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Settling behaviour of Syncrude sludge pond tailings after treatment by oil phase agglomeration

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REPORT RAPPORT

DATE: AUGUST 1990

No. EC-1202-90S

SUBJECT — SUJET

SETTLING BEHAVIOUR OF SYNCRUDE SLUDGE POND
TAILINGS AFTER TREATMENT BY OIL PHASE AGGLOMERATION

FOR — POUR

SLUDGE FUNDAMENTALS CONSORTIUM c/o AOSTRA

AUTHORS — AUTEURS

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EXECUTIVE SUMMARY

Clay-Organic Interactions: NRC modelling studies project

Objectives

- Selective removal of bitumen and hydrophobic solids from sludge
- Determine effect on sludge settling
- Characterisation of separated fractions
- Restoration of sludge by readdition of components

Highlights

- Oil phase agglomeration was used to remove bitumen and hydrophobic solids from sludge.
- Treatment resulted in sludge differentiation into four layers: clear water, a colloidal suspension, a thin, dark brown interface layer and a clean well compacted sediment.
- About 80% of the sludge solids reported to the settled layers.
- Better results were obtained when sodium silicate was used for pH modification.
- Sodium silicate caused the release of humic material(?) into the water and also acted to reduce viscosity of sludge.
- The colloidal suspension was predominantly amorphous in nature and probably corresponded to the allophane fraction separated from oil sands in previous work.
- The interface layer corresponds to the 'globule' fraction identified in previous work and is known to be capable of stabilising emulsions.

ABSTRACT

The hot water process, used by Suncor and Syncrude to extract bitumen from the Athabasca Oil Sands, produces large volumes of tailings slurry. The fine grained sludge component of this waste is the most troublesome because of its stability and poor compactibility. Apparently, the sludge owes its stability to a complex interaction between organic coated, amorphous particles, clays and bitumen.

Recently, we have developed a novel technique for the recovery of organic material from the tailings streams of bitumen extraction plants. The separated fractions include residual bitumen, naphtha and solids associated with significant quantities of strongly adsorbed organic matter which is largely insoluble in common solvents. After separation of these hydrophobic components, the cleaned sludge was found to show altered settling behaviour.

The present work represents the preliminary results of a systematic study on the settling behaviour of cleaned sludge after removal of various amounts of organic material using an oil phase agglomeration technique. The effect of amount of collector and agitation time on the extent of organic matter removal were studied. After treatment the settling behaviour of the cleaned sludge samples was observed.

Gravity settling was carried out in graduated glass cylinders for different periods of time. The cleaned sludge was found to separate into four layers: relatively clean water on top followed consecutively by a suspension of colloidal solids, a thin brown layer and a clean compacted solids layer. Solids from these four layers were studied by x-ray diffractometry to determine the type and degree of crystallinity of the minerals. Elemental analyses for aluminum, iron and organic carbon were carried out.

The results are discussed in terms of a sludge model involving interaction between organic coated, surface active solids, bitumen emulsions and well defined clay particles.

- Sludge treated with sodium silicate and mixed without removing bitumen and OPS showed some differentiation into layers but no interface fraction could be identified.

Interpretation

- The interface solids may be present in the sludge as stabilisers for emulsified bitumen. This is consistent with the sludge structure proposed by Kessick in which surface active, organic coated hydrophobic solids are associated loosely through water-in-bitumen emulsion particles adsorbed to clay surfaces.
- The variable ratio between OPS and bitumen recovered from sludge indicates that these components may be part of two different stabilising mechanisms. The OPS may be fine particles capable of interacting among themselves to form a gel structure independent of the bitumen based Kessick type structure.

INTRODUCTION

The production of large quantities of intractable clay sludges during the extraction of bitumen from Athabasca oil sands by the Hot Water process represents a significant environmental problem. These sludges have a gel-like consistency and contain about 75 w/w% water. Further dewatering beyond this point is extremely slow (Camp, 1977). At the present time the sludges are impounded behind sand dykes.

In previous work we developed a novel technique for the selective recovery of residual organic matter from the tailings streams produced by bitumen extraction plants. The approach involved the application of oil phase agglomeration, using a mixer with contra-rotating stirring blades and vacuum still bottoms as the collecting oil phase. (Kumar et al, 1986, Majid and Ripmeester, 1983, Sirianni et al, 1969, 1981). The removal of the organic matter from the tailings greatly altered its settling behaviour. In this investigation a number of experiments were carried out to study the settling behaviour of sludge treated to remove hydrophobic materials to different degrees. X-ray diffraction, carbon, aluminum and iron analyses were carried out on the solid fractions separated from the treated, settled sludge.

METHODS

Sample Description and Handling

The sample of sludge used in this work was supplied by Syncrude Research Ltd.; it had been pumped from the seventeen metre level of their tailings pond into 200 L plastic drums (Danielson 1989). Each drum was subsequently mixed, subdivided into 5 L plastic jugs and stored in a cooler at 10°C. Before further subdivision at IEC, each jug was shaken vigorously by hand. At NRC the samples were stored at room temperature. Table I lists the physicochemical properties of the sludge as provided by Syncrude (Mackinnon, 1988), the values in parentheses were obtained at NRC.

Table I. Physicochemical Properties of Syncrude Sludge

Property	Value
pH at $17.8 \pm 0.5^\circ\text{C}$	7.83 ± 0.03
Conductivity (mS cm^{-1})	1.6 ± 0.01
Total solids [Grav] (wt%)	26.6 ± 0.1
Bitumen [OWS] (wt %)	0.9 ± 0.05 (1.1 ± 0.2)
Solids [OWS] (wt %)	25.61 ± 0.14 (26.5 ± 0.9)
Density (calculated) (g mL^{-1})	1.19
Solids $< 44 \mu$ (%)	99.2 ± 1.0
Solids $< 22 \mu$ (%)	94.9 ± 1.9
Solids $< 11 \mu$ (%)	83.7 ± 2.1

Recovery of Bitumen and Oil Wettable Solids

A stirring device with two sets of contra-rotating blades (grease kettle) was used for mixing (Sirianni et al, 1969). A known amount of reduced still bottoms (obtained from Esso Research Ltd.) was applied to the stirrer blades of the mixer to act as the collector phase for the hydrophobic components of the sludge. Stoddard solvent was used to adjust the collector oil viscosity to the most effective level. The original sludge volume was 500 mL. Sodium silicate solution was used to bring each suspension to pH 10. At the end of each test the collector phase was washed several times with 0.01% sodium silicate solution to remove entrained, water dispersible solids.

