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COST 68/2 - SLUDGE CHARACTERIZATION

A Study on

SLUDGE CHARACTERIZATION BY DISTRIBUTION OF WATER

by

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OUTLINE

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1. SAMMENDRAG

Det forutsettes av kloakkvann inneholder fire typer av vann:

1. Fritt vann som kan fjernes ved sedimentering
2. Adsorpsjonsvann, bundet inni og mellom fnokkene i slammet, som kan fjernes ved mekanisk avvanning
3. Kapillært vann som er bundet til de enkelte partikler på grunn av overflatekrefter
4. Cellevann som bare kan fjernes ved bruk av termisk energi.

Ved bruk av lang tids sedimentering og laboratorie-sentrifuge med høy hastighet av aktivt slam inneholder 63% fritt vann, 32,5 % adsorpsjonsvann, 1,0% kapillært vann og 3,5% cellevann. Andre slamtyper inneholder de samme vanntyper, men i andre forhold. Det ser ut til at fordelingen av de enkelte vanntyper kan ha sammenheng med fortykkings- og avvanningsegenskaper og slammets stabilitet.

2. ABSTRACT (in English)

It is hypothesized that wastewater sludge contains four types of water:

1. Free water which can be removed by settling
2. Floc water, trapped inside and between flocs, which can be removed by mechanical dewatering
3. Capillary water which is bound by surface tension to the individual particles, and
4. Particle water which can be removed only by thermal energy.

It is shown, using long term settling tests and a high speed test-tube centrifuge, that activated sludge contains about 63 per cent free water, 32.5 per cent floc water, 1.0 per cent capillary, and 3.5 per cent particle water. Other sludges also contain all four types of water, but in different proportions. It is suggested that the distribution of sludge water be related to sludge dewatering and thickening, as well as sludge stability.

3. INTRODUCTION

The objective of this study was to characterize sludges by the distribution of water within the sludge. It can be hypothesized that a wastewater sludge contains four types of water, as illustrated in Figure 1.

1. Free water

Sludge flocs have significant structural strength and are in fact used as building blocks in the formation of a lattice structure which prevents gravitational settling past some point of solids concentration. Free water is thus defined as that which can be removed by simple gravitational settling.

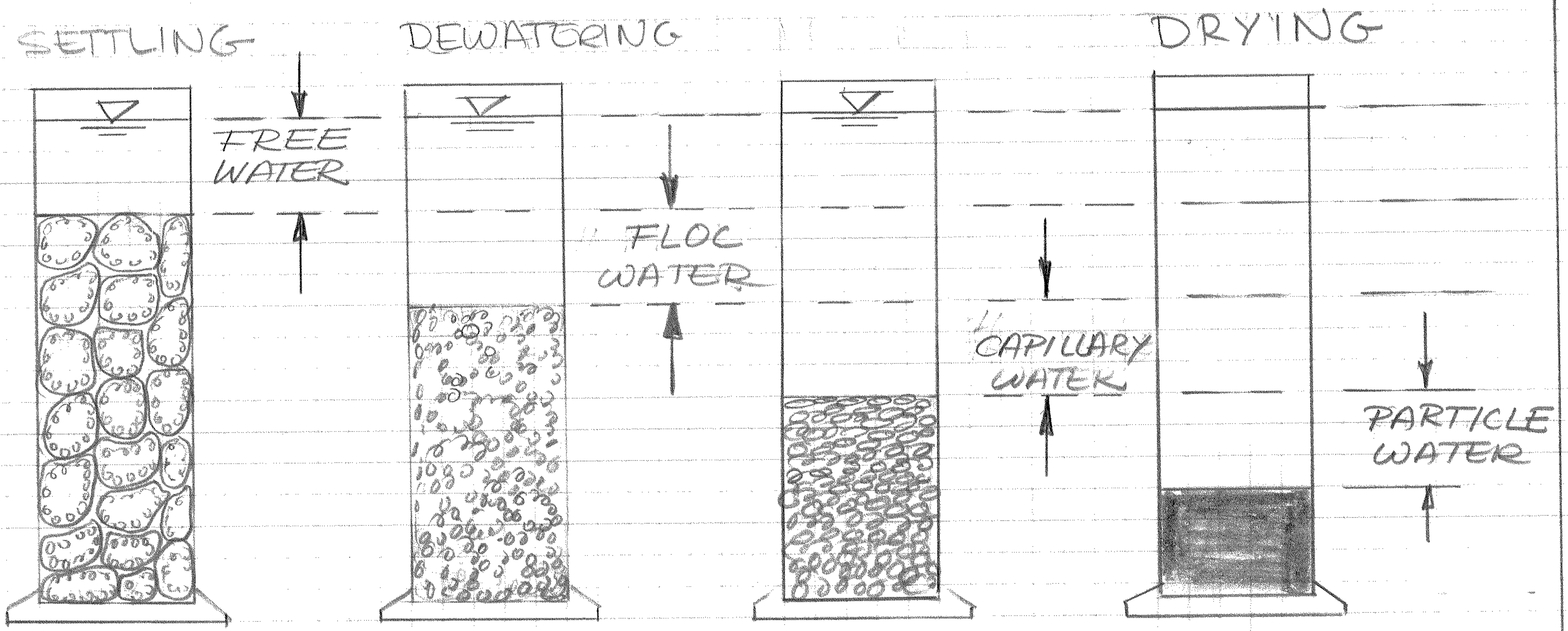
Obviously, any other acceleration (e.g. 100 gravities) might have been used for this definition, but 1 gravity is both simple and useful, since this is the force used in conventional settling tanks and thickeners.

