Piggery Wastewater Characteristics Associated with Particle Size and Settling Time.

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Abstract

Solid-liquid separation is used widely as a waste treatment process. A wide range of solid-liquid separators have been applied to agriculture overseas, but their application in New Zealand has been limited.

This study has determined levels of pollution parameters associated with particle size and settling time for wastewater from a New Zealand piggery. This information has been used to compare the effectiveness of sieving and settling on separating solids from piggery wastewaters.

It was found that a high proportion (75-90 %) of COD, TS, VS and TP were associated with filtrable solids, and therefore indicate that some form of solid-liquid separation can remove high levels of these parameters. Only low levels of TKN were associated with filtrable solids so their removal by solid-liquid separation is limited.

The study revealed that removal of particles in the 500-2000 um range will not remove high levels of COD, TS, VS, TP or TKN and to to remove substantial levels of the first four parameters, particles less than 500 um need to be removed.

Settling tests demonstrated that high levels of COD, TS and VS were removed in a short time period (5 minutes), and that substantial levels of all parameters were settled in longer time periods.

Comparison of the two trials reveals that very small aperture

sieves would be required to achieve a similar removal of all parameters, compared with a five minute sedimentation period. Sedimentation appears to be an effective waste treatment option for piggery wastewater. Further research is required to quantify performance in the field and find practical methods of disposal or utilization for the separated sediment.

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Table of Contents

Chapter		Page
1.	INTRODUCTION	1
	1.1 Agricultural Wastes	1
	1.2 Agricultural Pollution in New Zealand	2
	1.3 Solid-Liquid Separation in Agriculture	6
	1.4 Statement of Problem	8
2.	LITERATURE REVIEW	10
	2.1 Characteristics of Pig Manure	10
	2.11 General Characteristics	10
	2.12 Particle Size Distribution	12
	2.2 Solid-Liquid Separation	15
	2.21 Solid-Liquid Separation Systems	15
	2.22 Processes/Principles Used for Solid-Liquid Separation	15
	2.221 Solid-Liquid Separation by Density Difference	16
	2.222 Solid-Liquid Separation by Containment on a Medium	17
	2.3 Performance of Solid-Liquid Separators	20
	2.31 Screens and Filters	21
	2.311 Stationary Units	21

2.312 Rotating Screens 23

2.313 Vibrating Screens 25

2.314 Multistage Devices 29

2.315 Filtration 30

2.4 Sedimentation 32

2.41 Sedimentation Systems 34

2.42 Sedimentation Research 34

2.5 Fate of Separated Components 37

2.51 Separated Components 37

2.6 Summary and Conclusions 43

3. OBJECTIVES OF THE STUDY 45

3.1 Objectives 45

3.2 Scope of Study 46

4. METHOD AND MATERIALS 47

4.1 Introduction 47

4.2 Experimental Design 48

4.21 Sieving Trial 48

4.22 Settling Trial 49

4.3 Sample Collection 51

4.4 Analytical Techniques 52

5. RESULTS AND DISCUSSION 56

5.1 Characteristics of Collected Wastewater Samples 56

5.2 General Trial Results 57

5.21 Sieving Trial 57

5.22 Settling Trial 66
5.23 Comparison of Sieving Versus Settling as a Method of Piggery Waste Treatment 74
5.3 Correlation Between Specific Parameters 78
5.31 BOD versus COD Correlation 78
5.32 COD versus VS/TS Correlation 79
5.4 Effect of total solids concentration on Solid-Liquid Separation 81
5.5 Comparison of Results with Other Research 86
5.51 Sample Variation 86
5.52 Particle Size Distribution and Settling 86
5.6 Design from Data 89

6. SUMMARY AND CONCLUSIONS 91

7. RECOMMENDATIONS FOR FURTHER RESEARCH 94

APPENDICES: 95
I Management Systems at the Pork Industry Board Piggery, Old West Road, Palmerston North 95
II Data Manipulation Methods 97
III (a) Two-way Analysis of Variance for Sieve Apertures of 500-2000 um 100
(b) Two-way Analysis of Variance for Sieve Apertures of 500-2000 um (interaction excluded) 102

(c) One-way Analysis of Variance and 95 % Confidence Intervals for each Parameter 104

IV One-way Analysis of Variance and 95 % Confidence Intervals for Sieving and Settling Sample Total Solids Concentration 106

REFERENCES 107

List of Tables

	Page
1.1 Summary of Point Source Discharges to New Zealand Rivers in 1984	5
1.2 Relative Concentrations of Various Wastewaters	6
2.1 Freshly Voided Pig Manure Characteristics	11
2.2 Characteristics of Piggery Wastewaters	12
2.3 Summary of Performance of Stationary Screens	22
2.4 Summary of Performance of Rotating Screens	24
2.5 Summary of Performance of Vibrating Screens	27
2.6 Summary of Performance of Filtration Devices	31
2.7 Summary of Swine Sedimentation Research	36
5.1 Mean Wastewater Characteristics	56
5.2 Regression of Percent Removal of Wastewater Parameters versus Aperture Size	63
5.3 Mean Percent Removal of Each Parameter Sieving (500 um - 2000 um)	64
5.4 Regression of Percentage Removal of Wastewater Parameters versus Log of Time	72
5.5 Parameter Removal Rate: Percent per Minute Over Time Period Shown	73
5.6 Settling Time Compared with Sieve Aperture, Total Solids	75
5.7 Settling Time Compared with Sieve Aperture, Volatile Solids	75

5.8 Settling Time Compared with Sieve Aperture,
Chemical Oxygen Demand 76
5.9 Settling Time Compared with Sieve Aperture,
Total Kjeldahl Nitrogen 76
5.10 Settling Time Compared with Sieve Aperture,
Total Phosphorus 77
5.11 Correlation of BOD versus COD 78
5.12 Correlation of COD versus VS 80
5.13 Correlation of COD versus TS 80
5.14 Regression of Individual Samples for Sieving
Trial 82
5.15 Regression of Individual Samples for Settling
Trial 82
AIII.a Two-way Analysis of Variance, COD 100
AIII.a Two-way Analysis of Variance, TS 100
AIII.a Two-way Analysis of Variance, VS 100
AIII.a Two-way Analysis of Variance, TP 101
AIII.a Two-way Analysis of Variance, TKN 101
AIII.b Two-way Analysis of Variance, COD 102
AIII.b Two-way Analysis of Variance, TS 102
AIII.b Two-way Analysis of Variance, VS 102
AIII.b Two-way Analysis of Variance, TKN 103
AIII.b Two-way Analysis of Variance, TP 103
AIII.c One-way Analysis of Variance and 95 % CI,
COD 104
AIII.c One-way Analysis of Variance and 95 % CI, TS 105
AIII.c One-way Analysis of Variance and 95 % CI, VS 104
AIII.c One-way Analysis of Variance and 95 % CI,

TKN 105
AIII.c One-way Analysis of Variance and 95 % CI, TP 105
AIV.1 One-way Analysis of Variance and 95 % CI,
TS Sieving 106
AIV.2 One-way Analysis of Variance and 95 % CI,
TS Settling 106

List of Figures

	Page
2.1 Particle Size Distribution of Swine Wastewater	13
2.2 Schematic Diagram of Hydrocyclone	18
2.3 Schematic Diagram of Settling Regions	33
4.1 Schematic Diagram of Settling Cylinder	50
5.1 Sieve Performance, Percent Removal TS	58
5.2 Sieve Performance, Percent Removal VS	59
5.3 Sieve Performance, Percent Removal COD	60
5.4 Sieve Performance, Percent Removal TKN	61
5.5 Sieve Performance, Percent Removal TP	62
5.6 Settling Performance, Percent Removal TS	67
5.7 Settling Performance, Percent Removal VS	68
5.8 Settling Performance, Percent Removal COD	69
5.9 Settling Performance, Percent Removal TKN	70
5.10 Settling Performance, Percent Removal TP	71
5.11 TS Concentration versus Removal Rate (sieving)	83
5.12 TS Concentration versus Removal Rate (settling)	84
AII.1 Percentage Removal of TS, Time versus Column Height	99

Abbreviations

BOD = Biochemical Oxygen Demand

CI = Confidence Interval

COD = Chemical Oxygen Demand

CH = Methane

C:N Ratio = Carbon: Nitrogen Ratio

Cu = copper

DDT = 1,1-bis(p-chlorophenyl)-2,2,2-trichloroethene

DO = Dissolved Oxygen

DM = Dry Matter

Ha = Hectare

kg = kilogramme

l = litre

log = logarithm base 10

ln = natural logarithm

ml = millilitre

mg = milligramme

MJ = Megajoule

mm = millimetre

NPS = non-point source

PE = population equivalent

ppm = parts per million

PS = point source

t = tonne

TKN = Total Kjeldahl Nitrogen

TP = Total Phosphorus

TS = Total Solids

um = micrometre (micron)

VS = Volatile Solids

1. Introduction

1.1 Agricultural Wastes.

The constituents of agricultural wastes which can affect water quality include organic matter, nutrients, suspended solids, toxic substances, waste heat and pathogens (Hickey and Rutherford,1986). Several problems are associated with these constituents. Organic matter stimulates microbial respiration, and may cause deoxygenation (which affects aquatic insects and fish), and it may cause the growth of sewage fungus (which can aggravate dissolved oxygen (DO) depletion and can smother benthic invertebrate habitats) (Hickey and Rutherford, 1986). Nutrients, especially nitrogen and phosphorus, can increase the growth rate and the biomass of aquatic plants. These plants can clog channels, and cause aesthetic problems and diurnal DO variation (Hickey and Rutherford, 1986). Suspended solids can reduce the aesthetic water quality and light infiltration, as well as blocking water channels, possibly smothering benthic invertebrate habitats (McColl,1982). Toxic substances can cause disturbed function and possibly death in plants and animals (Hellawell, 1986). In addition some potentially toxic substances such as DDT and mercury can be accumulated to toxic levels. Heat can reduce the DO levels of fresh waters by raising the temperature and increasing the rate of biochemical reactions (some of which require oxygen), and reducing the level of oxygen held in a saturated solution. The discharge of pathogens into water cause problems of possible disease in other organisms and so restrict further use of that water.

The main methods used in agriculture to measure the physical, chemical and biological characteristics of wastewaters are:

(a) Solids, these can be total solids or any fraction of interest such as suspended or volatile solids.

(b) Turbidity and colour, which can relate to the solids concentration in waters, and may impart undesirable visual effects on receiving waters.

(c) Chemical characteristics are broken into inorganic and organic constituents. Biochemical and chemical oxygen demand (BOD, COD) are the two most commonly used measures of organic contamination.

(d) Biological characteristics of waste waters can include the estimation of numbers of any living organisms. Estimating the presence of a specific pathogen can be difficult and so the more simple measure of faecal coliforms is used to predict the possibility of the presence of pathogenic organisims.

The range of tests used to assess the characteristics of agricultural wastewater will vary depending upon the specific waste and the methods of treatment and disposal.

1.2 Agricultural Pollution in New Zealand.

In New Zealand, agricultural point source waste discharges contribute significantly to total point source discharges to fresh waters, (Dakers and Painter, 1982; Ferrier and Marks, 1982; Hickey and Rutherford, 1986). Agricultural point source discharges emanate mainly from cowsheds and piggeries. Estimates by Hickey and Rutherford (1986) state that agricultural point source discharges to fresh waters total 0.7-2.0 million population equivalents (P.E.) (see table 1.1) compared with 0.2 - 0.7 million P.E. for sewage discharge. It would appear that although sewage waste accounts for the greatest potential organic and nutrient load (nitrogen and phosphorus), its effect on natural waters is minimised for the following reasons: (a) the number of sewage systems discharging to fresh waters is only about 49% of total discharges (Hickey and Rutherford, 1986), and (b) that in 1986 all communities with populations greater than 1000 persons operated satisfactory sewage disposal systems (Fitzmaurice, 1987). In addition Hickey and Rutherford, (1986) stated that although the meat and dairy processing industries potentially produce large volumes of waste, modernisation programmes have resulted in fewer, larger factories, which have improved waste treatment facilities.

It would appear from the research of Hickey and Rutherford, (1986) that the treatment of agricultural point source discharges has the ability to significantly reduce the levels of potentially polluting discharges to rivers. In fact, it would appear that the level of pollution caused by the discharges from cowsheds and piggeries may be greater than that estimated previously by Hickey and Rutherford (1986), as Wilcock (1986) emphasised that small point source discharges such as from piggeries and dairies are often difficult to identify, and may be included as non-point source (NPS) in estimates of loads to receiving waters.

Table 1.1 shows that even though there is significantly more cowsheds than piggeries discharging wastes to rivers in New Zealand (7850 cf. 220 respectively), piggeries are still discharging 25%, 36%, and 44% of the total BOD, N and P load attributable to PS discharges, respectively. This point was supported by Dakers and Painter (1982), and would indicate that a greater reduction in polluting load from agricultural PS discharges could more easily be achieved by improving piggery waste treatment methods than dairy waste treatment methods. Since implementation of improved waste treatment would be required on much fewer properties. In addition the conclusions reached by Hickey and Rutherford,(1986) do not highlight the fact that piggery wastes are more concentrated than cowshed wastes, and that agricultural wastes are more concentrated than municipal wastes (Moore et al, 1975). Although the concentration of flushed cowshed and piggery wastes, and domestic wastes vary considerably the following information in table 1.2 (Tchobanoglous and Schroeder, 1985; Vanderholm et al, 1984) indicates the relative concentrations of each.

Table 1.1

Summary of Point Source Discharges to New Zealand Rivers in 1984.

(Hickey and Rutherford, 1986).

	Total Produced[1]				Discharged to Rivers			
	No.	BOD	N	P	No.	BOD	N	P
Sewage	197[2]	4	4	4	96[2]	0.2	0.6	0.7
Cowsheds	14317	1.8	1.7	1.6	~7850	0.6	0.7	1.0
Dairy Factories	50	2	0.4	0.7	23	0.3	0.1	0.2
Meatworks	39	3[3]	2[3]	1.3[3]	18	0.7	0.6	0.6
Pulp and Paper	7	0.7	0.4	0.3	6	0.3	0.2	0.1
Piggeries	503	0.6	0.9	1.8	~220	0.2	0.4	0.8

Notes: [1]BOD, N and P figures are population equivalents x 1/1000000, where 1 PE= 77g (BOD)/Cap/day, 11g(N)/cap/day and 1.8g (P)/cap/day.

[2]Populations greater than 1000, include some industry.

[3]After primary treatment.

Table 1.2

Relative Concentrations of Various Wastewaters.

	Cowshed(flushed)	Piggery(flushed)	[1]Domestic
BOD average	1500 mg/l	------	272.5 mg/l
range	1000-4500	2880-12,800	-----
COD average	6600	------	443
range	5000-11,000	7000-32,800	-----
Total N average	208	1738	42
range	100-325	1075-2500	-----
Total P average	35.2	537	11.4
range	10-?	109-950	-----

[1]These figures are averages of four indusrialized countries, not including New Zealand (USA, UK, Japan and F.R.of Germany)

1.3 Solid-Liquid Separation in Agriculture.

Solid-liquid separation may be practiced for three main reasons:

(a)to reduce total solids which may cause blockages in pumps, pipes and waste reticulation components,

(b)to reduce the organic load on subsequent waste treatment processes,and

(c)to concentrate or recover waste components for further digestion or utilization.

Solid liquid separation is a common primary treatment process used to reduce total solids and organic loading on secondary municipal and industrial wastewater treatment systems in New Zealand (Ferrier and Marks, 1982; Moore el al, 1975). Although it is not widely practiced in pig farming, where it is applied separation is more commonly achieved with large aperture wedgewire screens (0.5-1.5mm) (Dakers and Painter 1982) and gravitational settling is seldom used. Conversely in municipal and industrial wastewater treatment gravitational sedimentation for solid separation is commonly practiced and in addition more efficient setting is commonly acieved by the use of chemical coagulants (Ferrier and Marks,1982).

More use could be made of solid-liquid separation as a unit process in the treatment of high concentration piggery wastewaters. Wall et al (1987) state that there is a lack of design information suitable for the above objective and that there is a further need to quantify the reduction in organic loading due to solid-liquid separation in piggery wastewaters. This is backed up by Dakers and Painter (1982), who state that there is a need for better quantitative information on solid-liquid separation devices to enable them to be designed with greater confidence. They also state that lagoons are becoming a popular agricultural waste treatment method. However there are several problems with their use:(a)some piggeries may be limited by the land area available for disposal, and (b) more research is required on sludge accumulation and desludging techniques. Both these problems can be

reduced to a certain extent if primary treatment is practiced prior to lagoon disposal, thus reducing the organic load, the land area reqired, and minimising sludge accummulation.

It would appear that the screens used in piggery solid-liquid separation may satisfactorily remove suspended solids which are likely to cause blockages in the waste treatment system, but do not necessarily reduce organic load to any significant extent.In contrast to this sedimentation has been shown to significantly reduce total solids and organic load in several animal wastewaters (Moore et al, 1975). It would also be of use to quantify the level of nitrogen and phosphorus removed by any solid-liquid separation process for the following reasons:

(a)eutrophication in natural waters is most commonly limited by the absence of nitrogen and phosphorus (Vollenweider 1968). Consequently quantification of the reduction in nitrogen and phosphorus content due to solid-liquid separation is useful in waste treatment systems designed to minimise eutrophication.

(b)nitrogen and phosphorus are commonly required as soil fertilizers, and their concentration into a solid or slurry fraction could be applied to soils and contribute to soil fertility without the associated waste liquid. The latter (liqiud) dilutes the nutrient concentration, and may limit application during wet periods throughout the year.

1.4 Statement of Problem.

To date solid-liquid peparation has been used in piggeries to prevent mechanical blockages of pumps, pipelines and irrigation systems. There are now situations where solid-liquid separation is being considered by pig farmers in New Zealand to reduce organic loading on waste treatment systems such as lagoons, and also to retrieve waste components for further utilization, such as nutrients which can be applied as fertiliser to the land.

In New Zealand the design of solid-liquid separation systems to achieve particular objectives is difficult, since it is unclear what particle sizes must be removed to achieve a significant reduction in organic loading or retention of utilizable components.

In addition methods not commonly used in agricultural waste treatment for solid-liquid separation may be worthy of consideration. Lessons can be learnt from municipal and industrial waste treatment, especially in the area of sedimentation, but because of differences in waste characteristics, plant scale and management expertise these are not necessarily directly transferable to piggeries without further research.

2.Literature Review.

2.1 Characterisation of Pig Manure.

2.11 General Characteristics.

The characteristics of raw pig manure vary according to age, physiological state, type of ration being fed, production practices and environment (Day, 1983; Loehr, 1974; O'Callaghan et al 1971; Overcash et al, 1975; Pearce, 1977; Vanderholm, 1984,). The type of ration is the single most important factor influencing the characteristics of animal waste so therefore it was surprising to find that of all the papers reviewed, only four presented in any detail the type of ration which was fed. In the research of both Jett et al (1975) and Kottwitz & Schultze (1984) the pigs were fed a diet consisting mainly of ground corn and soyabean meal, with small portions of additives. In the research of O'Callaghan et al (1971) the diet consisted mainly of barley meal and wheatings while Barth (1985) compared the effect of different feeds on manure characteristics and showed that a 40% increase in TS was produced by changing from a 100% corn diet to a 50% corn and 50% barley diet. In New Zealand by contrast the predominant feed is barley with meat, fish or bone meal. Variation to this does occur throughout the country where whey, maize meal of food wastes may be fed (Cornes, Pers Comm). Overcash et al (1975) have reported a multitude of data on raw pig manure production from various sources which varies considerably from that reported by Vanderholm (1984). Since Vanderholm (1984) has endeavoured where possible to use New Zealand data, this is used in table 2.1 to illustrate the likely characteristics of raw pig manure in New Zealand piggeries and also to demonstrate the effect of different rations on those characteristics. Kottwitz and Schulte (1984) and O'Callaghan (1971) also point out that pig feeding practices can change with time and this should be taken into consideration when using historical data on waste characteristics.

Table 2.1

Freshly Voided Pig Manure Characteristics.