After washing, the collector oil was dissolved in toluene in order to remove it from the mixer blades. This solution was transferred to a soxhlet extractor to separate the solids from the oil phase. After drying, a hydrophobic, dark powder remained; this material has been described previously (Majid and Ripmeester, 1986) as oil phase solids (OPS). Toluene was evaporated from the collector oil by means of a Brinkman Rotovaporator at 80°C under reduced pressure. The

recovery of bitumen was estimated from the original and final weights of the collector oil and the amount of bitumen originally present in the sludge.

Settling Tests

The cleaned sludge, after removal of bitumen and OPS, was transferred to graduated glass cylinders (500 mL). The combined aqueous suspensions from the collector oil washing step were centrifuged and the separated solids added to the contents of the graduated cylinders; in most cases the supernatant liquor was used to restore the sludge to its original volume. In a few cases the sludge was diluted. The cylinders were sealed using parafilm in order to prevent evaporation losses during settling periods of up to 90 days. While settling, the treated sludges separated into a number of well defined layers. The interface height (cms) of the various layers was recorded along with the elapsed time. On completion of each test the layers were removed separately and dried at $100 \pm 10^{\circ}\text{C}$ to determine the solids content.

Analysis

The organic carbon content of the solids fractions obtained from the settling tests was determined using a Leco CR12 carbon analyzer after decomposing any carbonate carbon with dilute HCl. Quantitative Inductively Coupled Plasma Atomic Emission (ICP-AES) spectroscopy was used to determine aluminum and iron.

Mineralogy

The mineral (crystalline) composition of the samples was determined semi-quantitatively by comparing their x-ray diffraction (XRD) peak intensities with those of standards. XRD patterns were recorded using a SCINTAG PAD V automated powder diffractometer equipped with a graphite monochromator, using Co K α radiation ($\lambda = 1.7902 \text{ \AA}$). The amount of each mineral was estimated by multiplying the peak intensity of the characteristic reflection for the respective mineral by the intensity factor for that mineral, as determined from XRD data for a set of standard mixtures. The standards were measured under identical

experimental conditions, including sample preparation, radiation source and diffraction geometry. The amount of poorly-crystalline components (x-ray amorphous) was expressed by the difference of 100 and the total percentage of crystalline components.

RESULTS AND DISCUSSION

A number of experiments, under different conditions, were carried out in a grease kettle to remove bitumen and OPS from the sludge samples. A list of the experimental conditions for these runs are given in Table II. The main variables investigated were the amount of collector oil and the agitation time.

The effect of the amount of collector oil on the recovery of bitumen and OPS is demonstrated on Figure 1. In these tests the pH and agitation times were kept constant. These plots indicate that recovery of both bitumen and OPS is roughly proportional to the amount of collector oil used. Figure 2 shows that collection of OPS and bitumen occur concurrently but the variation in the ratio of OPS/bitumen (Table II, column 9) shows that the OPS are not entirely present as part of the bitumen phase.

The contra-rotating blades of the grease kettle impose a kneading action on the oil so that new surface is continuously exposed as the oil phase moves through the sludge. Suspended particles, including bitumen and hydrophobic, organic coated solids (OPS) are occluded in the collector oil. Larger amounts of collector oil also provide a greater collecting surface sweeping through the suspension, thereby increasing collection efficiency.

Previous experience (Meadus and Puddington, 1973) has determined that the capacity of oil to absorb hydrophobic particles is limited. This capacity may be related to the number of 'active' absorbing sites in the oil (i.e. functional groups). As the oil reaches its saturation point it becomes more selective in terms of the hydrophobic character of the particles with which it is in contact and particles with less affinity to the oil are rejected.

Table III lists the volume percent distribution of the fractions obtained in the various settling tests. The degree of differentiation between the separated layers does not appear to depend entirely on the amount of bitumen and OPS collected from the sludge, see Figures 4 and 5, as removal of even minor amounts of the selected components caused rapid formation of a distinct sediment layer that was not observed for any of the blanks. However, additional removal of the selected components did result in a more rapid compaction of the sediment layer.

A relatively clear water (<5 w/w% solids) layer formed slowly in all cases. There appeared to be a gradual increase in the volume of this layer as more OPS and bitumen were removed. However, these results were somewhat unreliable because of the indistinct interface and the consequent difficulty in achieving a clean separation of the layer for solids determination.

These results suggest that either bitumen and/or OPS are involved in the formation of a structure which is capable of entrapping the bulk of the sludge solids, which would otherwise settle relatively easily. Selective removal of the active components disrupts the sludge structure allowing it to separate into three fractions which then settle at different rates. The presence of organic material, closely associated with fine minerals, has been suggested as being necessary for gel formation (Kessick, 1979). Organic coated particles of this kind are known to impart considerable stability to oil-in-water emulsions (Van Olphen, 1976).

It has been proposed that the structure of oil sand sludge is derived from the interaction between the organic coated, surface active particles, emulsified bitumen droplets and clays. Sodium silicate is noted for its ability to alter the surface condition of hydrophobic solids, either by displacement of organic coatings or by modifying the surface by direct adsorption to form a hydrophilic film. Whatever the mechanism the presence of a conditioning agent, such as sodium silicate, appears to be essential for sludge destabilisation. Use of an alternative, such as sodium hydroxide, did not result in structure breakdown.

Table II (column 8) shows the amount of OPS collected per 100 g of oil. With the exception of test 6 the values are quite close (14 ± 6 g OPS/100 g oil) regardless of the oil to sludge ratio. This would indicate that the oil was 'saturated' with solids under all the conditions tested. Thus, greater amounts of oil would be needed to remove all the OPS present in the sludge. Test #6 appears to be anomalous with respect to its high OPS to oil ratio even though it was mixed for 168 hours. Results for test 5, also mixed for 168 hours, showed an OPS to oil ratio similar to the other results mixed for only 24 hours. Further work will be carried out to resolve these discrepancies.

Gravity Settling Tests

In previously reported work it was noted that treatment of tailings pond sludge to remove residual bitumen altered the settling behaviour of the sludge (Siriani and Ripmeester, 1981). It appeared that the removal of bitumen and associated OPS destroyed the gel-like structure of the sludge, allowing more rapid settling of some components. This report presents the preliminary results of a more detailed study of the settling behaviour of treated sludge. For comparison purposes blank tests were also carried out in which the sludge was mixed in the grease kettle for the same period of time as in the bitumen recovery tests but in the absence of collector oil. Blank tests were made at the natural pH and pH 10.