2. Floc water

With a high enough force (either vacuum pressure, or centrifugal) the floc structure can break down. The water released from within flocs is termed "floc water". Conventional dewatering operations remove various quantities of this floc water.

When this floc water is removed, the individual particles are formed in a lattice structure which prevents further dewatering. A considerable force is necessary to squeeze more water out, since this water is held by surface tension.

FIGURE 1 | HYPOTHETICAL DISTRIBUTION OF WATER IN SLUDGE



SETTLING

DEWATERING

DRYING

Flocs provide structural rigidity which prevents further settling.

Flocs are destroyed. Structural strength of particles prevents further dewatering

Capillary water between the particles is driven off. Only remaining water is bound to particles

Particle water can be removed only by thermal energy (drying).

3. Capillary water

The water thus trapped with the particles is termed "Capillary Water". This water is bound by surface tension to the particles and is very difficult to remove mechanically. It is not, however, water associated chemically with the cell structure.

4. Particle water

Water in a biological cell exists in the outer slime covering and inside the cell wall, either as chemically or physically bound to the cell. Its removal is possible only by heat drying and the complete destruction of the cell. For inorganic particles this water is simularly bound to the particles and can be drawn off only by thermal energy.

The total volume (or weight) of sludge is thus a summation of the solids and the four types of water, or

$$\text{Total weight} = W_{\text{solids}} + W_{\substack{\text{free}\\ \text{water}}} + W_{\substack{\text{floc}\\ \text{water}}} + W_{\substack{\text{capillary}\\ \text{water}}} + W_{\substack{\text{particle}\\ \text{water}}}$$

There is no doubt that the abilities of various processes to thicken or dewater a given sludge depend a great deal on what fraction of the water is in what form. The simplest case is obviously that the absence of free water makes gravitational thickening impossible.

In addition, the character of sludge changes as it is stabilized, and the changes in the distribution of water could lead to some indication of the degree of stabilization.

Surprisingly little work has been done on characterizing sludges by distribution of water. The first attempt was by HEUKELEKIAN and WEISBERG (1956), who used the concept of "bound water" to characterize sludge stability. Bound water was defined as that which does not freeze at 0 °C due to its chemical bounding. The theory is sound, but the method of measurement is extremely difficult and imprecise. (EIKUM 1973.)

MÖLLER (1964), reporting work of PÖPEL et al. (1958) and BATEL (1954), classifies water into three categories,

1. Water that can be removed by thickening (about 70per cent)
2. Capillary and adhesion water and pore water (about 22 per cent), and
3. Adsorbed, surface, and cell water, which can be removed only by thermal energy (about 8 per cent).

Unfortunately, the methods involved in determining these values, are not reported. Möller's paper is nevertheless a valuable attempt at categorizing water in sludge.

LAUBENBERGER and HARTMANN (1971) suggest three different types of water in a sludge floc,

1. Water within the organism
2. Capillary water within the particles, and
3. Stagnant water in the interstices formed by the agglomeration of the particles.

They define a "particle" as a group of organisms and a "floc" as a group of particles.

LAUBENBERGER and HARTMANN use THOMAS' alfa value (1964) to describe the proportion of water in the floc, and relate this to floc size.

The alfa value is defined as

$$\alpha = \frac{\text{volume of water in the floc}}{\text{volume of sludge solids in the floc}}$$

As alfa decreases, the flocs are denser and settle easier. It was shown that aeration tends to decrease alfa, as does the mixing of different sludges.

The problem with using the alfa value is that its measurement is quite difficult. The total volume of the floc must first be obtained by visual observations, the water fraction is calculated from density measurements, and the solids fraction from a mass balance. Such procedures make thewide applicability of the alfa value unlikely.

It must be conluded that, based on a search of the literature, no simple test exists for the measurement of the distribution of water within sludge.

