Sludge Dewatering and the Treatment of Sludge Liquors

J A Slim, D G Devey and J W Vail

WRC Report NO. 82/1/84

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SLUDGE DEWATERING AND THE TREATMENT OF SLUDGE LIQUORS

REPORT TO THE

WATER RESEARCH COMMISSION

BY THE

CITY ENGINEER'S DEPARTMENT
PORT ELIZABETH

WRC REPORT No. 82/1/84

WATER RESEARCH COMMISSION

CONTRACT REPORT

PART I

MECHANICAL DEWATERING OF ZIMPRO HEAT-TREATED AND UNTREATED SEWAGE SLUDGES

PART II

THE TREATMENT OF WASTE LIQUORS FROM THE ZIMPRO HEAT-TREATMENT OF SEWAGE SLUDGES

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by

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City Engineer's Department,

PORT ELIZABETH

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SYNOPSIS

In Part 1 the results obtained during a full-scale evaluation of the dewatering capabilities of a rotary drum vacuum filter, a filter belt press, a filter plate press and two types of centrifuge are described for both Zimpro thermally conditioned (heat-treated) and non-heat-treated sewage sludges, with and without the addition of a polyelectrolyte conditioning agent. Performance criteria are solids capture, cake dryness, machine capacity and polyelectrolyte consumption but other factors which influence the choice of mechanical dewatering equipment are mentioned. The effect of heat-treatment reaction temperature and time on sludge dewatering characteristics are demonstrated and certain characterisation test results are related to machine performance.

In Part II, experiments to determine the aerobic biodegradability of the highly polluted waste liquors from the Zimpro process are described and the trend towards anaerobic digestion for the treatment of these liquors is discussed.

A detailed assessment of the costs of the Zimpro process is given.

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GENERAL INTRODUCTION

From 1977 to 1979 the Water Research Commission undertook a survey of the water management and waste-water problems of local authorities to identify their most urgent and important research needs. The Study Group which assisted the Commission in this task included representatives from all the major municipalities. Later a Research Review Committee for Local Authorities was established and it soon become apparent that, among the many problem areas in which research would be justified, the treatment and disposal of sewage sludges was considered by local authorities to deserve attention of the highest priority. In 1979 the Water Research Commission drew up a Master Plan for research on municipal sludge treatment and disposal, which included an exhaustive list of potential projects, and identified those areas to which priority should be given. Among the priorities was a proposal to investigate sludge dewatering and the treatment of sludge liquors.

Sludge dewatering is obviously a vital and usually costly element in the sludge treatment and disposal process. Dewatering efficiency can have a profound effect on subsequent sludge disposal costs. Sludge dewatered to a high cake solids content is easier to handle, cheaper to transport and cheaper to incinerate. A high solids capture during dewatering, resulting in a "clean" centrate or filtrate, can significantly affect the cost of treating these waste liquors. Conversely, local conditions may dictate a particular method of sludge disposal and the sludge dewatering system employed must then be chosen to meet the situation in the most efficient way.

A variety of mechanical equipment is available for dewatering sewage sludges but not all of it is suited to all situations or to all the types of sludge. The choice of the right equipment is a major factor influencing subsequent running costs. Nor can a dewatering process be considered in isolation from the treatment the sludge receives before dewatering. In fact to minimise costs it is essential that pre-treatment, or conditioning as it is usually referred to, and the dewatering process be optimised. Sludge thickening, by gravity or by dissolved air flotation, and chemical conditioning, often by means of a polyelectrolyte flocculation aid, are the most common pre-treatments applied before mechanical dewatering. Thermal conditioning is less popular in South Africa but has found favour at a number of sewage treatment works in the USA and Europe.

The Fishwater Flats Water Reclamation Works, which treats the bulk of Port Elizabeth's sewage, was finally chosen for a project on the evaluation of mechanical dewatering of sewage sludges because:

(a) facilities existed for both chemical and thermal (Zimpro) conditioning of sludge,

(b) there was a scarcity of information in South Africa at that time on the dewatering of thermally conditioned sludge, and

(c) for reasons explained later in this report, Port Elizabeth was committed to mechanical dewatering, prior to sludge disposal by incineration or to land remote from the sewage works and, because the centrifuges installed at the works had proved to have a disappointing performance, an evaluation of other systems of dewatering would be of great assistance to the City Council.

It was expected that thermally conditioned (heat-treated) sludge would prove relatively easy, and therefore relatively inexpensive, to dewater. But, on the other hand, the Zimpro process is capital and energy intensive and highly mechanised while the waste liquors derived from it are highly polluted. To give perspective to the system as a whole, it was decided that a study of the treatment and biodegradability of heat-treatment waste liquors should be included in the dewatering investigation and that the final report should include an assessment of the cost of the Zimpro thermal conditioning process itself.

Dewatering efficiency does not depend only on the equipment and pre-conditioning. The chemical and physical properties of a sludge have a major effect on its dewatering characteristics. The Master Plan therefore included a priority project on sludge characterisation, with special reference to the evaluation of those properties which would correlate well with mechanical dewatering performance. This project was undertaken by the CSIR's National Institute of Water Research, and will be the subject of a separate report. Liaison between those involved on the two projects was maintained through a Working Sub-Committee and through the project Steering and Management Committees.

In 1981 the Water Research Commission and the City Council of Port Elizabeth entered into a contract by which the former subsidised a project entitled "Sludge Dewatering and the Treatment of Sludge Liquors", to be carried out by the City Engineer's Department at the Fishwater Flats Water Reclamation Works in Port Elizabeth. This report describes the experimental work undertaken and the results obtained.

PART I

THE MECHANICAL DEWATERING OF ZIMPRO HEAT-TREATED AND UNTREATED SEWAGE SLUDGES

1 INTRODUCTION

1.1 BACKGROUND TO THE PROJECT

The experimental work described in this report was carried out at Port Elizabeth's main water reclamation works which is situated at Fishwater Flats on the edge of a tidal estuary, within a few hundred metres of a bathing beach. The choice of site for the works was based on economic considerations, dictated by topography and the need to be close to the industrial centres to facilitate the distribution of reclaimed water.

Because of its situation, sludge drying beds and lagoons or sludge storage of any kind, were not permitted on the works site. There is no arable or pasture land within easy pumping distance. For these reasons it was decided to design a sludge treatment process consisting of mechanical dewatering and incineration, followed by ash disposal on site. At the time this was an economic solution. The system finally chosen, gravity thickening, Zimpro heat-treatment and centrifuging, was intended to render the sludge as close to auto-thermic as possible prior to incineration. Dewatering to a relatively high solids content was, and still is, a vital link in the chain because of the marked effect of cake dryness on the cost of incineration and because, if an agricultural outlet were found, the haulage distances involved would favour a reduction in sludge mass and volume. The inclusion of the Zimpro process had the added advantage that, in the cases of agricultural use or disposal to tip, the treated sludge could not fail to meet the most stringent health requirements for pathogens and parasitic ova.

It became clear subsequently that the dewatering performance of the centrifuges was disappointing. They would not, as had originally been anticipated, give a high rate of solids capture without the use of a polyelectrolyte flocculation aid and the required dose rate was unacceptably high. Without the polyelectrolyte the fine solids in the centrate, which is returned to the head of the works, eventually caused severe operational problems in the sludge thickeners which, in turn, had an adverse ripple effect on many other operations. The incinerator was eventually closed down, because the very steep rise in the price of diesel fuel made it uneconomic, but the outlets subsequently found for the sludge, as an agricultural soil conditioner and as an industrial fuel, did not diminish the need for a high cake dryness. Investigation of the mechanical dewatering of heat-treated sludge, from the point of view of both solids capture and cake dryness, was therefore of considerable interest to Port Elizabeth at the time the project reported here was begun. To extend the relevance of the project it was decided to include sludge that had not been heat-treated in the investigation.

1.2 TREATMENT PROCESSES

The design capacity of the Fishwater Flats Works is 112 Mℓ/day. It treats about 90 per cent of the City's sewage. The sewerage reticulation system is such that the inflow to the works is separated into predominantly domestic and predominantly industrial sewage. The current average dry weather flow in the two streams is 40 Mℓ/d and 20 Mℓ/d respectively. Separation of the two streams is maintained throughout the liquid treatment processes but the sludge is combined for treatment and disposal.

The liquid treatment process is conventional, consisting of screening, grit removal, primary sedimentation, activated sludge oxidation with surface aerators and secondary settlement of the activated sludge; provision is made for settled activated sludge return to the head of the aeration tanks and for the wastage of excess activated sludge.

Sludge from the primary sedimentation tanks is thickened in two 1,24 Mℓ gravity thickeners, after grit removal. The thickening achieved is usually from 0,5 per cent total solids to about 6,0 per cent. Waste activated sludge is thickened in two other gravity thickeners, of the same dimensions as those for the primary sludge, and a total solids concentration of 2,0 percent can usually be achieved. Overflow from the primary thickeners is returned to the industrial sewage, upstream of the primary sedimentation tanks, and the activated sludge thickener overflow goes directly to the head of the industrial aeration tanks. The thickened sludge can then be conditioned in two ways before being mechanically dewatered by centrifuging. In the first case only chemical conditioning (polyelectrolyte) is employed, but this route is not normally used. The second and normal route is thermal conditioning by the Zimpro wet-air oxidation process (heat-treatment) which is described in more detail below. With the centrifuges at present in use, additional conditioning with polyelectrolyte is required after heat-treatment. The centrate from the centrifuges is returned to the industrial sewage stream at the head of the works.

1.3 ZIMPRO HEAT-TREATMENT PROCESS

Sludge is drawn into a balance tower from the four thickeners in a preset pattern using timer-controlled pneumatic valves. From there it is macerated and pumped to a sludge holding tank. From this slowly stirred tank, the sludge passes through a second maceration stage to high pressure pumps which increase the system pressure to between 2000 kPa and 2200 kPa. Air is introduced into the sludge stream and the mixture passes through the inner tubes of two, in-series, heat exchangers to the reactor vessel. Steam is injected into the reactor and the temperature rises to 180-195 °C. Retention time in the reactor is approximately 30 minutes. The treated sludge passes through the outer annulus of the heat exchangers, where it is cooled by transfer of heat to the incoming sludge. The system pressure is automatically reduced as the treated sludge passes through control valves to consolidation tanks. In the two sealed consolidation tanks the sludge thickens prior to being pumped to the centrifuges. Each tank is fitted with a mechanical scraper. Supernatant overflow is returned to the head of the industrial stream.

At the current inflow to the Works of 60 Mℓ per day about 25 t per day of mixed primary and waste activated sludge dry solids are generated for heat treatment. During heat-treatment about 30 per cent of these solids are broken down and dissolve to form the waste liquors, the volume of which averages about 0,6 Mℓ per day.

Part II of this report describes an investigation into the biodegradability and treatment of the waste liquors derived from the thickening and dewatering of heat-treated sludge. Included as an Appendix to Part II is a summary of heat-treatment costs.

1.4 SLUDGE PROPERTIES

The table below sets out some of the properties typical of the sludges used in this investigation:-

A. thickened primary,

B. thickened secondary,

C. a mixture, in equal proportions by volume, of thickened primary and activated sludges (i.e. feed to heat-treatment or direct to dewatering), and

D. thickened, heat-treated sludge (i.e. feed to dewatering).

Sludge type	A	B	C	D
Total solids (%)	6,0	1,8	4,0	7,8
Capillary suction time (18) (secs)	60-100	15-25	100-200	15-60
Specific resistance to filtration (mkg^{-1})	$1,4 \times 10^{13}$- 2×10^{14}	1×10^{13}- 5×10^{13}	6×10^{13}- 2×10^{14}	2×10^{11}- 5×10^{12}
<u>On dry solids</u>				
Organic and Volatile matter (%)	81	80	80	75

There are a number of operational variables on a sewage treatment works that can affect the dewatering properties of the sludges. Some of these, such as the composition of the incoming sewage, cannot be controlled but it was always intended that this project should investigate the dewatering of sludges under the practical conditions which occur on a treatment works, as opposed to rigidly controlled laboratory conditions.

Of the controllable variables, the properties of the activated sludge and the reaction time and temperature of heat treatment are the most significant. The former depends on a number of factors such as aeration conditions, sludge age, feed/mass ratio in the aeration tank liquors and time spent in thickening. During the investigations these factors were kept as constant as possible but, because bulking of the activated sludge was prevalent, the settling properties of this sludge varied, leading to variations in its solids content after thickening. The heat-treatment plant operating conditions were controlled within the range in which the dewatering characteristics of the heat-treated sludge remain virtually constant; these are the operating conditions recommended by the manufacturer. A limited investigation of the effects of reaction temperature and time on sludge dewatering characteristics and the composition of the waste liquors is reported in Appendix A to this part of the report. The results confirm that the dewatering characteristics of the heat-treated sludges used in these investigations will not have varied as a result of heat-treatment plant operating conditions.

1.5 DEFINITION OF TERMS

An explanation of some of the terms used in this report are given below.

(i) Heat-treatment. The thermal conditioning of sludge by means of the Zimpro wet-air oxidation process at a temperature of 180-195 °C and a reaction time of 27-30 minutes. It is an aerobic system, not to be confused with anaerobic thermal conditioning as in the Porteous process.

(ii) Heat-treated sludge. A mixture, in equal proportions by volume, of thickened primary and thickened waste activated sludge, which has been subjected to heat-treatment and subsequently allowed to thicken under gravity.

(iii) Un-treated sludge. A mixture of primary and waste activated sludges (as in (ii) above) which has not been heat treated.

(iv) Polyelectrolyte. A cationic flocculant, Zetag 57, used in aqueous solution. Extensive tests have shown this polymer to be the most suitable dewatering aid for the sludges generated at the Fishwater Flats works.

(v) Chemical conditioning. The addition of a polyelectrolyte to a sludge prior to mechanical dewatering.

(vi) Total solids (TS). The mass of solids contained in a sludge, as determined by evaporation of the sludge to dryness at 105 °C. Usually expressed at % m/m. The term is synonomous with dry solids (DS).

(vii) Suspended Solids (SS). The mass of sludge solids suspended in a sludge liquor, as determined by filtering the liquor and drying the residue so obtained at 105 °C. Usually expressed as mg/ℓ.

(viii) Filter test (FT). The volume of filtrate produced in 5 minutes from 100 mℓ of sludge, at a suction of 40 kPa, through a 55 mm Whatman No. 1 filter paper.

(ix) Capillary suction time (CST), using both the 10 mm and 18 mm funnels. A standard test (IWPC, 1981).

(x) Specific resistance to filtration (SRF). A standard test (IWPC, 1981).

(xi) Centrifuge Sludge Volume Index (CSVI). The percentage by volume of centrifuge cake, obtained by subjecting a sludge sample to a given centrifugal force for a given time, divided by its percentage suspended solids. A compressibility factor can be derived from the ratio of the CSVI at 1000 rpm to the CSVI at 2990 rpm. (Fourie 1982).

(xii) Centrifuge Cake Water Retention Index (CCWRI). The mass of water retained in the centrifuge cake by a unit mass of dry solids after centrifuging at 2680 'g' for 5 minutes (Fourie, 1983). However, in these investigations the test was modified to give a centrifugal force of 1350 'g'.

Definitions (viii)-(xii) refer to sludge dewatering characterisation tests. Discussion of the results obtained with these tests will be found in Appendix B to Part I of this report.

2. ROTARY DRUM VACUUM FILTER

2.1 INTRODUCTION

A rotary drum vacuum filter consists of a cylindrical drum covered by a filtration medium, usually cloth, which rotates partially submerged in a bath of sludge. A vacuum is applied to the inner face of the drum causing the liquid to be drawn through the medium and a layer of sludge to be deposited on the outer surface. Application of the vacuum continues after the filter medium has emerged from the liquid sludge, drawing more water from the sludge layer and resulting in the formation of a sludge cake.

The revolving drum is made up of segments of equal size and the face or deck of the drum is constructed of a series of grids; the whole deck is covered with the filter cloth. Each segment or compartment is connected to a rotary control valve.

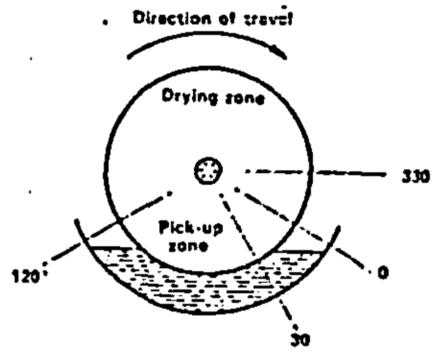
The sludge bath consists of a semi-cylindrical tank which extends the full width of the filter drum and the sludge solids are kept in suspension by means of a mechanically operated agitator.

Approximately 25 to 30% of the filter surface area is submerged and a vacuum is applied, by means of a control valve, to the submerged segments, so drawing the filtrate through the cloth and depositing the sludge solids onto its surface. The cake increases in thickness as the evacuated section of the drum passes through the liquid sludge. When the section of the drum on which the cake has now formed emerges from the liquid sludge, the vacuum continues to be applied, air passes through the cake and additional filtrate is drawn from the sludge.

The vacuum is applied until the drum has rotated through some 330° when air pressure is applied outwards by means of the control valve. The air lifts the cake away from the cloth as it passes over a doctor blade which is set tangentially to the drum, causing the sludge cake to be discharged.

Diagrammatic representations of a rotary drum vacuum filter are shown in figures 2.1 and 2.2:

Figure 2.1



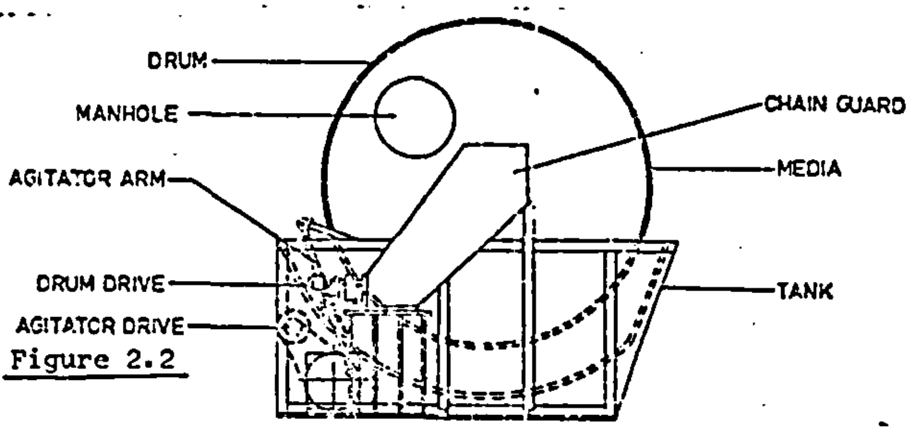


Figure 2.2

Figure 2.1 Sequence of operation of rotary drum vacuum filter

Figure 2.2 Section through a rotary drum vacuum filter

2.2 EXPERIMENTAL EQUIPMENT AND LAYOUT

The vacuum drum filter used for the experimental work was a pilot scale unit with a drum having a circumference of 1,45 m and a width of 0,28 m, giving an effective surface area of 0,406 m^2. The unit was completely self-contained having its own vacuum and filtrate pumps.

There are many types of cloth suitable for use on a vacuum filter and a considerable amount of preliminary laboratory work, using a 0,00929 m^2 filter leaf apparatus, was necessary to determine the best cloth for the sludges to be tested. The cloth finally chosen was a multifilament polypropylene material (type POPR 808F). The depth of immersion of the drum in the feed sludge was kept constant at 0,088 m throughout the tests, equivalent to a 29% immersion of the total filtration area. The feed sludge was held in a 4500ℓ capacity asbestos cement tank fitted with an electrically driven stirrer to ensure that the sludge solids were kept in suspension. Sludge was fed from this holding tank, by gravity, to the bath of the vacuum filter. A constant head device ensured a constant drum immersion depth and sludge overflowing from the device was returned to the sludge holding tank. The layout for the equipment is illustrated in Figure 2.3.

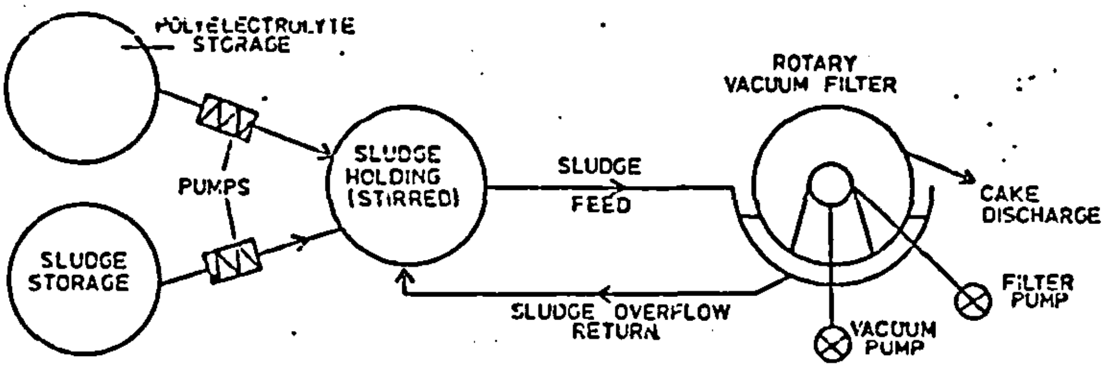


Figure 2.3 Rotary drum vacuum filter test equipment

The vacuum produced at the drum remained at a constant -35 to -40 kPa throughout the tests. Dosing of the polyelectrolyte was carried out by adding the required volume of a 0,1% m/v solution to the sludge in the holding tank.

2.3 EXPERIMENTAL PROCEDURES

The operational variables which were investigated were as follows:-

(i) Speed of rotation . The speed of rotation of the filter drum could be varied from a minimum of 12 to a maximum of 48 revolutions per hour (rph). For test purposes four rotation speeds were chosen, namely 12, 24, 36, and 48 rph.

(ii) Polyelectrolyte dosage. The level of polyelectrolyte addition ranged from zero to a level at which maximum flocculation was achieved, namely 1,7 kg/t of dry solids in the case of heat-treated sludge and 6,7 kg/t in the case of untreated sludge.

A total of 92 runs were made, of which 64 were on heat treated sludge (4 drum speeds; 4 polyelectrolyte concentrations; 4 test runs on each) and 28 on untreated sludge (4 drum speeds; five polyelectrolyte concentrations; 1 or 2 test runs on each).

In each run the machine was operated until stable conditions were achieved before testing began. During a test run a number of samples of feed sludge, cake and filtrate were taken and composites of these individual samples were used for analysis.

The tests carried out on the feed sludge samples were:

(a) Percentage total solids.
(b) Capillary suction time (CST), using both the 10 mm and the 18 mm funnels.
(c) Specific resistance to filtration (SRF).
(d) Centrifuge cake water retention index (CCWRI).

The tests carried out on the filter cake and the filtrate were total solids and suspended solids respectively.

2.4 RESULTS

(i) Heat treated sludge, without polyelectrolyte : see Table 2.1
Heat treated sludge, with polyelectrolyte : see Table 2.2
(ii) Untreated sludge : see Table 2.3.

2.5 DISCUSSION OF RESULTS

To simplify presentation, the averages of the replicate runs were determined and plotted as single points in Figures 2.4 - 2.8.

2.5.1 Heat treated sludge: Figure 2.4 shows the relationships between polyelectrolyte dosage and vacuum filter output, expressed in kg/m^2h, at the four different drum speeds and demonstrates that the output from the vacuum filter increases with drum speed. Addition of polyelectrolyte also increases the output from the filter but this effect is reduced as the concentration of polyelectrolyte increases, especially at low drum speeds. It is important to note that excellent outputs are obtained with no addition of polyelectrolyte, an important economic advantage.

Figure 2.5 expresses the relationship obtained between cake dryness and polyelectrolyte dosage at the four different drum speeds. Although there is some scatter, it can be seen that cake dryness is adversely affected by the addition of polyelectrolyte. The higher the concentration the wetter the cake. This relationship is also affected by drum speed, the lower speeds produce the drier sludge cakes. Cake dryness varied from a minimum of 36% at 1,7 kg polylectrolyte/t TS to a maximum of about 42% total solids without polyelectrolyte.

In all of the tests the solids capture achieved by the vacuum filter was excellent, varying from a minimum of 98% up to a maximum of 99,8%.

2.5.2 Untreated sludge: Figure 2.6 shows the relationship between polyelectrolyte dosage and vacuum filter output at the four different drum speeds. At the higher speeds the relationship is of the same form as that for heat treated sludge; output increases with drum speed and with polyelectrolyte dose, though the latter effect becomes less marked at the higher dosage rates. At lower drum speeds and low polyelectrolyte doses the situation is not so straightforward. In the first place it was found that a cake would not form on the filter without the addition of polyelectrolyte. Untreated sludge cannot, therefore, be dewatered by means of a vacuum filter without prior conditioning. As the polyelectrolyte dose is increased, at the lower drum speeds, cake production appears to rise rapidly. The reason for this effect is not clear but, because it applies only in a region of very high polyelectrolyte doses and very low cake outputs, it probably cannot be regarded as having any real significance. To put these considerations in perspective it should be pointed out that, even at the highest drum speed and a polyelectrolyte dose as high as 6,7 kg/tTS, the output is only about one third of that obtained from the dewatering of heat treated sludge without the addition of any polyelectrolyte.

Figure 2.7 shows the relationship obtained between cake dryness and polyelectrolyte dosage at the four different drum speeds. There is considerable scatter of results but generally the cake dryness improves with increased polyelectrolyte dosages. To a lesser degree the drum speed also affects cake dryness with the drier cakes being produced at the lower speeds.

Cake dryness varied from a minimum of approximately 13% to a maximum of 27% total solids, but the latter is only achieved at a polyelectrolyte dose of 6 kg/tTS.

Figure 2.8 shows the relationship between the polyelectrolyte dosage and the percentage capture of solids by the machine. At all four speeds the capture improves as the polyelectrolyte dosage is increased. There is also a less marked trend for the capture to improve as the drum speed is decreased.

Solids capture varies from approximately 94% to a maximum of 98% at a polyelectrolyte dose of 6 kg/tTS.

FIGURE 2.4

DEWATERING OF HEAT TREATED SLUDGE BY VACUUM FILTRATION

POLYELECTROLYTE DOSAGE v VACUUM FILTER OUTPUT kg $m^{-2}h^{-1}$

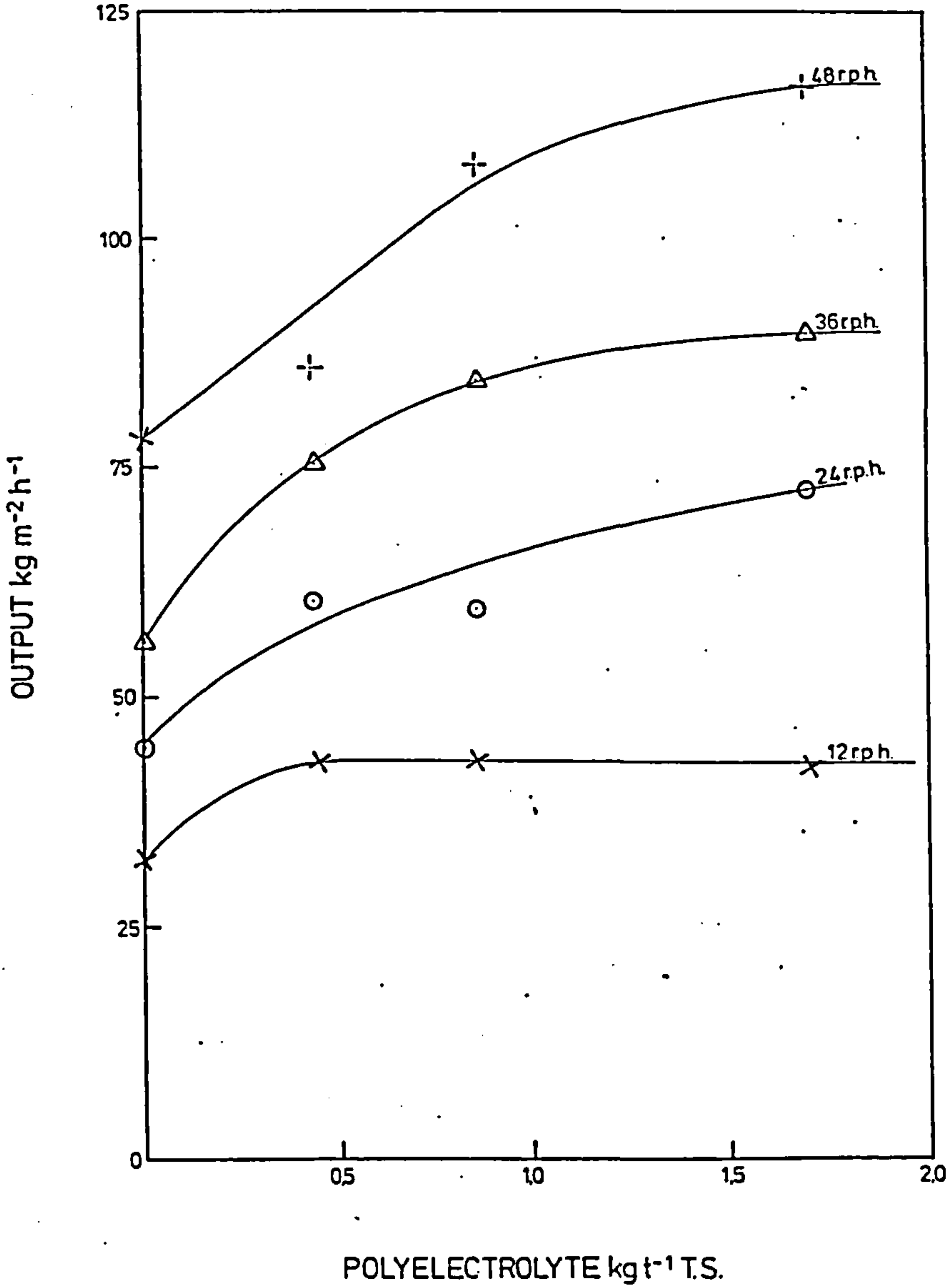


FIGURE 2,5

DEWATERING OF HEAT-TREATED SLUDGE BY VACUUM FILTRATION.

POLYELECTROLYTE DOSAGE v % TOTAL SOLIDS IN CAKE .

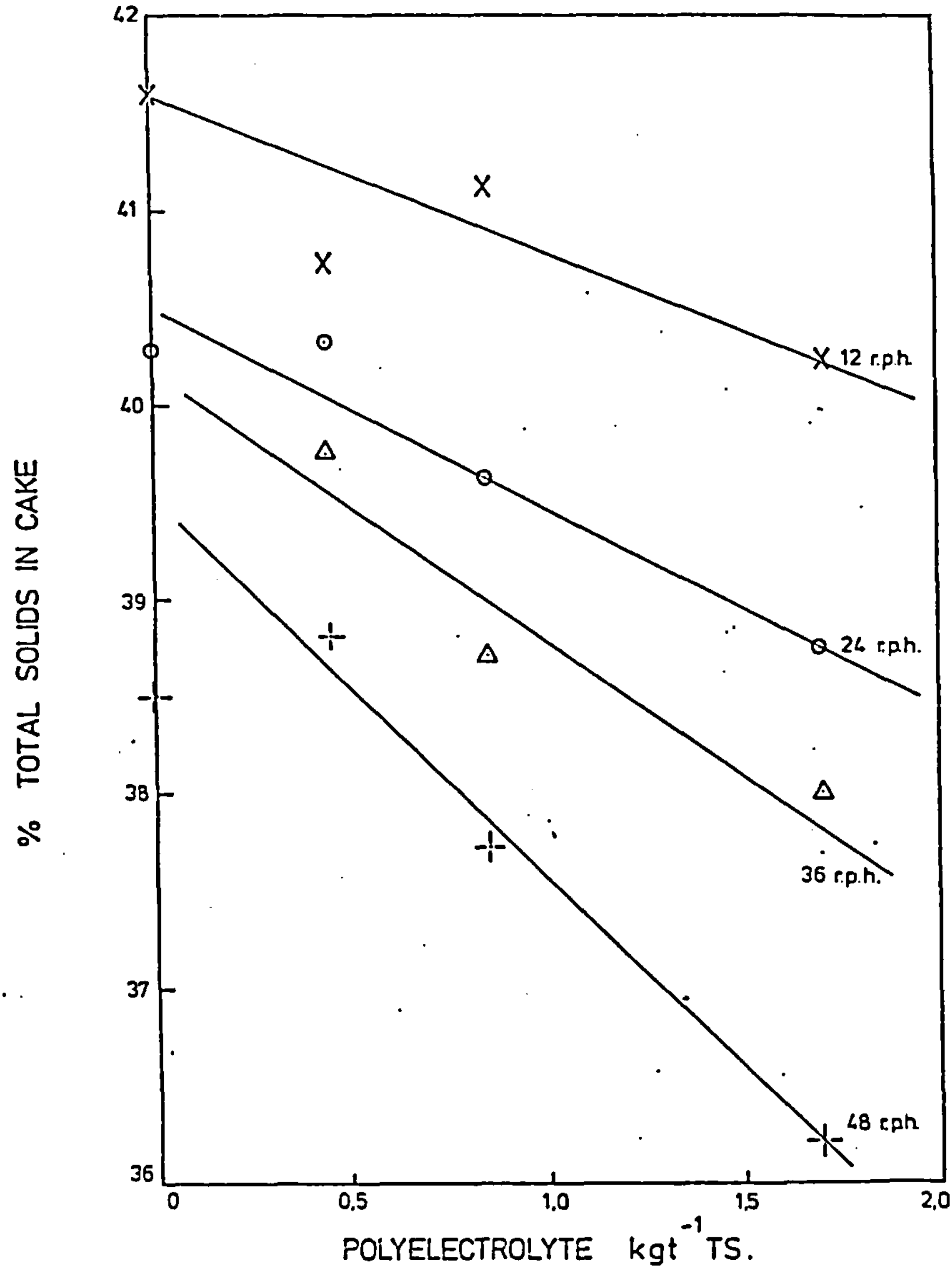
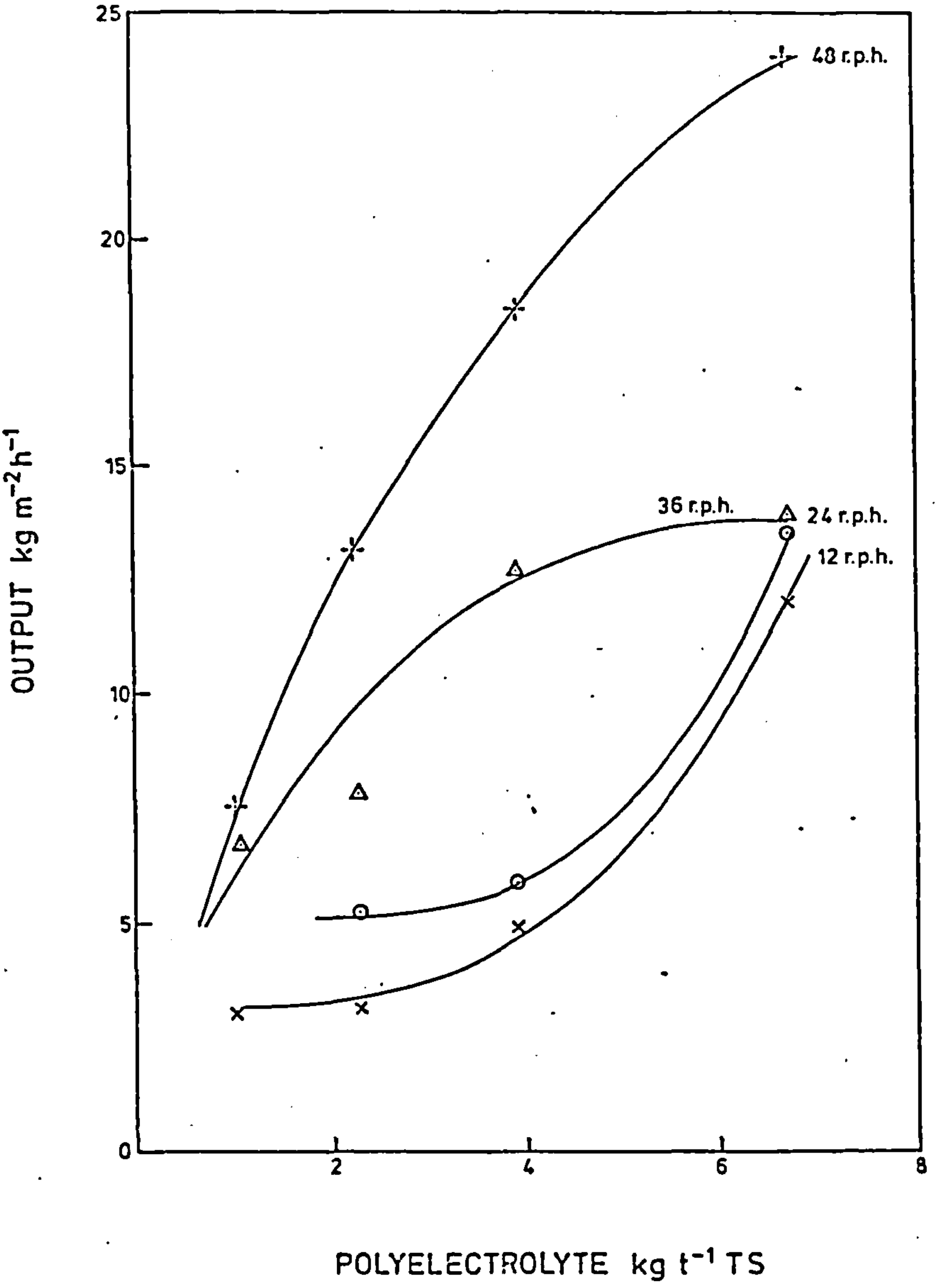


FIGURE 2,6

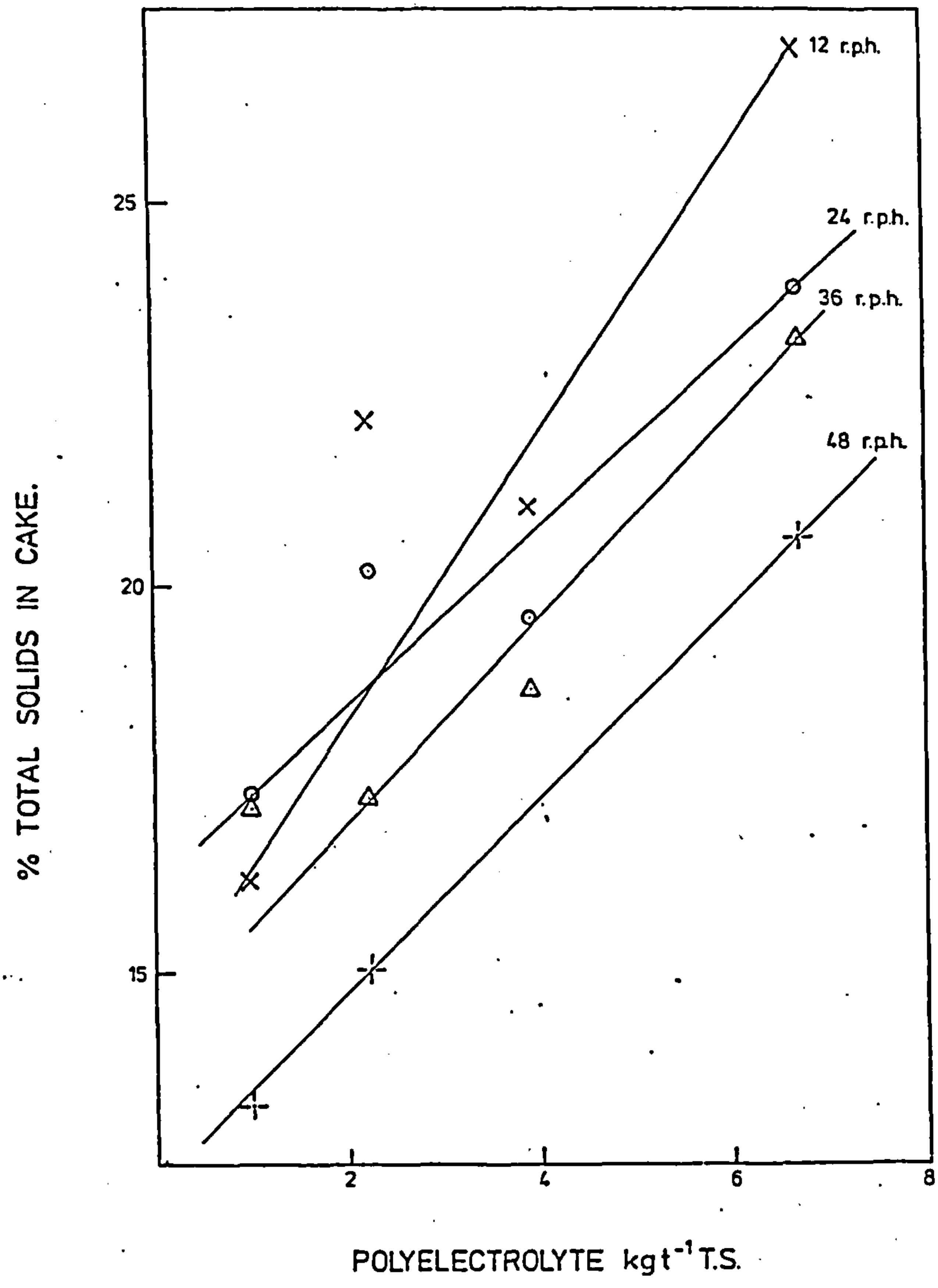
DEWATERING OF UNTREATED SLUDGE BY VACUUM FILTRATION

POLYELECTROLYTE DOSAGE v VACUUM FILTER OUTPUT $kg\ m^{-2}h^{-1}$



DEWATERING OF UNTREATED SLUDGE BY VACUUM FILTRATION.