Treated sludges rapidly separated into four distinct regions. A relatively clear water layer (water) formed at the top followed by a stable suspension (suspension) of very fine particles. Between the suspension and a layer of relatively well compacted, lighter coloured solids (sediment) a thin layer of dark brown solids (interface) formed. In the case of the blank tests only a narrow clear water layer formed on top of the largely undifferentiated sludge. Figure 3 illustrates the results of settling tests for a typical treated sludge (test #4). The photograph (Figure 3a) shows the differentiation into layers after 90 days settling. The data for unconditioned and conditioned sludges were obtained from blank tests at the natural pH and pH 10 respectively, using sodium silicate solution for pH modification. This reagent is often used as a viscosity modifier during sludge handling. A reduction in sludge viscosity could explain the weak differentiation into layers observed for the blank test treated with sodium silicate.

into the water being removed. Thus, the measured solids contents determined for the water layers are higher than the true values.

Distribution of Solids Between Sedimented Fractions

The solids distributions between the various fractions are listed in Table V. Figure 7 shows the solids (percent of total) captured in the sediment for a number of tests carried out under the same conditions but with different amounts of OPS removed. These results again demonstrate that either removal of only a small amount of OPS is necessary to break the sludge structure or that OPS separation is totally irrelevant. In summary 77 ± 8 w/w% of the total solids settle rapidly into the sediment and interface layers, while 22 ± 5 w/w% of the solids remain in suspension and settle very slowly.

Elemental and X-ray Diffraction Analysis of Settled Fractions

Table VI summarises the elemental analysis of fractions separated during the various tests. In terms of aluminum and iron content all fractions were very similar. The sediment fractions had the lowest carbon content, this corresponded to the visual impression of clean, uncontaminated solids. The suspension solids had almost the same composition as the solids in the 'clear' water phase indicating that the latter are probably a finer subfraction of the suspension solids. The interface layers had a significantly higher carbon content than other fractions and seem to correspond to the 'globules' identified in earlier work (Kotlyar et al, 1990). This fraction is known to stabilise emulsions and is believed to play an active role in the formation of sludge.

Semiquantitative X-ray diffraction analysis (Tables VII and VIII) showed that the sediment solids consisted largely of crystalline forms of mica, kaolinite and quartz. The other fractions showed these minerals in significantly lesser amounts. X-ray amorphous material was found to predominate over crystalline species in all the other fractions. These poorly crystalline minerals have been identified as aluminosilicates; possibly allophane (Kotlyar et al in press).

A few tests were carried out on diluted sludge (Bain, 1976). The sludge differentiation in these cases was never as clear as that obtained with undiluted samples; compare tests 5 and 6 in Table III.

Solids Content of Sediment Fractions

Table IV lists the solids content of the various fractions separated after treatment and settling for different periods of time. The results from each test were remarkably similar, indicating that removal of even a small proportion of the bitumen and OPS had a major effect on separability of the solids fractions. Settling of treated sludge for different times indicated only a slow change in sediment compaction. This is demonstrated on Figure 6 where results for both solids content and percent of total solids in the sediment layer are plotted as a function of settling time. For these three tests the original agglomeration conditions were the same, giving average values for bitumen and OPS removal of 26.0 ± 3.5 (w/w%) and 0.4 ± 0.1 w/w% of total solids respectively. While the percent solids in the sediment did not change much with time the proportion of total solids in this fraction increased significantly for settling times up to 90 days.

The interface fraction was a dark brown layer which formed on top of the sediment layer. With cleaned sludges the layer initially appeared as a band near the top of the graduated cylinders and gradually moved down as the sediment layer formed and then compacted. The layer had a solids content of 30-44 w/w%; in blank experiments this layer did not occur, indicating that it was somehow involved with the OPS and bitumen removed during the agglomeration treatment. The ratio of OPS to bitumen (Table II, column 9) was not constant, indicating that the solids recovered were not entirely entrained by the bitumen present in sludge.

The fraction containing slowly settling particles (7.5 ± 1.1 w/w% solids) occupied the bulk of the graduated cylinder. This material settled slowly to leave a clear but dark coloured water layer. This dark colour was only observed for those samples treated with sodium silicate solution and may be related to release of humic acids by this reagent. Attempts to separate the clear water layer from the suspension usually resulted in mixing of the layers with some solids being carried

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CONCLUSIONS

Treatment of sludge by oil phase agglomeration, to remove bitumen and OPS, results in destabilisation of the sludge, allowing about 80 w/w% of the solids to settle rapidly to a compact layer containing 60 w/w% solids. The use of sodium silicate to modify pH promotes this sludge structure breakdown. For blank experiments no differentiation of the sludge took place except for the formation of a narrow layer of clear water. The effect of using sodium silicate may be due to reduction in sludge viscosity or to the release of humic material into the water.

Very little bitumen or OPS needed to be removed in order to destabilise the sludge. Although removal of OPS from sludge shows an increasing trend with respect to higher bitumen recoveries there is no direct relationship between the amounts of the two phases removed during agglomeration. This suggests that the two components may be involved in more than one sludge stabilising mechanism. However, the results are consistent with the view that sludge stability is the result of interaction between bitumen and organic coated surface active particles.

RECOMMENDATIONS

- Use other conditioning agents for surface modification (e.g. sodium pyrophosphate).
- Test the role of bitumen and OPS by reintroducing them separately to cleaned sludge.
- Use more efficient means (but less selective) of removing bitumen and OPS from sludge (e.g. coke/coal oil agglomeration).

Table III. Volume % Distribution of Sludge Fractions Formed
During Settling Tests

Test* #	Sedimentation Time (Days)	<i>Volume % Distribution</i>			
		Water	Suspension	Interface	Sediment
2	90	7.0	93.0	-	-
3	90	15.0	63.0	4.0	18.0
4	90	7.2	67.5	6.0	19.3
5	90	28.6	53.1	4.9	13.4
6	90	20.0	52.0	3.0	25.0
7	20	3.0	77.0	2.0	18.0
8	40	5.0	80.0	2.0	13.0
9	90	3.3	64.0	3.3	29.4
10	40	5.0	75.0	4.0	16.0
11	40	3.0	82.0	1.0	14.0
12	20	3.0	77.0	1.0	19.0
13	90	5.0	69.5	3.0	22.5

* Experimental conditions as in Table II.

Table II. Test Conditions and Recovery Data for Bitumen and OPS Removal from Syncrude Sludge*

(1) Test #	(2) Ref #	(3) Dilution factor**	(4) Collector Oil (g/100g sludge)	(5) Mixing Time (hrs)	Recovery		(8) OPS (g/100g oil)	(9) <u>OPS</u> Bitumen
					(6) Bitumen (w/w% of total)	(7) OPS (w/w% of solids)		
1	4278-08	1.0	Blank [†]	24	5.0	0.01	-	-
2	4278-10	1.0	Blank	24	4.0	0.02	-	-
3	4278-16	1.0	3.4	6	31.1	1.25	9.7	0.97
4	4197-88	1.1	3.0	24	76.4	1.40	12.4	0.44
5	4197-94	3.5	1.9	168	49.0	1.10	15.3	0.56
6	4278-14	1.0	3.7	168	98.5	4.20	30.7	1.03
7	4278-40	1.0	1.0	24	24.2	0.55	14.6	0.55
8	4278-28	1.0	0.9	24	23.7	0.45	13.3	0.46
9	4197-97	1.1	1.0	24	30.0	0.30	8.0	0.24
10	4278-30	1.0	1.8	24	31.7	0.78	11.5	0.59
11	4278-26	1.0	1.8	24	38.7	0.64	9.4	0.40
12	4278-44	1.0	4.5	24	60.6	2.60	15.3	1.03
13	4197-102	1.15	4.0	24	74.6	2.20	14.6	0.71

[†] natural pH

* pH of sludge adjusted to ~10 with sodium silicate solution.

