925	146.520	16.262	0.560	1.793
380	1.471	375.118	162.060	19.706	0.520	2.732
570	11.033	37,874	116,940	14,378	1,000	0.184
570	9.457	71,693	184,200	18,373	0.857	0.347
570	6,305	152.067	226,500	22,490	0.571	0.737
570	5.832	250.236	260.760	27.683	0.529	1,212
570	5.517	377.953	295.320	32.992	0.500	1.830
760	22 117	71 / 57	245 880	25 020	1 000	0 250
760	23.11/	152 067	243.000	23.525	0.655	0.233
760	13 660	250 925	355 500	38 540	0.591	0.952
760	12 600	370 8/3	356 820	45 547	0.545	1 380
700	12.009	575.045	550.020	43.347	0.545	1.000
950	49.912	37.736	187.800	25.749	1.000	0.110
950	39.404	71.457	306.000	31.876	0.789	0.208
950	28.896	148.898	358.620	40.144	0.579	0.433
950	26.269	257.874	437.880	50.297	0.526	0.750
950	24.693	377.008	467.100	58.875	0.495	1.096
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pH value 5.7 (Distilled Water)

 $K_{L}^{a} = c(HP/V)^{a} (Vs)^{b}$

Agitation Speed rpm	Power Input HP/1000 gals.	Superficial Velocity ft/hr	K _L A hr ⁻¹	(HP)a (Vs) ^b	P/Po	Q/ND_{I}^{3} x 10^{2}
285	0.946	33,091	38,820	5,207	1.000	0.320*
285	0.788	59,961	59,100	6.445	0.833	0.528*
285	0.709	117,697	75,600	8,540	0.750	1.140*
285	0.709	179,606	89.280	10.450	0.750	1.740*
285	0.630	253.031	99.720	11.760	0.667	2.448*
285	0.946	37.736	40.500	5.544	1.000	0.366
285	0.788	71.220	60.120	6.997	0.833	0.690
285	0.630	150.217	73.860	9.167	0.667	1.452
285	0.630	247.461	86.700	11.636	0.667	2,400
285	0.552	372.283	115.500	13.430	0.583	3.672
380	2.837	38.012	68.940	8.513	1.000	0.276
380	2.837	38.012	68.940	8.513	1.000	0.276
380	2.102	71.220	106.020	10.230	0.741	0.517
380	1.681	151.142	131.460	13.442	0.593	1.098
380	1.471	247.461	155.280	16.154	0.519	1.798
380	1.471	374.173	180.060	19.682	0.519	2.719
570	11.033	0.000	1.380	0.000	1.000	0.000
570	11.033	37.480	110.760	14.307	1.000	0.181
570	8.669	71.220	182.040	17.708	0.786	0.346
570	6.305	151.142	217.260	22.424	0.571	0.732
570	5.832	248.150	263.220	27.572	0.529	1.200
570	5.517	374.154	269.580	32.834	0.500	1.812
760	27.320	0.000	2.040	0.000	1.000	0.000
760	25.218	37.618	156.660	19.738	0.923	0.137
760	23.117	70.965	263.820	25.844	0.846	0,258
760	14.711	150.689	305.580	31.087	0.538	0.547
760	13.660	248.150	340.140	38.335	0.500	0.901
760	12.609	377.953	365.640	45.439	0.462	1.368
950	49.912	0.000	4.680	0.000	1.000	0.000*
950	49.912	32.697	168.960	24.045	1.000	0.095*
950	28.896	117.224	305.340	35.810	0.579	0.341*
950	42.031	59.232	259.260	29.881	0.842	0.172*
950	26.269	178.917	340.080	42.238	0.526	0.520*
950	24.956	252.087	382.740	48.776	0.500	0.733*
950	49.912	37.343	191.160	25.620	1.000	0.108
950	42.031	70.965	299.880	32.575	0.842	0.206
950	27.583	150.689	365.280	39.654	0.553	0.438
950	26.269	249.547	417.540	49.514	0.526	0.725
950	23.642	374.173	436.560	57.683	0.474	1.087