POLYELECTROLYTE DOSAGE v % TOTAL SOLIDS IN CAKE.



DEWATERING OF UNTREATED SLUDGE BY VACUUM FILTRATION.

POLYELECTROLYTE DOSAGE v % SOLID CAPTURE.

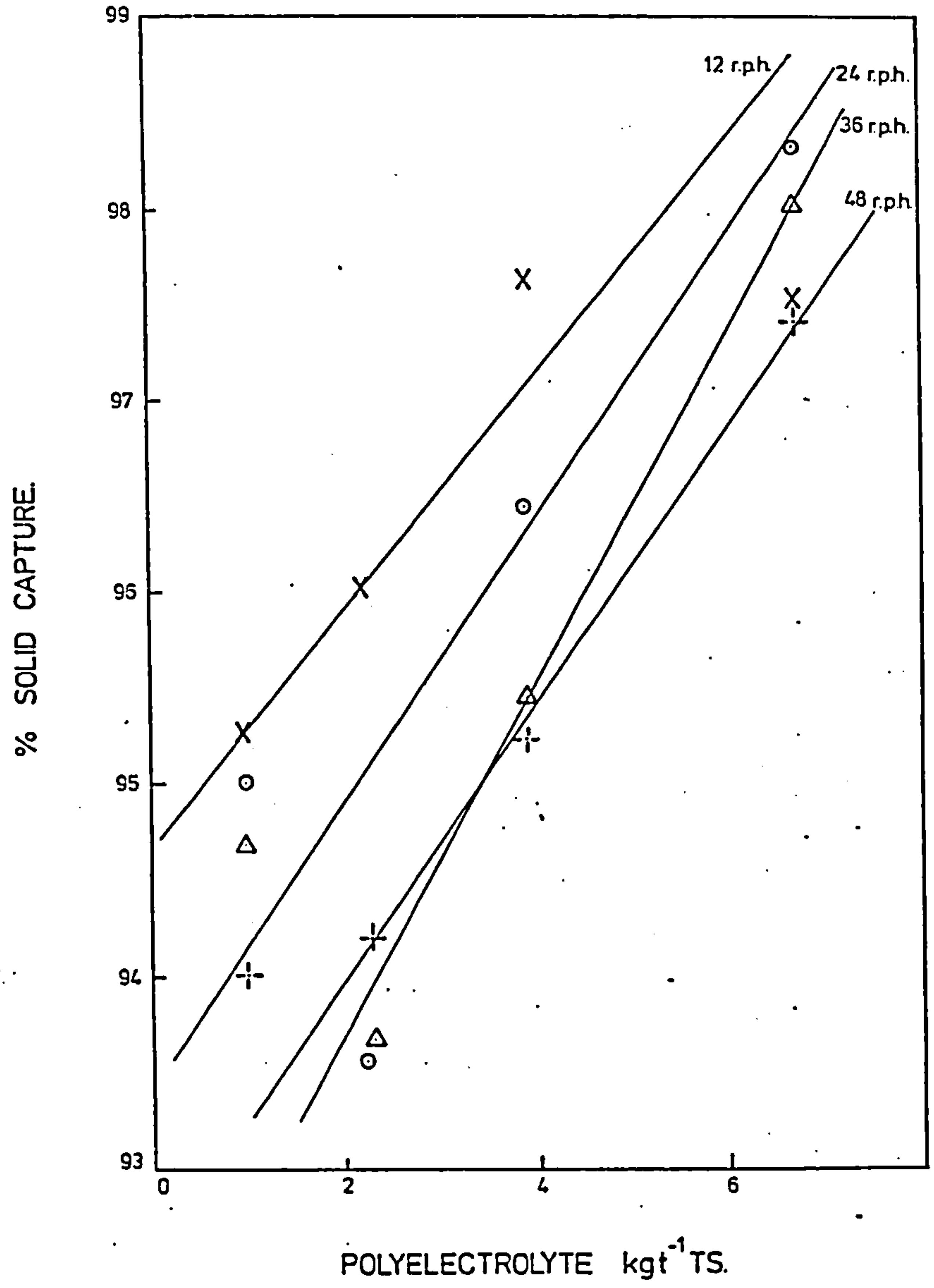


TABLE 2.1

VACUUM FILTER - HEAT TREATED SLUDGE WITHOUT POLYELECTROLYTE

	Feed sludge - unconditioned					Vacuum drum	Solids processed			Filtrate	Capture
Run No.	% TS	CST 18 (secs)	CST 10 (secs)	SRF mkg^{-1}	CCWRI	speed rph	kg/h	kg/m^2h	Cake TS %	SS mg/ℓ	%
1	8,61	17,8	41,7	$1,76 \times 10^{11}$	2,975	12	20,58	50,69	40,48	1610	98,5
2	"	"	"	"	"	24	32,16	79,21	38,99	1740	98,4
3	"	"	"	"	"	36	32,88	80,99	36,20	2090	98,1
4	"	"	"	"	"	48	42,36	104,33	36,29	2130	98,1
5	8,78	15,8	40,9	$2,56 \times 10^{11}$	2,818	12	12,30	30,30	38,29	652	99,4
6	"	"	"	"	"	24	15,47	38,10	37,46	630	99,4
7	"	"	"	"	"	36	20,52	50,54	36,59	1040	99,1
8	"	"	"	"	"	48	32,72	80,59	38,29	1030	99,1
9	6,00	14,2	37,0	$2,67 \times 10^{11}$	3,748	12	5,60	13,79	42,12	728	99,0
10	"	"	"	"	"	24	9,30	22,91	41,19	1200	98,3
11	"	"	"	"	"	36	12,40	30,54	38,47	1500	97,9
12	"	"	"	"	"	48	19,40	47,78	37,96	1520	97,9
13	6,10	10,5	27,8	$1,35 \times 10^{11}$	3,509	12	14,92	36,75	45,49	640	99,1
14	"	"	"	"	"	24	15,30	37,68	43,49	1096	98,5
15	"	"	"	"	"	36	24,70	60,84	43,02	1168	98,4
16	"	"	"	"	"	48	31,97	78,75	41,48	1228	98,3

TABLE 2.2

VACUUM FILTRATION – HEAT TREATED SLUDGE CONDITIONED WITH POLYELECTROLYTE

	Feed sludge – unconditioned % TS	CST 18 (secs)	CST 10 (secs)	SRF mkg^{-1}	CCWRI	Polymer dose kg/t TS	Feed sludge + Polyelectrolyte % TS	CST 18 (secs)	CST 10 (secs)	SRF mkg^{-1}	CCWRI	Vacuum drum speed rph	Solids Processed kg/h	Solids Processed kg/m^2h	Cake TS %	Filtrate SS mg/ℓ	Capture %
17	9,86	16,9	46,8	$1,38 \times 10^{11}$	3,064	0,44	9,33	13,5	31,0	$7,51 \times 10^{10}$	2,843	12	24,08	59,31	44,51	322	99,7
18	"	"	"	"	"	"	"	"	"	"	"	24	30,51	75,15	41,76	342	99,7
19	"	"	"	"	"	"	"	"	"	"	"	36	43,88	108,08	40,84	428	99,6
20	"	"	"	"	"	"	"	"	"	"	"	48	52,5	128,69	39,19	682	99,4
21	12,82	23,3	59,0	$2,88 \times 10^{11}$	2,212	"	11,91	19,6	33,8	$2,56 \times 10^{11}$	2,237	12	16,10	39,66	39,53	404	99,8
22	"	"	"	"	"	"	"	"	"	"	"	24	25,16	61,97	39,64	552	99,7
23	"	"	"	"	"	"	"	"	"	"	"	36	25,60	63,05	38,65	820	99,5
24	"	"	"	"	"	"	"	"	"	"	"	48	31,60	77,83	37,05	824	99,5
25	5,66	11,2	22,5	$1,73 \times 10^{11}$	4,594	"	5,51	11,9	25,9	$1,59 \times 10^{11}$	3,775	12	7,30	17,98	41,37	446	99,3
26	"	"	"	"	"	"	"	"	"	"	"	24	10,10	24,88	42,06	416	99,3
27	"	"	"	"	"	"	"	"	"	"	"	36	15,05	37,07	41,43	520	99,2
28	"	"	"	"	"	"	"	"	"	"	"	48	18,10	44,58	39,89	860	98,6
29	8,19	19,4	46,5	$2,68 \times 10^{11}$	3,207	"	7,86	17,3	42,0	$1,99 \times 10^{11}$	2,489	12	22,80	56,16	37,49	610	99,4
30	"	"	"	"	"	"	"	"	"	"	"	24	32,76	80,69	37,73	950	99,0
31	"	"	"	"	"	"	"	"	"	"	"	36	37,80	93,10	38,08	1220	98,5
32	"	"	"	"	"	"	"	"	"	"	"	48	37,38	92,07	39,06	1930	98,0
33	12,80	26,2	77,8	$2,64 \times 10^{11}$	2,314	0,85	11,38	20,2	55,2	$2,30 \times 10^{11}$	2,266	12	19,20	47,29	40,64	452	99,7
34	"	"	"	"	"	"	"	"	"	"	"	24	22,40	55,17	38,41	608	99,6
35	"	"	"	"	"	"	"	"	"	"	"	36	38,52	94,88	37,23	626	99,6
36	"	"	"	"	"	"	"	"	"	"	"	48	45,36	111,72	36,55	884	99,5
37	5,46	10,5	27,8	$1,35 \times 10^{11}$	3,509	"	4,92	8,2	18,0	$3,95 \times 10^{10}$	3,310	12	12,17	29,98	41,11	288	99,5
38	"	"	"	"	"	"	"	"	"	"	"	24	18,07	44,51	39,51	161	99,7
39	"	"	"	"	"	"	"	"	"	"	"	36	24,45	65,15	39,23	192	99,7
40	"	"	"	"	"	"	"	"	"	"	"	48	30,64	75,47	39,38	596	98,9
41	9,38	16,4	38,7	$1,36 \times 10^{11}$	2,903	"	8,70	9,6	22,7	$3,42 \times 10^{10}$	2,924	12	29,70	73,15	41,65	264	99,8
42	"	"	"	"	"	"	"	"	"	"	"	24	40,15	98,89	39,84	260	99,8
43	"	"	"	"	"	"	"	"	"	"	"	36	51,06	125,76	38,49	392	99,6
44	"	"	"	"	"	"	"	"	"	"	"	48	70,55	173,77	36,03	332	99,7
45	6,45	16,7	50,0	$2,49 \times 10^{11}$	3,807	0,85	6,08	10,6	22,8	$7,76 \times 10^{10}$	3,608	12	10,77	26,53	41,52	340	99,5
46	"	"	"	"	"	"	"	"	"	"	"	24	16,32	40,20	40,72	352	99,5
47	"	"	"	"	"	"	"	"	"	"	"	36	21,20	52,22	39,94	418	99,4
48	"	"	"	"	"	"	"	"	"	"	"	48	28,64	70,54	38,93	874	98,8
49	13,33	35,2	95,1	$3,45 \times 10^{11}$	2,247	1,69	10,27	17,4	49,6	$2,27 \times 10^{11}$	2,492	12	14,33	35,30	39,67	314	99,8
50	"	"	"	"	"	"	"	"	"	"	"	24	27,76	68,37	39,15	280	99,8
51	"	"	"	"	"	"	"	"	"	"	"	36	37,32	91,92	37,55	646	99,5
52	"	"	"	"	"	"	"	"	"	"	"	48	43,44	107,00	35,82	568	99,6
53	7,66	17,0	47,4	$2,38 \times 10^{11}$	3,312	"	6,87	11,2	24,7	$4,90 \times 10^{10}$	3,149	12	23,80	58,62	39,50	130	99,8
54	"	"	"	"	"	"	"	"	"	"	"	24	33,50	82,51	38,14	174	99,8
55	"	"	"	"	"	"	"	"	"	"	"	36	42,00	103,45	38,46	178	99,8
56	"	"	"	"	"	"	"	"	"	"	"	48	55,08	135,67	36,18	282	99,7
57	5,76	13,0	33,8	$2,64 \times 10^{11}$	4,276	"	5,24	8,8	16,9	$1,83 \times 10^{10}$	3,253	12	12,53	30,86	42,18	236	99,6
58	"	"	"	"	"	"	"	"	"	"	"	24	15,60	38,42	41,23	276	99,5
59	"	"	"	"	"	"	"	"	"	"	"	36	21,86	53,84	39,93	340	99,4
60	"	"	"	"	"	"	"	"	"	"	"	48	28,90	71,18	38,26	480	99,2
61	6,93	16,2	42,8	$3,13 \times 10^{11}$	3,550	"	6,01	10,3	23,1	$8,8 \times 10^{9}$	3,387	12	20,33	50,07	39,43	116	99,8
62	"	"	"	"	"	"	"	"	"	"	"	24	40,68	100,20	37,51	116	99,8
63	"	"	"	"	"	"	"	"	"	"	"	36	44,28	109,06	36,12	132	99,8
64	"	"	"	"	"	"	"	"	"	"	"	48	62,40	153,69	34,58	146	99,8

TABLE 2.3

VACUUM FILTRATION - UNTREATED SLUDGE CONDITIONED WITH POLYELECTROLYTE

	Feed sludge - unconditioned					Polymer	Feed sludge + Polyelectrolyte					Vacuum drum speed	Solids Processed			Filtrate	Capture
	% TS	CST 18 (secs)	CST 10 (secs)	SRF mkg^{-1}	CCWRI	dose kg/t TS	% TS	CST 18 (secs)	CST 10 (secs)	SRF mkg^{-1}	CCWRI	rph	kg/h	kg/m^2h	Cake TS %	SS mg/ℓ	%
65	4,81	104,9	346,1	$7,942 \times 10^{13}$	6,200	Nil	-	-	-	-	-	12	Cake did not form on cloth and				
66	"	"	"	"	"	"	-	-	-	-	-	24	no filtrate produced				
67	"	"	"	"	"	"	-	-	-	-	-	36					
68	"	"	"	"	"	"	-	-	-	-	-	48					
69	"	"	"	"	"	1,01	4,52	94,8	319,4	$5,628 \times 10^{13}$	6,478	12	1,22	3,00	16,12	2920	95,3
70	"	"	"	"	"	"	"	"	"	"	"	24	2,60	6,40	17,24	3020	95,0
71	"	"	"	"	"	"	"	"	"	"	"	36	2,63	6,48	17,18	3210	94,7
72	"	"	"	"	"	"	"	"	"	"	"	48	3,04	7,49	13,22	3970	94,0
73	"	"	"	"	"	2,27	4,27	43,4	135,3	$1,507 \times 10^{13}$	6,150	12	1,15	2,83	18,86	1660	97,0
74	"	"	"	"	"	"	"	"	"	"	"	24	2,95	7,27	18,60	2900	94,7
75	"	"	"	"	"	"	"	"	"	"	"	36	4,02	9,90	16,45	2980	94,7
76	"	"	"	"	"	"	"	"	"	"	"	48	6,70	16,50	15,87	3320	94,2
77	4,94	102,9	343,4	$6,414 \times 10^{13}$	5,910	"	4,23	66,9	216,3	$5,074 \times 10^{13}$	6,062	12	1,44	3,55	25,72	2500	95,0
78	"	"	"	"	"	"	"	"	"	"	"	24	1,33	3,28	21,63	3940	92,4
79	"	"	"	"	"	"	"	"	"	"	"	36	2,28	5,62	17,95	4000	92,6
80	"	"	"	"	"	"	"	"	"	"	"	48	4,00	9,85	14,13	-	-
81	4,81	104,9	346,1	$7,942 \times 10^{13}$	6,200	3,93	3,91	19,5	53,8	$3,99 \times 10^{12}$	5,491	12	2,23	5,49	18,14	1500	96,7
82	"	"	"	"	"	"	"	"	"	"	"	24	2,63	6,48	18,69	1660	96,6
83	"	"	"	"	"	"	"	"	"	"	"	36	5,26	12,96	15,58	1880	96,4
84	"	"	"	"	"	"	"	"	"	"	"	48	8,79	21,65	18,29	1720	96,5
85	4,81	104,9	346,1	$6,414 \times 10^{13}$	6,200	"	3,97	22,6	55,1	$4,13 \times 10^{12}$	5,498	12	1,73	4,26	24,03	940	98,0
86	"	"	"	"	"	"	"	"	"	"	"	24	2,13	5,25	20,44	1860	96,2
87	"	"	"	"	"	"	"	"	"	"	"	36	5,16	12,71	21,64	2740	94,3
88	"	"	"	"	"	"	"	"	"	"	"	48	6,22	15,32	23,54	2900	93,9
89	4,81	104,9	346,1	$6,414 \times 10^{13}$	6,200	6,70	3,63	11,7	26,2	$9,6 \times 10^{11}$	5,452	12	4,88	12,02	26,98	1060	97,5
90	"	"	"	"	"	"	"	"	"	"	"	24	5,53	13,62	23,81	740	98,3
91	"	"	"	"	"	"	"	"	"	"	"	36	5,70	14,04	23,28	870	98,0
92	"	"	"	"	"	"	"	"	"	"	"	48	9,76	24,04	20,38	1160	97,4

3. FILTER BELT PRESS

3.1 INTRODUCTION

A filter belt press consists of two endless belts of synthetic fibre mesh, the upper acting as a press and the lower as a filter, which pass through a system of rollers revolving at constant speed. As the two belts enter the roller system they converge and as they leave they separate again.

A schematic diagram of a filter belt press is shown in figure 3.1.

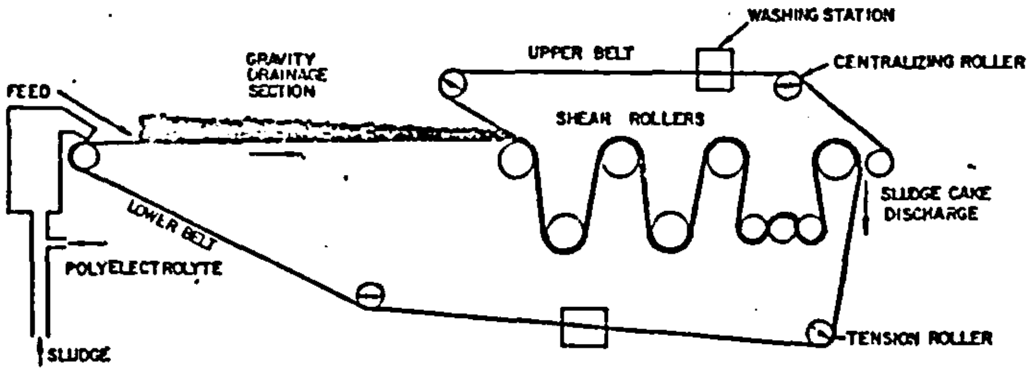


Figure 3.1 Configuration of a typical filter belt press

The sludge to be dewatered is conditioned with a suitable chemical (usually a polyelectrolyte) in a vortex mixing device prior to its discharge onto the moving filter belt.

Dewatering occurs in three separate zones:- (i) an initial gravity or free draining zone in which free water drains rapidly through the filter belt; (ii) a compression zone in which the two belts converge, compress the sludge and so accelerate the removal of water; (iii) a shear and final compression zone in which high pressure and shear forces are exerted on the sludge sandwiched between the two belts and more water is expelled. At the end of the roller system the two belts separate and the sludge cake which has formed between them is discharged with the aid of a doctor blade.

Two belt washing stations are provided which use high pressure water jets to clean the belts after the discharge of the sludge cake.

3.2 EXPERIMENTAL LAYOUT AND EQUIPMENT

The filter belt press used in these trials was a full scale unit, the smallest in the manufacturer's range of machines.

The unit was completely self-contained with built-in sludge and polyelectrolyte dosing pumps. The width of the belt was 0,5 m.

The feed sludge was held in a 4500 ℓ asbestos cement tank, fitted with an electrically-driven stirrer to ensure that the sludge solids were kept in suspension. Sludge was pumped from this tank through a vortex mixing device, in which polyelectrolyte was added to the sludge, and so onto the gravity zone of the press. A diagrammatic representation of the experimental layout is given in Figure 3.2.

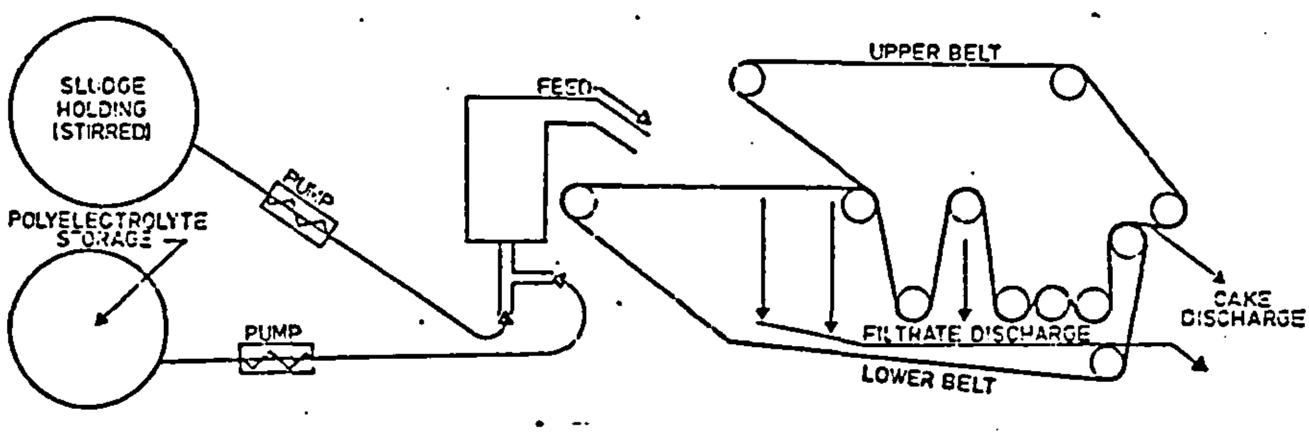


Figure 3.2 Filter belt press test equipment

3.3 EXPERIMENTAL PROCEDURES

Initial optimization trials showed that the sludge capacity of the machine, as measured by the belt loading rate and expressed as total solids per square metre of belt surface per minute (kg TS/m². min.), was controlled by the sludge solids feed rate (itself controlled by the sludge feed solids concentration and sludge feed pumping rate), the belt speed and the polyelectrolyte dose. The simplest way to operate the equipment was to optimise the polyelectrolyte dose and sludge feed rate for any given belt speed and sludge feed concentration. The process variables investigated were therefore:-

(i) Belt speed. The equipment was run at three different speeds, 2,4 m/min., 4,0 m/min. and 7,5 m/min., which are low, medium and high rates respectively within the manufacturer's recommended range.

(ii) Feed solids concentration. At each speed a series of runs was made. Sufficient sludge for each run was stored in the holding tank, where it was stirred to ensure a constant feed sludge solids concentration for each run. The solids concentrations varied between runs, depending on the performance of the consolidation tanks or the thickeners. The combination of different belt speeds and different feed solids concentrations gave a wide range of belt loadings.

(iii) Polyelectrolyte dose and sludge feed rate. These were optimized for each run by:- (a) setting an initially high polyelectrolyte dose; (b) increasing the sludge feed rate until the sludge just began to fall off the sides of the belt and (c) trimming back on the polyelectrolyte dose until the sludge just stayed on the belt. It was found experimentally that, even with heat-treated sludge, this equipment cannot achieve a reasonable degree of solids capture and dewatering without the aid of a polyelectrolyte.

A total of 42 runs was made, 22 on heat-treated sludge and 20 on untreated sludge. Each run was of approximately 5 hours' duration; snap samples of sludge feed, sludge cake and filtrate were taken hourly and composited in equal proportions prior to analysis. Total solids were determined in the feed sludge and sludge cake and suspended solids in the filtrate. Capillary suction time (CST) and the 5 min. filter test (FT) were carried out on the feed sludge.

3.4 RESULTS

(i) Heat treated sludge, with polyelectrolyte : see Table 3.1 .

(ii) Untreated sludge, with polyelectrolyte : see Table 3.2.

3.5 DISCUSSION OF RESULTS

3.5.1 Heat-treated sludge.

The dewatering performance (as measured by per cent capture and cake solids) was related to belt loading as shown in Figures 3.3 and 3.4. However, there was a good deal of scatter in the results and the correlation was poor. A much more positive and inverse relationship was found to exist between dewatering performance and belt speed, the lowest belt speed giving the best performance in regard to cake solids, solids capture and filtrate quality (see table). At the lowest belt speed of 2,4 m/min. a cake averaging 44% solids, with a mean capture rate of 98%, could be achieved.

De-watering performance v. belt speed and belt loading (heat treated sludge)

Belt speed m/min.	Belt loading kg TS/m². min.	% TS in cake		% solids capture		SS in filtrate (mg/ℓ)	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
2,4	0,54 - 1,31	43,8	2,62	97,8	0,58	2090	721,5
4,0	0,31 - 0,83	38,8	1,87	96,3	0,83	2700	942,7
7,5	0,20 - 0,41	37,4	2,22	95,0	1,18	3750	946,0

SD = standard deviation

The differences in the mean results for each belt speed are very highly significant (99,9% probability level) between the 2,4 and 7,5 m/min. belt speeds, for all three criteria of dewatering performance, and significant (95% probability level), between the 4,0 m/min. speed and the other two speeds for percent capture.

The results also show that belt loading is inversely related to belt speed, which seems to indicate that the degree of initial dewatering by gravity filtration before the sludge reaches the first set of rollers is a critical factor in the process.

The quantity of polyelectrolyte required for optimum performance is inversely related to the concentration of solids in the sludge feed and ranges from 1,2 kg/tTS to 2,9 kg/tTS in the range of feed solids from 10,8% down to 5,1%. Because of this inverse relationship and because the highest cake solid percentage tends to be obtained at the lower polyelectrolyte doses, independently of belt speed (see table), it is clearly economical to run the equipment with the highest possible feed solids concentration.

	Poly. dose kg/t solids in sludge feed			
Heat-treated sludges	1,5-2,0	2,0-2,5	2,5-3,0	3,0-3,5
Average cake solids %	43,0	42,2	37,3	36,3

It should also be noted that the polyelectrolyte dose was adjusted to the minimum possible level for each run and presumably, if required, even cleaner filtrates could have been obtained at less economical dosage rates.

It appears that this equipment cannot satisfactorily dewater heat-treated sludge without polyelectrolyte. Typical results obtained without polyelectrolyte were as follows:-

Belt speed m/min.	Belt loading kg TS/m² min.	% TS in cake	% solids capture	SS in filtrate mg/ℓ
0,54	3,03	30,3	72,8	27660

3.5.2 Untreated sludge. The average dewatering performance for untreated sludge is shown in the table below. The polyelectrolyte dose ranged from 2-3 kg/tTS throughout. It was impossible to dewater untreated sludge without the addition of polyelectrolyte.

De-watering performance v. belt speed and belt loading (untreated sludge)

Belt speed m/min.	Belt loading kg TS/m² min.	% TS in cake (mean)	% solids capture (mean)	SS in filtrate (mean) mg/ℓ
2,4 (2 runs only)	0,5	19,0	98,9	318
4,0	0,38-0,54	19,5	99,1	286
7,5	0,16-0,29	19,0	98,5	467

It is unfortunate that, due to a fault which developed in the equipment, it was only possible to do 2 runs at a belt speed of 2,4 m/min., in the time available for the tests. However, the results indicate that the same inverse relationship between belt speed and belt loading applies to untreated sludge as to heat treated sludge. With untreated sludge, belt speeds appear to have little or no effect on the percent of solids in the cake or on solids capture.

The solids capture (98-99%) and the quality of the filtrate (below 500 mg/ℓ SS) are as good, if not better, than those obtained with heat-treated sludge but this is achieved with a slightly higher level of polyelectrolyte dosing. The cake solids concentration at 19% is, of course, much lower than with heat-treated sludge. The range of polyelectrolyte dosages (2,1 to 3,5 kg/tTS) is narrower with untreated sludge, presumably because the concentration of solids in the sludge feed is more uniform (2,3-3,3%) than is the case with heat-treated sludge.

FIGURE 3.3.

DEWATERING OF HEAT-TREATED SLUDGE BY FILTER BELT PRESS.

BELT LOADING v CAPTURE.

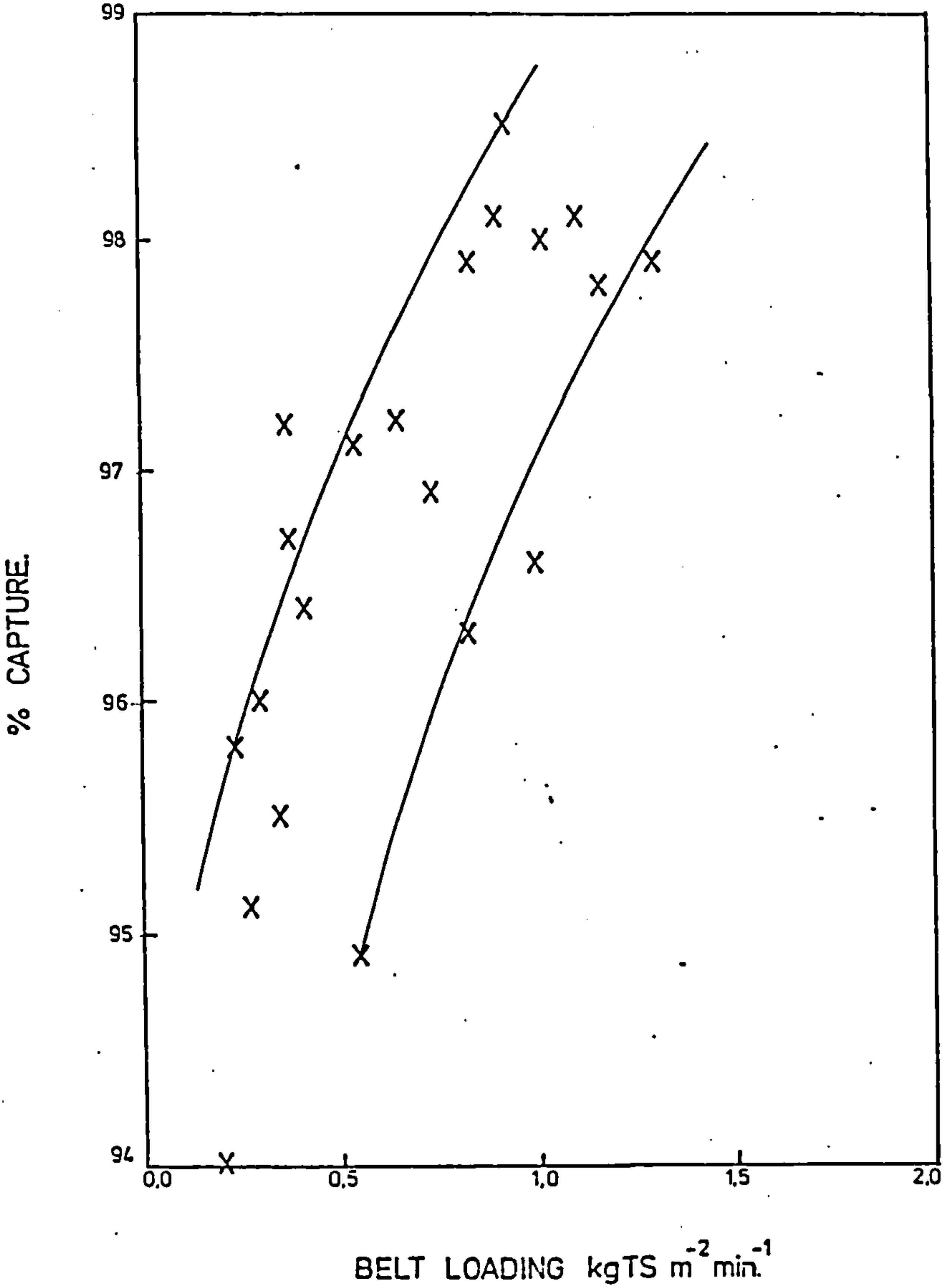


FIGURE 3.4

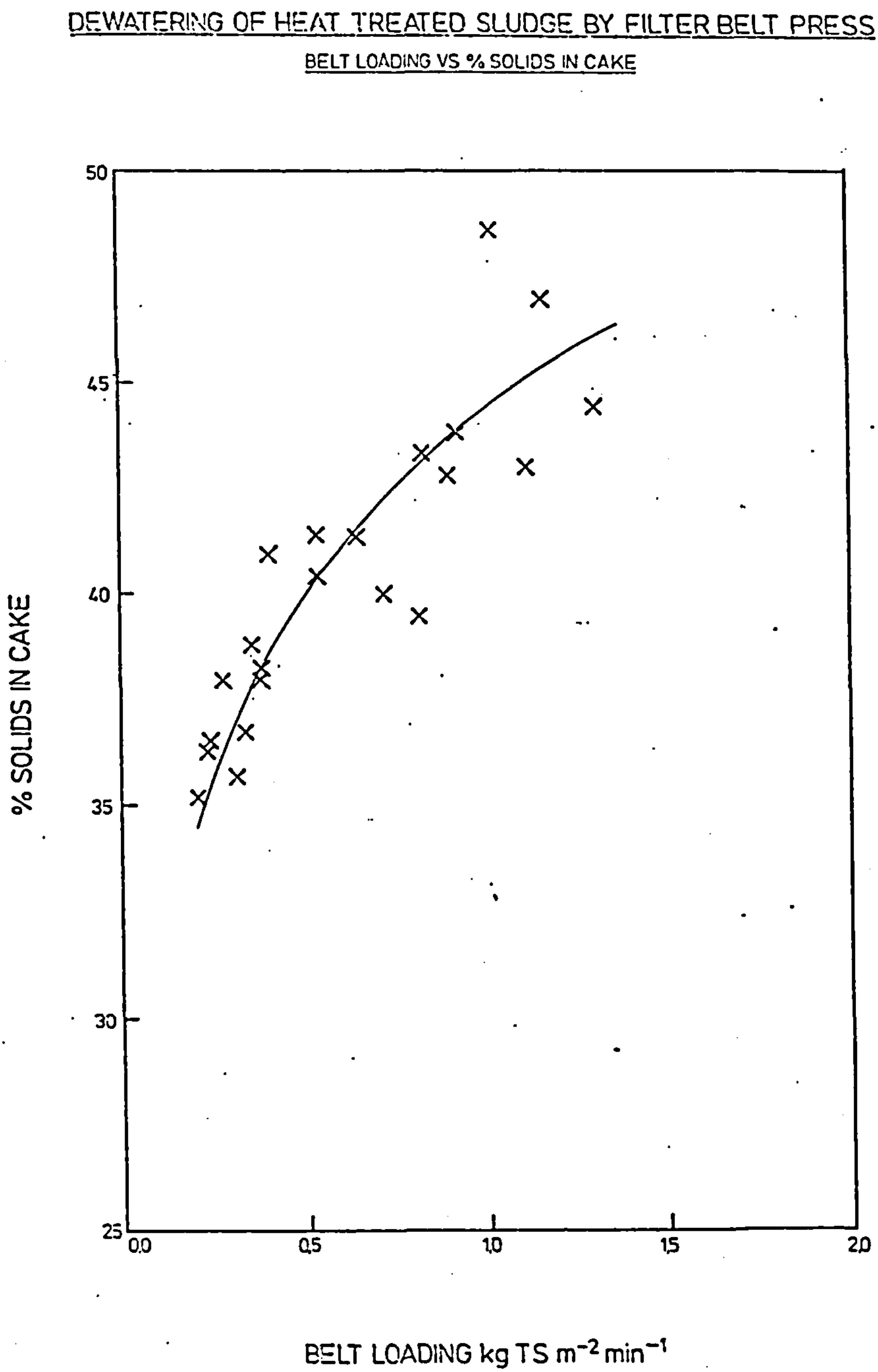

DEWATERING OF HEAT TREATED SLUDGE BY FILTER BELT PRESS
BELT LOADING VS % SOLIDS IN CAKE
% SOLIDS IN CAKE
50
45
40
35
30
25
0.0
0.5
1.0
1.5
2.0
BELT LOADING kg TS m⁻² min⁻¹