	Meal fed	Whey fed
Weight (kg)	50	50
Raw Manure (kg/day)	3.3	10.3
Density (kg/l)	1	1
TS (kg/day)	0.30	0.20
VS (%TS)	80	60
BOD (kg/day)	0.10	0.12
COD (kg/day)	0.29	0.24
Total N (kg/day)	0.023	0.021
Total P (kg/day)	0.0075	---

Different methods of removing waste from the housing has a major effect on the waste characteristics (Gilbertson et al, 1979). Hydraulic flushing is popular overseas (Barker and Drigger, 1980) and is by far the most popular system in New Zealand (Warburton, 1980), due to low construction and labour costs, and the ease of automation (Brodie, 1975; Jones & Nye, 1980). Due to dilution the characteristics of flushed wastewater vary from those given in table 2.1. Table 2.2 gives a typical range of characteristics encountered in piggery wastewater in New Zealand.

Table 2.2

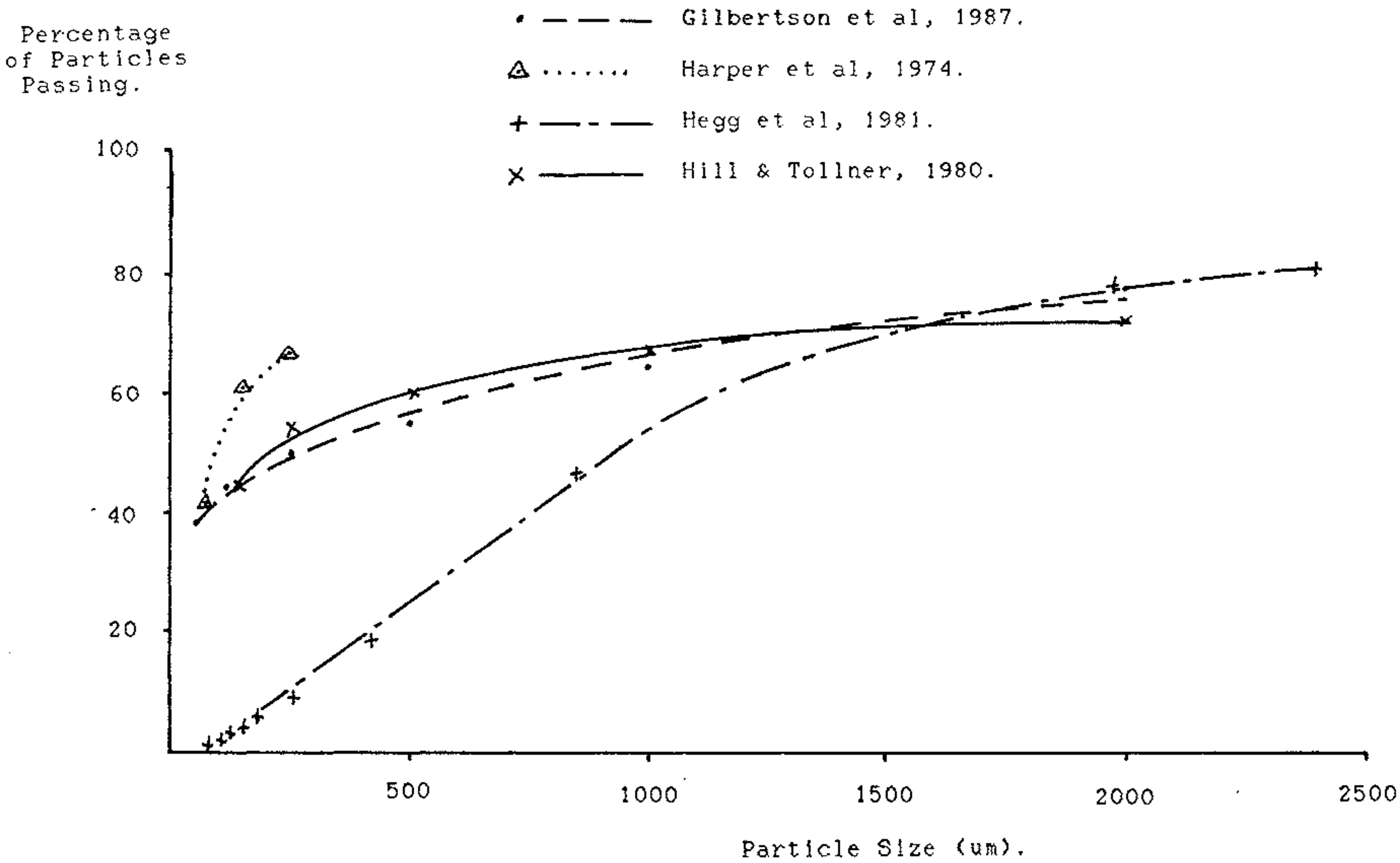
Characteristics of Piggery Wastewaters

Parameter	
TS range (mg/l)	5600-40,000
VS range (% of TS)	80
BOD range (mg/l)	2880-12,800
COD range (mg/l)	7000-32,800
Total N average (mg/l)	1738
range (mg/l)	1075-2500
Total P average (mg/l)	537
range (mg/l)	109-950

2.12 Particle Size Distribution.

Several people have investigated the particle size distribution of animal wastes. The results of particle size distribution for swine wastes from four studies have been presented in figure 2.1. There is considerable variation between them, although the results of Gilbertson et al (1987) and Hill & Tollner (1980) appear to be reasonably close over a range of particle sizes from 125 um to 2000 um. This is in contrast with the results of Payne (1986) who investigated the particle size distribution of swine waste from eleven commercial and one research piggery. Payne (1986) showed

Figure 2.1
Particle Size Distribution of Swine Wastewater.



that there was very little variation between piggeries with particle sizes less than 355 um and that most variation between piggeries occurred at about the 1000 um particle size. This fact would be particularly critical in the evaluation of solid-liquid separation screens used on farms , since the aperture sizes commonly range from 500 to 1500 um and therefore solids removal would be subject to considerable variation between farms.

There was considerable variation in the characteristics associated with particle size between the work of Harper et al (1974) and Hill & Tollner (1980). Harper et al (1974) indicated that a 250 um sieve removed 59% total nitrogen and 26% COD, while Hill & Tollner (1980) achieved 30-40% total nitrogen and 42% COD removal with a 250 um sieve.

In general Hill & Tollner (1980) found that as the aperture size reduced, so did the ratio of VS:TS. This indicated that organic material is retained on the sieves. In addition it was found that the COD of smaller particles was higher than that of larger particles. This is in agreement with Chang and Ribble (1975), who cited that Lindley (1970) demonstrated that the finest fraction of animal wastes degraded the easiest, and therefore different particle sizes have different biological properties. This fact has major implications in the use of separated solids for anaerobic digestion, since the concentration of coarser particles will not be concentrating the most reactive particles for anaerobic digestion.

For dairy, beef and poultry manure the particle size distribution changed with time of storage (Chang & Ribble, 1975). The same would be expected to occur with swine manure due to naturally occurring biochemical reactions.

2.2 Solid Liquid Separation. (based on Wall et al, 1987; Svarovsky, 1977).

2.21 Solid-Liquid Separation Systems.

There are three main objectives of solid liquid separation as stated in section 1.2. Perfect separation is technically feasible by distillation (Tchobanoglous & Schroeder, 1985), but in only few cases it is economically feasible, (eg. recovery of high value or extremely dangerous pollutants). Generally solid-liquid separation results in a stream of liquid contaminated with variable quantities of solids, and a stream of moist solids. This imperfection of separation is characterised in the following ways:

(a) separation efficiency, which is the mass fraction of solids removed, expressed as a percentage, and

(b) solids moisture content, which characterises the dryness of the solids recovered.

2.22 Processes/Principles Used for Solid-Liquid Separation.

There are two principles used to separate solids from a liquid suspension. (a) A density difference between solids and liquids can be used to float or settle solid particles, and (b) solid particles can be contained by a medium as in filtration or screening.

The following is a summary of methods used for solid liquid separation.

2.221 Solid-Liquid Separation by Density Difference.

(1) Flotation.

Flotation is a gravity separation process in which air or gas bubbles are attached to solid particles. It is not necessary for the separated solids to have a density lower than the fluid, but the agglomerate of particle and air will have a density lower than that of the fluid, and hence will float to the surface where they will accumulate. The success of this process depends on the formation of an ample supply of suitably small bubbles, and the attachment of these bubbles to solid particles. Bubbles may be generated by mechanical agitation or injection, dissolution of dissolved air under vacuum or after application of high pressure, and electroflotation. In the latter method, electrolytic dissociation of the water produces bubbles of hydrogen and oxygen.

(2) Gravity Sedimentation.

Gravity sedimentation operates continuously by feeding a suspension into a settling basin or chamber and while it is passing through, solids settle out. The solids are removed, together with a fraction of the liquid, as thickened underflow. The rest of the liquid overflows, more or less clarified or containing a minimum of suspended solids. Flocculating agents, and a process known as a "sludge blanket" may be used to enhance settling. Equipment used for this purpose are commonly called thickeners or clarifiers.

(3) Hydrocyclones.

A hydrocyclone is a conical shaped device which utilizes centrifugal and gravity forces to achieve solid-liquid separation. The suspension enters the hydrocyclone tangentially at the top. The bulk of the liquid is discharged from the top centre, while the remaining liquid and coarse solids leave through the apex of the cone (see figure 2.2).

(4) Sedimenting Centrifuge.

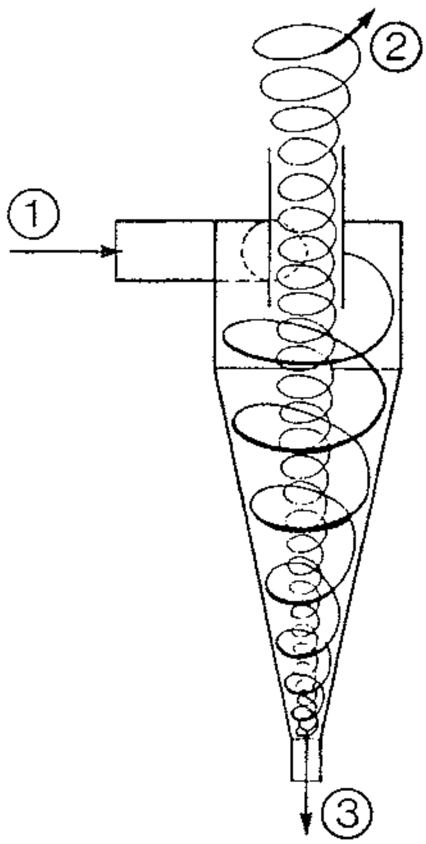
A sedimenting centrifuge consists of a bowl into which a suspension is fed and rotated at high speed. The separation process is based on a density difference between solids and liquids; the particles are subjected to centrifugal forces which make them move radially through the liquid either outwards or inwards, depending whether they are heavier or lighter than the liquid. The different types of centrifuge may be categorised according to the method of discharge of the solids.

2.222 Solid-Liquid Separation by Containment on a Medium.

(1) Filtration. (Svarovsky, 1977)

Filtration is defined as the separation of solids from liquids by passing a suspension through a permeable medium. There are basically two types of filters:

(a) surface filters, in which solids are retained on



1 Slurry

2 Liquid

3 Coarse solids (& liquid)

Figure 2.2

Schematic Diagram of a Hydrocyclone

the surface of the medium. These form a cake which improve filtration as it develops.

(b) Depth filters, where solids are deposited inside the medium, are capable of removing particles much smaller than the medium openings, and are used for much more dilute suspensions than surface filters.

Both filter types require a pressure drop as a driving force, this may be supplied by gravity, vacuum, pressure or centrifugal force.

(2) Screens.

Screening is the process of separating solids into groups each of which contain only particles of a specified size range. For example, in solid-liquid separation, a screen of fixed aperture size with a suspension flowing onto it will have a liquid and undersize particles passing through, with oversize particles and some liquid passing over the screen (i.e. particles are separated into two groups). Moving screens may have reciprocating, shaking, vibrating or rotating actions, which move screened solids off the surface of the screen to a collection vessel.

The capacity and efficiency of a screen is dependent on the characteristics of the influent and the type of screen. In general the following factors affect the capacity and efficiency:

(i) Screen size. Generally the wider the screen, the greater its capacity, and the longer the screen, the higher its efficiency.

(ii) Size distribution of the effluent. The particles which are relatively near to the size of the apertures are more difficult to separate by screening.

(iii) Open area. The larger the percentage of open area (the total area of aperture per unit area of screen surface) the more efficient the screen.

(iv) Screen slope and speed. These parameters affect the residence time of the material on the screen as well as the nature of its movement over the screen.

It should be noted that this is a list of the basic principles and processes involved in solid-liquid separation. In practice there are major variations within these methods. Solid-liquid separation is seldom used as an independent waste treatment process and so the requirements of the solid-liquid separation methods employed will not only depend upon influent waste characteristics, but also upon subsequent waste treatment methods. In addition a single solid-liquid separation device may not produce the required quality effluent for any particular purpose and so it is possible to combine two or more solid-liquid separation methods to obtain optimum performance.

2.3 Performance of Solid-Liquid Separators.

The following is a summary of the performance of a range of solid-liquid separators used in agricultural waste treatment. One of the major problems of comparison of this data was that the objectives for solid-liquid separation in each case was not the same, and hence different parameters were used to determine separator performance.

2.31 Screens and Filters.

There was a wide range of performance data for screen and filter devices. In this review the devices are categorised into units with similar modes of operation.

2.311 Stationary Units.

These are the most widely used solid-liquid separation devices used in New Zealand piggeries (Cornes, pers comm). They have no moving components so the initial and maintenance costs are relatively low, and apart from pumping the wastewaters across the screen and the removal of solids, there is no requirement for energy.

The performance of stationary screens in agricultural applications are summarised in Table 2.3

It is difficult to make generalizations about the reviewed data, however the following outlines the main points:

(a) Screen apertures ranged from 500-1500 um.

(b) The screens have been applied to beef, dairy and swine wastewaters.

(c) Problems were created by blockage of the screens with biomass (Bartlett et al, 1974; Dakers, 1979).

(d) Bartlett et al (1974) state that better separation efficiency was achieved at higher dilutions, (although this waste had a significantly higher DM concentration than any other reviewed).

(e) Shutt et al (1975) state better separation efficiency was

Table 2.3

Summary of Performance of Stationary Screens

Source	Animal	Screen Aperture um	Influent Solids %	% TS Removed by Screen	% BOD Removed by Screen	%COD Removed by Screen	% DM content of solids	Flow Rate l/min/m width
Bartlett et al 1974	Bovine	750	12	10	--	--	--	--
denBoer & Wall 1987	Swine	500	0.6-1.29	10-34	--	9-43	11.6	36-618
Farran, 1979.	Swine	500	1.55	16	24.4	30.7	8.1[1]	592
Graves et al 1971	Dairy	500	--	55-74	42-63	41-68	9.5	--
Hegg et al, 1981	Beef	500	0.97-4.41	--	--	--	13.3-22.5	--
Shutt et al, 1975	Swine	1000	0.2-0.7	35	62	69	9.1	300
	Swine	1500	0.2-0.7	9.8	34	24.2	6.0	500
Watson et al, 1975	Dairy	1000	---	42.6	--	33.7	13.0	667[2]

[1]21.5 % after 6 hours.

[2]Flow not measured, from manufacturers data.

achieved by the stationary screen rather than by a vibrating screen or cyclone, but at a lower DM concentration in the separated solids.

(f) Although the dry matter concentration of the separated solids ranged from 6%-22.5%, Farran (1979) states that after 6 hours drainage the DM concentration of separated solids reached 21.5% and was comparable with other more sophisticated methods of separation.

(g) This information is of limited use in screen design for general application. There is major variation in wastewaters tested (due to species differences) and it does not reveal any conclusive information on what effect a change in screen aperture or flow rate will have on screen performance.

2.312 Rotating Screens.

The performance of three rotating devices was summarised by Wall et al (1987) (see Table 2.4). Comparison of the performance of devices is complex since there are several differing modes of operation, and in contrast with stationary screens there is an extra variable of rotation speed. The rotating screen evaluated by Hegg et al (1981) was cylindrical and rotated on a horizontal axis with water fed in from the top, solids were scraped off the sides and liquid flowed out of the bottom.

In contrast Shirley and Butchbaker (1975) designed and evaluated a conical screen which was rotated on a vertical axis, where liquid flowed through the cone and solids were deposited off the outside edge. The rationale behind this design is that centrifugal forces are utilized in cleaning solids off the screen. Shirley and Butchbaker (1975) report that the screen was successful as a self

Table 2.4

Summary of Performance of Rotating Screens

Source	Animal	Screen Aperture um	Influent Solids %	% TS Removed by Screen	%COD Removed by Screen	% DM of Solids	Flow Rate l/min	Rotation Speed RPM
Hegg et al, 1981	swine	750	2.54	4	9	15.6	110-307	3.0-9.6
	swine	750	4.12	8	16	16.6	80-238	1.9-9.6
Shirley & Butchbaker, 1975	beef	3000	--	--	--	7	9.8-24.4[2]	50-52[3]
Miner & Verley, 1975	swine	NA	0.05-1.2	20-80	--	4.3	17.8-26.5	--
Keeley, 1983	sheep	500	2.1	23.5[1]	29.5	7.3	95.6	--
	sheep	1000	4.4	8.5[1]	24	6.4	61.5	--

[1]suspended solids removed.

[2]kg/sec/m^2

[3]m/min peripheral speed

cleaning device and did not plug after several days of continuous operation.

The third device reported by Miner and Verley (1975) strictly speaking, was not a screen but a horizontally inclined rotating cylinder, with an internal helix to settle and feed solids out of the top end.

In New Zealand Contrashear Engineering Ltd produce a rotating wedgewire screen in which the effluent flow is fed into the centre of a horizontally rotating screen. The liquid fraction flows through the screen while the separated solids are moved out one end of the cylinder by metal lugs at 45 degrees to the direction of rotation. The results of trials by Keeley (1983) using a 500 um and a 1000 um screen separating sheep manure have been reported in table 2.4. Keeley's results indicated that a reduction in screen aperture size may increase the percentage of suspended solids and COD removed by screening, and increase the DM content of the separated solids.

In addition it should be noted that the initial, maintenance and running costs associated with this type of screen are substantially higher than for a stationary device.

2.313 Vibrating Screens.

Numerous vibrating screens are reported in the literature. It has been stated by Vanderholm (1984) that vibration has been used to assist the movement of particles across the screen and to reduce blockage. Table 2.5 summarises some of the performance data.

There was some variation in DM concentration of the separated solids. This was partially due to the fact that some separators were used to screen solids prior to anaerobic digestion and so the DM content of solids was kept low, since in some cases it was these solids which were used in the digester (Hill and Bolte 1984).

Shutt et al (1975) stated that at equivalent flow rates removal efficiencies of BOD and COD for stationary screens were better, although vibrating screens produced a better DM content of the separated solids. In addition they stated that both stationary and vibrating screens required cleaning to prevent biological blockage. Bartlett et al (1974) stated that with patented de-blinding rings an 18 mesh (980 um) vibrating screen treating bovine waste did not become blocked. However, they quoted no performance data for this screen and commented that there was substantial seepage from the solids stack.

As long as the screen is not overloaded, then flow rate has little effect on the DM of separated solids (Hegg et al, 1981). Also higher solids removal rates are achieved at higher solids concentrations, (Hegg et al, 1981) however their influent TS concentration only ranged from 1.02%-2.88%. Similar results were achieved by Haugen et al (1983) who state that the vibrating screen performed well with TS concentrations less than 7%. As would be expected, Hegg et al (1981) point out that for swine wastes, as screen apertures decrease the removal rates of TS and COD increase.

Safley and Fairbank (1983) summarised four sets of performance data in which vibrating screens were used to separate dairy manure. In general a decrease in screen aperture increased the solids removal rate. Solids removal is also influenced by influent solids concentration, and the DM concentration of separated solids ranged from 5.7%- 20%.

Table 2.5

Summary of Performance of Vibrating Screens

Source	Animal	Screen Aperture um	Influent Solids %	% TS Removed by Screen	% BOD Removed by Screen	%COD Removed by Screen	% DM Solids	Flow Rate l/min
Redman et al, 1983	swine	--	1.1	--	--	--	14	75
Prince et al, 1983	swine	980	3.2	--	--	--	30.7	75
Holmberg et al, 1983	swine	104-2450	2.9[1]	11.2-66.9	--	2.2-56	2.5-18	37.5-150
Hills &	dairy	2000	2.1	49	--	--	--	--
Kayhanian, 1985	dairy	800	3.2	65	--	--	--	--
Hill & Bolte, 1984	swine	234	2.34	--	--	--	7-10	457-685[2]
Shutt et al, 1975	swine	120-390	0.2-0.7	--	2.4-4.5	3.3-16.3	3.9-16.4	41-110

cont..