4. EXPERIMENTAL PROCEDURE

The experimental studies were conducted with a Sorvall desk-top centrifuge, model SS-1. This machine holds 8 tubes, 50 ml each, and can attain quite high centrifugal speeds. The radius was taken as the mean distance from centerline, as shown on Figure 2. The speed was measured with a strobe light (General Radio), and the centrifugal acceleration calculated as

$$\text{Centrifugal acceleration (x gravities)} = \frac{\omega^2 r}{g}$$

where ω = rotational speed,radians per second (note: rpm x 6.28 = radians per second)

r = radius, 8.5 cm

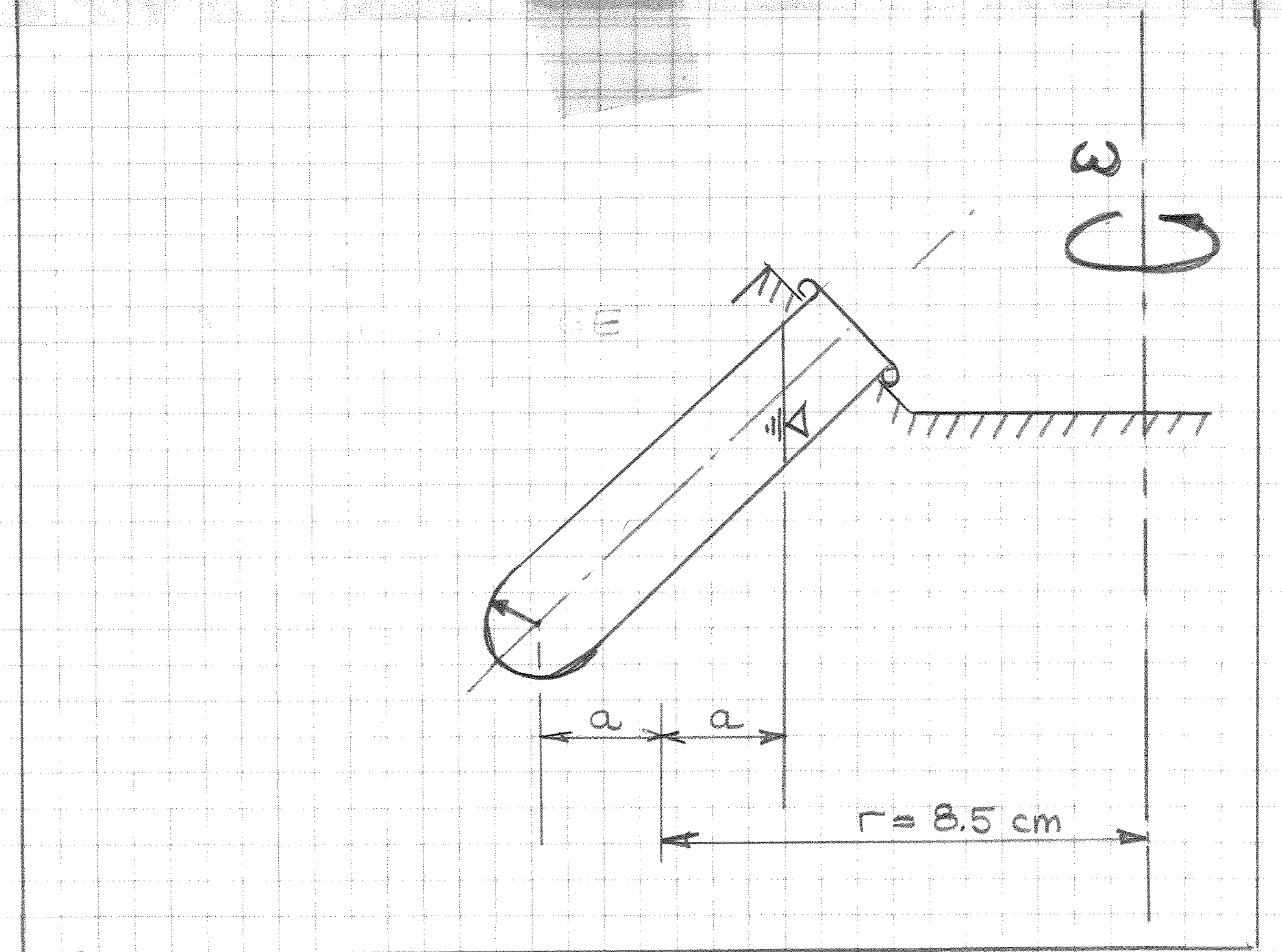
g = gravitational acceleration, 981 cm^2/sec.

Exactly 40 ml of sludge was poured into the test tubes and centrifuged. The speed was measured by a strobe light. After sufficient time (usually about 10 minutes for the high speeds), the machine was stopped and the clear centrate poured from the tubes into a dry 50 ml graduated cylinder. The difference between this volume and 40 ml is thus the volume of the sludge cake.

The sludge used was an activated biological sludge from the Kjeller extended aeration plant. The plant does not have a primary clafifier. In addition, lime, alum, and iron III precipitated primary effluents from the Kjeller experimental plant were tested.

The activated sludge for some tests was conditioned by an organic polyelectrolyte (a cationic Hercofloc), a dispersant (a laboratory detergent, Deconex), and heat created by boiling for five minutes.

FIGURE 2 SORVALL CENTRIFUGE SCHEMATIC



5. RESULTS AND DISCUSSION

Distribution of Water in Sludge

As noted earlier, sludges contain water which is attached in different ways to the solids and thus require different methods of removal. One method of classifying the water content of sludge is as shown on Figure 1.