TABLE 3.1

FILTER BELT PRESS : HEAT TREATED SLUDGE CONDITIONED WITH POLYELECTROLYTE

Belt Speed m/minute	Feed TS%	Cake TS%	Filtrate SS mg/ℓ	% Capture	Sludge Feed ℓ/min	Sludge Feed TS kg/min	Beltloading kg TS/m²/min	Poly kg/t TS	CST of feed (i)	CST(i) ÷ % TS	CST of feed + poly (ii)	CST(ii) ÷ % TS	Filter test (FT)	FT x % TS
0,54	8,18	30,32	27663	72,8	10	0,82	3,03	NIL	579	70,8	-	-	6	49,1
2,4	10,51	44,30	2864	97,9	15	1,58	1,31	1,58	184	17,5	89	8,47	19	119,7
2,4	2,41	41,25	748	97,1	27	0,65	0,54	3,83	68	28,2	16	6,64	44	106,0
2,4	9,14	42,86	2176	98,1	12	1,10	0,91	2,27	725	79,3	251	27,46	9	82,3
2,4	5,45	40,05	2144	96,6	22	1,20	1,00	2,31	91	16,7	161	29,54	41	218,0
2,4	10,02	42,98	2500	98,1	13,5	1,35	1,12	2,04	295	29,4	150	14,97	13	130,3
2,4	9,37	48,51	2304	98,0	13	1,22	1,02	1,95	111	11,9	66	7,04	31	290,5
2,4	10,78	46,97	2992	97,8	13	1,40	1,17	1,17	110	10,2	53	4,92	30	323,4
2,4	6,76	43,30	1724	97,9	15	1,01	0,84	2,34	299	44,2	-	-	18	121,7
4,0	9,52	39,48	4588	96,3	17,5	1,67	0,83	1,49	298	31,3	140	14,71	12	114,2
4,0	7,40	41,30	2540	97,2	17,5	1,30	0,65	1,92	309	41,8	133	17,47	20	148,0
4,0	6,20	40,37	3670	94,9	17,5	1,09	0,54	2,29	216	34,8	118	19,03	21	130,2
4,0	6,40	38,20	2530	96,7	12	0,77	0,38	2,82	252	39,4	92	14,38	19	121,6
4,0	6,06	38,79	1990	97,2	12	0,73	0,36	2,98	172	28,4	100	16,50	23	139,4
4,0	5,92	40,00	2116	96,9	24,5	1,45	0,73	1,72	101	17,1	79	13,34	36	213,1
4,0	4,52	36,83	2300	95,5	15	0,68	0,34	3,19	66	14,6	35	7,74	40	180,8
4,0	4,19	35,69	1890	96,0	15	0,63	0,31	3,45	75	17,9	36	8,59	29	121,5
7,5	8,12	37,98	4984	95,1	13	1,06	0,28	2,62	268	33,0	119	14,66	19	154,3
7,5	6,89	36,55	3508	95,8	13	0,90	0,24	3,09	183	26,6	102	14,08	21	144,7
7,5	5,05	35,20	3500	94,0	15	0,76	0,20	2,86	72	14,3	39	7,72	30	151,5
7,5	5,74	36,38	4300	93,6	15	0,86	0,23	2,51	77	13,4	55	9,58	32	183,7
7,5	5,87	40,97	2472	96,4	26	1,53	0,41	1,63(?)	94	16,0	64	10,40	34	199,6

TABLE 3.2

FILTER BELT PRESS : UNTREATED SLUDGE CONDITIONED WITH POLYELECTROLYTE

Belt speed m/min	Feed TS %	Cake TS %	Filtrate SS mg/ℓ	% Capture	Sludge Feed ℓ/min	Sludge feed TS kg/min	Belt loading kg TS/m²/min	Poly kg/t TS	CST of feed	CST of Feed + Poly	Feed CST/ % TS	Feed + Poly CST/% TS
2,4	2,41	19,03	324	98,9	25	0,60	0,50	3,31	104	24	43,2	9,96
2,4	2,31	18,99	312	98,8	25	0,58	0,48	3,45	92	19	39,8	8,23
4	2,65	19,06	228	99,3	41	1,08	0,54	2,55	111	37	41,9	13,96
4	2,58	19,20	250	99,2	41	1,06	0,53	2,61	109	21	42,2	8,14
4	2,48	18,16	250	99,1	41	1,02	0,51	2,72	116	35	46,8	14,11
4	2,38	17,20	230	99,2	41	0,98	0,49	2,84	82	44	34,5	18,49
4	2,41	18,44	258	99,1	38	0,92	0,46	2,86	129	42	53,5	17,43
4	2,55	19,74	444	98,5	30	0,77	0,33	2,96	110	54	43,1	21,18
4	2,73	22,24	368	98,8	30	0,82	0,41	2,76	163	51	59,7	18,68
4	2,54	19,85	250	99,1	30	0,76	0,38	3,11	118	30	46,5	11,81
4	2,89	21,25	196	99,4	30	0,87	0,43	2,74	166	48	57,4	16,61
4	2,71	19,26	300	99,0	30	0,81	0,41	2,92	132	46	48,7	16,97
4	2,80	20,50	350	98,9	30	0,84	0,42	2,12	106	26	37,9	9,29
4	2,61	19,32	304	99,0	30	0,78	0,39	2,27	95	22	26,4	8,43
7,5	2,46	17,79	580	97,9	25	0,65	0,16	2,61	79	47	32,1	19,11
7,5	2,63	17,04	544	98,2	25	0,66	0,16	2,44	116	39	44,1	14,83
7,5	2,81	21,76	400	98,8	39	1,10	0,29	2,39	131	20	46,62	7,12
7,5	2,68	20,80	420	98,6	39	1,05	0,28	2,51	95	18	35,5	6,72
7,5	2,85	19,46	412	98,8	39	1,11	0,23	2,24	119	37	41,8	12,98
7,5	2,50	17,17	448	98,5	39	0,98	0,26	2,55	96	33	38,4	13,20

4.0 FILTER PLATE PRESS

4.1 INTRODUCTION

A plate filter press consists of a series of parallel plates, each plate covered on both sides with a filter cloth and arranged in such a way that sludge can be introduced under pressure into the spaces between the plates. The assembly also provides for the drainage of the filtrate from each set of filter cloths. While the sludge is being pumped in and filtration is taking place the whole assembly of plates is kept closed by an hydraulic ram acting on one end of the assembly. After a suitable period of pressure application the rate of filtration drops rapidly indicating that dewatering is effectively complete, the press is opened and the sludge cake is removed. Usually plate presses are mounted so that the sludge cake can drop directly onto a conveyor belt or into a lorry. Pressing time varies considerably depending on sludge characteristics, and can be from as low as 1 hour to as long as 24 hours; the normal for a conditioned mixture of primary and secondary sewage sludges, or for an anaerobically digested sludge, is about 6 hours. Plates are usually manufactured from reinforced plastics or moulded rubber; cast iron, used in earlier models, was found unsuitable. Filter cloths are available in a wide range of woven synthetic fibres.

Filter plate pressing is a batch process and this distinguishes it from the other dewatering processes described in this report, all of which operate with a continuous feed. Details of the construction of a typical plate filter press are shown diagrammatically in Figures 4.1 and 4.2

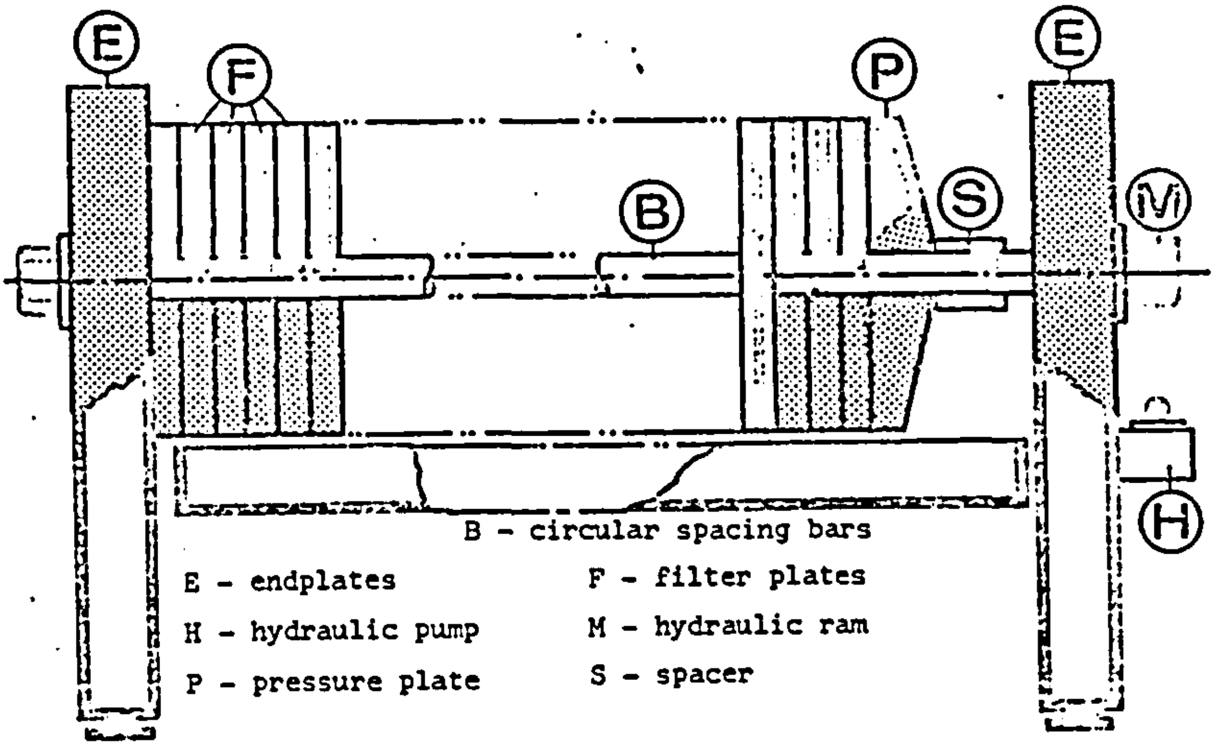


Figure 4.1 Section through a filter plate press

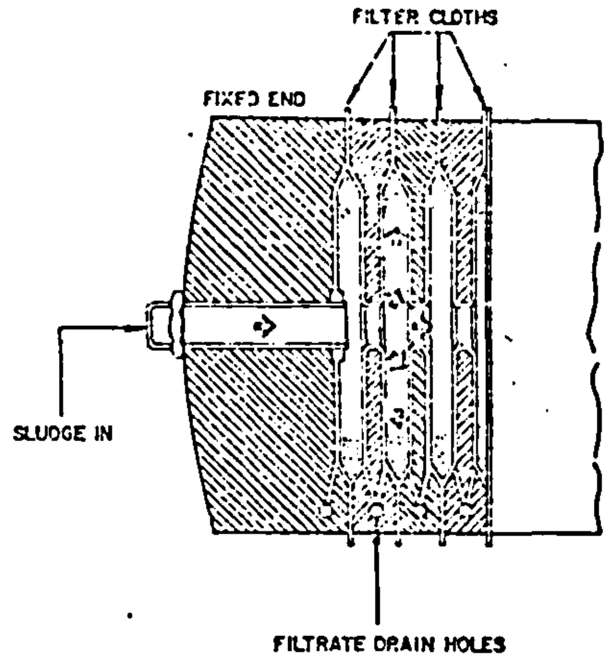


Figure 4.2 Section through filtration chambers: plate press

4.2 EXPERIMENTAL EQUIPMENT AND LAYOUT

The press used in this experimental work was a stock model from the manufacturers normal range of equipment. It consisted of nine filtration chambers between polypropylene plates. The plates were suspended from heavy-duty horizontal, round spacing bars which connected the two headplates. The assembly was closed by a manually operated hydraulic ram. The effective filtration area of each plate was 725 mm x 725 mm on each side and the filtration chamber thickness was 30 mm, giving an effective capacity per chamber of 0,0158 m^3 and a total capacity for the whole press of 0,142 m^3.

Preliminary trials were necessary on a variety of filter clothes to establish the most suitable material and the best cloth in terms of cake solids concentration and percent capture was found to be a woven polypropylene material, Propex 46.

Sludge was drawn from a holding tank, fitted with a stirrer to maintain a uniform solids concentration, and fed into a pressure holding vessel by means of a positive displacement pump. From the pressure vessel the sludge was fed into the press under operating pressures ranging from 600-1200 kPa. The volume of sludge pumped to the pressure holding vessel was automatically controlled by means of pressure switches. Polyelectrolyte dosing was from a small holding tank, containing a 0,1% m/v solution, by means of a positive displacement metering pump into the suction line of the sludge pump. The two pumps were electrically connected to operate in unison. Figure 4.3 illustrates the layout of the test equipment.

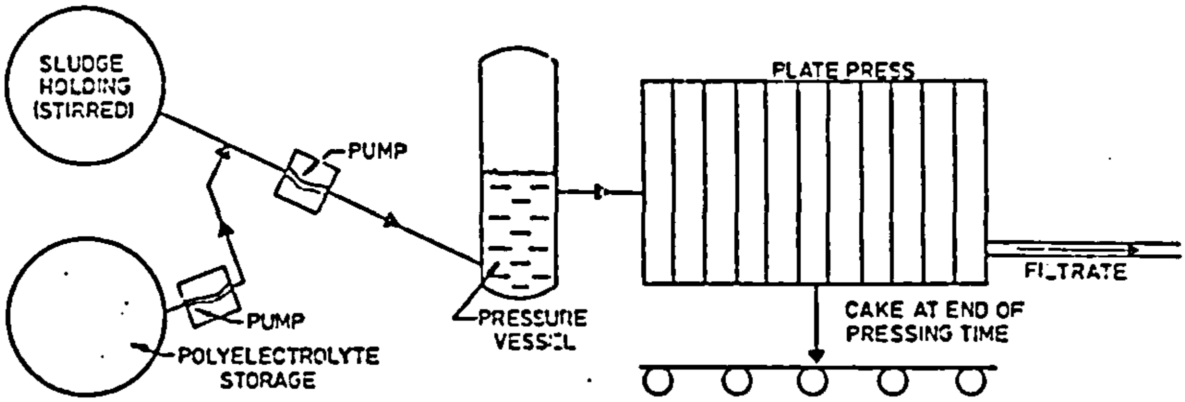


Figure 4.3 Filter plate press test equipment

4.3 EXPERIMENTAL PROCEDURES

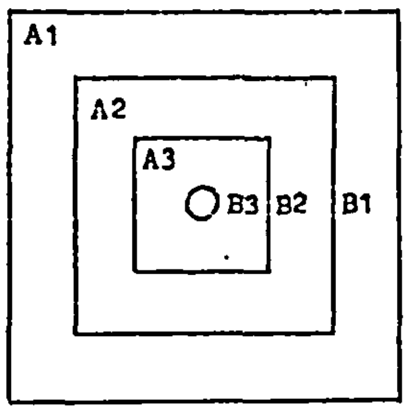
The performance of a plate press is assessed by the pressing time, sludge cake solids and solids capture. These will depend on the filtration characteristics of the sludge and the polyelectrolyte dose, of which only the latter can be controlled in practice. In preliminary optimisation trials, the doses of polyelectrolyte required to give minimum pressing times were determined for the two types of sludge, heat-treated and untreated, at the particular range of feed solids concentrations likely to be encountered during the tests. These feed solids concentrations were then maintained, within reasonable limits, during the runs in which polyelectrolyte conditioner was added. This procedure was departed from only in runs 20 and 21 (see Table.4.2) when higher than optimum doses of polyelectrolyte were added to illustrate that over-flocculation does not lead to a significant improvement in pressing time. The results for these two runs have been recorded but are not included in the performance calculations given below.

A total of 40 runs were made, 19 on heat-treated sludge without polyelectrolyte, 15 on heat-treated sludge with polyelectrolyte and 6 on untreated sludge with polyelectrolyte.

Samples were taken during each run from the holding tank and were composited in equal proportions. All feed sludge samples were tested for total solids, specific resistance to filtration (SRF) and filter-test (FT). Heat-treated sludge feeds were, in addition, tested for capilliary suction time (CST) (10 and 18 -mm funnels).

A composite filtrate sample was collected during each run on heat-treated sludge, conditioned and unconditioned, and untreated sludge with polyelectrolyte, and analysed for chemical oxygen demand, permanganate value, suspended solids, ammoniacal nitrogen and pH.

The moisture content of the cake produced after pressing varies significantly across the plate being wetter at the centre of the chamber. To obtain an average cake solids content it is necessary to take a number of samples across the plate and to combine the results for these in the ratio of the areas they represent. For each run two cakes were sampled, one from the second chamber and one from the seventh. Six samples were taken from each of them following the pattern illustrated below. After analyses the average values for (A1 + B1),(A2 + B2) and (A3 + B3) were determined and these three values were then combined in the ratio 5:3:1 to obtain a weighted average for the whole plate.



4.4 RESULTS

(i) Heat-treated sludge without polyelectrolyte: see table 4.1
(ii) Heat-treated sludge with polyelectrolyte: see table 4.2
(iii) Untreated sludge with polyelectrolyte: see table 4.3
(iv) Analysis of filtrate: see table 4.4

4.5 DISCUSSION OF RESULTS

Despite the range of feed solids concentrations covered in the various runs on each sludge, leading to a range of polyelectrolyte doses, expressed as kg/tTS, and a rather wide range of sludge cake dryness, the pressing times were relatively consistent for a particular sludge. The 95% confidence interval on the mean pressing time, for each of the three sludge categories, was less than ± ½ hour. Since the judgement of the end of a press run is to some extent subjective, this spread of results in the most significant performance characteristic, pressing time, is reasonable and justifies the use of averages to summarise the results and to facilitate discussion (see table below). To compare the full range of results for each sludge category, Tables 4.1 to 4.3 should be consulted.

	Average values for all runs		
	Heat-treated sludge without polyelectrolyte	Heat-treated sludge with polyelectrolyte	Untreated sludge with polyelectrolyte
Feed solids (%TS)	7,86	9,12	4,33
Polyelectrolyte dose kg/tTS	Nil	1,42	4,5
Pressing time (hours)	3,1	1,4	6,0
Cake solids (%TS)	50,8	46,2	36,4 *

* excluding one outlier - see Table 4.3

The results show that untreated sludge mixtures can be satisfactorily dewatered in a filter plate press, in the normal time of about 6 hours, but only if conditioned with high doses of polyelectrolyte. Heat-treatment of the sludge leads to a 50 % reduction in pressing time and excellent cake solids levels, even without the addition of polyelectrolyte. A further, very significant, decrease in pressing time, accompanied by a slight decrease in cake dryness can be achieved by adding about 1,4 kg/tTS of polyelectrolyte to the heat-treated sludge.

Table 4.4, filtrate analysis, shows that the filtrate from the plate press has remarkably low suspended solids levels, if one run with an apparently unrepresentative result is treated as an outlier. This is an important feature of plate press dewatering and means that solids capture is always very high, whether the sludge is heat-treated or not and whether or not polyelectrolyte is added in the former case.

TABLE 4.1 : PLATE FILTER PRESS

HEAT TREATED SLUDGE – WITHOUT POLYELECTROLYTE

RUN	Feed Sludge – Unconditioned					Pressing Time (Hours)	Cake Solids % TS	
	% TS	CST^{18} (Secs.)	CST^{10} (Secs.)	Filter Test(mℓ)	Spec. Res. (mkg^{-1})		Range Over 2 Plates	Weighted Average
1	5,54	30,5	98,5	42		2	32,3 – 57,0	44,0
2	3,27	24,7	67,4	59	$8,08 \times 10^{11}$	3	38,4 – 54,2	46,8
3	6,96	24,7	67,4	31	$1,36 \times 10^{12}$	3	28,3 – 57,7	50,6
4	5,82	21,8	206,5	35	$1,35 \times 10^{12}$	3	36,4 – 52,0	46,3
5	3,86	24,7	64,0	58	$1,15 \times 10^{12}$	3	29,0 – 58,6	49,8
6	6,57	27,5	122,4	39	$1,54 \times 10^{12}$	3	26,9 – 60,8	51,4
7	6,43	43,4	175,3	32	$1,59 \times 10^{12}$	3	24,3 – 52,9	43,1
8	6,35	30,8	133,8	43	$1,17 \times 10^{12}$	4	50,2 – 63,3	58,4
9	11,55	46,6	212,7	23	$2,45 \times 10^{12}$	4,5	24,6 – 58,5	53,5
10	8,45	50,1	177,3	33	$1,33 \times 10^{12}$	5	40,1 – 62,0	55,5
11	8,43	28,6	94,6	43	$5,58 \times 10^{11}$	1,5	32,4 – 58,7	49,0
12	8,65	41,4	267,5	24	$2,09 \times 10^{12}$	2,5	21,1 – 53,4	38,7
13	10,32	64,5	242,1	23	$2,35 \times 10^{12}$	4	49,9 – 60,3	55,0
14	10,14	69,8	377,4	21	$1,51 \times 10^{12}$	2	25,8 – 58,1	50,6
15	7,88	26,0	98,9	40	$9,56 \times 10^{11}$	2,25	26,6 – 58,8	51,8
16	8,50	60,8	283,7	22	$3,41 \times 10^{12}$	4,25	21,7 – 47,4	35,7
17	10,42	29,6	90,6	44	$4,25 \times 10^{11}$	3,0	58,1 – 64,5	62,5
18	9,41	–	–	44	$5,71 \times 10^{11}$	2,0	55,0 – 65,3	61,0
19	9,41	–	–	44	$5,71 \times 10^{11}$	1,0	44,0 – 61,6	54,7

HEATED TREATED SLUDGE CONDITIONED WITH POLYELECTROLYTE

RUN	Feed Sludge (before poly. addition)					Pressing Time (hrs)	Poly. dose (kg/t^{-1})	Cake Solids % (TS)	
	% TS	CST^{18} (Secs.)	CST^{10} (Secs.)	Filter Test (mℓ)	Spec. Res. ($m\ kg^{-1}$)			Range Over 2 Plates	Weighted Average
20	8,88	55,4	246,8	27	$1,59 \times 10^{12}$	0,83	6,2	26,7 - 57,4	34,7
21	7,35	58,8	207,8	26	$1,52 \times 10^{12}$	1,5	4,4	30,3 - 58,4	50,5
22	8,77	114,1	413,2	19	$2,95 \times 10^{12}$	1,9	1,8	28,2 - 52,6	42,6
23	8,09	65,0	243,4	23	$2,47 \times 10^{12}$	1,0	1,6	20,2 - 47,8	39,3
24	10,17	84,4	478,5	20	$2,52 \times 10^{12}$	1,3	1,0	34,6 - 58,5	49,9
25	10,50	90,1	400,6	15	$3,88 \times 10^{12}$	1,0	1,8	31,1 - 61,1	51,6
26	7,08	259,5	1223,4	14	$1,29 \times 10^{13}$	1,0	1,3	17,4 - 45,8	32,9
27	8,59	56,8	248,1	33	$1,01 \times 10^{12}$	1,0	2,2	29,3 - 63,1	42,9
28	6,69	63,7	249,3	33	$1,84 \times 10^{12}$	1,1	2,2	35,7 - 63,4	50,3
29	10,54	56,5	171,1	27	$1,02 \times 10^{12}$	1,0	1,6	37,4 - 62,4	48,1
30	9,82	90,6	179,9	24	$1,88 \times 10^{12}$	1,0	1,1	34,2 - 58,1	46,7
31	11,62	44,5	-	58	$2,52 \times 10^{11}$	2,0	0,86	31,1 - 66,5	47,0
32	10,40	-	-	38	$5,42 \times 10^{11}$	2,0	0,62	38,5 - 63,2	44,6
33	7,77	-	-	35	$1,58 \times 10^{12}$	1,5	1,4	30,6 - 62,2	52,8
34	8,58	-	-	27	$1,57 \times 10^{12}$	2,3	1,00	33,6 - 58,8	52,9

TABLE 4.3 : PLATE FILTER PRESS

UNTREATED SLUDGE CONDITIONED WITH POLYELECTROLYTE

RUN	Feed Sludge (before poly, addition)			Pressing Time (hrs.)	Poly. dose (kg/t^{-1})	Cake Solids % (TS)	
	% TS	Filter Test (mℓ)	Spec. Res. ($m\ kg^{-1}$)			Range Over 2 Plates	Weighted Average
35	4,16	5	$1{,}28 \times 10^{14}$	6,0	4,5	17,3 - 46,5	34,2
36	5,07	6	$2{,}62 \times 10^{13}$	6,0	4,5	11,1 - 20,6	17,1*
37	4,33	4	$1{,}01 \times 10^{14}$	6,0	4,5	27,9 - 41,4	37,5
38	5,35	6	$4{,}56 \times 10^{13}$	6,0	4,5	32,8 - 44,9	42,0
39	3,62	4	$9{,}01 \times 10^{13}$	6,0	4,5	23,2 - 41,4	33,7
40	3,45	7	$9{,}37 \times 10^{13}$	6,0	4,5	22,9 - 38,8	34,7

*Outlier

TABLE 4.4. : PLATE FILTER PRESS
FILTRATE ANALYSES (Results in mg/ℓ)

		Chemical Oxygen Demand	Permanganate Value	Suspended Solids	Ammoniacal Nitrogen (as N)	pH
Heat Treated Sludge without Polyelectrolyte	High	16493	1640	2348*	454	6,0
	Low	11125	960	208	291	4,5
	Average	14283	1392	746	349	-
Heat Treated Sludge with Polyelectrolyte	High	14992	1360	908	400	6,1
	Low	10544	680	156	190	4,6
	Average	12418	1076	382	303	-
Untreated Sludge with Poly-electrolyte	High	3548	100	324	154	6,9
	Low	1402	20	96	112	6,3
	Average	2227	54	213	141	-

*Outlier

5.0 CONCURRENT FLOW CENTRIFUGE

5.1 INTRODUCTION

A centrifuge operates on the principle of separating solids from liquids by sedimentation. The sedimentation force is greatly enhanced by rotating the sludge suspension at high speeds. There are many types of centrifuge on the market but this report is limited to consideration of the performance of two types of solid bowl decanter, the concurrent flow and the counter-current flow centrifuges. In the former, the flow of solids and centrate are in the same direction; the settling zone begins at the feed point, close to the solid bowl front end and the cake leaves the machine at the opposite end, thus permitting the maximum time for settlement and sludge consolidation. In the counter-current centrifuge the feed is introduced into the middle, or towards the rear, of the bowl and the flow of solids and centrate are in opposite directions, the cake leaving the machine at the sludge feed end and the centrate at the opposite (rear) end. The dosing of conditioning chemicals, restricted to polyelectrolyte in this investigation, takes place directly into the sludge feed; the flocculation time is therefore relatively short compared with other dewatering systems. Figures 5.1 and 5.2 illustrate the two types of centrifuge.

In both centrifuges, the sludge solids, deposited in the bowl, are driven to the inside surface of the bowl by centrifugal force and are then transported by a screw conveyor (the scroll) along the bowl wall and up a conical section (the beach), where they are further drained by centrifugal force before being discharged as a cake. The scroll rotates in the same direction as the bowl but at a slower speed, the difference being called the scroll differential speed. The liquid level (or pool depth) in the bowl is controlled by adjustable weirs.

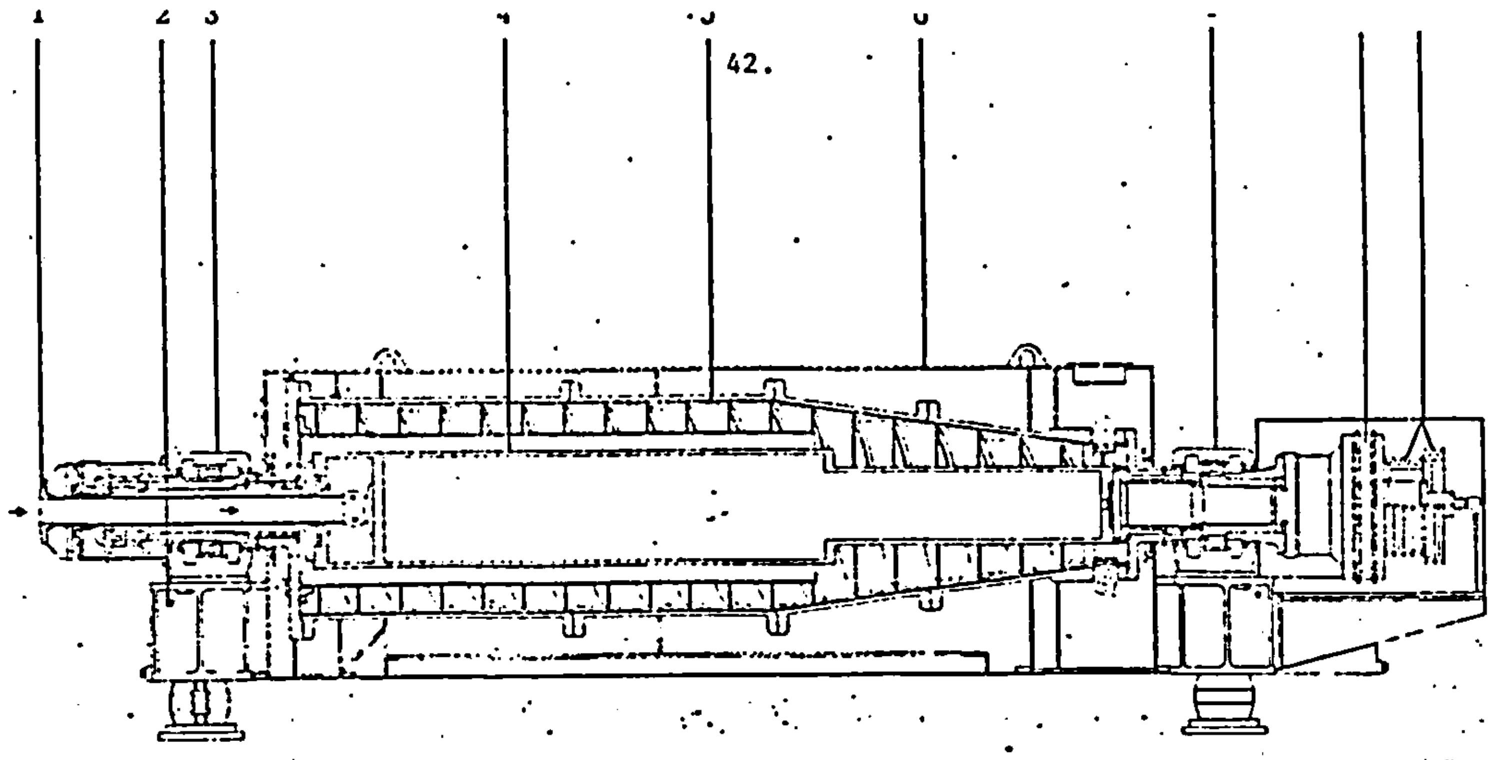


Figure 5.1: **Co-current flow centrifuge.**

(from WPCF Manual of Practice No. 20, 1983)

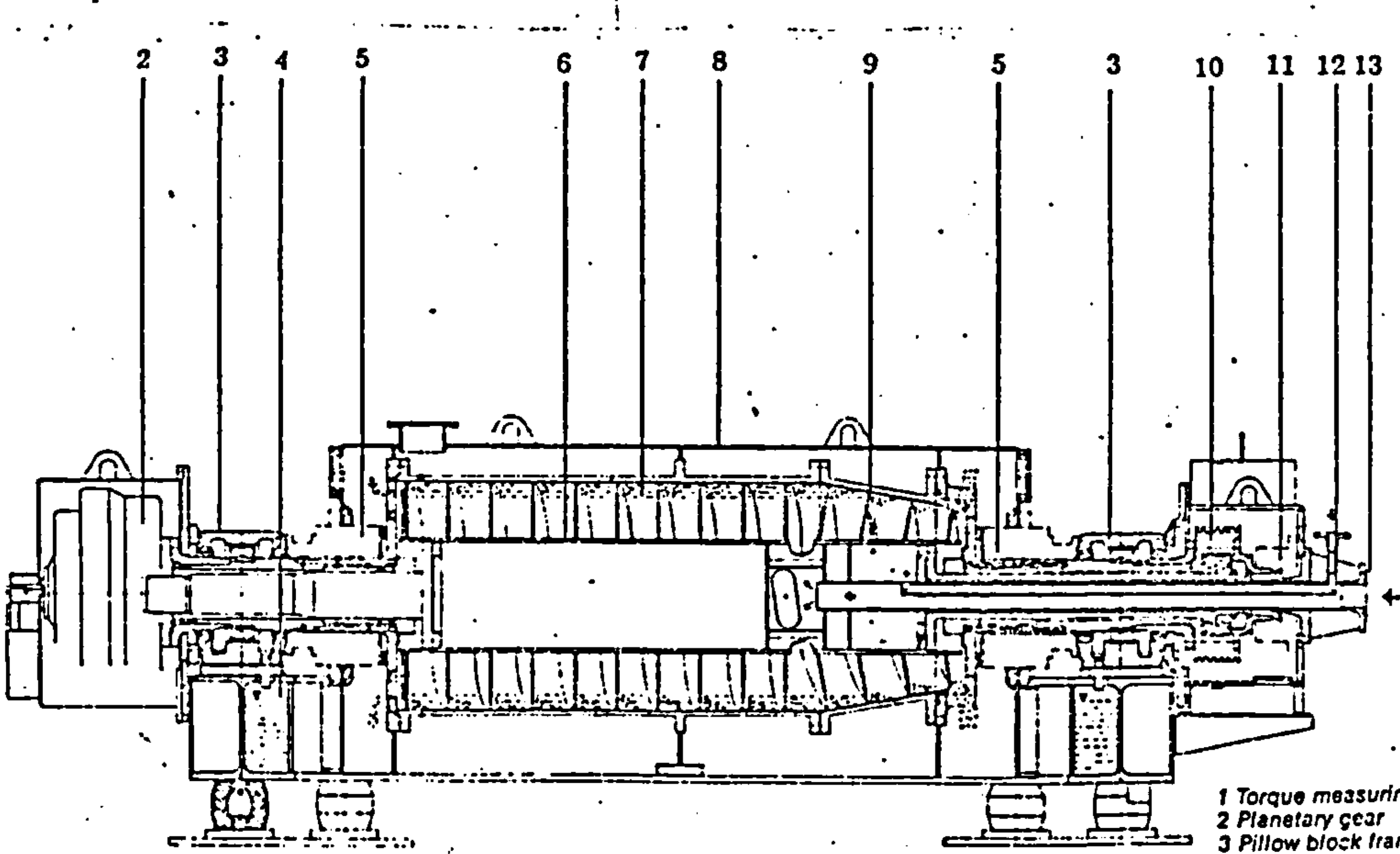


Figure 5.2: **Countercurrent flow centrifuge.**

(from WPCF Manual of Practice No. 20, 1983)

There is a large volume of literature available on the theoretical principles and practical performance of sewage sludge centrifuges. The following brief description of the factors involved is taken from RONEN (1981) and MEIRING (1982).

The dewatering performance of a centrifuge is dependent on machine variables and process variables. Each of these groups can be further subdivided into operational variables, which can be altered by the operator to suit performance to his requirements, and independent variables which are primarily functions of machine design and the physical and chemical characteristics of the sludge. The tables below summarise these variables.

Variables influencing solid-bowl centrifuge performance (Ronen, 1981)

Machine variables	Process variables
Operational variables	
Bowl speed	Hydraulic feed rate
Pool depth (weir height)	Solids load (% TS and rate)
Scroll differential speed	Polymer type, dosage and point of addition
Independent variables	
Bowl configuration	Chemical composition of sludge
Length of bowl	Physical characteristics of sludge
Diameter of bowl	
Beach angle and length	
Scroll type and configuration	

Effects of operational variables on centrifuge performance (Meiring, 1982)

Parameters	To increase cake dryness	To increase solids recovery
Bowl speed	Increase *	Increase *
Pool depth	Decrease	Increase
Scroll speed	Decrease	Decrease
Feed rate	Increase	Decrease
Feed consistency	Decrease	Increase
Use of flocculant	Use less	Use more

* Bowl speed increase above a certain value can result in the settling force exceeding the mechanical cohesion of the particles, leading to total rejection of the solids into the centrate.

The best way of expressing centrifuge dewatering performance is in terms of cake dryness, centrate clarity and solids recovery. The normal effect of the operational variables on the performance is also shown in the tables.

In the experimental work reported here, all the operational variables were investigated. The independent variables were restricted to two types of sludge, heat-treated and untreated, and to two types of machine, the con-current and the counter-current; the investigations on the latter are fully described in Section 6.

5.2 EXPERIMENTAL EQUIPMENT AND LAYOUT

The concurrent flow, solid-bowl, decanter centrifuge used in these tests was a standard item from the manufacturer's normal range of equipment. It had a 450 mm diameter bowl and a design feed capacity of about 5-6 m^3/h.

Sludge was fed to the centrifuge, by means of a variable speed positive displacement pump, from a 4500 ℓ sludge storage tank. Polyelectrolyte solution (0,05% m/v) was prepared in a separate, stirred tank and dosed into the flocculant dispersing unit on the centrifuge, also by means of a variable speed positive displacement pump. Both sludge feed and polyelectrolyte dose pumps were calibrated from tank levels before testing began. The experimental layout is shown diagrammatically in Figure 5.3.