Source	Animal	Screen Aperture um	Influent Solids %	% TS Removed by Screen	% BOD Removed by Screen	%COD Removed by Screen	% DM Solids	Flow Rate l/min
Haugen et al, 1983	dairy	1400	7.8-11	32-42	--	--	16.5-20.3	--
Hegg et al, 1981	dairy	635-1570	1.6-3.2	6-16	--	0.7	14.8-16.4	19-114
	beef	635-1570	1.0-1.9	8-16	--	3-12	5.7-14.8	14-103
	swine	635-1570	1.5-2.9	3-27	--	1-24	16.9-20.9	15-126
Gilbertson & Neinaber, 1979	beef	860	7.7	43	--	--	24	129

[1]range of 1.5-5.4.

[2]$l/min/m^2$

Ngoddy et al (1974), examined the vibrating screen for the solid-liquid separation of piggery wastewater. A general procedure for performance analysis and estimation of performance of this type of device was developed using methods of dimensional analysis. They reported that successful operation of the machine depended on establishing a pattern of travel over the screen cloth that gave the desired efficiency and final product consistency. This pattern was a function of:

(a) the physical properties of the material,

(b) the rotational speed of the drive motor, and

(c) the relative size of the weights and the phase differential in their angular motion.

These parameters required adjustment for the mesh size of the screen and for the relative size distribution, density and feed rate of the applied material.

Gilbertson and Neinaber (1979) tested three vibrating screens with beef cattle wastewater. They concluded that screen apertures less than 500 um would reduce the screen capacity to a point where inflow is difficult to control, and the total solids content of the manure must be such that the fluid will act as a liquid (approximately 6% solids).

2.314 Multistage Devices.

Multistage devices were reviewed by Wall et al, (1987). These combine some form of screening with a press device to achieve further dewatering. They are not widely applied to New Zealand agriculture due to their complexity and cost. None of the reviewed papers revealed any information on the removal of BOD or COD due to solids separation. In addition the dry matter content of the solids ranged from 16%-31%, which is not outside the performance for a stationary screen, especially after a short period of drainage as suggested by Faran (1979).

2.315 Filtration.

In this review screening and filtration have been differentiated by classifying flexible fabric devices as filters, although they may not necessarily build up a filter cake. Of the many filter devices reported comparison between these is difficult since they consist of different configurations. A summary of two such devices is reported in table 2.6.

Ferdnandes et al (1988) report on the performance of a continuous belt filter used for separating swine slurry. The belt was revolved at 1.2-5.2 m/min and continuously cleaned by an air blower. No plugging or mechanical problems were experienced with the filter over three months operation, even though filter apertures were only 100 um The hydraulic loading had no significant effect on separator performance. This is in agreement with other research on screens. In addition, increasing the TS concentration of the influent increased the removal efficiency of the separator.

Kroodsma (1986) tested the performance of an underfloor filter system, separating swine waste as it was produced by the animal. He tested several aperture sizes and concluded that 780x780 um was the most effective. This system was effective in restricting odours and concentrating swine waste for transport, but is naturally more

Table 2.6

Summary of Performance of Filtration Devices

Source	Animal	Screen Aperture um	Influent Solids %	% TS Removed by Screen	%COD Removed by Screen	% DM of solids	Flow Rate $m^3/m/m^2$
Ferdnandes et al 1988	swine	100	3-8	47-59	39-40	14-18	0.01-0.145
Kroodsma, 1986	swine	780x780	raw manure	85	80	32-35	--

capital intensive since filter netting needs to be installed in all housing.

Other filter devices reported have incorporated two stage processes and so have been classified as multistage.

2.4 Sedimentation.

The type of settling which can occur in the sedimentation process can be divided into four categories: discrete, flocculant, zone and compression settling (Metcalf and Eddy, 1979). The type of settling under any situation depends primarily on the influent solids concentration and the interaction between particles. Discrete settling occurs in relatively dilute suspensions where particles settle as individual entities with no significant interaction between particles. The velocity of any single particle will be a constant until it reaches the bottom. Flocculant settling also occurs in rather dilute suspensions, but particles tend to coalesce or flocculate. By coalescing the particles increase in mass and tend to settle faster. So the settling velocity of a particle is not constant.

Zone settling occurs in suspensions of intermediate concentration, in which interparticle forces are sufficient to hinder the settling of neighbouring particles. The particles then tend to remain in fixed positions with respect to each other, and the mass of particles settle as a unit. Finally, compression settling occurs when the weight of additional sedimented particles compress the structure of settled sludge. All four types of settling may occur in a sedimentation system as shown in fig 2.3.

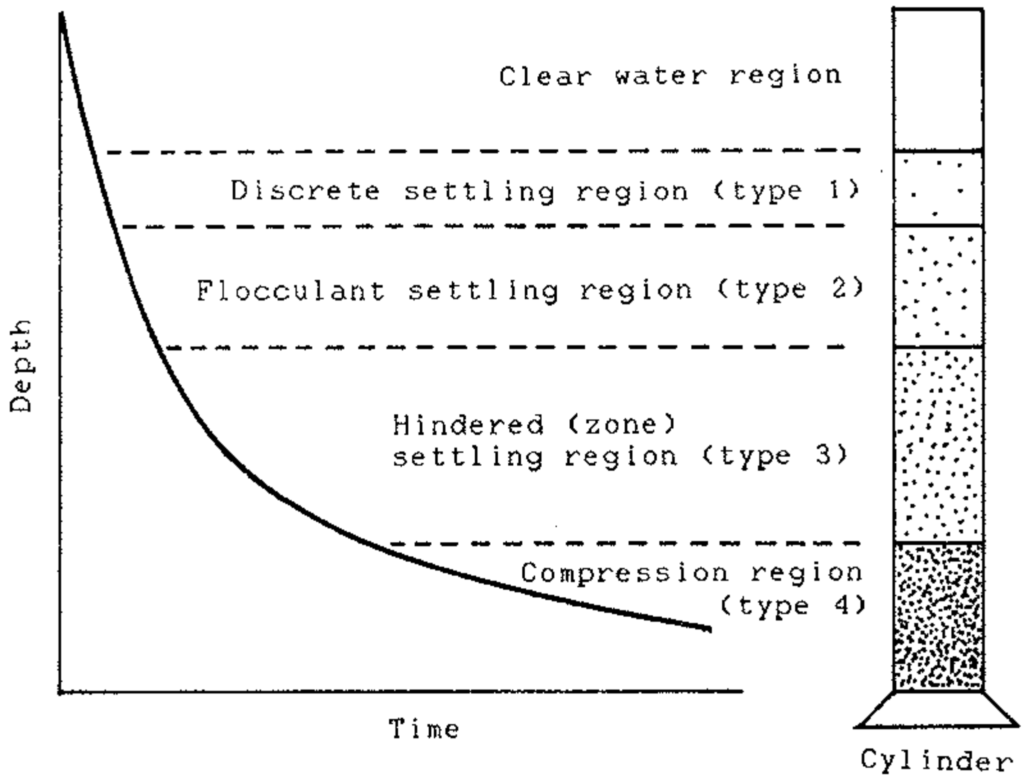


Figure 2.3
Schematic Diagram of Settling Regions.

2.41 Sedimentation Systems.

Sedimentation systems have been used in various agricultural applications. These have shown high reductions in TS and COD through sedimentation, but the sedimentation times varied from one to 90 days (Bartlett et al, 1975; Edwards et al, 1985; Glerum et al, 1971).

Edwards et al (1985) used a settling basin for cattle feed pad waste. With a one day retention time 48% TS and 51% COD was removed. Glerum et al (1971) used a sedimentation silo to settle swine waste. The waste was stored for 10 weeks and the total solids, BOD and COD were reduced by 81%-86%, 45%-53% and 75%-77% respectively. Bartlett et al (1975) did not report the percentage solids removal for dairy waste using a sedimentation bed, but did report that the effluent from the bed contained only 0.2% TS and that after 90 days drainage the settled solids had a DM percentage of 14.1.

These results indicate that sedimentation can be a useful treatment system in agriculture but do not indicate how sedimentation time or solids concentration affect settling performance.

2.42 Sedimentation Research.

The settling performance of swine wastes in settling columns have been reported by several workers, (Cullum et al, 1984; Fischer et al, 1975; Gilbertson and Nienaber, 1978; Jett et al, 1975; Moore et al, 1975; Payne, 1986; Shutt et al, 1975). Various influent concentrations were tested. In general the solids concentration had a major effect on the settling rate. Fischer et al (1975), Jett et al (1975), Moore et al (1975) and Shutt et al (1975) all stated that settling rate increased as the influent solids concentration reached 1% TS, and then reduced above this value. The accepted explanation for this fact is that suspensions with TS concentrations up to 1% would follow a flocculant type settling. With suspensions of less than 1% TS (say 0.5% TS) then the probability of particles coalescing and increasing in mass is reduced and so the settling rate is lower. Conversely, particles in suspensions with a total solids concentration greater than 1% tend to interfere with adjacent particles and hence zone settling occurs where particles remain in a fixed position with respect to each other, and settle more slowly as a unit.

There is agreement between all papers reviewed that a major proportion of total solids and COD can be removed in a relatively short sedimentation period. The results of 5 researchers are given in table 2.7.

Table 2.7

Summary of Swine Sedimentation Research.

Source %	TS Removal %	COD Removal	Settling Time (min)
Cullum et al, 1984	58	42	50
Jett et al, 1975	58-63	----	14
Gilbertson & Neinaber, 1979	65	----	15
Moore et al, 1975	38-55	20-46	1
	45-60	35-56	10
Payne, 1986	75[1]	----	10
Shutt et al, 1975	75[2]	55	30

[1] % of those solids that would settle in 1000 minutes.

[2] % of Total Suspended Solids.

In most studies no comment has been made on the concentration of the settled solids. This will depend upon how long they remain in the settling basin before removal and in many cases they will be used as feed for anaerobic reactors. However, it should be noted that these settled solids will contain a considerably higher COD per unit volume than the influent wastewater and so have a high polluting potential (Fischer et al 1975).

Only two researchers considered the increase in settling efficiency by using flocculants. Glerum et al (1971) stated that the use of flocculants for settling swine manure appeared costly and hence did not use them. On the other hand Hanna et al (1985) evaluated the use of several coagulants on cattle and swine wastewaters. Preliminary tests indicated that relatively low rates of $FeCl_3$ or chitosan (used independently) could improve settling performance economically. Further tests showed that the addition of 150 ppm $FeCl_3$ or chitosan improve the volatile solids settled in 100 minutes from 76% to 85%. They also state that it is important to match the waste with a particular coagulant to achieve optimum settling rates.

Olsen (1988) studied the effect of sedimentation of pathogenic and indicator bacteria in liquid pig manure. Sedimentation periods of 24 and 48 hours reduced concentrations of artificially added organisms by 0.1-0.8 log units, while coliform and total bacterial count of the indigenous flora were reduced by up to 1.5 log units.

2.5 Fate of Separated Components.

One major objective of waste treatment systems is that wherever possible; "components of the waste should be utilized for useful or productive purposes". In fact Dakers and Painter (1982) state that waste components should be viewed as a resource.

The products of solid-liquid separation are a stream of solids of varying moisture content, and a liquid with varying levels of solid contamination. Solid-liquid separation itself is a process which can render the components of flushed waste more useful.

2.51 Separated Components.

Once the solid fraction is removed from the slurry it must be stored and disposed of. It is generally accepted that at 15%-20% DM cattle and pig solids can be stored with minimal seepage (Hepherd &

Douglas, 1973; Pain et al, 1978; Sneath). Liquids may also require some form of storage before treatment or disposal, especially in land disposal systems where adverse soil conditions prevent land application (Bartlett et al, 1975). From this situation there are many possibilities for utilization and disposal.

Dumping solids as land fill is probably the easiest option. They may be easily loaded into a wagon as they are separated and the wagon emptied as regularly as required. There are several disadvantages with this disposal method, firstly no nutrients or soil conditioning properties of the waste are utilized. Secondly, seepage and odour problems may follow if the solid is too moist or in the vicinity of waterways or human dwellings. This dump should be isolated from human or animal contact to prevent possible contamination from pathogens.

Disposal onto land is an attractive option as any nutrients in the solid or liquid fraction are utilized (Chang & Ribble, 1975; Farran, 1979), and some soil conditioning effect may be realised (Dakers & Painter, 1982; Dale & Swanson, 1975). Again care must be taken to select a disposal site where seepage, runoff or drainage is not going to enter local water courses, and any odour between application and cultivation will not cause a nuisance (if cultivation is practiced). If cultivation is not practiced, application of solids should be at a rate that avoids pasture being smothered.

There are several problems associated with spreading manure on land. Weller & Willets (1977) state that: "Malodorous gases are produced during anaerobic storage of manure, and when it is spread on land these gases are released. Anaerobic storage can be prevented by aerating the manure. Alternatively, odours may be prevented by chemical treatment which inhibits bacterial action or by simply ensuring that regard for wind direction and local inhabitants is taken before spreading solids". Boutin et al (1988) state that there is a disease risk associated with land spreading animal manure, and that higher aero-contamination is associated with gun spreading than with tank spreading. However disease and toxic risk can be minimised by applying sludge to non-food chain crops, such as forestry (Bayes et al, 1987).

Day (1980) states that up to 60% of nitrogen can be lost by poor handling and storage. This problem may be overcome to some extent by the use of nitrification inhibitors which have been used by Sutton et al (1985) to increase corn yields from crops receiving animal wastes.

Heavy applications of manures may lead to nutrient imbalances and depressed crop or grass yields. This imbalance of N, P and K may result in the promotion of more tolerant and less productive species such as dock, thistle, nettle and coarse grasses, and continuous use of manures at high levels may also lead to a build up of trace elements to toxic levels (Weller & Willets, 1977). For example, pig slurry may contain high levels of copper due to supplementation of their diet with copper sulphate. Separated pig slurry solids have been analysed with copper and zinc levels as high as 400 ppm and 810 ppm DM respectively. Information by Meeus-Verdinne et al (1979) and Kroodsma (1986) on the effect of land spreading manure indicate that in the short term, application in quantities used for normal fertilising has no appreciable influence on the total copper and zinc content of the soil. In the long term however, repeated land spreading of relatively large amounts of liquid manure will give rise to problems, this is also likely to occur with land spreading of separated solids. To avoid possible hazards from a build up of copper in soil Batey et al (1972), suggest a maximum application of 9.5 kg/Ha Cu annually. For example, about 80 t/Ha separated solids could be applied if a waste contained 400 ppm Cu at a DM content of 30%.

Composting may be used to stabilise the waste either for dumping or for use as a soil conditioner or plant growth media. If utilized for the latter two uses some value may be derived from the product, but care must be taken to consider the effect of possible high levels of trace elements as in land disposal. Chang & Ribble (1975) state that composted wastes have lower nutrient values than raw manure.

Composting is an aerobic method of stabilising organic wastes. The process begins at ambient temperature but soon rises to between 40-70 degrees celsius due to microbiological activity. Aeration by turning or forced aeration by fans is used to keep the substrate aerobic and help prevent excessively high temperatures (greater than 60 degrees celsius), which inhibit desirable microbiological activity and hence slow the process. In addition lack of aeration will allow anaerobic conditions and malodours will result.

The separated solids do not appear to be ideal for composting, but composting will occur at DM contents of 18% (Pain et al, 1984). The addition of sawdust or straw may be necessary to increase the dry matter content to 50%-65% which is considered ideal (Vanderholm, 1984). In addition the nitrogen content and C:N ratio are critical for optimum composting conditions. Vanderholm (1984) states that wastes will compost well if the nitrogen content exceeds 2.5% on a dry weight basis and the C:N ratio is between 30:1 and 50:1. It would appear from data obtained from analysis of solid wastes from a local piggery that nitrogen may need to be added to facilitate ideal composting conditions. The nitrogen content of the separated solids ranged from 2.0-2.4% N before the addition of straw; obviously the addition of straw would reduce the nitrogen content below the ideal level.

Large scale composting is usually done either with forced aeration or with natural aeration and windrows which are periodically mixed (Vanderholm, 1984). The windrow is turned about once weekly to aerate, release ammonia and moisture, and to distribute pathogens to achieve a better kill. Stabilization should be achieved in 3-4 weeks, but may take longer under less ideal conditions (Farran, 1979).

The end product should be a relatively stable compost which is normally low in concentration of macro-nutrients. Pathogen content is low if thermophillic conditions (50-70 degrees celsius) have been maintained for a period. The main problem with producing compost for any particular end use is to produce the correct quality, consistently for the end user. Using separated solids as an animal feed ration has been reported. Chang and Ribble (1975) investigated the feed value of various portions of animal wastes. They showed that for dairy and beef cattle, and poultry the coarse fractions were higher in crude fibre, while the fine fractions contain higher crude protein levels. Gross energy levels ranged from 4.2-18 MJ/kg DM, but were not affected by particle size. Day (1980), suggests that refeeding separated solids can reduce feeding costs, but are better suited to ruminant refeeding since they can utilize fibre and non-protein nitrogen. He states that the solids need processing to reduce odours and disease risk, and common practices include ensiling and chemical treatment. Meisinger (1985), states that the ration may be fed to gestating sows, and Prince et al (1983) and Prince & Hill (1985) say that raw swine wastes (without treatment) may replace up to 60% of a sows diet without detrimental effects on production.

Fairbank et al (1975) suggested several novel uses such as insulation, domestic fuel through to livestock litter (bedding). The value of separated solids for bedding has been investigated by other researchers (Dale & Swanson, 1975; Lindley & Haugen, 1985; Safley & Fairbank, 1983. This is not really applicable to New Zealand conditions since animal bedding is rarely provided.

Farran (1979), and Graves et al (1971), state that solid-liquid separation can be utilized as part of a system to renovate animal waste flush water, so that it can be recycled for washing purposes. Different systems have evolved for piggeries and dairies, and are particularly useful in situations where water is in short supply or suitable sites for discharge of wastewater are unavailable.

The most widely reported use for separated components of animal wastes is for anaerobic digestion producing biogas. The components used depends upon the separation processes. Results of gravity settled components used for anaerobic digestion were reported by Fischer et al (1975), Hills & Kayhanian (1985) and Hill & Bolte (1984). About 50% of the potential methane production is lost in the supernatant fluid. On the other hand Yang et al (1985), showed that the dilute supernatant could be used for anaerobic digestion as long as the influent VS was about 25 g/l (which is probably above what would be expected from untreated flushed wastewater in New Zealand piggeries).

Other researchers have investigated the effect of screening liquid wastes on anaerobic digestion. Some of these have considered screening to remove the less degradable portion before anaerobic digestion. Hill & Tollner (1980), Hills & Kayhanian (1985), Hill & Bolte (1984), Holmberg et al (1983) investigated the use of screened solids for anaerobic digestion. Screening did not prove particularly suitable for this process since large portions of the total methane potential were left in the liquid fraction. Several workers investigated the effect of screening on the performance of the liquid fraction under anaerobic digestion. The results are variable. Liao et al (1984), state that screening off coarse solids increased the rate of methane production and CH_4 content of the biogas from dairy manure, while other researchers found that screening coarse solids reduced the volume of gas produced (Haugen et al, 1983; Lindley & Haugen, 1985; Lo et al, 1983; Lo et al, 1984; Pain et al 1984). Most researchers found that screening allowed a much shorter hydraulic residence time and consequently resulted in a smaller volume required for anaerobic digestion.

2.6 Summary and Conclusions.

(1). Potentially, piggery wastes in New Zealand contribute a relatively high polluting load to the environment. Any effort to reduce this in the form of waste treatment would be beneficial.

(2). Screens and other complex equipment are relatively costly to install and require a high degree of maintenance (Cullum et al, 1984). Shutt et al (1975) state that settling appears to be a reasonable treatment method compared with more complex devices. In addition it would appear that fabric filters are more capable of operating without blockage with smaller apertures than screens, resulting in more satisfactory operation and removal of smaller particles.

