DETERMINATION OF THE EFFECTS OF FISH SIZE AND FEED PELLET SIZE ON THE SETTLING CHARACTERISTICS OF RAINBOW TROUT (*SALMO GAIRDNERI*) CULTURE CLEANING WASTES

by

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ABSTRACT

This research reports on the determination of the effects of fish size and feed pellet size on the settling characteristics of Rainbow trout (*Salmo gairdneri*) culture, tank cleaning wastes.

Flocculant particle settling curves (Type II) were developed from settling column analysis of cleaning wastes from 11–311 gram Rainbow trout fed a moist pellet diet (Oregon Moist Pellet ®). Four feed pellet sizes were investigated: 3/32, 1/8, 5/32 and 3/16 inch.

Overall non-filterable residue removal curves and individual particle settling velocity distribution curves, derived from the Type II settling curve of each fish size and feed pellet size group, were compared. Slopes and y-intercepts of the linearized overall non-filterable residue removal curves and individual particle settling velocity distribution curves were compared using the Equality of Slope Test (S:SLTEST).

Results of the test for a common regression equation indicated there were no significant differences in the proportional distribution of particle sizes within the cleaning wastes. Variations observed in the initial rates of removal within the overall non-filterable residue removal curves were considered insignificant.

Settling trials were pooled in order to obtain single curves, characterizing the overall solids removal rate and the individual particle settling velocity distribution of the waste solids.

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1. INTRODUCTION

The effluent discharged from a freshwater trout farm or hatchery offers unique problems in the areas of wastewater treatment and management. While at times resembling that of a domestic water supply, effluents can reach strengths more frequently associated with conditions in a secondary sewage treatment plant.

In the past when fish farms were small and few in number, discharged farm effluents posed no significant problems. In some cases, the contribution of solids and dissolved nutrients to oligotrophic receiving waters provided a positive benefit in the form of increased primary productivity (Samis, 1983). However, as farms have grown rapidly in size and numbers, the discharge of untreated effluents has become a source of environmental concern.

A farm producing 50–75 tonnes/year of fish has an estimated water use of 500 l/ sec which is the equivalent demand of approximately 170,000 people (Warrer-Hansen, 1979a). Bergheim and Selmer-Olsen (1978) estimated the daily loading of organics and nutrient salts from a Norwegian fish farm to be in the order of 1260 population equivalents. In Idaho, the combined waste output from 49 hatcheries and farms located along a 27 mile section of the Snake River, has been estimated to be in the order of 63-73,000 pounds of biological contaminants daily (Klontz & King, 1975; Klontz et al., 1978). Fauré (1977) estimated that this would be the equivalent of a city of 1.2-1.5 million people discharging untreated sewage directly into the river on a daily basis.

Left untreated these effluents can have significant impacts on downstream receiving waters. Solids discharged in the form of unconsumed feed pellets and fish faeces can settle out in slow moving streams and rivers. The accumulation of solid wastes suffocates native stream flora and fauna, while providing a rich medium for less desirable, more pollution-tolerant plant and animal species (Mayo & Liao, 1969; Bodien, 1970; Brisbin, 1970). In turn, bacterial decomposition of the accumulated organic solids can reduce dissolved oxygen levels in the stream (Bergheim & Silversten, 1981), resulting in fish kills under extreme conditions (Solbé, 1982).

Nutritional enrichment from the discharge of dissolved nutrients such as ammonia and inorganic phosphorus can accelerate eutrophication in low flow streams (Sumari, 1982). At higher dilutions, the added enrichment encourages the growth of noxious algae species (*Cyanophyta spp.*) and bacterial groups commonly referred to as "sewage fungus" (Mantle, 1982).

In the past the focus of aquaculture waste research has centered on the areas of problem surveying (Liao, 1970; Sumari, 1982; EIFAC, 1982; DFO, unpublished) and waste quantification (Liao, 1970a; Scherb & Braun, 1971; Liao & Mayo, 1972; Speece, 1973; Knösche & Tscheu, 1974; EIFAC, 1982; Solbé, 1982). Based on the available literature it has been possible to identify the major relationships and to develop appropriate equations to predict the quantity and quality of the various waste constituents in fish culture effluents.

The quantity of these waste elements has been found to be a function of feed quantity (Brockway, 1950; Liao, 1970a; Liao et al., 1972; Willoughby et al., 1972; Liao & Mayo, 1974; Muir, 1978; Fauré, 1977), feed type (Solberg & Bregnballe, 1977;

Gunther et al., 1981; Butz & Vens-Cappell, 1982; Solberg & Bregnballe, 1982; Warrer-Hansen, 1982; Stechey, 1986), fish size (Wheaton, 1977) and temperature (Wheaton, 1977).

Feeding operations and cleaning activities have also been reported to influence the type and concentration of pollutants discharged. During normal operations the level of suspended solids in farm effluents is generally low, averaging approximately 7 mg/l (Liao, 1971). However, during cleaning operations, the concentrations of suspended solids have been shown to increase significantly. Liao (1970) reported that the level of suspended solids in the effluent increased during cleaning to an average of 96 mg/l, while Bergheim et al. (1984) reported concentrations ranging from 30 to 5800 mg/l.

Analysis of daily flows from the Summerland hatchery (British Columbia Fish and Wildlife) demonstrated that solids discharged during cleaning accounted for 20–25% of the total dishcharge of BOD_5 (5 day Biochemical Oxygen Demand) and suspended solids (Brisbin, 1970; Underwood McLellan, 1970). In a similiar report on U.S. hatcheries, Liao (1970) reported cleaning flows contributed 4–52% and 5–22% of the non-filterable residue and BOD respectively to the overall waste discharged. A survey of ten Canadian federal salmonid rearing facilities in British Columbia, reported cleaning flows containing 8–25% of the total waste (Underwood McLellan, 1977).

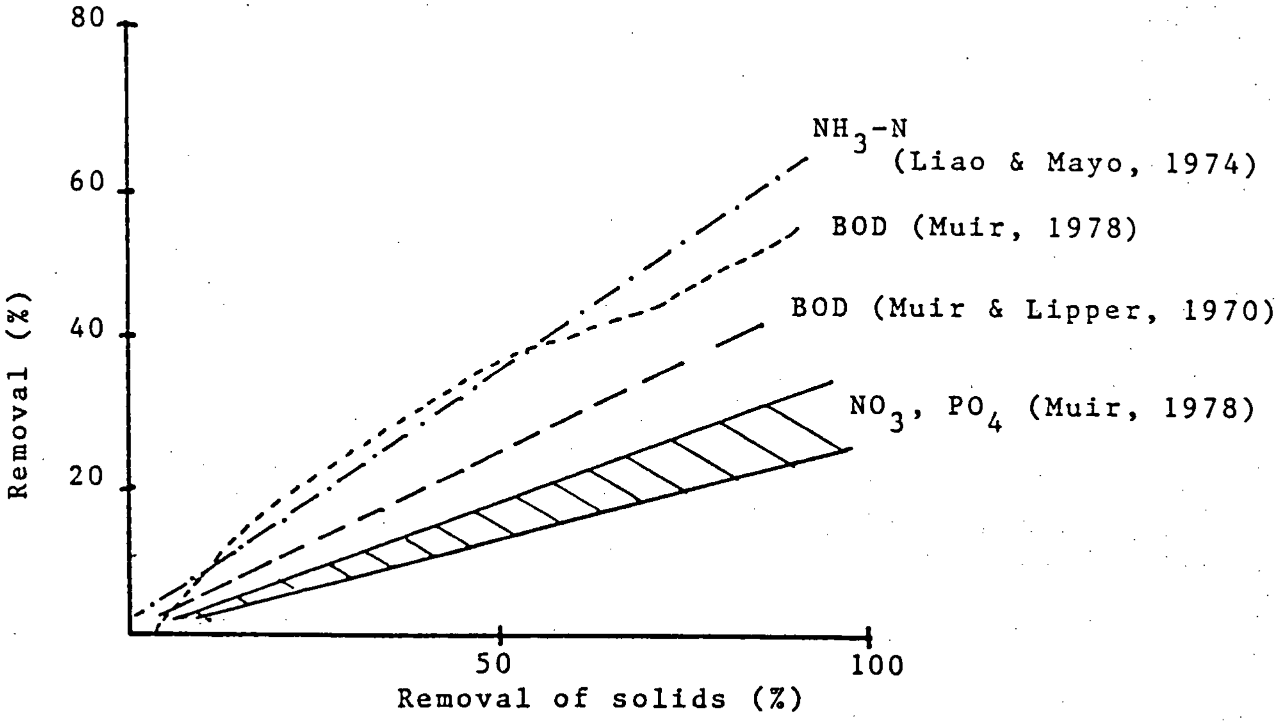
Analysis of fish culture wastes has shown a strong correlation between the removal of solids fraction and the removal of other soluble constituents. Figure 1.1 (Muir, 1982) summarizes the work reported on by Muir & Lipper (1970), Liao & Mayo (1974) and Muir (1978) on the removal of NH_3–N, NO_3 , PO_4 and BOD as a function of the removal of solids. In other work, Willoughby et al. (1972) reported that the removal of 90% of settleable solids resulted in an overall BOD reduction of 85%. Given the correlation illustrated in Figure 1.1, removal of the suspended solids fraction should be an important consideration in the treatment of fish culture effluents.

A variety of treatment systems have been surveyed which effectively reduce suspended solids (Underwood McLellan, 1979). However, of these systems, only sedimentation or gravity solid separation has been shown to be an economically viable method of treatment (Muir, 1978; Underwood McLellan, 1979; Warrer-Hansen, 1979).

In general, the treatment methods applied to fish culture wastes have been based on the assumption that fish wastes are characteristically similiar to human wastes. As such, standard domestic-type waste treatment systems have often been prescribed. However, inadequacies in the basic information relating to the characterization of the non-filterable residue from hatchery effluent wastes (Brown & Nash, 1979; Underwood McLellan, 1979) has often required that high margins of safety be incorporated into the design, significantly reducing their cost effectiveness.

The purpose of this thesis will be to adress inadequacies in the available information characterizing the physical and behavioral nature of the non-filterable residue, in trout culture cleaning wastes, within a gravity solids separation system. The thesis proposes to develop the overall non-filterable residue removal curves and individual particle size distribution curves, used in characterizing the settling behavior of a waste solid. The overall non-filterable residue removal curves and individual particle size distribution curves to be used to test the hypotheses that:1) Fish size significantly affects the

FIGURE 1.1 Removal of NH_3, NO_3, PO_4, and BOD as a function of solids(Muir, 1982)



settling behavior of the waste solids, and 2) Feed pellet size significantly affects the settling behavior of the waste solids. The results will be related to current design practices for gravity solids separation systems.

2. LITERATURE REVIEW

A sedimentation basin or clarifier can be utilized for removing metabolic waste solids from continuous flow or periodic cleaning flows discharged from fish farms or hatcheries (Huber & Valentine, 1978; Parker & Broussard, 1977). A number of solids removal efficiencies have been reported in the literature ranging from 25% to over 90% (Underwood McLellan, 1979). However, aside from removal efficiencies, the literature provides little background information on which to base the design or selection of a clarifier.

The proper selection and sizing of a solids separation system requires a thorough understanding of the physical characteristics of the wastes to be treated. Of primary concern is the variability in particle settling velocities within the waste solids and the factors which influence the settling characteristics.

A discrete, solid particle will accelerate in a quiescent fluid until drag (F_D) reaches equilibrium with the driving force (F) or gravitational force acting on the particle. Once equilibrium is reached, the particle no longer accelerates and begins to settle at a uniform velocity. The determination of the terminal velocity of the particle can thus be obtained by equating gravitational and drag forces acting on the particle.

The driving force (F), acting on the particle, is the net effect of the particle weight acting downwards and the buoyant force of the fluid acting upward. The driving force is given by (Clark et al., 1977);

$$F = (p_s - p)gV \qquad (2.1)$$

where p_s = density of particle

p = density of fluid

g = acceleration due to gravity

V = volume of particle

The drag force acting on a particle is a function of the fluid density, fluid viscosity, particle velocity and the projected area of the particle in the direction of motion. Expressed as

$$F_D = \frac{C_D A p v_s^2}{2} \qquad (2.2)$$

where F_D = drag force

C_D = Newton's drag coefficient

A = projected area of the particle in the direction of motion

v_s = particle velocity

p = density of fluid

Equating driving and drag forces for equilibrium conditions therefore yields

$$Vg(p_s - p) = \frac{C_D A p v_s^2}{2} \tag{2.3}$$

Rearranging equation 2.3 for v_s, the particle velocity, yields

$$v_s = \sqrt{\frac{2(p_s - p)gV}{C_D A p}} \tag{2.4}$$

If the particles are assumed to be roughly spherical in shape, then $V = \pi d^3/6$ and $A = \pi d^2/4$. Substituting these assumptions into equation 2.4 yields Newton's Law

$$v_s = \sqrt{\frac{4}{3}\frac{g}{C_D}\frac{(p_s - p)d}{p}} \tag{2.5}$$

Where d = particle diameter

The drag coefficient (C_D) is a function of the particle shape and the flow regime surrounding the particle. Expressed as a number, the Reynolds number (N_R) characterizes the flow conditions surrounding the particle (Equation 2.6).

$$N_R = \frac{vdp}{\mu} \tag{2.6}$$

Where V = relative velocity between main body of fluid and particle d = effective dimension of the particle (sphere=diameter)

p = fluid density

μ = dynamic viscosity of the fluid

The dynamic viscosity (μ) of a fluid is a measure of it's resistance to tangential or shear stress. Expressed as Newton seconds per square meter (N s/m²), values are a function of temperature and range from 1.781 to 0.890 for 0 and 25 °C respectively (Tchobanoglous, 1979).

When the Reynold's number is less than 2.0, viscous forces predominate and

$$C_D = 24/N_R \qquad (2.7)$$

As the Reynold's number increases through the range of 2–500, a transition zone occurs in which both inertia and viscous forces are effective. The drag coefficient (C_D) is therefore represented by

$$C_D = 18.5/N_R^{0.6} \qquad (2.8)$$

Above a Reynold's number of 500, viscous forces are not significant and the coefficient of drag remains constant at 0.4.

Substituting equation 2.7 into equation 2.5 generates Stokes law for small, low velocity particles. Expressed as

$$V = \frac{(p_s - p)gd^2}{18\mu} \qquad (2.9)$$

where V = terminal velocity of particle

p_s = density of particle

p = density of fluid

g = acceleration due to gravity

μ = dynamic viscosity of the fluid

d = particle diameter

The waste solids generated within a fish farm or hatchery are generally small, low velocity particulates. It should therefore be expected that Stokes Law (Equation 2.9) can be used to characterize their settling velocities.

Assuming this relationship to be correct, and the density and viscosity of the fluid to be constant, the settling velocity of the particles will thus be a direct function of the diameter and density of the particle. Any force which effectively alters either of these two factors will therefore alter the settling velocity of that particle.

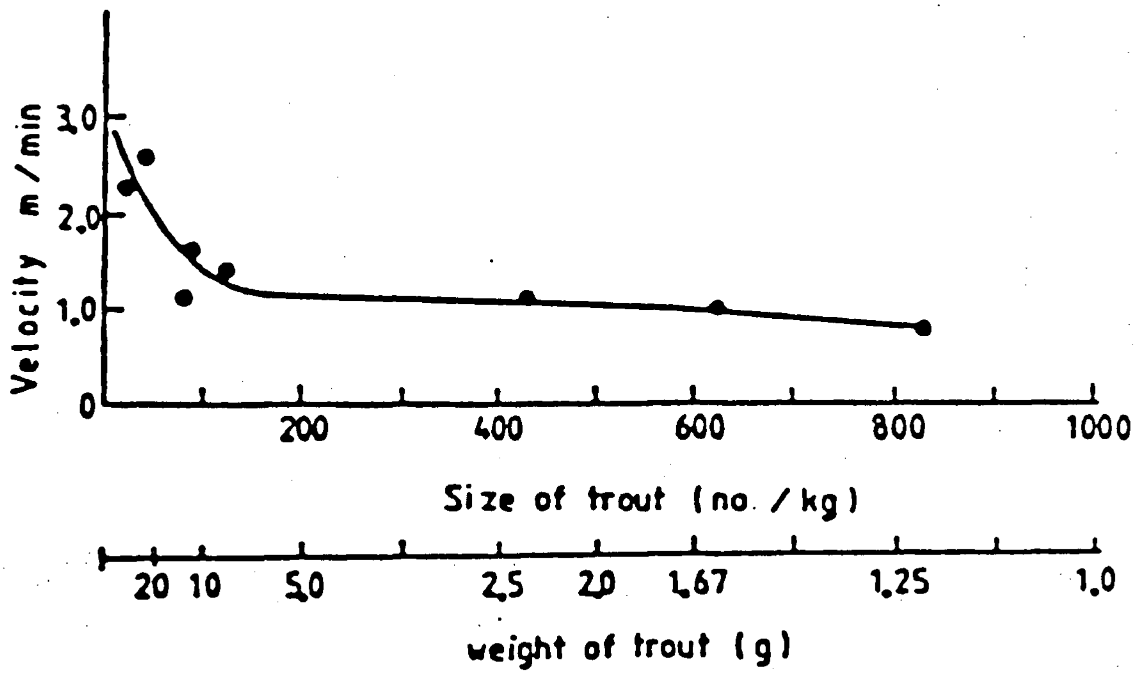
The size and density of particulate solids discharged from a fish farm or hatchery has been shown to be influenced by a variety of physical and site specific factors. These include; the species and size of fish contained (Wheaton, 1977), the type (Stechey, 1986) and pellet size of feed used (Walden & Birkbeck, 1974), the retention time of the waste within the containment unit (Warrer-Hansen, 1982) and by the amount of physical agitation and resuspension of the waste (Muir, 1978; Warrer-Hansen, 1979).

Warrer-Hansen (1979) reported settling rates for intact trout excreta to be generally high and dependent on the weight of fish (Figure 2.1). Results of settling tests on fresh excreta showed that on average, excreta from 20 gram fish settled at a rate of 3.3 cm/sec, while wastes from 5 gram fish settled at a lower rate of 1.7 cm/sec. Wastes from fish less than 5 grams were shown to settle at a correspondingly lower velocity. However, wastes which had been retained within the culture unit exhibited much lower settling velocities (Querellou et al., 1982). This was illustrated by Walden & Birkbeck (1974) who reported that wastes discharged from a hatchery exhibited two major settling fractions. Over 50% of solid particulates had settling velocities faster than 0.2 cm/sec, while 40% had settling rates faster than 0.51 cm/sec. Both of these settling velocities are significantly lower than those reported for fresh excreta (Warrer-Hansen, 1979).

It is assumed, and generally found that unless biologically or physio-chemically acted upon, waste solids are dispersed and uniformly passed through the culture system. However, waste solids often collect in areas of low velocity. The length of time a waste solid may be retained in a holding unit will thus be a function of the tank configuration, the velocity profile of the system, the degree of resuspension by fish and mechanical aeration, and by the method and schedule of cleaning.

Once a particulate is trapped in the culture unit, it is subjected to a variety of physical and chemical processes which can alter the particles physical characteristics. Bacterial decomposition, hydration and physical shearing all act to reduce the particles

FIGURE 2.1 Settling velocities for intact Rainbow trout excreta as a function of fish size (Warrer-Hansen, 1982)



size and density, thus reducing the settleability of the particle.

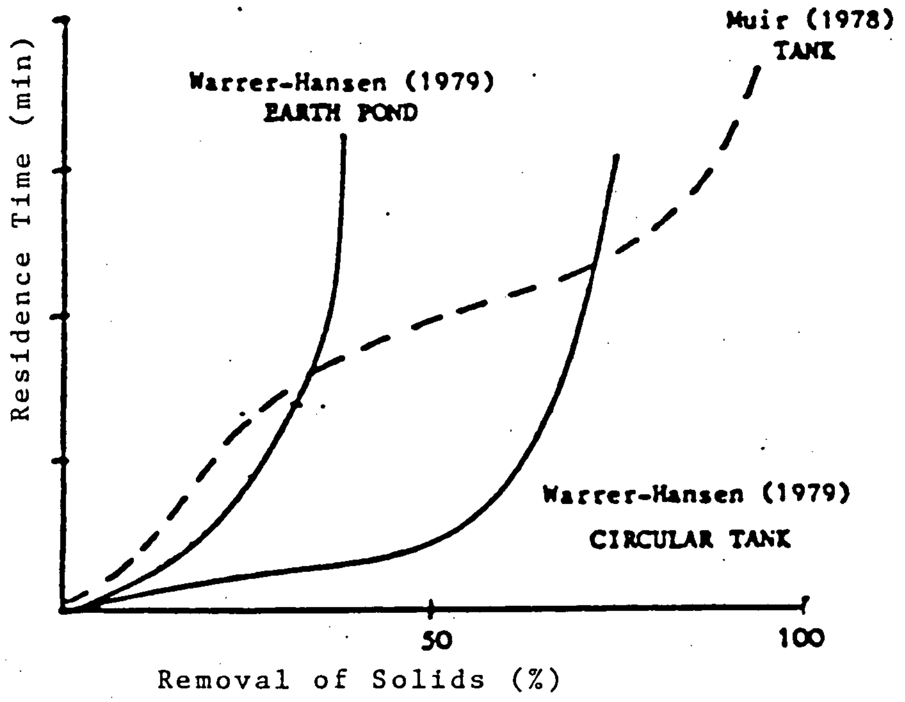
Warrer-Hansen (1982) summarized the results of settling trials on solid wastes discharged from 3 tank configurations; an earthen pond (Warrer-Hansen, 1979), a circular tank (Warrer-Hansen, 1979), and a tank of unspecified configuration (Muir, 1978), (Figure 2.2).

Warrer-Hansen (1979) observed that the wastes discharged from an earthen pond, exhibited poor settling characteristics. This he concluded was due to the extremely long retention times of solids within the tank, associated with the earth pond design. Low velocities, long residence times of water within the pond and infrequent cleaning all act to trap and hold waste solids for long periods of time. The waste solids are thus subjected to extensive bacterial decomposition and hydration. Frequent resuspension by fish during feeding, grading and harvesting, act to break up the solids into smaller, less settleable fractions. It is therefore not suprising that removal rates of less than 50% are observed even after 30 minutes.

The second configuration reported by Warrer-Hansen (1979), the circular tank, appears to provide conditions more conducive to rapid solids removal, as removal rates of 70% were achieved after 30 minutes. Muir (1978) reports complete solids removal (100%) after 40 minutes in wastes discharged from the unspecified tank configuration. However, assuming that conditions under which the waste solids were produced were the same (feed type, feed pellet size, fish size), the circular tank would be more desirable.

Figure 2.2 illustrates two distinct settling patterns. In both tank configurations reported

FIGURE 2.2 Relationship between residence time and solids removal (Warrer-Hansen, 1982)



on by Warrer-Hansen (1979), the bulk of solids removal occurred within the first 15 minutes of settling, after which time there was a gradual decline in the rate of removal with time. However, the curve reported by Muir (1978), shows that the bulk settling of settleable solids (>60%) occurs between 15 and 20 minutes after settling has begun. This would indicate that the wastes solids are relatively uniform in size and density, but lighter or smaller than wastes reported in Warrer-Hansen (1979). Although the circular tank configuration does not ultimately achieve the same level of removal (100%) as Muir (1978), it does achieve comparable levels of removal (below 70%) in significantly shorter residence times.

This is desirable for two reasons: 1) rapid solids removal reduces the residence time required to achieve a desired level of removal, which reduces the size of the gravity solids separation system and consequently the capital and operating costs of the system, 2) rapid solids settling reduces the need for totally quiescent conditions within the clarifier. This effectively reduces the potential for resuspension of the waste solids which may occur as a result of occassional turbulence within the treatment system.

Walden & Birkbeck (1974) reported that feed type and pellet size also influenced the settleability of the wastes produced. Although no specific data was introduced to quantify any differences between feed types, they did provide more specific results on pellet size. It was observed that wastes produced from fish fed 3/32 inch dry pellets, achieved 48-68% solids removal within the first 5 minutes, while wastes from fish fed a finer (grower crumbles) pellet size, took longer (15 minutes) to achieve similiar removals (55%).

In a recent study involving settling column analysis of a raceway cleaning effluent from an Ontario trout farm using Martins ® dry pellet feed, Stechey (1986) reports that effluents, with initial solids concentrations of 300–500 ppm, achieved 50% solids removal within 20 minutes. However, 60 minutes was required to obtain 65% solids removal.

The mode and length of time between cleanings, and the method of solids handling has also been shown to influence settleability. In a report prepared by Hydroscience Inc.(1977) on wastewater treatment and control in Idaho hatcheries, it was observed that cleaning operations employing vacuums or pumps for handling wastes, produced wastes of poor settleability. It was further observed that if pumps were to be used, then diaphragm type pumps should be employed as they minimized solids break-up.

Given the wide range of factors which influence the physical nature of the wastes and their subsequent settleability, it is not surprising that there is wide variation in reported clarifier design and treatment efficiency. A number of overflow rates and residence times have been reported in the literature as providing treatment for fish culture wastes. Liao & Mayo (1974) report that an overflow rate of 49,000 $l/m^2/day$, with a retention time of 15–30 minutes was adequate for treatment. Walden & Birkbeck (1974) reported that a retention time of 8–15 minutes at an upflow rate of 6.8–9.2 $m^3/m^2/day$ (converted from $gal/ft^2/day$) was sufficient to reduce suspended solids and BOD by 37–52% and 16% respectively. Sparrow (1981) reported that a 12 minute retention time in a 0.46m deep settling basin was sufficient to remove 90% of settleable solids. Bergheim and Selmer-Olsen (1978) suggested a medium retention period of 20 minutes would be sufficient to achieve satisfactory settling. Petit (1978) reported suspended solids removal of 92% after 30 minutes. Muir (1978) reported 66% of solids settled within 5 minutes while 90% settled within 15 minutes.

3. THEORY

A clarifier or sedimentation basin is designed for a particular waste by selecting a suitable settling velocity (V_o) such that all particles with settling velocities greater than V_o will be removed. The rate at which clarified water is produced can then be expressed as (Tchobanoglous, 1979)

$$Q = AV_o \tag{3.1}$$

where Q = flow rate (m^3/day)

A = surface area of clarifier (m^2)

V_o = settling velocity of waste particle (m/day)

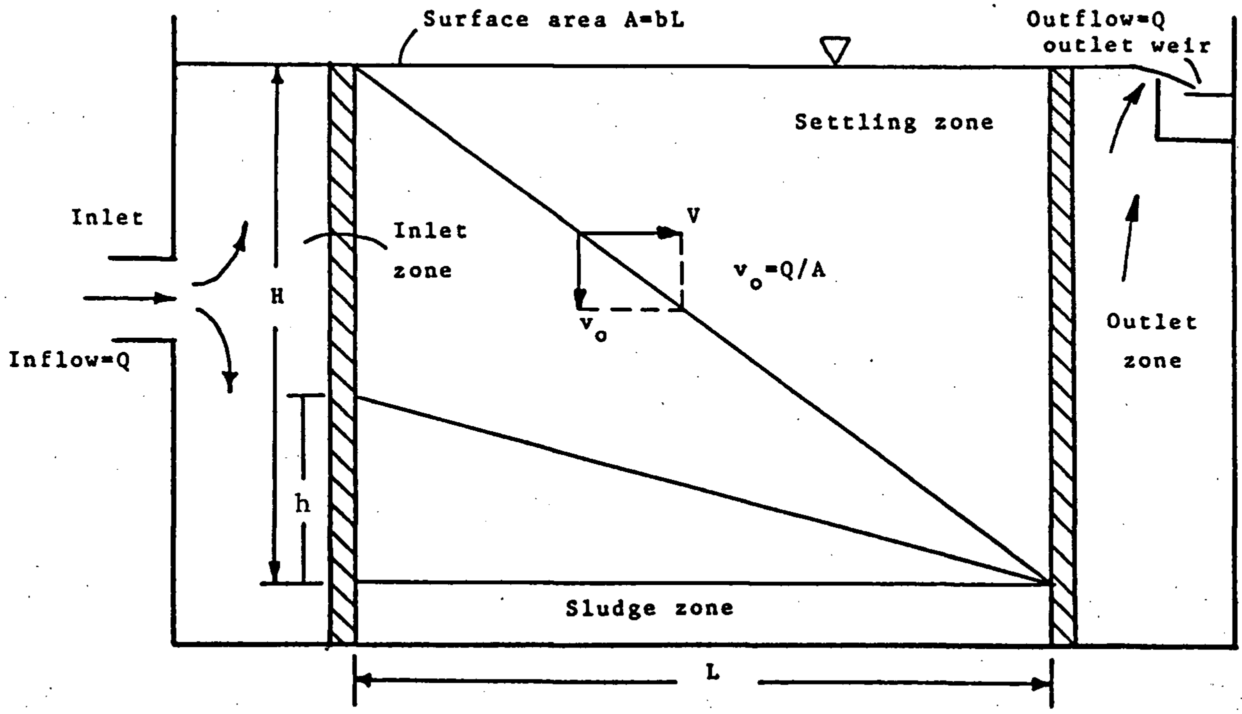
Rearranging equation 3.1 for V_o (Equation 3.2)

$$V_o = Q/A = \text{overflow rate } (m^3/m^2/\text{day}) \tag{3.2}$$

shows that the overflow rate or surface loading rate, is equivalent to the settling velocity (Figure 3.1).