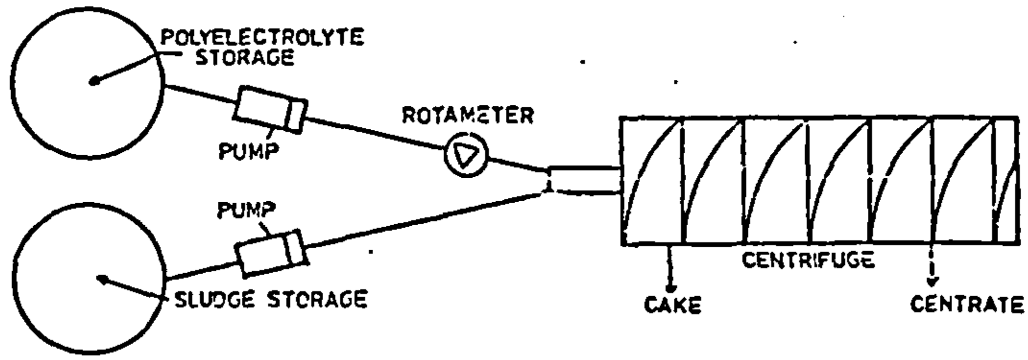


Figure 5.3 Centrifuge test equipment

5.3 EXPERIMENTAL PROCEDURES

Throughout the tests the bowl speed was set at 2100 rpm, on the advice of the manufacturer. The other operational variables were investigated, on both heat-treated and untreated sludges, as follows:

(a) Scroll differential speed. This was variable and four speeds were chosen, 4, 8, 12 and 16 rpm.

(b) Sludge loading. Three sludge feed rates were selected. 7,1 m^3/h, slightly over the machine's rated capacity, one mid-range at 4,6 m^3/h and one at the low level of 2,1 m^3/h. Because the capacity of the centrifuge was high in relation to the capacity of the sludge holding tank, solids concentration in the feed was not easy to control, especially in the case of untreated sludge, and variations in sludge loading did occur within a run. A particular problem arose with the untreated sludge when, on occasions, slugs of primary and waste activated sludge, drawn from their separate thickeners could reach the centrifuge without adequate mixing and lead to excessive variations in the physical characteristics of the feed sludge and to erratic results.

(c) Polyelectrolyte dose. Target doses were Nil, 0,5, 1,0 and 1,5 kg/t TS for heat-treated sludge and Nil, 1, 2 and 3 kg/t TS for untreated sludge. Due to the variations in the feed solids concentration, however, these did change during the different runs.

(d) Pool depth. The machine had four weir plate settings; to reduce the number of variables, only the maximum and minimum settings were tested.

The test procedure adopted was to set the scroll differential speed, the feed rate, the pool depth and carry out four runs at different polyelectrolyte dose rates; two more sets of four runs each were then carried out at different feed rates giving twelve runs in all. The twelve runs were then repeated at each of the four scroll speeds and the whole procedure repeated at the other pool depth, as follows:

4 poly-dose levels x 3 feed rates x 4 scroll speeds x 2 pool depths
= 96 runs for each sludge.

The feed sludges were sampled at regular intervals and the sub-samples composited to give one sample per four runs. These were analysed for:-

(a) Total solids %.
(b) Capillary suction time (CST) using both 10 mm and 18 mm funnels.
(c) Specific resistance to filtration (SRF).
(d) Centrifuge cake water retention index (CCWRI).

Because the feed sludge cannot be sampled after the polyelectrolyte has been added, it is not possible to characterise the sludge in the state in which it finally reaches the centrifuge bowl. This means that any correlation between sludge characteristics and centrifuge performance is unlikely except when polyelectrolyte is not being used.

Sludge cake and centrate were sampled at regular intervals and were composited to give one sample of each for each run to be analysed for total solids and suspended solids respectively.

5.4 RESULTS

(i)	Heat-treated sludge,	maximum pool depth	: see Table 5.1
	Heat-treated sludge,	minimum pool depth	: see Table 5.2
(ii)	Untreated sludge,	maximum pool depth	: see Table 5.3
	Untreated sludge,	minimum pool depth	: see Table 5.4

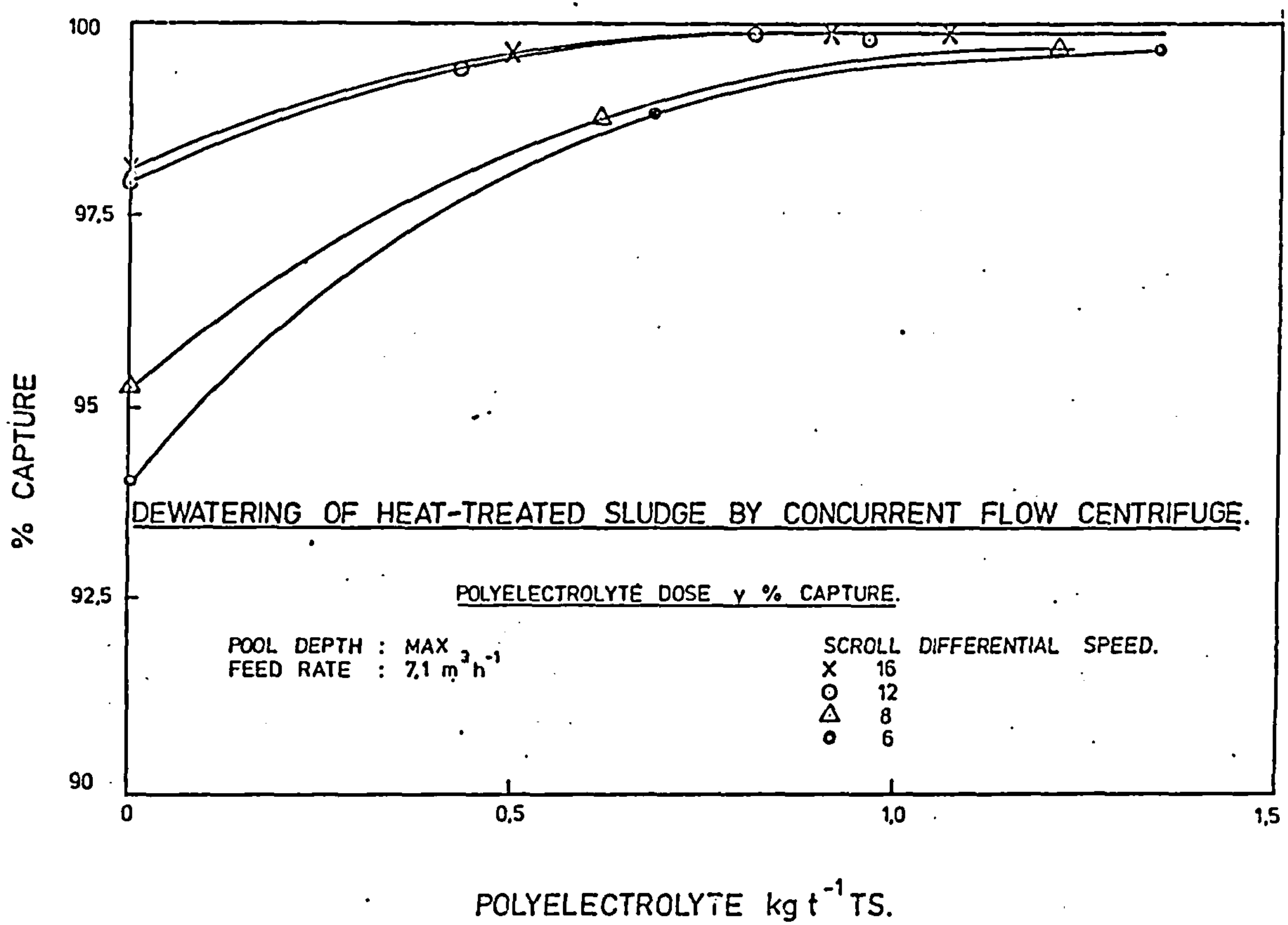
5.5 DISCUSSION OF RESULTS

5.5.1 Heat treated sludge. Figures 5.4 - 5.9 show the relationship between the polyelectrolyte dose and % capture at each of the other operational variables. The addition of polyelectrolyte increases solids capture but the effect of doses above about 0,5 kg/t TS is negligible and becomes less significant the higher the differential scroll speed and the lower the feed rate. % capture also tends to increase at the lower feed rates and the higher scroll differential speeds. Pool depth appears to have little effect at high differential scroll speeds. Without polyelectrolyte the best capture is obtained at higher scroll differential speeds over a wide range of sludge feed rates and regardless of weir height.

The results show clearly that this centrifuge is capable of excellent capture rates with very economical doses of polyelectrolyte. In fact, without any polyelectrolyte, a capture of 98% is readily obtained at the machine's recommended feed capacity of 5-6 m^3/h, a bowl speed of 2100 rpm and a scroll differential speed of 12-16 rpm. The addition of only 0,25% kg/t TS of polyelectrolyte will increase the capture to 99% and at 0,5 kg/t TS the capture can be as high as 99,5%, at the stated machine running speeds.

The results obtained for % cake solids show more scatter but, unlike the results normally quoted for centrifuge performance (see table in Section 5.1), the cake dryness definitely increases with polyelectrolyte dose (see Figures 5.10 and 5.11) and the shallower pool depth gives the higher cake solids. Cake dryness does not appear to be greatly affected by sludge feed rate. Cake solids of 33% can be achieved without polyelectrolyte, and 40% when the polyelectrolyte dose is 0,5 kg/t TS. Higher cake solids can be obtained without polyelectrolyte at the lower scroll differential speeds but with loss of capture.

5.5.2 Untreated sludge. For the reasons stated earlier, problems were experienced in obtaining a uniform feed sludge, considerable scatter in the results occurred and only general trends can be considered. As would be expected, increased polyelectrolyte dosing tends to increase percent capture and decrease cake dryness, although at the lowest scroll differential speed polyelectrolyte dosing has little effect at all (see Figures 5.12 and 5.13). There appears to be an optimum scroll differential speed at about 12 rpm for untreated sludge. Generally the machine performs as would be expected with untreated sludge (see table in Section 5.1) and a solids capture of about 75%, with a wet cake at about 20% solids, is all that can be achieved without polyelectrolyte. At a scroll differential speed of 12 rpm a solids capture of 97% can be reached with 2,5 kg/t TS of polyelectrolyte but, at this dose, a cake solids of only 19% is obtained.



DEWATERING OF HEAT-TREATED SLUDGE BY CONCURRENT FLOW CENTRIFUGE.
POLYELECTROLYTE DOSE v % CAPTURE.
POOL DEPTH : MAX
FEED RATE : 7,1 m³h⁻¹
SCROLL DIFFERENTIAL SPEED.
X 16
O 12
Δ 8
● 6
% CAPTURE
100
97,5
95
92,5
90
0
0,5
1,0
1,5
POLYELECTROLYTE kg t⁻¹ TS.

FIGURE 5,4

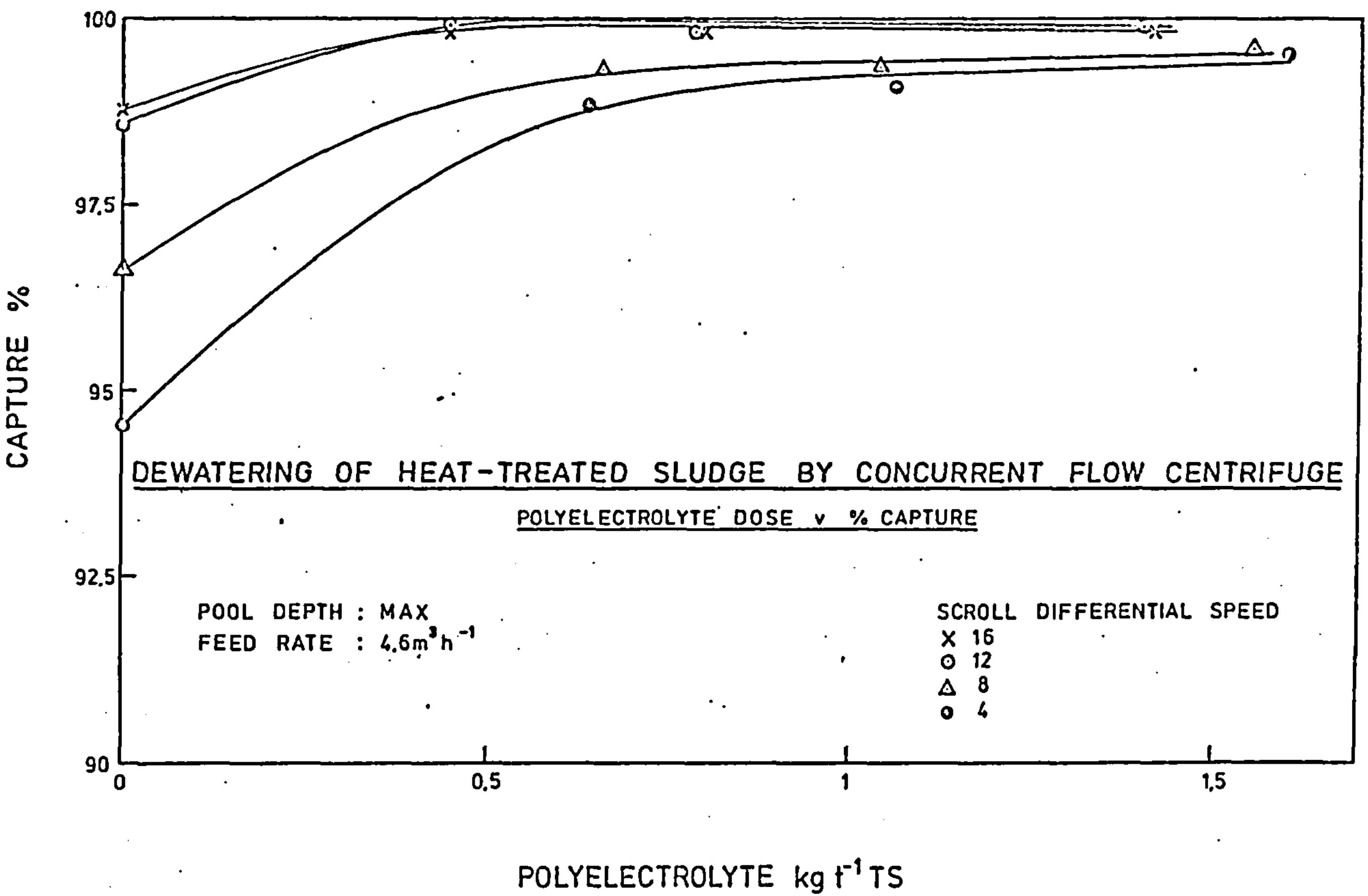
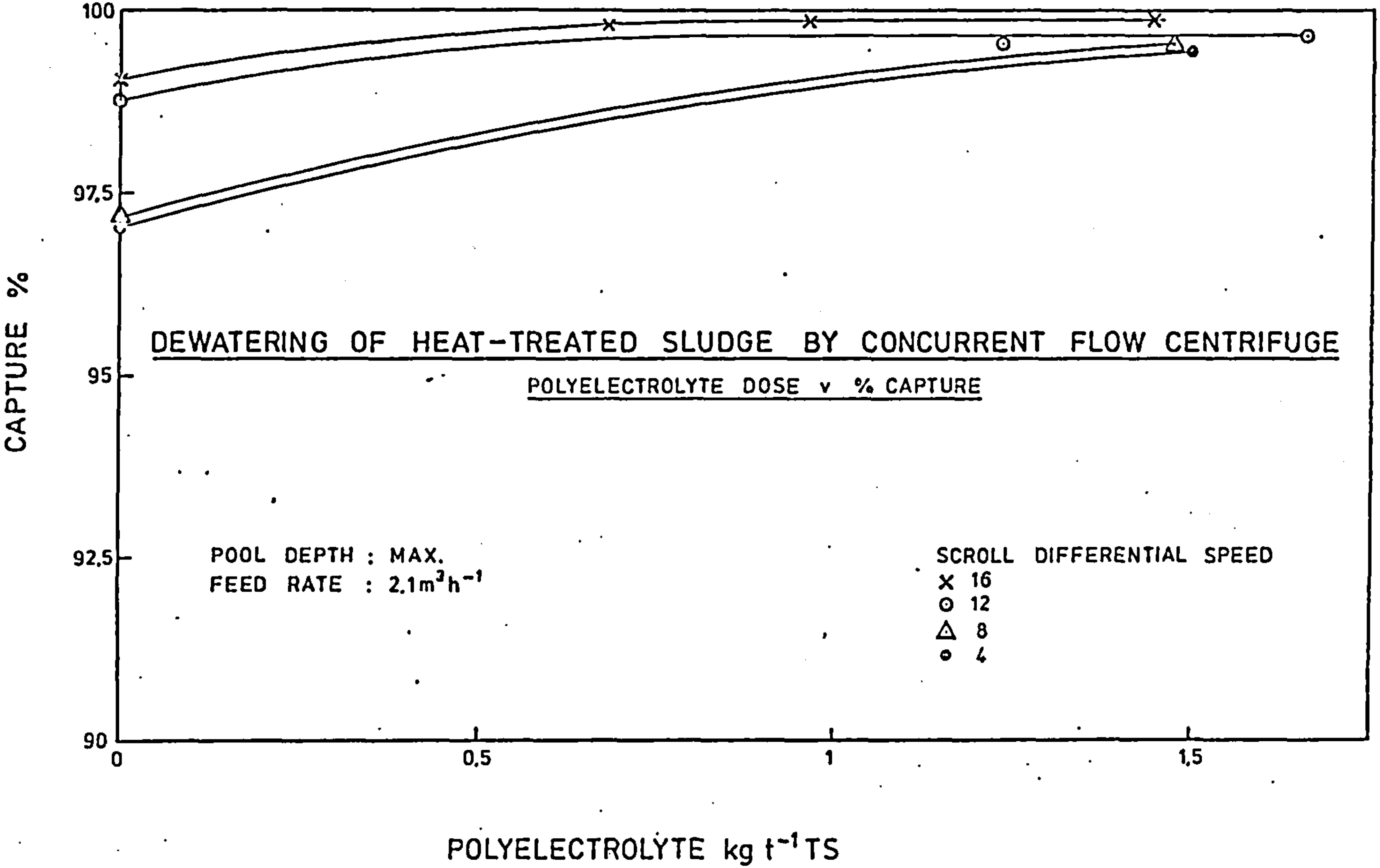

DEWATERING OF HEAT-TREATED SLUDGE BY CONCURRENT FLOW CENTRIFUGE
POLYELECTROLYTE DOSE v % CAPTURE
POOL DEPTH : MAX
FEED RATE : 4,6m³h⁻¹
SCROLL DIFFERENTIAL SPEED
× 16
⊙ 12
△ 8
o 4
CAPTURE %
100
97,5
95
92,5
90
0
0,5
1
1,5
POLYELECTROLYTE kg t⁻¹ TS

FIGURE 5,5



100
97,5
95
92,5
90
CAPTURE %
DEWATERING OF HEAT-TREATED SLUDGE BY CONCURRENT FLOW CENTRIFUGE
POLYELECTROLYTE DOSE v % CAPTURE
POOL DEPTH : MAX.
FEED RATE : 2.1m³h⁻¹
SCROLL DIFFERENTIAL SPEED
× 16
⊙ 12
△ 8
• 4
0
0,5
1
1,5
POLYELECTROLYTE kg t⁻¹ TS

FIGURE 5,6

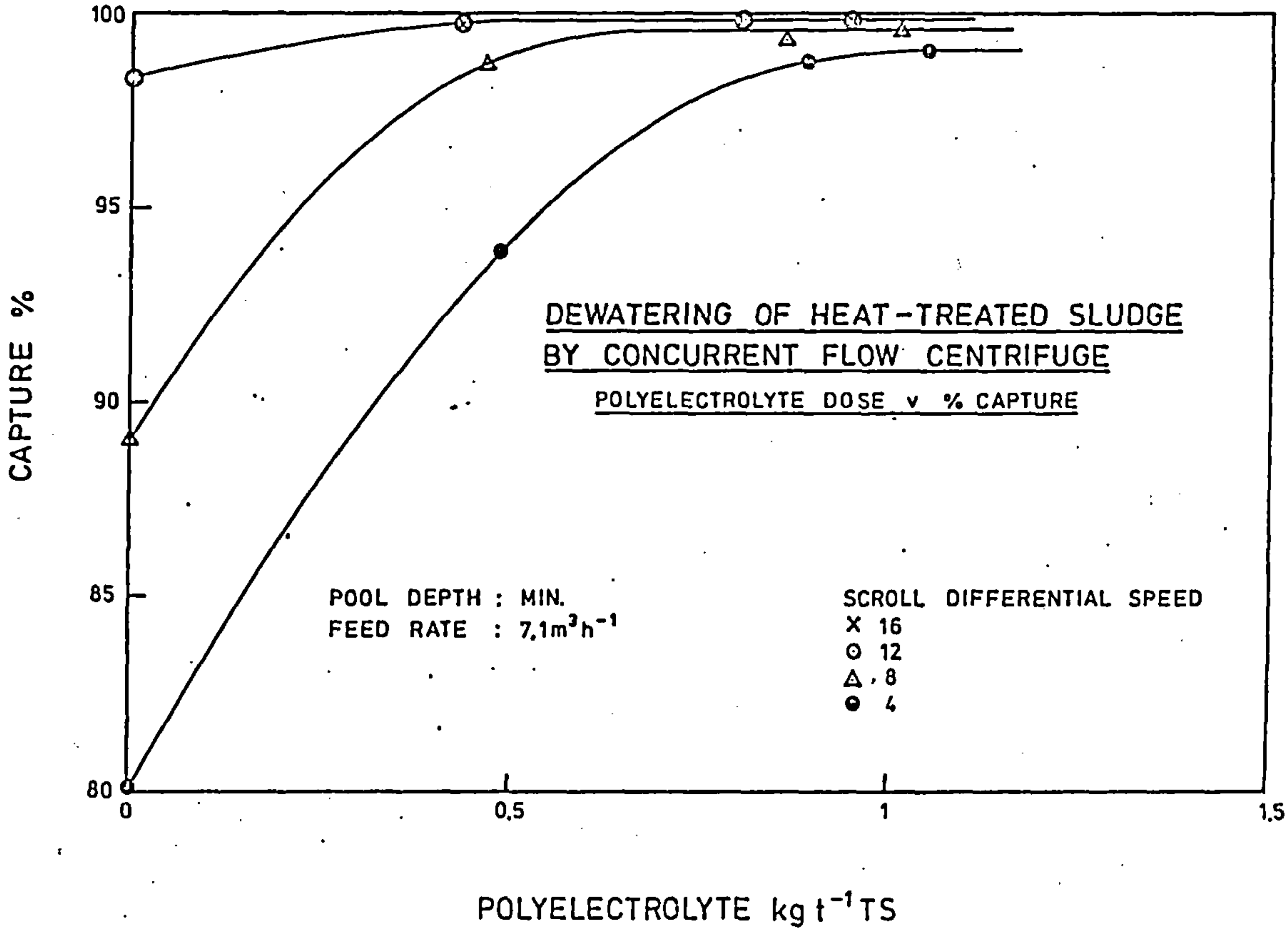

DEWATERING OF HEAT-TREATED SLUDGE
BY CONCURRENT FLOW CENTRIFUGE
POLYELECTROLYTE DOSE v % CAPTURE
CAPTURE %
100
95
90
85
80
0
0,5
1
1,5
POLYELECTROLYTE $kg\,t^{-1}$ TS
POOL DEPTH : MIN.
FEED RATE : $7,1 m^3 h^{-1}$
SCROLL DIFFERENTIAL SPEED
× 16
⊙ 12
△ 8
● 4

FIGURE 5,7

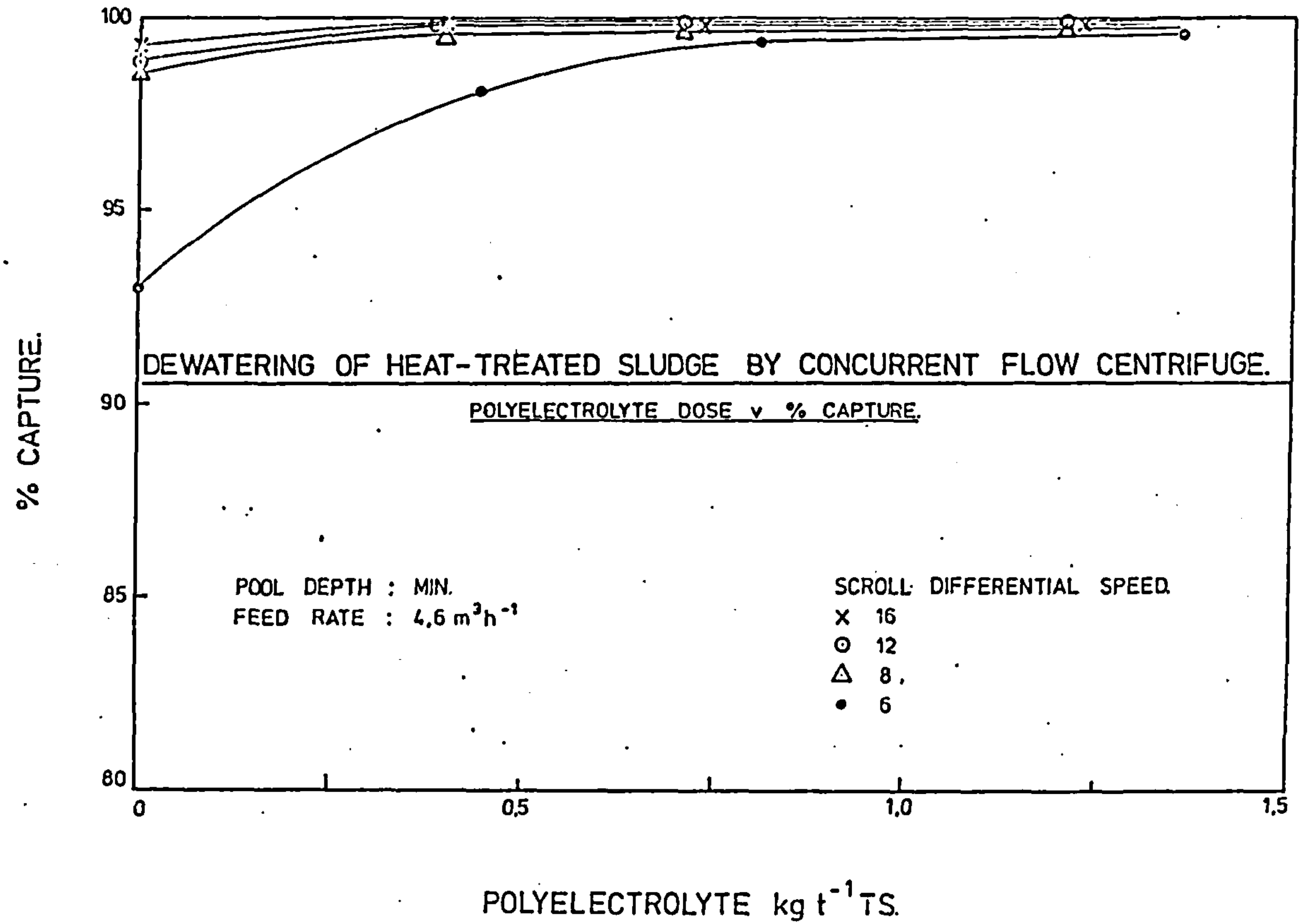

DEWATERING OF HEAT-TREATED SLUDGE BY CONCURRENT FLOW CENTRIFUGE.
POLYELECTROLYTE DOSE v % CAPTURE.
% CAPTURE.
100
95
90
85
80
0
0,5
1,0
1,5
POLYELECTROLYTE kg t⁻¹ TS.
POOL DEPTH : MIN.
FEED RATE : 4,6 m³h⁻¹
SCROLL DIFFERENTIAL SPEED
× 16
⊙ 12
△ 8
● 6

FIGURE 5,8

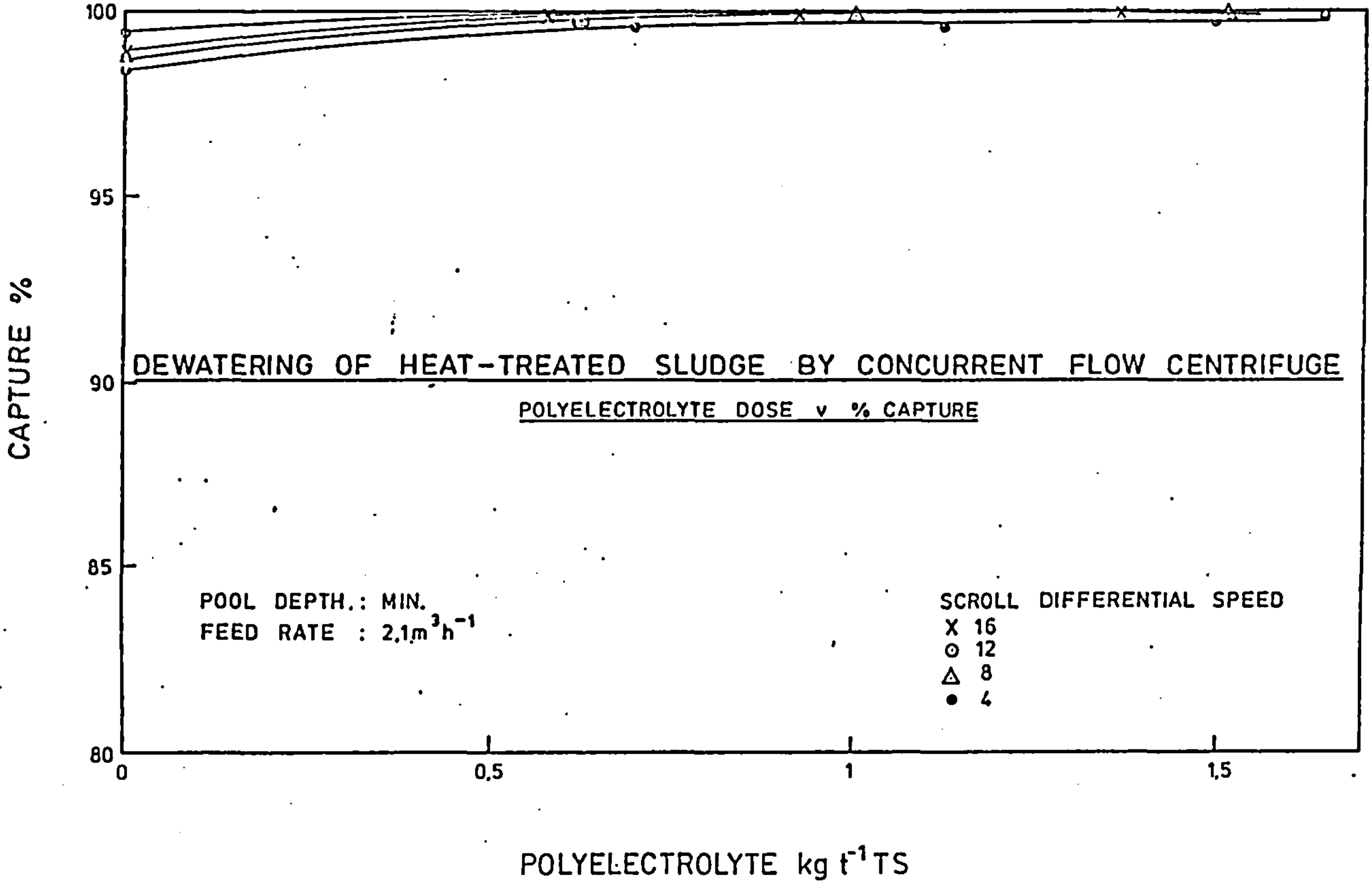

DEWATERING OF HEAT-TREATED SLUDGE BY CONCURRENT FLOW CENTRIFUGE
POLYELECTROLYTE DOSE v % CAPTURE
CAPTURE %
100
95
90
85
80
0
0,5
1
1,5
POLYELECTROLYTE kg t^{-1} TS
POOL DEPTH.: MIN.
FEED RATE : 2,1 $m^3 h^{-1}$
SCROLL DIFFERENTIAL SPEED
X 16
o 12
Δ 8
● 4

FIGURE 5,9

DEWATERING HEAT TREATED SLUDGE BY CONCURRENT FLOW CENTRIFUGE

POLYELECTROLYTE DOSE v % SOLIDS IN CAKE

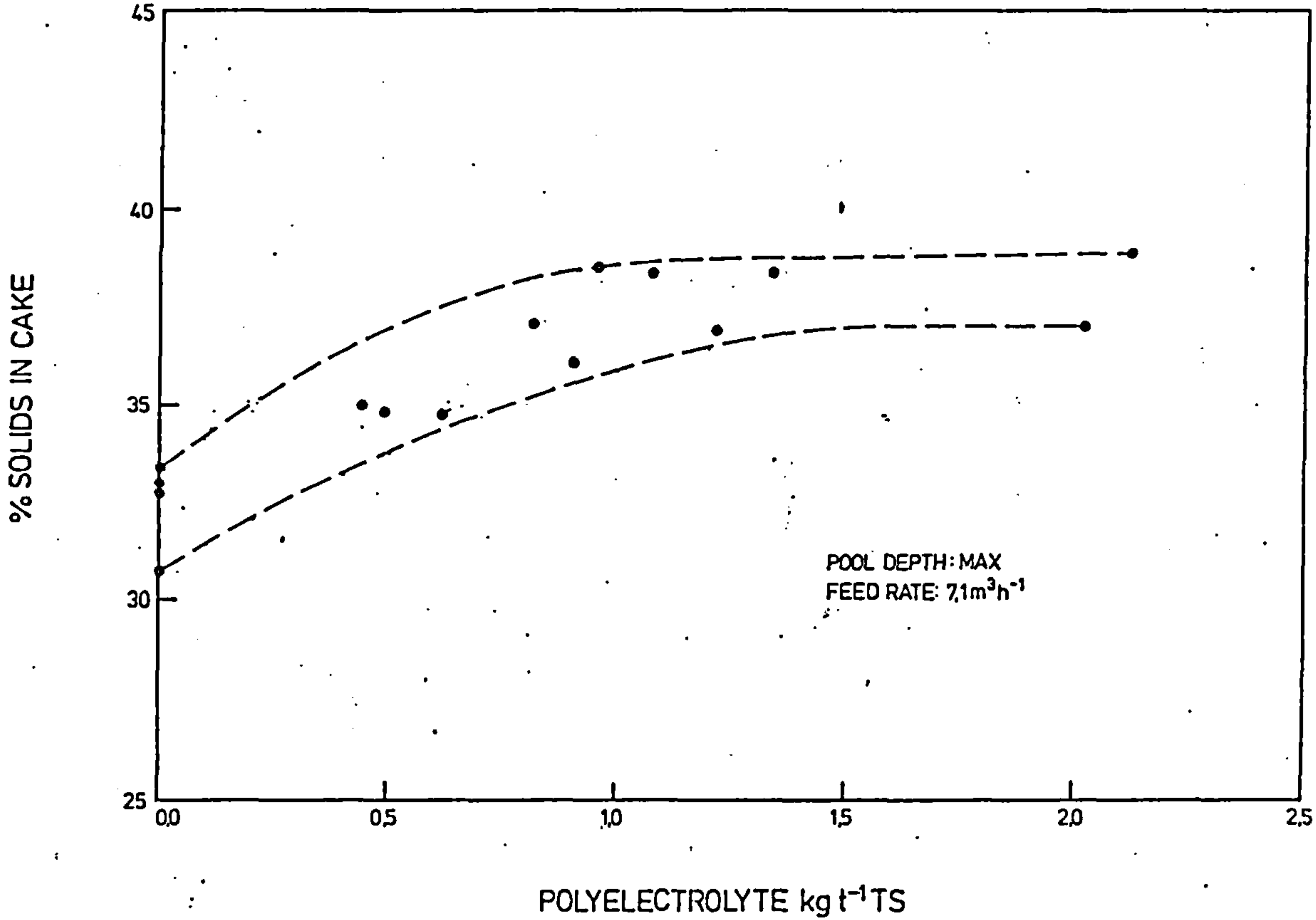


FIGURE 5.10

DEWATERING HEAT-TREATED SLUDGE BY CONCURRENT FLOW CENTRIFUGE.

POLYELECTROLYTE DOSE v % SOLIDS IN CAKE.

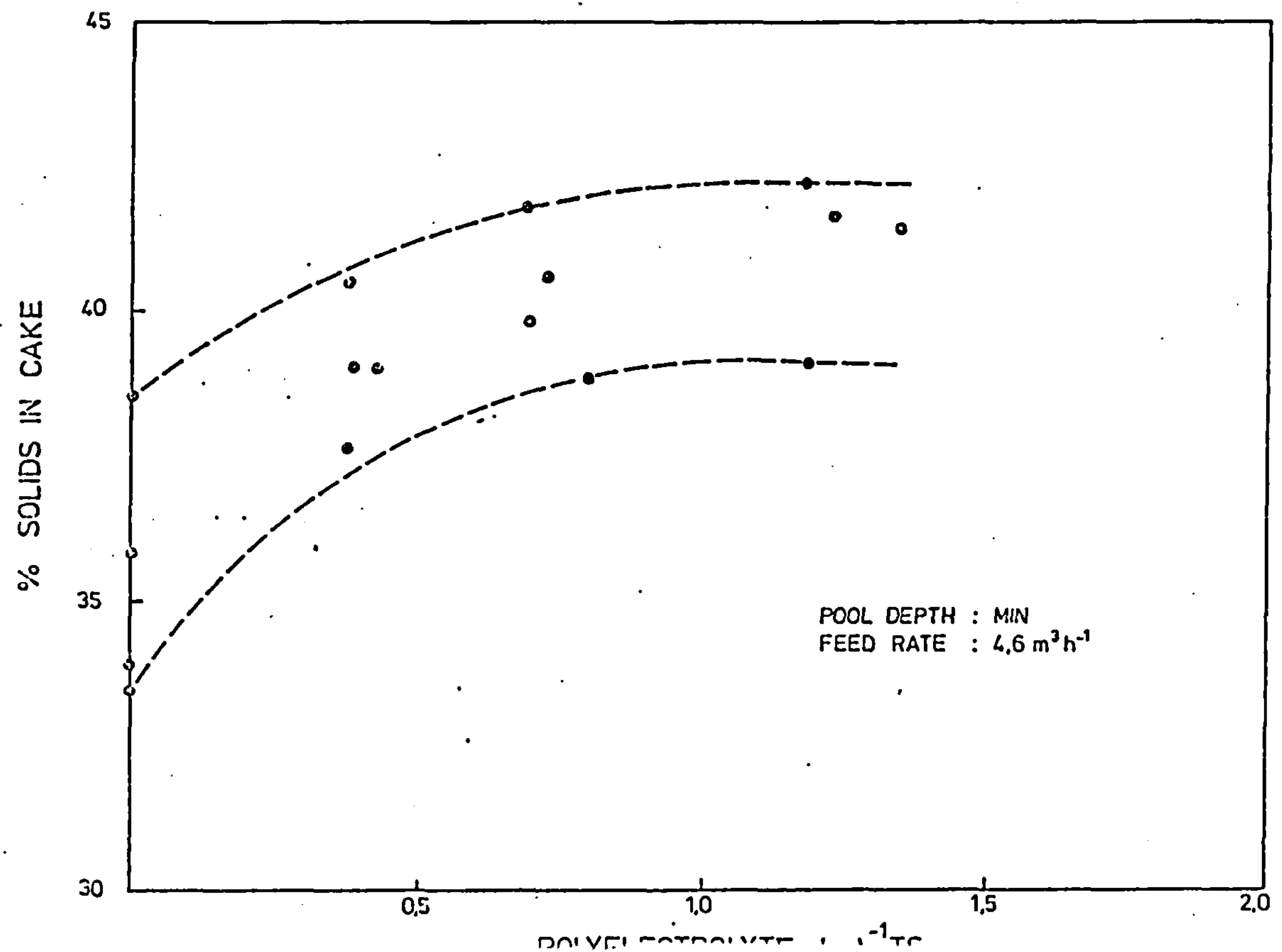


FIGURE 5.11.