(3).Even though several papers commented on the importance of the effect of feed practices on waste characteristics, only four papers reported the feed regimes in place. There seemed to be considerable variation in particle size versus removal rates of various parameters. In light of this it would seem essential that investigations dealing with aspects of the animal waste problem consider the conditions under which the animals are housed and fed, and the waste handled, to ensure that solutions actually relate to the waste produced. It must also be noted that feeding and management practices will change with time, and thus altering waste characteristics.

(4) The rate of biodegradation of swine wastewater is enhanced by solids removal (Harper et al, 1974). Solid-liquid separation can also be used to enhance the utilization of various components in piggery waste, although it does not appear to conclusively increase or decrease the performance of anaerobic digestion for biogas production.

3. Objectives of the Study.

3.1 Objectives.

The preceding review of the literature pertaining to solid-liquid separation of animal wastes revealed a wealth of information. Unfortunately the bulk of this is overseas data where different management and feeding practices are applied, and as such is not directly transferable to New Zealand conditions. Consequently, there is a need to quantify the performance of solid-liquid separation devices under New Zealand conditions so that it can be determined whether this is related to performance of these devices overseas, and to allow for the further development in New Zealand of the most suitable solid-liquid separation process in agriculture.

Piggeries in New Zealand are concentrated production units, producing high volumes of concentrated animal wastes (cf. other animals) at a point. This makes them more amenable to new treatment systems than some more diffuse and dilute animal wastes. Consequently it was decided to conduct research into piggery wastewaters under New Zealand conditions with the following objectives:

(a) to determine the levels of COD/BOD, total solids, volatile solids, total Kjeldahl nitrogen and total phosphorus associated with certain sized particles in the waste stream,

(b) to determine the levels of COD/BOD, total solids, volatile solids, total Kjeldahl nitrogen and total phosphorus settled in certain time periods, and

(c) to compare the results of screening and sedimentation on the removal of COD/BOD, total solids, volatile solids, total Kjeldahl nitrogen and total phosphorus.

3.2 Scope of the Study.

This study is limited to laboratory scale experiments to test the performance of screening and settling as waste treatment methods. The wastes from one commercial piggery were used to conduct the trials. The particular piggery used was selected on the basis that it used management and feeding practices common to a major proportion of New Zealand piggeries.

The study was limited to two relatively inexpensive and simple processes which may be easily adopted on a farm scale.

4. Method and Materials.

4.1 Introduction.

To achieve the above objectives two trials were conducted. Samples were either sieved or settled as outlined in the following sections.

Before these trials were commenced, two methods of screening the wastewaters were investigated to select the most appropriate method to be used in the trials. The first method investigated followed the following procedure:

(a) a 2 litre sample of wastewater was measured,

(b) this was passed through consecutively smaller aperture sieves, without vibration or recirculation,

(c) samples of the wastewater passing each sieve were taken and analysed for COD and TS,

(d) the reduction in each parameter due to sieving was calculated by subtraction.

The results of this trial clearly showed a reduction in both parameters as the waste was passed through each sieve.

The second method investigated involved recirculating waste water through a vibrating sieve so that if undersized particles had not passed in the first flow, then they would possibly be washed through with subsequent flows. The procedure was as follows:

(a) three samples were tested. From each sample 8, 400 ml aliquots were collected,

(b) seven of the eight aliquots were each passed through one vibrating sieve and recirculated at a constant flow rate with a peristaltic pump for 15 minutes,

(c) the filtrate from each aliquot was collected and analysed for COD and TS.

The rationale for collecting eight different aliquots and sieving only once, was that repeated vibration and recirculation would ultimately affect the particle size and hence affect sieve performance.

The results of this trial were varied and quite inconclusive. Both COD and TS passing through each consecutively smaller aperture sieve increased and decreased respectively in concentration. This was caused by the problems of collecting aliquots of similar concentration. In addition to this it was suspected that vibration and recirculation were reducing particle size and hence affecting the performance of each sieve.

It was decided that due to the above problems, and the fact that a one pass dry sieving technique more resembled the action of on farm wastewater screens, to conduct a trial using the method of the first preliminary trial.

4.2 Experimental Design.

4.21 Sieving Trial.

The dry sieving trial was conducted in the following manner:

(a) 5 samples of piggery wastewater were processed,

(b) each sample was subdivided into three, 2 litre subsamples,

(c) each subsample had a 100 ml aliquot taken for analysis of the original parameters present,

(d) each subsample was then passed through consecutively smaller aperture 200 mm diameter "Endocotts" test sieves, and finally filtered through Whatman GF/C filter paper. The sieve apertures were 2000 um, 1400 um, 1000 um, 500 um, 125 um and 45 um, while the aperture size of the glass fibre filter paper was 1.2 um.

(e) A 100 ml aliquot was taken for analysis from each subsample directly after passing each sieve, and reduction in each parameter was found by subtraction. Each aliquot was analysed for COD, TS, TVS, nitrogen, and phosphorus.

The reason for selection of the sieve apertures as given were:

(a) to approximate the action of screens used in the field for solid-liquid separation, which range from 500 um - 2000 um,

(b) all grain at the piggery from which samples were collected passes over a crushing mill and is then subject to a 3 mm sieve, which after digestion, defecation and washing under turbulent conditions leaves few particles greater than 2-3 mm, and

(c) to ensure that the effect of removing very small particles was revealed even though this method of removing them may be impractical in the field.

4.22 Settling Trial.

The settling trials were conducted in a 2m high sedimentation cylinder. The cylinder (as shown in figure 4.1) was constructed

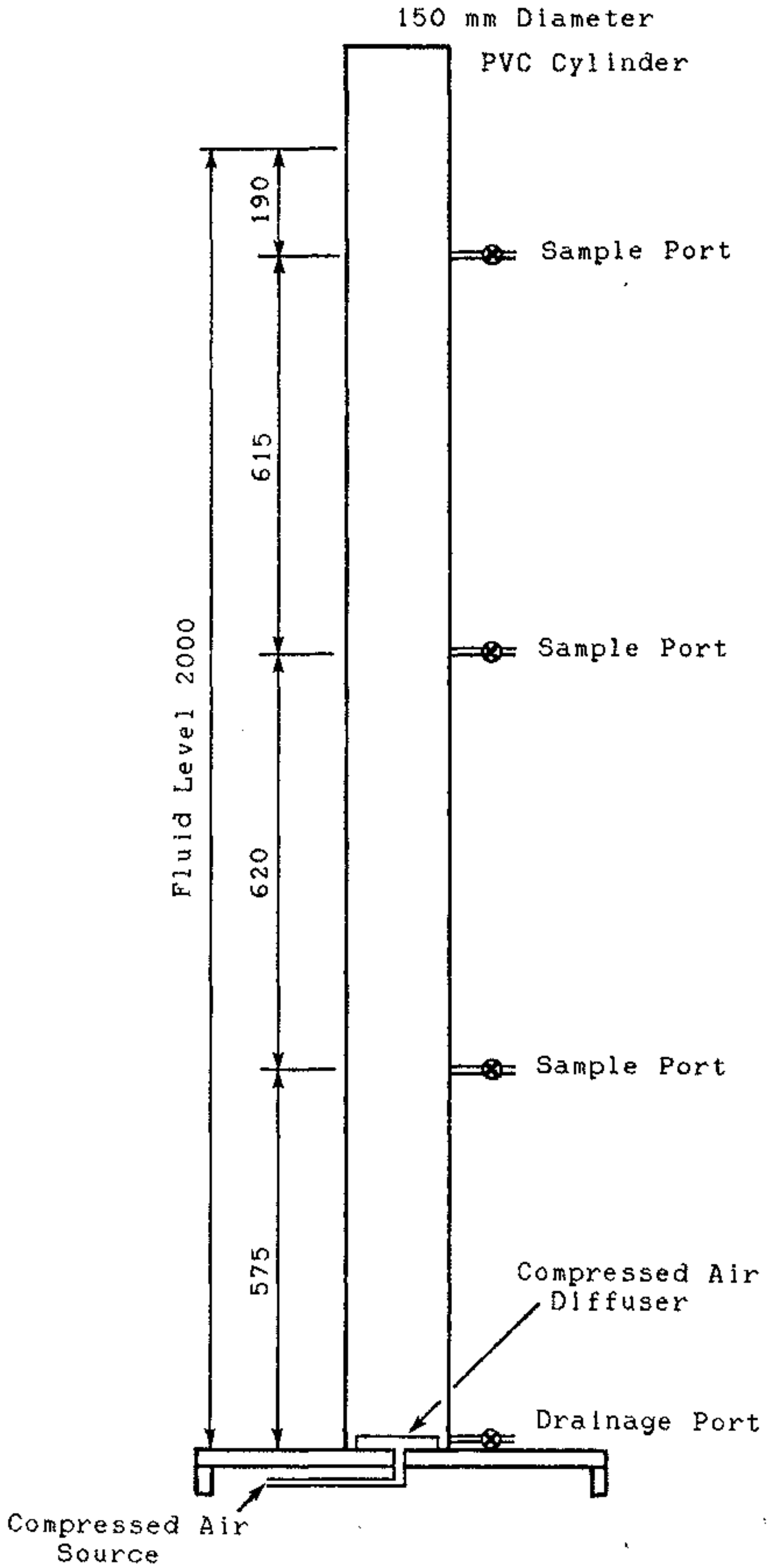


Figure 4.1
Schematic Diagram of Settling Cylinder.

of 150mm diameter uPVC pipe, with sampling ports at 190 mm, 805 mm and 1425 mm from the top. It had a drainage port at the bottom and mixing was facilitated by compressed air entering through a diffuser at the bottom.

The following procedure was used to test the performance of settling piggery wastewater:

(a) 5 samples were tested,

(b) each sample consisted of 35.3 litres of piggery wastewater,

(c) each sample was poured into the sedimentation cylinder (filling the cylinder to the 2m level) and mixed with compressed air for 2 minutes,

(d) while mixing was in progress three, 100 ml samples were taken for analysis of initial levels of each parameter,

(e) samples were then taken from each of the sampling ports 5, 10, 30, 60, 90 and 180 minutes after mixing was stopped,

(f) all samples were analysed for COD, TS, TVS, nitrogen and phosphorus.

4.3 Sample Collection.

Piggery wastewater samples were collected as and when necessary. Collection consisted of manual sampling of an outlet drain from the Pork Industry Board's piggery, situated on Old West Road, Tiritea. Samples were collected between 7.30 and 8.00 am from the sow house washdown, and taken forthwith to the laboratory for trial work.

It was accepted that collection of samples as and when necessary was the most practical option for the following reasons:

(a) it would be impossible to process all the samples in a time period which would not affect the physical or chemical constituents of the waste,

(b) even if one large sample was collected for all trials there would still be difficulties in obtaining uniform concentration for all samples,

(c) there was no storage method available which would prevent physical and chemical changes in the wastewater over time, and

(d) variability in the concentration of the piggery wastewater gave certain advantages to the trial in that it was possible to observe the effect on the solid-liquid separation processes due to concentration.

The Pork Industry Board's piggery at Old West Road was selected as the site for wastewater collection for several reasons. This piggery is in close proximity to Massey University where the trials were conducted. It uses feeding, management and washdowm practices which are common to a large number of piggeries in New Zealand, thus giving the results of these trials wider application. Details of feeding and management practices are given in appendix I.

4.4 Analytical Techniques.

Sub-samples taken during the experiment were used in the following analyses.

(a) Chemical Oxygen Demand (COD).

The COD is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant (Standard Methods, 1985). COD was selected since it is a relatively quick and easy method of obtaining the oxygen demand. An empirical relationship between COD and BOD was obtained.

The COD was determined by the closed reflux, titrimetric method using 2 ml samples in standard 10 ml ampoules, as described in Standard Methods (1985). Each sample was duplicated in this test and a standard COD solution was used to check method accuracy. Sample dilution was required to obtain sample COD in measurable range.

(b) Biochemical Oxygen Demand, (BOD).

The BOD determination is an empirical test in which standard laboratory procedures are used to determine the relative oxygen requirements of wastewaters, effluents and polluted waters. The test measures the oxygen required for the biochemical degradation of organic material (carbonaceous demand) and the oxygen used to oxidise inorganic material such as sulphides and ferrous iron. It may also measure the oxygen used to oxidise reduced forms of nitrogen (nitrogenous demand) unless their oxidation is prevented by an inhibitor (Standard Methods, 1985).

BOD's were determined using Hach manometric BOD meters. Samples were diluted up to 20 fold as required and held in an incubator at 20 degrees celsius for 5 days. This method of BOD determination is quicker and as accurate as traditional methods (Warburton, 1977).

Only a sufficient proportion of samples were analysed to establish an empirical relationship between the BOD and COD samples.

(c) Solids.

Both total solids (TS) and volatile solids (VS) were measured using standard procedures (Standard Methods, 1985). TS is the term applied to the material residue left in a vessel after evaporation of a sample and subsequent drying in an oven at 103-105 degrees celsius. VS is the fraction of TS which is lost if sample is ignited in an oven at 550 ± 50 degrees celsius. VS offer an approximation of the amount of organic matter present in the solid fraction of wastewaters.

Disposable aluminium foil containers were used to take 90-100 ml samples. The dishes were passed through a muffle furnace at 500 ± 50 degrees celsius prior to initial weighing, and were subsequently handled with tweezers.

(d) Nutrient Analyses.

Nitrogen and phosphorus have been measured since they are commonly limiting as nutrients in natural waters as well as agricultural soils. Hence their removal is useful in reducing eutrophication of natural waters, and providing a nutrient source for soils.

Both Total Kjeldahl Nitrogen (TKN) and total phosphorus were measured using the method outlined by Twine and Williams (1971).

TKN is defined as the "sum of organic nitrogen and ammonia nitrogen", and does not include nitrogen in the forms of azide, azine, azo, hydrazone, nitrate, nitrite, nitro, nitroso, oxine and semicarbazone (Standard Methods, 1985).

The method outlined by Twine and Williams (1971) was adapted to use a 5 ml sample. Four drops of acid were added to this sample to prevent volatilization of ammonia, and it was then dried at 105 degrees celsius until evaporated. This sample was then digested in 4 ml of digest solution at 350 degrees celsius for four hours. The resulting digested sample was diluted 10 fold with distilled water and TKN and TP were analysed by a "Technicon Autoanalyser" in the Department of Soil Science, Massey University. Standard nutrient solutions and blank solutions of distilled water were used to check the accuracy of method. Some samples were duplicated.

5. Results and Discussion.

5.1 Characteristics of Collected Wastewater Samples.

Table 5.1 shows the mean characteristics for the wastewater samples collected for both trials.

Table 5.1

Mean Wastewater Characteristics.

Trial I.

Parameter	Unit	Mean	Standard Deviation	Maximum	Minimum
COD	mg/l	24351	5885	33445	14983
TS	percent	1.5005	0.3592	2.0323	0.9398
VS	percent TS	74.3	5.3	84.0	67.9
TKN	mg/l	1566	527	2557	815
TP	mg/l	581	217	855	246

Trial II.

Parameter	Unit	Mean	Standard Deviation	Maximum	Minimum
COD	mg/l	29287	9379	46595	12864
TS	percent	1.827	0.6635	2.5902	0.6661
VS	percent TS	78.0	3.5	82.4	71.7
TKN	mg/l	1584	497	2253	761
TP	mg/l	473	133	692	271

The above data indicates that there is considerable variation in wastewater characteristics from the piggery from day to day.

This data is consistent with the general characteristics of piggery wastewater in New Zealand as presented by Vanderholm (1984).

The variability of COD and TS is greatest in the samples collected for trial II, while variability of the other parameters is greatest in trial I.

5.2 General Trial Results.

Raw data for both trials has been manipulated to a more useful form. The methods used in manipulation have been presented in appendix II.

5.21 Sieving Trial.

All data were reduced to a common factor of cumulative percent removal of a particular parameter after passing a certain aperture size sieve. Log of the sieve aperture size was regressed against the percentage removal of each parameter associated with that aperture. Regression curves and equations are presented in figures 5.1-5.5 and table 5.2 respectively.

The results of this trial show that there is a very high correlation between the log of the sieve aperture size and percentage removal of each parameter tested.

After passing through the 1.2 um glass fibre filter all parameters except TKN were reduced by 75-90%. Since the glass fibre filter paper used is that normally used in the filtrable solids test (Gilliland, pers comm), then it can be concluded that

Figure 5.1
Sieve Performance, Percent Removal TS.

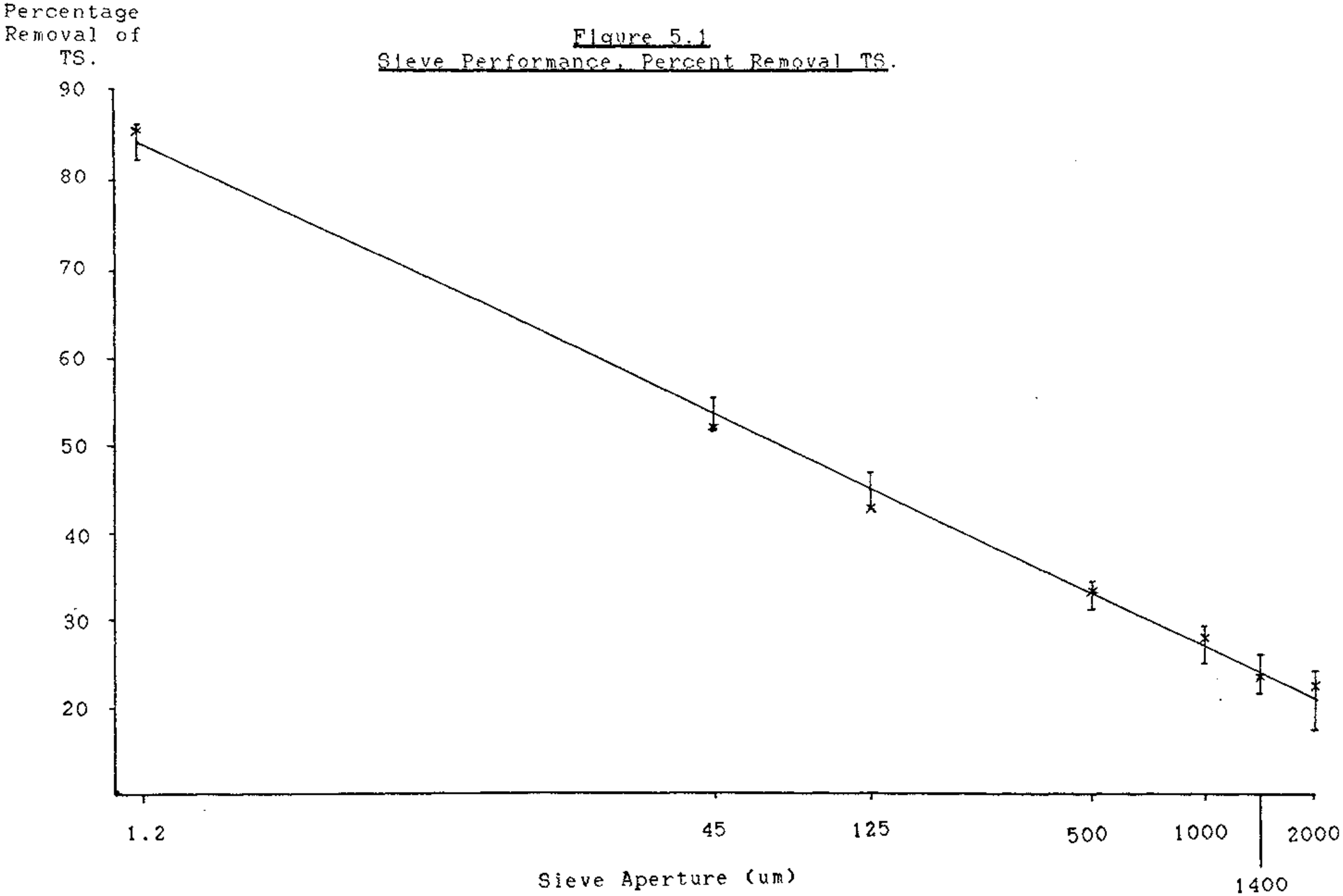


Figure 5.2

Sieve Performance, Percent Removal VS.