c = 8.58a = 0.39

7-11

b = 0.48

Temperature 35[°]C

pH value 10.0

$$K_{La} = c(HP/V)^{a}(Vs)^{b}$$

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Agitation Speed rpm	Power Input HP/1000 gals.	Superficial Velocity	K _l ahr ⁻¹	(HP) ^a (Vs) ^b	P/Po	Q∕NDĭ
		ft/hr				x 102
285	1.024	37.618	43.080	5.710	1.000	0.365
285	0.788	/0.965	62.100	6.985	0.769	0.690
285	0.709	150.217	76.860	9.595	0.692	1.452
285	0.709	244.705	91.440	12.114	0.692	2.388
285	0.709	372.283	112.260	14.803	0.692	3.598
380	2.837	37.618	62.820	8.471	1.000	0.274
380	1.996	70.965	94.380	10.012	0.704	0.516
380	1.576	150.217	123.720	13.072	0.556	1.092
380	1.471	245.394	143.460	16.090	0.519	1.788
380	1.471	370.374	168.300	19.586	0.519	2.692
570	11.033	37,480	115,620	14.307	1.000	0.181
570	8.826	70,965	180.480	17.801	0.800	0.312
570	6.305	149.744	214.800	22.325	0.571	0.724
570	5.674	246.772	251,520	27,209	0.514	1,195
570	5.359	371.319	274.980	32.349	0.486	1.799
760	25,218	37,205	164,160	19.635	1.000	0.136
760	22.066	70,728	245,220	25.342	0 875	0.150
760	15,131	150,689	297.840	31,428	0.600	0.547
760	13,660	249,429	335,100	38,430	0.542	0.905
760	12.609	377.953	363.720	45.439	0.500	1.373
950	47 285	37 205	20/ / 80	25 045	1 000	0 108
950	47.205	70 728	215 180	20.040	0.880	0.100
950	28 896	151 142	388 440	52.523 40 432	0.009	0.203
950	25.744	-J	300.440	40.452	0.011	0.433
950	23.642	377 008	722.TOD	40.732 57 800	0.544	1 006
220	23.042	577.000	400.320	J/.072	0.000	T.020
		2				

a = 0.39

c = 8.58

b = 0.48

Temperature 35⁰C

pH value 11.0

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 $K_{La} = c(HP/V)^{a}(Vs)^{b}$

Agitation Speed rpm	Power Input HP/1000 gals.	Superficial Velocity ft/hr	K _L a hr ⁻¹	(HP) ^a (Vs) ^b	P/Po	Q/ND_{I}^{3} x 10^{2}
0.05	1 100					
285	1.103	37.618	39.720	5.876	1.000	0.365
285	0.788	70.965	61.500	6.985	0.714	0.688
285	0.709	149.744	80.640	9.581	0.643	1.452
285	0.709	244.705	93.420	12.114	0.643	2.376
285	0.709	371.319	113.280	14.784	0.643	3.600
380	2.837	37.480	60.660	8.456	1.000	0.272
380	2.312	70.965	98.700	10.596	0.815	0.515
380	1.576	149.744	120.480	13.052	0.556	1.088
380	1.471	248.150	145.020	16.176	0.519	1.804
380	1.471	377.008	167.040	19.753	0.519	2.738
570	11.033	37.343	105.660	14.281	1.000	0.181
570	8.669	70.965	170.040	17.678	0.786	0.343
570	5.674	149.744	202,980	21.433	0.514	0.725
570	5.359	246.772	223.260	26.613	0.486	1.195
570	5.044	375.118	260.280	31.753	0.457	1.817
760	25,218	37, 343	147.540	19,669	1.000	0.136
760	21,015	70,728	226,080	24.868	0.833	0.257
760	14,711	150,217	277.500	31.040	0.583	0.546
760	13,660	246.083	306,180	38,183	0.542	0.894
760	12.609	376.063	330.780	45.330	0.500	1.368
950	47,285	37,343	170,760	25,090	1,000	0.109
950	39,404	70.965	260,100	31.771	0.833	0 206
950	27.583	150,197	294.360	39,592	0.583	0.437
950	25.744	248.150	344,220	48,997	0.544	0.721
950	23.642	374,173	352,500	57.683	0.500	1.087
1			5521500	22.000	0.000	1.007