FIGURE 5,12.

DEWATERING OF UNTREATED SLUDGE BY CONCURRENT FLOW CENTRIFUGE

POLYELECTROLYTE DOSE v % SOLIDS IN CAKE.

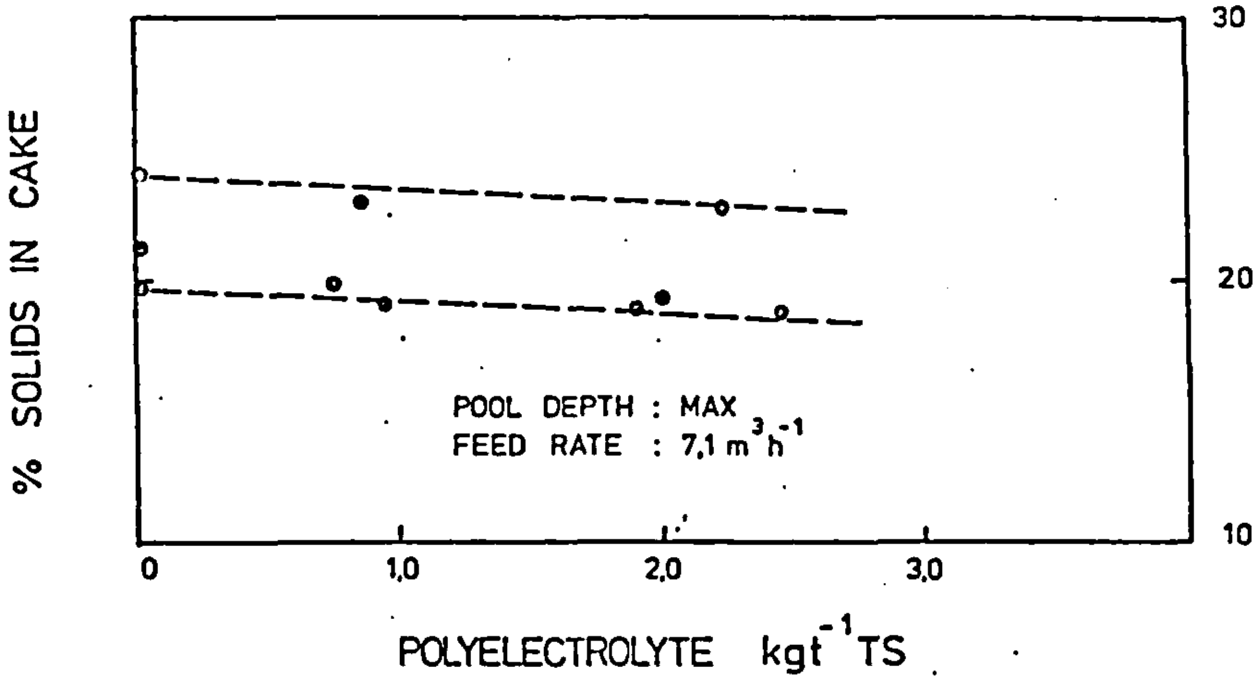


FIGURE 5,13.

DEWATERING OF UNTREATED SLUDGE BY CONCURRENT FLOW CENTRIFUGE

POLYELECTROLYTE DOSE v % SOLIDS IN CAKE.

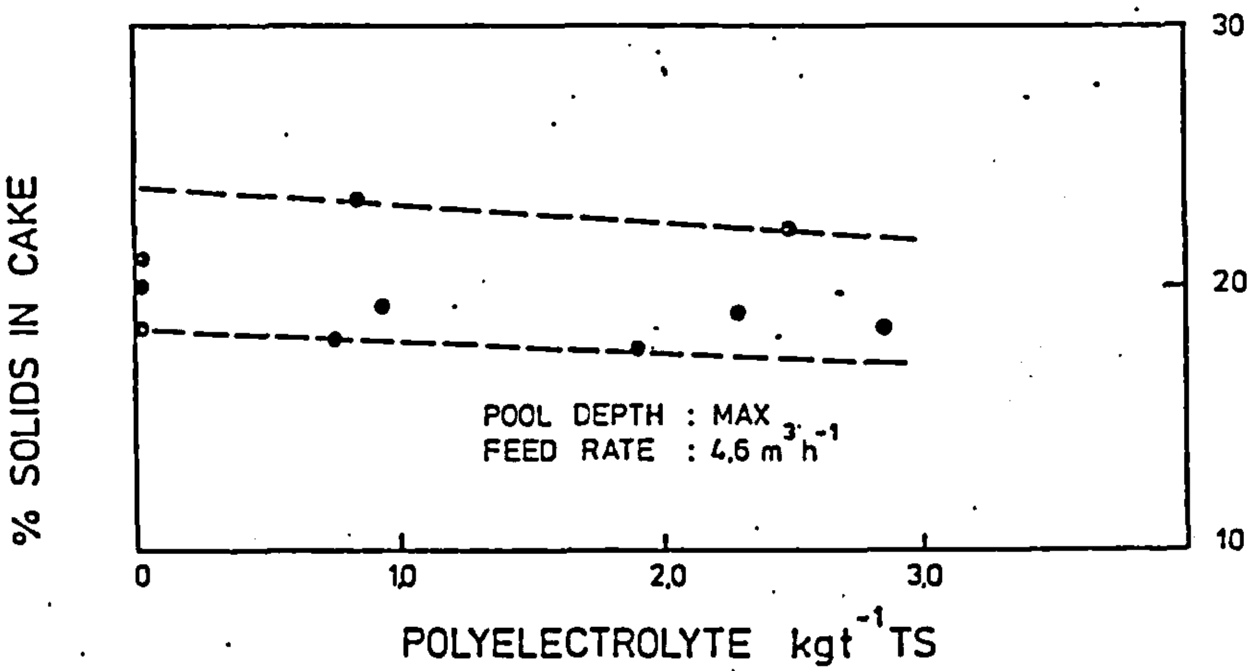


TABLE 5.1

CONCURRENT CENTRIFUGE – HEAT TREATED SLUDGE

Run No.	Centrifuge Conditions: Bowl speed rpm	Centrifuge Conditions: Scroll Diff. Speed rpm.	Centrifuge Conditions: Weir Plate No.	Feed Rate m^3/hr	Poly dosage kg/ton TS	Feed Sludge (before poly addition): % TS	Feed Sludge: CST 10 (secs)	Feed Sludge: CST 18 (secs)	Feed Sludge: CCWRI	Feed Sludge: SRF mkg^{-1}	Cake TS %	Centrate SS mg/ℓ	% Capture
1	2100	16	MAX	2,07	Nil	10,69	61,6	20,0	2,207	$0,325 \times 10^{12}$	33,75	1510	99,0
2				2,07	0,68						40,65	236	99,8
3				2,07	0,96						40,09	192	99,9
4				2,07	1,44						41,71	146	99,9
5				4,63	Nil	9,27	69,5	19,2	2,739	$0,379 \times 10^{12}$	33,03	1550	98,8
6				4,63	0,45						37,18	304	99,75
7				4,63	0,80						41,16	208	99,83
8				4,63	1,36						41,46	170	99,86
9				7,09	Nil	9,07	60,5	21,0	2,826	$0,423 \times 10^{12}$	32,85	2100	98,3
10				7,09	0,49						34,76	414	99,66
11				7,09	0,91						36,00	260	99,79
12				7,09	1,07						38,29	208	99,82
13		12		7,09	Nil	10,14	70,1	22,6	2,422	$0,438 \times 10^{12}$	33,38	3088	97,86
14				7,09	0,44						35,07	468	99,67
15				7,09	0,81						37,06	248	99,82
16				7,09	0,96						38,51	286	99,79
17				4,63	Nil	9,31	78,2	23,6	2,850	$0,486 \times 10^{12}$	33,04	1820	98,59
18				4,63	0,45						36,42	232	99,81
19				4,63	0,79						41,93	126	99,89
20				4,63	1,35						42,13	128	99,89
21				2,07	Nil	8,50	82,1	23,9	2,887	$0,579 \times 10^{12}$	33,35	1276	98,88
22				2,07	0,77						41,89	1334	98,74
23				2,07	1,21						43,68	484	99,54
24				2,07	1,81						43,39	302	99,71
25		8		2,07	Nil	4,54	58,1	16,9	3,520	$0,786 \times 10^{12}$	30,98	1500	97,17
26				2,07	1,47						37,45	198	99,62
27				2,07	1,69						41,84	172	99,66
28				2,07	2,25						41,36	152	99,70
29				4,63	Nil	4,44	54,1	17,5	3,537	$0,745 \times 10^{12}$	32,44	1728	96,62
30				4,63	0,66						35,15	344	99,32
31				4,63	1,03						35,92	320	99,37
32				4,63	1,55						39,80	210	99,58
33				7,09	Nil	4,29	54,9	19,0	3,632	$1,026 \times 10^{12}$	30,64	2332	95,29
34				7,09	0,61						34,66	630	98,71
35				7,09	1,21						36,75	260	99,46
36				7,09	1,91						36,94	162	99,67
37		4		7,09	Nil	3,87	59,1	20,5	3,807	$1,339 \times 10^{12}$	32,63	2568	94,10
38				7,09	0,68						34,57	536	98,77
39				7,09	1,34						38,28	262	99,39
40				7,09	2,12						38,68	194	99,55
41				4,63	Nil	4,28	68,3	21,3	3,752	$1,419 \times 10^{12}$	34,48	2654	94,53
42				4,63	0,69						34,73	544	98,88
43				4,63	1,07						38,04	400	99,17
44				4,63	1,60						39,73	212	99,56
45				2,07	Nil	3,48	60,4	21,4	3,809	$1,641 \times 10^{12}$	29,80	1140	97,10
46				2,07	1,89						35,78	252	99,35
47				2,07	2,21						38,47	218	99,43
				2,07	2,94						40,18	144	99,62

TABLE 5.2

CONCURRENT CENTRIFUGE – HEAT TREATED SLUDGE

Run No.	Centrifuge Conditions: Bowl speed rpm	Scroll Diff. Speed rpm.	Weir Plate No.	Feed Rate m^3/hr	Poly dosage kg/ton TS	Feed Sludge (before poly addition): % TS	CST 10 (secs)	CST 18 (secs)	CCWRI	SRF mkg^{-1}	Cake TS %	Centrate SS mg/ℓ	% Capture
1	2100	16	MIN	2,07	Nil	11,09	58,9	18,9	2,595	$0,293 \times 10^{12}$	31,92	1780	98,95
2				2,07	0,58						42,51	158	99,89
3				2,07	0,92						42,67	148	99,90
4				2,07	1,38						43,22	134	99,91
5				4,63	Nil	10,18	57,3	20,5	2,617	$0,351 \times 10^{12}$	35,78	1672	98,82
6				4,63	0,39						39,07	258	99,81
7				4,63	0,73						40,60	148	99,89
8				4,63	1,23						41,68	118	99,91
9				7,09	Nil	10,31	67,9	20,5	2,701	$0,399 \times 10^{12}$	32,62	2296	98,47
10				7,09	0,43						38,84	194	99,86
11				7,09	0,80						39,71	136	99,90
12				7,09	0,94						39,31	142	99,90
13		12		7,09	Nil	10,46	65,2	23,0	2,738	$0,506 \times 10^{12}$	32,59	2348	98,46
14				7,09	0,43						36,70	208	99,86
15				7,09	0,78						41,47	144	99,90
16				7,09	0,93						42,27	118	99,92
17				4,63	Nil	10,54	75,8	23,9	2,652	$0,499 \times 10^{12}$	33,93	1376	99,10
18				4,63	0,38						40,57	140	99,90
19				4,63	0,70						41,80	106	99,92
20				4,63	1,19						42,24	148	99,89
21				2,07	Nil	10,15	81,4	25,6	2,769	$0,506 \times 10^{12}$	35,14	744	99,48
22				2,07	0,63						41,40	174	99,85
23				2,07	1,01						41,61	194	99,86
24				2,07	1,51						41,95	208	99,84
25		8		2,07	Nil	10,07	79,5	25,7	2,760	$0,494 \times 10^{12}$	35,05	1552	98,90
26				2,07	0,63						42,24	192	99,05
27				2,07	1,01						43,95	132	99,90
28				2,07	1,52						43,09	150	99,89
29				4,63	Nil	10,59	89,2	28,4	2,761	$0,634 \times 10^{12}$	33,36	1868	99,79
30				4,63	0,38						37,65	274	99,81
31				4,63	0,70						39,81	184	99,87
32				4,63	1,19						39,12	336	99,77
33				7,09	Nil	9,56	91,9	29,1	2,876	$0,770 \times 10^{12}$	35,87	13570	89,18
34				7,09	0,47						35,38	1328	98,98
35				7,09	0,86						35,30	604	99,54
36				7,09	1,02						37,10	508	99,61
37		4		7,09	Nil	9,24	96,8	29,6	2,921	$0,692 \times 10^{12}$	39,32	22450	80,29
38				7,09	0,48						39,52	7310	93,82
39				7,09	0,89						40,11	1276	98,93
40				7,09	1,05						40,48	1028	99,14
41				4,63	Nil	9,32	92,4	31,2	2,963	$0,805 \times 10^{12}$	38,56	8620	92,83
42				4,63	0,43						38,96	2220	98,18
43				4,63	0,80						38,85	512	99,58
44				4,63	1,35						41,40	310	99,74
45				2,07	Nil	9,16	88,1	28,1	3,064	$0,706 \times 10^{12}$	38,16	1712	98,57
46				2,07	0,70						40,05	370	99,69
47				2,07	1,12						41,22	236	99,69
48				2,07	1,67						44,02	132	99,89

TABLE 5.3

CONCURRENT CENTRIFUGE - UNTREATED SLUDGE

Run No.	Centrifuge Conditions: Bowl speed rpm	Centrifuge Conditions: Scroll Diff. Speed rpm.	Centrifuge Conditions: Weir Plate No.	Feed Rate m^3/hr	Poly dosage kg/ton TS	Feed Sludge (before poly addition): % TS	Feed Sludge (before poly addition): CST 10(secs.)	Feed Sludge (before poly addition): CST 18(secs.)	Feed Sludge (before poly addition): CCWRI	Feed Sludge (before poly addition): SRF mkg^{-1}	Cake TS %	Centrate SS mg/ℓ	% Capture
1	2100	16	MAX	2,07	Nil	5,24	-	445,8	4,73	1,57 x10^{14}	19,71	17560	73,00
2				2,07	1,27						17,81	12020	82,64
3				2,07	1,47						16,93	13800	80,20
4				2,07	2,18						15,50	8620	88,47
5				4,63	Nil	3,94	-	453,4	7,10	2,12 x10^{14}	18,66	20000	55,15
6				4,63	0,95						19,24	14760	67,73
7				4,63	1,91						17,55	9740	79,70
8				4,63	2,86						18,45	3600	92,67
9				7,09	Nil						19,78	13980	69,42
10				7,09	0,95						19,18	18500	58,71
11				7,09	1,91						18,88	14100	69,40
12				7,09	2,47						18,75	14200	69,20
13		12		7,09	Nil	4,86	-	438,8	5,51	1,60 x10^{14}	21,26	15200	74,02
14				7,09	0,77						19,88	10500	86,89
15				7,09	2,00						19,38	7600	87,67
16				4,63	Nil						21,07	14400	75,53
17				4,63	0,77						18,03	7200	88,73
18				4,63	2,32						19,00	1070	98,35
19				2,07	Nil						19,60	15400	74,14
20				2,07	1,31						18,49	6200	90,27
21				2,07	2,36						17,57	2300	96,53
22		8		2,07	Nil	3,68		276,0	8,45	1,66 x10^{14}	14,97	11600	74,23
23				2,07	1,73						12,20	8400	82,88
24				2,07	3,11						14,69	1300	97,33
25				4,63	Nil	3,05	450,2	82,5	15,86	7,20 x10^{13}	10,14	18800	47,09
26				4,63	1,23						11,33	15200	57,94
27				4,63	3,70						-	-	-
28		4		7,09	Nil	4,34		363,7	6,92	1,78 x10^{14}	23,13	16400	66,96
29				7,09	0,86						22,80	15000	70,05
30				7,09	2,24						22,60	14600	70,94
31				4,63	Nil	4,50		359,2	6,44	1,52 x10^{14}	19,94	16600	68,84
32				4,63	0,84						23,23	16000	69,21
33				4,63	2,51						22,02	15800	69,90
34				2,07	Nil	4,70		446,4	5,69	1,68 x10^{14}	22,77	14000	74,81
35				2,07	1,36						21,12	14200	74,82
36				2,07	2,44						20,93	12200	78,63

TABLE 5.4

CONCURRENT CENTRIFUGE - UNTREATED SLUDGE

Run No.	Centrifuge Conditions: Bowl speed rpm	Scroll Diff. Speed rpm.	Weir Plate No.	Feed Rate m^3/hr	Poly dosage kg/ton TS	Feed Sludge: % TS	CST 18(secs)	CCWRI	SRF m/kg	Cake TS %	Centrate SS mg/ℓ	% Capture
1	2100	16	MIN	2,07	Nil	5,49	129,2	6,52	$5,37 \times 10^{13}$	19,06	19200	72,31
2				2,07	1,45					16,60	8180	89,51
3				2,07	1,87					17,24	1810	97,73
4				2,07	2,32					17,31	1160	98,55
5				4,63	Nil	4,46	144,4	7,91	$6,82 \times 10^{13}$	21,78	21120	58,30
6				4,63	0,90					19,11	16400	69,16
7				4,63	1,69					19,07	11840	78,32
8				4,63	2,53					17,21	1480	97,52
9				7,09	Nil	4,79	119,3	6,86	$5,23 \times 10^{13}$	19,08	14320	75,79
10				7,09	0,78					10,44	15520	79,40
11				7,09	1,57					15,56	7780	88,17
12				7,09	2,03					15,92	3510	94,76
13		12		7,09	Nil	3,50	147,2	9,80	$6,85 \times 10^{13}$	18,29	27180	26,24
14				7,09	1,06					16,36	14020	65,56
15				7,09	2,15					17,60	17600	55,24
16				7,09	2,78					16,20	8480	79,95
17				4,63	Nil	4,72	122,8	6,67	$4,91 \times 10^{13}$	16,69	15980	73,15
18				4,63	0,80					21,21	10480	81,84
19				4,63	1,59					19,86	6740	88,73
20				4,63	2,39					18,66	1580	97,48
21				2,07	Nil	4,62	116,0	7,47	$5,63 \times 10^{13}$	20,20	13480	75,89
22				2,07	1,73					18,62	2660	95,61
23				2,07	2,23					19,21	4380	92,63
24				2,07	2,76					19,83	830	98,62
25	2100	8		2,07	Nil	2,99	120,0	12,24	$7,93 \times 10^{13}$	18,20	13120	60,48
26				2,07	2,67					14,84	4660	87,15
27				2,07	3,44					14,44	5680	84,32
28				2,07	4,27					13,74	3440	90,77
29				4,63	Nil	3,29	147,5	10,83	$8,57 \times 10^{13}$	13,31	16640	56,48
30				4,63	1,14					16,92	11300	70,35
31				4,63	2,28					19,88	9640	74,30
32				4,63	3,43					20,07	6460	83,04
33				7,09	Nil	5,05	117,2	6,69	$5,21 \times 10^{13}$	21,12	13600	78,10
34				7,09	0,74					19,41	14080	77,76
35				7,09	1,49					23,95	21740	62,64
36				7,09	1,93					23,52	12640	79,23
37		4		7,09	Nil	6,80	112,4	5,26	$2,70 \times 10^{13}$	27,35	21820	73,80
38				7,09	0,55					25,39	14620	83,30
39				7,09	1,11					22,52	11720	87,31
40				7,09	1,43					19,78	15620	83,63
41				4,63	Nil	3,09	123,0	11,82	$6,86 \times 10^{13}$	23,84	22960	28,43
42				4,63	1,22					18,38	19960	39,72
43				4,63	2,43					23,51	7000	79,72
44				4,63	3,65					23,56	11080	67,31
45				2,07	Nil	3,20	132,5	11,61	$7,99 \times 10^{13}$	17,98	13540	62,39
46				2,07	2,49					21,15	9680	73,10
47				2,07	3,22					22,71	8400	76,58
48				2,07	3,99					23,06	5840	83,87

6.0 COUNTER-CURRENT FLOW CENTRIFUGE

6.1 INTRODUCTION

The principles of centrifuge operation and the differences between concurrent and counter-current centrifuges are discussed in Section 5.1.

6.2 EXPERIMENTAL EQUIPMENT AND LAYOUT

The counter-current flow, solid-bowl, decanter centrifuge used in these tests was a standard item from the manufacturer's normal range of equipment. It had a 418 mm diameter bowl and a design feed capacity of about 8 m^3/h.

The experimental layout was the same as for the concurrent flow centrifuge (see Figure 5.3) except that this machine was fitted on-line into the sewage works sludge feed system. This meant that sludge was derived directly from the heat-treatment consolidation tank, or from the gravity thickeners in the case of untreated sludge, and no sludge holding tank was used. Polyelectrolyte was dosed as a 0,1% m/v solution into the flocculant dispersing unit on the centrifuge by means of a variable speed positive displacement pump. The rotameter on the polyelectrolyte feed line was used to adjust and control dose rates but actual dose rates were determined from the measurement of tank levels. The sludge feed rates were measured by means of an ultrasonic flow meter which was calibrated before test work began.

6.3 EXPERIMENTAL PROCEDURES

After preliminary tests at different bowl speeds, a speed of 2550 rpm was used throughout at the request of the manufacturer. The other operating variables investigated on both heat-treated and untreated sludges were as follows:-

(a) Scroll differential speed. This was variable but most runs were carried out at speeds of 2,4; 4,4; 8,4; 12,4; and 16,4 rpm.

(b) Sludge loading. Three sludge feed rates were selected. A high rate at 13 m^3/h, one at the machine's rated capacity of 8 m^3/h and one low rate at 4 m^3/h. As in the case of the concurrent flow centrifuge it was not always easy to control the concentration of solids in the sludge feed, particularly with untreated sludge (see Section 5.3).

(c) Polyelectrolyte dose. Target doses were Nil, 0,5, 1,0 and 1,5 kg/tTS for heat-treated sludge and Nil, 1, 2 and 3 kg/tTS for untreated sludge. Target doses were not always achieved, however, because of variations in the feed solids concentrations.

(d) Pool depth. Three weir heights were selected, on the recommendation of the manufacturer. The weir plates were numbered 4, 4½ and 5 in ascending order of pool depth.

The test procedure was to set the pool depth and sludge feed rate, without polyelectrolyte, and carry out a series of runs at different scroll differential speeds. Each series was then repeated at different polyelectrolyte dose rates for each of several sludge feed rates. Finally the sets of runs so obtained were repeated for each of the two remaining pool depths. A total of 211 runs were completed, 113 on heat-treated sludge and 98 on untreated sludge.

The feed sludges were sampled at regular intervals and combined to make one composite sample for each 3 runs. These were analysed for:-

(a) Total solids % (TS)
(b) Capilliary suction time (CST) using both 10 mm and 18 mm funnels
(c) Centrifuge sludge volume index (CSVI) at 1000 and 2990 rpm
(d) Solids % in the 2990 rpm cake
(e) Specific resistance to filtration (SRF)

Because the feed sludge cannot be sampled after the polyelectrolyte has been added, it is not possible to characterise the sludge in the state in which it finally reaches the centrifuge bowl. This means that any correlation between sludge characteristics and centrifuge performance is unlikely except when polyelectrolyte is not being used.

Sludge cake and centrate were sampled at regular intervals and combined to give one sample of each for each run, to be analysed for total solids and suspended solids respectively.

6.4 RESULTS

(i) Heat-treated sludge : see Table 6.1
(ii) Untreated sludge : see Table 6.2

6.5 DISCUSSION OF RESULTS

6.5.1 Heat-treated sludge. Figures 6.1-6.3 show the relationship between the polyelectrolyte dose and % capture at each of the other operational variables. The addition of polyelectrolyte increases solids capture but its effect is slightly different at the various feed rates. At 4 m^3/h, about half the machine's rated capacity, polyelectrolyte dose has little effect above about 0,5 kg/tTS. At 8 m^3/h, however, the effect of polyelectrolyte continues to increase up to levels over 1,0 kg/tTS. A levelling off appears to occur above 0,5 kg/tTS at the feed rate of 13 m^3/h, but this is not certain as the higher polyelectrolyte doses were not tested at this particular feed rate. Weir height (pool depth) does not appear to have an important influence but the effect of feed rate is significant. The best solids capture, at a given polyelectrolyte dose, is obtained at the lowest feed rate of 4 m^3/h. Higher scroll differential speeds tend to give better capture.

Without polyelectrolyte the best capture is obtained at the highest scroll differential speed and there is little difference between the feed rates of 4 m^3/h and 8 m^3/h. At 13 m^3/h, without polyelectrolyte, there is a marked deterioration in capture but this feed rate is well above the machine's rated capacity.

In summary, for heat-treated sludge, this centrifuge can achieve 91% capture at a polyelectrolyte dose of 0,5 kg/tTS when it is operated at a feed rate of 8 m^3/h, a scroll differential speed of 16 rpm and the greatest pool depth. At a feed rate of 4 m^3/h, however, about half the machine's rated capacity, a capture of 97% can be achieved with only 0,5 kg/tTS of polyelectrolyte. Without polyelectrolyte the best capture is about 92%, at the 4 m^3/h feed rate.

The results obtained for cake solids show more scatter but unlike the concurrent centrifuge, increasing the polyelectrolyte does not have a significant effect on cake dryness. As would be expected, the other variables tend to have the opposite effect to those obtained with % capture; decreasing scroll differential speed, shallower pool depths and increasing feed rates tend to improve cake dryness. Without polyelectrolyte a cake-solids of 35% is obtained at the feed rate of

8 m^3/h and 16 rpm scroll differential speed. With polyelectrolyte, and the same machine settings, cake solids of 33% can be achieved at a polyelectrolyte dose of 0,5 kg/tTS.

6.5.2 Untreated sludge. For the reasons stated earlier (see Section 5.3), problems were experienced in obtaining a uniform feed sludge, considerable scatter in the results occurred and only general trends can be discussed. Increasing the polyelectrolyte dose increases capture up to a dose of about 1 kg/tTS; scroll differential speeds and pool depth do not have much effect, though there is some evidence that a differential speed of 12 rpm is the optimum (see Figures 6.4 and 6.5). Without polyelectrolyte the better capture is obtained at 4 m^3/h feed. In Figures 6.6 and 6.7, polyelectrolyte dose is plotted against cake dryness to illustrate that, at both feed rates, the effect of polyelectrolyte is to narrow the band of cake solids values, regardless of scroll differential speed and pool depth, from the wide range of 16-26% solids at Nil polyelectrolyte to about 20-23% at very high dose rates.

It appears that a capture of only 70% and a cake solids of about 22% can be reached without polyelectrolyte and a feed rate of 8 m^3/h. At half this feed rate the capture improves to 80%. With polyelectrolyte, captures of 96-98% can be achieved at both feed rates and dose rates in the range 1 to 1,5 kg/tTS. Cake solids levels remain in the region of 20%.

FIGURE 6.1

DEWATERING OF HEAT-TREATED SLUDGE: COUNTER CURRENT CENTRIFUGE

POLYELECTROLYTE DOSE v % CAPTURE

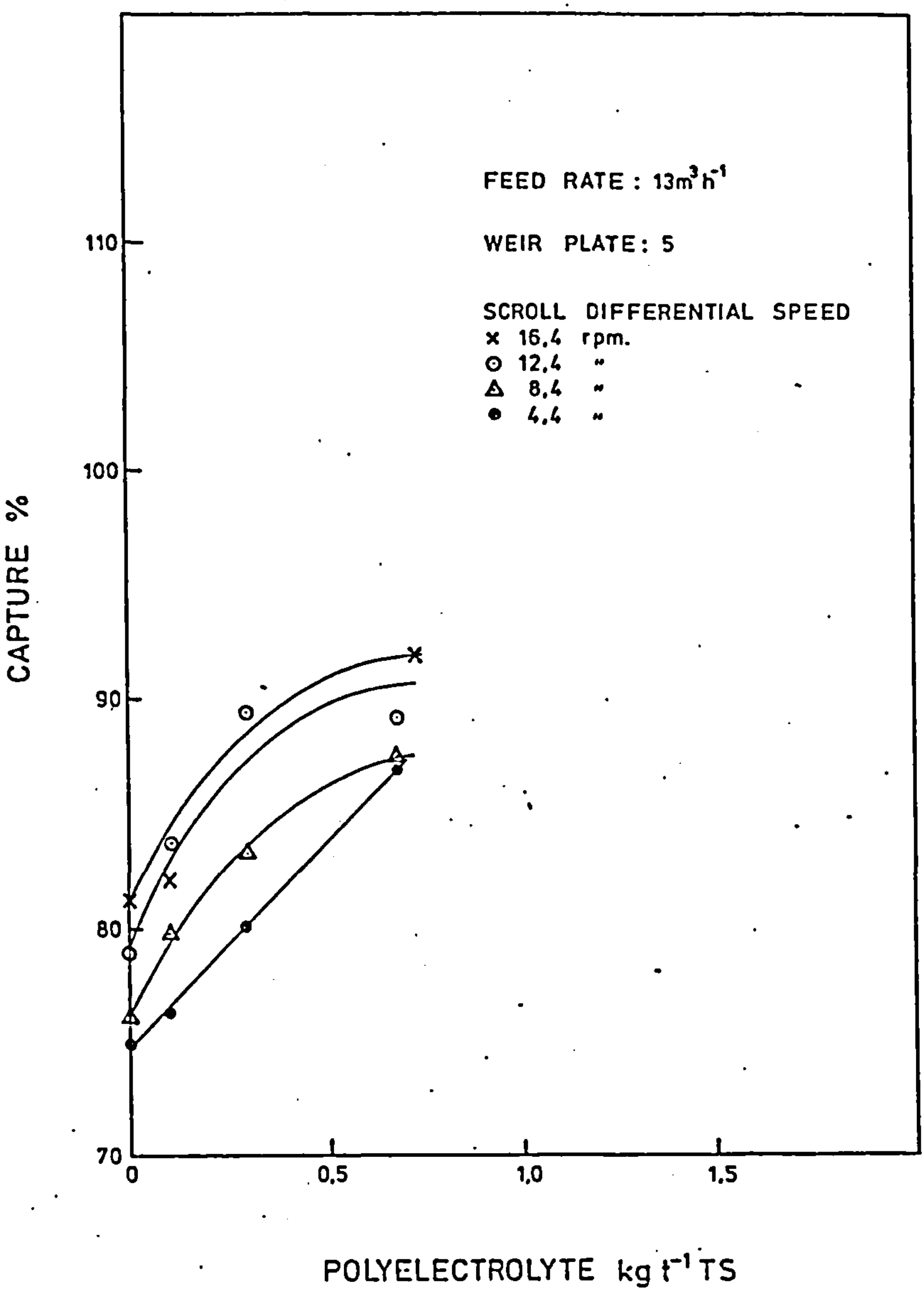


FIGURE 6,2

DEWATERING OF HEAT-TREATED SLUDGE: COUNTER CURRENT CENTRIFUGE

POLYELECTROLYTE DOSE v % CAPTURE

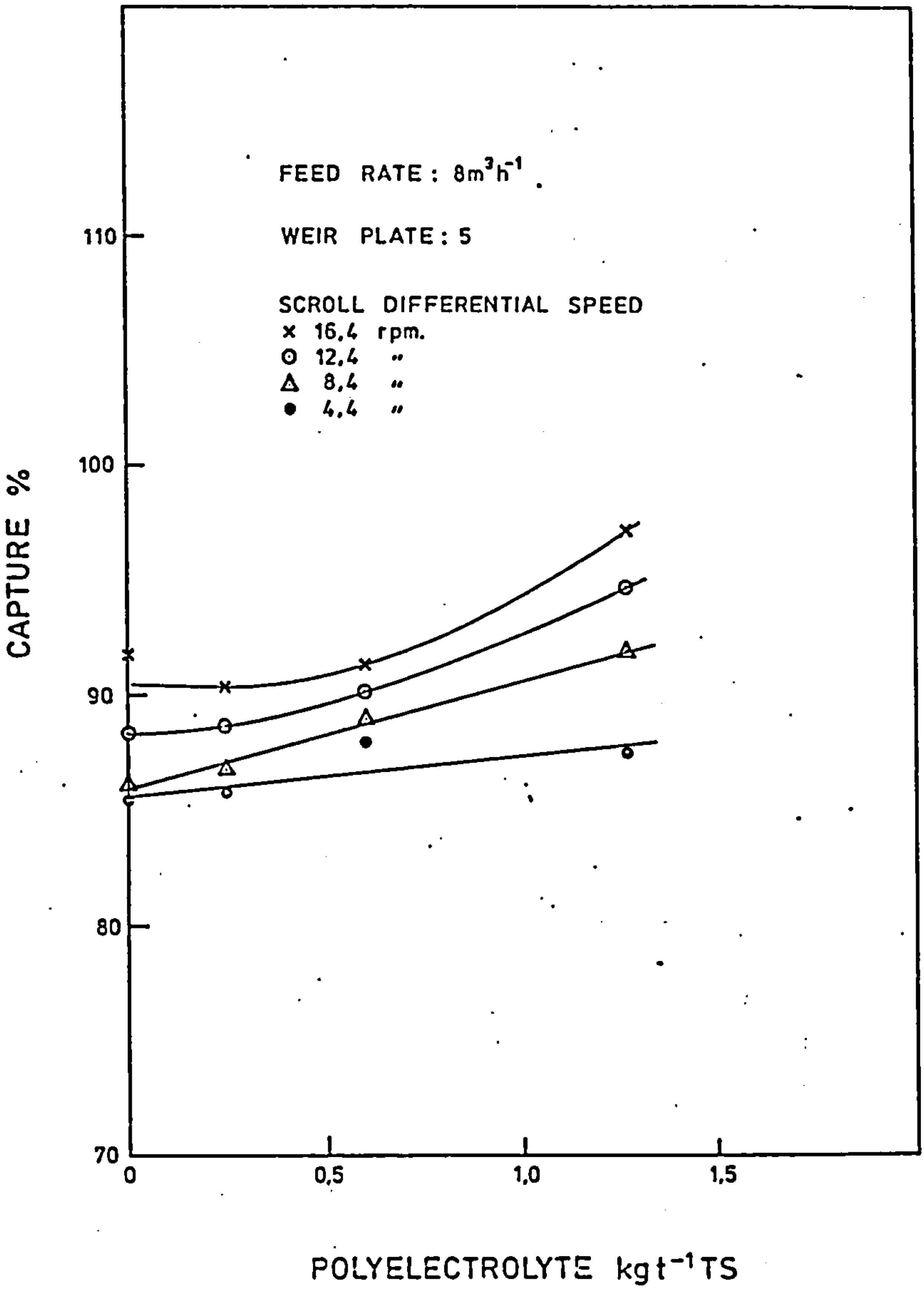
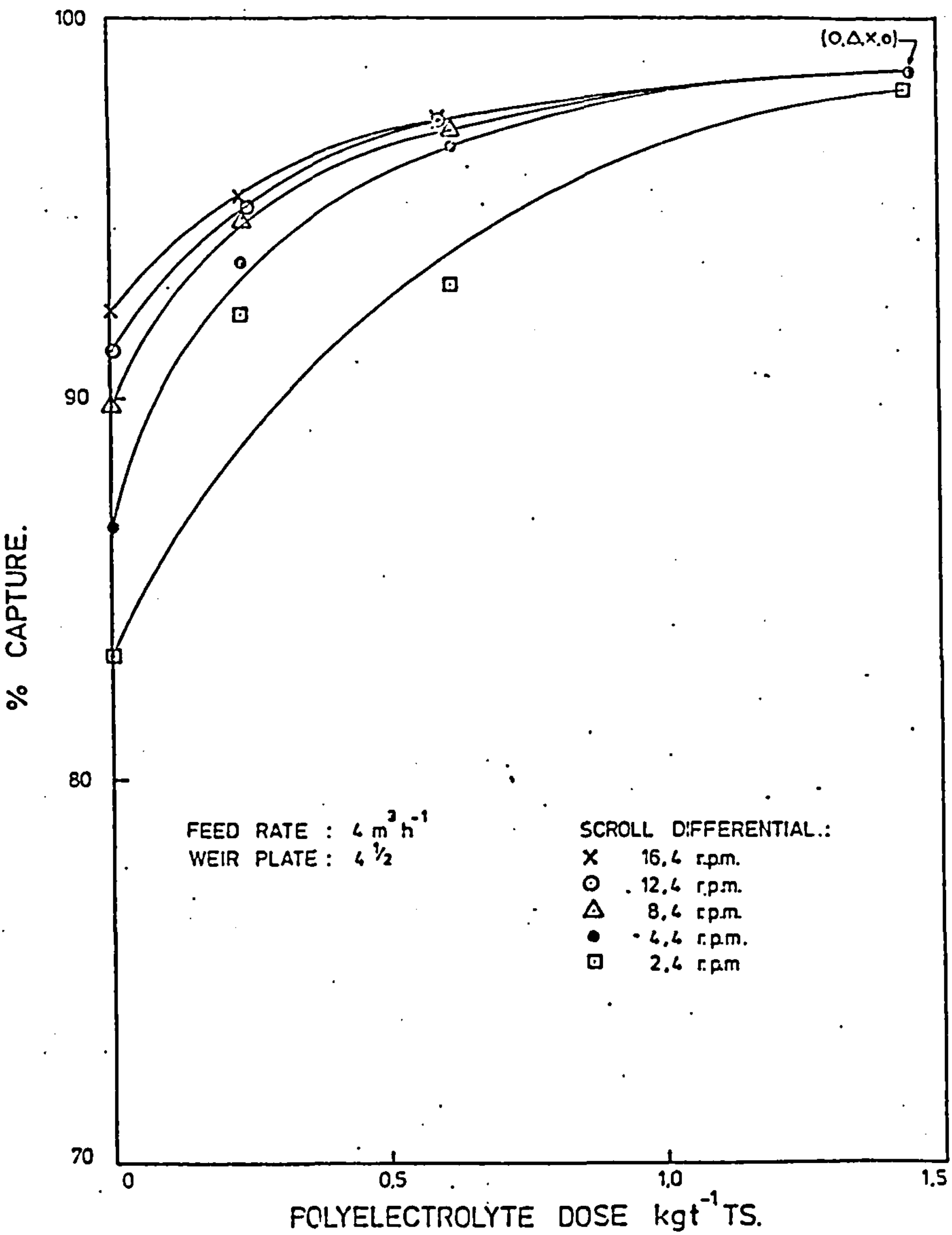


FIGURE 6.3.