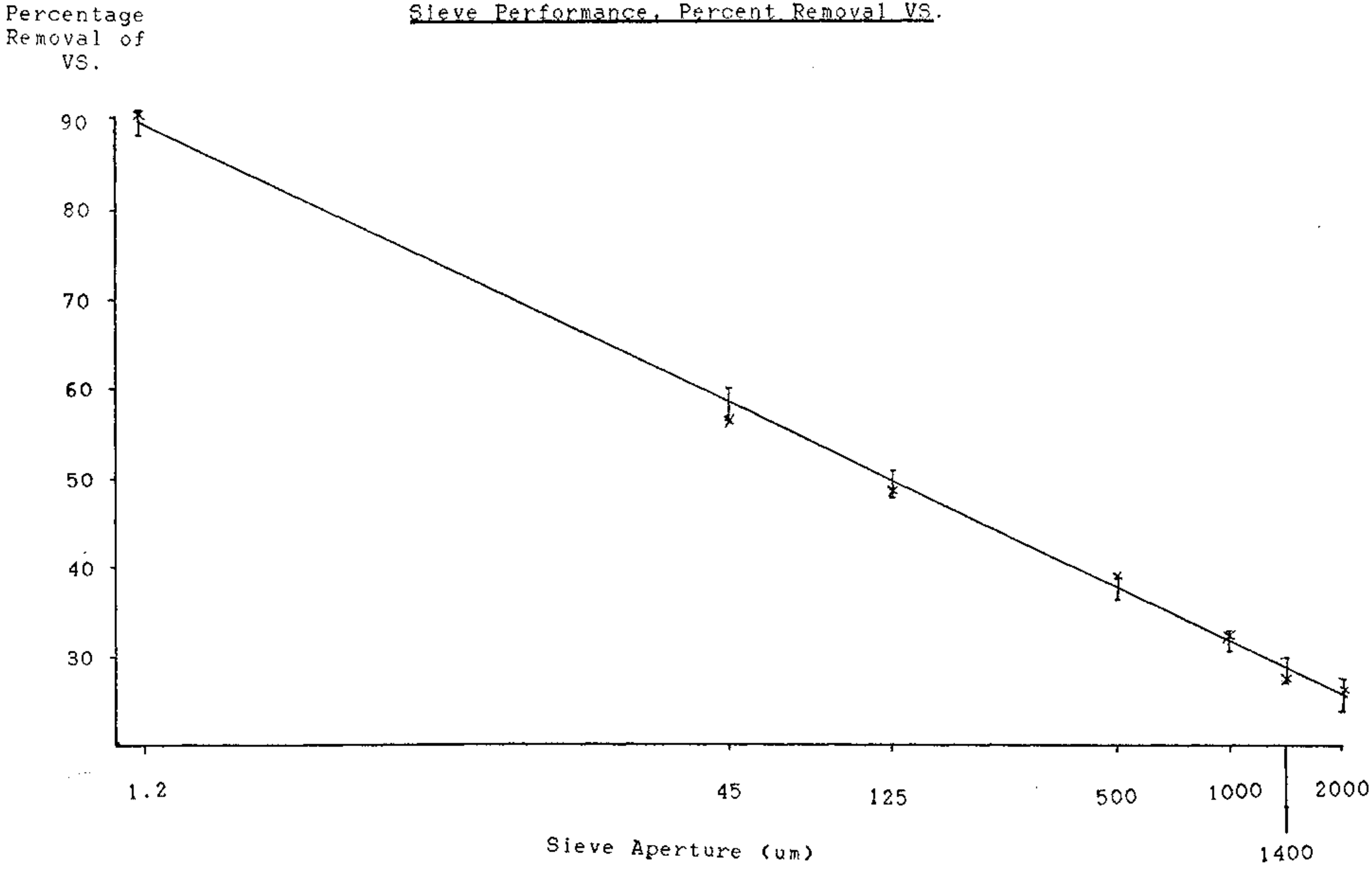


Figure 5.3

Sieve Performance, Percent Removal COD.

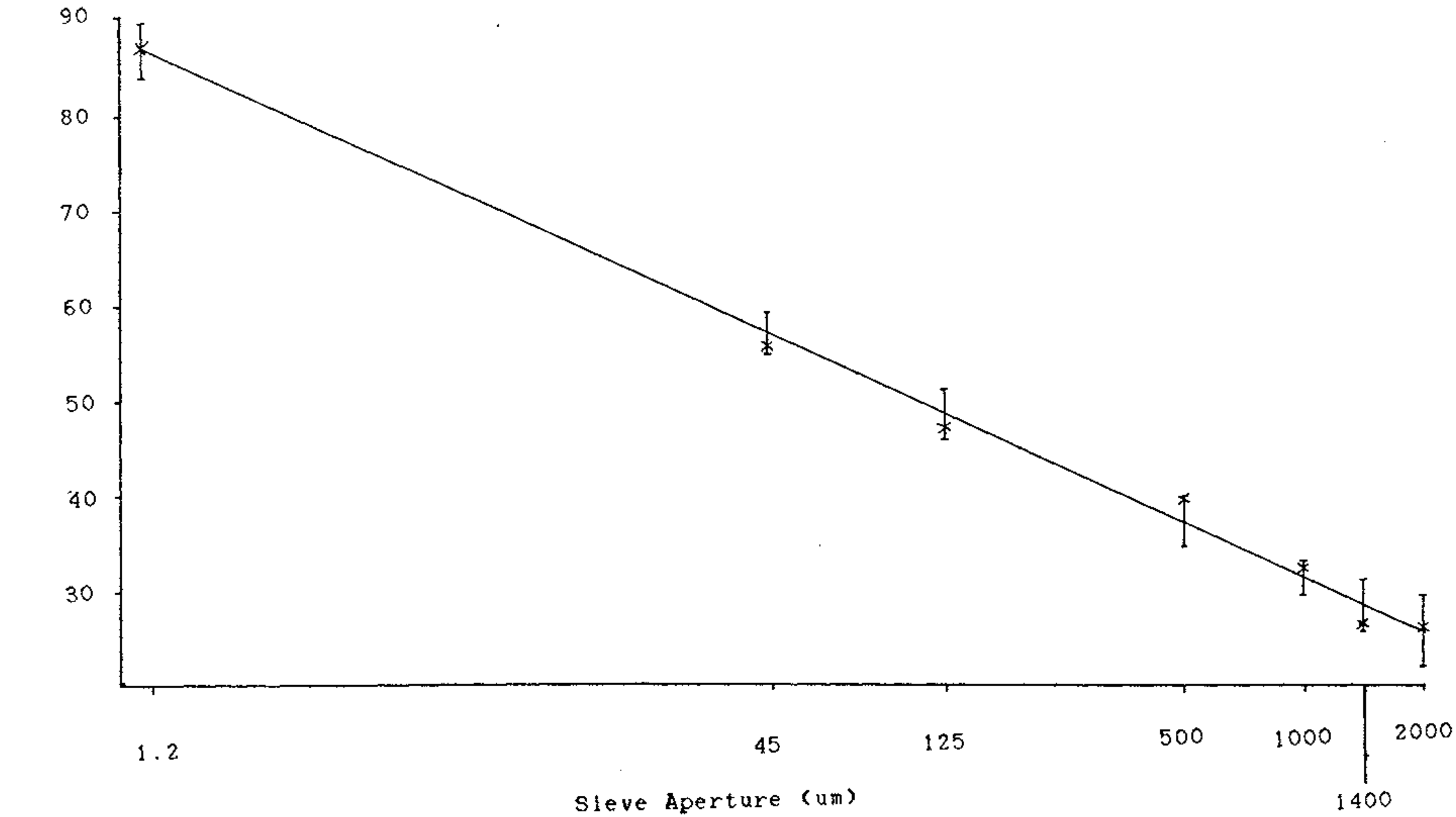


Figure 5.4
Sieve Performance, Percent Removal TKN.

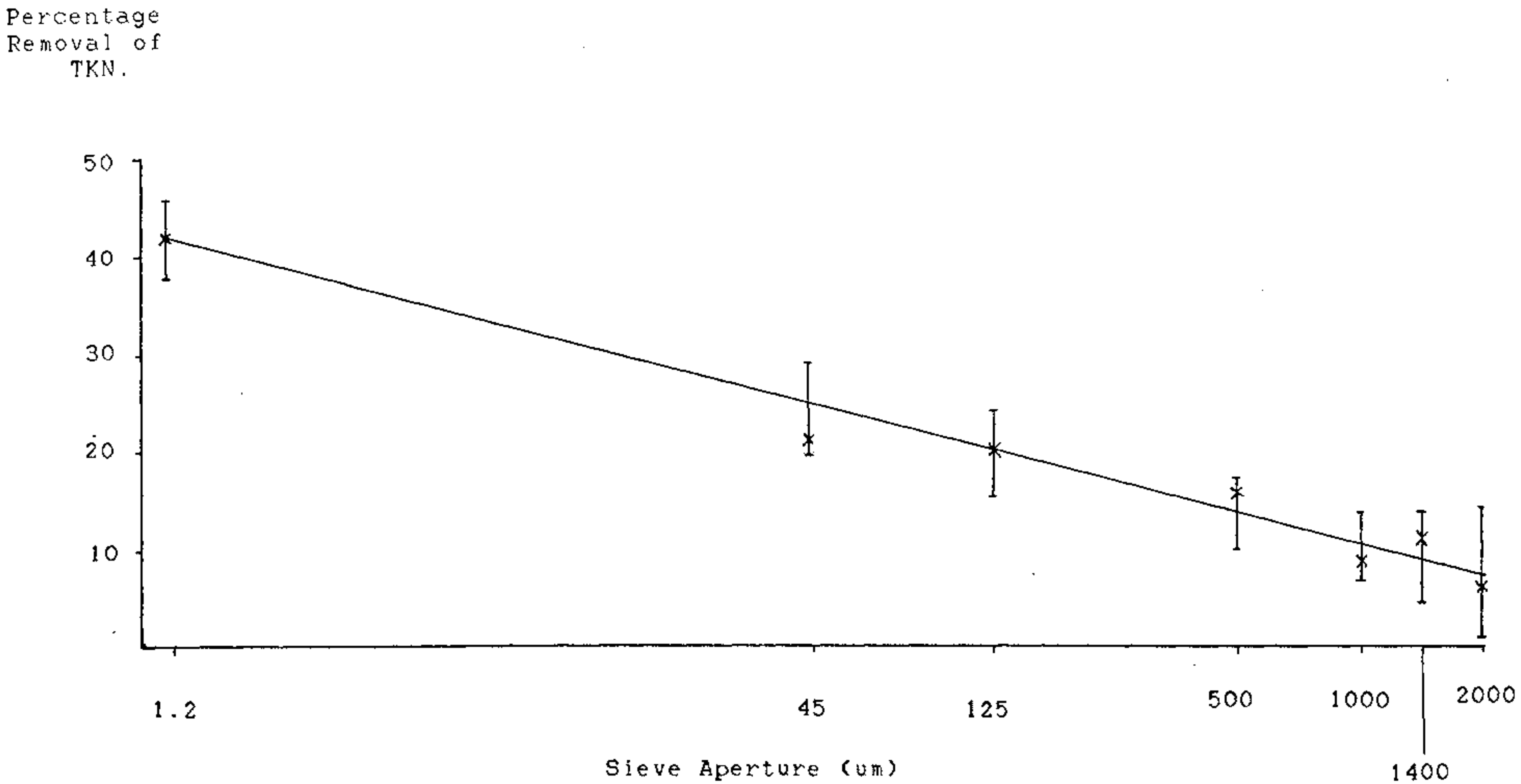
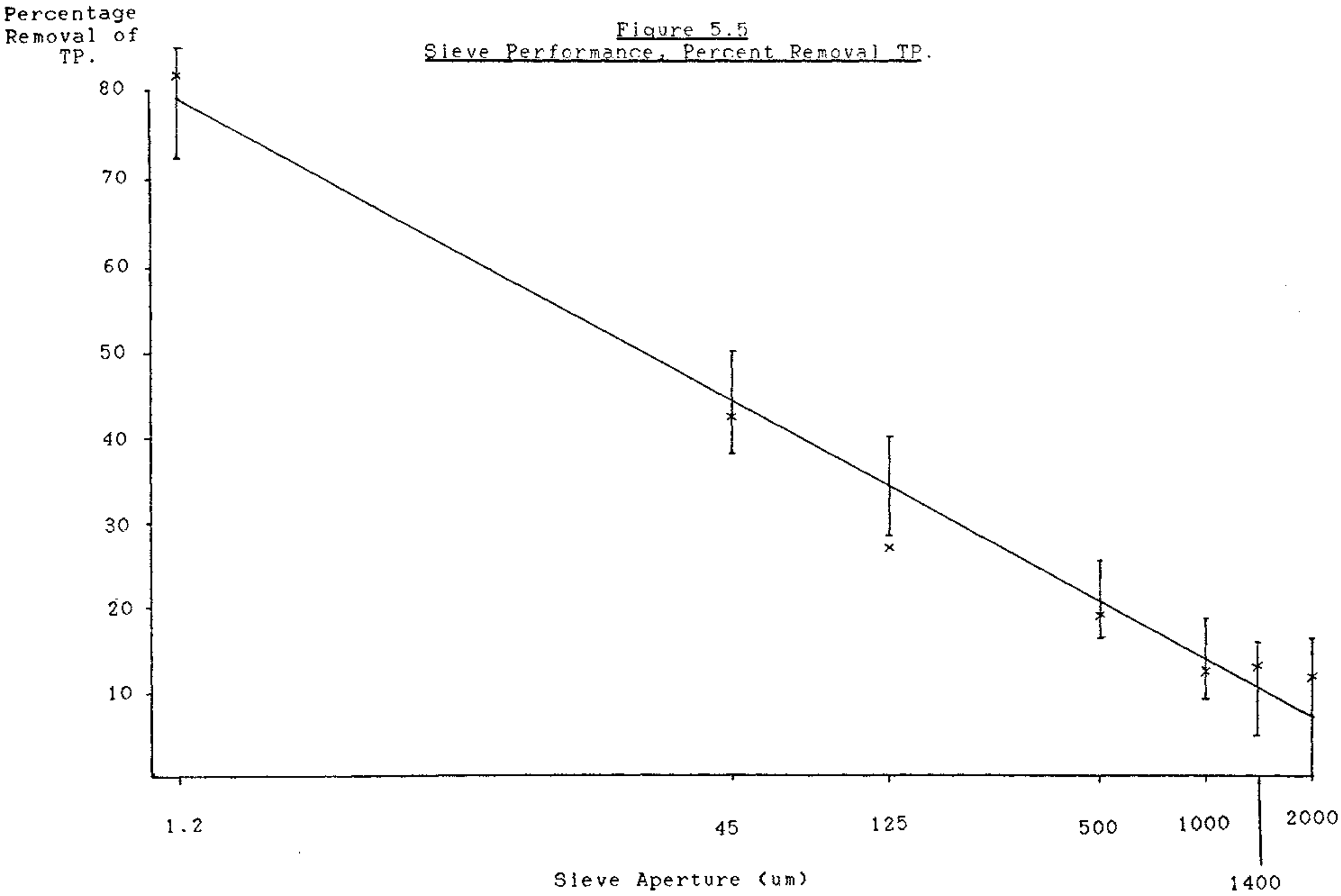


Figure 5.5
Sieve Performance, Percent Removal TP.



TKN is the only parameter which is not largely associated with filtrable solids (suspended solids). It would be expected that any solid-liquid separation process which removes high levels of filtrable solids, would remove high levels of all parameters measured, except TKN.

Table 5.2

Regression of Percent Removal of Wastewater Parameters versus Aperture Size.

Dependent Variable % Removed	Independent Variable Aperture opening(um)	Constant	Correlation Coefficient (r^2)
COD =	-18.94 log x	+87.89	0.9940
TS =	-19.80 log x	+85.78	0.9961
VS =	-19.81 log x	+91.03	0.9982
TKN =	-10.48 log x	+42.14	0.9769
TP =	-22.37 log x	+80.96	0.9742

The 95% confidence interval has been derived for each parameter at each aperture size tested and is shown in figures 5.1-5.5. The confidence interval indicates the variation of each parameter estimate. It can be seen from figures 5.1-5.5 that the confidence interval or variation about the parameter estimate for COD, TS and VS was reasonably narrow, but in the region of 500-2000 um there was some overlap of the confidence interval between aperture openings.

On the other hand the confidence interval for both TKN and TP are wider indicating that there was wider variation in TKN and TP than for the other parameters. This would be expected for TKN since a large proportion of the nitrogen in pig faeces would be expected to be in the form of ammonium, and thus not associated with the particulate organic matter normally affected by physical sieving.

In all parameters tested there was overlap of the 95% confidence interval over the range of 500-2000 um. Since this was in the region of aperture size for most New Zealand piggery screens, a two-way analysis of variance has been conducted on the data in this range for each parameter to determine if there is a significant difference at the 95% level between each of the four sieves. Average values of each parameter removed by each sieve are given in table 5.3.

Table 5.3

Mean Percent Removal of Each Parameter Sieving

	(500um-2000um sieves)			
	500	1000	1400	2000
COD	39.5	32.4	26.1	25.3
TS	32.5	27.0	23.2	22.0
VS	38.6	32.0	27.9	26.3
TKN	15.6	9.1	11.4	7.8
TP	21.9	14.3	13.9	10.0

The two-way analysis of variance (appendix III.a) revealed that at the 95 % significance level there was no interaction between sample concentrations and removal of each parameter, at each aperture size. This means that with different sample concentration, as aperture size changes, the consecutive removal of each parameter on each sieve had the same general relationship for sieves ranging from the 500 to 2000 um and sample concentration ranging from 0.94 to 2.03 % TS.

Since there was no significant interaction at the 95 % level then a two-way analysis of variance was conducted, including the interaction sum of squares, in the error term (appendix III.b). The second two-way analysis of variance revealed two points:

(a) that there was no significant difference (at the 95 % level) between concentrations for COD, VS and TKN, but

(b) there was a significant difference between some of the aperture sizes for all parameters. Since this analysis did not reveal which aperture sizes were significantly different, then a one-way analysis of variance was conducted on aperture sizes only, for each parameter. This is shown in appendix III.c along with the 95 % confidence intervals for each mean, showing which aperture sizes are significantly different. Examination of the 95 % confidence intervals revealed that for all parameters there was a significant difference between the performance of a 2000 um sieve compared with the 500 um sieve. For some of the parameters there was a significant difference between the 1400 um sieve compared with the 500 um sieve, and the 1000 um sieve compared with the 500 um sieve. In no cases was the performance the 2000 um sieve significantly different from the 1400 um sieve, and for only two parameters was the performance of the 2000 um sieve significantly different from the 1000 um sieve (i.e. for TS and VS).

The conclusion drawn from this analysis was that although there was an apparent improvement in performance of sieves as aperture size decreased (except two points for TKN, see table 5.3), over the range of sieve apertures compared (500-2000 um):

(a) a significant improvement in performance would not be achieved by changing from a 2000 um to 1400 um sieve for any parameters,

(b) a change from a 2000 um to a 1000 um sieve will only give a significant improvement in performance for some parameters (TS and VS), and

(c) a significant improvement in performance of all parameters would only be achieved by changing from a 2000 um to a 500 um sieve.

5.22 Settling Trial.

All data for the settling trial was converted to a common factor of percentage removal of each particular parameter after time. Settling curves have been drawn up for each sample and the percentage removal of each parameter over time determined. The settling curves and method of calculation are presented in appendix II. The results are presented in Figures 5.6- 5.10 as the percentage removal of each parameter versus log of time.