7-13

a = 0.39

c = 8.58

c = 0.48

Temperature 35°C

pH value 12.5

 $K_{La} = c(HP/V)^{a}(Vs)^{b}$

Agitation Speed rpm	Power Input HP/1000 gals.	Superficial Velocity ft/hr	K _L a hr ⁻¹	(HP) ^a (Vs) ^b	P/Po	Q/ND_1^3 x 10^2
		· · · · · · · · · · · · · · · · · · ·		<u> </u>		
005		07 0/0		<		
285	1,182	37.343	43.740	6.014	1.000	0.361
285	0.867	/0./28	67.500	7.237	0.733	0.685
285	0.788	149.291	81.780	9.965	0.667	1.452
285	0.709	243.996	90.360	12.097	0.600	2.364
285	0.709	374.173	126.960	14.839	0.600	3.624
380	2.627	37.480	70.680	8.208	1.000	0.272
380	2.102	70.728	113.460	10.196	0.800	0.514
380	1.681	149.744	131.100	13.382	0.640	1,088
380	1.576	245.394	155.880	16.525	0.600	1.788
380	1.471	374.173	179.040	19.682	0.560	2.719
570	10.245	37.343	125.040	13.878	1.000	0.181
570	8,669	70,728	186,660	17.649	0.846	0.343
570	5,989	149.744	220,500	21.886	0.585	0.725
570	5,517	246.083	263,580	26.878	0.538	1,192
570	5.044	374.173	277.320	31.715	0.492	1.812
760	26.269	37,205	167.580	19,947	1.000	0.136
760	22.066	70.728	253.080	25.342	0.840	0.257
760	14.711	149.744	303,120	30,994	0.560	0.544
760	13,660	246.083	345,660	38,183	0.520	0.894
760	12.609	374.173	349.980	45.221	0.480	1.360
950	49,912	36,949	188,580	25,491	1.000	0.107
950	39,404	70.256	274,620	31,619	0.789	0.204
950	27 583	149 724	342 840	39 532	0 553	0 436
950	24 956	246 083	375 960	48 217	0 500	0 715
950	22.329	374.173	419.040	56.421	0.447	1.087

7-14

c = 8.58a = 0.39

a = 0.48

(D) Temperature 40°C

pH value 1.0

 $K_{L}a = c(HP/V)^{a}(Vs)^{b}$

Agitation Speed rpm	Power Input HP/1000 gals.	Superficial Velocity ft/hr	K _L a hr ⁻¹	(HP) ^a (Vs) ^b	P/Po	Q/ND ₁ x 10 ²
285	1.024	37.736	50,460	6.145	1.000	0.366
285	0.788	70.965	70.260	7.572	0.769	0.688
285	0.709	150.689	91.500	10.557	0.692	1.464
285	0.709	248.150	104.280	13.530	0.692	2.404
285	0.709	377.008	136.560	16.659	0.692	3.653
380	2.942	37.618	73.080	9.367	1.000	0.274
380	2.207	70.965	121.860	11.444	0.750	0.516
380	1.681	150.689	141.540	14.924	0.571	1.094
380	1.576	246.772	174.540	18.586	0.536	1.788
380	1.576	376.063	227.220	22.919	0.536	2.732
570	11.033	37.480	127.020	15.887	1.000	0.181
570	9.457	71.220	205,980	20.552	0.857	0.345
570	6.147	150.689	260.940	25.102	0.557	0.730
570	5.674	246.083	297.180	31.025	0.514	1.192
570	5.674	246.083	297.180	31.025	0.514	1.192
570	5.359	376.063	330.120	37.443	0.486	1.822
760	25.218	37.343	180.900	22.092	1.000	0.136
760	19.965	70.728	279.000	27.639	0.792	0.257
760	14.711	149.744	363.960	35.511	0.583	0.544
760	13.660	246.772	399.660	44.193	0.542	0.896
760	12.609	376.063	455.460	52.774	0.500	1.368
950	48.598	37.205	231.240	28.689	1.000	0.108
950	39.404	70.728	387.540	36.304	0.850	0.205
950	28.896	150.689	484.980	46.700	0.595	0.438
950	26.269	247.461	544.200	57.527	0.541	0.720
950	24.956	377.953	562.380	69.570	0.514	1.098