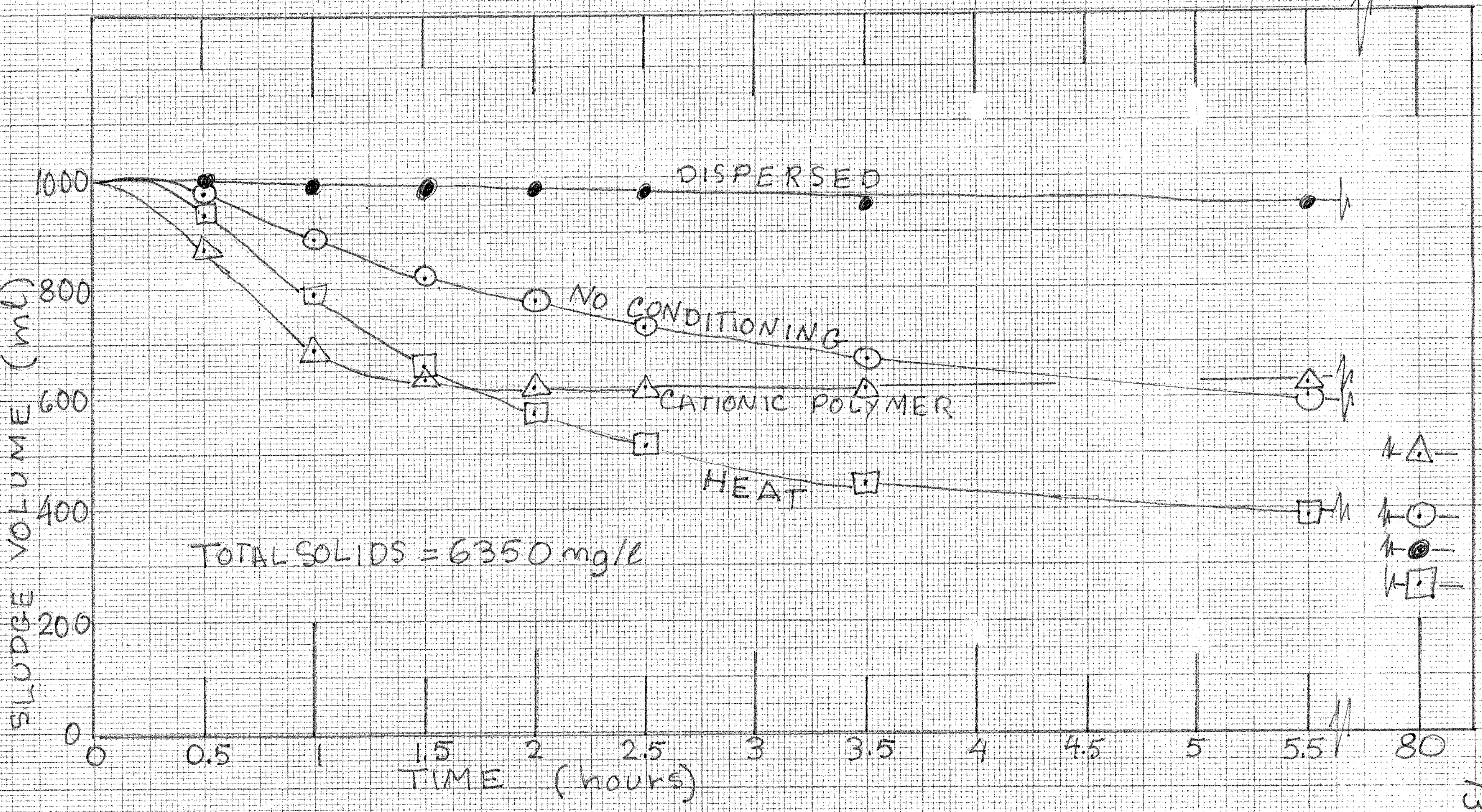
The free water is not bound to the solids in any way and can be removed by simply settling the solids by gravity. This is the water removed in a thickening process.

The water trapped in the floc structure travels with the floc, and can be removed only by destroying the floc. The water bound to the particles by capillary action can be removed only by very large physical force or, as with the particle water, by thermal drying.

It should be possible to test the above hypothesis by simple gravitational settling tests with activated sludge, conditioned with polymers, heat, and a dispersant. It can be assumed that the dispersant destroys some of the floc structure, and this is very evident from the homogeneous appearance of the sludge. This sludge thus should have less "floc water". The addition of a polymer should actually increase the floc structures and thus increase the proportion of floc water. The heat treated sludge can be assumed to have more compact particles and thus would contain even less bound or floc water.

The results of such an experiment are shown on Figure 3. The dispersed sludge, having less floc structure, settles very slowly, since the escaping water must travel through a fine filter. The polymer-conditioned sludge settles the fastest, since the increased floc structure allows easy routes for the escaping water. Heat treatment, which would have produced smaller, but more compact particles, also settled very rapidly.

FIGURE 3 GRAVITATIONAL SETTLING OF ACTIVATED SLUDGE.