It can be seen in figures 5.6-5.10 that there is a linear relationship between log time and percent removal of each parameter for up to 60 minutes settling. For settling durations longer than 60 minutes there is a distinct reduction in settling rate for all parameters. This indicates that a high percentage of

Figure 5.6
Settling Performance, Percent Removal TS

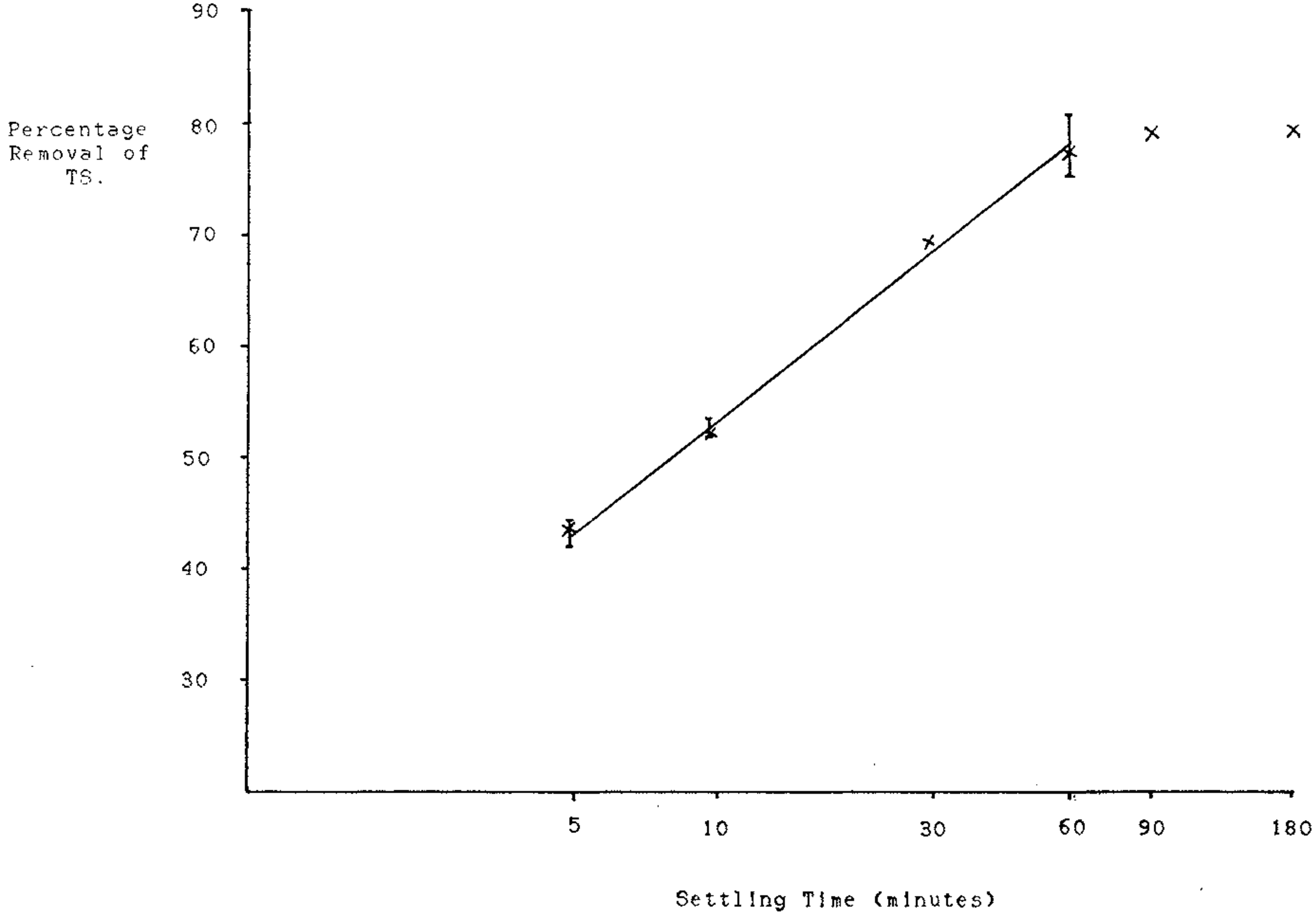


Figure 5.7

Settling Performance, Percent Removal VS.

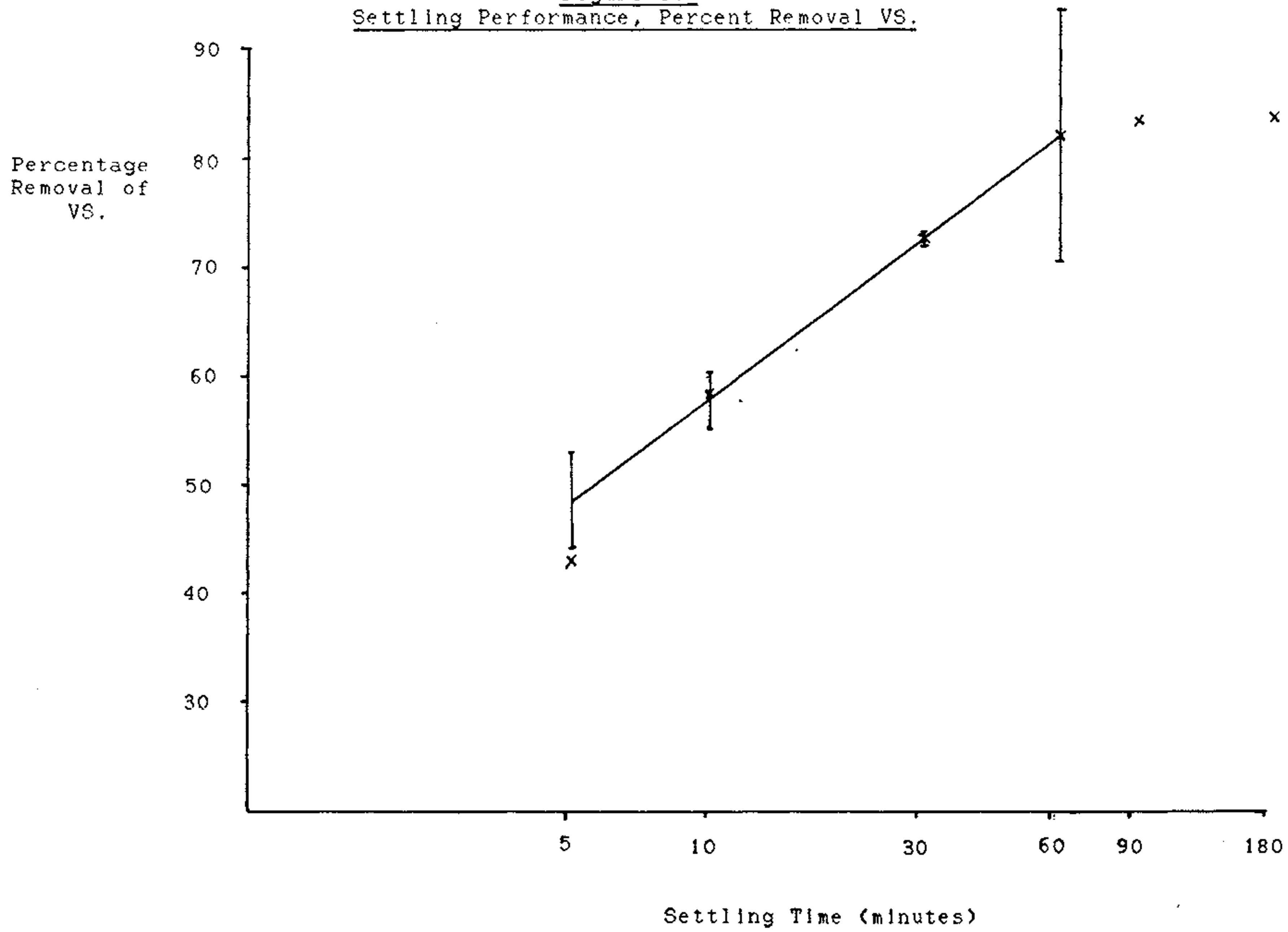


Figure 5.8
Settling Performance, Percent Removal COD.

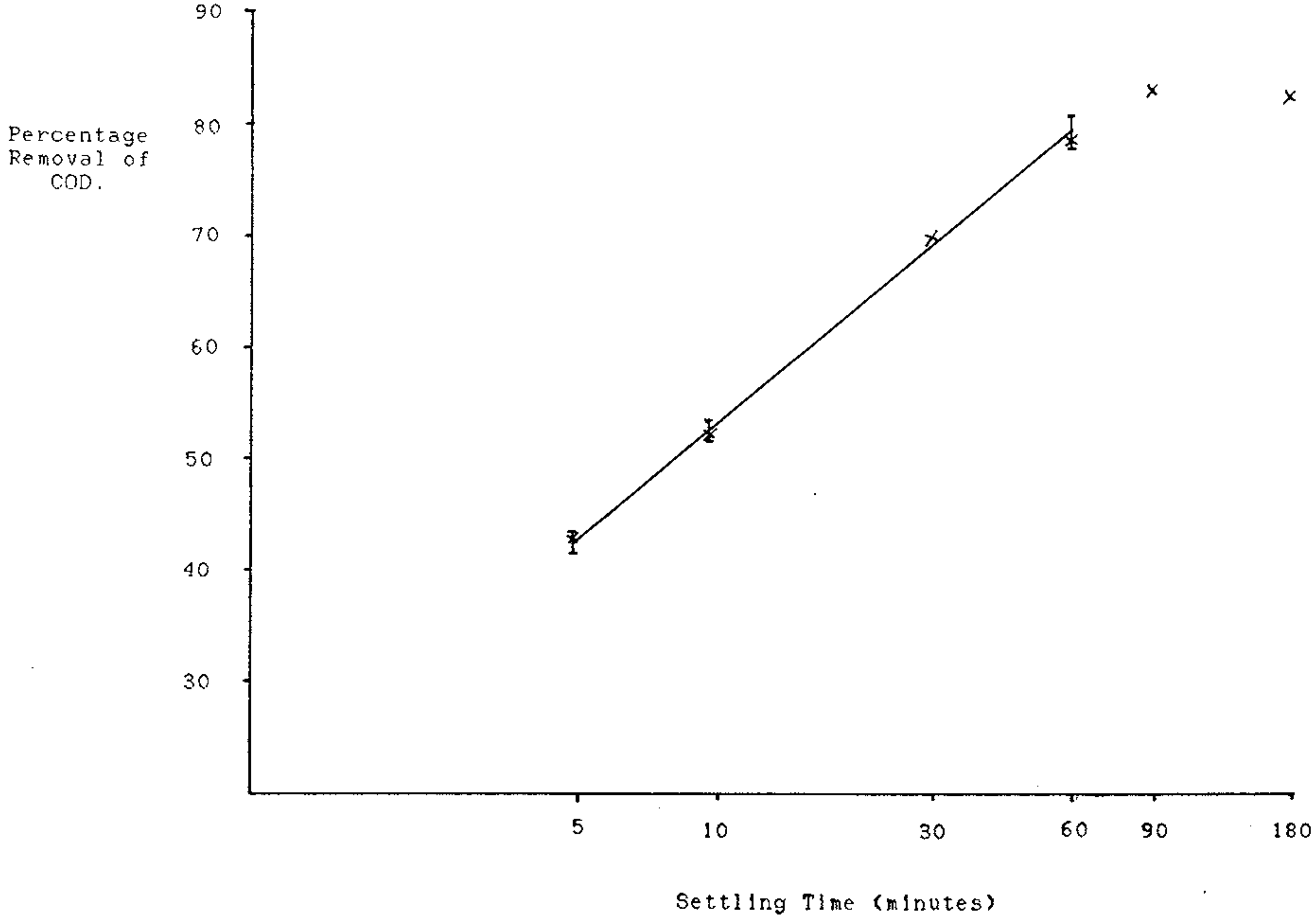


Figure 5.9

Settling Performance, Percent Removal TKN.

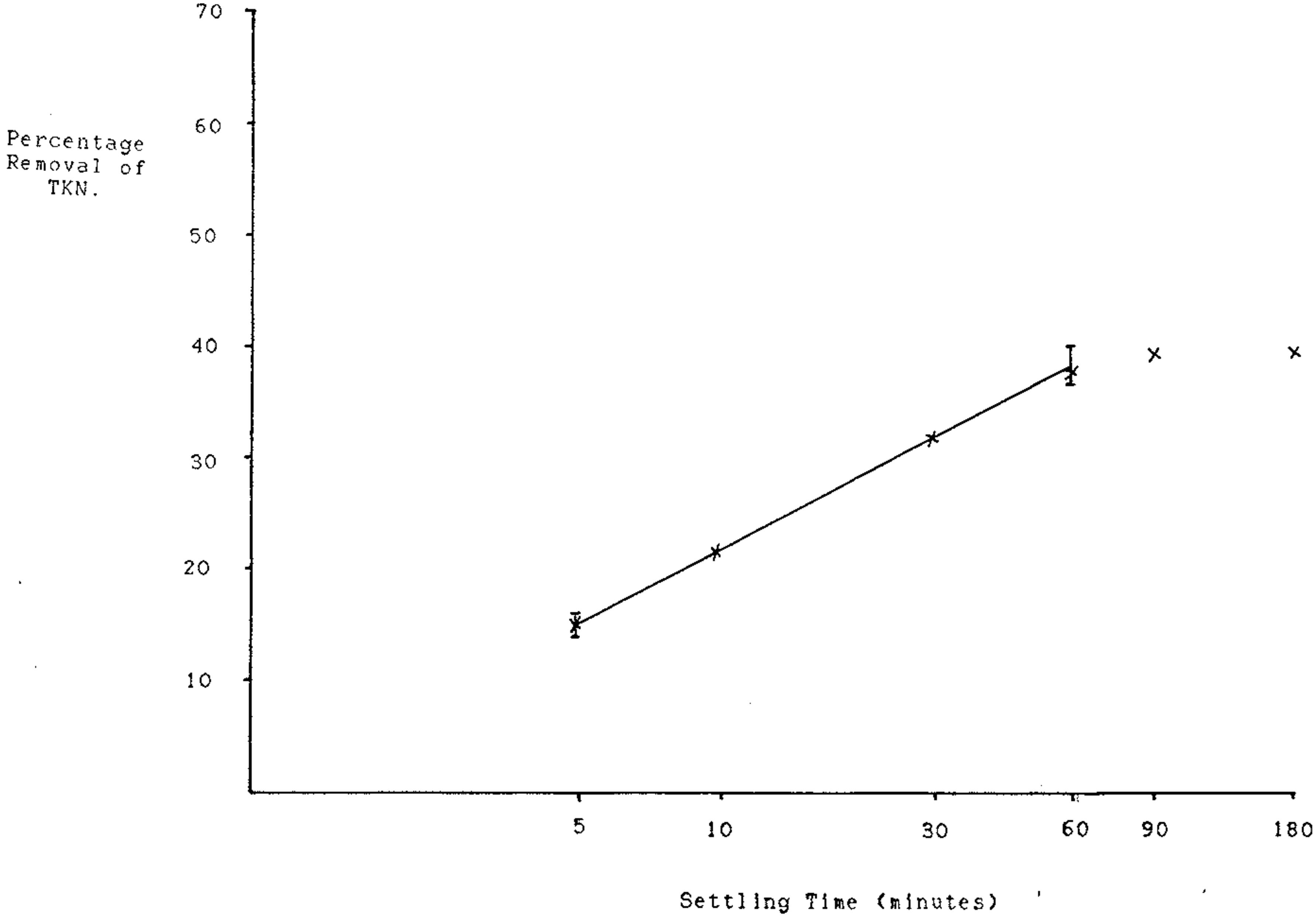
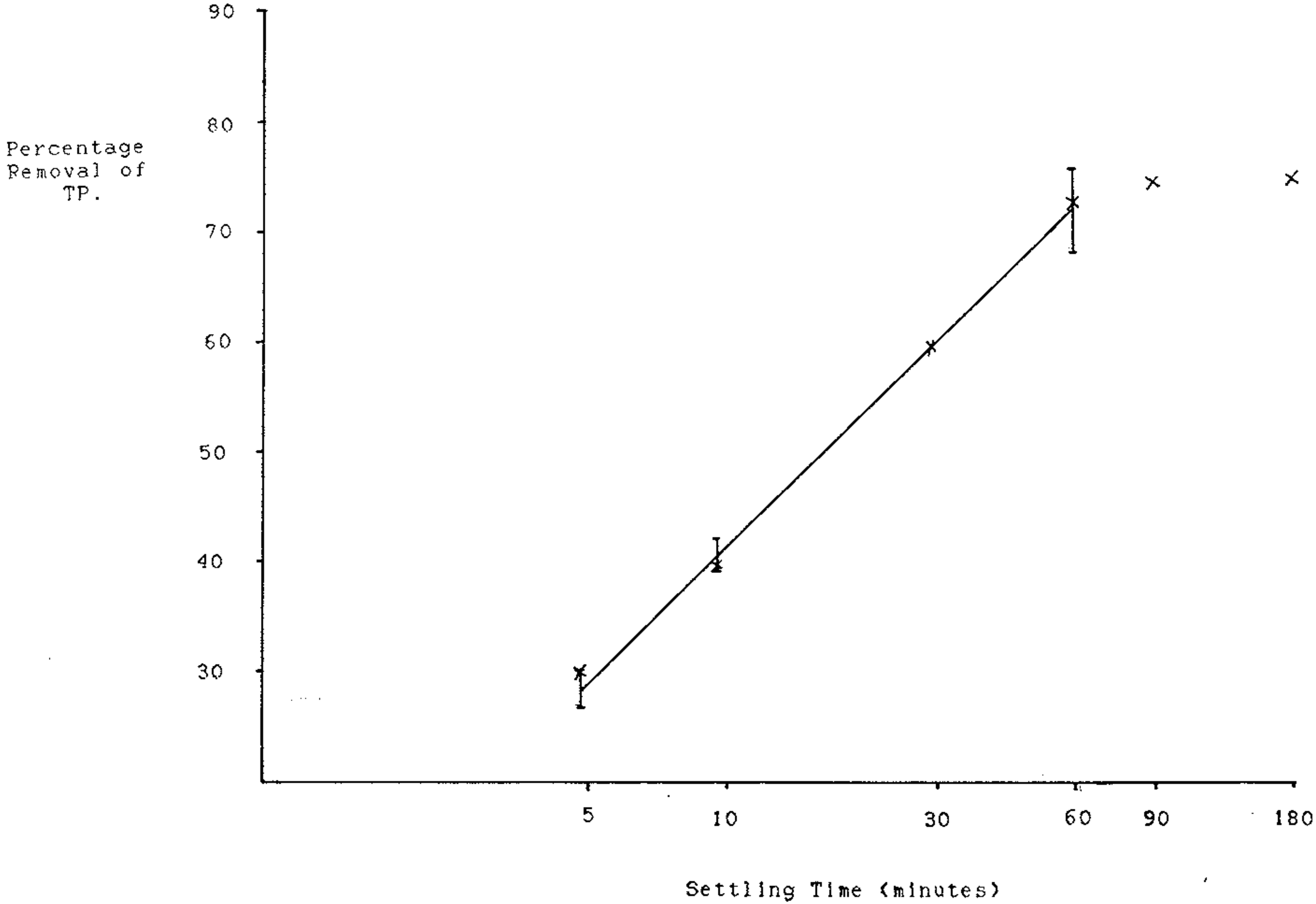


Figure 5.10
Settling Performance, Percent Removal TP.



the settleable solids are removed in the first 60 minutes of settling and therefore there is little point in designing a piggery washdown sedimentation system to settle for durations longer than 60 minutes. Regression equations for each parameter versus log time have been calculated for the first 60 minutes of settling. These are presented in table 5.4. The correlation coefficients for these regressions are high showing a high correlation between each parameter removed and log time.

Table 5.4

Regression of Percentage Removal of Wastewater Parameters versus Log of Time.

Dependent Variable % Removed	Independent Variable Time (minutes)	Constant	Correlation Coefficient (r^2)
COD =	34.00 log x	+18.95	0.9991
TS =	32.44 log x	+20.33	0.9973
VS =	31.25 log x	+26.53	0.9999
TKN =	21.40 log x	+ 0.26	0.9995
TP =	40.25 log x	+ 0.37	0.9974

The regression equations for all parameters take the form:

$$y = m \log x + c, \qquad (1)$$

where, y = % removal of any parameter,

x = settling time (minutes),

m = removal of any particular parameter for a 1 unit increase in time,

c = constant.

As shown in figures 5.6-5.10 this was a straight line increasing with time. As log x was used in equation 1 then a straight line indicates that dy/dx changed with time. By differentiating equation 1 an equation for the rate of removal of any parameter at time x was obtained. To differentiate equation 1 the log was converted to natural log (ln) by the constant 0.4343:

$$y = 0.4343\ m\ \ln x + c, \qquad (2)$$

differentiating equation 2 reveals:

$$dy/dx = 0.4343\ m\ /x \qquad (3).$$

It can be seen from this equation that as settling time, (x) increases then the rate of removal of any particular parameter (dy/dx) will reduce by 1/x.

The general equation 3 can now be applied to the regression equations for each parameter to find the rate of removal at any particular time. The integral (or original regression equation) can be used to determine the rate of removal of each parameter over any particular time period (by subtraction) as shown in table 5.5

Table 5.5

Parameter Removal Rate: Percent per Minute Over Time Period Shown.