** Calculated as ratio of final and original sludge volume.

Note: Solids content of sludge taken as 26.5 w/w%, see Table I.

Table V. Distribution of Total Solids in Sludge
Fractions Obtained from Settling Tests

Test* #	<i>Solids Content (w/w% of total solids)</i>			
	Water	Suspension	Interface	Sediment
2	0.4	99.6	-	-
3	2.9	19.2	8.1	69.8
4	1.4	32.5	9.0	57.1
5	4.6	20.2	11.1	64.1
6	2.6	13.0	4.8	79.6
7	0.7	28.0	2.8	68.5
8	0.7	24.1	5.4	69.7
9	ND	17.3	7.7	75.0
10	0.2	19.8	8.2	71.8
11	0.2	24.5	7.7	67.6
12	0.7	25.8	5.1	68.4
13	0.8	17.0	3.5	78.7

* Experimental conditions as listed in Table II

- No layer observed

Table IV. Solids Content of Sludge Fractions
Obtained from Settling Tests

Test* #	<i>Solids Content w/w%</i>				Settling Time (days)
	Water	Suspension	Interface	Sediment	
2	1.7	23.0	-	-	90
3	4.2	6.7	36.6	58.9	90
4	4.0	9.9	30.6	61.0	90
5	1.3	3.1	20.9	56.5	90
6	3.3	6.2	32.5	56.1	90
7	5.9	8.7	39.0	59.9	20
8	4.4	8.0	34.5	60.2	40
9	ND	7.9	43.0	61.3	90
10	1.3	7.3	36.9	61.3	40
11	2.1	6.6	44.2	61.2	40
12	6.0	7.6	42.6	60.6	20
13	3.9	6.5	40.7	60.6	90
Avg.	3.9 ± 1.6**	7.5 ± 1.1**	38.1 ± 4.6**	60.1 ± 1.6**	

* Experimental conditions listed in Table II

- Layer not present

** not including tests 2 and 5

Table VII. Semi-quantitative x-ray Diffraction Analysis of Solid fractions from Syncrude Sludge Pond Tailings

Exp. No. 1	Concentration range (wt.%) ²											
	Water			Suspension			Interface			Sediment		
	Mica	Kaolinite	Quartz	Mica	Kaolinite	Quartz	Mica	Kaolinite	Quartz	Mica	Kaolinite	Quartz
2	ND	ND	ND	*	*	-	**	**	*	**	**	**
3	**	*	-	**	**	-	**	**	*	**	**	**
4	ND	ND	ND	ND	ND	ND	**	**	*	**	**	**
5	ND	ND	ND	**	*	-	**	**	-	**	**	**
6	**	*	-	**	**	-	**	**	*	**	*	*
7	*	*	-	*	*	*	**	**	*	**	**	**
8	*	*	-	*	*	*	**	**	*	**	*	*
9	ND	ND	ND	**	*	-	**	**	*	**	**	**
10	**	***	*	*	*	*	**	**	*	**	*	*
11	ND	ND	ND	*	*	-	*	**	*	*	*	*
12	**	*	*	*	*	*	*	**	*	**	**	*
13	ND	ND	ND	**	*	-	**	**	*	**	**	*

1) As in Table II.

2) - not detected;

* 1-10%, minor;

** moderate, ~10-30%;

*** major >30%

ND = not determined.

In addition to the amount of major minerals listed in the table, small amounts of the following minerals were also detected in some of these fractions: chlorite, trace (<1%) in sediment from experiments 6, 9; microcline, * (10-30%) in sediment from experiments 1, 3, 4; plagioclase, * (10-30%) in sediment from experiment 4.

Table VI. Elemental Analysis of Solids from Sludge
Fractions Obtained from Settling Tests

Test* #	Elemental Concentrations (w/w%)											
	Water			Suspension			Interface			Sediment		
	C	Fe	Al	C	Fe	Al	C	Fe	Al	C	Fe	Al
2	12.5±0.3	1.8	8.4	21.3±0.3	2.2	8.6	15.7±0.2	2.3	10.1	3.8±0.1	2.4	10.3
3	11.4±0.3	2.1	10.0	6.6±0.4	2.3	13.0	13.7±0.3	3.1	11.9	2.8±0.2	2.6	11.1
4	-	-	-	6.6	3.1	16.7	14.6	5.2	15.5	1.9	2.9	13.4
5	3.2±0.1	-	-	6.8±0.1	3.4	16.7	12.9±0.1	3.0	18.8	3.9±0.2	2.7	9.5
6	3.5±0	2.5	11.0	2.5±0	2.5	11.7	4.4±0.1	3.4	11.0	0.95±0	3.9	9.0
7	8.4±0			10.0±0			10.9±0.1			2.7±0		
8	14.3			11.8±1.0			28.8±0.3			2.4±0		
9	-	-	-	8.3	3.2	17.0	18.1	4.2	17.1	2.7	3.4	12.3
10	8.2			7.5±0			16.1±0			1.6±0		
11	7.2			9.8±0.1			23.3±0.1			2.3±0.1		
12	7.3±0.1			8.3±0.3			16.9±0.1			2.0±0.1		
13	20.8	-	-	6.7	2.7	14.6	12.0	4.0	15.5	1.7	3.3	10.1
Avg.**	10.4±5.1	2.1±0.4	9.8±1.3	9.0±4.7	2.7±0.4	13.6±3.2	15.9±6.4	3.7±1.0	13.5±2.9	2.3±0.8	3.1±0.6	11.0±1.6