From the geometry of Figure 3.1, it can be seen that if the area of the triangle, having legs H and L, represents 100% removal of particles, then the removal or particles having settling velocities less than V_o (V_s) will be in the ratio h/H. Given the depth a particle will settle is equal to the product of the settling velocity of that particle, and the retention time (t_o), then the ratio at which particles with settling

FIGURE 3.1 Schematic of an ideal rectangular sedimentation basin, indicating the settling path of discrete particles



velocities less than V_o will be removed will be

$$\frac{h}{H} = \frac{V_s t_o}{V_o t_o} = \frac{V_s}{V_o} \tag{3.3}$$

The efficiency of a sedimentation basin is a measure of the removal of suspended solid particulates at a given overflow rate V_o. From the discussion and observation of Figure 3.1, for a clarification rate of V_o, it has been shown that those particles having settling velocities greater than V_o will be completely removed. The fraction of particles removed from the suspension will thus be $1-C_o$, where C_o represents the fraction of particles with settling velocities less than V_o. However, for each size particle with a settling velocity less than V_o, it has been shown that the fraction removed would be equal to the ratio of V_s/V_o. Therefore, when considering the efficiency of the sedimentation basin for removing particles within this category, the percentage removal of these particles is given by (Clark et al, 1977)

$$\int_0^{C_o} \frac{V_s}{V_o}\, dc \tag{3.4}$$

The overall removal of suspended solids in a clarifier with a designed overflow rate of V_o is thus determined using equation 3.5. Expressed as a total percent removal

$$\text{Total \% Removal} = (1 - C_o) + \int_0^{C_o} \frac{V_s}{V_o}\, d_c \tag{3.5}$$

where C_o = fraction of particles having settling velocities less than V_o

Equation 3.5 is generally solved by integration of the area between 0 and a selected overflow rate (V_o) on the particulates settling velocity distribution curve (Figure 3.2).

Figure 3.2 can be derived in two ways; 1) by selective sieve analysis and hydrometer tests in combination with Newton's Law (Equation 2.5), or 2) using settling column analysis of the waste. For the purpose of continuity of discussion, the application of method 2 will be described during the discussion of Type II settling and the derivation of the Type II or flocculant particle settling curve.

The overflow rate (V_o) is subsequently chosen such that the desired percentage of suspended solids removal can be achieved. However, this design procedure is only effective if the waste solids conform to Type I or discrete particle settling only.

In Type I settling, each particle behaves as an individual entity and settles at a uniform rate determined by equations 2.1-2.9. The particle is said to follow a linear path, illustrated in Figure 3.3.

Chesness et al. (1975) observed that fish culture wastes exhibited two forms of settling behavior. In effluents of low suspended solids concentrations, like those produced during normal hatchery operations, Type I settling predominates. However, during cleaning and feeding operations, suspended solids concentrations can increase to levels where particulates begin to collide and coalesce, assuming the settling velocity of the new, larger or heavier particle. The particles exhibiting Type II or flocculant settling will thus follow a curvlinear path as illustrated in Figure 3.4.

FIGURE 3.2 Discrete particle velocity cumulative frequency distribution

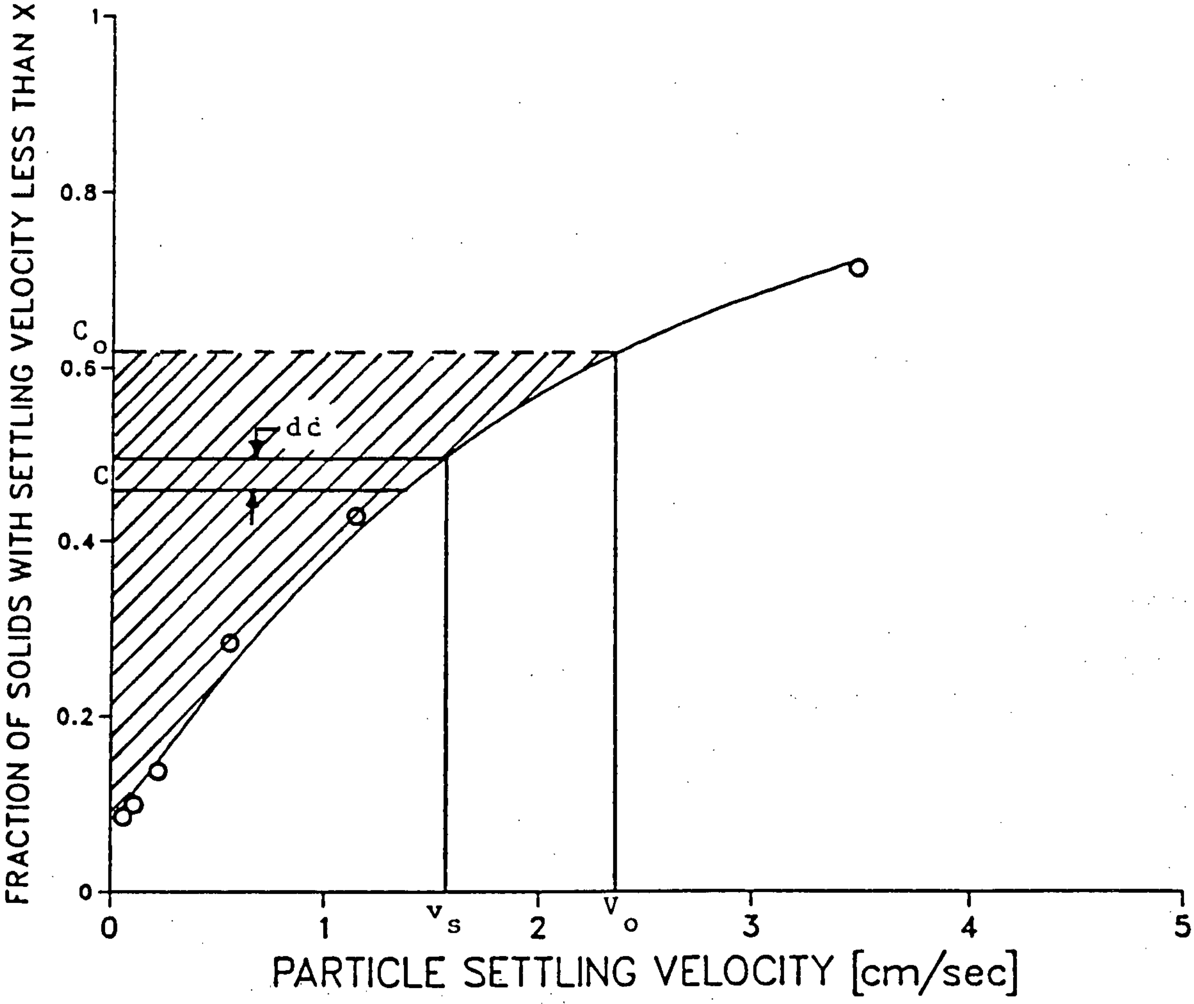


FIGURE 3.3 Path trajectory of particles in discrete particle settling

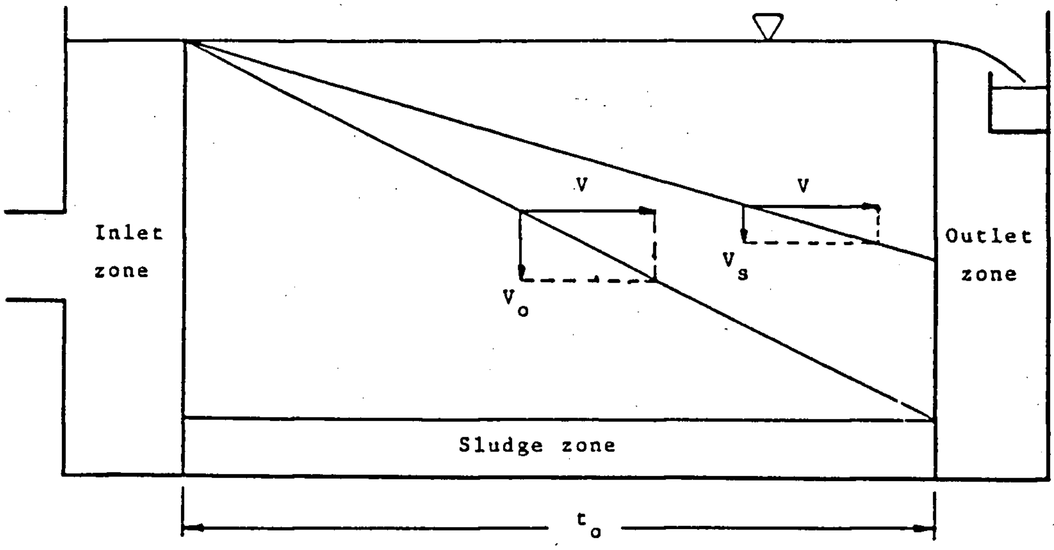
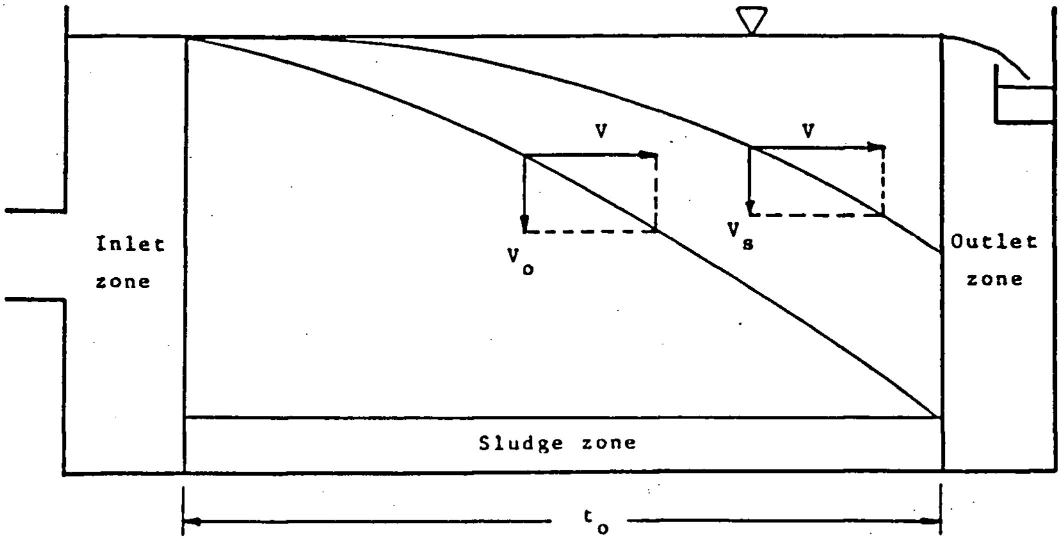


FIGURE 3.4 Path trajectory of particles in flocculant particle or Type II settling



The degree to which coalescence or agglomeration may occur will be due in part to the opportunity for contact between particles. This in turn is related to a number of factors, including; the suspended solids concentration, the range of particle sizes present in the waste, the distance the particles are to settle, and the velocity gradient within the system.

In Type I settling, the overall solids removal efficiency is a function of the overflow rate only and independent of the depth of the clarifier. However, in Type II settling, where particle interaction will be a function of depth and time, retention time and clarifier depth must also be considered when determining solids removal efficiency. Given the high level of particle interaction in Type II settling, the necessary design parameters can no longer be set on the basis of a simple mathematical relationship as in Type I settling. Overall suspended solids removal efficiency can presently be determined by empirical methods only. This is accomplished using a settling column equal in height to the clarifier depth, and of at least 15 cm in diameter (Tchobanoglous, 1979).

The settling column is used to approximate conditions within a clarifier in order to produce a graphical representation of the rate of solids removal as a function of time and depth. Effluent samples collected from the settling column are analyzed for non-filterable residue and subtracted from the initial non-filterable residue concentration in order to determine the level of removal of non-filterable residue over time. Expressed as a percentage of the initial concentration, the level of non-filterable residue removed, is plotted as a function of residence time and sample port depth. With the inclusion of iso-concentration curves, representing points of equal levels of removal, the Type II or flocculant particle settling curve is obtained (Figure 3.5).

The overall level of solids removal, within the column, at a specific residence time (T), is then determined by integrating the percent solids removal over the height of the column using equation 3.6.

$$\text{Overall \% solids removal} = \frac{\Delta h_1 \frac{(R_1+R_2)}{2} + \Delta h_2 \frac{(R_2+R_3)}{2} + \ldots \Delta h_n \frac{(R_n+R_{n+1})}{2}}{(\Delta h_1 + \Delta h_2 + \ldots \Delta h_n)} \qquad (3.6)$$

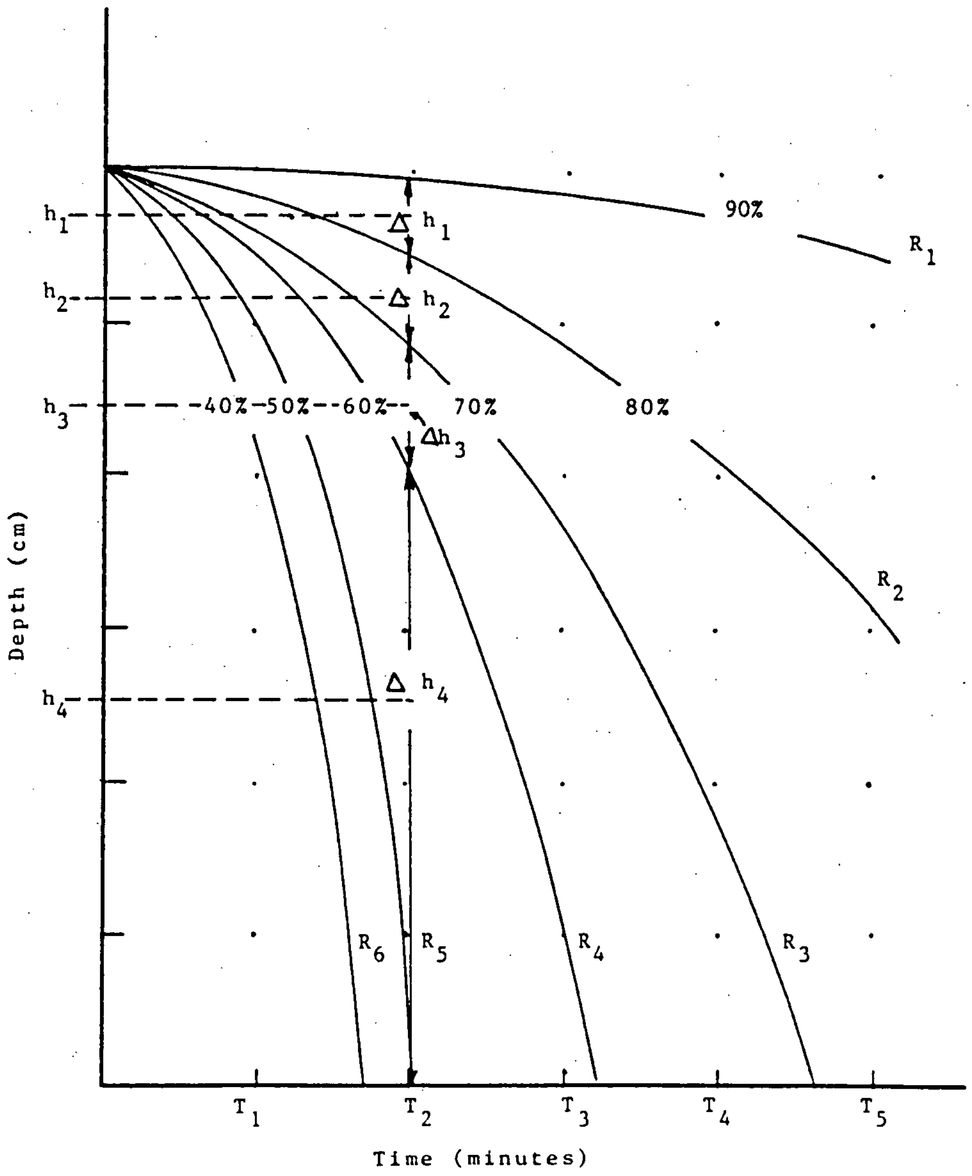
where $\Delta h_n \frac{(R_n+R_{n+1})}{2}$ = average solids removal concentration within a section of the column depth h.

As an example to illustrate the use of equation 3.6, the overall non-filterable residue removal concentration will be determined from Figure 3.5 for a residence time of T_2. For the example shown in Figure 3.5, equation 3.6 may be rewritten as

$$\frac{\Delta h_1}{h_5}\frac{(90+80)}{2} + \frac{\Delta h_2}{h_5}\frac{(80+70)}{2} + \frac{\Delta h_3}{h_5}\frac{(70+60)}{2} + \frac{\Delta h_4}{h_5}\frac{(60+50)}{2} \qquad (3.7)$$

where h_5 = height of the settling column

FIGURE 3.5 Type II or flocculant particle settling curves (Note: Percentage removal curves (R_n) are interpolations of the solids fraction removed as a function of residence time and column depth)



Results of the computations are summarized in Table I

TABLE I Summary of integration calculations of flocculant particle removal for a residence time T_2

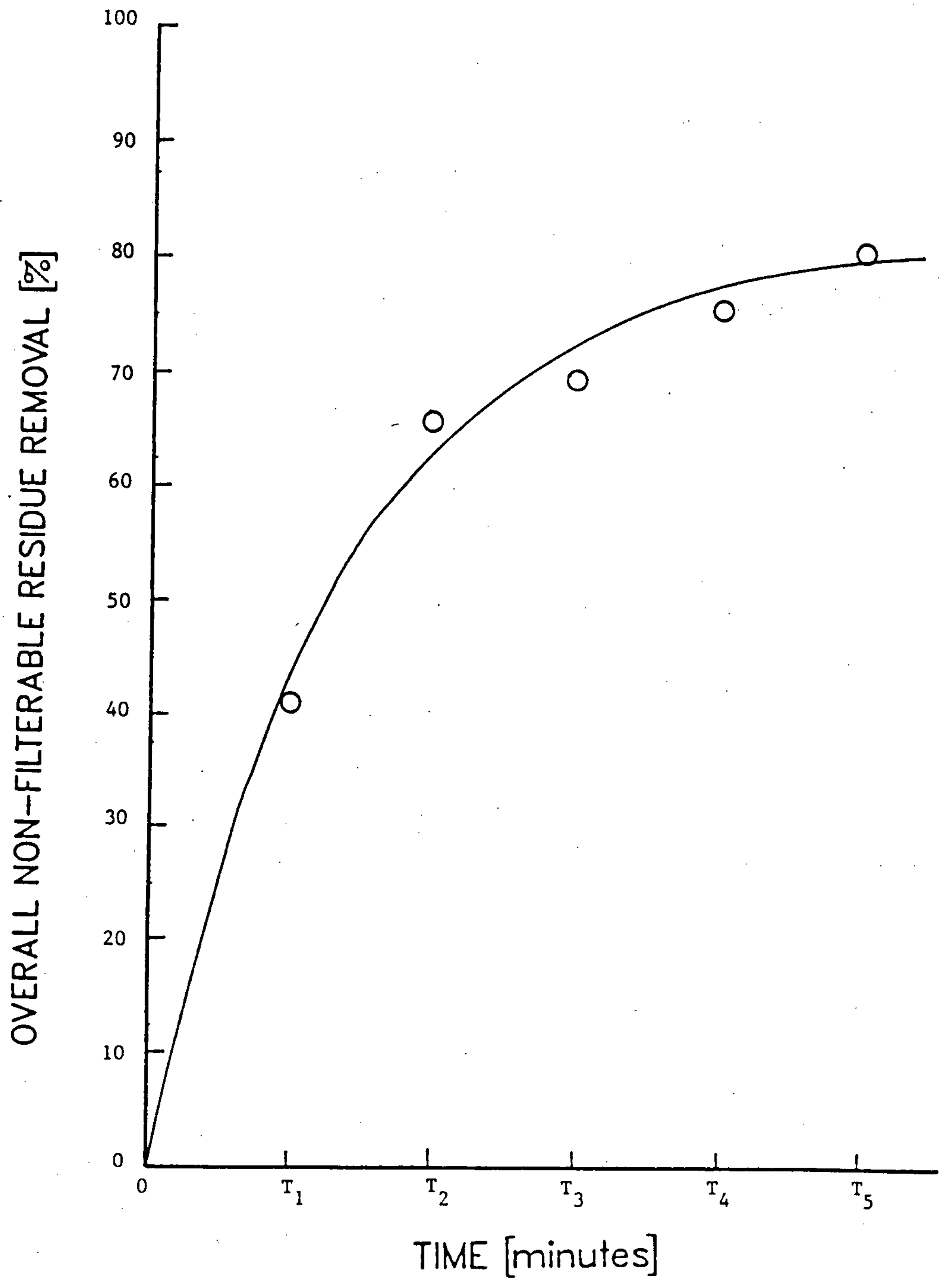
$\frac{h_n}{h_5}$	x	$\frac{R_n+R_{n+1}}{2}$	=	Percent Removal
0.10	x	$\frac{(90+80)}{2}$	=	8.5
0.10	x	$\frac{(80+70)}{2}$	=	7.5
0.13	x	$\frac{(70+60)}{2}$	=	8.45
0.67	x	$\frac{(60+50)}{2}$	=	36.85
1.00		Total % Removal	=	61.3

Continuing this integration for each unit of time, thus provides a graphical representation of the level of solids removal as a function of residence time (Figure 3.6). The solids removal curve illustrated in Figure 3.6 is then used in sizing the clarifier by selecting the residence time required to achieve the desired % solids removal.

As previously discussed, the settling column may also be used to derive the individual particle settling velocity distribution curve.

The iso-concentration curves on the Type II settling curve represent lines or points of equal levels of non-filterable residue removal. However, they also represent the maximum trajectories of particle settling paths for a specific concentration in a flocculant suspension. For example, in Figure 3.5, 60% of the particles will have

FIGURE 3.6 Overall non-filterable residue removal curve



velocities greater than h_2/T_2 at the time the particles reach a depth of h_2. Simplified, the curve shows that for a particle to be removed from the column, it's settling velocity must be greater than the depth to be traversed (h_2) divided by the allowed time or residence time (T_2). Therefore for the same example, the curve shows that 50% of the particles have settling velocities greater than h_5/T_2 (V_o) and will therefore be removed. However, within our discussion of discrete particle settling, it was shown that particles with settling velocities less than V_o (V_s) will be removed in the ratio of V_s/V_o. The overall level of removal as a function of settling velocities is therefore obtained by integration of the Type II settling curve using equation 3.5. Where $1 - C_o$ represents the percentage of solids with settling velocities greater than V_o (h_t/T_o). The second term within equation 3.5 therefore represents the fraction or percentage of particles with settling velocities V_s less than V_o which are removed.

The total fraction of particles which are removed with settling velocities greater than, equal too and less than h_t/T_o (V_o) is

$$(1 - C_o) + \frac{h_4(R_4 - R_5)}{h_t} + \frac{h_3(R_3 - R_4)}{h_t} + \dots \frac{h_1(R_{n-1} - R_n)}{h_t} \quad (3.8)$$

Where $1-C_o$ = fraction of particles removed at the maximum depth (h_t) of the settling column given a residence time T_o

h_t = total depth of settling column or clarifier

h_n = depth within the column at vertical midpoint between particle trajectory curves R_n and R_{n-1}

In Figure 3.5 the fraction of particles removed at a residence time of T_2 is expressed as

$$50 + \frac{h_4(60-50)}{h_5} + \frac{h_3(70-60)}{h_5} + \frac{h_2(80-70)}{h_5} + \frac{h_1(90-80)}{h_5} \tag{3.9}$$

However, this calculation has already been indirectly solved in the derivation of the overall non-filterable residue removal curve. The overall non-filterable residue removal curve is a graphical representation of the level of solids removal as a function of residence time. Restated, this curve is a representation of the percentage of particles with settling velocities greater than h_t/T_o. Figure 3.6 may therefore be rearranged as the percentage of non-filterable residue with settling velocities greater than h_t/T_o (Figure 3.7).

The individual particle settling velocity distribution curve can therefore be obtained from Figure 3.7 by plotting the residual of 1 – (the fraction of non-filterable residue with settling velocities greater than h_t/T_o), to obtain the fraction of non-filterable residue with settling velocities less than h_t/T_o (Figure 3.8).