Period (minutes)	TS	VS	COD	TKN	TP
0-5	8.60	9.67	8.54	3.04	5.70
5-10	1.95	1.88	2.05	1.29	2.42
10-15	1.14	1.10	1.20	0.75	1.42
15-30	0.65	0.63	0.68	0.48	0.80
30-60	0.33	0.31	0.34	0.21	0.40

Table 5.5 clearly shows that the first five minutes of settling was by far the most effective at removal of all parameters. In effect, increasing settling time from 5 to 10 minutes caused between 58-81 % reduction in the rate of removal of each parameter by settling. To increase the settling time by this magnitude would involve a sedimentation tank of twice the dimensions, and so it clearly becomes more costly to remove (by settling) each extra increment of any particular parameter as settling time increases (since settling time is proportional to tank volume if flow rate remains constant).

5.23 Comparison of Sieving Versus Settling as a Method of Piggery Wastewater Treatment.

The results of the two trials conducted in this study give a basis for deciding which solid-liquid separation process may be most suitable in a particular situation, with certain objectives. This should not be taken as one method of solid-liquid separation being better than the other. In table 5.6-5.10 the percent reduction in each parameter has been calculated for settling times of 5, 10, 15, 30 and 60 minutes from each regression equation. The regression equation for sieving was used to calculate the sieve aperture which would be required on average to achieve the same level of removal of each parameter.

Table 5.6

Settling Time Compared with Sieve Aperture;

Total Solids.

Settling Time (minutes)	Percentage Reduction	Sieve Aperture Required to Achieve Same % Reduction TS.
5	43.00	145 um
10	52.77	46.5
15	58.48	23.9
30	68.25	7.7
60	78.01	2.5

Table 5.7

Settling Time Compared with Sieve Aperture;

Volatile Solids.

Settling Time (minutes)	Percentage Reduction	Sieve Aperture Required to Achieve Same % Reduction VS.
5	48.37	142.4 um
10	57.78	47.7
15	63.28	25.2
30	72.69	8.4
60	82.10	2.82

Table 5.8

Settling Time Compared with Sieve Aperture;

Chemical Oxygen Demand.

Settling Time (minutes)	Percentage Reduction	Sieve Aperture Required to Achieve Same % Reduction COD.
5	42.71	242.9 um
10	52.95	69.9
15	58.94	33.8
30	69.17	9.7
60	79.41	2.8

Table 5.9

Settling Time Compared with Sieve Aperture;

Total Kjeldahl Nitrogen.

Settling Time (minutes)	Percentage Reduction	Sieve Aperture Required to Achieve Same % Reduction TKN.
5	15.22	370.4 um
10	21.66	90.0
15	25.43	39.3
30	31.87	9.6
60	38.31	2.3

Table 5.10

Settling Time Compared with Sieve Aperture;

Total Phosphorus.

Settling Time (minutes)	Percentage Reduction	Sieve Aperture Required to Achieve Same % Reduction TP
5	28.51	221.1 um
10	40.63	63.5
15	47.71	30.7
30	59.84	8.8
60	71.96	2.5

This data shows that at the shortest settling time of 5 minutes, to achieve an equivalent percent removal of any particular parameter a sieve with apertures of between 372- 142um is required. Obviously, as settling time increases then the aperture size of a sieve to achieve similar performance decreases.

Two important points arise:

(a) 372- 142 um aperture sizes are substantially smaller than those in commercial operation in New Zealand piggeries at present, although flexible screens with apertures as low as 100 um have been used overseas (Ferdnandes et al, 1988), and

(b) it would be expected that as screen aperture size decreases then associated blockage problems would increase. This may necessitate the use of flexible or vibrating screens and the use of a driving force in the screening operation, increasing the cost of operation.

5.3 Correlation Between Specific Parameters.

There are several parameters which may be compared to investigate the degree of correlation. Sieving and sedimentation are inherently different separation processes, hence the characteristics of their resulting substrate will differ. Therefore for each comparison two separate correlations have been undertaken, one for sieving and the other for settling.

5.31 BOD versus COD correlation.

This correlation is required to give an estimate of BOD without analysing BOD for each sample. For the number of samples being analysed it would have been impossible to analyse each sample, since limited equipment was available to perform the tests, and they require a 5-day incubation period.

The results of the correlation are given in table 5.11.

Table 5.11

Correlation of BOD versus COD.

Dependent Variable (BOD, mg/l)	Independent Variable (COD, mg/l)	Constant	Correlation Coefficient (r^2)
x(sieving)=	0.17y	+2574	0.8222
x(settling)=	0.14y	+2890	0.6623

The correlation coefficient for settling was low since a breakdown of the incubation equipment meant that only four samples were analysed. The use of this equation for predicting the expected BOD of a sample from the COD would be quite suspect. On the other hand 12 samples were analysed for sieving. The correlation coefficient indicates that correlation between BOD and COD was strong, and this regression equation would be expected to give a reasonable estimate of BOD from a sample COD.

5.32 COD versus VS/TS Correlation.

COD, VS and TS were analysed for all samples. The tests for VS and TS are relatively simple and easy where as the test for COD is more complex. If a strong relationship exists between COD and either VS or TS, then this could mean COD could be predicted in future trials by doing a limited number of COD analyses and establishing a relationship between COD and VS or TS for the particular waste in question. In selecting these parameters for comparison the nature of each analysis was considered. It would be expected that there would be at least some relationship between COD and VS, since COD measures the oxygen equivalent of the organic matter content of the sample, and VS gives a rough approximation of the amount of organic matter present in the solid fraction. Hence as the organic matter content of the sample changes so too would COD and VS. Following on from this since the VS is a measure of a fraction of the TS then a relationship between COD and TS may also be expected.

Table 5.12

Correlation of COD versus VS.

Dependent Variable COD(mg/l)	Independent Variable VS(g/100ml)	Constant	Correlation Coefficient (r^2)
x(sieving)=	21,491y	+519	0.9279
x(settling)=	18,768y	+2068	0.9238

Table 5.13

Correlation of COD versus TS.

Dependent Variable COD(mg/l)	Independent Variable TS(g/100ml)	Constant	Correlation Coefficient (r^2)
x(sieving)=	16,059y	-733	0.9431
x(settling)=	15,974y	+1398	0.3390

The correlation coefficients for COD versus VS shows that there was a high degree of correlation between these two parameters for both sieving and settling. On the other hand the correlation coefficients for COD versus TS was high for sieving and low (unreliable) for settling. It would appear that all correlations except COD versus TS (settling) would be reliable indicators of COD for future trials. An explanation of this low correlation (COD vs TS, settling) would be that the inorganic constituents are likely to be much denser than the organic constituents. This is not a problem when sieving or when only measuring the organic constituents, but when considering both organic and inorganic under a settling regime, then the denser inorganic components are likely to settle at a much faster rate than the organic solids. Therefore they will be removed disproportionately to their presence in the wastewater.

5.4 Effect of Total Solids Concentration on Solid-Liquid Separation.

Since the initial concentration of each sample for both trials varied throughout the course of the trials, there was an opportunity to determine whether sample TS concentration affected either of the solid-liquid separation processes. A one-way analysis of variance was conducted on the initial concentration of each sample, for TS for both trials, to determine if there was a significant difference between any sample concentrations. The results of this analysis (appendix IV) show that there is a significant difference between some samples at the 95 % significance level. The 95 % confidence interval has been calculated for each sample and is presented in appendix IV. This reveals that there was a significant difference between at least 3 samples in both trials.

Since there was a significant difference between TS concentration of some samples the effect of sample concentration has been determined in the following manner. For each TS sample in both trials, a linear regression has been conducted. The results are presented in tables 5.14 and 5.15.

Table 5.14

Regression of Individual Samples for Sieving Trial

Sample	Dependent Variable % Removed	Independent Variable Sieve Aperture, um	Constant	Correlation Coefficient (r^2)
1	TS =	-20.4 log x	+86.0	0.9946
2	TS =	-18.5 log x	+84.7	0.9962
3	TS =	-21.5 log x	+88.5	0.9902
4	TS =	-19.9 log x	+83.9	0.9911
5	TS =	-19.2 log x	+86.3	0.9917

Table 5.15

Regression of Individual Samples for Settling Trial

Sample	Dependent Variable % Removed	Independent Variable Sieve Aperture, um	Constant	Correlation Coefficient (r^2)
1	TS =	39.2 log x	+ 9.0	0.9980
2	TS =	36.3 log x	+15.0	0.9998
3	TS =	32.3 log x	+21.1	0.9937
4	TS =	27.9 log x	+17.2	0.9949
5	TS =	26.6 log x	+39.3	0.9781

For both trials a graph of TS concentration versus the rate of TS removal was prepared, (figures 5.11 & 5.12). For the sieving trial the rate of removal of TS for each regression is over a narrow range from 18.5 log aperture size to 21.5 log aperture size. This, in conjunction with the observation that the points

Figure 5.11
TS Concentration versus Removal Rate.
(Sieving)

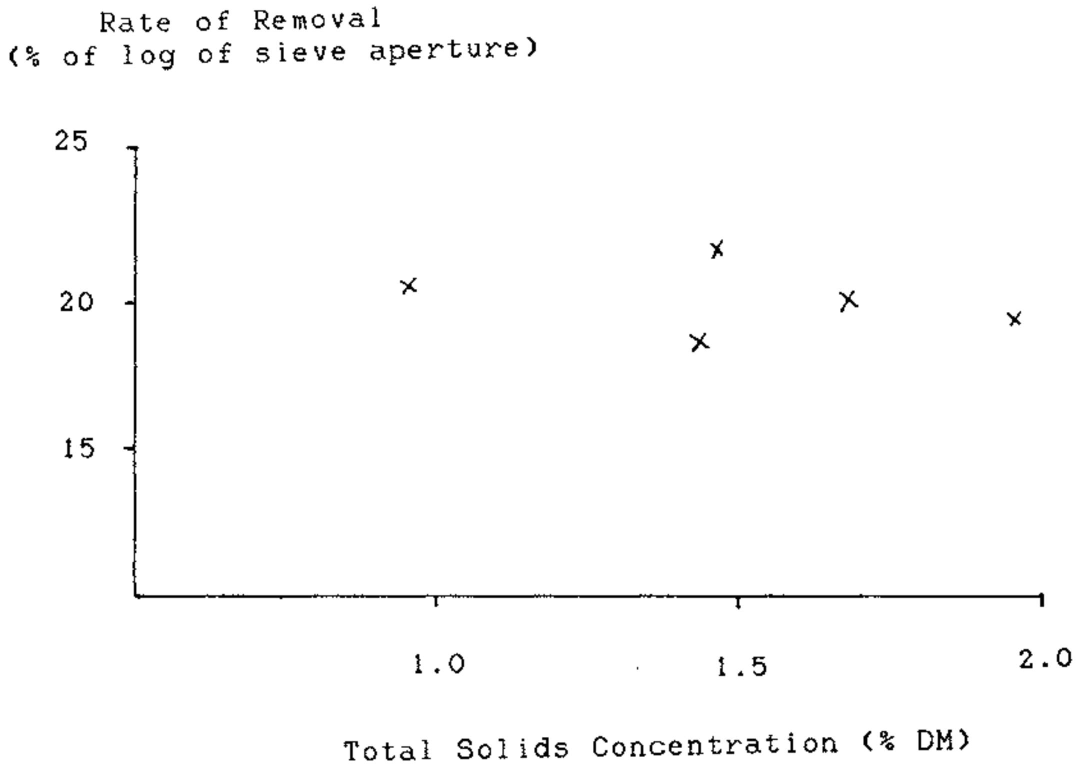
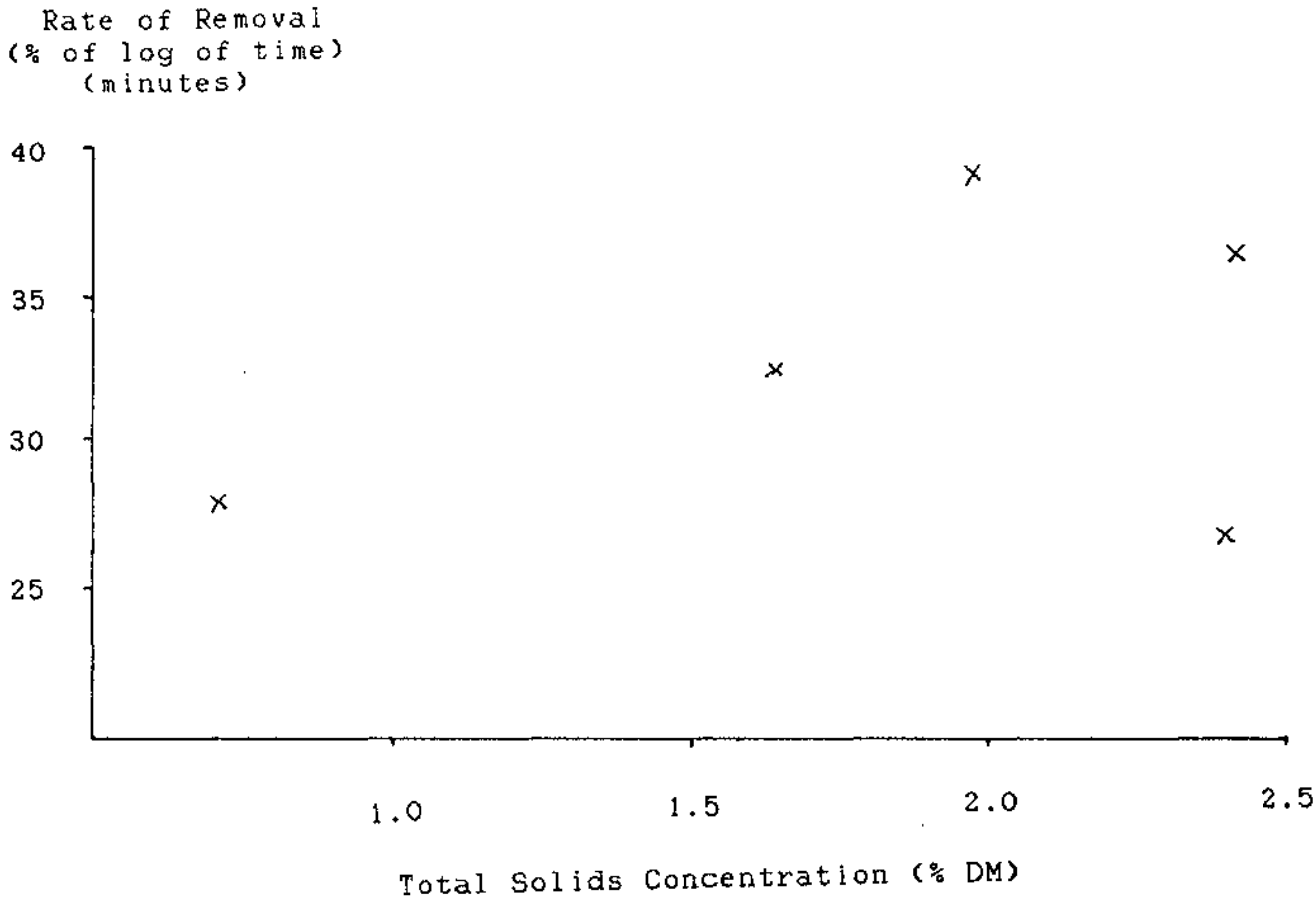


Figure 5.12
TS Concentration versus Removal Rate.
(Settling)



on figure 5.11 appear to reveal no trend would tend to indicate that over the TS concentrations tested by sieving there appears to be no effect on the performance of the sieves due to TS concentration.

On the other hand the settling trial had a wider range of TS removal rates (26.6 log time to 39.2 log time). Observation of the points in figure 5.12 tend to indicate that at low TS concentrations (0.7 % TS) the removal rate was low, and that removal rate increased as TS concentration increased, up to about 2.0 % TS. Above a TS concentration of 2.0 % the removal rate tended to reduce.

This general trend of increasing TS removal rate as TS concentration changes, then a reduction in TS removal rate after some optimum TS concentration is in agreement with Jett et al (1975) and Fischer et al (1975). This trend is explained by the type of settling that occurs as TS concentration changes, as detailed in section 2.42. Although the trend is in agreement with the above authors the TS concentrations where optimum settling rates are achieved appear to be higher in this trial (ie. 1.9 % TS compared with 1.0 % TS from Jett et al (1975) and Fischer et al (1975)). The reason for this is unclear, but does indicate the need to determine TS concentration before designing a sedimentation system for treatment of piggery wastewaters.

5.5 Comparison of Results With Other Research.

5.51 Sample Variation.

High variation in wastewater samples collected is shown in Table 5.1. This is in agreement with Farran (1979) who states in his trials "this occurred even though wastes were agitated in the sump. Such variability illustrates the problem which any waste treatment system has to contend with when handling piggery wastewater in practice".

Comparison of measured parameters with Farran (1979) shows that the mean levels of COD, TS and TKN were approximately similar, although variation was greater in Farran's results. The level of VS and TP were substantially higher in this trial. This may be a result of differing pig diets, which Farran (1979) has neglected to describe.

5.52 Particle Size Distribution and Sieving.

The particle size distribution as shown in figure 5.2 is in agreement with the results of Hill & Tollner (1980) and Gilbertson et al (1987)(figure 2.1), in the range of particle sizes from 125 um to 2000 um. Below this range the results of this trial show a much greater removal rate than the above authors. The general trends are the same; removal of TS down to 500 um is reasonably low, below 500 um the rate of removal of TS for a unit decrease in sieve aperture size is increasing. It appears from the results of these trials that to remove high levels of TS sieve apertures less than 500 um are required. This conclusion is in contrast with the results of Hegg et al (1981) who show that the percent removal of TS versus particle size is reasonably linear (figure 2.1), and therefore that a reduction in aperture opening size will have a similar effect between 74 to 2400 um. The reason for this discrepancy is not clear.

Comparing the results of COD and nitrogen removal with that of Hill & Tollner (1980) and Harper et al (1974) for a 250 um aperture, shows further variation. Although a 250 um sieve was not used in this trial the performance of a 250 um sieve has been predicted for the purposes of comparison from the regression equation in table 2.5. The COD removal would be expected to be about 42.5 %, which is close to that shown by Hill & Tollner (1980) at 42 %, but higher than that achieved by Harper et al (1974) at 26 %. The removal of nitrogen on the 250 um aperture is difficult to compare since this and the research of Hill & Tollner (1980) measured only TKN, while Harper et al (1974) measured total nitrogen. However this trial shows by far the lowest nitrogen removal at only 17 %, Hill & Tollner (1980) showed a 30-40 % removal while the research of Harper et al (1974) showed a 59 % total nitrogen removal.

Comparison of these results with the results of other research using a stationary screen to separate swine wastewater again reveals major variation. The influent solids concentration was similar to that of denBoer & Wall (1987) and Farran (1979) using a 500 um screen. The removal of TS and COD at 33 % and 40% respectively is within the range quoted by denBoer & Wall (1987), noting that they revealed a wide range. Both TS and COD were considerably higher than the removal quoted by Farran (1979) for a 500 um stationary screen (see table 2.3). The influent solids concentration for the wastewaters tested by Shutt et al (1975) at 0.2-0.7 % TS were considerably lower than in this trial. Removal of TS and COD on a 1000 um stationary screen was much higher than found in this trial, where as the removal on a 1500 um stationary screen was lower for TS and similar to this trial for COD removal.

The results of this section further support Farran's (1979) statement that there is considerable variation in piggery wastewaters. It is difficult to determine why these variations occur but it does emphasise a need to know the feed, housing and management conditions under which pigs are kept before attempting to analyse the characteristics of their waste and performance of any waste treatment process, and before extrapolating data from a waste treatment system to another location.

The results of the settling trial appear to be in close agreement with the results of Jett et al (1975), Gilbertson & Neinaber (1979) and Moore et al (1975), and slightly higher than the performance quoted by Cullum et al (1984) (table 2.7 compared with tables 5.6 & 5.7). It would appear that regardless of feed types, high levels of TS and COD may be removed by settling in reasonably short time periods (5 to 10 minutes). This would indicate that the solid fraction of most piggery wastewaters may be of similar density and so may not be as dependent on feed type as the screening process appears to be.

5.6 Design From Data.

Even though it was not an objective of this study to determine design parameters for solid-liquid separation using screens or sedimentation, determination of levels of each parameter removed by certain aperture size sieve or settling time can be used to determine the design of on farm scale solid-liquid trials using the processes tested in this study.