DEWATERING OF HEAT TREATED SLUDGE - COUNTERCURRENT FLOW CENTRIFUGE.

POLYELECTROLYTE DOSE v % CAPTURE



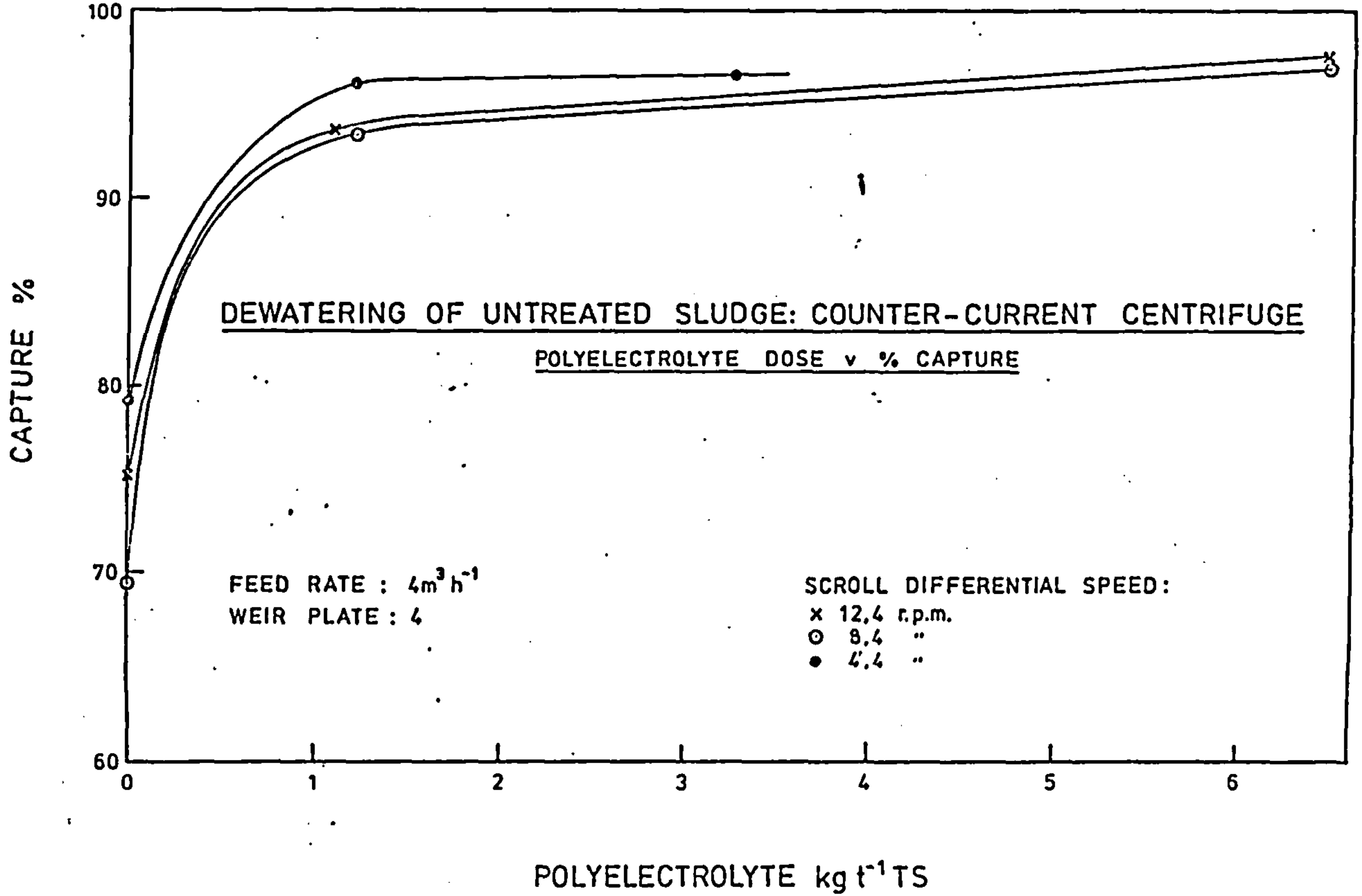

DEWATERING OF UNTREATED SLUDGE: COUNTER-CURRENT CENTRIFUGE
POLYELECTROLYTE DOSE v % CAPTURE
CAPTURE %
100
90
80
70
60
0
1
2
3
4
5
6
FEED RATE : 4m³h⁻¹
WEIR PLATE : 4
SCROLL DIFFERENTIAL SPEED:
× 12.4 r.p.m.
○ 8.4 "
● 4.4 "
POLYELECTROLYTE kg t⁻¹ TS

FIGURE 6.4

DEWATERING OF UNTREATED SLUDGE: COUNTER-CURRENT CENTRIFUGE

POLYELECTROLYTE DOSE v % CAPTURE

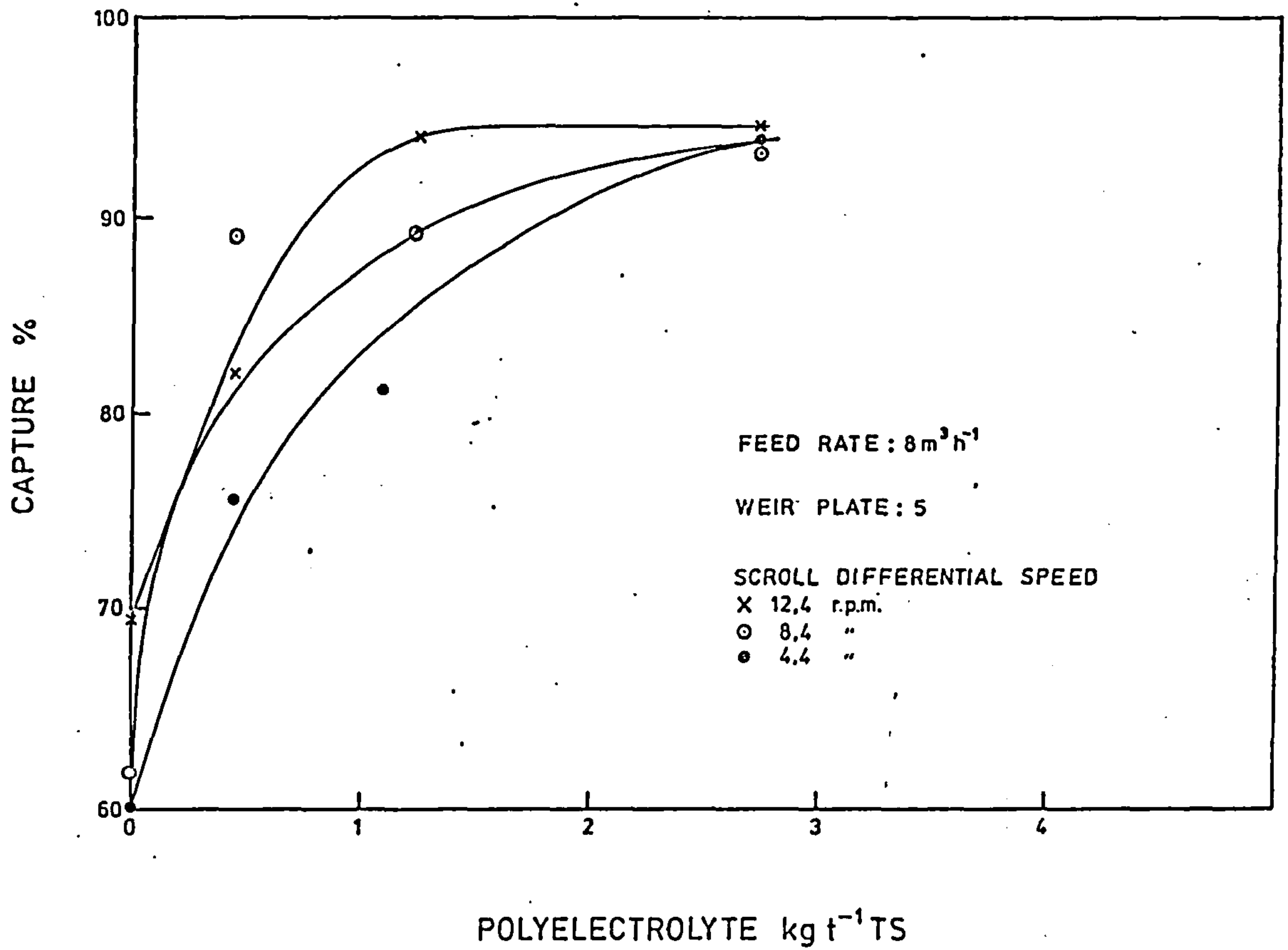


FIGURE 6.5

DEWATERING OF UNTREATED SLUDGE-COUNTERCURRENT CENTRIFUGE

POLYELECTROLYTE DOSE v % SOLIDS IN CAKE

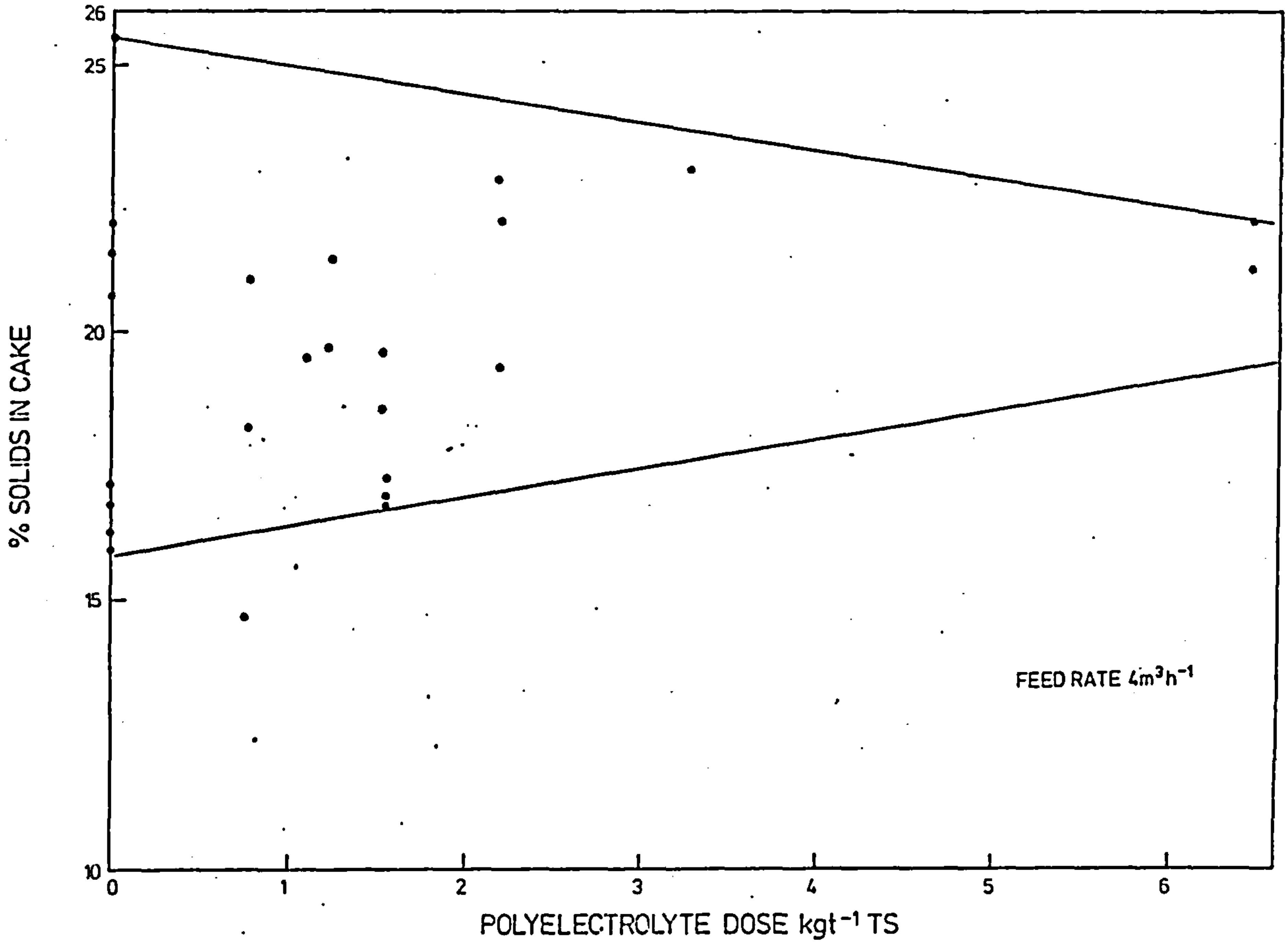


FIGURE 6.6

DEWATERING OF UNTREATED SLUDGE: COUNTER CURRENT CENTRIFUGE

POLYELECTROLYTE DOSE v % SOLIDS IN CAKE

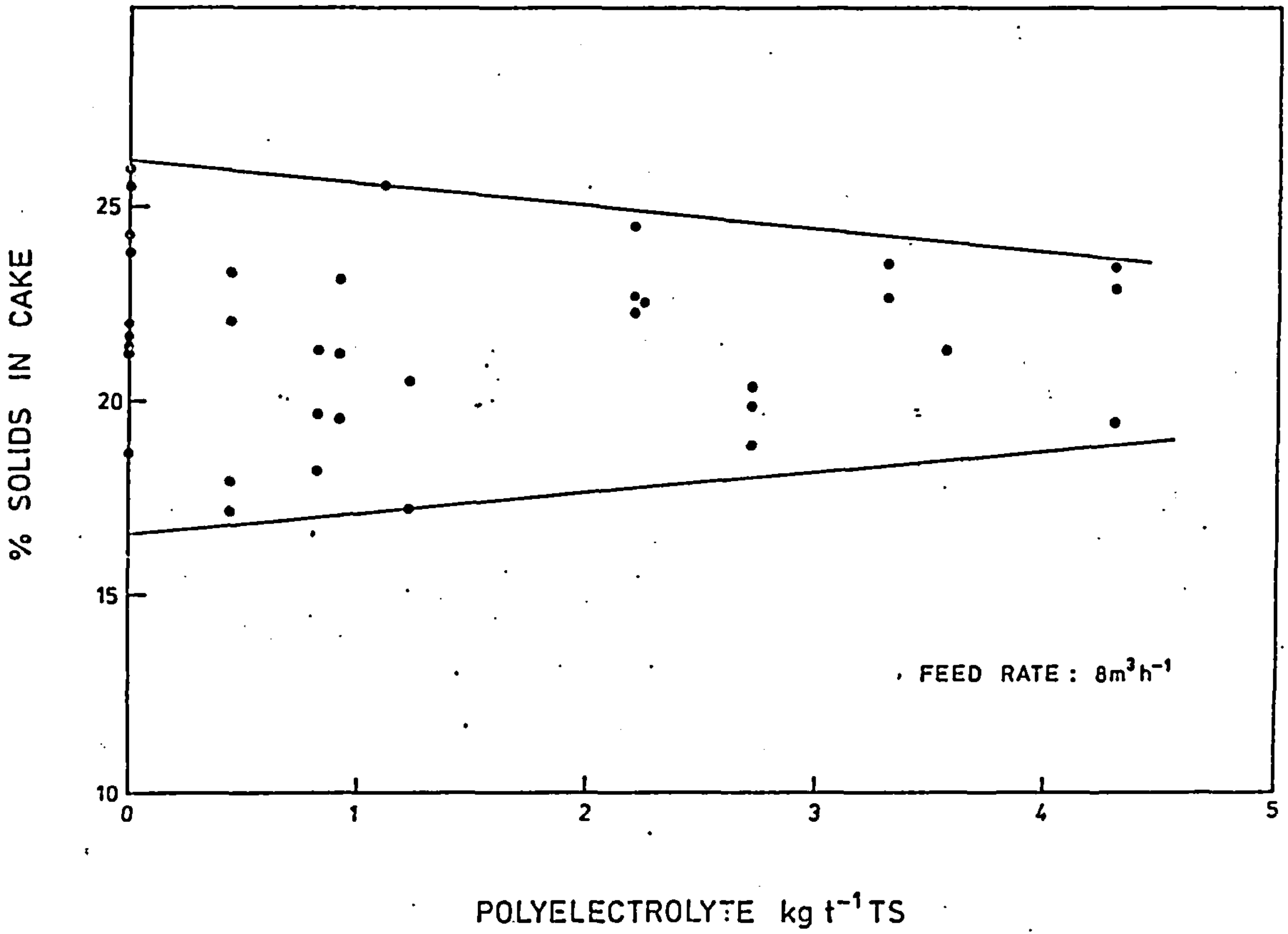


FIGURE 6,7

TABLE 6.1

COUNTER-CURRENT CENTRIFUGE - HEAT-TREATED SLUDGE

	Centrifuge Conditions					Feed Sludge (before poly addition)										
Run No.	Bowl Speed rpm	Scroll Diff. Speed rpm	Weir Plate No.	Feed Rate m^3/hr	Poly dosage kg/t TS	% TS	CST^{10} (secs)	CST^{18} (secs)	$CSV1^{1000}$	$CSV1^{2990}$	$\frac{CSV1^{1000}}{CSV1^{2990}}$	% Solids at 2990	SRF $mkg^{-1}.10^{12}$	Cake TS %	Centrate SS %	% Capture
1	2550	16,4	5	13	Nil									39,97	2,465	81,2
2		12,4		13	Nil	10,43	100,1	27,5	7,000	4,078	1,717	24,52	0,810	42,18	2,693	79,2
3		8,4		13	Nil									42,95	3,096	75,8
4		4,4		13	Nil									43,31	2,973	75,0
5		4,4		13	0,103	9,87	94,6	25,9	7,019	4,099	1,712	24,40	0,794	44,91	2,816	76,3
6		8,4		13	0,103									45,00	2,419	79,8
7		12,4		13	0,104									42,71	1,986	83,7
8		16,4		13	0,104	9,84	93,5	25,2	6,923	4,043	1,712	24,74	0,696	39,84	2,195	82,2
9		16,4		13	0,290									41,14	1,296	89,7
10		12,4		13	0,301									41,93	1,263	89,4
11		8,4		13	0,301	9,47	93,1	24,7	7,008	4,142	1,692	24,15	0,839	45,04	1,939	83,1
12		4,4		13	0,301									45,19	2,245	80,3
13		4,4		13	0,676									46,98	1,392	87,2
14		8,4		13	0,676	9,04	95,4	25,2	7,282	4,284	1,700	23,34	0,854	45,55	1,370	87,5
15		12,4		13	0,676									48,02	1,191	89,0
16		16,4		13	0,725									39,79	0,831	92,1
17		4,4		8	Nil	8,43	97,4	24,8	7,432	4,474	1,661	22,35	1,026	43,98	1,450	85,6
18		8,4		8	Nil									42,11	1,422	86,0
19		12,4		8	Nil									34,18	1,278	88,4
20		16,4		8	Nil	8,55	90,4	24,1	7,317	4,413	1,658	22,66	1,018	21,58	1,218	90,9
21		4,4		8	0,239									43,38	1,468	85,7
22		8,4		8	0,245									39,37	1,347	86,8
23		12,4		8	0,245	8,31	97,2	23,8	7,479	4,485	1,668	22,30	1,019	34,11	1,211	88,6
24		16,4		8	0,245									29,81	1,101	90,1
25		4,4		8	0,598									42,00	1,098	88,3
26		8,4		8	0,598	7,84	111,7	28,3	7,615	4,731	1,610	21,14	1,675	39,82	1,045	89,0
27		12,4		8	0,598									32,02	0,984	90,2
28		16,4		8	0,609									27,22	0,908	91,3
29		4,4		8	1,268	7,71	115,7	30,6	7,603	4,824	1,576	20,73	1,612	41,49	1,164	87,4
30		8,4		8	1,268									39,64	0,691	92,7
31		12,4		8	1,268									35,43	0,511	94,7
32		16,4		8	1,268	7,71	116,7	31,0	7,835	4,873	1,608	20,52	1,874	18,65	0,357	97,2
33		4,4		4	Nil									36,72	0,877	90,8
34		2,4		4	Nil									41,06	1,016	89,6
35		6,4		4	Nil	8,04	118,7	30,0	8,036	4,754	1,690	21,03	1,745	20,18	0,893	93,0
36		2,4		4	0,478									42,73	0,445	95,5
37		4,4		4	0,473									40,65	0,454	95,5
38		6,4		4	0,473	8,12	117,1	31,8	7,874	4,807	1,638	20,80	1,854	38,68	0,362	96,4
39		2,4		4	0,703									40,86	0,408	95,9

TABLE 6.1

COUNTER-CURRENT CENTRIFUGE - HEAT-TREATED SLUDGE

	Centrifuge Conditions					Feed Sludge (before poly addition)										
Run No.	Bowl Speed rpm	Scroll Diff. Speed rpm	Weir Plate No.	Feed Rate m^3/hr	Poly dosage kg/t TS	% TS	CST^{10} (secs)	CST^{18} (secs)	$CSV1^{1000}$	$CSV1^{2990}$	$\frac{CSV1^{1000}}{CSV1^{2990}}$	% Solids at 2990	SRF $mkg^{-1}.10^{12}$	Cake TS %	Centrate SS %	% Capture
40	2550	4,4	5	4	0,664	8,60	135,1	36,2	7,212	4,552	1,584	21,97	2,118	41,05	0,471	95,6
41		6,4		4	0,664									36,88	0,646	94,1
42		2,4	4½	8	Nil									41,22	2,655	74,8
43		4,4		8	Nil	8,65	139,3	35,4	7,714	4,597	1,679	21,75	2,003	40,86	2,639	75,0
44		8,4		8	Nil									39,60	2,336	78,2
45		12,4		8	Nil									35,46	2,369	85,1
46		16,4		8	Nil	11,50	183,2	47,0	6,439	3,879	1,660	25,78	2,117	35,19	3,131	79,9
47		16,4		8	0,118									36,23	1,970	87,6
48		12,4		8	0,131									37,58	1,667	87,8
49		8,4		8	0,131	10,38	170,9	47,7	6,900	4,559	1,513	21,93	2,358	39,97	1,640	87,8
50		4,4		8	0,131									41,92	2,016	84,6
51		2,4		8	0,126									41,16	3,095	77,0
52		2,4		8	0,443	10,75	171,6	39,6	7,207	4,323	1,667	23,13	2,218	43,44	0,331	97,7
53		4,4		8	0,443									43,09	2,498	81,5
54		8,4		8	0,461									41,16	2,202	83,2
55		12,4		8	0,461	10,34	173,1	41,8	7,053	4,275	1,650	23,39	1,895	37,54	1,894	86,0
56		16,4		8	0,461									32,94	1,443	90,0
57	2550	6,8	4	13	Nil	7,41	86,3	23,6	7,957	4,922	1,617	20,32	1,25	43,15	2,355	72,18
58		9,2		13	Nil	6,99	90,1	23,4	7,881	4,937	1,596	20,25	1,27	38,42	2,204	72,64
59		12,4		13	Nil	7,39	82,9	26,4	7,537	4,777	1,578	29,93	1,31	34,16	2,237	74,62
60		16,4		13	Nil	7,17	98,5	25,1	6,887	4,709	1,463	21,24	1,43	33,11	1,958	77,26
61		16,4		13	0,358	6,07	93,9	22,7	7,120	5,007	1,422	19,97	1,73	32,27	1,188	83,50
62		12,4		13	0,399	5,46	79,8	20,5	7,566	5,055	1,497	19,78	1,65	32,83	1,204	80,92
63		9,2		13	0,720	3,29	33,1	13,5	8,422	4,888	1,723	20,46	1,04	34,21	0,537	85,01
64		6,8		13	0,617	3,97	33,4	13,6	8,247	4,962	1,662	20,15	0,996	37,11	0,726	83,34
65		6,8		13	0,442	9,85	105,4	33,3	7,114	4,340	1,639	23,04	1,33	39,95	2,695	77,89
66		6,8		13	0,868	10,02	112,8	31,1	7,225	4,333	1,667	23,08	1,34	40,12	2,516	79,90
67		6,8		8	1,242	9,47	101,6	27,2	7,419	4,447	1,668	22,49	1,35	41,37	0,741	93,86
68		6,8		8	0,363	9,00	124,3	30,4	7,523	4,581	1,642	21,83	1,43	38,07	1,875	83,27
69		9,2		8	0,359	9,10	113,8	31,1	7,707	4,621	1,668	21,64	1,41	35,71	1,851	84,01
70		12,4		8	0,338	9,67	119,2	35,1	7,290	4,336	1,681	23,06	1,50	35,43	1,841	85,40
71		16,4		8	0,357	9,14	107,1	30,0	7,697	4,586	1,678	21,80	1,54	33,83	1,726	85,48
72		16,4		8	Nil	9,36	110,9	33,3	7,595	4,610	1,648	21,69	1,54	33,40	2,291	81,09
73		12,4		8	Nil	8,84	116,4	31,6	7,897	4,738	1,667	21,11	1,54	33,93	2,122	81,07
74		9,2		8	Nil	9,17	115,2	32,7	7,758	4,624	1,678	21,63	1,52	36,61	2.185	81,01
75		6,8		8	Nil	9,45	129,3	34,6	7,589	4,505	1,685	22,20	1,40	37,77	2,358	80,04
76		4,4		4	Nil	9,22	130,0	32,8	7,639	4,573	1,671	21,87	1,54	37,83	1,271	89,21
77		6,8		4	Nil	9,00	131,0	33,4	8,018	4,674	1,715	21,39	1,58	34,55	1,375	88,23
78		9,2		4	Nil	9,31	134,2	34,8	6,979	4,365	1,599	22,91	1,79	33,31	0,906	92,79

TABLE 6.1

COUNTER-CURRENT CENTRIFUGE - HEAT-TREATED SLUDGE

	Centrifuge Conditions					Feed Sludge (before poly addition)										
Run No.	Bowl Speed rpm	Scroll Diff. Speed rpm	Weir Plate No.	Feed Rate m^3/hr	Poly dosage kg/t TS	% TS	CST^{10} (secs)	CST^{18} (secs)	$CSV1^{1000}$	$CSV1^{2990}$	$\frac{CSV1^{1000}}{CSV1^{2990}}$	% Solids at 2990	SRF $mkg^{-1}.10^{12}$	Cake TS %	Centrate SS %	% Capture
79	2550	12,4	4	4	Nil	9,41	133,7	34,5	7,594	4,520	1,680	22,13	1,71	30,60	0,963	92,68
80		16,4		4	Nil	9,54	120,4	35,1	7,318	4,417	1,657	22,64	1,69	28,29	0,788	94,37
81		16,4		4	0,812	10,05	135,4	37,1	7,264	4,145	1,752	24,12	1,64	30,29	0,299	97,99
82		12,4		4	0,876	9,31	112,2	32,6	7,713	4,387	1,758	22,80	1,55	30,20	0,255	98,09
83		9,2		4	0,919	10,19	115,0	33,9	7,458	4,156	1,790	24,06	1,61	31,76	0,165	98,89
84		6,8		4	1,033	9,06	113,4	32,0	8,032	4,645	1,729	21,53	1,81	33,67	0,145	98,83
85		4,4		4	1,097	9,52	120,9	31,9	7,587	4,371	1,736	22,88	1,70	40,43	0,112	99,10
86		4,4		4	0,661	9,88	138,6	37,2	7,130	4,265	1,672	23,45	1,74	37,99	0,204	98,46
87		4,4		4	0,252	9,54	129,9	36,1	7,316	4,428	1,652	22,59	1,77	37,45	0,861	93,12
88		2,0		4	Nil	9,74	137,8	35,8	7,352	4,372	1,682	22,87	1,62	41,94	0,950	92,34
89		16,4	4X	8	1,015	)10,38	173,7	42,6	6,444	4,320	1,492	23,15	1,858	36,81	0,774	94,8
90		12,4		8	1,015	)								40,27	0,562	95,9
91		8,4		8	1,015	)								39,71	0,919	93,3
92		4,4		8	1,030	)								42,16	1,489	88,6
93		2,4		8	1,030	)10,23	147,5	41,2	7,063	4,635	1,524	21,57	1,723	41,26	2,299	82,1
94		2,4		4	Nil	)								43,48	2,137	83,2
95		4,4		4	Nil	)								45,11	1,725	86,5
96		8,4		4	Nil	)10,27	152,7	38,1	6,551	4,335	1,511	23,07	1,653	34,30	1,431	89,8
97		12,4		4	Nil	)								34,63	1,233	91,2
98		16,4		4	Nil	)								31,98	1,176	92,0
99		16,4		4	0,244	)10,37	136,8	38,1	6,861	4,426	1,550	22,59	1,642	32,29	0,729	95,1
100		12,4		4	0,244	)								31,58	0,784	94,8
101		8,4		4	0,238	)								37,18	0,758	94,8
102		4,4		4	0,238	)10,64	141,7	40,3	6,970	4,493	1,551	22,26	1,628	37,06	0,931	93,6
103		2,4		4	0,238	)								41,37	1,090	92,2
104		2,4		4	0,620	)								44,13	1,069	92,1
105		4,4		4	0,620	)10,56	136,6	35,4	6,876	4,405	1,561	22,70	1,629	43,43	0,459	96,7
106		8,4		4	0,620	)								41,77	0,467	96,7
107		12,4		4	0,601	)								33,68	0,430	97,3
108		16,4		4	0,601	)10,89	160,2	42,1	6,805	4,369	1,558	22,89	1,699	33,76	0,459	97,1
109		16,4		4	1,441	)								36,54	0,285	98,1
110		12,4		4	1,437	)								37,91	0,265	98,3
111		8,4		4	1,437	)10,92	149,7	39,5	6,861	4,377	1,568	22,85	1,481	37,98	0,246	98,4
112		4,4		4	1,437	)								41,49	0,240	98,4
113		2,4		4	1,437	)								44,17	0,277	98,1

TABLE 8.2

COUNTER-CURRENT CENTRIFUGE – UNTREATED SLUDGE

	Centrifuge Conditions					Feed Sludge (before poly addition)											
Run No.	Bowl Speed rpm	Scroll Diff. Speed rpm	Weir Plate No.	Feed Rate m^3/hr	Poly dosage kg/t TS	% TS	CST^{10} (secs)	CST^{18} (secs)	$CSV1^{1000}$	$CSV1^{2990}$	$\frac{CSV1^{1000}}{CSV1^{2990}}$	% Solids at 2990	SRF $mkg^{-1}.10^{12}$	Cake TS %	Centrate SS %	% Capture
1	2550	4,4	4½	13	Nil									28,68	1,837	62,0
2	2550	8,4	4½	13	"	4,38	147,6	38,5	9,005	5,977	1,506	16,73	15,60	25,57	1,827	62,8
3	2550	12,4	4½	13	"									23,76	1,772	64,3
4	2550	12,4	4½	13	0,67									18,80	0,347	93,2
5	2550	8,4	4½	13	0,67	4,07	138,9	33,2	8,993	6,796	1,323	14,71	18,12	21,57	1,035	78,3
6	2550	4,4	4½	13	0,93									24,71	1,083	76,8
7	2550	4,4	4½	13	1,43									26,02	1,326	74,7
8	2550	8,4	4½	13	1,43	4,55	142,7	32,3	7,110	6,042	1,177	16,55	14,27	23,10	1,112	79,4
9	2550	12,4	4½	13	1,43									20,56	1,044	81,2
10	2550	12,4	4½	13	2,56									21,49	0,857	83,1
11	2550	8,4	4½	13	2,56	4,24	138,3	32,5	7,741	6,311	1,226	15,84	17,66	23,44	0,964	80,6
12	2550	4,4	4½	13	2,56									24,43	1,107	77,4
13	2550	4,4	4½	8	Nil									25,98	1,567	68,6
14	2550	8,4	4½	8	"	4,41	134,5	32,8	9,599	6,567	1,462	15,23	12,31	21,61	1,616	68,5
15	2550	12,4	4½	8	"									21,41	1,599	68,9
16	2550	12,4	4½	8	4,28									19,46	0,286	93,9
17	2550	8,4	4½	8	4,28	3,81	133,9	31,3	9,627	6,845	1,406	14,61	16,95	23,43	0,267	94,1
18	2550	4,4	4½	8	4,28									22,77	0,317	93,0
19	2550	4,4	4½	8	2,21									24,52	0,224	95,2
20	2550	8,4	4½	8	2,21	3,94	128,3	33,7	9,289	6,599	1,407	15,15	15,83	22,30	0,131	97,2
21	2550	12,4	4½	8	2,21									22,64	0,128	97,3
22	2550	12,4	4½	8	0,81									18,18	0,184	96,4
23	2550	8,4	4½	8	0,81	4,06	125,6	29,2	9,892	6,448	1,534	15,51	17,26	19,69	0,350	93,0
24	2550	4,4	4½	8	0,81									21,34	1,210	74,4
25	2550	4,4	4½	4	Nil									27,27	1,127	77,3
26	2550	8,4	4½	4	"	4,35	129,1	31,6	9,294	6,899	1,347	14,50	12,74	25,52	0,915	81,9
27	2550	12,4	4½	4	"									17,11	1,062	80,6
28	2550	12,4	4½	4	0,77									14,69	0,362	93,6
29	2550	8,4	4½	4	0,77	4,15	118,6	36,6	10,012	6,717	1,491	14,89	14,32	18,40	0,172	96,8
30	2550	4,4	4½	4	0,77									20,86	0,153	97,0
31	2550	4,4	4½	4	2,21									22,01	0,230	94,8
32	2550	8,4	4½	4	2,21	3,71	142,9	35,3	11,283	7,612	1,482	13,14	18,26	22,70	0,246	94,4
33	2550	12,4	4½	4	2,21									19,37	0,082	98,2
34	2550	4,4	5	4	Nil									15,89	0,415	91,3
35	2550	8,4	5	4	"	3,73	106,6	26,5	10,298	6,976	1,476	14,34	15,96	16,13	0,709	84,7
36	2550	12,4	5	4	"									12,59	0,936	80,9
37	2550	12,4	5	4	1,56									16,67	0,065	98,7
38	2550	8,4	5	4	1,56	3,85	132,9	32,0	11,174	7,902	1,414	12,66	19,88	16,73	0,112	97,7
39	2550	4,4	5	4	1,56									18,47	0,112	97,7
40	2550	4,4	5	4	1,54									19,61	0,103	96,7
41	2550	8,4	5	4	1,54	2,69	82,4	25,6	11,765	8,078	1,456	12,38	18,92	17,19	0,115	96,4
	2550	12,4	5	4	1,54				No samples taken					–	–	–
4[illegible]	2550	4,4	5	8	Nil									18,67	1,175	60,1

TABLE 6.2

COUNTER-CURRENT CENTRIFUGE - UNTREATED SLUDGE

	Centrifuge Conditions					Feed Sludge (before poly addition)										
Run No.	Bowl Speed rpm	Scroll Diff. Speed rpm	Weir Plate No.	Feed Rate m^3/hr	Poly dosage kg/t TS	% TS	CST^{10} (secs)	CST^{18} (secs)	$CSV1^{1000}$	$CSV1^{2990}$	$\frac{CSV1^{1000}}{CSV1^{2990}}$	% Solids at 2990	SRF $mkg^{-1}.10^{12}$	Cake TS %	Centrate SS %	% Capture
43	2550	8,4	5	8	Nil									22,93	1,602	61,8
44	2550	12,4	5	8	"	3,77	113,7	31,1	10,195	7,358	1,386	13,59	10,76	22,73	1,308	69,3
45	2550	12,4	5	8	0,45									17,80	0,821	82,0
46	2550	8,4	5	8	0,44									17,08	0,520	89,1
47	2550	4,4	5	8	0,44	3,81	126,9	31,5	10,097	6,867	1,470	14,56	17,46	23,31	1,065	75,5
48	2550	4,4	5	8	1,09									25,50	0,816	81,2
49	2550	8,4	5	8	1,23									20,50	0,420	89,3
50	2550	12,4	5	8	1,23	3,36	121,4	30,8	10,291	7,358	1,399	13,59	18,83	17,06	0,245	94,1
51	2550	12,4	5	8	2,73									18,93	0,232	94,3
52	2550	8,4	5	8	2,73									19,90	0,223	93,4
53	2550	4,4	5	8	2,73	2,93	119,0	30,1	12,291	8,300	1,481	12,05	21,25	20,44	0,205	93,9
54	2550	4,4	5	13	Nil									22,84	1,724	63,3
55	2550	8,4	5	13	"									22,31	1,829	61,0
56	2550	12,4	5	13	"	4,16	129,5	32,4	10,510	6,290	1,671	15,90	15,10	22,31	1,829	61,0
57	2550	12,4	5	13	0,62									20,80	1,315	73,0
58	2550	8,4	5	13	0,59									25,78	1,419	71,1
59	2550	4,4	5	13	0,59	4,33	131,6	32,3	9,788	6,039	1,621	16,56	13,37	26,68	1,504	69,2
60	2550	4,4	5	13	1,51									29,49	1,322	72,7
61	2550	8,4	5	13	1,53									24,02	0,936	81,1
62	2550	12,4	5	13	1,53	4,25	115,8	31,7	10,163	7,086	1,434	14,11	11,70	20,56	0,886	82,7
63	2550	12,4	5	13	2,56									21,42	0,119	97,7
64	2550	8,4	5	13	2,30									23,05	0,144	97,6
65	2550	4,4	5	13	2,30	4,73	153,4	37,1	9,507	5,905	1,610	16,94	13,35	27,38	0,718	87,1
66	2550	4,4	4	13	Nil									30,17	1,981	62,2
67	2550	8,4	4	13	"									26,11	1,942	62,6
68	2550	12,4	4	13	"	4,62	184,6	45,1	9,680	6,494	1,491	15,40	16,56	23,10	1,928	63,6
69	2550	12,4	4	13	0,24									20,73	1,471	73,4
70	2550	8,4	4	13	0,29									20,97	1,034	77,4
71	2550	4,4	4	13	0,29	3,92	141,2	39,3	10,341	6,923	1,494	14,44	17,38	22,93	1,174	73,8
72	2550	4,4	4	13	1,59									25,69	1,476	66,1
73	2550	8,4	4	13	1,37									25,60	1,345	74,3
74	2550	12,4	4	13	1,37	4,54	140,2	37,7	9,288	7,092	1,310	14,10	18,17	21,49	1,406	73,9
75	2550	12,4	4	13	2,32									21,21	1,238	77,2
76	2550	8,4	4	13	2,29									24,41	1,435	73,1
77	2550	4,4	4	13	2,29	4,60	168,6	40,2	9,934	6,975	1,424	14,33	17,37	25,02	1,515	71,4
78	2550	4,4	4	8	Nil									25,51	1,728	67,0
79	2550	8,4	4	8	"									24,33	1,810	62,8
80	2550	12,4	4	8	"	4,32	181,8	45,8	10,051	7,180	1,400	13,93	25,72	23,91	1,627	66,9
81	2550	12,4	4	8	0,92									19,59	1,141	78,1
82	2550	8,4	4	8	0,92									21,17	1,902	61,3
83	2550	4,4	4	8	0,92	4,30	147,8	40,6	10,848	7,294	1,487	13,71	18,57	23,13	1,865	61,6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]									28,00	1,169	76,0

TABLE 6.2

COUNTER-CURRENT CENTRIFUGE - UNTREATED SLUDGE

	Centrifuge Conditions				Feed Sludge (before poly addition)										
Run No.	Bowl Speed rpm	Scroll Diff. Speed rpm	Weir Plate No.	Feed Rate m^3/hr	Poly dosage kg/t TS	% TS	CST^{10} (secs)	CST^{18} (secs)	$CSV1^{1000}$	$CSV1^{2990}$	$\frac{CSV1^{1000}}{CSV1^{2990}}$	% Solids at 2990	SRF $mkg^{-1}.10^{12}$	Cake TS %	Centrate SS %	% Capture
85	2550	8,4	4	8	2,24									25,51	1,228	75,5
86	2550	12,4	4	8	2,24	4,37	169,7	38,0	10,898	7,064	1,543	14,16	21,36	22,48	1,252	75,5
87	2550	12,4	4	8	3,57									21,16	0,810	84,7
88	2550	8,4	4	8	3,30									22,64	0,111	98,1
89	2550	4,4	4	8	3,30	4,73	152,9	36,2	9,934	7,107	1,398	14,08	14,70	23,46	0,091	98,5
90	2550	4.4	4	4	Nil									22,16	1,177	79,3
91	2550	8,4	4	4	"									20,59	1,611	69,4
92	2550	12,4	4	4	"	4,47	172,5	45,6	10,231	7,198	1,421	13,89	19,85	21,43	1,318	75,1
93	2550	12,4	4	4	1,10									19,51	0,382	93,3
94	2550	8,4	4	4	1,22									19,71	0,320	93,6
95	2550	4,4	4	4	1,22	4,04	142,2	35,9	10,663	7,710	1,383	12,97	17,64	21,27	0,187	96,2
96	2550	4,4	4	4	3,27									23,09	0,175	96,4
97	2550	8,4	4	4	6,47	2,04	83,5	23,4	12,164	8,880	1,371	11,26	74,50	21,19	0,066	97,1
98	2550	12,4	4	4	6,47									22,04	0,049	97,8

7. SUMMARY AND REVIEW (PART 1)

It is not easy to summarise and compare concisely the performances of the various items of dewatering equipment reported in detail in previous sections. This is for two reasons. Firstly, the optimum machine settings for one particular performance requirement are not necessarily the best settings for another requirement. For example the best settings for sludge output are not the optimum for cake dryness on the vacuum filter. Similarly, with centrifuges and untreated sludge, the addition of polyelectrolyte improves solids capture at the expense of cake dryness and there are numerous other instances of conflicting performance criteria. Secondly, the items of equipment operate in very different ways. Filter plate pressing, for example, is a batch process while a centrifuge operates continuously.