FIGURE 3.7 Graphical representation of the percentage of non-filterable residue particulates with settling velocities greater than X

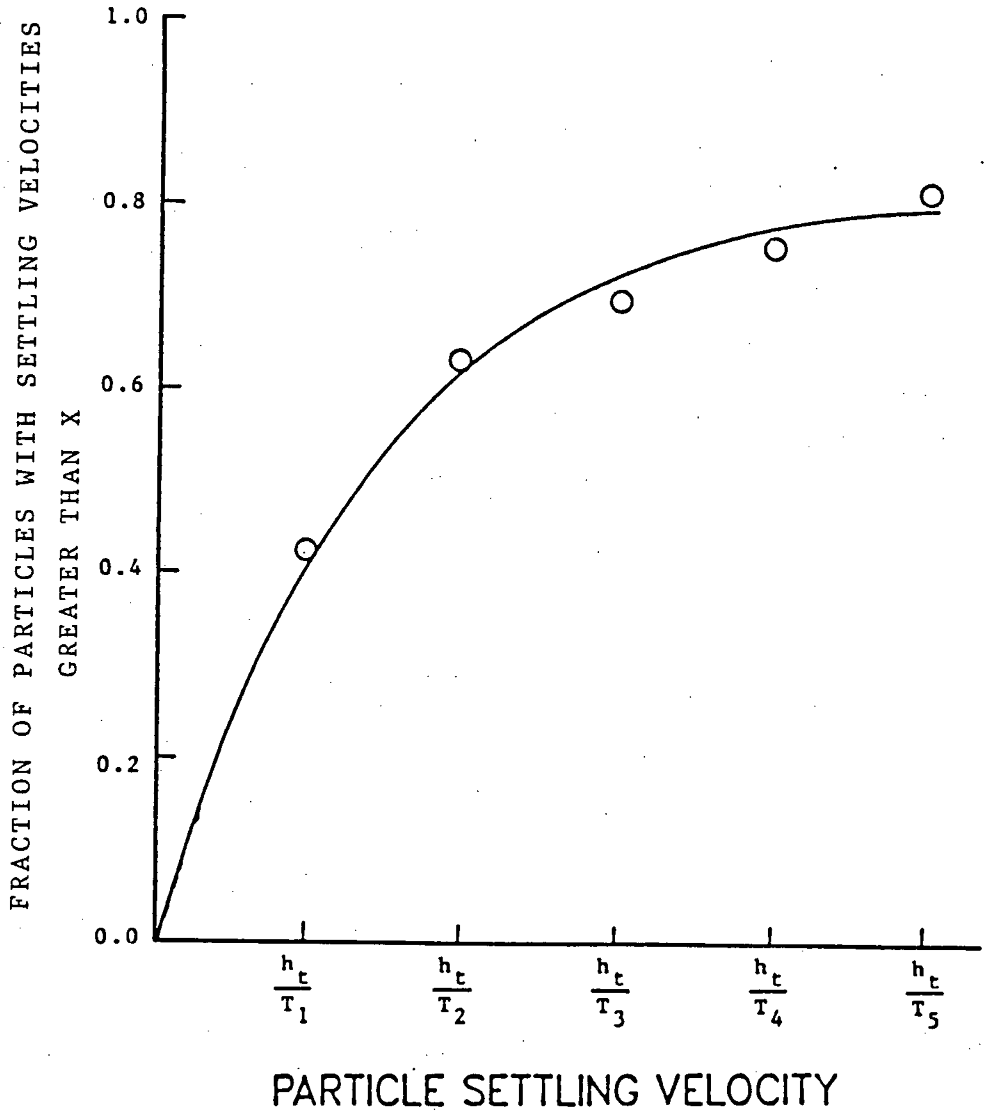
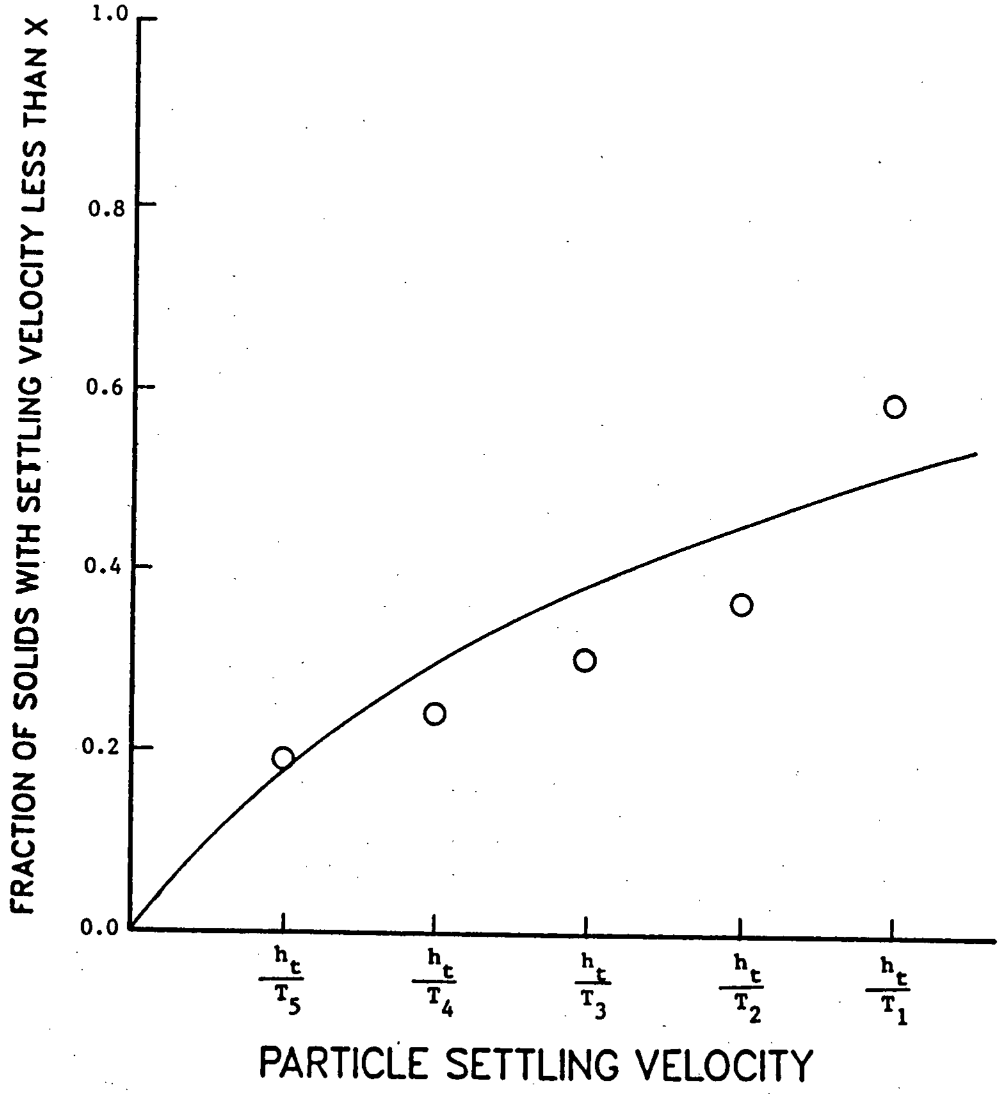


FIGURE 3.8 Individual particle settling velocity distribution curve



4. MATERIALS AND METHODS

4.1. SPECIES

Rainbow trout (*Salmo gairdneri*) were selected for use in this study as representative of the family of salmonids presently raised in British Columbia. The selection of the species was based primarily on two factors; 1) the entire life cycle from egg to market, occurs in fresh water, 2) Rainbow trout are grown extensively in the Lower Mainland for both the commercial and sports fishery markets. The species was therefore readily available at all times and in the sizes required. Rainbow trout were obtained from two sources; Fraser Valley Trout Hatchery (Ministry of Environment, Fish and Wildlife Branch) and Spring Valley Trout Farm.

4.2. FISH SIZE

Uniform populations were chosen on the basis of weight. Weight classes were selected from the feed manufacturers feeding guide to provide waste trials for the lower, middle and upper range of fish sizes recommended for each pellet size used. Table II summarizes the pellet sizes used, and the corresponding weight classes. The use of three weight classes for each pellet size used was chosen to provide a means of comparing the effects of weight on waste solid settling rates, independent of pellet size. Overlap of weight classes amongst pellet sizes, provided a means of comparing the effects of pellet size, on waste settling rates, independent of weight. The weight sizes used in the study ranged from 11 to 311 grams.

TABLE II Weight classes and corresponding feed pellet sizes used in waste trials

Group #	Fish Size (grams)	Standard Deviation	n	Feed Pellet Size(inches)*	Water Temp (°C)
1	11.0	1.4	200	3/32	4.5
2	17.0	1.2	140	3/32	6.0
3	21.0	1.3	83	3/32	4.5
4	21.0	1.3	83	1/8	4.5
5	41.0	3.3	104	1/8	7.5
6	54.0	3.1	150	1/8	4.5
7	54.0	3.9	150	5/32	4.5
8	72.0	2.9	100	5/32	7.5
9	93.1	4.1	100	5/32	4.5
10	89.0	2.5	89	3/16	4.5
11	311.0	23.7	25	3/16	5.0

* Oregon Moist Pellet: Moore-Clarke Feed Mills, Laconner Washington

n Population size in holding tanks

4.3. FEED TYPE AND PELLET SIZE

Oregon Moist Pellet ®, produced by Moore-Clark, was used in the feed-waste trials. The fish in each weight class were fed the feed pellet size, at a rate recommended by the manufacturers feeding guide. The feed was distributed on a daily basis over a 15 hour period in 8 equal portions by means of an automated type feeding system. The pellet sizes used in the feed-waste trials, as summarized in Table II, were the 3/32, 1/8, 5/32, and 3/16 inch pellet.

4.4. LABORATORY SET UP

4.4.1. Containment

Each test population was held in 200 litre (50 gallon) oval fibre glass tanks (Figure 4.1) which were obtained from the Department of Fisheries and Oceans West Vancouver Marine Laboratory. Each tank was equipped with a 10 cm (4 inch) central standpipe drain which regulated the water level within the tank and reduced the discharge of settled waste solids.

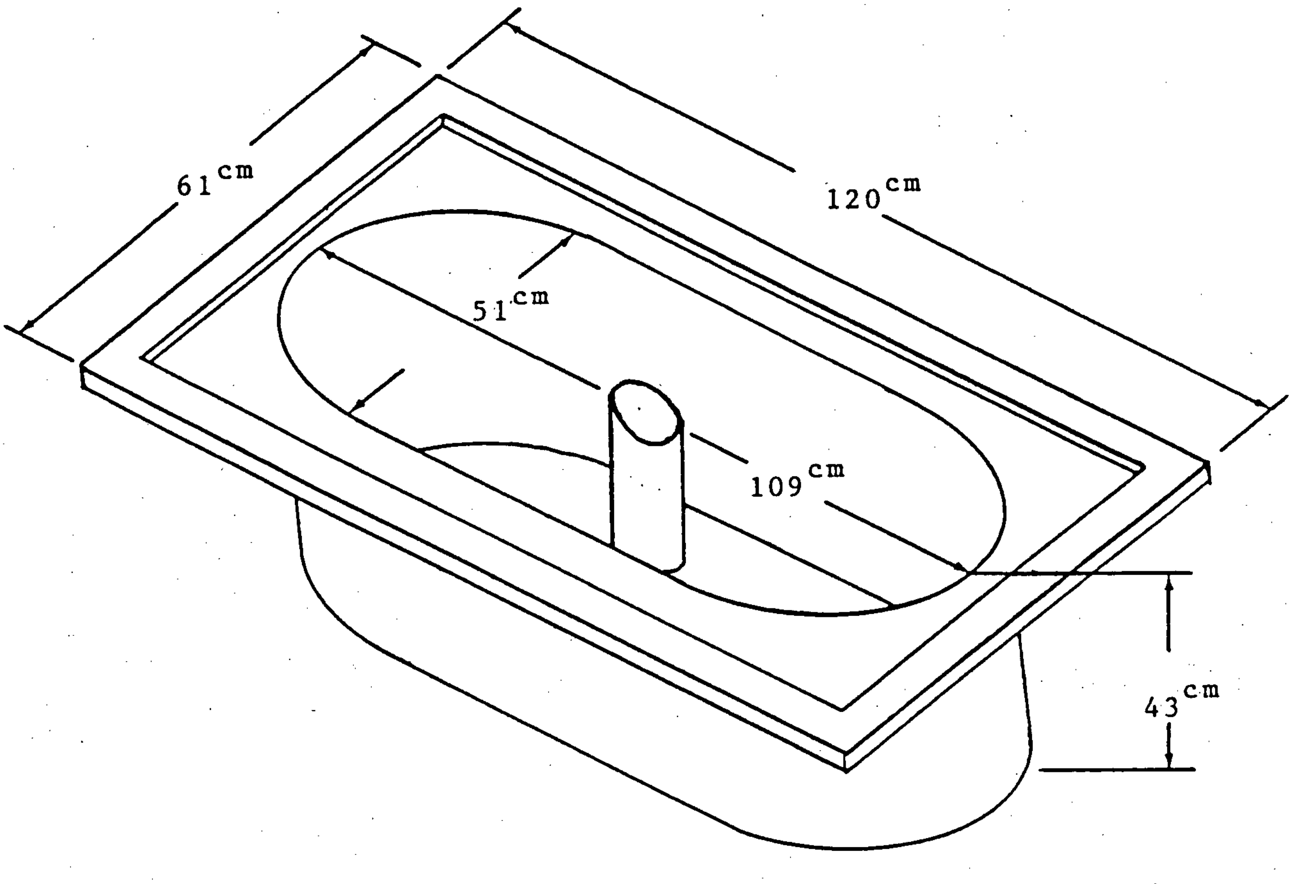
4.4.2. Water Supply

Each tank was provided with dechlorinated water through an over-head pipe. Overall flow rates were controlled at the main supply level by means of a constant head tower. Individual tank flow rates were maintained using a 1.3 cm (1/2 inch) ball valve.

Water temperature ranged from 4 °C to 7 °C during the course of the study.

Flow rates for each test population were based on two factors; 1) the minimal flow

FIGURE 4.1 Schematic of 200 litre fibre glass tanks



rate required to prevent scouring of the tank bottom and loss of solids, and 2) the minimal flow rate required to maintain suitable water quality within the holding tanks.

4.4.3. Aeration

Aeration was provided at the main constant head tower, and at each 200 litre tank using a venturi aspirator attached to the 1.3 cm (1/2 inch) valve. Aeration was maximized at the air/water interface of the water jet stream by adjusting the angle of the water stream from the aspirator to 60 $^{\circ}$ (from the horizontal)(Chesness et al., 1973).

4.4.4. Stocking Density

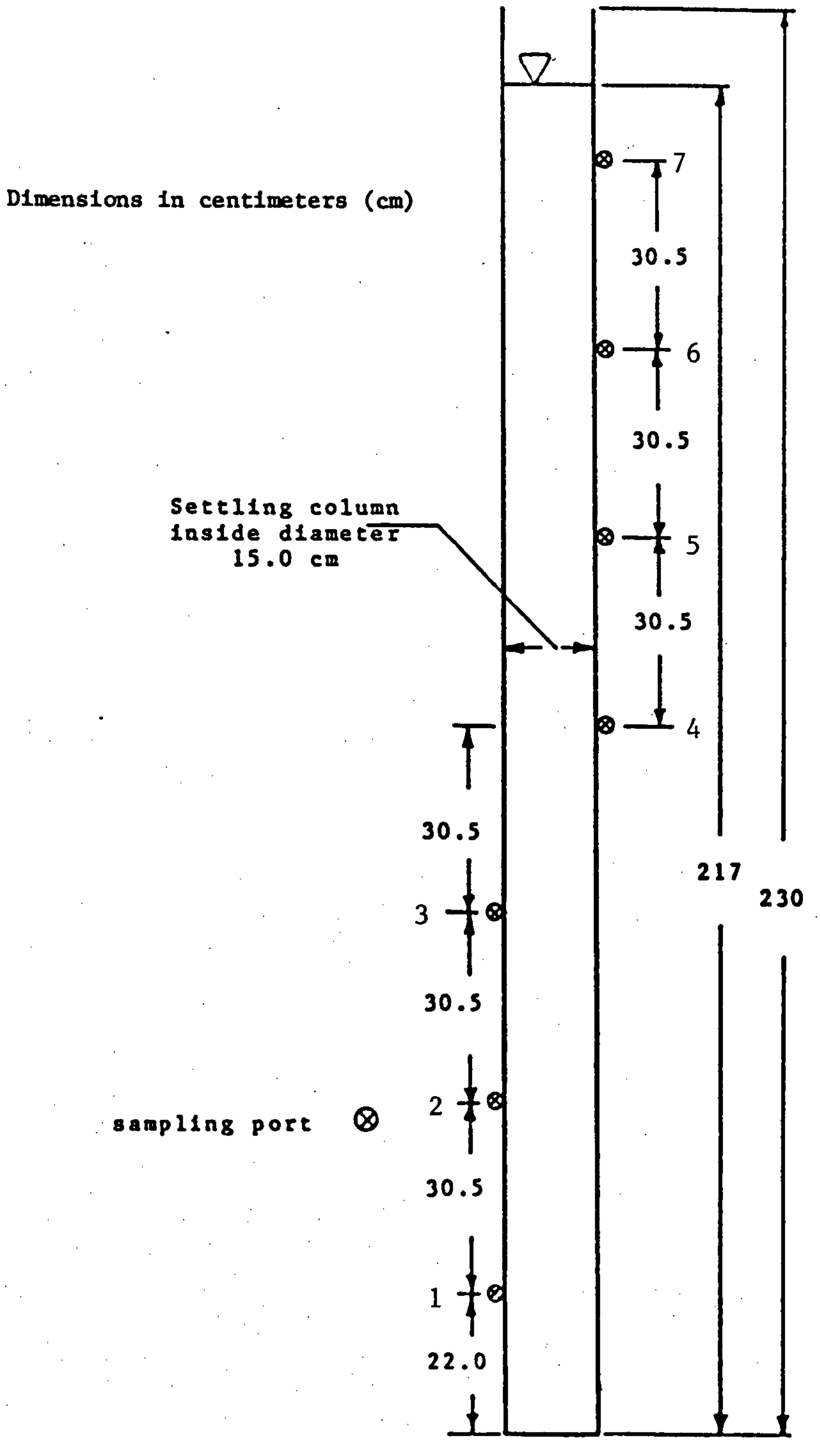
Stocking densities were selected on the basis of; 1) the number of fish available within the size range desired, and 2) the number of fish in a particular size class required to produce a measurable quantity of waste solids.

4.5. SETTLING COLUMN

A plexiglass column, 230 cm in height by 15 cm in diameter was used in the settling rate trials. The column was equipped with 7 sampling portes, located, starting at 22 cm from the bottom of the column and then continuing up the column at 30.5 cm intervals (Figure 4.2).

Pressurized air was supplied to the base of the column to provide mixing.

FIGURE 4.2 Schematic of settling column used in settling trials



4.6. EXPERIMENTAL PROCEDURE

Weight classes were acclimatized to the feed and pellet sizes for a period of three days prior to waste collection. This was carried out to insure that the wastes produced were of the pellets being fed, and to insure that the fish were feeding normally.

The tanks were thoroughly cleaned of any accumulated solids prior to waste solids collection. The solid wastes were then allowed to accumulate over a 24 hour period. During this 24 hour period, the fish were fed according to the program outlined in Section 4.3. At the end of the 24 hour period, the settled solids were collected from the tank and placed in the settling column. Collection of the settled waste solids from the bottom of the holding tanks was carried out using a modified vacuum siphon tube. A modified 2x2x2 cm (3/4x3/4x3/4 inch) T-fitting, attached to the end of the siphon hose produced a configuration similiar to the floor wand of a vacuum cleaner . This increased the functional area of the siphon and reduced turbulence. The large diameter of the tubing used in the siphon, and the low vacuum pressures used also prevented the fragmentation of the fecal pellets and unconsumed feed pellets.

To minimize the shear forces inherent in transfering the collected waste solids from the collection buckets to the settling column, the column was first partially filled to a depth of 180–200 cm with clarified effluent from the collection buckets. The settled solids were then added to the column. Rinse water from the collection buckets was used to bring the total column depth to 217–220 cm.

Mixing of the effluent within the column was accomplished using the compressed air system, located at the base of the column. The release of compressed air at the bottom of the column produced conditions similiar to an air lift pump. The use of the air lift pump system for mixing did not appear to effect the particle sizes. Although care was taken, during the collection and manipulation of the waste solids, to minimize particle fragmentation, it must be assumed that in a hatchery or farm situation, fragmentation of fecal pellets and unconsumed feed pellets will occur. This is unavoidable as the solid particulates are subjected to shear forces during mechanical aeration and as the waste effluent cascades through a series of raceways or ponds.

Two sets of 100 ml samples were taken from each sampling port during mixing as a test for uniformity, and to provide a baseline concentration from which further samples would be compared. Mixing was terminated immediately after the last mixing sample was taken.

After termination of aeration, 100 ml samples were then collected from each sample port at 1, 3, 6, 15 and 30 minute intervals. A final 200 ml sample was taken from each port at 60 minutes.

Each sample taken from the column was then filtered through preweighed 5.5 cm Whatman ® glass fibre filters (934-AH). The filters and non-filterable residue were then dryed at 105 °C for 24 hours.

After 24 hours the filters and residue were removed from the drying oven and placed in a desiccator to cool, after which time they were weighed and the amount of non-filterable residue determined.

The two sets of samples collected during mixing were pooled and an average taken in order to provide a baseline or starting concentration from which the level of non-filterable residue removed would be obtained. The level of non-filterable residue removed in each sample was calculated as the difference between this initial non-filterable residue and the amount of non-filterable residue present on each of the sample filter papers. The level of non-filterable residue removed, expressed as a fraction or percentage of the baseline or starting concentration was then plotted as a function of residence time and sample port depth to provide the framework for the Flocculate particle or Type II settling curve illustrated in Figure 3.5. The Type II settling curves were then used in the derivation of the overall non-filterable residue removal curves and the individual particle settling velocity distribution curves as outlined in Chapter 3.

The sampling procedure used in this study differed from the standard methods reported in the literature, in that no makeup water was added to the column after a sample was taken. This modification required that a variable column height be used when calculating settling velocities from the Type II settling curve.

5. RESULTS AND DISCUSSION

Non-filterable residue removal curves and individual particle settling velocity distribution curves are used to characterize a waste solids settling behavior. These curves were selected for use in this study as a means of evaluating and comparing the effects of fish size and feed pellet size on the settleability of the waste solids produced. Although the study deals primarily with waste produced during the feeding of a moist pellet diet, similiar trials were carried out using a dry pellet feed (Purina Trout Chow ®), and will be discussed where appropriate.

In producing the non-filterable residue removal curves and individual particle settling velocity distribution curves to be presented in this study, a number of assumptions were made. Waste solids produced from the feeding trials were allowed to accumulate in the holding tanks over a 24 hour period prior to collection and analysis. During this time, the waste solids, composed of faeces and unconsumed feed pellets, were subjected to hydration and physical shearing. These two processes, combined with periodic resuspension of the solid particulates, resulted in the breakup of solid particulates and the loss of some solids. Due to the arrangement of the tank discharge, and the large volumes of water used, it was not possible to determine the quantity or sizes of the waste solids lost. However, it was assumed that under actual operating conditions these same solids would be lost through resuspension. They would therefore form part of the average daily waste loading of the farm. As this study was concerned primarily with the treatment of the significantly higher strength cleaning flows (Liao, 1970; Bergheim et al., 1984), we were interested in only that fraction which was retained within the culture unit. The waste solids lost through resuspension were therefore ignored.

Initially the study proposed to evaluate, in addition to fish size and feed pellet size, the effect of feed type on the physical characteristics of the waste produced. Two feeds were selected which represented alternate milling processes; 1) a frozen feed (Oregon Moist Pellet ®), produced by Moore-Clark and 2) a dry pellet (Purina Trout Chow ®) produced by Ralston Purina.

In feeding trials using the Oregon Moist Pellet ® feed, sufficient solids were retained within the tanks to produce the desired solids removal and particle settling velocity distribution curves. However, in trials using the dry pellet feed, of the three pellet sizes used, only the #4 size produced any measurable quantity of waste solids. In trials using the #3 and #5 pellet sizes, most of the solids were lost. Those solids which were retained, only after severely restricting water flow through the tanks, tended to form a gelatinous mat which adhered to the tank bottom and discharge screens.

It was also observed that in trials using the #4 pellet, a large quantity of yellowish grit was found to collect in the tank. This may have been undigested corn particulates or part of the vitamin premix.

Due to this inability to obtain consistent measurable quantities of waste solids, it was decided to terminate further studies using the dry pellet feed.

Once the accumulated waste solids had been collected, they were placed in the settling column for analysis. The column simulates a portion of a clarifier or sedimentation basin. Sampling ports located along the side of the column allow for samples of the effluent to be withdrawn for analysis.

The settling column can be used to derive the non-filterable residue removal and individual particle settling velocity distribution curves used in this study provided two conditions are met; 1) the waste solid particulates are uniformly distributed within the column, and 2) quiescent conditions exist in the column during sampling.

Waste solids were kept in suspension within the column using compressed air. Compressed air was released at the bottom of the column and allowed to rise through the column, creating conditions similar to an air lift pump. The bubbles produced were kept large to reduce air flotation of the waste particulates. In this process, small bubbles adhere to the solid particles in suspension, producing lift. The solids subsequently float to the surface where they collect as a foam or scum. However, even with the large bubbles used some flotation of small solid particulates was observed. Once aeration was terminated , small low velocity waste solid particulates continued to rise, forming a scum at the surface of the column. No attempt was made to quantify the amount of solids removed by this process, as agitation of the layer resulted in it's breakup and settlement. It is assumed however that in review of the high rate of settleable solids removal observed within the first 5–8 minutes (Figure 5.5 - 5.15), the air flotation removal of these low density particulates does not contribute significantly to the overall rate of removal during this period. The inclusion of these particulates only slightly reduces the slope of the overall non-filterable residue removal curve during the first 5–8 minutes of settling.

As a test for uniformity of waste solids within the column, two sets of samples were collected from each sampling port during mixing of the waste effluent. From this set of samples it was observed that there was a high degree of variability in the concentration of suspended solids within the column (Table III). In general, suspended solids concentrations increased from the top of the column, down to the bottom. A general decline in the overall level of suspended solids within the column over time was also observed. Both of these observations indicated that some settling of solids was occurring during mixing. However, increasing the level of aeration to over come this settling, resulted in loss of the waste water out of the top of the column. It was decided therefore that some settling of solids was unavoidable.

For the purpose of this study, a mean of the twelve samples taken during mixing, as shown in Table III, was used as the initial solids concentration or baseline concentration. However, using a mean value in the percent removal calculations to represent a column with varying suspended solids concentrations provided some error in the values obtained. At the top of the column, actual solids concentrations will be higher than the mean used, therefore the percentage of solids removal calculated from the samples taken from this region will be overstated. However, the opposite is true for the lower portion of the column. The use of a mean suspended solids concentration will underestimate the actual percentage of solids removed.

Given that the non-filterable residue removal curves reflect the rate of removal within the entire column, small localized variations will tend to be buffered out. To minimize the possible spread between the mean concentration used in our calculations and the actual initial solids concentration, sampling for the settling trials was begun immediately after the last mixing samples were taken.

TABLE III Variability of initial non-filterable residue concentrations as a function of column depth

	Trial I		Trial II	
Sample Port*	Sample 1 (grams)	Sample 2 (grams)	Sample 1 (grams)	Sample 2 (grams)
1	0.0631	0.0582	0.0629	0.0754
2	0.0689	0.0598	0.0720	0.0654
3	0.0583	0.0474	0.0665	0.0604
4	0.0540	0.0472	0.0651	0.0620
5	0.0550	0.0455	0.0651	0.0614
6	0.0503	0.0432	0.0624	0.0626
	X = 0.0542		X = 0.0651	
	S = 0.0078		S = 0.0045	
Initial Concentration		542 mg/l		651 mg/l

* Refer to Figure 4.2 for settling column sample port location

Note: Non-filterable residue in Trial I and Trial II is based on sample volume of 100 ml.

The second requirement in running settling trials in the column is that quiescent conditions be maintained within the column. The settling column was located in the fish culture lab, which due to the high volumes of water contained in the holding tanks, maintained an ambient temperature equal to the incoming water. The effluent placed in the column was therefore free of any external temperature gradients, and the convection currents which are produced when a gradient exists.

Some minor upwelling was observed at the start of the settling trials as a result of the air lift pump mixing system used. However, this was generally of short duration. The column was observed to be quiescent within 5 to 7 minutes after termination of aerated mixing.

Given that the waste solid particulates were uniformly distributed within the column, and that the column was quiescent, the settling column can be used to approximate conditions within a clarifier or settling basin. Samples collected from the column can thus be used to derive the Type II or flocculant particle settling curves for the waste. The flocculant particle settling curve can in turn be used to obtain the overall non-filterable residue removal curve and the individual particle settling velocity distribution curve for the waste.