Of interest are the data for the final compacted height, assumed to be at 80 hours. x) The polymer-conditioned sludge has a strong floc structure and thus resists compaction under one gravitational force. The granular heat-treated sludge compacts the best as expected. Destruction of the floc structure by the dispersant allowed this sludge to settle better than the polymer-conditioned or untreated sludge.

Such long-term settling tests also define the "free water" fraction of the sludge as the water removed by simple gravitational settling.

Tests with high-speed centrifuges can be used for establishing the fraction of "floc" and "capillary" water. By spinning a sludge at various high centrifugal speeds, it is possible to obtain curves similar to those shown on Figures 4 and 5. As the centrifugal speed is increased, the volume occupied by the sludge cake decreases to a constant value. At this point, it is assumed that all of the flocs have collapsed and the water enclosed in them has been released. Thus the change in sludge volume between free settling and the constant volume at high centrifuge speeds is considered to be "floc water".

Effective mechanical dewatering can remove the floc water by collapsing the flocs. But further dewatering must be by the destruction of the structural lattice formed by the particles, thus releasing the capillary water, or by the total destruction of the particles.

The data on Figure 4 and 5 (and other data not graphed, but included in the Appendix) show another plateau at even higher centrifugal speeds.

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x) Such long-term tests on biological sludge are possible by adding approximately 0.5% formaldehyde. This arrests all biological action, but does not alter the sludge physical characteristics (NISSEN AND VESILIND, 1973).

FIGURE 4. WATER IN POLYMER-FLOCCULATED ACTIVATED SLUDGE.