In addition, quite apart from performance criteria, there are a number of other factors which must be taken into account in choosing a sludge dewatering system. Ease of operation and maintenance are two obvious points for consideration. Another factor is the compactness of the equipment as this affects the size of the building required to house it. The amount of polyelectrolyte required for effective dewatering has a profound effect on running costs, as chemical conditioners are very expensive. Finally, the initial capital cost is a major issue, especially when the cost of borrowing money is high.

To summarise this section of the report, therefore, it was decided to mention briefly, under each item of equipment, the main features of its performance and then to list the advantages and disadvantages associated with it. No attempt has been made to compare capital costs as there are too many extraneous and variable factors which affect these. Untreated sludge, without polyelectrolyte, is not satisfactorily dewatered by any of the machines tested and the results obtained with this sludge are not included in the summary below.

VACUUM FILTER

Heat-treated sludge:	solids capture:	99% with 0,5 kg poly/tTS. 98-99% without polyelectrolyte.
	cake solids:	38-39% with 0,5 kg poly/tTS;high output. 42% without polyelectrolyte.
Untreated sludge:	solids capture:	96% with 2,5 kg poly/tTS;low output.
	cake solids:	19% with 2,5 kg poly/tTS;low output.

Advantages

1. Continuous process.
2. Simple to house.
3. High solids capture and cake dryness with heat-treated sludge.
4. Polyelectrolyte not necessarily required with heat-treated sludge.
5. Wide choice of filter cloths available.

Disadvantages

1. Maintenance of ancillary equipment may be expensive.
2. Cloth change requires experienced operator.
3. Acid washing required to remove scale from grid and interior pipework.
4. Cloth washing required at regular intervals (possibly with detergent).
5. Open equipment - possible odour problems.

FILTER BELT PRESS

Heat-treated sludge:	solids capture:	98% with 1,5 to 2,0 kg poly/tTS.
	cake solids:	43% with 1,5 to 2,0 kg poly/tTS.
Untreated sludge:	solids capture:	98-99% with 2,0 to 3,0 kg poly/tTS.
	cake solids:	19% with 2,0 to 3,0 kg poly/tTS.

Advantages

1. Continuous process.
2. Simple to house.
3. Low mechanical maintenance costs.
4. Visible gravity drainage zone enables operator to make minor running adjustments.
5. Integral, continuous belt washing.

Disadvantages

1. Replacement belts expensive. Belt change requires experienced operator.
2. Belt washings reduce solids capture.
3. Open equipment - possible odour problems.
4. Cannot dewater heat-treated sludge without polyelectrolyte

FILTER PLATE PRESS

Heat-treated sludge:	solids capture:	99% with or without polyelectrolyte.
	cake solids:	46% with 1,4 kg poly/tTS (1,4h press time). 51% without poly (3,0 h press time).

Untreated sludge:

solids capture: 99% with poly of 4-5 kg/tTS.
cake solids: 36% with poly of 4-5 kg/tTS (6 h press time).

Advantages	Disadvantages
1. Low mechanical maintenance costs.	1. Batch process; not necessarily a problem at low pressing times.
2. Wide choice of filter cloths available.	2. Specially designed double storey building required to house presses.
3. High solids capture and cake dryness with both types of sludge.	3. Cloth maintenance (washing etc) may be expensive.
4. Polyelectrolyte not required with heat-treated sludge.	4. Labour intensive unless automated.
	5. Safeguards required to control risk of pressure "blow-outs" of sludge.
	6. Untreated sludge requires relatively high doses of polyelectrolyte.

CENTRIFUGES

Concurrent Flow

Heat-treated sludge:

solids capture: 99,5% with 0,5 kg poly/tTS.
98% without polyelectrolyte.

cake solids: 40% with 0,5 kg poly/tTS
39% without poly; at low diff.scroll speeds (i.e. at low capture).
33% without poly; at high diff.scroll speeds (i.e. at high capture.)

Untreated sludge:

solids capture: 97% with 2,5 kg poly/tTS
cake solids: 19% with 2,5 kg poly/tTS.

For this machine, all the summarised results were obtained at full rated capacity.

Counter-Current Flow

Heat-treated sludge:

solids capture: 97% with 0,5 kg poly/tTS (at ½ rated capacity).
91% with 0,5 kg poly/tTS (at full rated capacity).
92% without polyelectrolyte (at ½ rated capacity).

cake solids: 33% with 0,5 kg poly/tTS; at full capacity but with low capture.
35% without polyelectrolyte; at full capacity but with low capture.

Untreated sludge:

solids capture: 96-98% with 1-1,5 kg poly/tTS
cake solids: 20% with 1-1,5 kg poly/tTS.

(both types of centrifuge)

Advantages	Disadvantages
1. Continuous process.	1. High operating speeds; high maintenance costs; requires specialised knowledge and equipment for mainten-.....

2. Compact; simple to house.	2. Feed sludge must be macerated or well screened and de-gritted to prevent blockages and minimise wear.
3. Simple to set and operate, provided feed sludge properties do not vary.	3. High energy requirement.
4. Enclosed equipment; fewer odour problems.	4. Requires constant attention to optimise chemical conditioner consumption.
5. High solids capture and cake dryness with heat-treated sludge using concurrent flow machine with low polyelectrolyte dosage.	

8. REFERENCES

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PART I

APPENDIX A

EFFECT OF HEAT-TREATMENT REACTION TEMPERATURE AND TIME ON HEAT-TREATED SLUDGE DEWATERING CHARACTERISTICS

1. EXPERIMENTAL PROCEDURE

The Zimpro heat-treatment plant at the Fishwater Flats Water Reclamation Works consists of two identical streams. It was therefore possible to test the two variables, reaction temperature and reaction time, concurrently on the same sludge feed. One stream was operated at a fixed flow rate of 400 ℓ/min. (equivalent to a reaction time of 30 minutes) while the temperature was increased from 150°C in 10°C steps to 200°C, the maximum permitted for the equipment. Simultaneously the second stream was operated at a fixed temperature of 190°C and the flow rate was increased from 225 ℓ/min. to 470 ℓ/min. in a total of six steps (reaction time from 54 min. to 26 min.). The volume of the reactor and heat exchangers is 12,12 m^3 for each stream.

At each set of conditions the two streams were allowed to stabilise for one hour before readings and samples were taken. Four samples were taken, during each half-hour run, from both of the treated sludge lines and from the common feed line. The individual samples were immediately tested on-site for CST(10) and CST(18) as well as temperature. Subsequently they were combined to give a single composite for each run, as were the feed sludge samples, and tested the next day in the laboratory at ambient temperature. The reason for this procedure was to discover whether heat-treated sludge is more easily dewatered at the higher temperatures at which it emerges from the treatment plant, and therefore should be pumped to the dewatering equipment with the minimum of cooling.

The analyses undertaken on the samples, in addition to the on-site tests mentioned above, were:-

(i)	Feed and treated sludge composites	% total solids (at 105°C)
		% volatile matter in total solids
		CST(10)
		CST(18)
		SRF

(ii) On the filtrate from the treated sludge composites : % total solids (at 105°C)
COD
colour
% dissolved solids (from which % solubilisation was calculated)

2. RESULTS

The results for the 6 test runs are given in Table A.1.

3. DISCUSSION OF RESULTS

The effects of reaction temperature and time on capilliary suction time (CST(10) and CST(18) are illustrated in Figures A1 and A2.

Increasing reaction temperature resulted in a very significant improvement in CST up to a temperature of about 180°C, after which it had little effect. Below 30 min., increasing reaction time had a small adverse effect on CST but, thereafter, a marked improvement up to about 50 mins., followed by a levelling off. In practice it is not possible to operate the process above a retention time of about 30-35 min. because of problems that arise with tube scaling. The plant is, therefore, normally operated at a reaction time of 27-30 min. (400-450 ℓ/min.) and a temperature in the range 180-195°C. These operating conditicns were maintained during the experimental work described in the other sections of this report.

Table A1 also shows the expected close correlation between reaction temperature and filtrate COD and colour, and the extent of the solubilisation of the feed sludge solids. All three properties tend to level off to steady values above 180°C reaction temperature.

A comparison of CST and specific resistance to filtration of the feed and the treated sludges clearly illustrates the profound effect which heat treatment has on these dewatering characteristics.

A comparison of the on-site treated sludge analyses with those carried out in the laboratory indicates that cooling of the treated sludge has no adverse effect on its CST value, provided the sludge has been treated at a temperature over 180°C.

FIGURE A.1

THE EFFECT OF HEAT-TREATMENT REACTION TEMPERATURE ON CST OF SLUDGE

REACTION TIME - 30 MINS.

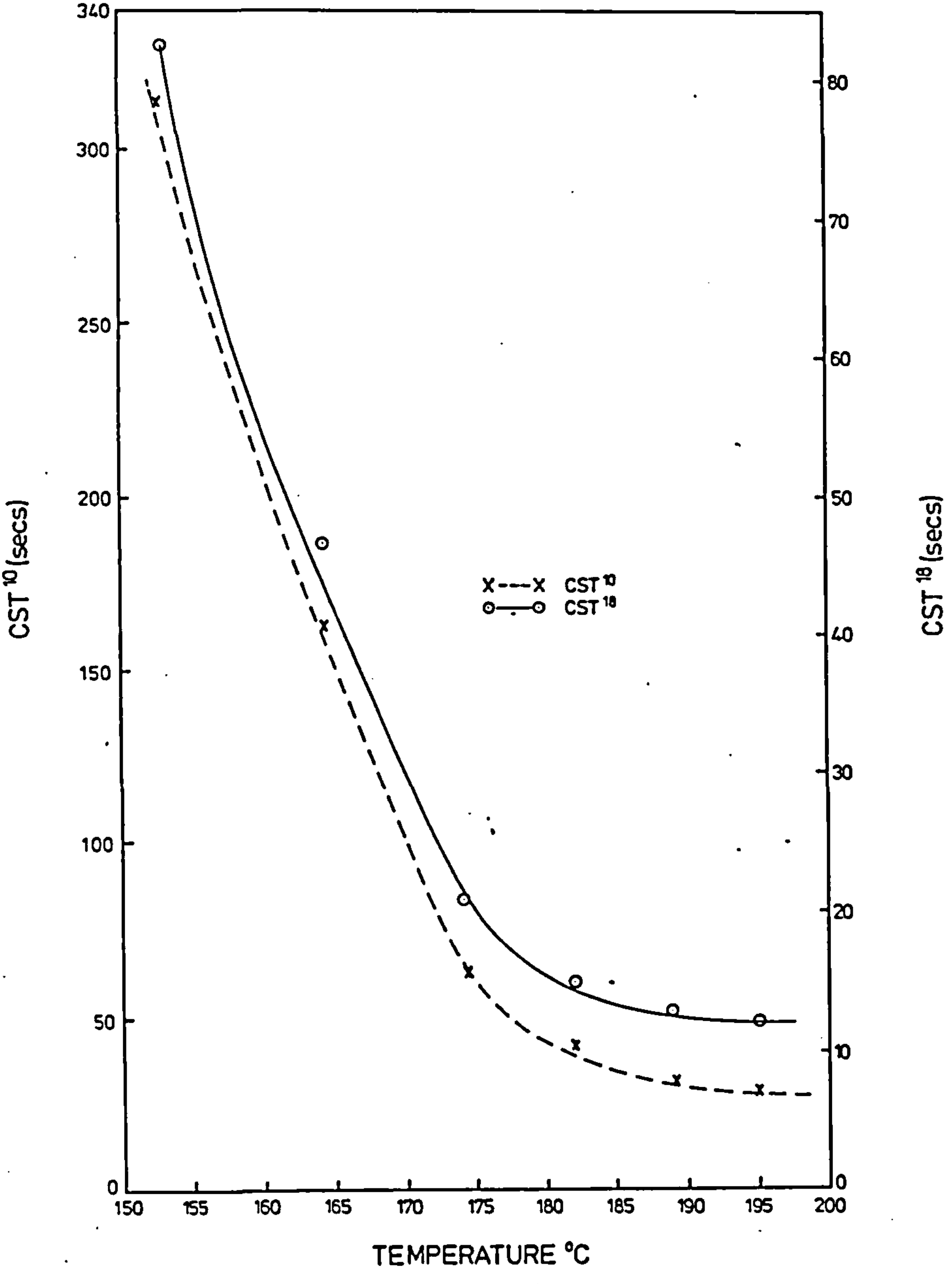


FIGURE A.2.

THE EFFECT OF HEAT TREATMENT REACTION TIME ON CST OF SLUDGE.

REACTION TEMPERATURE: 190°C.

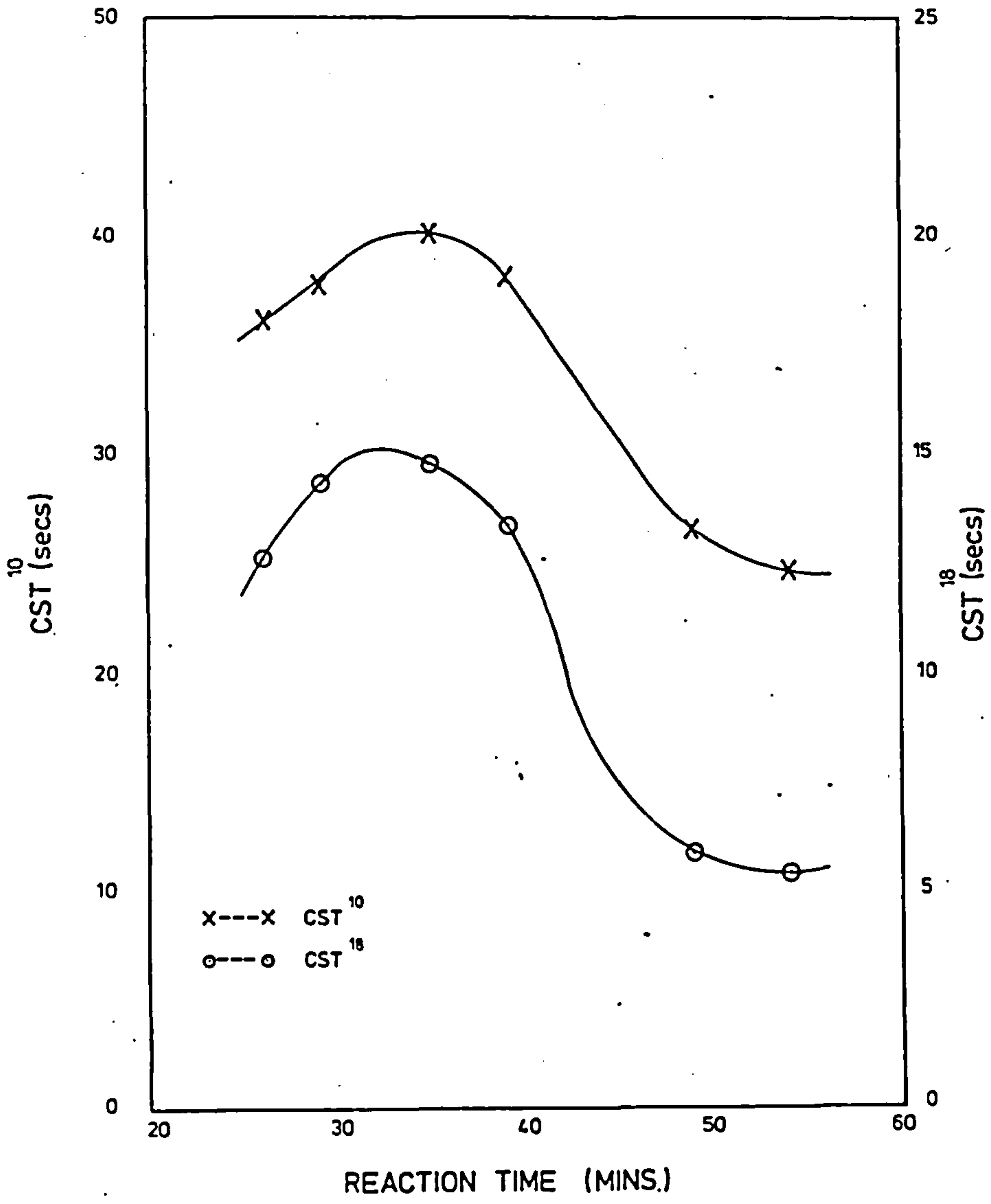


TABLE A.1

THE EFFECT OF REACTION TEMPERATURE AND REACTION TIME ON SLUDGE DEWATERING CHARACTERISTICS

ZIMPRO HEAT-TREATMENT

Run	Plant Conditions				Treated Sludge Analysis (on site)				Treated Sludge Analysis (in laboratory)			Filtrate Analysis			%
	Reaction Time (mins)	Target Temp. °C	Reaction Temp. °C	Temp. °C	Av.CST^{10} (secs)	CST^{18} (secs)	Total solids %	Volatile Matter %	CST^{10}(secs)	CST^{18}(secs)	SRF m kg^{-1}	COD mgℓ^{-1}	Dissolved solids %	Colour(Hazen)*	Solubilisation
TREATED SLUDGE															
Stream 1. Fixed Flow, Variable Temperature															
A	30	150	153	46,7	-	129,3	3,68	79,20	313,9	83,9	$1,97x10^{13}$	9236	0,91	70	18,8
B	30	160	164	46,5	-	97,0	3,80	78,83	163,6	44,5	$8,69x10^{12}$	11001	1,02	85	18,0
C	30	170	174	51,7	54,8	30,9	3,55	78,46	63,1	21,1	$1,47x10^{12}$	13669	1,19	125	30,2
D	30	180	182	51,2	41,1	14,3	3,81	78,52	41,7	14,9	$7,05x10^{11}$	13607	1,25	150	29,7
E	30	190	189	53,5	26,2	10,4	3,85	79,43	32,1	11,5	$3,74x10^{11}$	14921	1,32	150	30,5
F	30	200	195	55,7	23,1	9,0	3,84	78,43	28,6	11,2	$2,93x10^{11}$	14305	1,27	150	32,5
Stream 2. Fixed Temperature, Variable Flow															
A	54	190	195	62,7	18,6	7,6	3,33	78,29	24,5	10,3	$2,66x10^{11}$	14818	1,23		
B	49	190	196	49,3	24,4	9,3	3,32	78,91	26,5	10,7	$3,13x10^{11}$	14962	1,28		
C	39	190	189	50,3	34,5	12,8	3,41	81,06	38,1	13,3	$5,33x10^{11}$	14263	1,21		
D	35	190	188	52,5	42,9	15,4	3,65	80,83	40,2	14,7	$6,82x10^{11}$	14572	1,25		
E	29	190	189	56,0	38,7	14,2	3,80	81,12	37,5	14,2	$5,74x10^{11}$	14059	1,23		
F	26	190	194	53,8	29,8	11,6	3,71	80,85	36,2	12,6	$4,33x10^{11}$	14223	1,23		
FEED SLUDGE															
							3,76	80,60	1205	225,5	$1,55x10^{14}$	-	0,21	-	-

*Colour after x50 dilution with water

PART 1

APPENDIX B

SLUDGE CHARACTERISATION

The possibility of devising a relatively simple laboratory test or tests to predict the dewatering characteristics of sewage sludges has always been an attractive one and the subject of a great deal of research. Tests of this nature would provide methods for monitoring the effects of works operating variables on the properties of the sludge produced. They would also simplify the optimization of conditioning prior to dewatering. However, the complexity of the physical and chemical composition of sludges, and the variation in sludge properties from one sewage works to another, are so great that the development of such tests is no easy matter.

In this project a number of characterisation tests were performed on the feed sludges to the various items of dewatering equipment. Some of them were standard tests, some were developed more recently by the National Institute for Water Research, CSIR (Fourie 1982, 1983). For a very brief definition of the tests refer to Section 1.5. The results obtained are fully reported in the tables in Sections 2-6 and discussed below. No attempt was made to investigate any of the problems of characterisation nor was any development work undertaken on the tests themselves. The whole question of sludge characterisation in relation to dewatering is being studied in depth by the National Institute for Water Research,CSIR, and will be the subject of a separate report.

Filter Plate Press

Capillary suction time (CST), specific resistance to filtration (SRF) and the filter test (FT) were carried out on the feed sludges prior to the addition of polyelectrolyte. The configuration of the test equipment made it impossible to sample after polyelectrolyte had been added. No correlations were observed between the test results and machine performance. It is probable that the tests used do not adequately represent the degree of compression filtration that takes place in a plate press but in any case it is debatable whether any correlations can be expected if the sludge cannot be characterised in the form in which it is actually dewatered i.e. after the addition of polyelectrolyte.

Filter Belt Press

CST and FT were determined on the sludge feeds before and after the addition of polyelectrolyte. No correlations between the test results and dewatering performance could be found, even if the results were corrected for the varying feed sludge solids concentrations. Possibly the lack of correlation is due to the complex nature of the dewatering which takes place in this machine; gravity drainage, compression filtration and shear all occur.

Vacuum Filter

CST, SRF and the centrifuge cake water retention index (CCWRI) were determined in this series of tests. It was possible to sample the sludges both before and after the addition of polyelectrolyte.. The vacuum drum filter operates by straightforward filtration and, as expected, a relationship was found between SRF and machine output (see Figure B1). The results for both heat-treated and untreated sludge, with and without polyelectrolyte, are plotted and illustrate clearly the very significant effect which the heat-treatment process has on sludge by reducing its specific resistance to filtration.

A reasonably linear inverse correlation was found between CST (10) and machine output for heat-treated sludge (see figure B2). The relationship between CST and output for untreated sludge was less clear. As might be expected there appeared to be no relationship between CCWRI and machine output. It is interesting to note that the CCWRI test is relatively insensitive to the addition of polyelectrolyte to the feed sludge and does not show the significant drop in values which occurs with the SRF test.

Centrifuges

CST, SRF and CSVI tests were undertaken on the counter-current centrifuge and CST, SRF and CCWRI tests on the concurrent flow machine. The feed sludges could not be sampled after the addition of polyelectrolyte and only the results from the runs without polyelectrolyte have been examined for possible correlations. No relationship was found between % capture and CST or CSVI. The relationships between % capture and CCWRI for both types of sludge and both machines are shown in Figures B3 and B4, and between % capture and SRF in Figure B5 for the counter current centrifuge. Each point is the average CCWRI for all scroll speeds. Unfortunately the SRF results for the concurrent centrifuge tended to group at the two extreme ends of the SRF range and any relationship that may exist did not emerge.

The results obtained indicate that, within limits, the CCWRI and SRF tests can be used to predict centrifuge dewatering efficiency as measured by % capture, in the case of heat-treated and untreated sludges which have not been conditioned with polyelectrolyte.

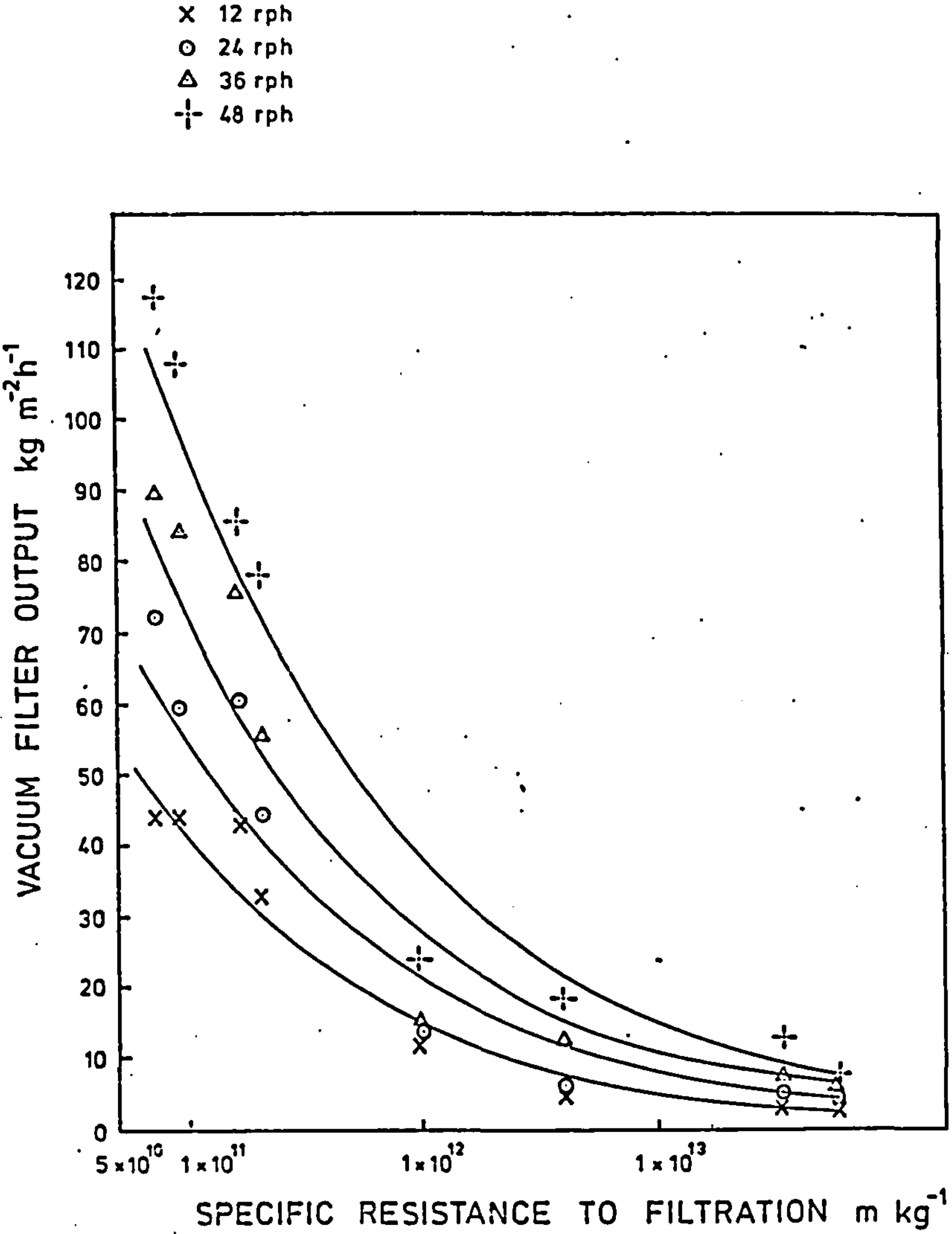
Relationship between CST and SRF

It has been reported (IWPC, 1981) that a direct relationship exists between the CST and the SRF, provided the CST results are adjusted for the solids concentration in the sludge. The results reported here confirm this. The usefulness of the correlation lies in the fact that the CST and solids concentration in a sludge can be measured relatively quickly while the SRF is a time consuming test. Converting all results to SRF has the advantage that the filterability of different sludges can be directly compared regardless of solids concentrations.

FIGURE B.1

DEWATERING OF HEAT TREATED AND UNTREATED SLUDGES BY VACUUM FILTRATION

SPECIFIC RESISTANCE TO FILTRATION v VACUUM FILTER OUTPUT
(lines of best fit)



FIGURE

DEWATERING OF HEAT TREATED SLUDGE BY VACUUM FILTRATION.

CST (10) v VACUUM FILTER OUTPUT.

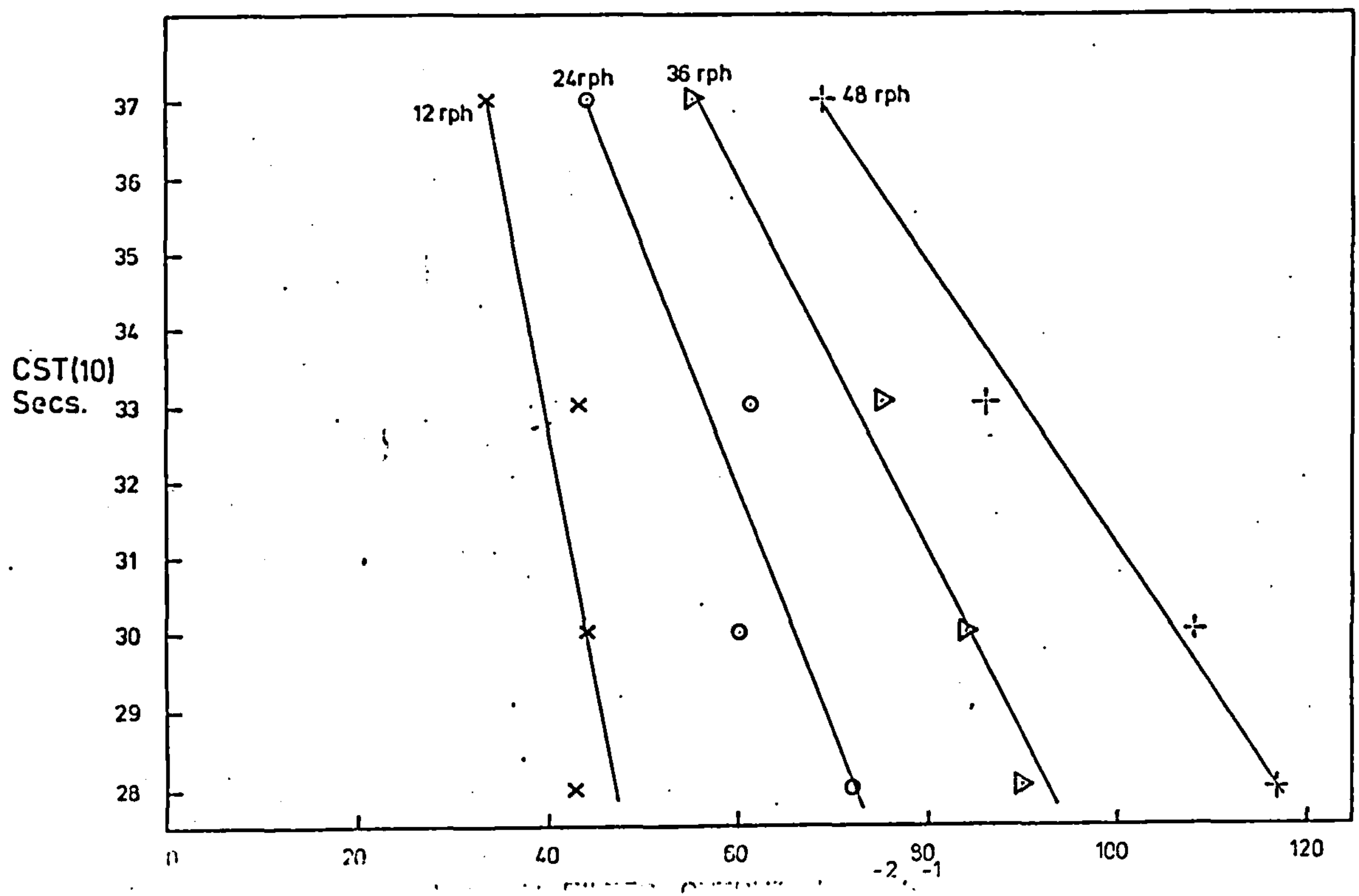
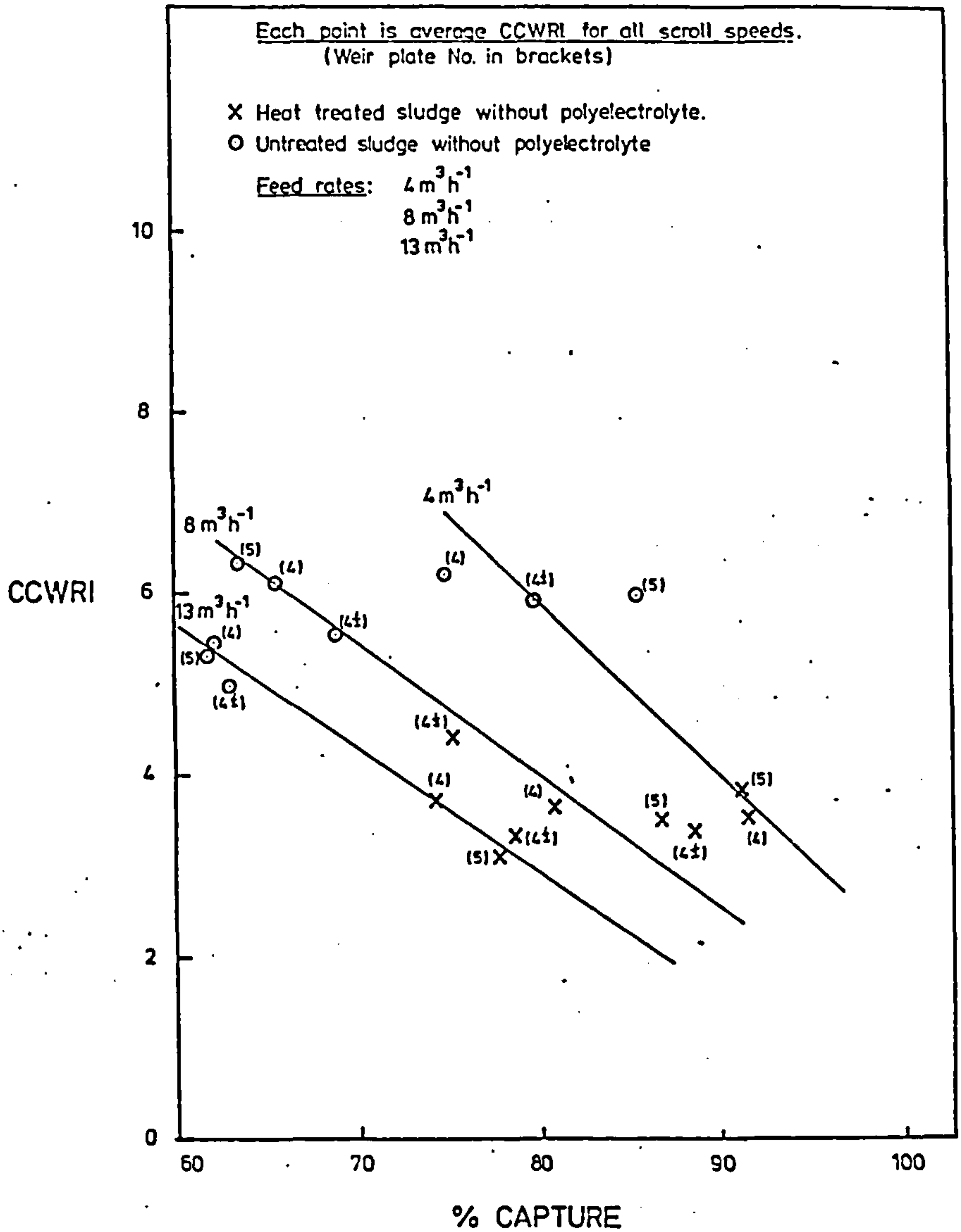


FIGURE B3.