As previously discussed, the two sets of samples collected during mixing were used to determine the baseline initial non-filterable residue concentration within the settling column (Table III). Samples collected after termination of mixing were then measured for non-filterable residue and compared to the initial concentration to determine the level of non-filterable residue removed over time (Table IV). The level of

TABLE IV Non-filterable residue concentrations for a sample settling trial

Sample #	Sample Port Location *	Non-Filterable Residue (grams)	% Removal	Residence Time (min)
1	1	0.0399	26.4	1:00
1	2	0.0432	20.3	
1	3	0.0381	29.7	
1	4	0.0349	35.6	
1	5	0.0410	24.4	
1	6	0.0282	48.0	
2	1	0.0297	45.2	3:00
2	2	0.0305	43.7	
2	3	0.0296	45.4	
2	4	0.0262	51.7	
2	5	0.0285	47.4	
2	6	0.0209	61.4	
3	1	0.0243	55.2	6:00
3	2	0.0242	55.3	
3	3	0.0207	61.8	
3	4	0.0168	69.0	
3	5	0.0167	69.2	
3	6	0.0121	77.7	
4	1	0.0143	73.6	15:00
4	2	0.0142	73.8	
4	3	0.0135	75.1	
4	4	0.0119	78.0	
4	5	0.0108	80.1	
4	6	0.0085	84.3	
5	1	0.0100	81.5	30:00
5	2	0.0114	79.0	
5	3	0.0103	81.0	
5	4	0.0094	82.7	
5	5	0.0075	86.2	
5	6	0.0062	88.7	
6	1	0.0071	86.9	60:00
6	2	0.0074	86.3	
6	3	0.0077	85.8	
6	4	0.0079	85.4	
6	5	0.0070	87.1	
6	6	0.0069	87.3	

* Refer to Figure 4.2 for location of settling column sampling port

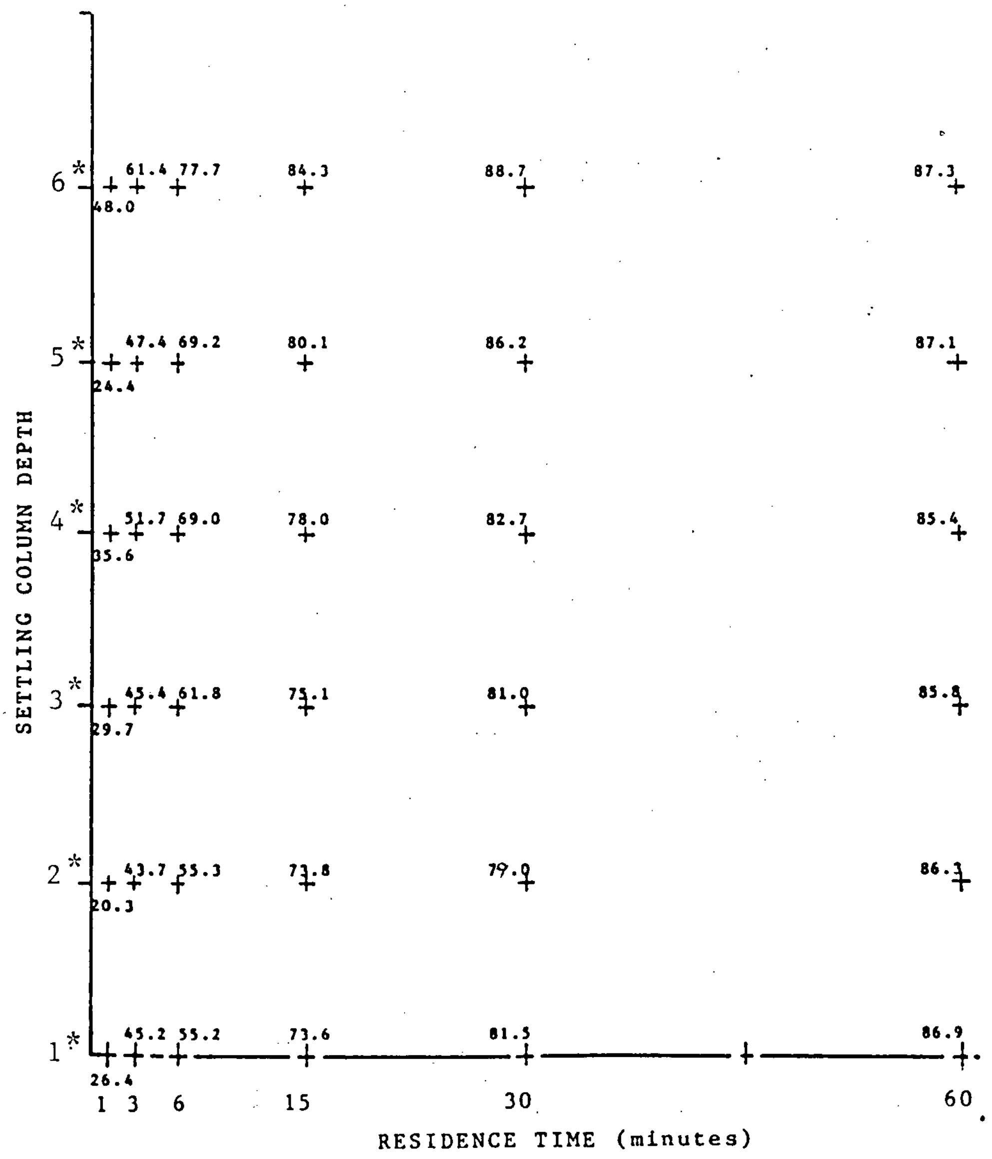
non-filterable residue (X_o), expressed as a percentage, was then plotted as a function of column depth and residence time in order to provide the frame work for the Type II settling curves (Figure 5.1). With the inclusion of iso-concentration lines, representing points of equal levels of non-filterable residue removal, the Type II or flocculant particle settling curve was obtained (Figure 5.2).

The Type II settling curve (Figure 5.2) thus provided a graphical representation of the level of solids removal over time at various depths within the settling column. However, to be of use as a design tool, it was necessary to know what the overall level of solids removal was for the entire column. This was obtained from the Type II curve by integration of the various iso-concentration curves using equation 3.6 as outlined in Chapter 3. Plotting of the resulting overall non-filterable residue removal concentrations for each unit of time resulted in the overall non-filterable residue removal curve (Figure 5.3).

The individual particle settling velocity distribution curve was in turn obtained by plotting the residual of $1-X_o$, where X_o is the level of overall non-filterable residue removed at a residence time T_o (expressed as a fraction), against the particle settling velocity as outlined in Chapter 3. Figure 5.4 illustrates the resulting individual particle settling velocity distribution curve from the example data provided in Table IV.

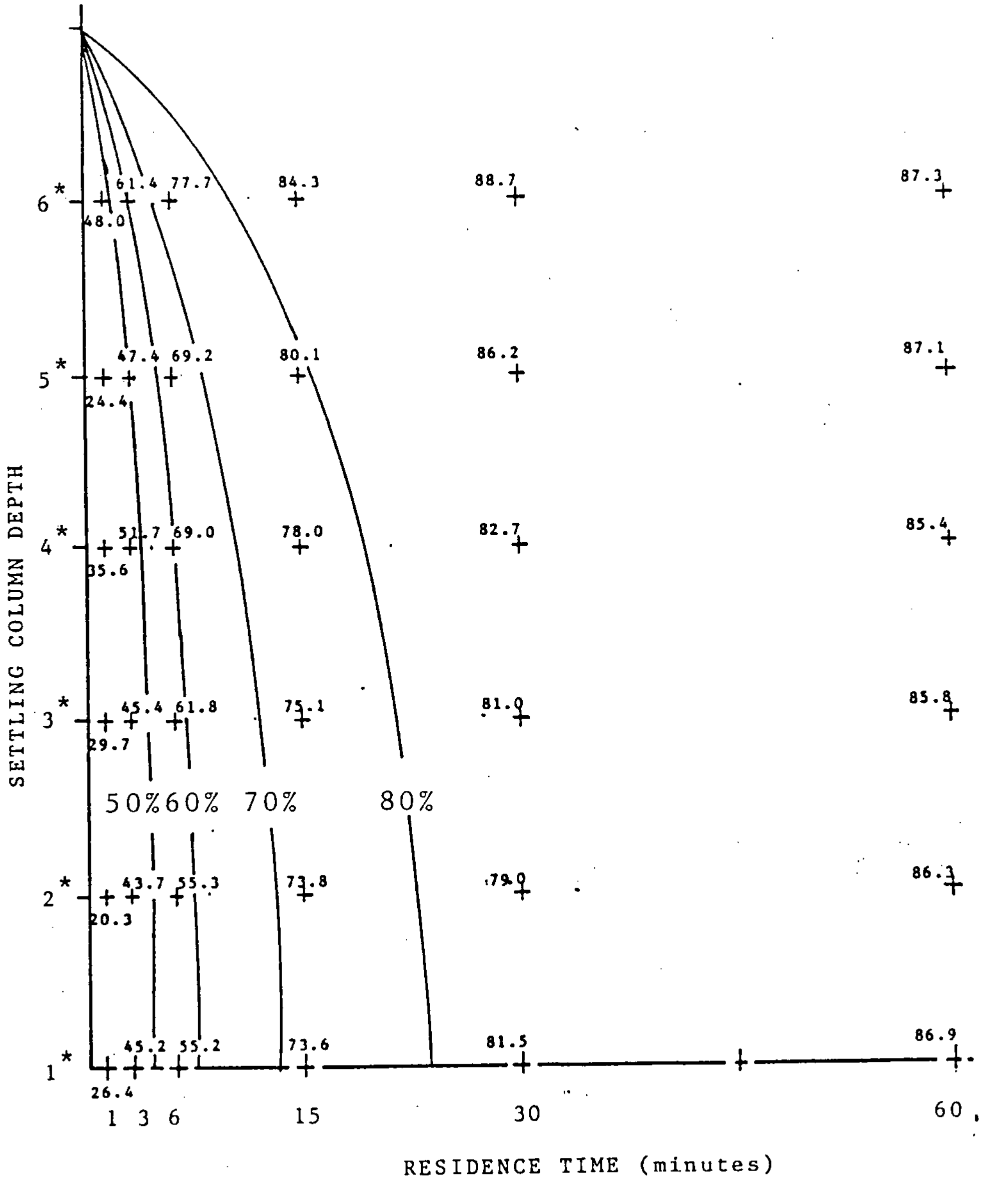
Overall non-filterable residue removal curves (Figure 5.5 - 5.15) and individual particle settling velocity distribution curves (Figure 5.16 - 5.26), were subsequently derived for each of the test groups summarized in Table II.

FIGURE 5.1 Percentage of non-filterable residue removed as a function of residence time and column depth for data given in Table III



* Refer to Figure 4.2 for sample port location and depth

FIGURE 5.2 Type II or flocculant particle settling curves for example data in Table IV



* Refer to Figure 4.2 for sample port location and depth

FIGURE 5.3 Overall non-filterable residue removal curve for example data in Table IV

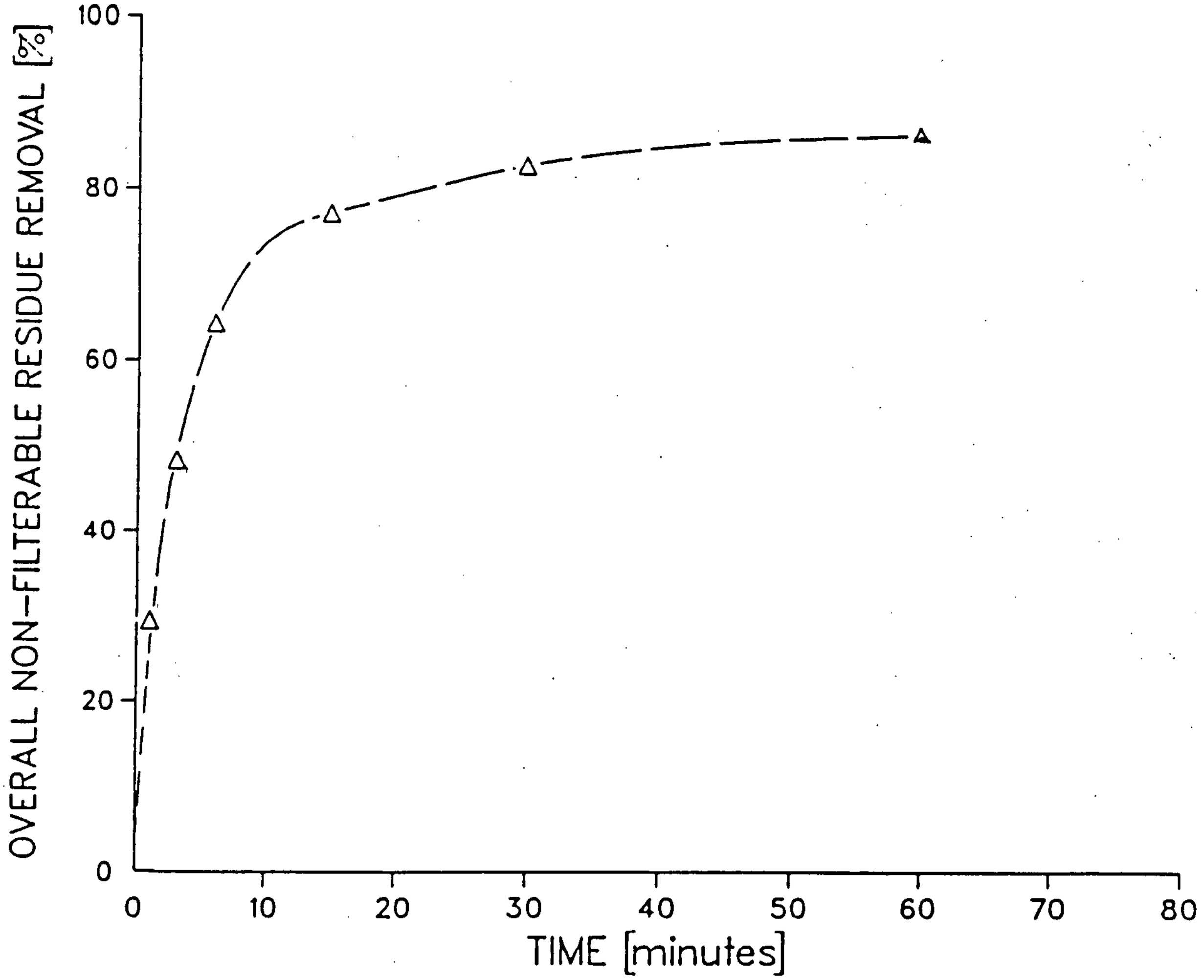


FIGURE 5.4 Individual particle settling velocity distribution curve for example data in Table IV

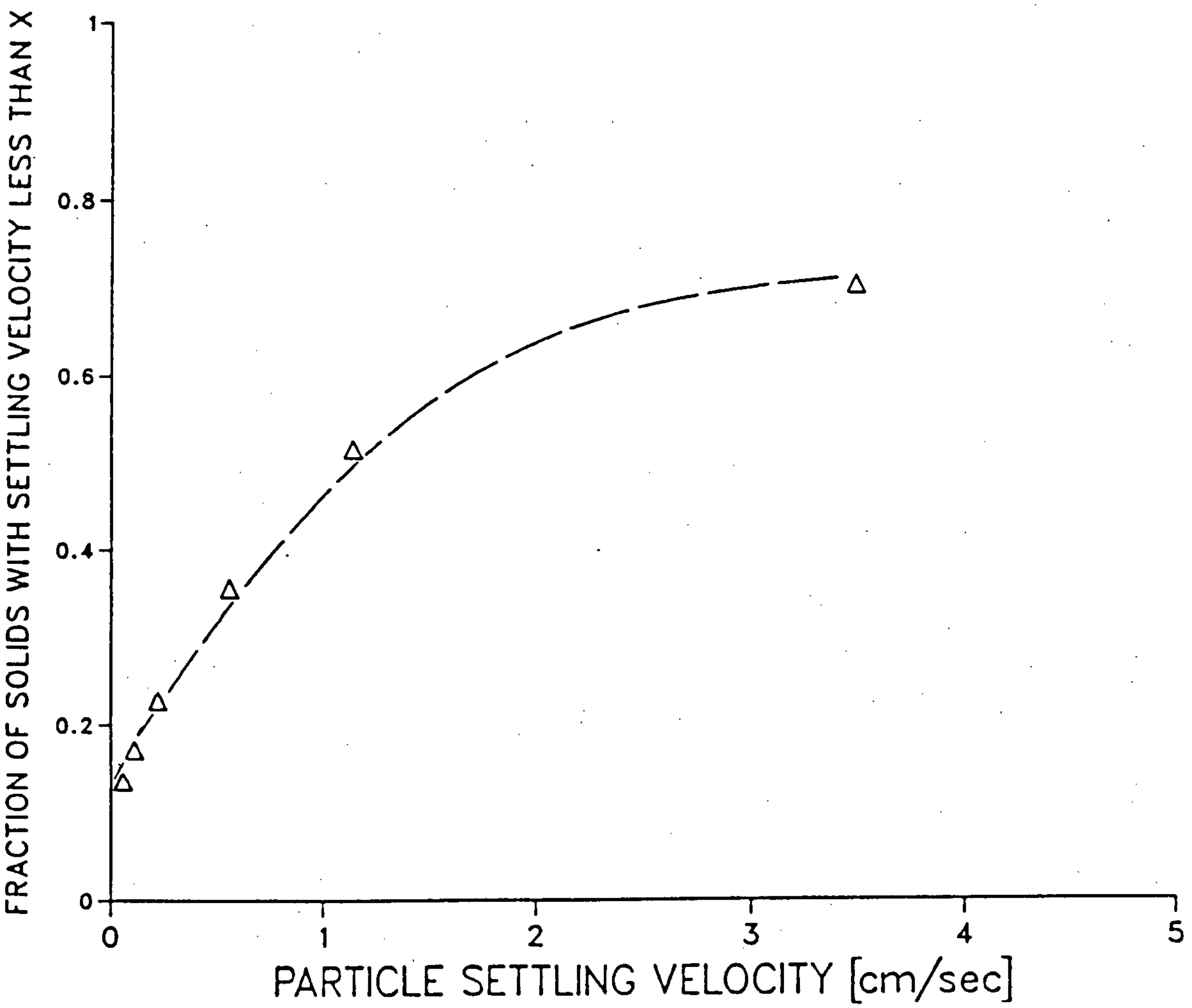


FIGURE 5.5 Overall non-filterable residue removal curves for 11 gram Rainbow trout fed 3/32 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

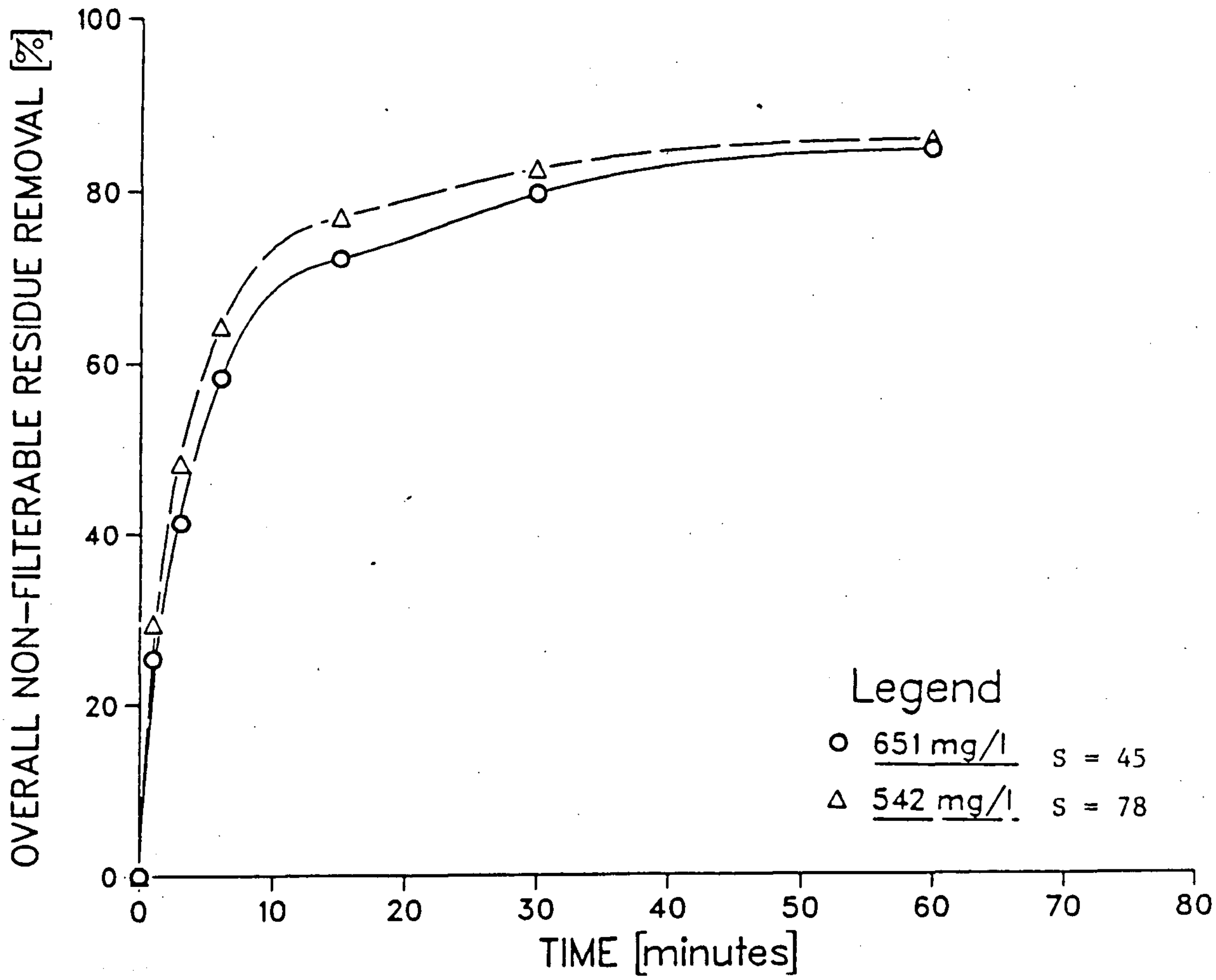


FIGURE 5.6 Overall non-filterable residue removal curves for 17 gram Rainbow trout fed 3/32 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

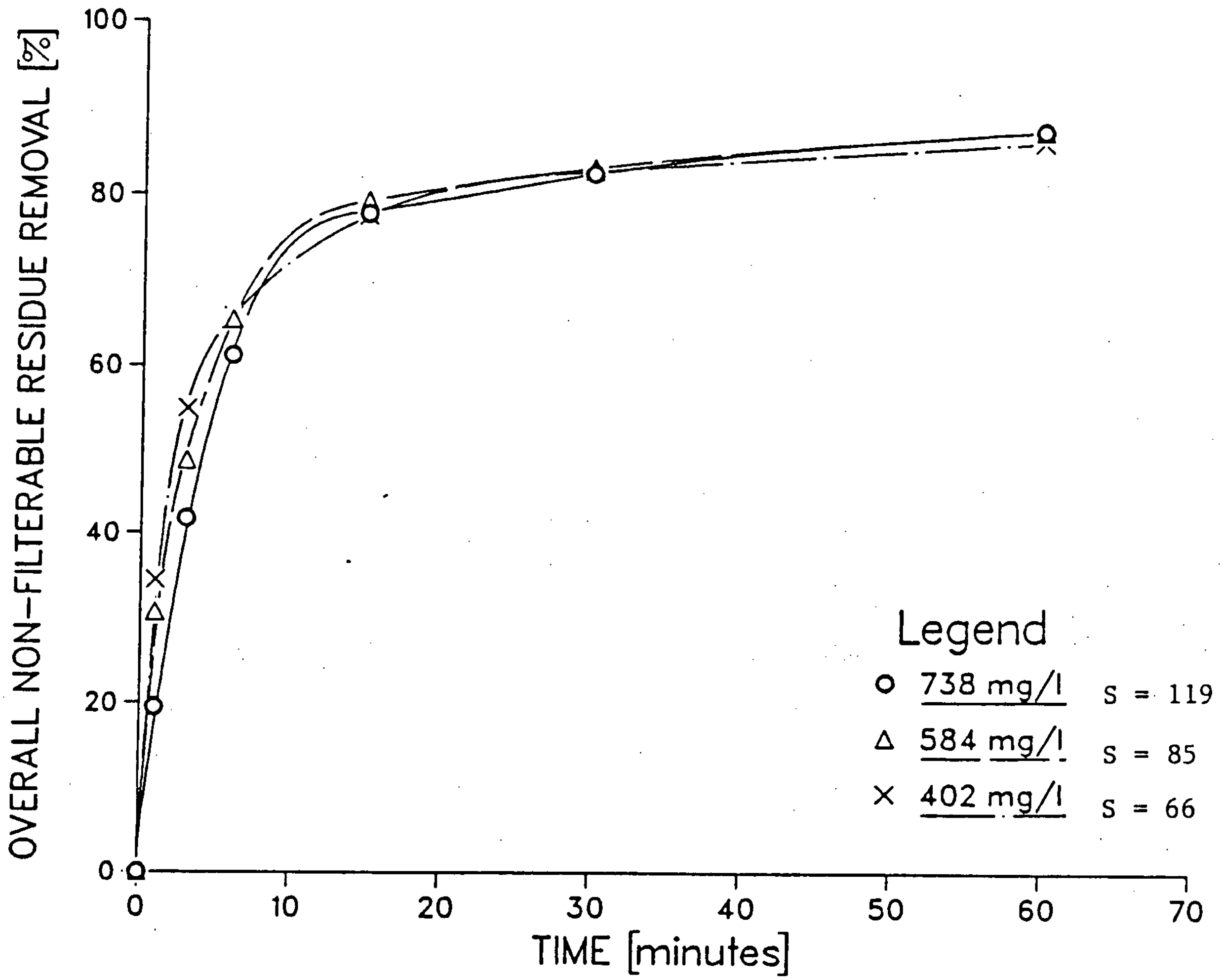


FIGURE 5.7 Overall non-filterable residue removal curves for 21 gram Rainbow trout fed 3/32 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

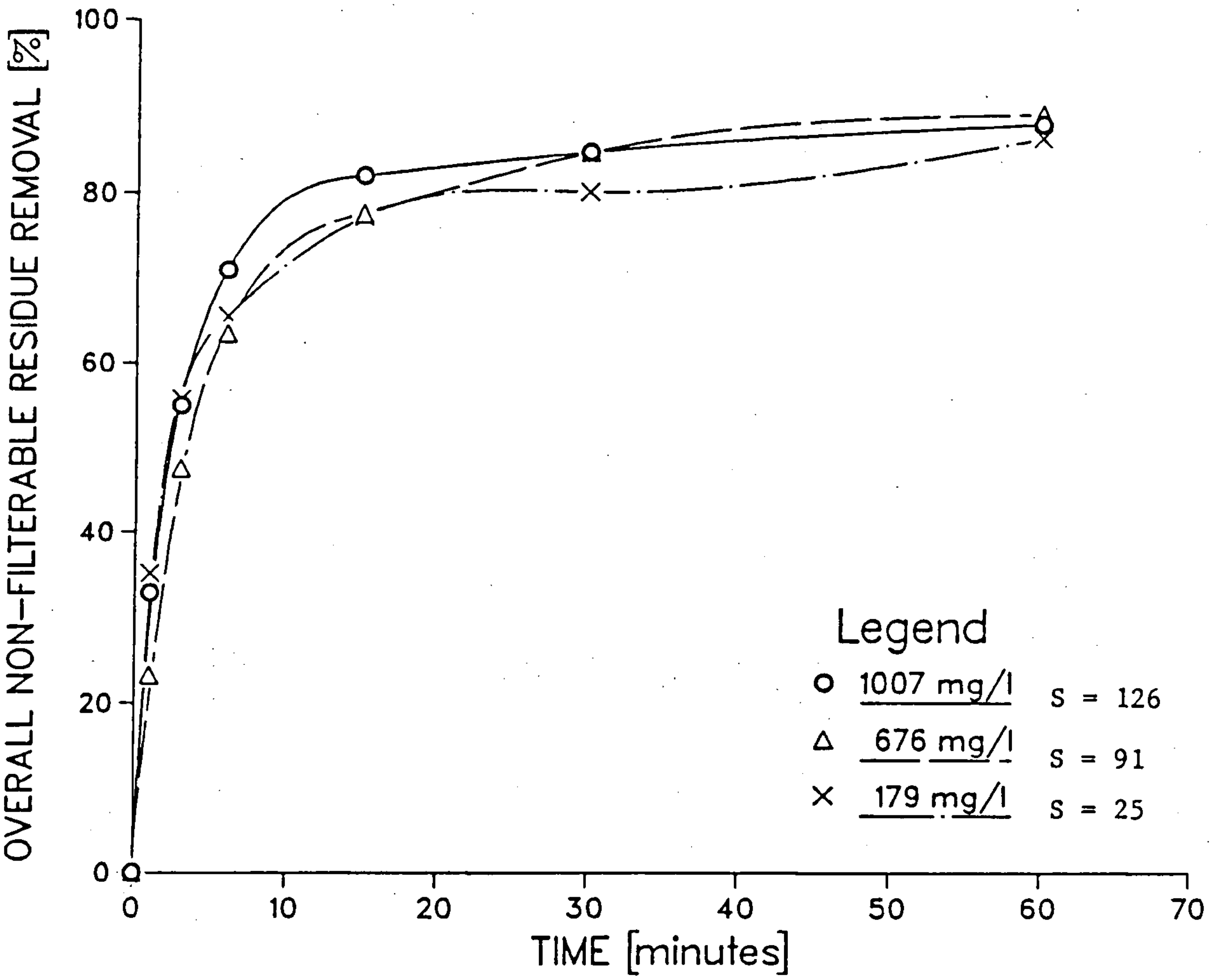


FIGURE 5.8 Overall non-filterable residue removal curves for 21 gram Rainbow trout fed 1/8 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