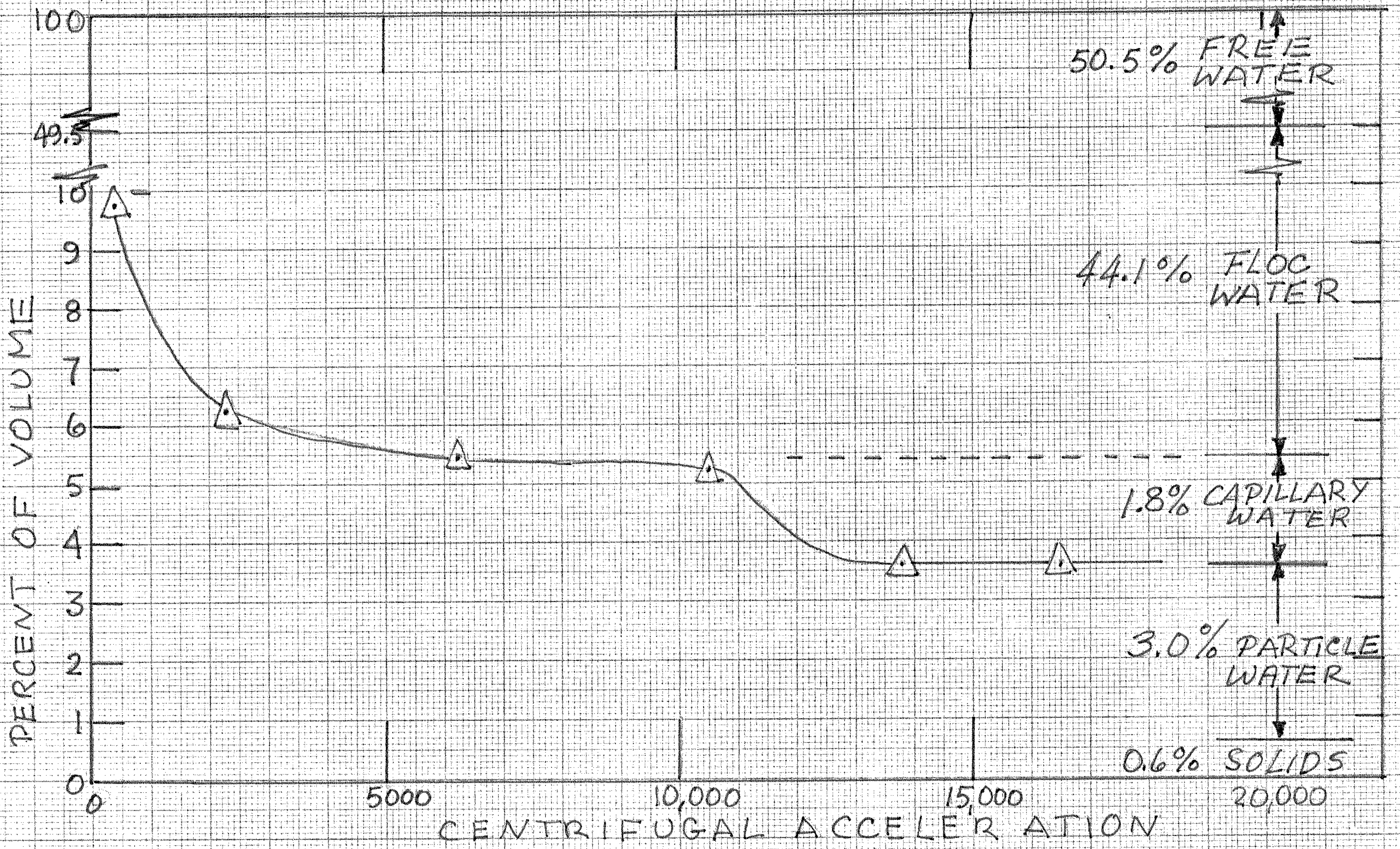
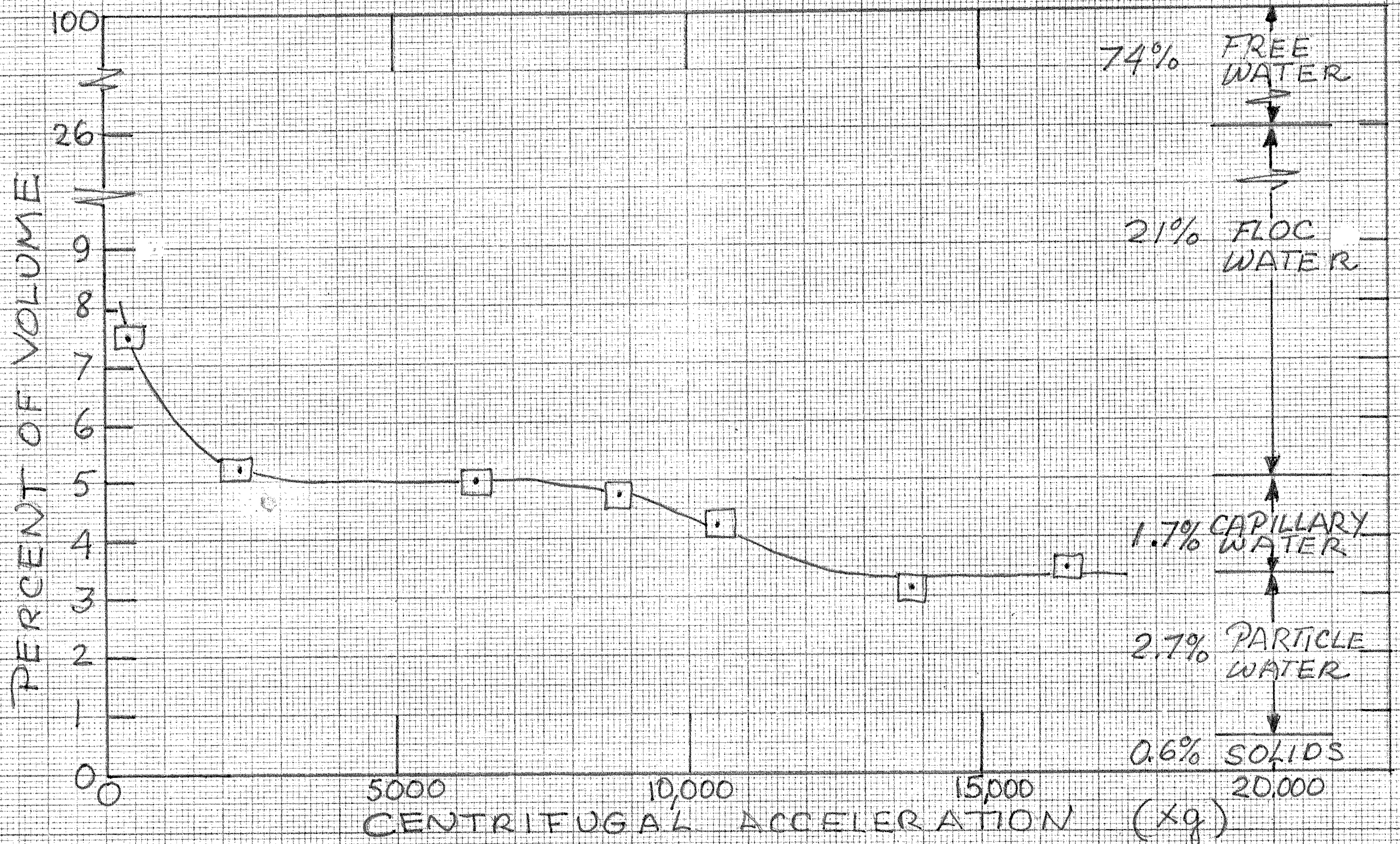


FIGURE 5. WATER IN HEAT-TREATED ACTIVATED SLUDGE.



It is reasonable to suggest that at this extremely high force, the capillary water is driven out and only the water in the individual cells remains. It is thereby possible to calculate the capillary water, and by substraction using the equation on page 7, the cell or particle water.

Table 1 is a summary of the distribution of water in activated sludge with three types of conditioning. As expected, the free water is least for the polymer flocculated sludge since much of the water is trapped within the flocs. The amount of capillary plus particle water is almost constant regardless of conditioning, indicating that the ability of the particles to hold water was not changed appreciably. The effect of the dispersant and heat treatment was to decrease the floc water, as expected.