a = 0.40

c = 8.82

b = 0.50

Temperature 40°C

pH value 1.5

 $K_{L}a = c(HP/V)^{a}(Vs)^{b}$

Agitation Speed rpm	Power Input HP/1000 gals.	Superficial Velocity	K _L a hr ⁻¹	(HP)a (Vs) ^b	P/Po	Q/ND ³ I
		ft/hr			<u></u>	x 10 ²
285	1.024	37.736	44.640	6.145	1.000	0.366
285	0.788	70.965	68.040	7.572	0.769	0.688
285	0.630	151.142	92.580	10.085	0.615	1.464
285	0.630	246.083	110.760	12.852	0.615	2.388
285	0.630	376.063	133.620	15.870	0.615	3.648
380	2.942	37.618	98.220	9.367	1.000	0.273
380	2.312	70.965	124.920	11.660	0.786	0.516
380	1.786	150.217	160.440	15.267	0.607	1.092
380	1.576	248.858	195.780	18.664	0.536	1.812
380	1.576	376.063	238.920	22.919	0.536	2.732
570	11.033	37.618	135.600	15.916	1.000	0.182
570	6.305	149.291	273.600	25.241	0.571	0.724
570	5.674	245.394	309.960	30.982	0.571	1.189
570	5.359	376.063	367.140	37.443	0.486	1.822
760	25.218	37.480	195.780	22.133	1.000	0.137
760	22.066	70.728	313.800	28.771	0.875	0.257
760	14.711	150.689	401.280	35.622	0.583	0.540
760	13.660	247.461	422.460	44.255	0.542	0.899
760	12.609	376.063	416.400	52.774	0.500	1.368
950	47.285	37,480	225,600	28,480	1.000	0.109
950	42.031	70,728	380,760	37,256	0.889	0.205
950	27,583	150,217	496,800	45.766	0.583	0.437
950	26,269	246,083	569,100	57.367	0.556	0.715
950	24.956	376,063	559,200	69.397	0.528	1.093
		2.2.200	2071200		0.520	±•000

c = 8.82a = 0.40

b = 0.50

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Temperature 40⁰C

pH value 5.7

$$K_{L}^{a} = c(HP/V)^{a}(Vs)^{b}$$

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Agitation Speed rpm	Power Input HP/1000 gals.	Superficial Velocity ft/hr	K _L a hr ⁻¹	(HP) ^a (Vs) ^b	P/Po	Q/ND_1^3 × 10 ²
285	1.024	37.736	41.640	6.145	1.000	0.366
285	0.788	71.220	66.060	7.586	0.769	0.828
285	0.709	150.689	86.160	10.557	0.692	1.464
285	0.630	247.461	.93.000	12.888	0.615	2.398
285	0.630	375.118	121.200	15.850	0.615	3.636
380	2.942	37.618	70.440	9.367	1.000	0.274
380	2.102	69.488	107.520	11.105	0.714	0.505
380	1.576	151.142	141.000	14.564	0.536	1.098
380	1.576	247.461	172.380	18.612	0.536	1.800
380	1.471	376.063	188.340	22.293	0.500	2.732
570	11.821	0.000	1.440	0.000	1.000	0.000
570	11.033	37.618	122.160	15.916	0.933	0.182
570	9.457	69.252	189.780	20.268	0.800	0.336
570 ·	6.305	150.689	222.060	25.358	0.533	0.730
570	5.674	247.461	266.220	31.111	0.480	1.200
570	5.359	361.870	295.320	36.733	0.453	1.752
760	26.269	0.000	3.000	0.000	1.000	0.000
760	25.218	37.618	156.900	22.173	0.960	0.137
760	21.015	70.965	244.500	28.260	0.800	0.258
760	14.711	150.689	297.300	35.622	0.560	0.540
760	13.660	246.772	334.080	44.193	0.520	0.804
760	12.609	377.953	333.540	52.906	0.480	1.368
950	49.912	0.000	4.800	0.000	1.000	0.000
950	42.031	70.965	30 8. 040	37.318	0.842	0.206
950	28.896	150.689	336.000	46.700	0.579	0.438
950	26.269	246.772	363.660	57.447	0.526	0.718
950	23.642	376.063	412.920	67.908	0.474	1.093