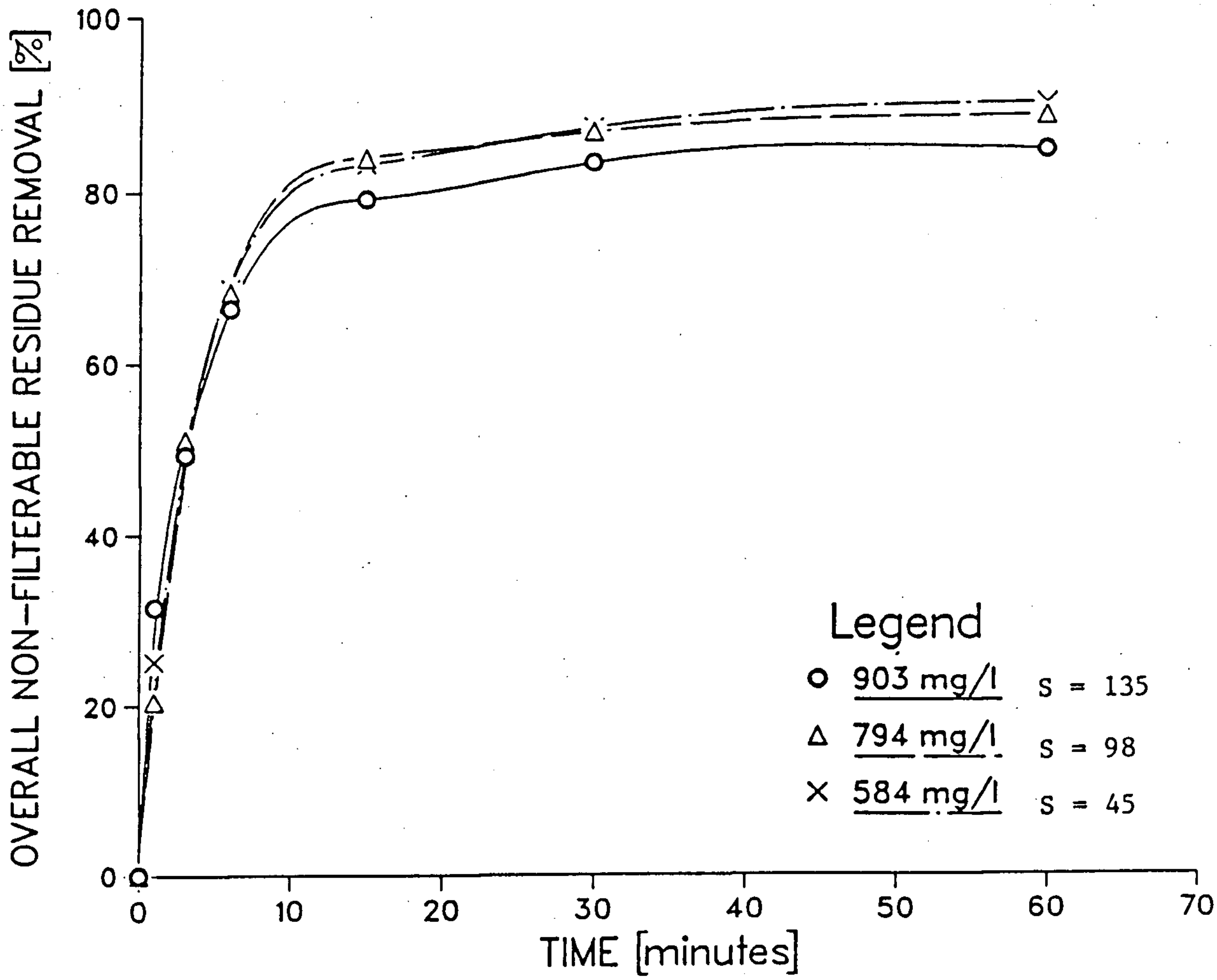


FIGURE 5.9 Overall non-filterable residue removal curves for 41 gram Rainbow trout fed 1/8 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

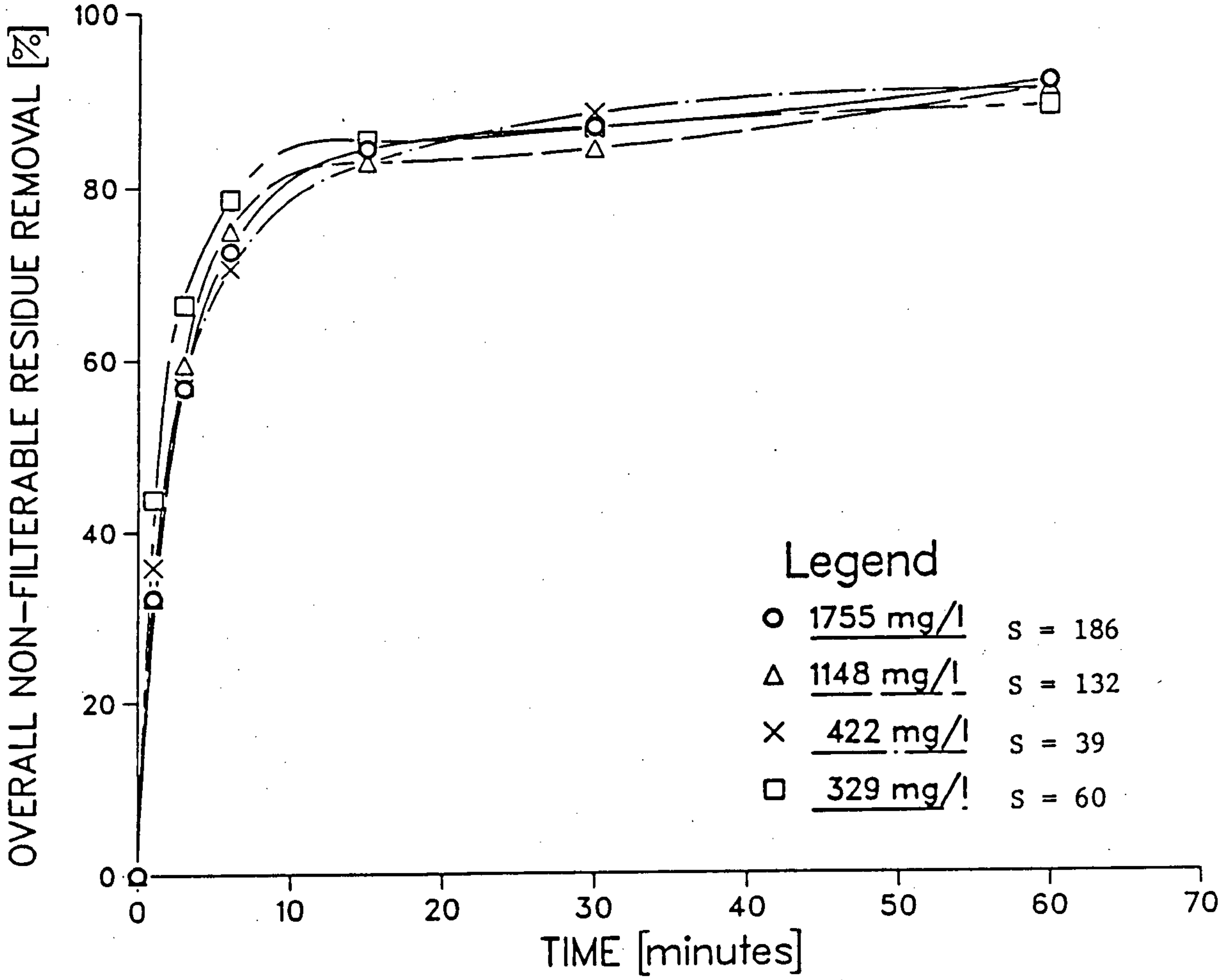


FIGURE 5.10 Overall non-filterable residue removal curves for 54 gram Rainbow trout fed 1/8 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

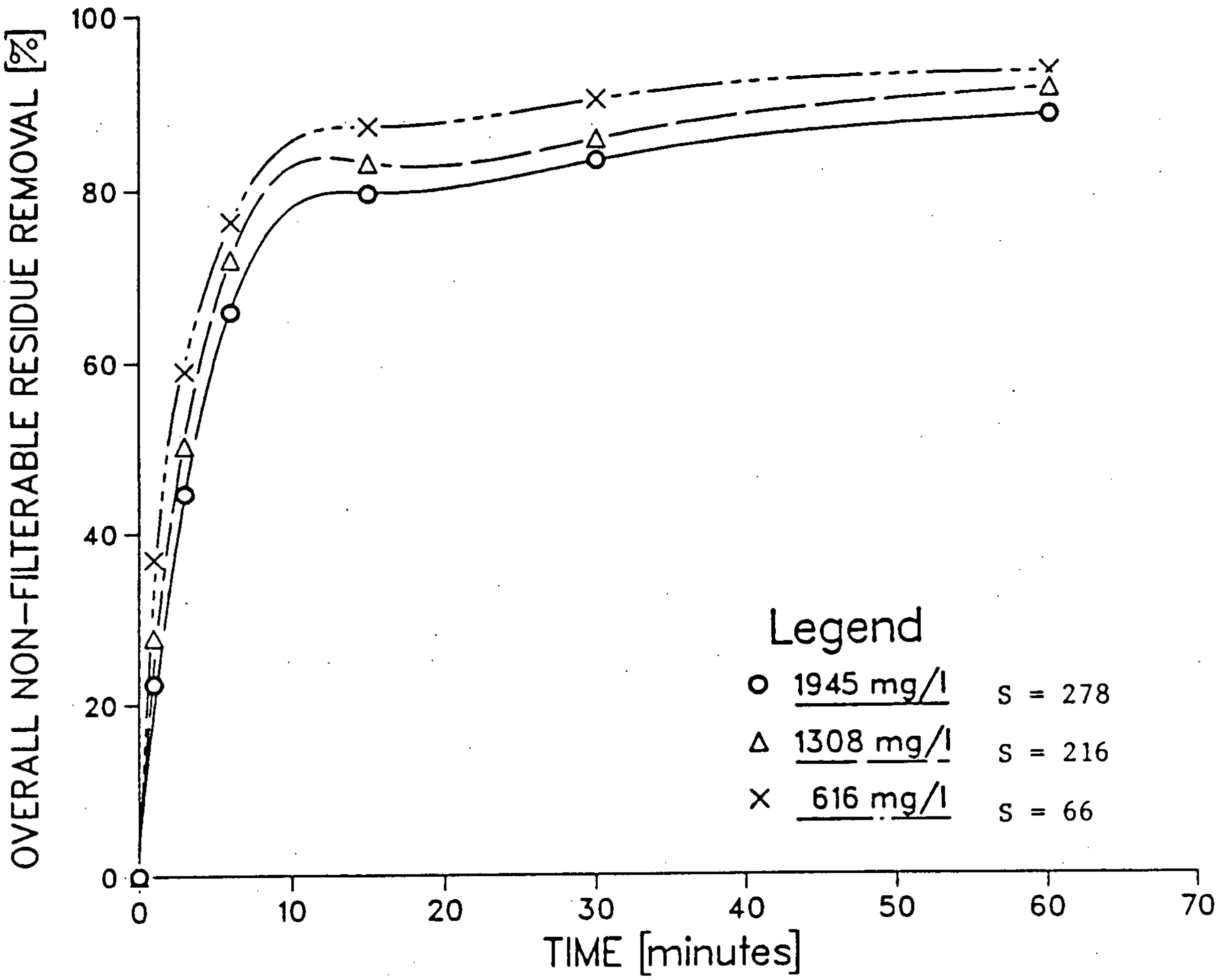


FIGURE 5.11 Overall non-filterable residue removal curves for 54 gram Rainbow trout fed 5/32 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

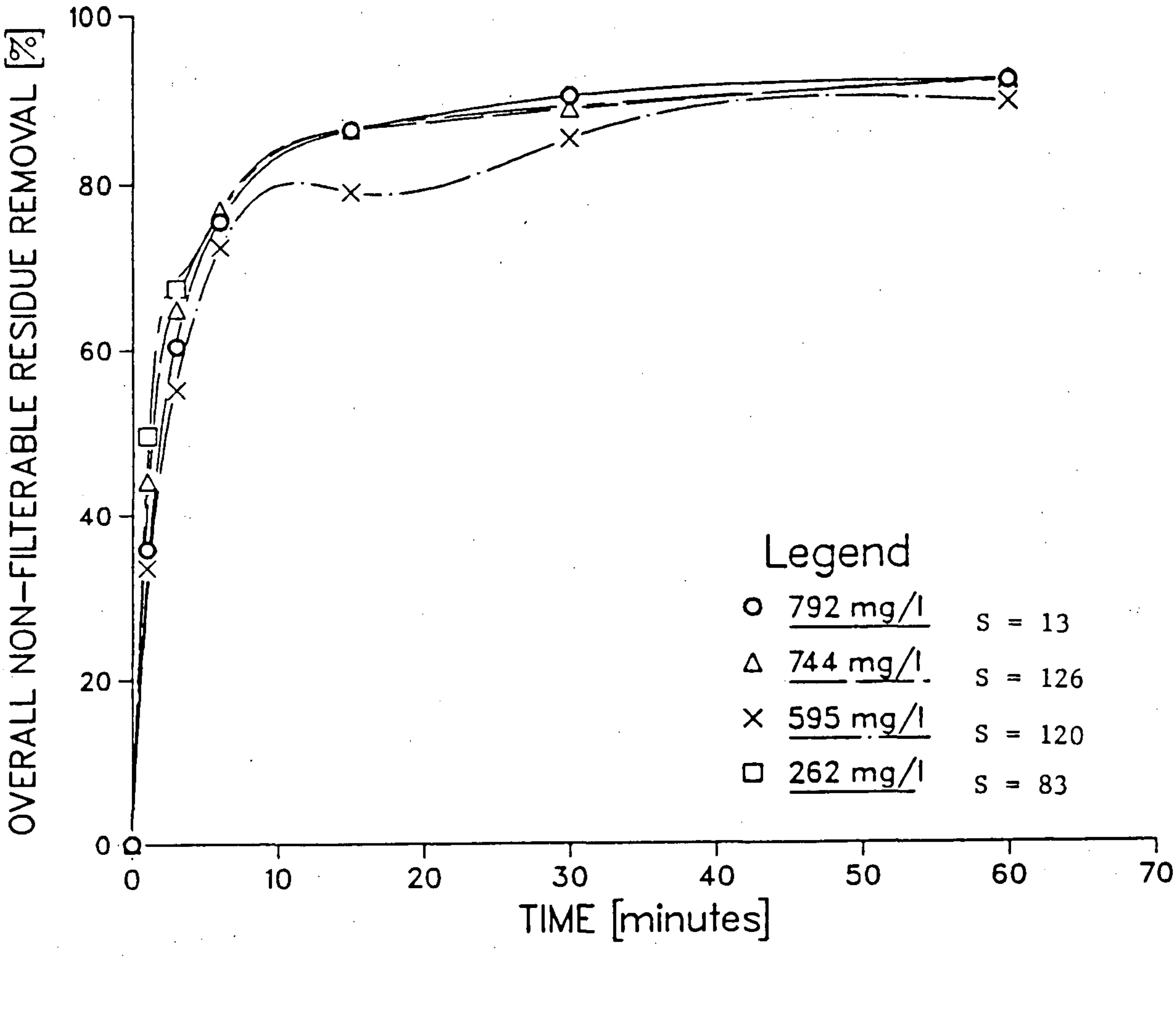


FIGURE 5.12 Overall non-filterable residue removal curves for 73 gram Rainbow trout fed 5/32 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

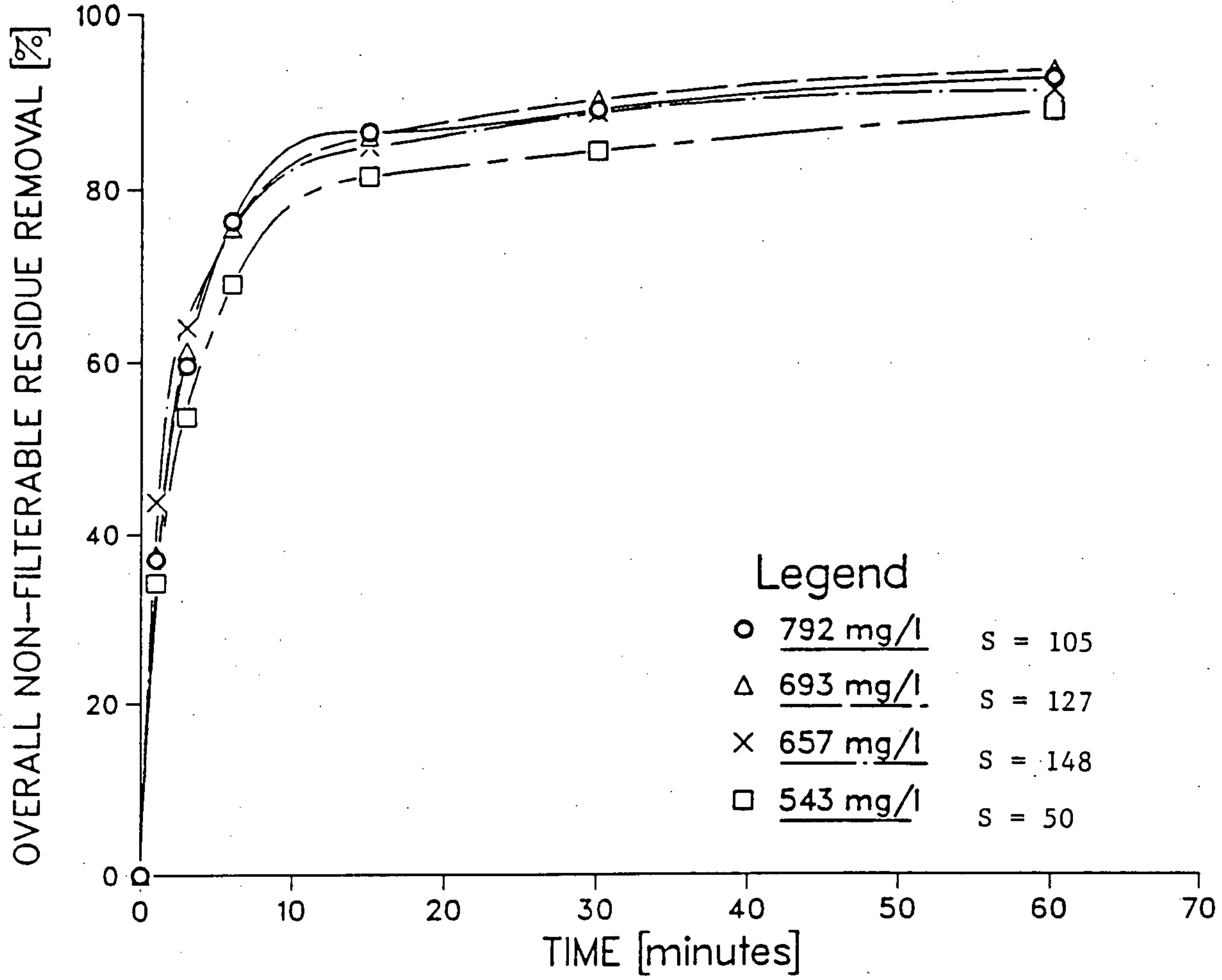


FIGURE 5.13 Overall non-filterable residue removal curves for 93 gram Rainbow trout fed 5/32 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

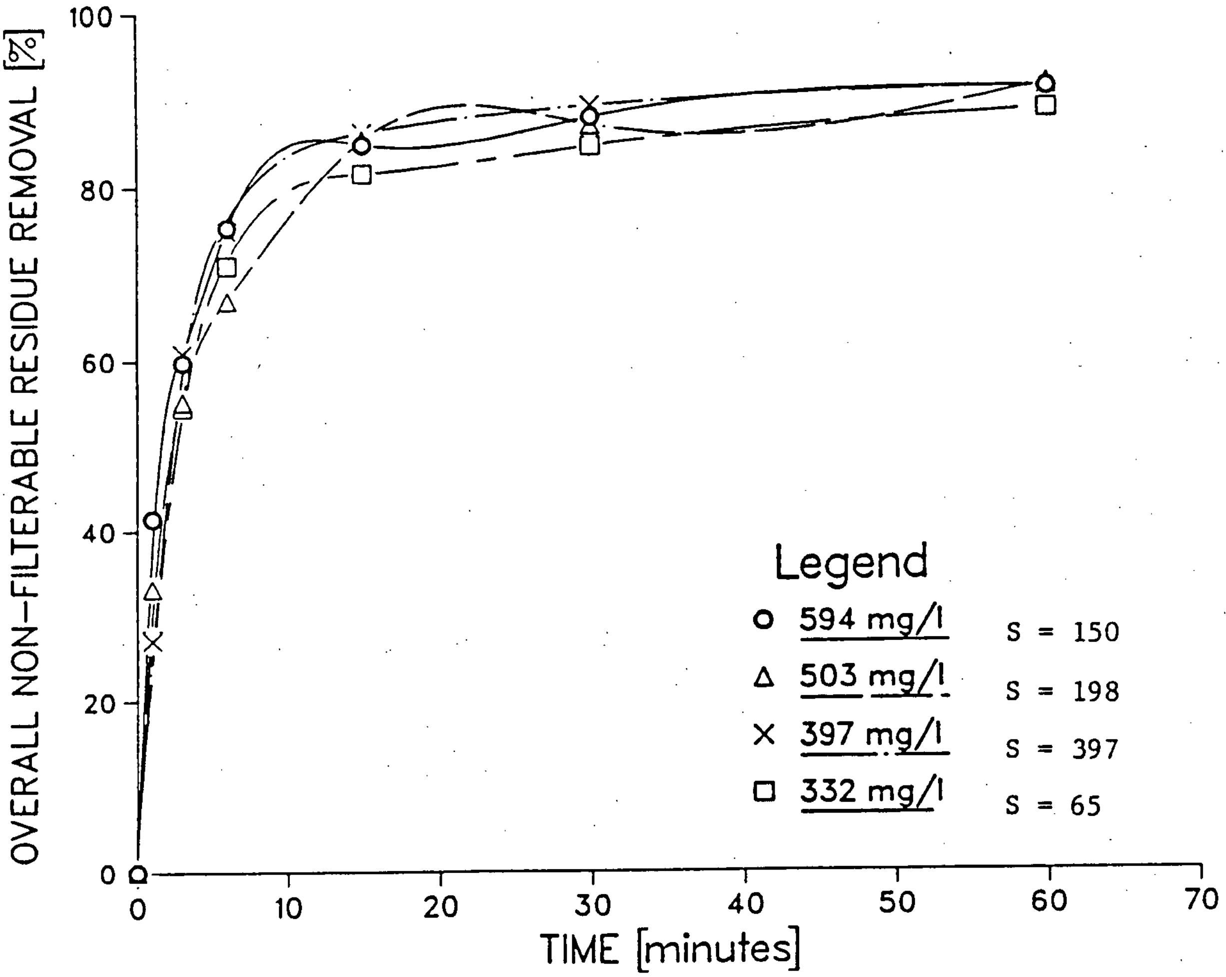


FIGURE 5.14 Overall non-filterable residue removal curves for 89 gram Rainbow trout fed 3/16 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

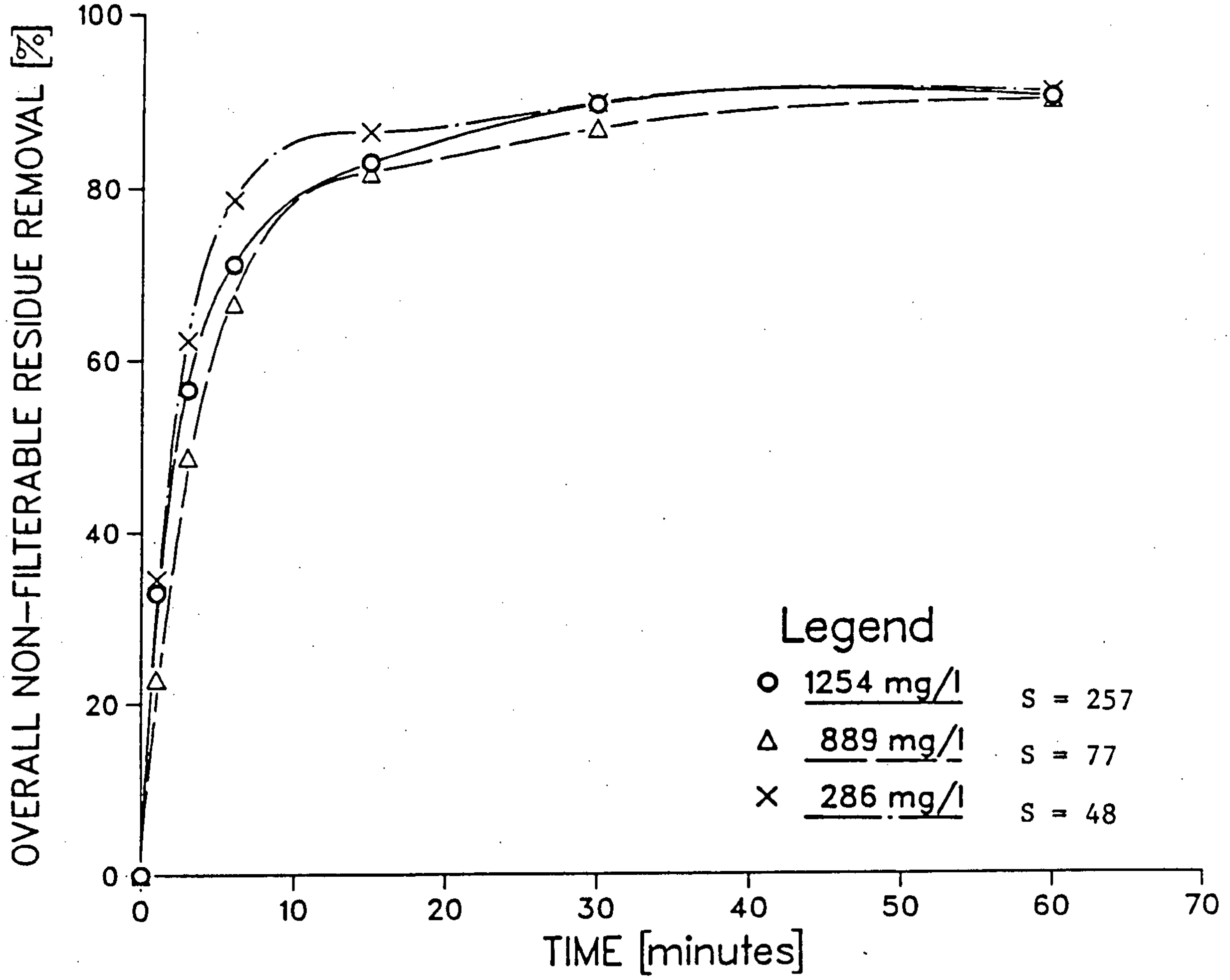


FIGURE 5.15 Overall non-filterable residue removal curves for 311 gram Rainbow trout fed 3/16 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