* Experimental conditions as listed in Table II

- not determined because of insufficient sample or sample loss

** not including tests 2 or 5

Effect of Quantity of Collector Oil on Bitumen and OPS Recovery

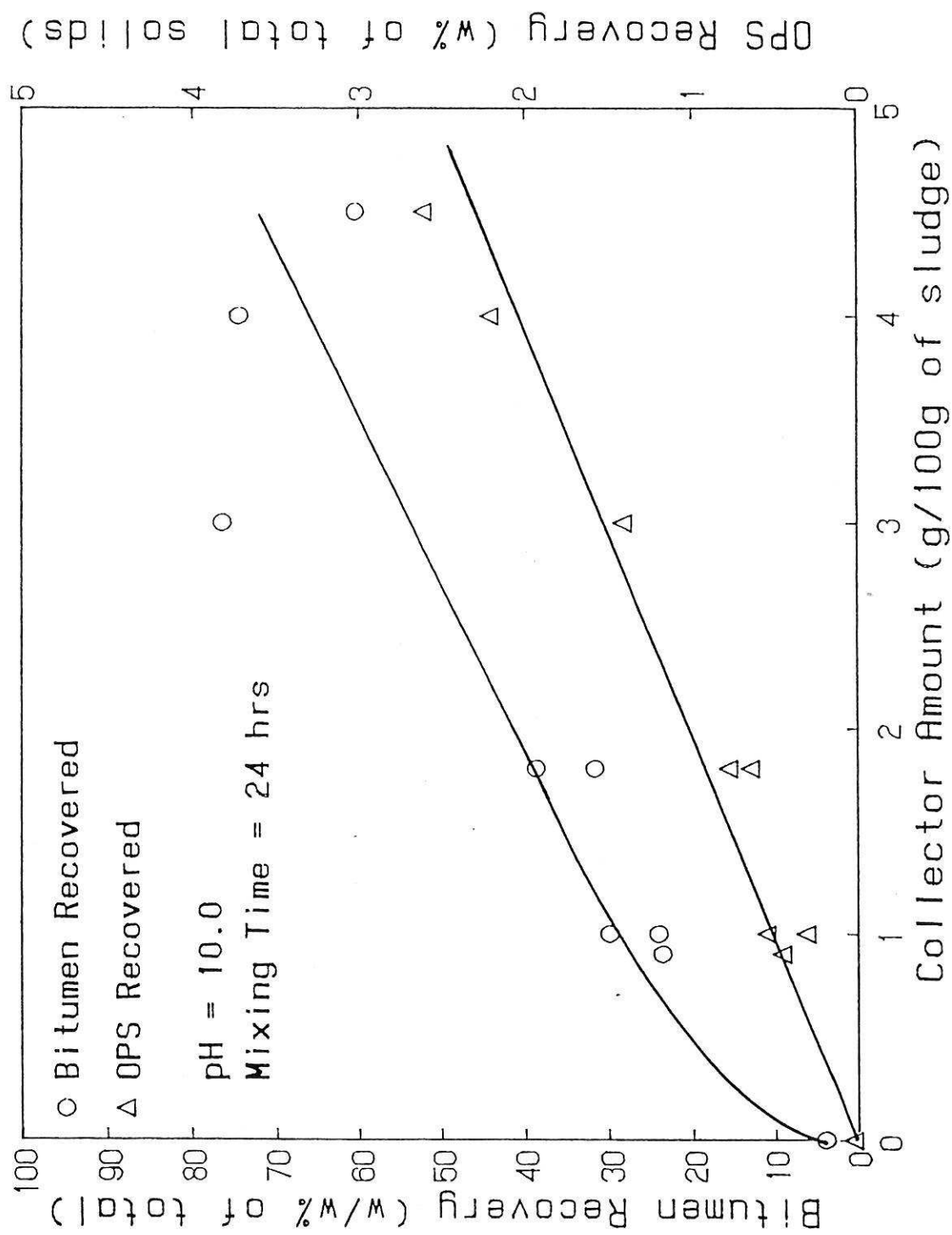


Figure 1

Table VIII. Distribution of x-ray amorphous material in various fractions from Syncrude Sludge pond Tailings

Test # ¹	Concentration of x-ray amorphous material ²			
	Water	Suspension	Interface	Sediment
2	ND	***	**	**
3	***	***	**	--
4	ND	ND	***	--
5	ND	***	**	--
6	***	***	***	**
7	***	***	***	--
8	***	***	***	--
9	ND	***	**	--
10	***	***	***	--
11	ND	***	***	--
12	***	***	***	--
13	ND	***	**	--

1) As in Table II.

2) Semi-quantitative as listed in Table VII.