7–17

c = 8.82

a = 0.40

b = 0.50

SULFITE OXIDATION PROCESS

.

Temperature = $35^{\circ}C$

Shaft speed = 950 rpm

Superficial Velocity ft/hr	Power Input (HP/1000 gals)	Time (min)	Sulfite Conc.(N)	$K_{La \times 10^{-2}}$ (hr ⁻¹)	Average K_å x 10 ⁻² (hr ⁻¹)
37.74	47.28	0.0	1.324		
		10.0	1.234	12.21	
		20.0	1.116	14.20	
		30.0	1.026	13.54	
		40.0	0.948	12.82	
		50.0	0.882	12.04	
		60.0	0.802	11.82	12.8
70.97	38.09	0.0	0.790		
		10.0	0.656	18.29	
		20.0	0.484	20.80	
		30.0	0.322	21.27	
		40.0	0.168	21.16	20.4
149.29	28.90	0.0	1.256		
		5.0	1.148	29.44	
		10.0	1.040	29.44	
		15.0	0.926	29.89	
		20.0	0.860	26.91	28.9
245.39	26.27	0.0	0.860		
		5.0	0.718	38.78	
		10.0	0.598	35.91	37.3
360.92	24.96	0.0	0.390		
		3.5	0.292	42.04	45.1
		7.0	0.152	48.18	
0.0		0.0	0.190		
		6.0	0.188		
		12.0	0.186		

Temperature = $35^{\circ}C$

Shaft speed = 570 rpm

Superficial Velocity ft/hr	Power Input (HP/1000 gals)	Time (min)	Sulfite Conc.(N)	$K_{L^{a} \times 10^{-2}}$ (hr ⁻¹)	Average K _L a x 10 ⁻² (hr -1)
36.55	10.56	0.0 0.6 20.0 40.0	1.212 1.192 1.122 1.048	6.07 6.63 10.40	6.24
67.14	9.46	0.0 10.0 20.0	1.046 0.962 0.910	10.44 9.89	10.17
140.46	6.30	0.0 8.0 15.0	0.910 0.864 0.806	6.24 8.56	7.40
227.38	5.52	0.0 8.0 15.0	0.806 0.740 0.668	13.00 12.90	12.1
344.83	5.20	0.0 8.0 15.0	0.668 0.594 0.526	12.00 12.60	12.3
0.0		0.0 15.0	0.526 0.516	15.0	

Temperature = $35^{\circ}C$

Shaft speed = 285 rpm

.

Superficial Velocity ft/hr	Power Input (HP/1000 gals)	Time (min)	Sulfite Conc.(N)	$K_{La \times 10^{-2}}$ (hr ⁻¹)	$\begin{array}{c} {}^{\rm Average}_{\rm K_La~x~10}^{-2}\\ {}^{\rm (hr^{-1})}\end{array}$
38.01	0.71	0.0 10.0 31.0	1.318 1.298 1.286	2.73 1.43	2.08
71.21	,0.71	0.0 34.0 77.0 96.0	1.296 1.272 1.240 1.216	0.90 0.97 1.12	1.00
148.36	0.63	0.0 25.0 50.0	1.216 1.192 1.172	1.28 1.19	1.23
241.23	0.63	0.0 15.0 52.0 90.0	1.172 1.148 1.084 1.050	2.36 2.36 1.86	2.19
351.45	0.63	0.0 25.0 50.0	1.052 1.020 0.966	1.64 2.32	1.98
0.0		0.0 25.0	0.956 0.958		