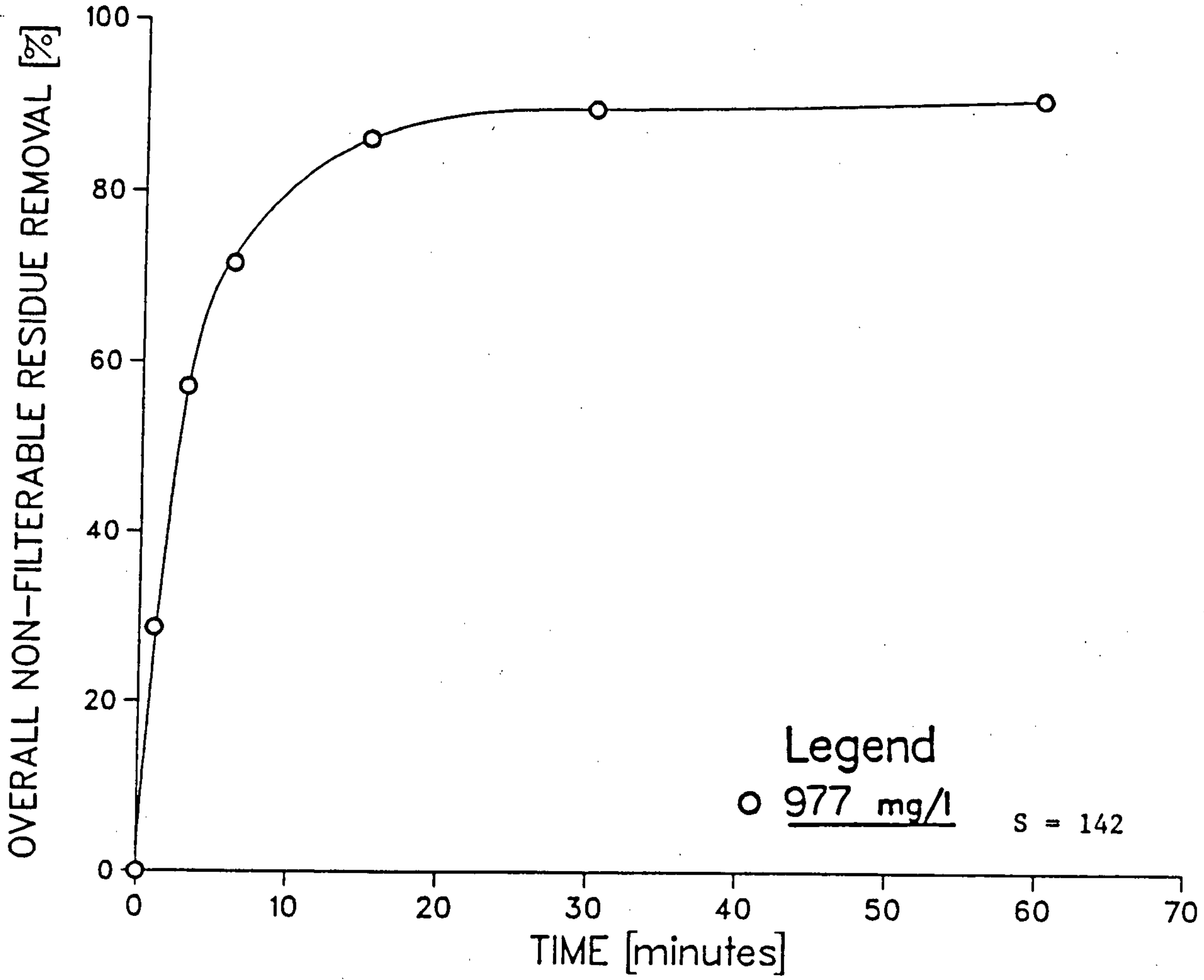


FIGURE 5.16 Individual particle settling velocity distribution curves for 11 gram Rainbow trout fed 3/32 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

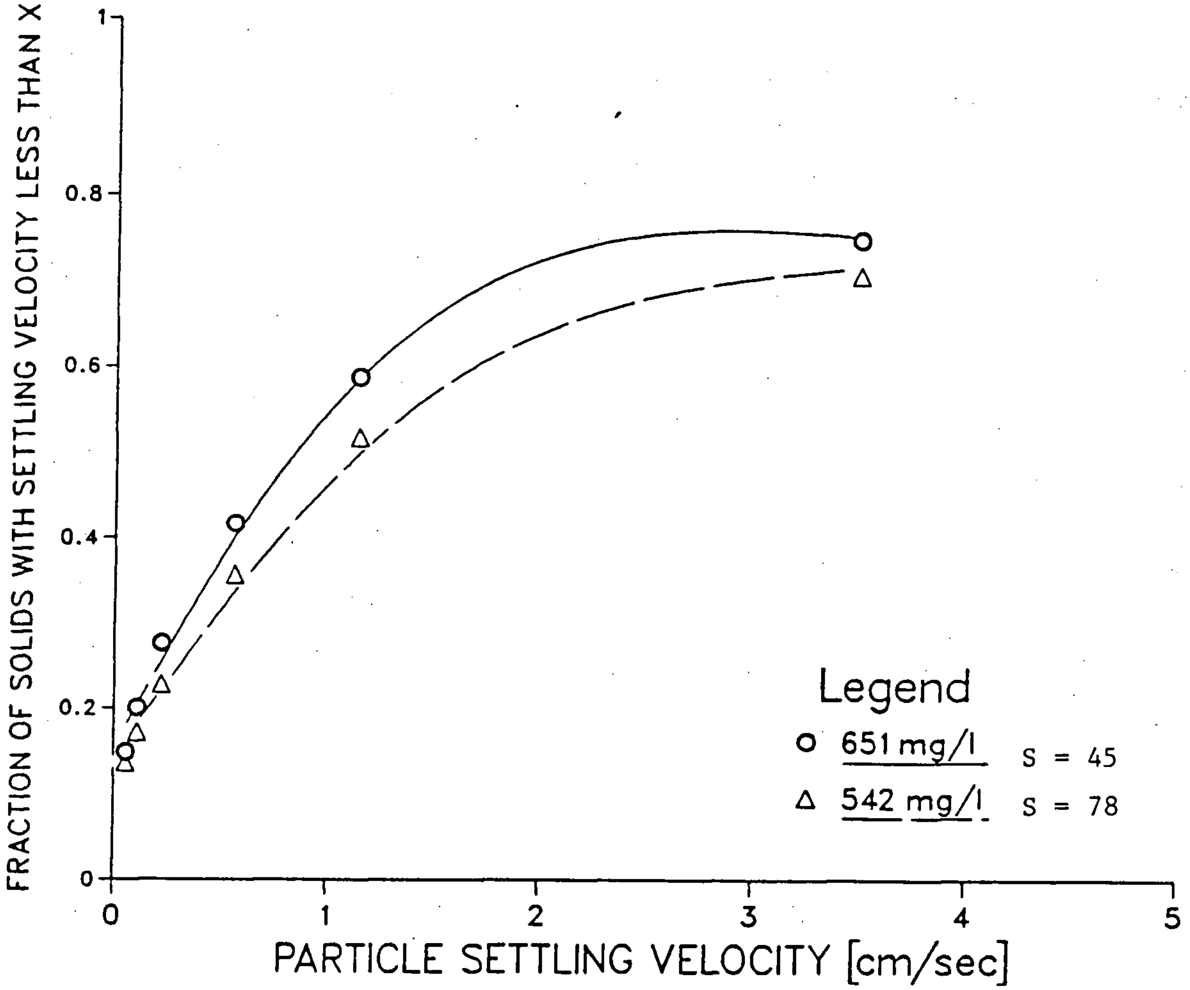


FIGURE 5.17 Individual particle settling velocity distribution curves for 17 gram Rainbow trout fed 3/32 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

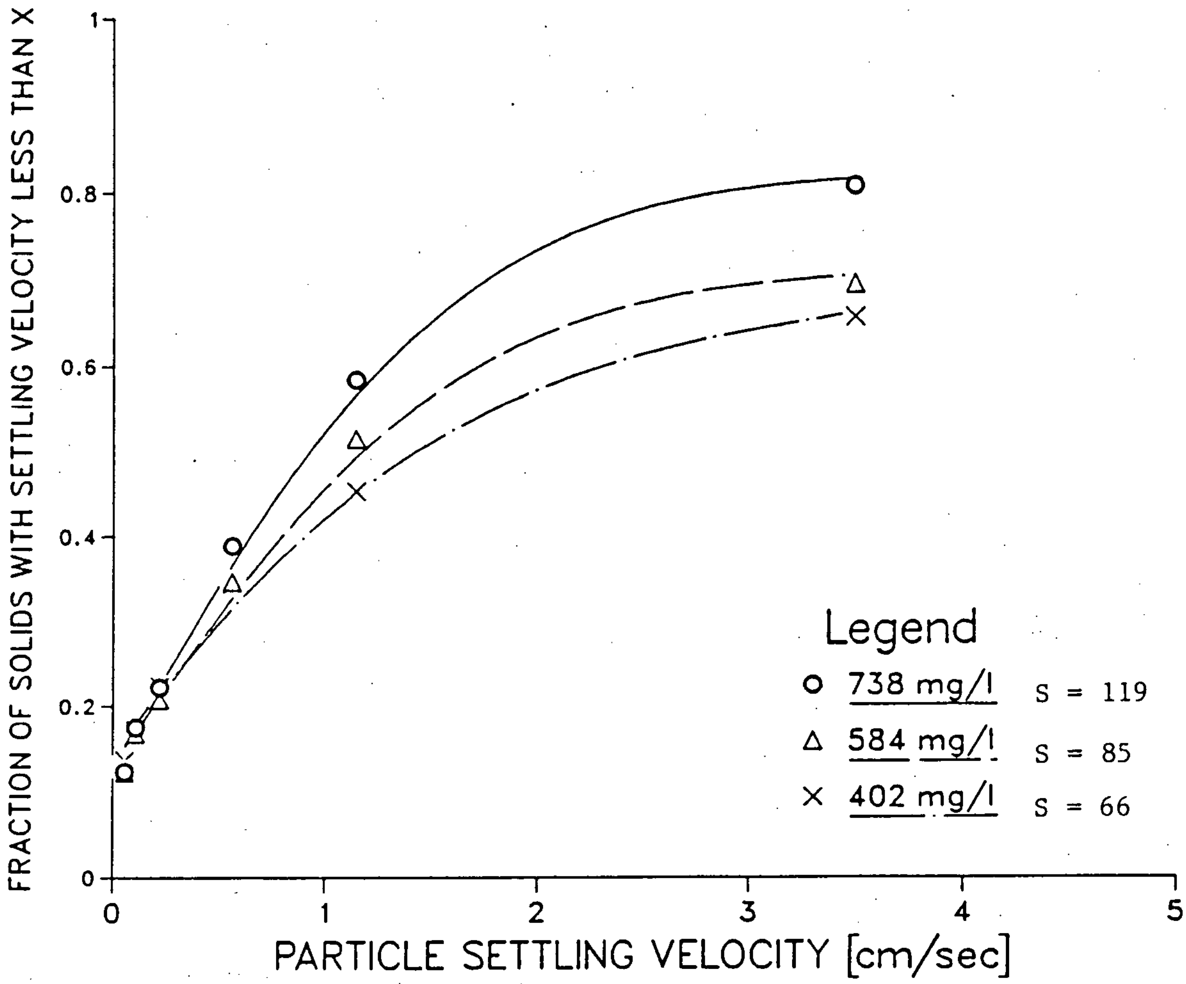


FIGURE 5.18 Individual particle settling velocity distribution curves for 21 gram Rainbow trout fed 3/32 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

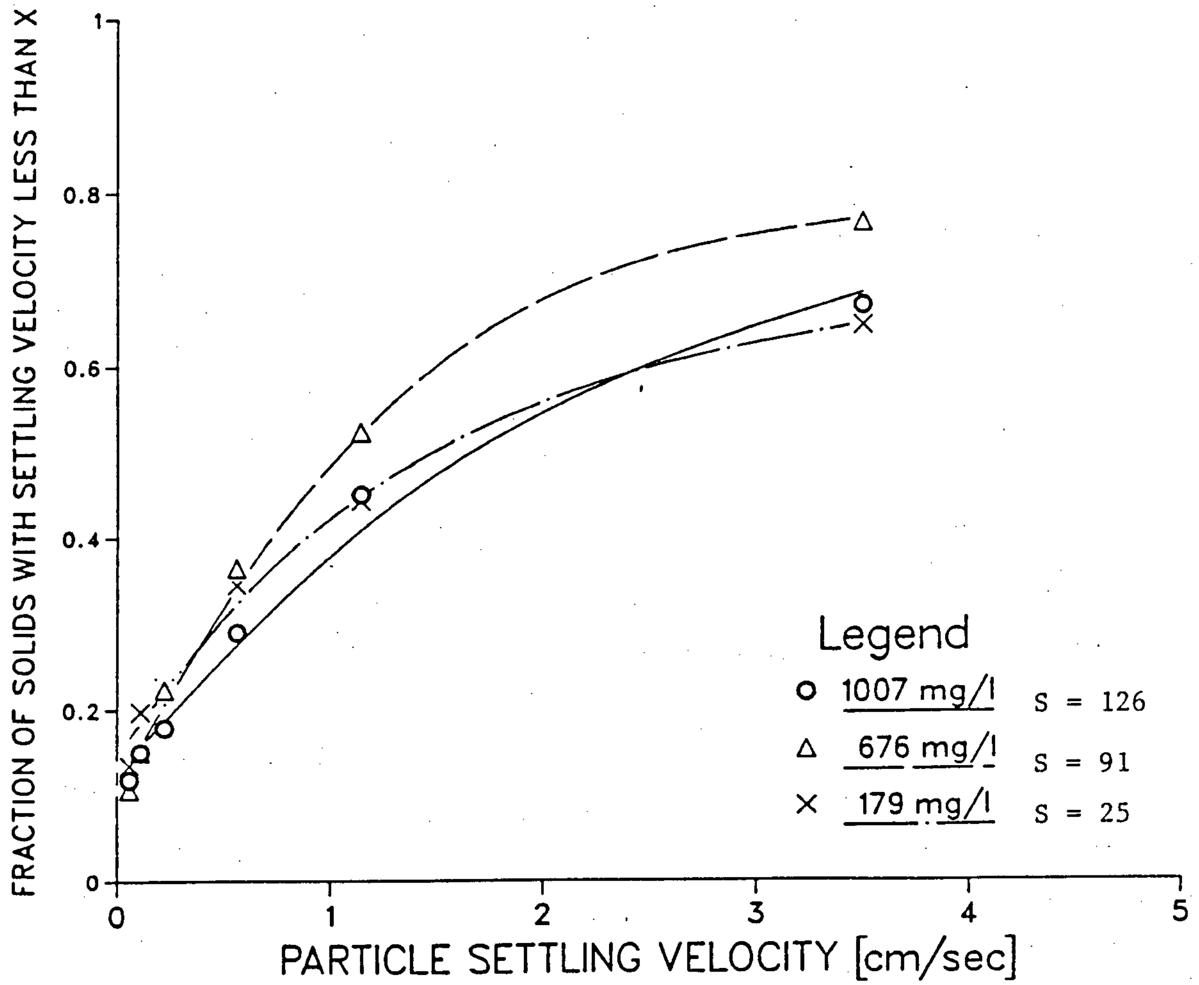


FIGURE 5.19 Individual particle settling velocity distribution curves for 21 gram Rainbow trout fed 1/8 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

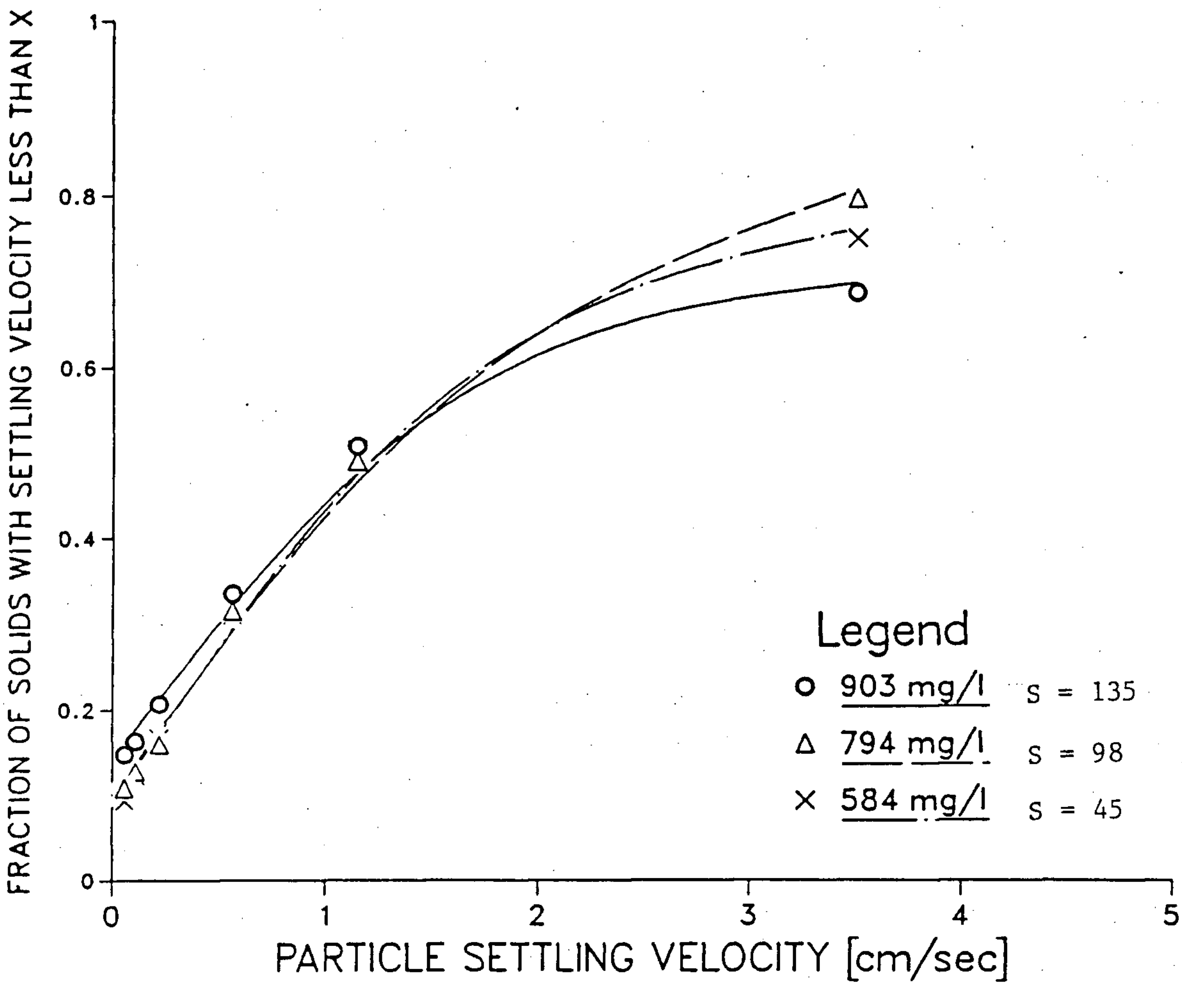


FIGURE 5.20 Individual particle settling velocity distribution curves for 41 gram Rainbow trout fed 1/8 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

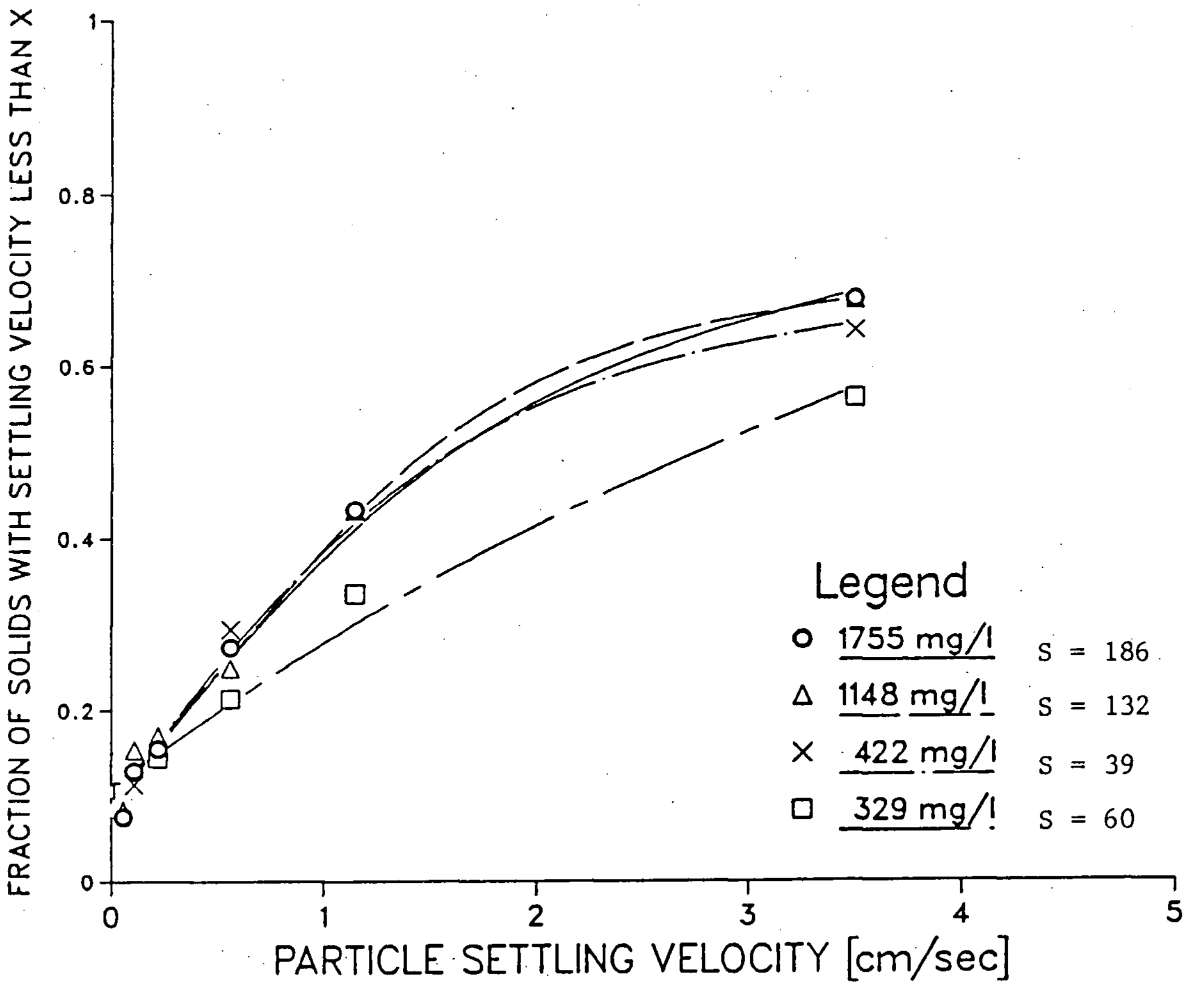


FIGURE 5.21 Individual particle settling velocity distribution curves for 54 gram Rainbow trout fed 1/8 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

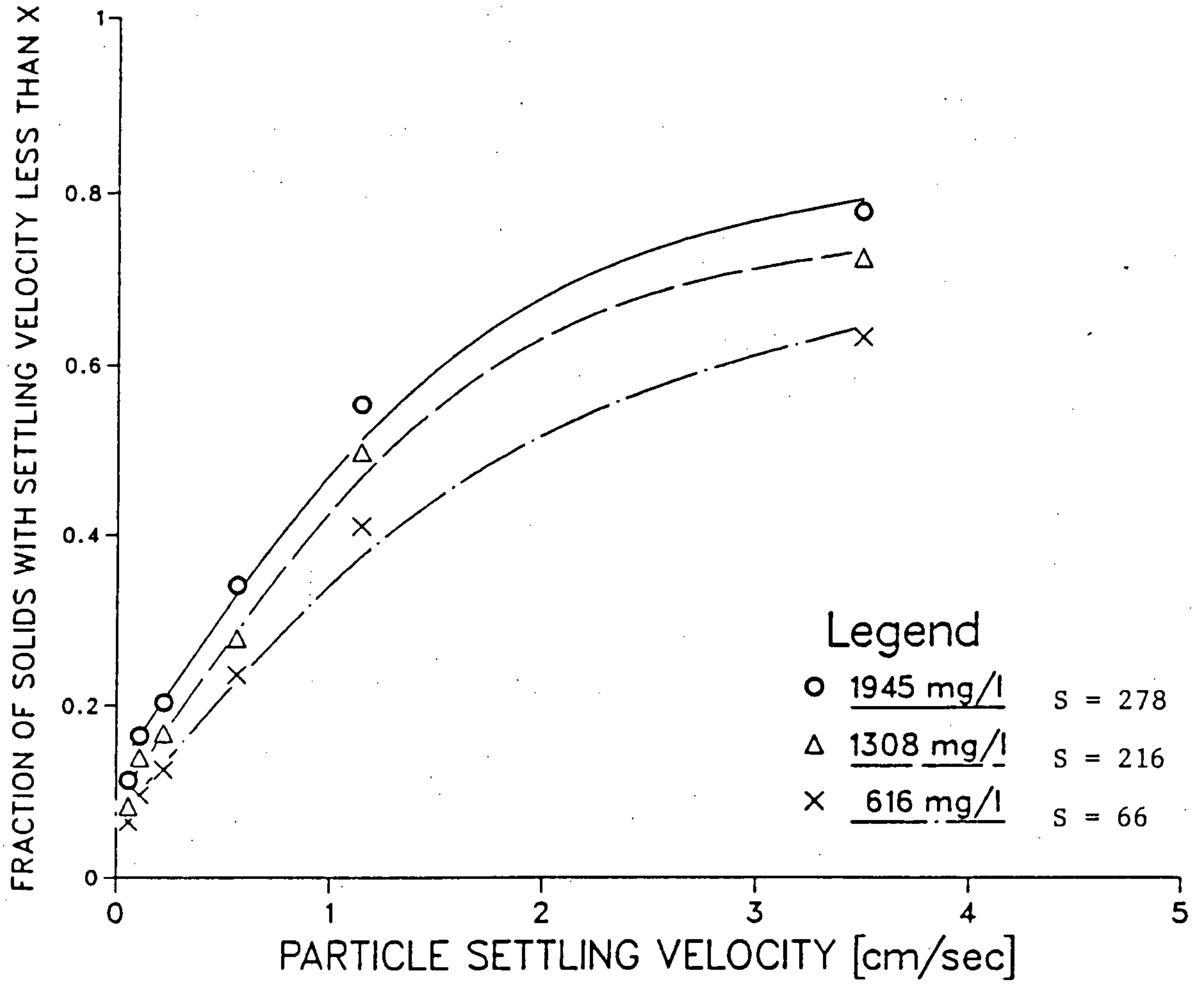


FIGURE 5.22 Individual particle settling velocity distribution curves for 54 gram Rainbow trout fed 5/32 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