Settling Curves for Treated and Untreated Syncrude Sludge

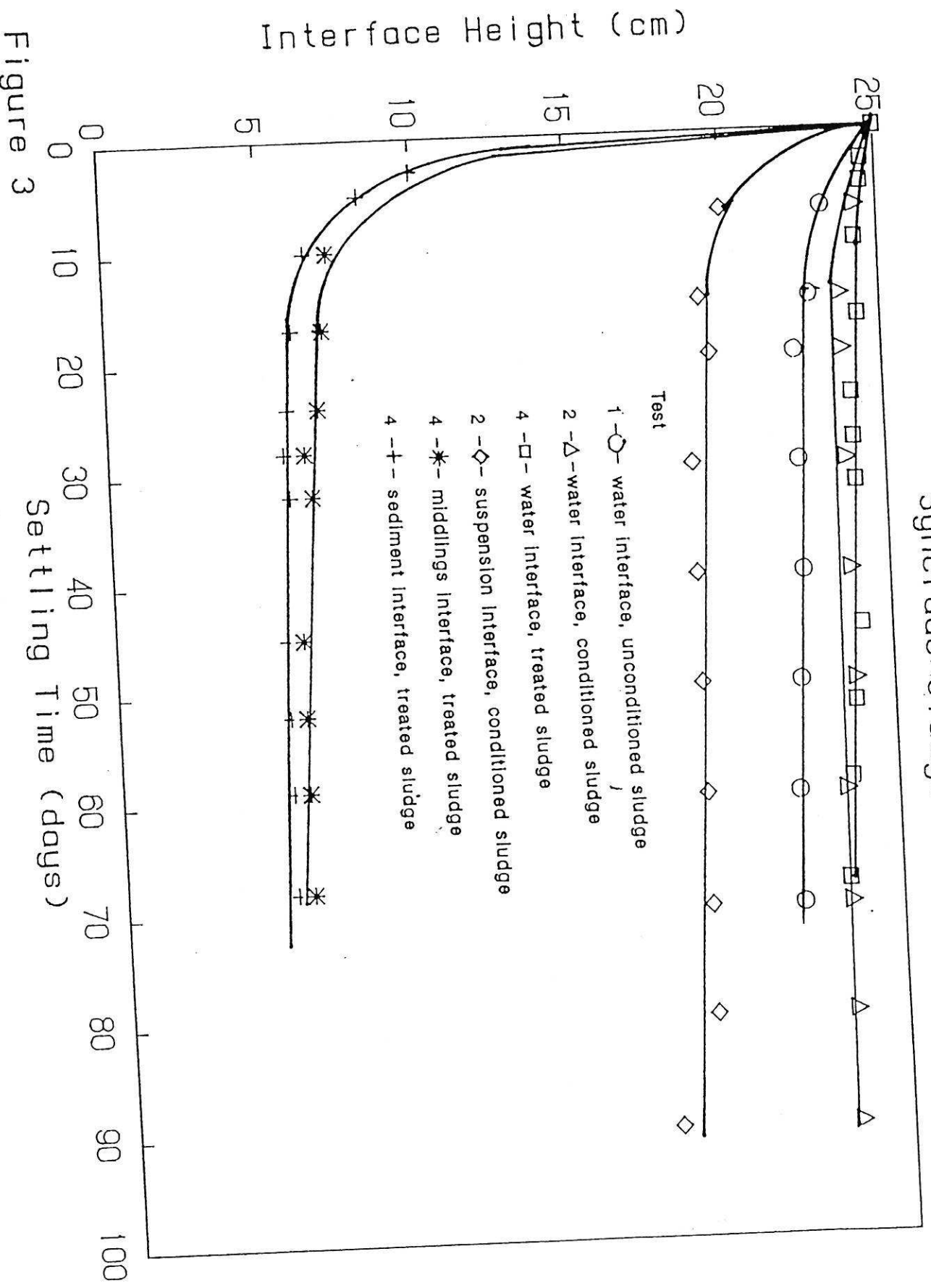
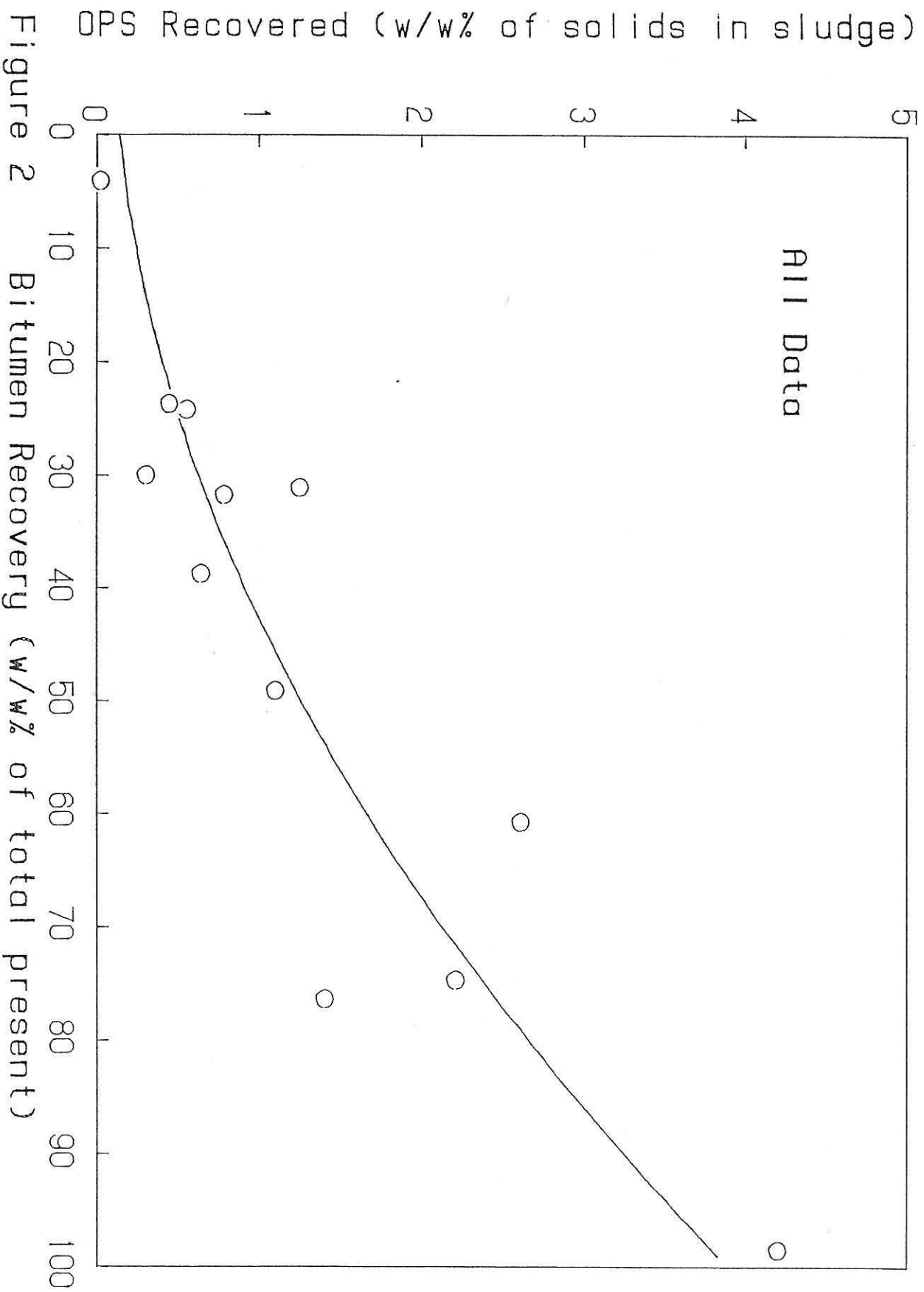