TABLE 1. DISTRIBUTION OF WATER IN ACTIVATED SLUDGE

	Type of Treatment			
	None	Polymer	Heat	Dispersant
Free water	62	50.5	74	68
Floc water	33.1	44.1	21	27.1
Capillary water	0.9	1.8	1.7	1.5
Particle water	3.4	3.0	2.7	2.8
Solids	0.6	0.6	0.6	0.6
Per cent	100	100	100	100

These figures agree with those reported by Möller, and support the findings of LAUBENBERGER and HARTMANN.

Some very incomplete data for three other sludges are shown on Figure 6. Based on these data, and long-term settling tests, the distribution of water can be calculated as shown on Table 2.

FIGURE 6. WATER IN THREE DIFFERENT SLUDGES.

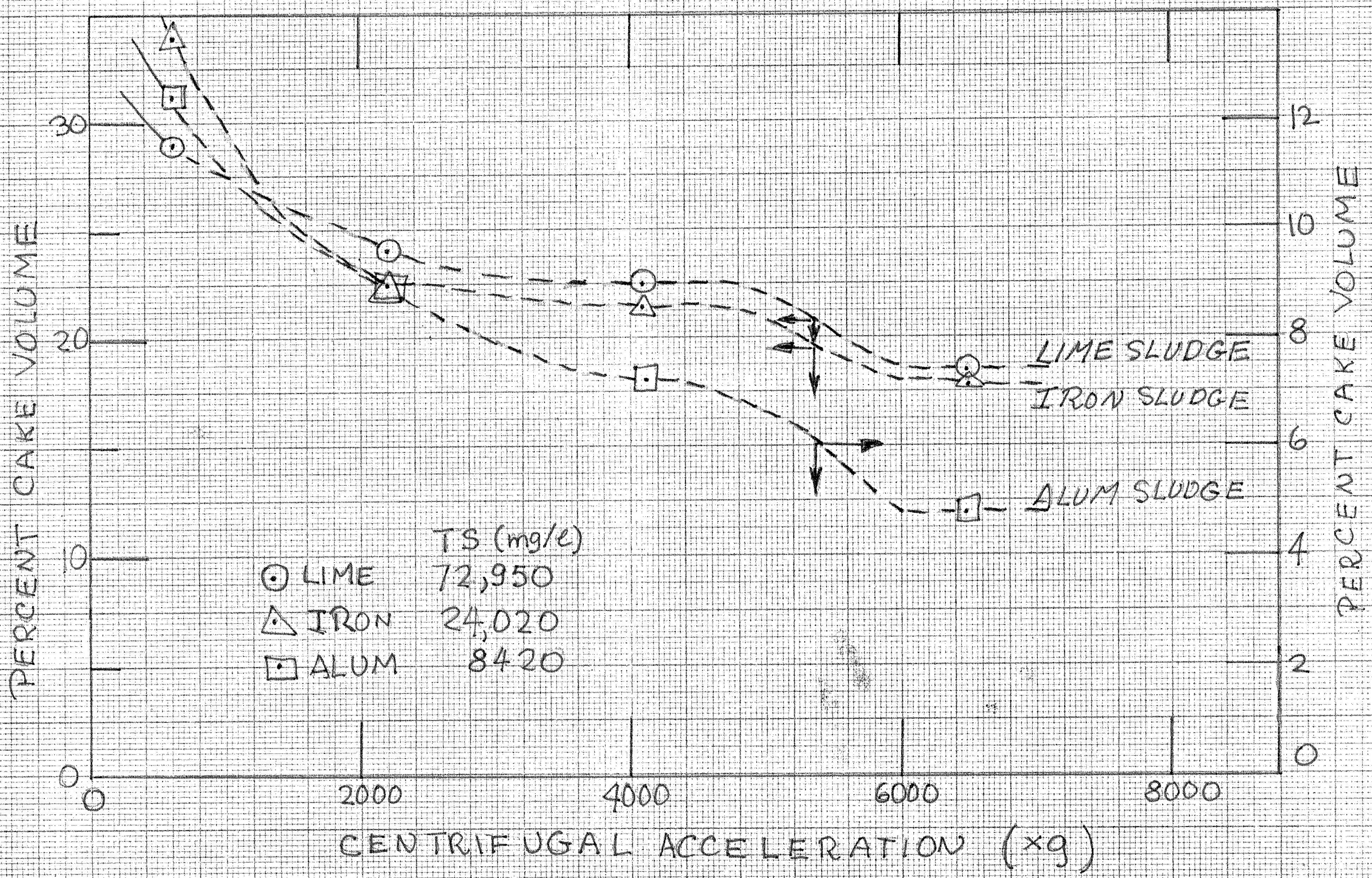


TABLE 2. DISTRIBUTION OF WATER IN THREE SLUDGES

	Sludge		
	Lime	Iron	Alum
Free water	25.5	37	62.5
Floc water	52.0	41.5	30.3
Capillary water	3.7	3.0	2.4
Particle water	11.5	16.1	4.0
(Solids)	7.3	2.4	0.8
Per cent	100	100	100

It must be again emphasized that the data on Figure 6 are really not sufficient for drawing the curves as shown. It is significant, however, that the curves seem to have the same shape, showing a constant cake volume, followed by a drop. Additional data are necessary to better define the water distribution in these sludges.