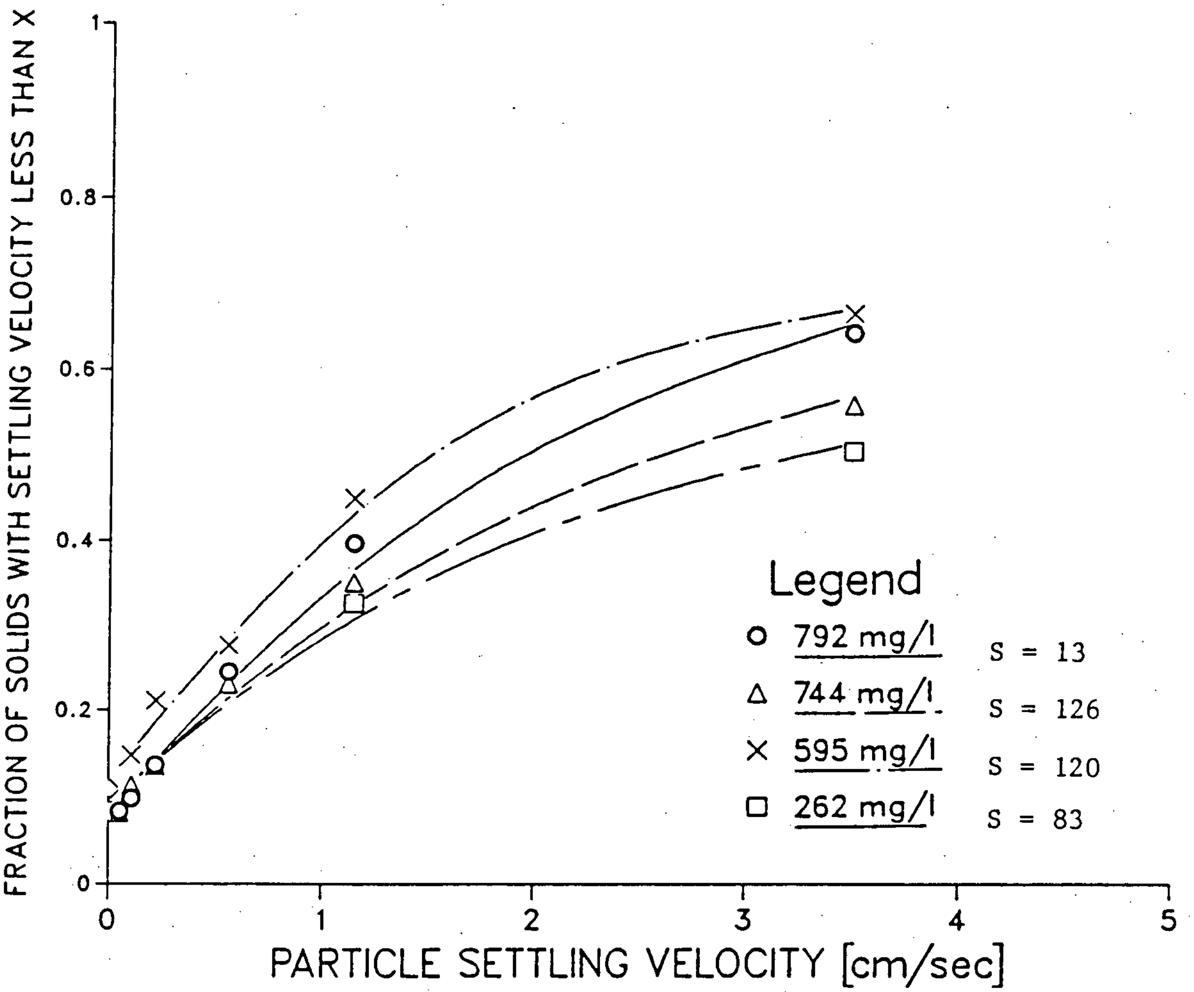


FIGURE 5.23 Individual particle settling velocity distribution curves for 73 gram Rainbow trout fed 5/32 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

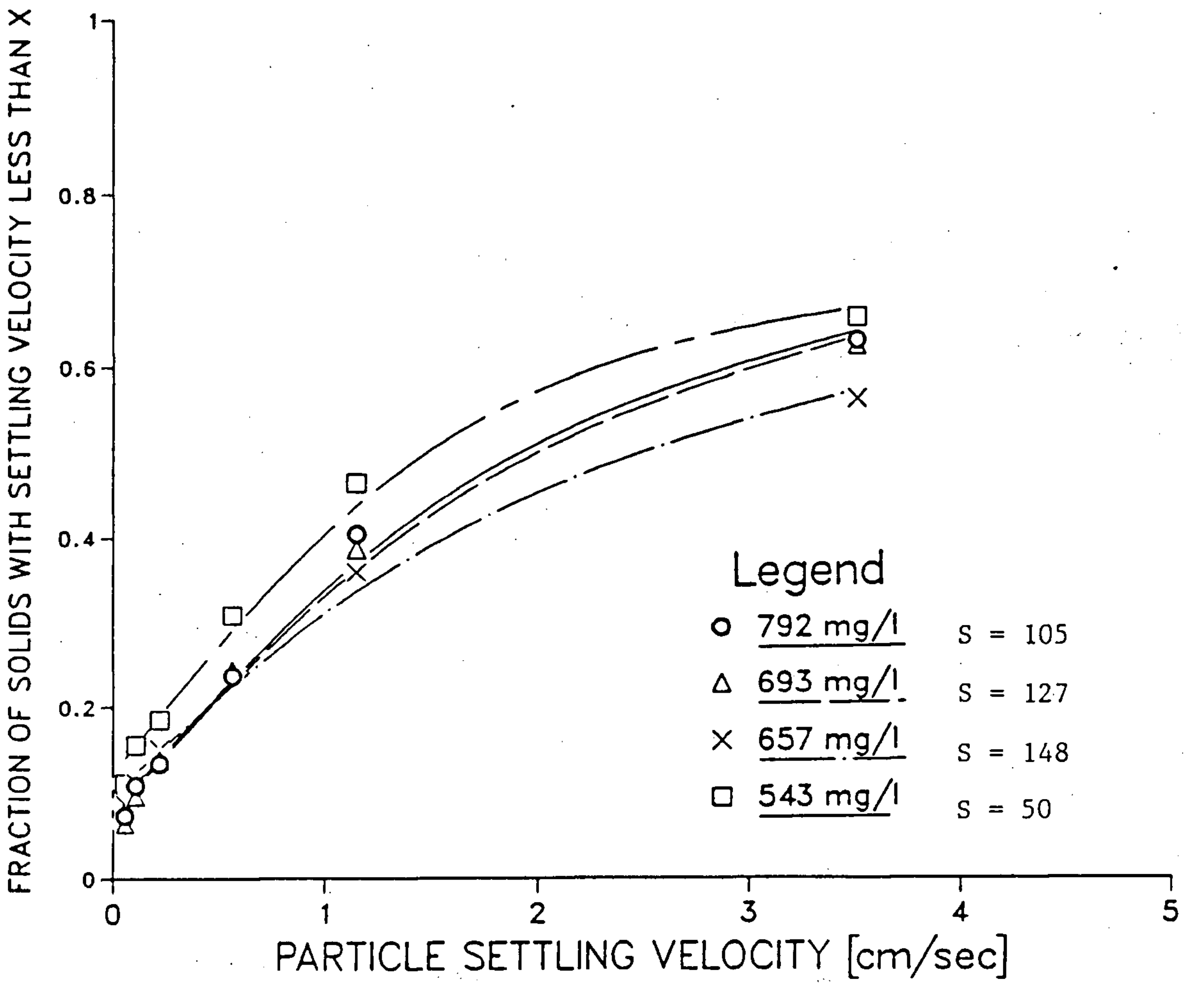


FIGURE 5.24 Individual particle settling velocity distribution curves for 93 gram Rainbow trout fed 5/32 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

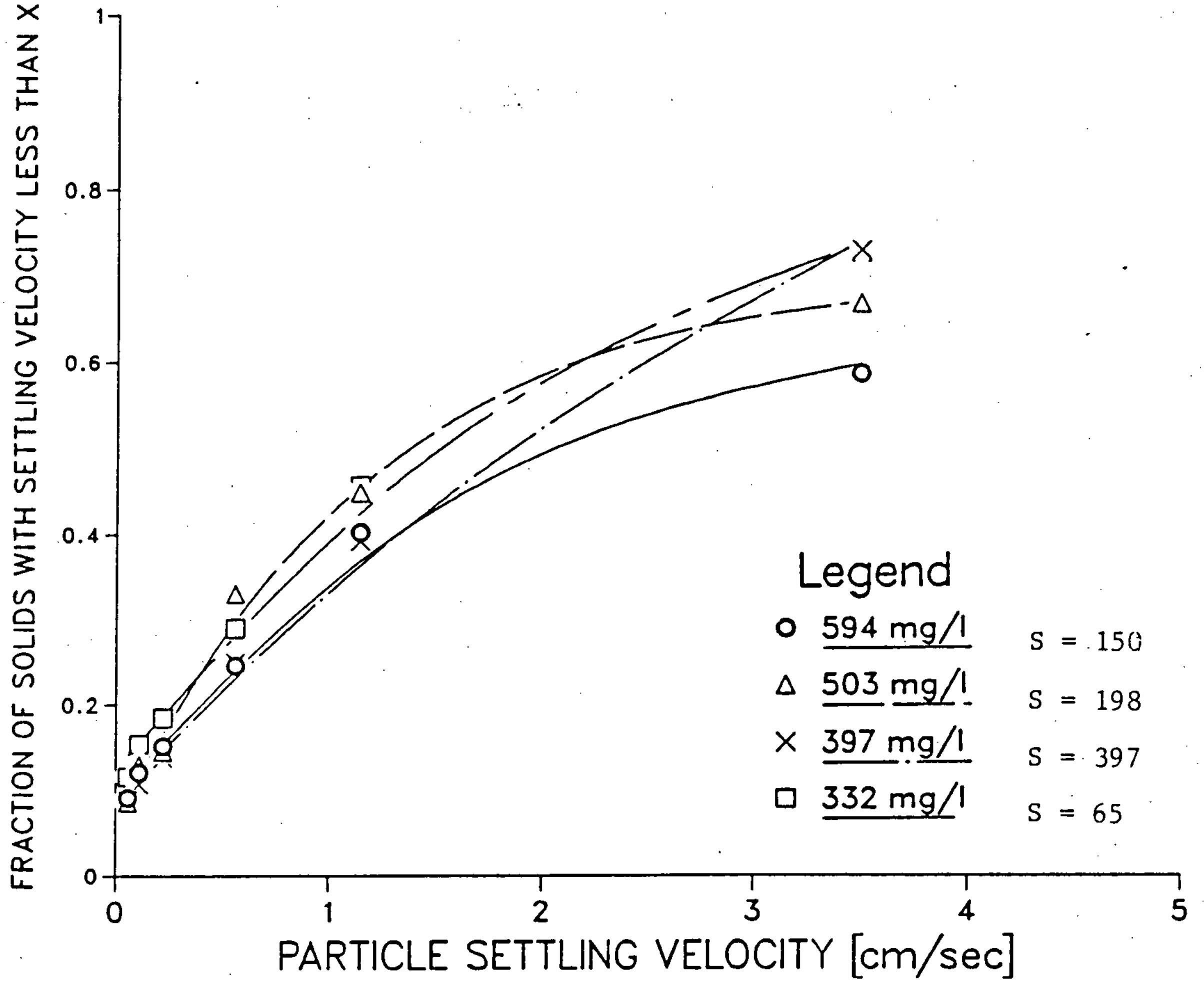


FIGURE 5.25 Individual particle settling velocity distribution curves for 89 gram Rainbow trout fed 3/16 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)

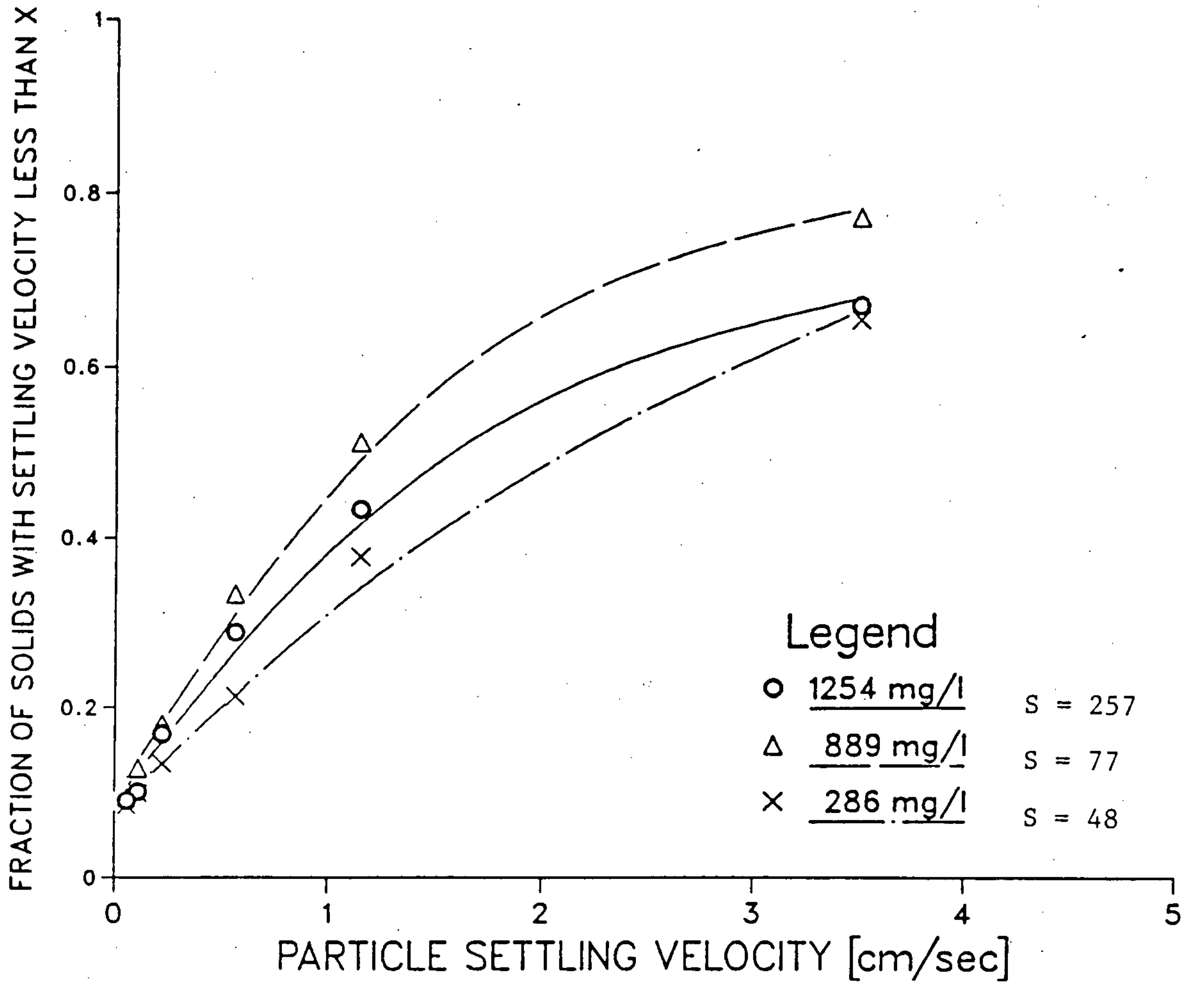
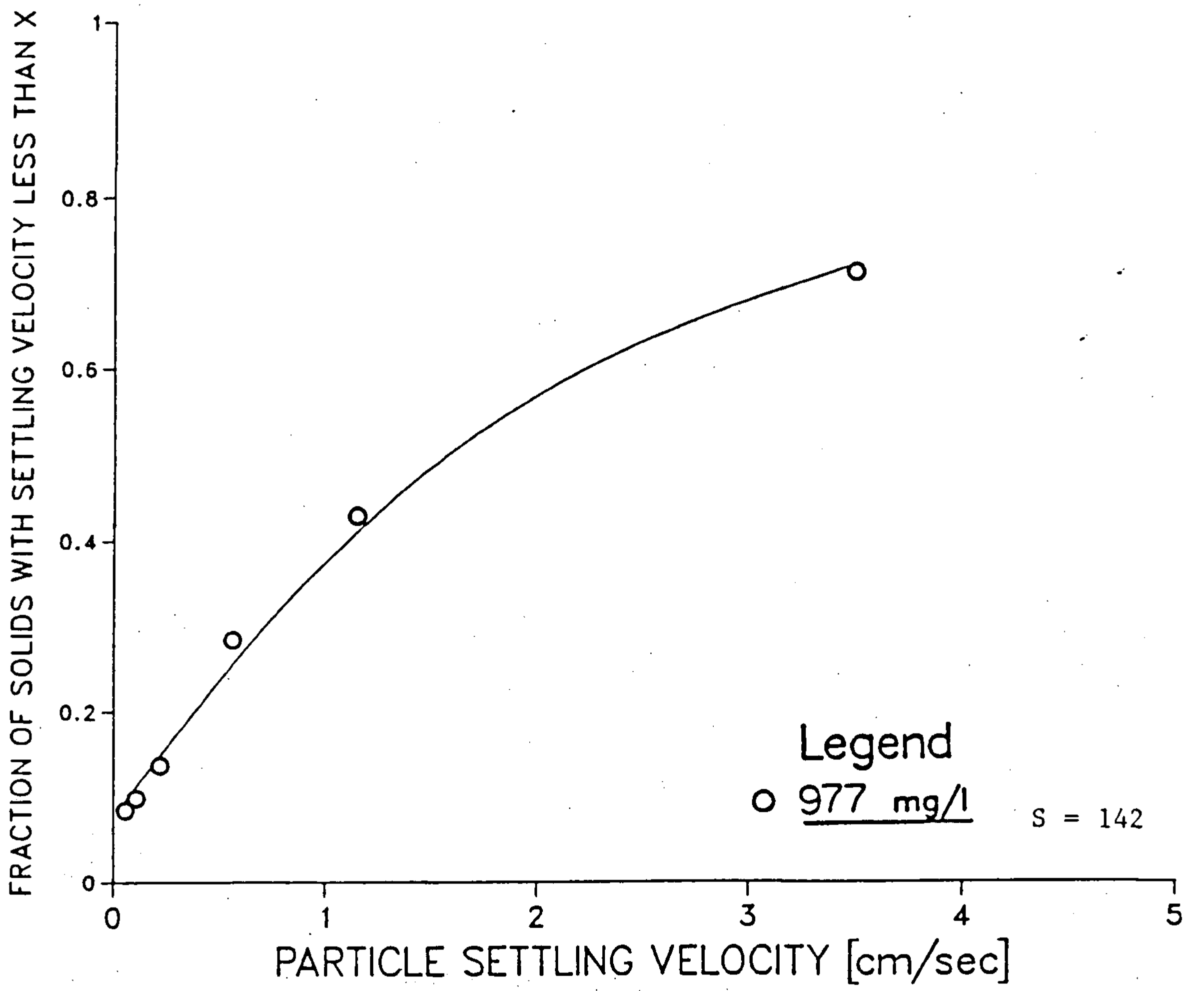


FIGURE 5.26 Individual particle settling velocity distribution curves for 311 gram Rainbow trout fed 3/16 OMP feed pellets
(Note: Legend indicates initial non-filterable residue concentrations)



Comparison of the settling curves within a feed pellet size and between feed pellet sizes should therefore identify any differences in the settling behavior of the wastes, related to fish size and feed pellet size respectively. However, the form of the non-filterable residue removal curve is not ideally suited to analysis. Statistical procedures for handling complex non-linear functions are often complicated and more difficult than for handling linear relationships. In some situations, however, it may be possible to transform the x, and/or y variables in such a way that the resulting function is close to being linear. A linear regression model can then be formulated in terms of the transformed variables, and the appropriate analysis can be based on the transformed data (Bhattacharyya & Johnson, 1977).

The data from the settling trials was therefore transformed in an effort to obtain an approximate linear function. Two transformations were tested; LogX,Y and X,X/Y, a linearization of the hyperbolic relationship

$$Y = (AX)/(B + X) \tag{5.1}$$

Where Y = percentage of non-filterable residue removed

X = residence time (minutes)

A,B = constants

Equation 5.1 is then linearized using the relationship

$$Z = b_o + b_1 X \tag{5.2}$$

Where $Z = X/Y$ (5.2.1)

$b_0 = B/A$ (5.2.2)

$b_1 = 1/A$ (5.2.3)

Both transformations produced linear regressions with high r^2 (Sample Coefficient of Determination) values, of 0.87 - 0.99 and 0.9996 - 1.0000 respectively. However, the use of the LogX,Y transformation to fit the severe curve in the data is only valid at short residence times. The relationship obtained in this transformation assumes that as the residence time increases, so will the level of solids removal. Removal rates of greater than 100% are thus possible at long residence times. This is clearly impossible. However, in the hyperbolic relationship, as the residence time increases the non-filterable residue removal curve increases to an asymptote or maximum level which is less than 100%. This more accurately represents the situation occurring in the level of removal of non-filterable residue as a function of time. The hyperbolic function and it's linearized transformation was subsequently selected for this study.

It is important to note that in cases where the range in Y values is small, the r^2 can be misleading. When Y is small, the transformation X/Y is similiar to dividing X by a constant (k). When X/k is plotted as a function of X it will naturally produce a perfect fit linear regression. Therefore the transformation should only be used when the variation in Y values is large. Within the data obtained in the settling trials, the level of removal (Y) varies from 24 - 93% during the 60 minute retention time (X). This should be sufficiently large to permit the use of the X,X/Y transformation. Appendix I summarizes the hyperbolic and the corresponding linear regression equations for each of the overall non-filterable residue removal curves illustrated in Figures 5.5

- 5.15.

Differences in the overall non-filterable residue removal curves could now be identified by comparing the linear regression equations for each X,X/Y transformed data group.

Regression equations may differ for two reasons; 1) they have different slopes, that is they are not parallel , or 2) if they are parallel, they may differ in level; that is their intercepts are not equal . Two hypothesis that must be considered and tested are therefore:

1) Slopes of linear functions are the same, slopes are parallel
2) Intercepts of linear functions are the same, intercepts are equal

One computer program suitable for performing these two tests is the Equality of Slope Test program S:SLTEST. SLTEST is a self-contained program, available through the public file S:SLTEST. A copy of the program description may be obtained through the computing center.

Simply, SLTEST computes the linear regression equation for each set of data and tests whether the differences in the regression coefficients between groups are due to sampling error, or may be attributed to differences between groups. The program uses the F-test to check the hypothesis that each regression coefficient is identical among all groups. Depending on the result of the F-test, the program will do one of two things:

1) If the hypothesis is rejected, that is, the regression coefficients are different, SLTEST will: a) find for each pair of equations the first regression coefficient in

which the above equations differ, or b) find, for each pair of equations, all the regression coefficients in which the above equations differ.

2) If the hypothesis is not rejected, SLTEST will test the hypothesis that a common equation can be used for all samples; that is, SLTEST will test if the intercepts with the y-axis are equal.

SLTEST was subsequently used to test for similarities in the regression coefficients and y-intercepts of the regression equations representing the overall non-filterable residue removal curves.

As part of the experimental design, each waste group, identified by a weight class and feed pellet size, was replicated. The replications of the settling trials were to be used as a check for uniformity and reproducibility of the Type II settling curves. However, due to the highly variable hydraulic conditions within the tank, the amount of accumulated solids present after 24 hours was never constant. The initial solids concentration in each settling trial was therefore different.

The degree of Type II or flocculant particle settling in a system, has been shown to be a function of the suspended solids concentration, the particle size distribution, the velocity gradient within the system, and the distance the particles are to settle. Changing the initial solids concentration, while maintaining the latter three factors constant, should therefore affect the level of Type II settling present and subsequently the rate of solids removal. We may therefore expect some differences in the rates of solids removal between replications with different initial solids concentrations.

Therefore, before comparisons could be made between waste groups it was first necessary to determine if variations in the initial non-filterable residue concentrations were significant. The first hypothesis to be tested therefore was: 1) a single regression equation can be used to represent the replicated settling curves in each group.

If the hypothesis is accepted, then the replicate curves in each group can be represented by a single equation. The variation observed in the solids removal curves within the group are therefore not significant. Analysis of the groups is simplified through the use of the single regression equation. However, if the hypothesis is rejected, indicating that the variability observed in the inital non-filterable residue concentrations is significant, then the analysis of the settling characteristics must also include the effects of concentration. Further analysis between groups would have to take initial solids concentration into consideration.

The linear regression equations summarized in Appendix I were subsequently compared using SLTEST at confidence levels of 0.05 and 0.01 (95% and 99%), to determine if the regression equations within each group could be pooled and represented by a single, common regression equation.

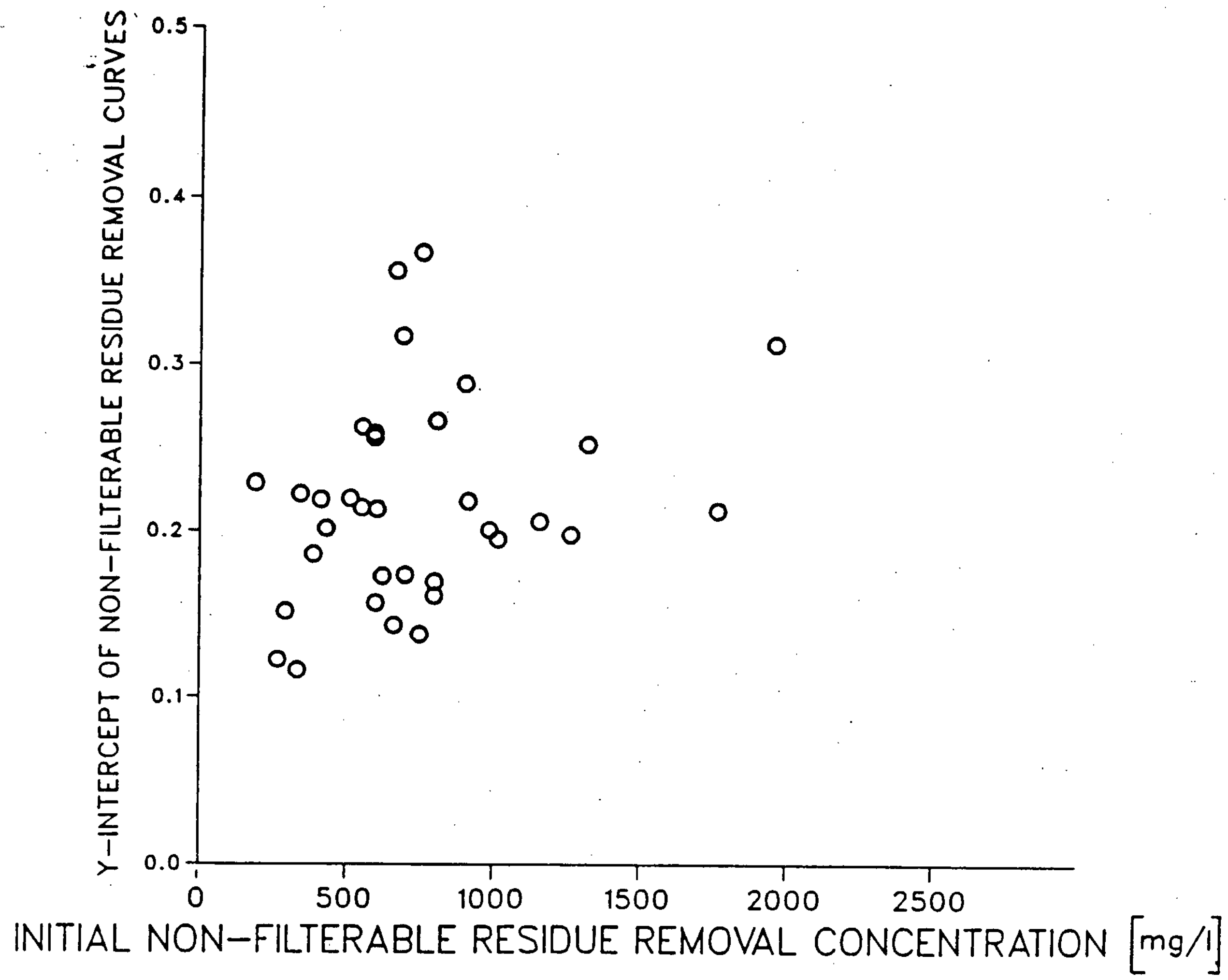
Results of SLTEST at both confidence levels indicated that a common slope of 0.011 was present in all groups. However, common regression equations for each group were not possible due to statistically significant variations in the y-intercepts (0.0116 - 0.0369).