Figure 3

Correlation between Bitumen Removal and OPS Collection



Effect of Bitumen Removal on Sediment Volume and Water Recovery

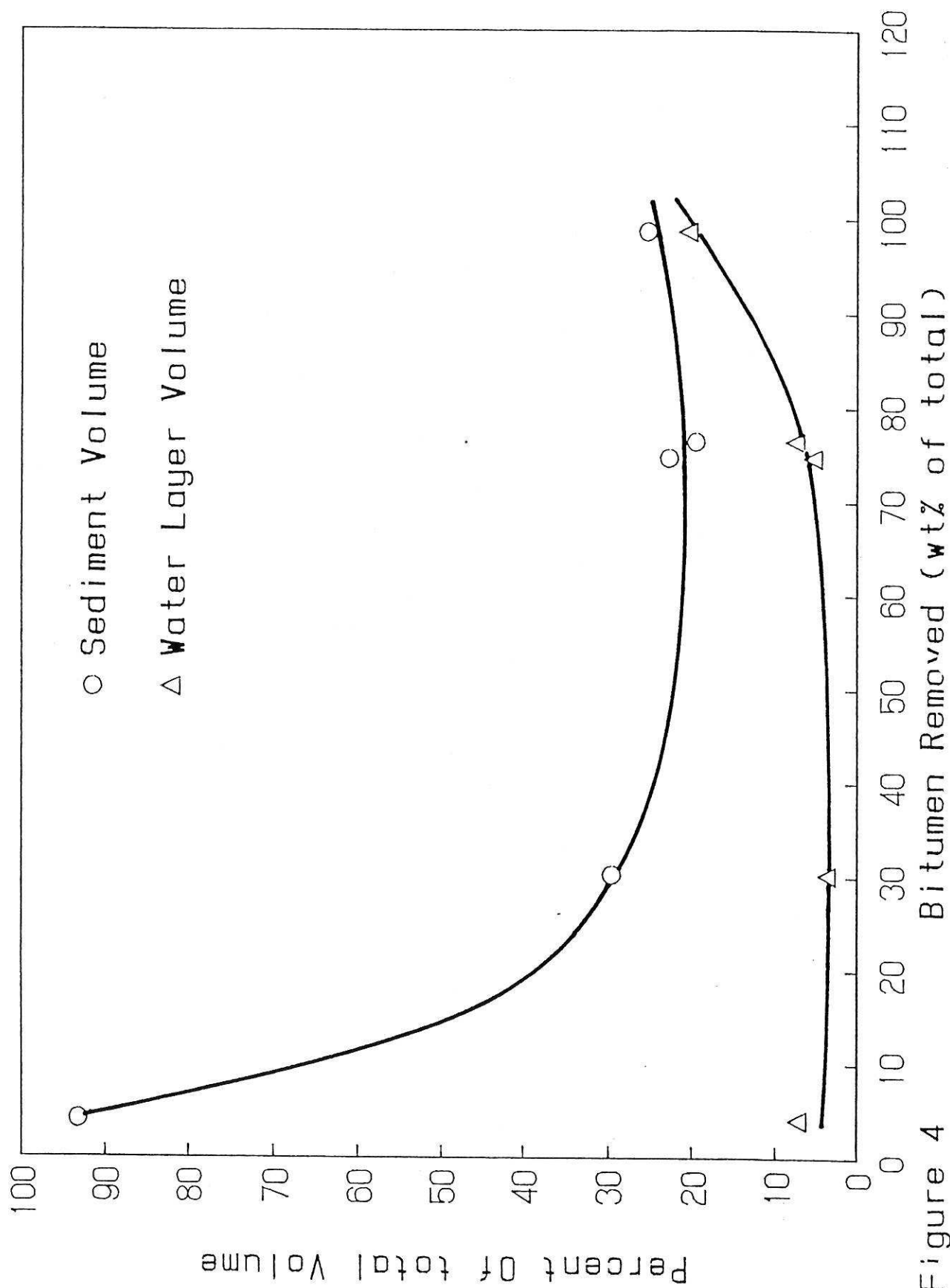


Figure 4

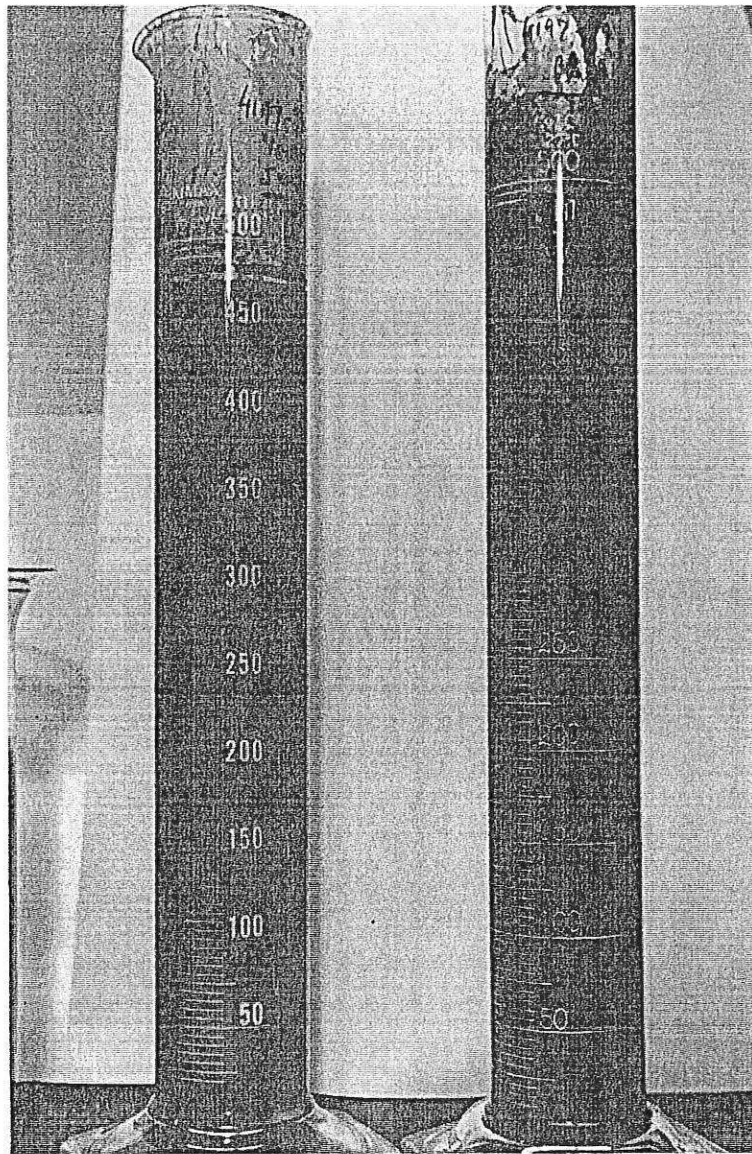


Figure 3a Differentiated Sludge Layers
after Treatment and Settling