The design procedure should include these steps:

(a) determine objectives of waste treatment system,

(b) determine whether solid-liquid separation will achieve any of the objectives listed in (a),

(c) if solid-liquid separation will achieve any of the objectives of the wastewater treatment system, then use regression equations to determine the screen size or sedimentation time required to achieve the objectives, (if several objectives are met then use the minimum screen aperture size or maximum settling time,

(d) decide whether this is a realistic screen aperture size or settling time with regard for operating problems or construction costs. For example a 10 minute settling time may achieve a 53 % TS reduction where as a 5 minute settling time may achieve a 43 % TS reduction. For an extra 5 minutes of settling time only a 10 % increase in TS is achieved at the cost of a sedimentation tank of twice the volume. It may then be decided to accept the lower TS reduction in view of the lower construction costs required, and

(e) to account for less than optimum conditions of solid-liquid separators in the field, the detention times should be multiplied by a factor of 1.25-1.5 (Metcalf & Eddy, 1979). There is no such published safety factor for screens.

The results of these trials have not determined the effect of flow rate on screen performance or the concentration of solids or slurry from either process.

The effect of flotation of low density particles has been overlooked in the sedimentation trials. This should be taken into account in the design of farm scale sedimentation trails, by incorporating a baffle device on the liquid surface to prevent these flotables exiting with the effluent flow.

6. Summary and Conclusions.

Solid-liquid separation is used widely as a waste treatment process. A wide range of solid-liquid separators have been applied to agriculture overseas, but their application in New Zealand has been limited.

Application of overseas research into solid-liquid separation of agricultural wastes in New Zealand is unreliable since New Zealand livestock feeding, housing and management techniques differ markedly from overseas conditions, which in turn influences wastewater characteristics. In New Zealand, piggeries contribute a major potential source of environmental pollution, but are relatively few in number compared with other agricultural point sources of pollution (ie. cowsheds) and so appear to be prime candidates for research into the reduction of pollution discharges.

This study has determined the levels of five pollution parameters associated with particle size and settling time, for wastewaters from a New Zealand piggery. This information has been used to compare the effectiveness of sieving and settling on separating solids from piggery wastewaters. The trials have been conducted on a laboratory scale.

Based on the results of this study the following conclusions were drawn:

(i) there is considerable variation in piggery wastewater characteristics from day to day,

(ii) a high proportion of all parameters measured (75-90 %), except TKN are associated with filtrable solids, therefore it is expected that some form of solid-liquid separation can remove high levels of all parameters measured, except TKN,

(iii) for sieves, considerable variation in the removal of given parameters under given aperture sizes occurred between this and other research,

(iv) to achieve substantial reductions in all parameters by sieving (except TKN), particles less than 500 um need to be removed, since 63-80 % of all parameters were associated with particles less than 500 um,

(v) only 14-37 % of all parameters were associated with particles in the 500-2000 um range, and reduction of sieve apertures in this range did not significantly improve the removal of all parameters measured in this trial,

(vi) for settling, the rate of removal of all parameters reduces with time, a major proportion of all parameters are removed in the first 5 minutes of settling, and a high proportion of all parameters which are removed by long term settling will actually settle in 60 minutes,

(vii) in comparing screening with sedimentation, it would appear that very small aperture screens would be required to enable screening to achieve the same level of removal of each parameter as settling for relatively short time periods,

(iix) this trial fails to reveal any effect due to TS concentration on sieving performance, but does tend to indicate an effect on settling performance due to TS concentration,

(ix) the use of regression equations to predict the performance of solid-liquid separation processes tested in this trial should be used with caution, and preferably tested on a farm scale basis in light of the variability in performance of solid-liquid separators between researchers, to determine if this variability in performance also exists between piggeries in New Zealand employing similar feeding, housing and management techniques, and

(x) it would appear that high correlation between COD and VS could be used to advantage in future piggery solid-liquid separation trials to reduce time and complexity.

7. Recommendations for Further Research.

This is a preliminary study investigating the pollution parameters associated with particle size and settling time of piggery wastewaters. The results suggest that sedimentation is a very effective waste treatment process for piggery wastewaters. Farm scale tests using sedimentation should be undertaken to determine the following:

(a) the performance of sedimentation applied on a farm scale,

(b) the concentration of various parameters in the underflow slurry from a sedimentation system,

(c) methods of utilizing or disposing of the slurry produced by sedimentation, and

(d) to test whether flocculants can be used to economically improve the performance of sedimentation.

Appendix I.

Management Systems at the Pork Industry Board Piggery Old West Road, Palmerston North.

The Pork Industry Board Piggery at Old West Road, Palmerston North is primarily a pig breeding centre. The breeding unit is based on 180 sows and progeny from these sows is evaluated for breeding throughout New Zealand. Run in conjunction with this breeding unit is a 1500 pig fattening operation which fattens for slaughter progeny not required for breeding purposes.

A barley based diet supplemented with 7 % meat and bone meal is the base diet fed to all animals. The level of feeding and supplementation with vitamins and minerals depends upon the class of swine. Finishing and weaner pigs are fed ad lib, and the base diet is supplemented with 1-2 % blood and fish meal, and vitamins and minerals. The sows diets vary depending on physiological condition. Empty and gestating sows are fed at maintenance level with the base diet only (approximately 2.5 kg/day/sow). Lactating sows are fed ad lib a similar diet to the finishing pigs, except that the proportions of supplementation varies.

The barley feed is crushed by a hammer mill on site and passed through a 3000 um screen before mixing supplements. All supplements are mixed on site.

The feed is delivered to the weaner and fattening houses by automatic conveyor, while sows and guilts are manually fed.

All pigs are housed in standard buildings. Ventilation of these buildings is thermostatically controlled by raising or lowering a curtain wall. The temperature is kept in the range of 18-24 degrees celsius. Pen flooring depends on class of swine. Weaners are housed in pens with a complete grating floor, finishing pigs are housed in pens with only one third of the floor grated, while sows are housed in crates or pens with only their hind feet over grating.

All pens are washed down daily to remove dung and urine. The washing system consists of manual hosing with high pressure hoses.

Pig liveweights range from weaner and finishing pigs which are grown up to 85 kg over a 20 week period. Guilts average about 110-120 kg while sows are up to 260-270 kg.

Appendix II.

Data Manipulation Methods.

(a) Trial I (sieving).

All data was collected in the form of absolute level of each parameter after passing a certain aperture size sieve. This was converted to cumulative percentage removal of each parameter after passing each sieve by the following equation:

$$y(n) = [m - x(n)]/ m \times 100 \quad (1)$$

where ; $y(n)$ = cumulative % removal of parameter on all sieves with apertures greater than and equal to sieve (n),

$x(n)$ = level of parameter remaining in sieved effluent after passing sieve 'n',

m = total level of parameter in initial sample.

(b) Trial II (settling).

The data for trial II was collected in the form of absolute level of each parameter at a particular port height in a specific time. The mode of settling was assumed to be substantially flocculant type and was analysed in the normal manner as shown by the following method (Metcalf & Eddy, 1985).

A grid of settling time (x-axis) versus sampling port height (y-axis) was drawn as in figure AII.1. The percentage removal of each parameter at each sample port and time was calculated as for trial I (equation 1) and transposed onto the grid at the appropriate time and height, point. The percentage removal figures on the grid were used to interpolate curves of common percentage removal of each parameter (as done in a contour survey plot) on figure AII.1. From this diagram the percentage removal of each parameter in a 2 metre settling tank, over a certain time can be calculated. The following equation is used:

$$\text{Percent Removal} = \left(\frac{\Delta h(1)}{h(t)} \times \frac{R(1)+R(2)}{2}\right) + \left(\frac{\Delta h(2)}{h(t)} \times \frac{R(2)+R(3)}{2}\right) \ldots$$

$$\ldots + \left(\frac{\Delta h(n)}{h(t)} \times \frac{R(n-1)+R(n)}{2}\right)$$

where; $\Delta h(n)$ = difference in height of consecutive contour lines of percentage removal of parameter,

$h(t)$ = total height of column,

$R(n)$ = percentage removal of the nth contour line.

Example: from figure AII.1.

The percent removal of TS in 30 minutes is:

(1) $$\frac{0.35}{2} \times \frac{100 + 80}{2} = 15.75$$

(2) $$\frac{0.525}{2} \times \frac{80 + 70}{2} = 19.65$$

(3) $$\frac{1.05}{2} \times \frac{70 + 50}{2} = 31.5$$

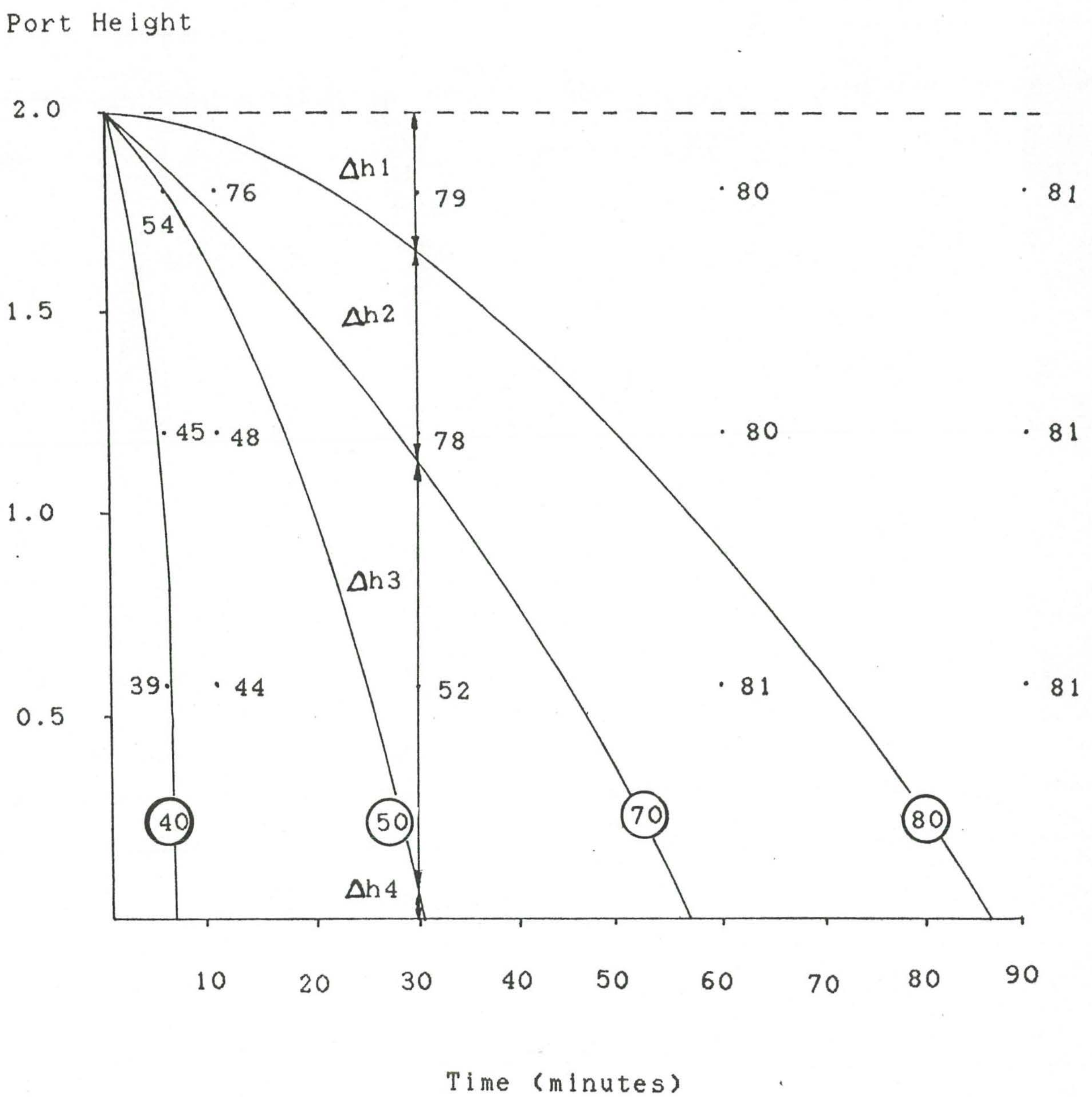
(4) $$\frac{0.075}{2} \times \frac{50 + 49.6}{2} = 1.87$$

Total solids removal = 68.81 %

The percentage removal at a range of times for all parameters were calculated and then used for log time versus percent removal of each parameter, as shown in Chapter 5.

Figure AII.1
Percentage Removal of TS, Time versus Column Height.

Sample 1.



Appendix III.

(a) Two-way Analysis of Variance for Sieve Apertures of 500-2000 um.

Table AIII.a COD.

Source	df	SS	MS	F	f
Sample	4	1645.6	411.4	6.13	2.61
Apertures	3	1813.5	604.5	9.0	2.84
Interaction	12	1563.2	130.3	1.94	2.00
Error	37	2483.3	67.1		

Table AIII.a TS.

Source	df	SS	MS	F	f
Sample	4	241.1	60.28	2.36	2.61
Apertures	3	959.9	320.0	12.55	2.84
Interaction	12	616.8	5.14	0.20	2.00
Error	38	968.5	25.5		

Table AIII.a VS

Source	df	SS	MS	F	f
Sample	4	164.0	41.0	1.47	2.61
Apertures	3	1302.6	434.2	15.55	2.84
Interaction	12	165.0	13.75	0.49	2.00
Error	37	1033.0	27.9		

Table AIII.a TP

Source	df	SS	MS	F	f
Sample	4	1553.8	388.5	4.51	2.74
Apertures	3	676.7	225.6	2.62	2.98
Interaction	12	425.3	35.4	0.4	2.15
Error	26	2237.7	86.1		

Table AIII.a TKN

Source	df	SS	MS	F	f
Sample	4	129.1	32.3	1.07	2.73
Apertures	3	396.5	132.2	4.4	2.96
Interaction	12	247.8	20.7	0.7	2.13
Error	27	811.3	30.1		

Note: Sample = sample concentration

F = calculated value

f = 'f' table value

(b) Two-way Analysis of Variance for Sieve Apertures of 500-2000 um.

(Interaction Excluded).

Table AIII.b COD

Source	df	SS	MS	F	f
Sample	4	1645.6	411.4	0.82	2.56
Aperture	3	1813.5	604.5	1.21	2.79
Error	49	4046.5	499.6		

Table AIII.b TS

Source	df	SS	MS	F	f
Sample	4	241.1	60.3	2.93	2.56 *
Aperture	3	959.9	329.0	15.53	2.79 *
Error	50	1030	20.6		

Table AIII.b VS

Source	df	SS	MS	F	f
Sample	4	164	41.0	1.68	2.56
Aperture	3	1302.6	434.2	17.7	2.79 *
Error	49	1198	24.5		

Table AIII.b TKN

Source	df	SS	MS	F	f	
Sample	4	129.1	32.3	1.19	2.61	
Aperture	3	396.5	132.2	4.86	2.84	*
Error	39	1059.1	27.2			

Table AIII.b TP

Source	df	SS	MS	F	f	
Sample	4	1553.8	388.5	5.5	2.61	*
Apertures	3	676.7	225.6	3.22	2.84	*
Error	38	2662.9	70.1			

Note: * = signifigant at 95 % level

F = calaculated value

f = 'f' table value

(c) One-way Analysis of Variance and 95 % Confidence Interval

for each Parameter.

Table AIII.c COD

```
ANALYSIS OF VARIANCE ON C1
SOURCE     DF        SS          MS         F
C3          3      1867         622      5.85
ERROR      53      5638         106
TOTAL      56      7506
                                   INDIVIDUAL 95 PCT CI'S FOR MEAN
                                   BASED ON POOLED STDEV
LEVEL       N      MEAN       STDEV  ---+---------+---------+---------+---
    1      12     25.29       11.74   (--------*--------)
    2      15     26.09       11.14     (-------*-------)
    3      15     32.35        9.84             (-------*--------)
    4      15     39.51        8.57                      (-------*-------
                                     ---+---------+---------+---------+---
POOLED STDEV =    10.31              21.0      28.0      35.0      42.0
```

Table AIII.c TS

```
ANALYSIS OF VARIANCE ON C1
SOURCE     DF        SS          MS         F
C3          3     953.6       317.9     13.19
ERROR      53    1277.6        24.1
TOTAL      56    2231.2
                                   INDIVIDUAL 95 PCT CI'S FOR MEAN
                                   BASED ON POOLED STDEV
LEVEL       N      MEAN       STDEV  --+---------+---------+---------+---
    1      12    22.008       5.913  (-----*-----)
    2      15    23.200       4.993     (----*----)
    3      15    27.007       4.527            (----*----)
    4      15    32.527       4.286                      (----*----)
                                     --+---------+---------+---------+---
POOLED STDEV =    4.910              20.0      25.0      30.0      35.0
```

Table AIII.c VS

```
ANALYSIS OF VARIANCE ON C1
SOURCE     DF        SS          MS         F
C3          3    1270.1       423.4     16.09
ERROR      53    1394.5        26.3
TOTAL      56    2664.6
                                   INDIVIDUAL 95 PCT CI'S FOR MEAN
                                   BASED ON POOLED STDEV
LEVEL       N      MEAN       STDEV  ----+---------+---------+---------+-
    1      12    26.267       6.260   (-----*----)
    2      15    27.933       5.281       (----*----)
    3      15    32.047       4.885              (----*----)
    4      15    38.553       4.129                         (----*----
                                     ----+---------+---------+---------+-
POOLED STDEV =    5.129                25.0      30.0      35.0      40.0
```

Table AIII.c TKN

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F
C3	3	420.2	140.1	5.17
ERROR	43	1164.4	27.1	
TOTAL	46	1584.7		

LEVEL	N	MEAN	STDEV
1	8	7.750	4.601
2	12	11.417	5.698
3	13	9.115	5.651
4	14	15.590	4.607

POOLED STDEV = 5.204

```
INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV
-----------+----------+----------+------
(---------*----------)
            (---------*--------)
      (-------*-------)
                       (-------*-------)
-----------+----------+----------+------
          8.0       12.0       16.0
```

Table AIII.c TP

ANALYSIS OF VARIANCE ON C1

SOURCE	DF	SS	MS	F
C3	3	851.9	284.0	2.95
ERROR	42	4041.5	96.2	
TOTAL	45	4893.4		

LEVEL	N	MEAN	STDEV
1	9	9.989	5.114
2	12	13.900	10.688
3	12	14.279	10.509
4	13	21.885	10.649

POOLED STDEV = 9.809

```
INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV
------+----------+----------+----------+
 (--------*----------)
        (-------*--------)
        (--------*---------)
                   (-------*-------)
------+----------+----------+----------+
     7.0       14.0       21.0       28.0
```

Note: level = aperture opening size

where 1 = 2000 um

2 = 1400 um

3 = 1000 um

4 = 500 um

Appendix IV.

One-way Analysis of Variance and 95 % Confidence Intervals for Sieving and Settling Sample TS Concentrations.

Table AIV.1

TS Sieving.

FACTOR	4	1.6726	0.4182	31.34
ERROR	10	0.1334	0.0133	
TOTAL	14	1.8061		

LEVEL	MEAN	STDEV
C1	0.9507	0.0176
C2	1.4303	0.2040
C3	1.4713	0.0308
C4	1.6850	0.1419
C5	1.9647	0.0607

POOLED STDEV = 0.1155

```
INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV
----------+---------+---------+----
(---*--)
           (---*--)
            (---*--)
                (---*---)
                      (---*---)
----------+---------+---------+----
        1.20      1.60      2.00
```

Table AIV.2

TS Settling.

ANALYSIS OF VARIANCE

SOURCE	DF	SS	MS	F
FACTOR	4	5.9461	1.4865	69.28
ERROR	10	0.2146	0.0215	
TOTAL	14	6.1606		

LEVEL	MEAN	STDEV
C1	1.9751	0.0681
C2	2.4147	0.0585
C3	1.6457	0.2629
C4	0.7043	0.0348
C5	2.3940	0.1700

POOLED STDEV = 0.1465

```
INDIVIDUAL 95 PCT CI'S FOR MEAN
BASED ON POOLED STDEV
--+---------+---------+---------+---
                         (--*--)
                                (--*--)
                   (--*---)
 (--*--)
                                (--*--)
--+---------+---------+---------+---
0.60      1.20      1.80      2.40
```

Note: level = samples 1-5

factor = sample concentration.

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