A rejection of the hypothesis on this basis would appear to indicate that within the range of initial concentrations observed in the settling trials (179 - 1945 mg/l), varying the concentration did statistically affect the settling rate of the waste solids. This is not surprising given the influence of concentration on the degree of flocculant settling present in a suspension. At higher concentrations the opportunity for particle contact is greater. Large, high velocity particulates can collide and coalesce with smaller less settlable fractions, thereby facilitating their removal. The rate of removal of non-filterable residue would subsequently be higher in the beginning, declining over time as the concentration is reduced. A high correlation between the initial concentration and the level of the y-intercept might therefore be expected. However, when the y-intercepts and the initial concentrations are compared within waste groups and between groups (Figure 5.27), no correlation is evident ($r^2 = 0.077$). Results of the regression indicate approximately 8% of the variability in the y-intercepts is explained by the concentration effect.

The low correlation observed between the level of the y-intercept and the initial concentration may be an indication that; 1) the range of concentrations observed in the settling trials may be below the level at which Type II settling occurs, or 2) if Type II settling is occurring at higher concentrations, it's contribution to the overall rate of removal is insignificant. In either case it must be assumed that the variation observed in the initial concentrations are not responsible for the variations in the y-intercepts.

In comparing the replications within each waste group, it has been assumed that, given the feed pellet size and fish size were kept constant, wastes in each replication should also be relatively uniform. However, it is impossible to control the amount of fragmentation of faeces and unconsumed feed pellets resulting from repeated

FIGURE 5.27 Variability of the y-intercept of the linearized overall non-filterable residue removal curves as a function of the initial non-filterable residue concentration



resuspension and massication by fish. Some variation in the range of particle sizes might therefore be expected. This could account for variations observed in the y-intercepts. Wastes with a higher proportion of larger, faster settling particulates would show a high level of removal within the early stages of settling, compared to a waste with a lower proportion of the same size particles. However, the presence of a common slope within the settling trials indicates there is a similarity in the settling pattern of the waste solids. Given the assumption that the waste solids are behaving as discrete entities, the proportional distribution of particle sizes and their respective settling velocities should therefore be similar.

One method of determining the validity of this assumption is to test the regression equations of the individual particle settling velocity distribution curves for a common regression equation.

The individual particle settling velocity distribution curves were subsequently linearized using the relationship in equations 5.1 - 5.2.3 and compared using SLTEST. Results of SLTEST at a confidence level of 0.01 indicated that the pooled regressions can be represented by a single, common equation (Equation 5.3).

$$Y = 92.59X/(2.01 + X) \qquad (5.3)$$

Where X = settling velocity of particles (cm/sec)

Y = fraction of particles with settling velocities less than X

The proportional distribution of particle sizes within waste groups and between waste groups must therefore be considered identical.

Analysis of the linearized overall non-filterable residue removal curves and the subsequent determination of the source of the variations in the y-intercepts, has been based on the premise that the difference in the y-intercepts is significant. It was therefore concluded that the settling characteristics of the wastes must also be significantly different. However, the submission of a common regression equation, characterizing the pooled linearized individual particle settling velocity distribution curves, indicates that the proportional distribution of particle sizes within the wastes is identical. It should therefore be assumed that if all extraneous factors such as turbulence , short circuiting and upwelling within the column are kept constant, wastes from different size fish or different size feed pellets should behave in a similar manner. The variability observed within the y-intercepts must therefore be considered the result of factors outside of those controlled in the settling trials.

Evaluation of the results of the SLTEST has also been based on the premise that given no common regression equation is possible due to statistically significant variations in the y-intercepts, that these variations should be considered important when designing a sedimentation basin. The variations observed in the settling behavior of the waste solids might be considered significant, assuming a clarifier could be ideally designed with no turbulence or short circuiting. However, given the nature of the design process in which the settling curves are to be used, and the general inclusion of a large safety factor (Warrer-Hansen, 1982), any differences observed between the settling curves could be ignored for design purposes. It may therefore be assumed that within the retention time (24 hours), fish sizes (11g-311g), feed type (OMP), and feed pellet sizes (3/32–3/16) used, there is no significant difference in the settling behavior of the waste solids produced.

A single curve can therefore be used to characterize the settling behavior of the waste solids produced in the study. The individual non-filterable residue removal percentiles and individual particle settling velocity distribution fractions were subsequently pooled in order to produce the single overall non-filterable residue removal curve (Figure 5.28) and the individual particle settling velocity distribution curve (Figure 5.29).

Analysis of Figure 5.28 shows that a residence time of 10–15 minutes is sufficient to reduce the non-filterable residue by 82%. However, the curve also shows that holding the effluent longer than 15 minutes, does not provide any appreciable increase in solids removal. Increasing the residence time to 30 minutes, effectively doubling the retention time, only increased the level of solids removal an additional 4 %. While holding the effluent for 60 minutes produced a total increase of only 7%. Therefore, selecting a retention time greater than 15 minutes does not effectively increase the level of solids removal. Selecting a retention time greater than 15 minutes also increases, unnecessarily the size of the system, and consequently, the cost.

In a summary of capital, operating and maintenance costs as a function of surface area (Figure 5.30), Underwood McLellan (1979) show that for small sedimentation basins (<1000 m^2), these three costs increase linearly with increasing surface area. However, as the surface area of the sedimentation basin increases (>1000 m^2), capital, operating and maintenance costs begin to increase at a faster rate. It is therefore desirable to select a residence time which minimizes the size of the treatment system,

FIGURE 5.28 Overall non-filterable residue removal curve for Rainbow trout fed an Oregon Moist Pellet diet

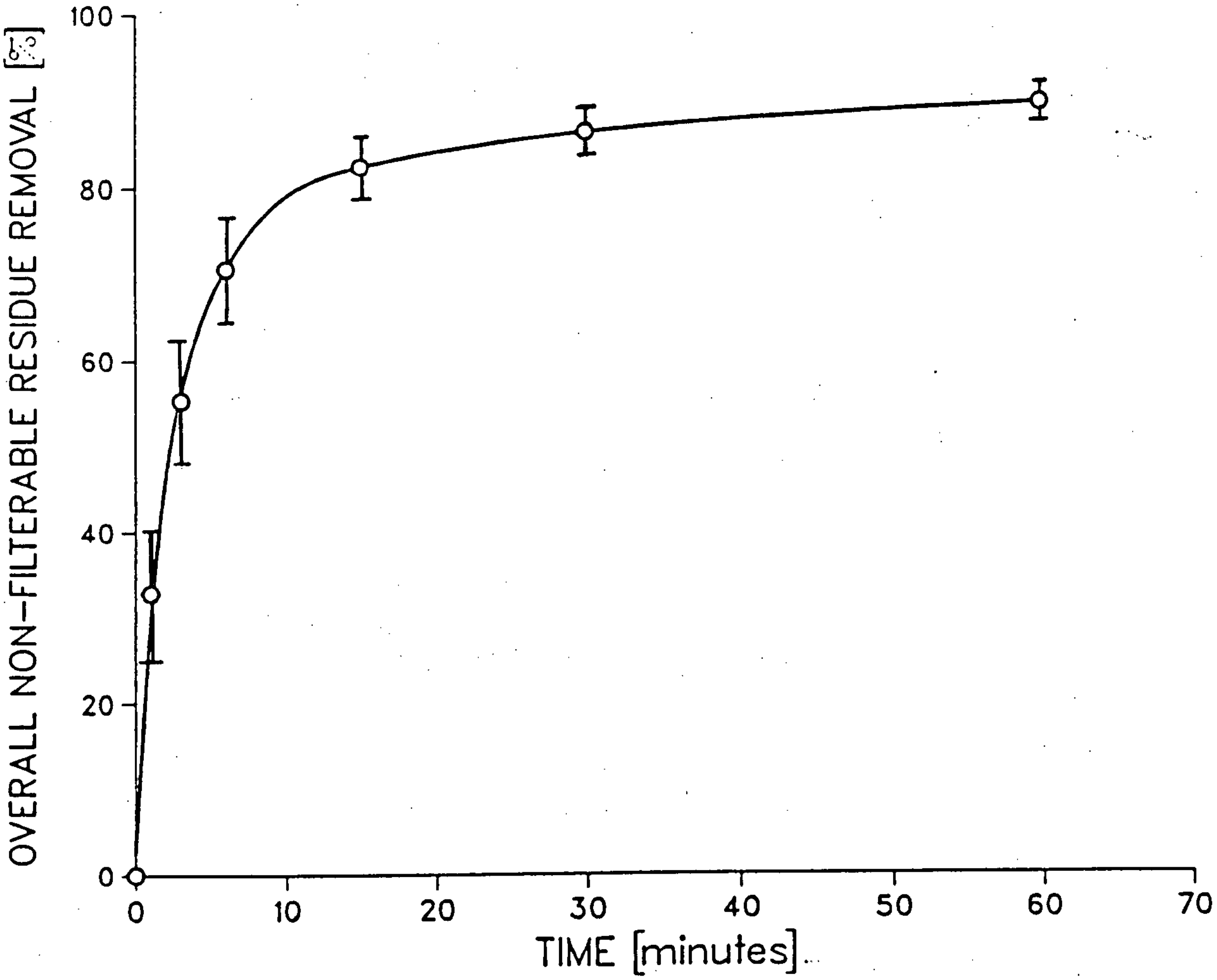


FIGURE 5.29 Individual particle settling velocity distribution curve for Rainbow trout fed an Oregon Moist Pellet diet

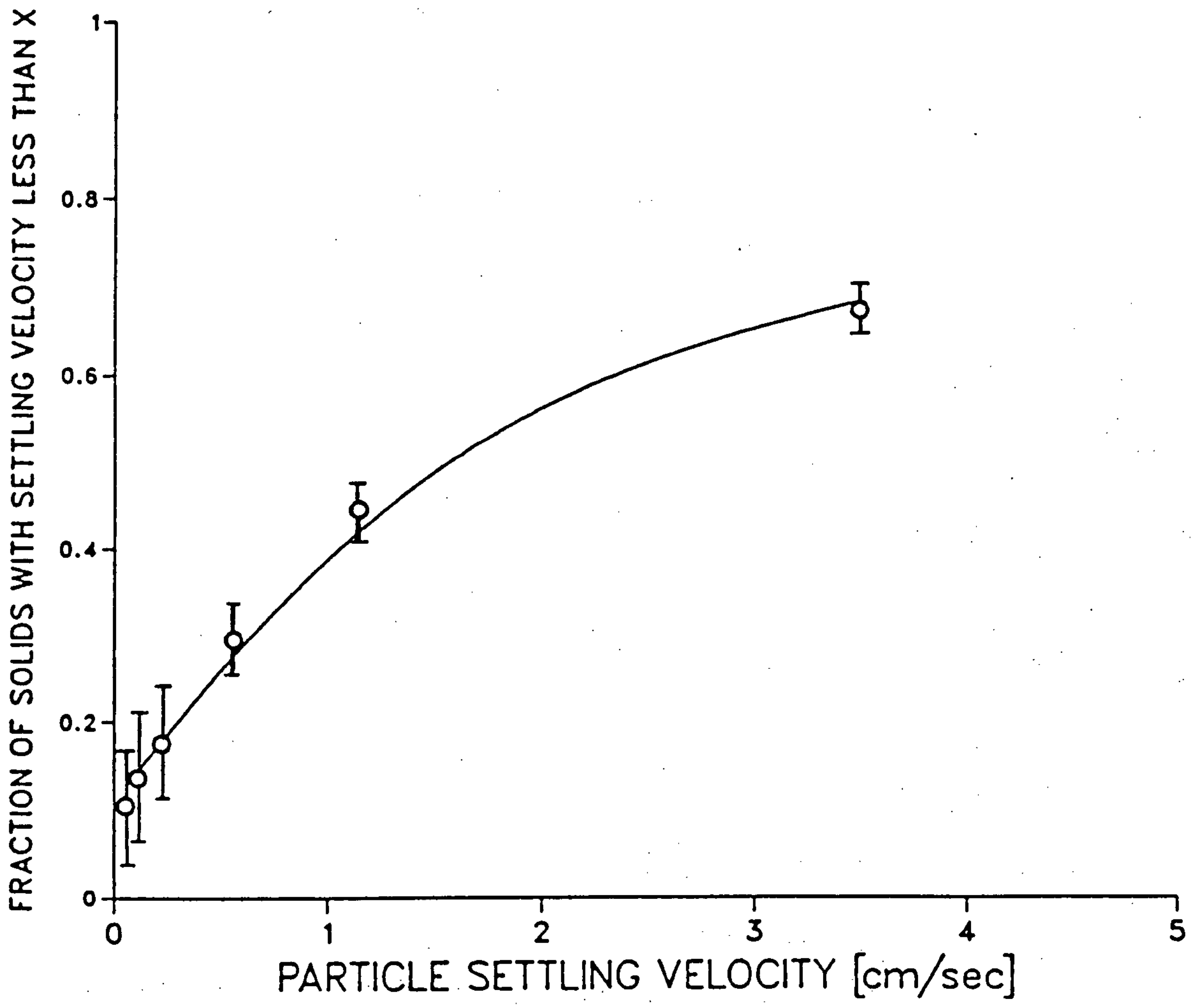
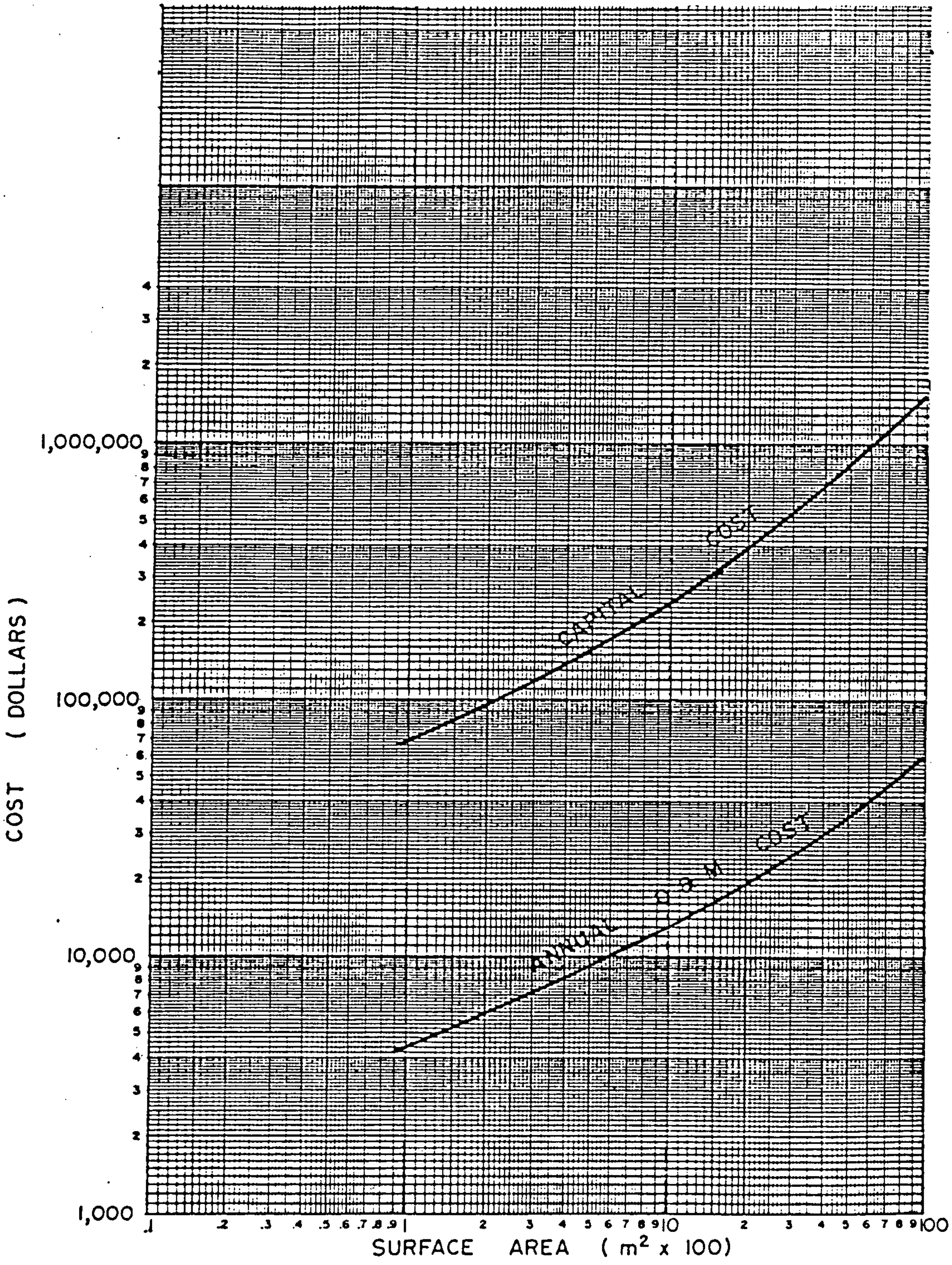


FIGURE 5.30 Summary of capital, operating and maintenance costs for a sedimentation basin as a function of surface area (Underwood McLellan, 1979)



while still achieving the desired level of solids removal.

Holding the effluent in contact with the settled solids for long periods is also undesirable as decomposition and leaching of the organic solids reduces the level of dissolved oxygen (O_2) and increases the level of dissolved nutrients in the clarified effluent.

Figure 5.28, illustrating the distribution of individual particle settling velocities within the waste solids, shows the solids particulates settled at significantly higher rates than reported by Walden & Birkbeck (1977) or Stechey (1986). Walden & Birkbeck (1977) report that the waste solids exhibited two main settling fractions. Over 50% of the solids settled faster than 0.2 cm/sec, while 40% had settling rates faster than 0.51 cm/sec. Using these velocities for comparison, the waste solids generated from feeding the Oregon Moist Pellet ® feed, showed over 80% of the solids had settling rates faster than 0.2 cm/sec, while 72% had settling rates faster than 0.51 cm/sec.

The purpose of this study was; 1) to characterize the settling behavior of waste solids from a trout culture unit as a function of fish size and feed pellet size, and 2) relate the results to current gravity solids separation system design proceedures.

Using the overall non-filterable residue removal curves, and individual particle settling velocity distribution curves, it was possible to show that solid wastes retained for 24 hours exhibited uniform settling behavior. Differences in settling rates of fresh excreta, reported as a function of fish size (Wheaton, 1977; Warrer-Hansen, 1979) or pellet size (Walden & Birkbeck, 1974) were negated by physical and chemical processes occurring in the holding tank.

The curves produced in this study provide the basis for the selection of a suitable retention time and depth for a gravity solids separation system to treat the cleaning flows from a fish farm or hatchery employing a 24 hour cleaning cycle.

Appendix II summarizes the use of the overall non-filterable residue removal curve and individual particle settling velocity distribution curve for sizing a gravity solids separation system for a fish farm producing 50–75 tonnes of fish a year, utilizing approximately 500 liters of water per second.

6. CONCLUSION

The findings of this study can be summarized as follows: Flocculant particle or Type II settling curves were used to derive the overall non-filterable residue removal and individual particle settling velocity distribution curves for Rainbow Trout (*Salmo gairdneri*) culture cleaning wastes. Analysis of the curves using the Equality of Slope Test (S:SLTEST), showed that there was no significant difference in the settling behavior of the particulate solids when wastes from different size fish or different size feed pellets were compared. A single curve was therefore used to characterize each of the non-filterable residue removal curves (Figure 5.28) and individual particle settling velocity distribution curves (figure 5.29) derived in the study.

The overall non-filterable residue removal curve showed that the bulk of the waste solids removal (>80%) occurs within the first 15 minutes of settling. Holding the waste longer than 15 minutes did not contribute significantly to the overall level of solids removal.

The individual particle settling velocity distribution curve showed the solids produced in the study using the Oregon Moist Pellet ® feed settled at a faster rate than reported in the literature for non-fresh excreta, but slower than for fresh excreta.

Differences due to fish size and feed pellet size in the settling behavior of the waste solids, reported in the literature, were not apparent when the waste solids were retained within the culture tank for 24 hours.

7. RECOMMENDATIONS FOR FUTURE WORK

7.1. RESIDENCE TIME

Muir (1978) and Warrer-Hansen (1979;1982) have shown that the length of time the waste solids are retained within the culture unit can significantly reduce the settleability of those solids. In our study, we selected a retention time of 24 hours as being fairly representative of the length of time waste solids would be retained in a commercial fish farm or government hatchery employing a daily cleaning schedule of the ponds or raceways. The overall solids removal and individual particle settling velocity distributions were subsequently higher than generally reported in the literature where longer retention times are involved. One area for further work would therefore be to quantify the effects of retention time on the settleability of waste solids. The results to be used as a management tool in scheduling tank cleaning intervals for optimum solids removal efficiency within the gravity solids separation system.

A further area of research associated with residence time, is the amount of physical shearing, hydration and resuspension of the waste solids within the culture units. These parameters all act to reduce the particle size and density of the waste solids. However, the magnitude of these processes will be a function of the flow rate, hydraulic characteristics of the tank and the stocking density, all of which are site specific.

The waste solids collected in our study were subjected to physical agitation and resuspension as a result of the high stocking densities used in the small 200 litre tanks. However, it is difficult to judge if these conditions would be comparable to those found in the larger production units. In some raceways and circular ponds, dead zones provide a collection point for waste solids, which may then undergo little physical shearing. While some solids may be subjected to extreme physical agitation as the effluent cascades from one raceway to another, or is circulated by a mechanical aeration unit. Given that these are all site specific factors, one recommendation is to compile a series of settling curves for a variety of farms and hatcheries, to determine if the waste solids can be characterized by the holding system used (eg. raceway, Burrows pond, circular pond etc.).

7.2. FEED TYPE

This research has shown that the waste solids produced from Rainbow trout fed the Oregon Moist Pellet ® diet, settle at a higher rate than reported in the literature for dry pellet feeds (Walden & Birkbeck, 1974; Stechey, 1986).

An attempt was made to compare the OMP feed with a dry pellet feed (Purina Trout Chow ®). However, the hydraulic conditions within the holding tank units used, were not suitable and very little waste solids were retained. It is therefore recommended that a different holding tank be used which will retain the solid wastes, or use cleaning wastes from farms or hatcheries using the dry feed, in the settling trials.

Similiar settling trials could also be carried out on other pellet feeds such as EWOS ®, Rangen ®, and BIO-Dyne ®. Other feed types which might be investigated are trash fish, and the wet feeds which are produced on site at the farms, now being used extensively in the salmon farming industry.

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APPENDIX I

TABLE V SLTEST generated regression equations for overall non-filterable residue removal curves (Figures 5.5 - 5.15)

Group #	Fish Size*	Feed Pellet Size (inch)	Non-Filterable Residue (conc)**	Linear Transformation	Hyperbolic Equation
1	11.0	3/32	651	Y=0.036 + 0.011X	Y=89.3X/(3.19+X)
			542	Y=0.026 + 0.011X	Y=89.6X/(2.35+X)
2	17.0	3/32	738	Y=0.037 + 0.011X	Y=92.7X/(3.41+X)
			584	Y=0.026 + 0.011X	Y=90.8X/(2.33+X)
			402	Y=0.022 + 0.011X	Y=88.8X/(1.95+X)
3	21.0	3/32	1007	Y=0.020 + 0.011X	Y=90.7X/(1.78+X)
			676	Y=0.032 + 0.011X	Y=93.6X/(2.98+X)
			179	Y=0.023 + 0.011X	Y=88.6X/(2.03+X)
4	21.0	1/8	903	Y=0.022 + 0.011X	Y=88.3X/(1.93+X)
			794	Y=0.027 + 0.011X	Y=93.5X/(2.49+X)
			584	Y=0.026 + 0.011X	Y=94.6X/(2.45+X)
5	41.0	1/8	1755	Y=0.021 + 0.011X	Y=95.1X/(2.03+X)
			1148	Y=0.021 + 0.011X	Y=93.7X/(1.94+X)
			422	Y=0.020 + 0.011X	Y=94.3X/(1.91+X)
			329	Y=0.012 + 0.011X	Y=90.9X/(1.06+X)
6	54.0	1/8	1945	Y=0.031 + 0.011X	Y=92.9X/(2.92+X)
			1308	Y=0.025 + 0.011X	Y=95.0X/(2.4 +X)
			616	Y=0.017 + 0.011X	Y=96.2X/(1.67+X)

* Fish size in grams

** Initial non-filterable residue concentration in mg/litre

X = Residence time (minutes)

Y = Non-filterable residue removed at residence time X (%)

TABLE V (cont.) SLTEST generated regression equations for overall non-filterable residue removal curves (Figures 5.5 - 5.15)

Group #	Fish Size*	Feed Pellet Size (inch)	Non-Filterable Residue (conc)**	Linear Transformation	Hyperbolic Equation
7	54.0	5/32	792	Y=0.016 + 0.011X	Y=94.2X/(1.53+X)
			744	Y=0.014 + 0.011X	Y=93.6X/(1.30+X)
			595	Y=0.021 + 0.011X	Y=91.7X/(1.96+X)
			262	Y=0.012 + 0.011X	Y=93.2X/(1.14+X)
8	73.0	5/32	792	Y=0.017 + 0.011X	Y=94.9X/(1.62+X)
			693	Y=0.017 + 0.011X	Y=95.9X/(1.67+X)
			657	Y=0.014 + 0.011X	Y=93.0X/(1.34+X)
			543	Y=0.021 + 0.011X	Y=91.4X/(1.96+X)
9	93.0	5/32	594	Y=0.016 + 0.011X	Y=92.9X/(1.46+X)
			503	Y=0.022 + 0.011X	Y=94.3X/(2.07+X)
			397	Y=0.019 + 0.011X	Y=94.0X/(1.75+X)
			332	Y=0.022 + 0.011X	Y=91.2X/(2.03+X)
10	89.0	3/16	1254	Y=0.020 + 0.011X	Y=94.1X/(1.87+X)
			889	Y=0.029 + 0.011X	Y=94.9X/(2.75+X)
			286	Y=0.015 + 0.011X	Y=93.9X/(1.43+X)
11	311.0	3/16	977	Y=0.020 + 0.011X	Y=94.8X/(1.91+X)

* Fish size in grams

** Initial non-filterable residue concentration in mg/litre

X = Residence time (minutes)

Y = Non-filterable residue removed at residence time X (%)

APPENDIX II

Figures 5.28 (overall non-filterable residue removal curve) and 5.29 (individual particle settling velocity distribution curve) can be used to estimate the overflow rate (m^3/m^2/hour) and residence time for various per cent solids removal.

In the example to be discussed, a fish farm producing 50–75 tonnes per year uses an estimated 500 l/sec or 1800 m^3/hour. From the observations and discussions of the overall non-filterable residue removal curve (Figure 5.28) it was concluded that holding the effluent longer than 15 minutes did not effectively contribute to the overall level of solids removal. Therefore, assuming a maximum residence time of 15 minutes will provide for 82% removal of the non-filterable solids.

An overflow rate or surface loading rate can thus be obtained by selecting a suitable settling velocity (V_o) from the individual particle settling velocity distribution curve (Figure 5.29) such that 82% of the solid particulates will be removed. From Figure 5.29 it can be observed that 82% of the particles have settling velocities greater than 0.2 cm/sec (7.2 m/hour).

From the discussion of Equations 3.1 and 3.2 it was shown that the settling velocity is the equivalent of the overflow rate or surface loading rate. A settling velocity of 7.2 m/hour is therefore the equivalent of a loading rate of 7.2 m^3/m^2/hour. Introducing a safety factor of 1.5 to reduce turbulence (Warrer-Hansen, 1982), yields a surface loading rate of 5 m^3/m^2/hour.

Given the water consumption of the farm is 1800 m^3/hour, the necessary basin area will be:

$$\text{Surface area of clarifier} = \frac{\text{Flow rate}}{\text{Overflow rate}}$$

$$= \frac{1800\ m^3/hour}{5\ m^3/m^2/hour} = 360\ m^2$$

Therefore, a farm utilizing 1800 m^3/hour, requiring 82% of non-filterable solids removal, will require a sedimentation basin with a depth of 1.25 m and a surface area of 360 m^2. A width of 10–20 meters will maintain the water velocity in the settling zone within the 2–4 cm/sec maximum velocity suggested to prevent scouring and resuspension of the already settled solids (Warrer-Hansen, 1982).