Effect of Settling Time on Amount and Concentration of Solids in Sediment Layer

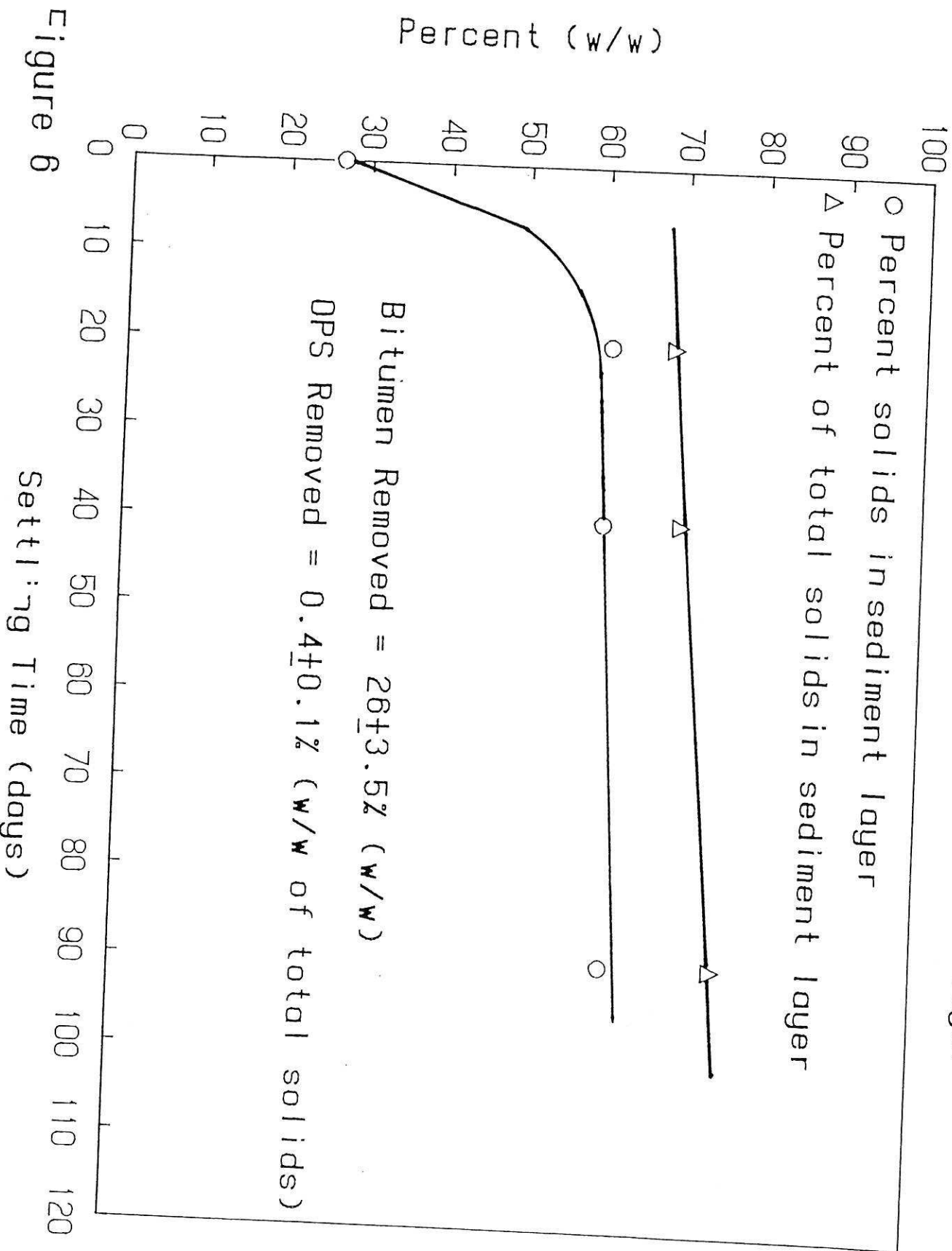


Figure 6

Effect of OPS Removal on Sediment Volume and Water Recovery

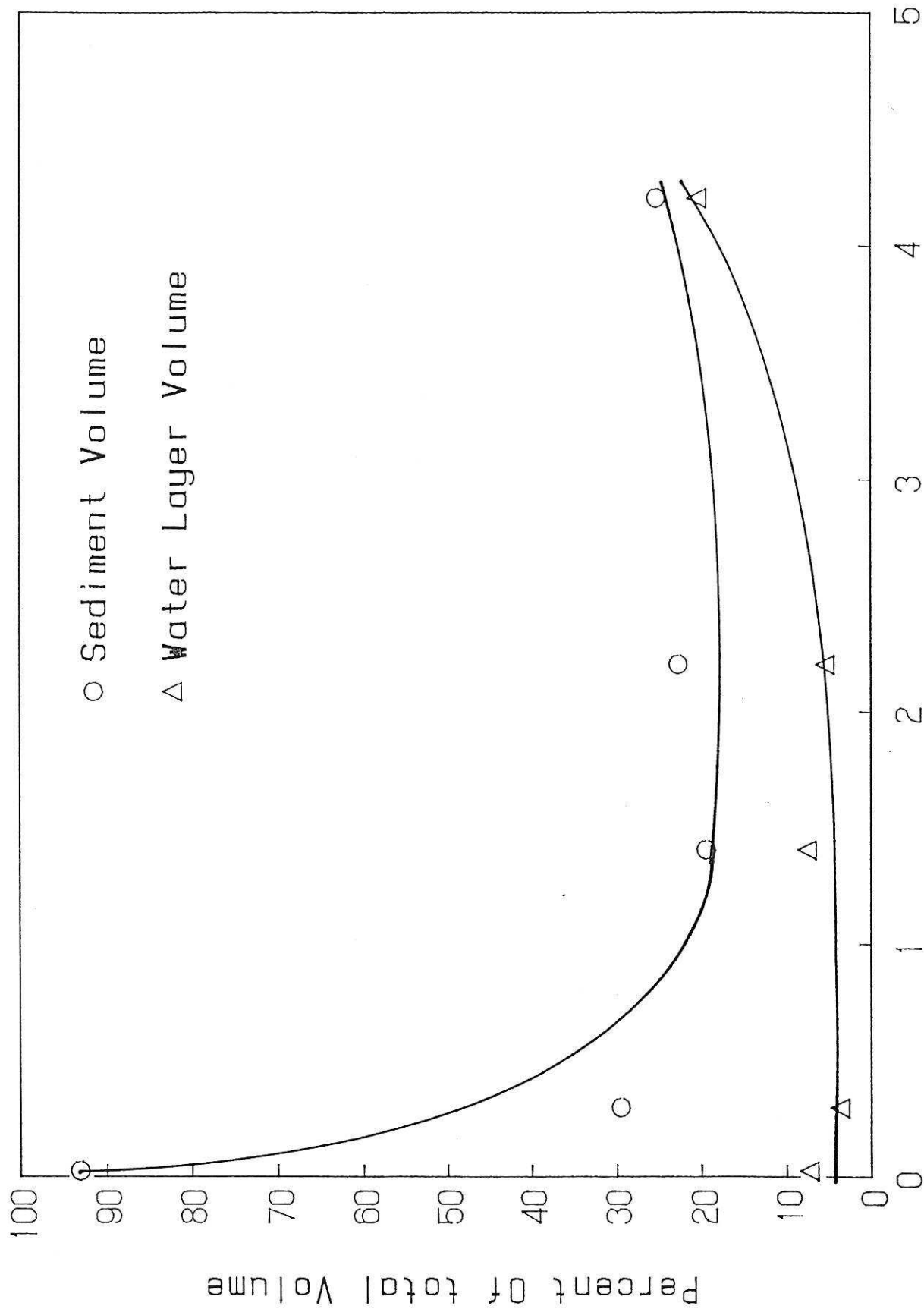


Figure 5 OPS Removed (wt% of total solids)

Effect of OPS Removal on Solids Distribution in Sediment Layer