6. CONCLUSIONS

1. Based on settling and test-tube centrifuge results, the hypothesized distribution of water in wastewater sludge is shown to be reasonable.

2. The activated sludge tested has approximately the following distribution of water:

a)	Free water,removable by gravitational thickening	63,0 per cent
b)	Floc water, removed by mechanical dewatering	32.5 " "
c)	Capillary water, tied to the particles with) sufficient strength as to make its removal) very difficult by mechanical means)	1.0 " "
d)	Particle water, removed only by thermal drying	3.5 " "
		100.0 per cent of water.

3. Preliminary indications are that other sludges can be similarly characterized, although the data are insufficient for drawing any firm conclusions.

4. It is recommended that other experiments be conducted to see how the distribution of water is influenced by such processes as aerobic digestion, etc. Similarly, it would be interesting to relate the distribution of water to such sludge characteristics as specific resistance, cake solids, drying, etc.

7. REFERENCES

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APPENDIX

All data, included those reported in the text,

are included herein

<u>Date</u>: 25 July 1973

<u>Centrifuge</u>: Sorvall SS-1

<u>Sludge</u>: Lime slurry, TS = 72,950 mg/l

rpm		4800	6650	8250	
x g		2187	4072	6460	600
Initial Vol.	ml	40	40	40	40
Final Vol.	ml	30.4	31.0	32.5	28.4
Cake Volume	%	24	22.5	18.8	29

Final height in settling test (%); 74.5

<u>Sludge</u>: Activated sludge, TS = 5070 mg/l

I.V.	ml	40	40	40	40
F.V.	ml	37.5	37.7	37.5	36.8
Cake	%	6.2	5.8	6.2	8.0

Final height in settling test (%); 26

<u>Sludge</u>: Alum sludge, TS = 8420 ml

I.V.	ml	40	40	40	40
F.V.	ml	36.4	37.1	38.1	35.0
Cake	%	9.0	7.2	4.8	12.5

Final height in settling test (%); 37.5

<u>Sludge</u>: Iron slurry, TS = 24,020 mg/l

I.V.	ml	40	40	40	40
F.V.	ml	31.0	31.4	32.6	26.4
Cake	%	22.5	21.5	18.5	34

Final height in settling test (%); 63

Date: 27 July 1973

Centrifuge: Sorvall SS-1

Sludge: Activated sludge, TS = 6350 mg/l, SS = 6100 mg/l

rpm		2000	6750	9600	12,300
x g		385	4250	8500	13,700
Initial Vol.	ml	40	40	40	40
Final Vol.	ml	36.0	37.5	37.5	38.1
Cake volume	%	10.0	6.2	6.2	4.8

Final height in settling test (%); 38.5

Sludge: Activated sludge with polymer

I.V.	ml	40	40	40	40
F.V.	ml	35.5	38.0	37.9	38.5
Cake	%	11.2	5.0	5.2	3.8

Final height in settling test (%); 49

Sludge: Activated sludge with dispersant

I.V.	ml	40	40	40	40
F.V.	ml	30.9	37.3	38.0	38.4
Cake	%	22.8	6.8	5.0	4.0

Final height in settling test (%); 33.5

Sludge: Activated sludge with heat treatment

I.V.	ml	40	40	40	40
F.V.	ml	36.1	37.6	38.4	38.5
Cake	%	9.8	6.0	4.0	3.8

Final height in settling test (%); 26.5

Date: 2 August 1973

Centrifuge: Sorvall SS-1

Sludge: Activated sludge SS = 5460 mg/l

rpm		4900	8250	10,700	13,400	12,200	2000
x g		2300	6250	10,500	16,500	13,800	400
Initial Vol.	ml	40	40	40	40	40	40
Final Vol.	ml	37.5	37.5	38.0	38.3	38.5	36.3
Cake Volume	%	6.25	6.25	5.0	4.25	3.75	9.25

Final height of sludge in settling cylinder (%); 35

Sludge: Activated sludge with cationic polymer

I.V.	ml	40	40	40	40	40	40
F.V.	ml	37.5	37.8	37.9	38.55	38.55	36.1
Cake	%	6.25	5.50	5.25	3.62	3.62	9.75

Final height of sludge (%); 44

Sludge: Activated sludge with dispersant

I.V.	ml	40	40	40	40	40	40
F.V.	ml	37.1	37.9	38.1	38.55	38.6	32.5
Cake	%	7.25	5.25	4.75	3.62	3.5	18.75

Final height of sludge (%);

Sludge: Activated sludge, boiled (heat treated)

I.V.	ml	40	40	40	40	40	40
F.V.	ml	37.9	38.0	38.3	38.6	38.75	37.0
Cake	%	5.25	5.0	4.25	3.5	3.12	7.5

Final height of sludge (3); 35