COUNTERCURRENT FLOW CENTRIFUGE.

% CAPTURE v CCWRI.



CONCURRENT FLOW CENTRIFUGE

% CAPTURE v C.C.W.R.I.

Each point is average C.C.W.R.I. for all scroll speeds.

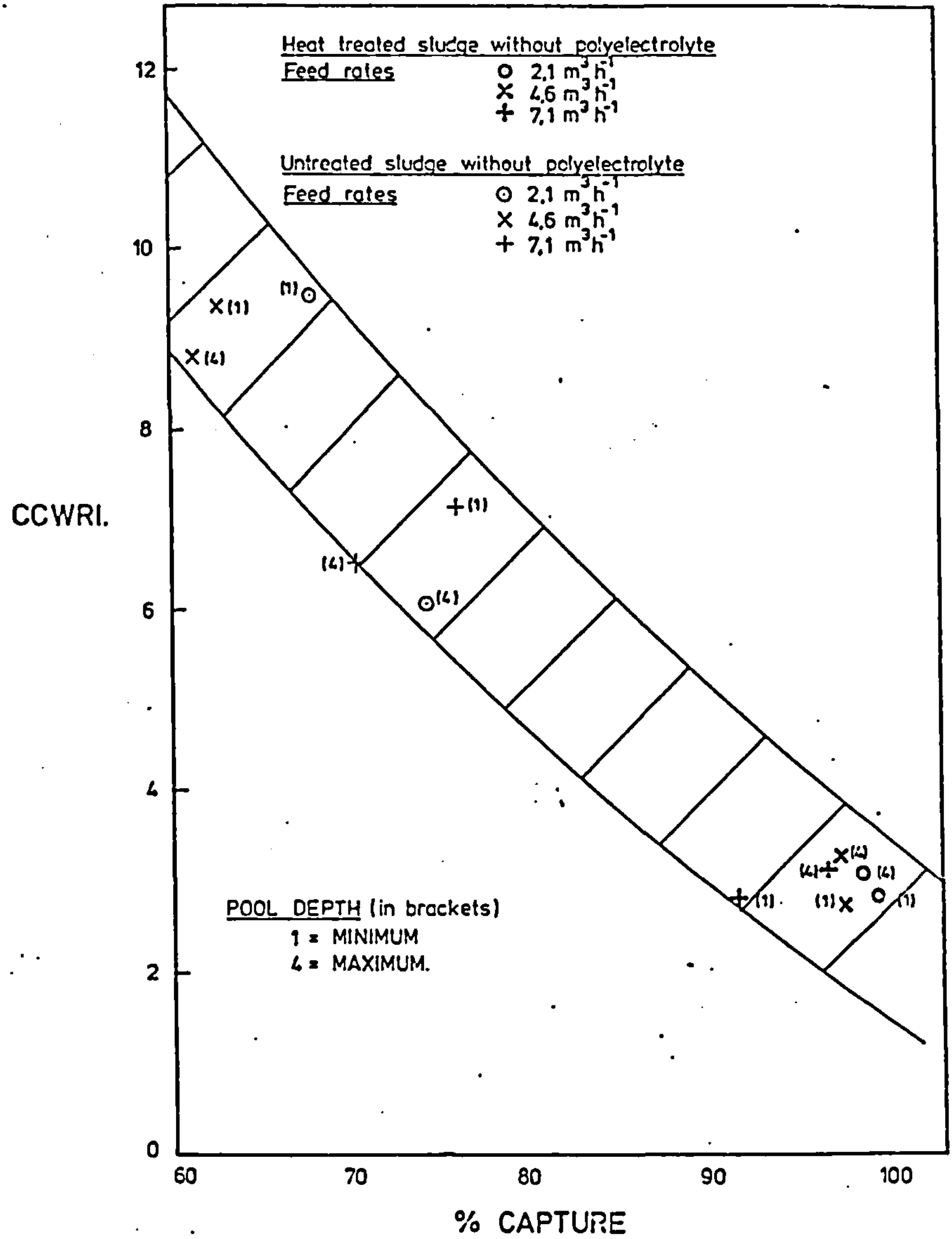


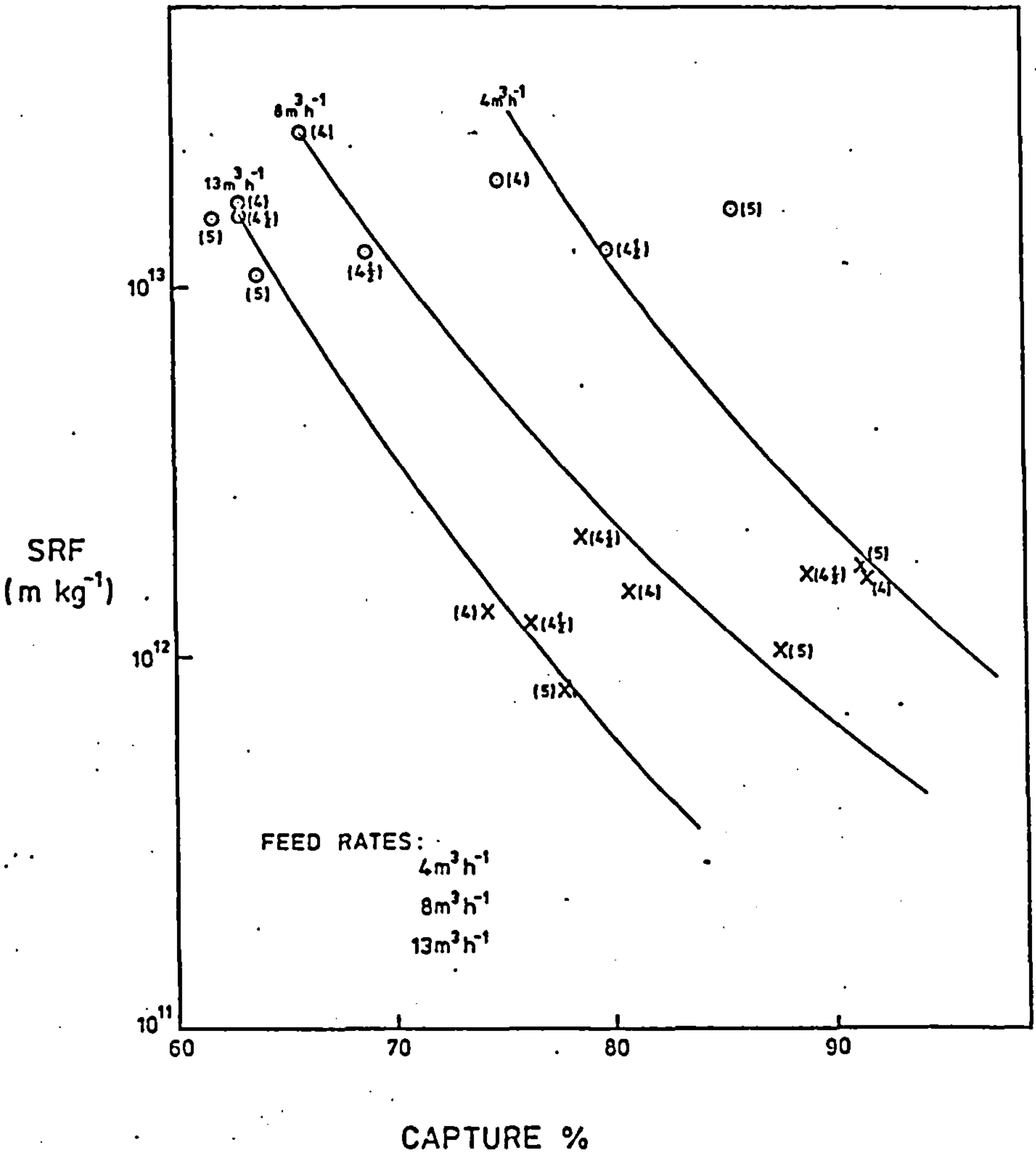
FIGURE B.5

COUNTERCURRENT FLOW CENTRIFUGE

% CAPTURE v SPECIFIC RESISTANCE TO FILTRATION (SRF)

Each point is average SRF for all scroll speeds
(Weir plate No. in brackets)

X Heat–Treated Sludge without polyelectrolyte
⊙ Untreated Sludge without polyelectrolyte



PART II

THE TREATMENT OF WASTE LIQUORS FROM THE ZIMPRO HEAT-TREATMENT OF SEWAGE SLUDGES

1 GENERAL INTRODUCTION

The treatment of waste liquors from a Zimpro wet-air oxidation plant, or heat-treatment plant as it is referred to in this report, has nothing to do with the dewatering capabilities of the equipment dealt with in the earlier sections. Nevertheless the disposal of filtrates or centrates from sludge dewatering is an integral part of the total sludge treatment process and if these wastes are very highly polluted or are only partially biodegradable they may present unusual technical or economic difficulties in the operation of a sewage treatment works. For these reasons it was decided to investigate the biodegradability of heat-treatment waste liquors as an adjunct to the project on the dewaterability of heat-treated sludge.

Originally it was envisaged that the investigation would be concerned only with aerobic treatment because, at the Fishwater Flats sewage works, the waste liquors are returned to the head of the works and mixed with the incoming raw sewage (in the industrial stream) for treatment. Later, however, it became apparent that anaerobic digestion of this type of waste has much to recommend it, particularly because it can be operated without the production of any waste solids (which is not always the case with aerobic digestion) and because the methane gas produced can contribute to the fuelling of the heat-treatment plant itself. No pilot-plant work was done on anaerobic digestion but a section is included which summarises some of the research done by the authors and other investigators and reports on the results obtained with a full scale plant operating in Germany.

At the request of the Steering Committee a cost estimate of the Zimpro heat-treatment process has been attempted and is included as Appendix A to this part of the report. The Zimpro process is known to be capital and energy intensive and highly mechanised and, while the excellent dewatering capabilities of the heat-treated sludge are not in doubt (see Part I), an estimate of the cost of the process would be helpful to those considering the use of this system for the first time, in the same way that the potential biodegradability of the waste liquors is of interest.

2 AEROBIC AND ANAEROBIC TREATMENT

2.1 INTRODUCTION

At the Fishwater Flats Works in Port Elizabeth heat-treatment waste liquors are derived from: (a) the overflow (or decant) from the sludge consolidation (thickener) tanks, situated between the heat-treatment plant and the dewatering equipment and (b) the dewatering equipment itself, in this case counter-current flow centrifuges. The volume of waste liquors from these two sources is approximately 0,6 Mℓ from a total of 25 t of sludge dry solids fed into the heat-treatment plant daily. It has the following average composition:

Chemical oxygen demand	-	14 000 mg/ℓ
Permanganate value	-	1 300 "
Ammoniacal nitrogen (as N)	-	340 "
Total dissolved solids	-	9 400 "

Its suspended solids level can fluctuate widely depending on the performance of the treated sludge consolidation tanks and the dewatering equipment. At present the level is in the region of 1500 mg/ℓ.

The disposal of such a heavily polluted waste is a matter of considerable significance in the operation of the works as a whole. Assuming a COD of 800 mg/ℓ for domestic sewage, the 0,6 Mℓ/day produced from the heat-treatment plant is equivalent to about 10,5 Mℓ of normal sewage, or about 20 percent of the average dry weather COD load to the works at the present time. The COD load is not the only significant factor; the biodegradability and dissolved solids are obviously of great importance in determining the quality of the final effluent and, in this connection, the colour of the liquors, which are believed to contain relatively high proportions of fulvic and humic acids, is of particular concern since these compounds are known to be intractable.

On the other hand when assessing the probable cost of disposing of these wastes it must be remembered that 30 per cent of the sludge solids produced on the works (primary and waste activated sludge) is solubilised in the heat-treatment process, significantly reducing the mass of sludge solids for dewatering and final disposal.

2.2 AEROBIC TREATMENT : ACTIVATED SLUDGE PILOT PLANT

2.2.1 Equipment layout and experimental procedures. At the time this work was begun a spare 20 Mℓ aeration tank was available at the works. It was decided to construct a pilot plant to assess the possibility of using the 20 Mℓ tank for the aeration of the 0,5 Mℓ of waste liquors which were at that time being produced. In other words, the pilot plant feed rate and tank capacity were designed to give a hydraulic retention time of 40 days in the hope that no excess waste activated sludge would be produced. The pilot plant consisted of the following equipment, illustrated in Figure 2.1:

(a) heat-treatment waste liquor holding tank, 200 ℓ capacity with air sparge mixer,
(b) aeration tank, 800 ℓ capacity, fed manually at the rate of 5 ℓ every 6 hours and aerated by means of a coarse bubble diffuser ring and
(c) settlement tank, a 137 ℓ circular galvanised steel tank with a conical hopper bottom having a 20° slope and with a pumped sludge return system from the bottom of the hopper to the head of the aeration tank.

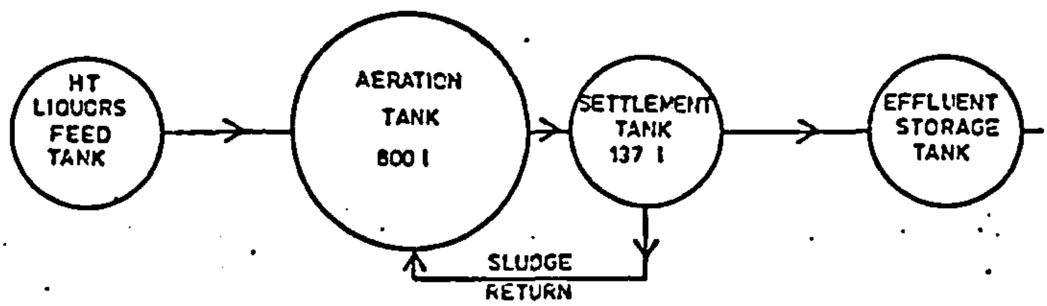


Figure 2.1 Activated sludge pilot plant

The aeration tank operating conditions were as follows:

Average MLSS	:	11500 mg/ℓ	(see Figure 2.2)
Average sludge loading	:	0,3 kg COD/kg MLSS.day	(see Figure 2.2)
Ratio aeration tank/ settlement tank capacity	:	6:1 (c.f. full scale 6,2:1)	
Sludge return rate	:	10:1 (equivalent to full scale operation)	
Waste activated sludge	:	Nil	

Start-up and acclimatization was carried out using a mixture of activated sludge and domestic raw sewage. The feed for the experiment was taken only from the heat-treatment consolidation tank overflow. Because of the long retention time and the very high level of mixed liquor suspended solids in the aeration tank difficulties were experienced in operating the secondary settlement tank, particularly with scum formation. Otherwise the plant ran well and results covering a period of 100 days were obtained.

2.2.2 Results. The COD and ammonia (N) values obtained for the feed and effluent are shown in Figures 2.3 and 2.4 and in the table below:

	Pilot Plant - Activated Sludge					
	Average Feed (mg/ℓ)		Average Effluent (mg/ℓ)		Average Reduction %	
	COD	NH_3-N	COD	NH_3-N	COD	NH_3-N
1st 50 days	14833	309	2345	104	84,2	66,3
2nd 50 days	12053	368	2038	98	83,1	73,3
100 days	13557	334	2205	102	83,7	69,5

The average effluent COD of 2200 mg/ℓ gives a biodegradability of 84 per cent under the conditions pertaining to this pilot plant. These conditions were set to determine the ultimate biodegradability, by means of activated sludge, and it is not suggested that such long retention times could be used in practice.

2.3 AEROBIC TREATMENT : LABORATORY STUDIES

To modify the pilot plant to enable it to treat mixtures of waste liquors in raw sewage would have presented some very difficult practical problems. It was decided, therefore, to pursue the investigation by means of laboratory techniques, published by DREWS (1981), for determining the biodegradability of industrial wastes. The first of these involves recirculating the waste over a packed column, on which a biological film has been established by prior acclimatization with the same waste, until soluble COD reaches a minimum. The second method is a batch activated sludge process involving aeration for a fixed period of time after acclimatization, and includes sludge recycle and excess sludge wastage. The two methods have the advantage that they enable the waste liquor to be tested either alone or in admixture with sewage.

Numerous runs were made with both techniques and the results are recorded in Tables 1.1 and 1.2.

The laboratory studies confirm those obtained with the activated sludge pilot plant. A reduction in COD of about 84-86 per cent can be achieved by the aerobic treatment of heat-treated liquors alone or in admixture with raw sewages. This degree of biodegradability is only slightly less than that obtained with industrial and domestic sewages on their own. However, even with a biodegradability as high as 84 per cent, considerable dilution of the effluent will be necessary to meet, for example, the General Standard; this is because of the very high initial COD of these wastes. If the situation at Fishwater Flats Works is typical, where an average dry weather sewage flow of 60 Mℓ per day yields about 0,6 Mℓ of waste liquors, the hundredfold dilution thus available should be sufficient.

2.4 AEROBIC TREATMENT : COLOUR REMOVAL

It was noticed during the pilot-plant and laboratory tests that the strong, brown colour, which is so characteristic of Zimpro heat-treatment waste liquors, was not entirely removed by aerobic treatment. An attempt was made to quantify the reduction in a series of runs using the laboratory batch activated sludge process, with the results given below. Colours on the raw sewage samples could not be determined because of turbidity.

COLOUR REMOVAL FROM HEAT-TREATMENT LIQUORS
DURING A 23-HR BATCH ACTIVATED SLUDGE TEST

Sample	Colour - Hazen Units	
	Feed	Effluent
HTL x 10 dilution with distilled water	400	250 - 300
HTL x 20 " " " "	250	200
HTL x 30 " " " "	200 - 225	125 - 150
HTL x 40 " " " "	150	100 - 125
Domestic sewage	-	70 - 85
Industrial sewage containing HTL	-	200 - 225

HTL : Heat treatment liquors

The results confirm that the colour in the waste liquors is not easily removed by aerobic treatment, probably because it arises from the presence of such biologically intractable and highly coloured compounds as fulvic and humic acids. However it seems that dilutions of up to one hundred fold should be available in the normal sewage treatment situation and these would be adequate to bring down the level of the colour of the final effluent to acceptable levels.

2.5 ANAEROBIC DIGESTION

In recent years considerable interest has arisen overseas in the anaerobic digestion of Zimpro heat-treatment waste liquors. In addition to the conventional contact process, as normally used in sewage sludge digestion, new processes are being developed that are especially suited to wastes with low solids levels. Typical of the new processes are the upward flow anaerobic sludge blanket (UASB) process and fixed-bed or fixed-film fluidised bed anaerobic reactors. In the conventional contact process start-up is very slow, because it takes time to build up an active bio-mass from a low-solids feed, and there is always a danger of excessive foaming or solids wash-out. With the newer systems hydraulic retention is dissociated from active bio-mass retention, without the need for sludge recycling in most cases. This overcomes most of the start-up problems and permits a great reduction in hydraulic retention time and hence in digester volume and heating requirement. Another advantage is that mechanical mixing is not required. All the systems mentioned, including the contact process, can be operated on heat-treatment waste liquors in such a way as to yield no excess waste solids in the treated effluent.

The table shows performance data, taken from various sources, of laboratory scale and full scale anaerobic digestion of heat treatment liquors. Only the data from report No. 2, for the Emscher Sewage Purification Works, Germany, are derived from a full scale conventional digestion plant. This plant had, at that time, been running successfully for 2 years and valuable operational and cost experience had been gained.

COD REDUCTION AND VOLUME OF GAS PRODUCED FROM THE ANAEROBIC TREATMENT OF HEAT TREATMENT LIQUORS (VARIOUS REPORTS)

Report from	Equipment	Loading kg COD/ m^3/day	Retn. (days)	% COD redn.	ℓ gas/kg COD removed
1. CSIR, Cape Town, (Ross, 1981)	Laboratory digester (23°C)	2	4	75	320
2. Emscher Plant, Germany (Schlegel and Kalbskopf, 1981)	Full scale (2 years operation) (35°C)	1,9	8	67	393
3. Environment Centre, Ontario, Canada. (Hall and Jovanovic, 1982)	Lab. digesters (35°C)				
	(a) Upflow filter	21	0,6	67	370
	(b) Downflow filter	20	0,6	58	350
	(c) UASB *	6	2	71	400
	(d) Fluidised bed	22	0,6	50	310
4. University of Wisconsin, USA. (Schwarz and Baere, 1981)	Lab Digester (filter & UASB *)	20	3	60	300-500
5. City Engineer's Laboratory, Port Elizabeth	Lab. digester (batch) (38°C)	1,6	7	68	460

(N.B. Theoretical yield 540 ℓ gas/kg COD removed)

None of the above methods give rise to any solid residues for disposal

* UASB = Upflow anaerobic sludge blanket

The high-rate methods mentioned in reports 3(a), (b) and (d) and 4, involving anaerobic filters and fluidised beds have not been developed beyond the laboratory or pilot-plant scale. They claim loading rates ten times greater than the conventional digestion process and hence would require reactors one-tenth of the size. The method in report 3(c), the upflow anaerobic sludge blanket (UASB) process, is used on a commercial scale for the purification of trade wastes in Europe and America. Pilot plants have also been developed in South Africa, by the CSIR, for trade wastes (ROSS, 1980). The process has not yet been applied full-scale to the treatment of heat-treatment liquors and there appear to be some problems in its operation, even for readily biodegradable trade wastes. Nevertheless the method has potential and because relatively high loading rates are possible, the capital expenditure on the digester could be as little as one-third that of the lower-loaded conventional method. Reports 1 and 5 listed in the table are of interest as they refer to waste liquors from two operating Zimpro plants in South Africa at Milnerton, near Capetown, and at Port Elizabeth. Although only on a laboratory scale, the results confirm those obtained at the Emscher Works for retention time and percent COD removal (the differences in retention time for roughly equal loading rates are due to the difference in the strength of the liquors at the three works). It is particularly interesting to note that the test on the Milnerton liquors was carried out at 23.°C.

The results quoted show that Zimpro heat-treatment liquors are biodegradable to a level of about 70 percent of their original COD by means of anaerobic digestion at very low retention times compared with conventional sludge digestion. The COD reduction is less than that achieved by aerobic digestion but, nevertheless, the process could prove to be the cheaper one because of the high capital cost of aeration plant and because the methane generated in the anaerobic process can be used to reduce conventional fuel consumption in the heat-treatment plant. For example at the Emscher Works (Bottrop Central Sludge Treatment Plant), it is claimed that 2000-3000 m^3/d of heat treatment liquors (COD 15000 mg/ℓ) are anaerobically digested in 3 x 6000 m^3 digesters to produce 9000 m^3/d of gas, and a COD reduction of 70 per cent, at a capital and running cost equivalent to about 6 c./kg COD removed (1981 prices), without any credit for gas utilization. Once the plant has been modified to make full use of the gas, it is expected that the full capital and running costs of the digestion will be recovered. The capital and running costs of aeration were estimated at 9,2 c/kg removed for the Fishwater Flats Works in 1981.

3 SUMMARY AND CONCLUSIONS (PART II)

The aerobic treatment and biodegradability of waste liquors from a Zimpro plant, treating a mixture of primary and waste activated sludges, were investigated in pilot-plant and laboratory studies at the Fishwater Flats

Water Reclamation Works in Port Elizabeth. In the case of anaerobic digestion, information was obtained from overseas and a limited amount of laboratory testing undertaken. The following conclusions may be drawn:

(i) The waste liquors represent a considerable additional load on the sewage works. They have an average COD of 14 000 mg/ℓ, an average dissolved solids content of 9400 mg/ℓ and a strong, persistent colour. About 0,6 Mℓ per day are generated from an incoming sewage average dry weather flow of 60 Mℓ per day.

(ii) The liquors are highly polluted because approximately 30 per cent of the sludge solids entering the heat-treatment plant are solubilised in the process. This represents a significant saving in the cost of solids dewatering and disposal.

(iii) The COD can be reduced by 84 per cent by means of conventional activated sludge aerobic treatment, either of the liquors alone or in admixture with sewage. In practice the latter method would be preferred.

(iv) The quantity of liquors generated is such that a one hundredfold dilution is available in the works final effluents. At this dilution, the residual COD, the dissolved salts and the colour can be reduced to acceptable levels.

(v) Anaerobic digestion offers a more economic and equally effective means of treating these liquors. Successful experience has been gained overseas using a conventional, contact digestion process. By utilizing the methane as a fuel for the heat treatment process, full recovery of digestion costs (capital and running) can be realised. Treatment of the waste liquors need not, therefore, contribute significantly to sludge treatment costs.

(vi) High rate digestion, by means of fixed film or fluidised bed reactors, has been successfully researched and if the process proves viable at full-scale it offers even more advantages to the anaerobic digestion disposal route.

(vii) The actual 1983 running and capital costs for the Zimpro heat-treatment plant in Port Elizabeth (see Appendix A) were R32,8 and R13,5 respectively per ton dry solids. When comparing these cost figures with another system of sludge treatment that does not include the Zimpro process, credit must be given for the 30% reduction in the quantity of sludge solids requiring dewatering and disposal.

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PILOT PLANT AEROBIC DIGESTION OF HEAT-TREATMENT WASTE LIQUORS.

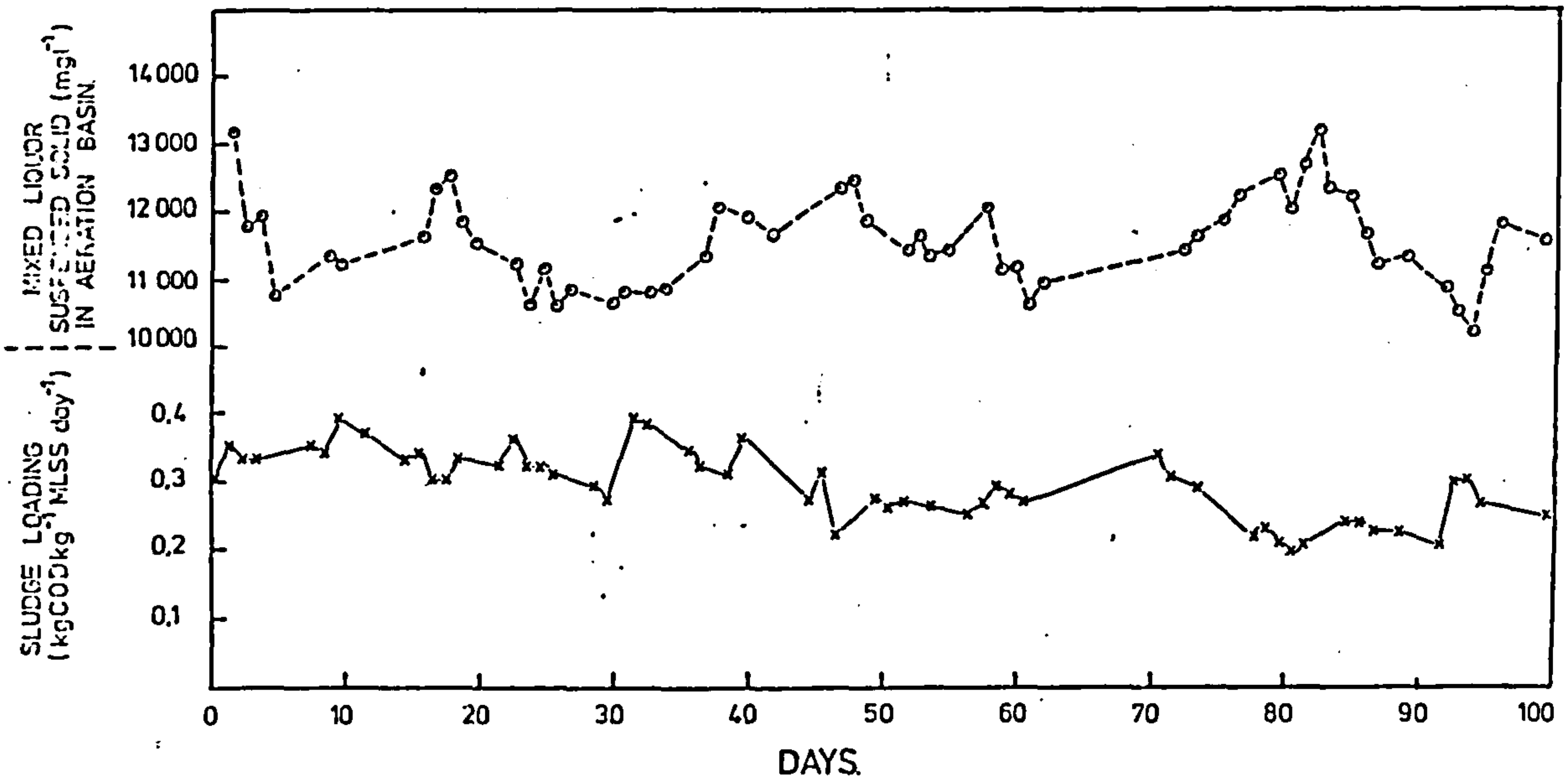

FIGURE 2,2

PILOT PLANT AEROBIC DIGESTION OF HEAT-TREATMENT WASTE LIQUORS

COD OF FEED AND EFFLUENT

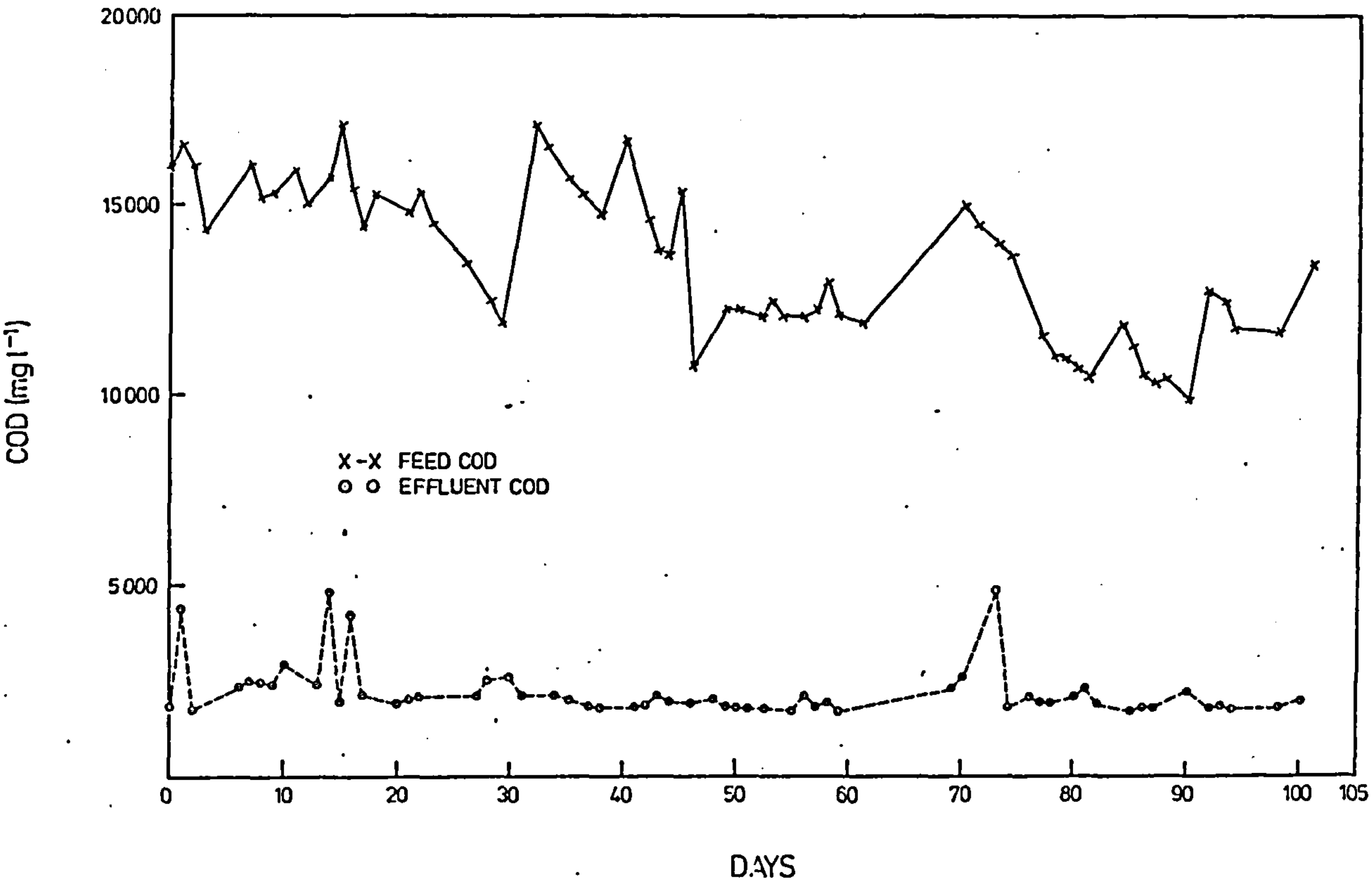

FIGURE 2.3

PILOT PLANT AEROBIC DIGESTION OF HEAT-TREATMENT WASTE LIQUORS.

AMMONIACAL NITROGEN OF FEED AND EFFLUENT.

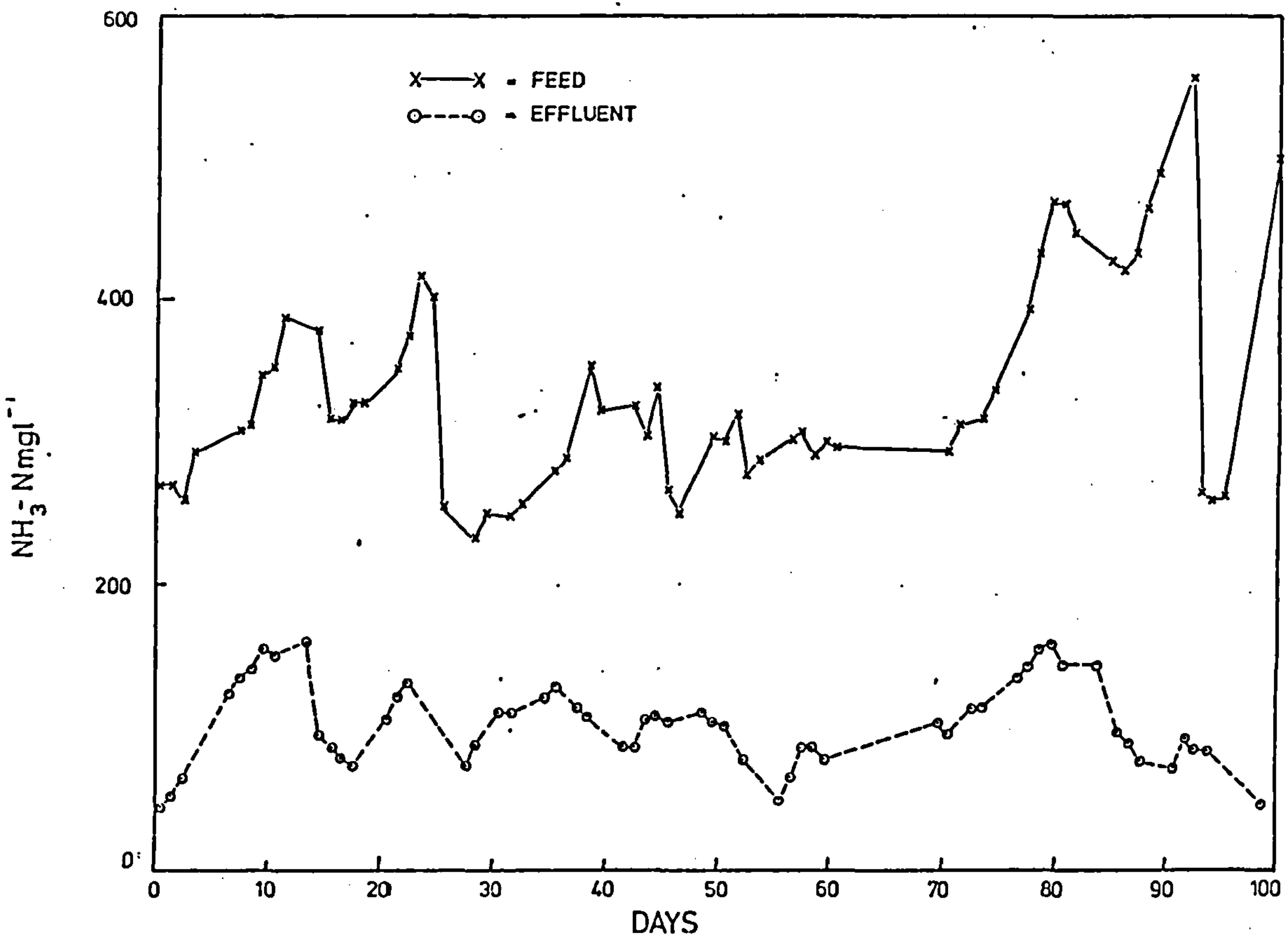

FIGURE 2,4

TABLE 1.1

BIODEGRADABILITY OF HEAT TREATMENT WASTE LIQUORS LABORATORY PACKED COLUMN METHOD

Sample	DILUTION Diluent	DILUTION No. of Dilutions	Feed Filtered COD mg/ℓ	Effluent Minimum Filt. COD mg/ℓ	Hours to Min. COD	Biodegradability %
HTL	NIL	NIL	11710	1814	168	84,5
HTL	NIL	NIL	8083	1285	163	84,1
HTL+IS	IS	5	2318	279	168	88,0
HTL+IS	IS	2	4678	685	95	85,4
HTL+DS+IS	IS+DS	5	1974	232	140	88,2
IS	NIL	NIL	727	59	164	91,9
IS	NIL	NIL	538	97	92	82,0
DS	NIL	NIL	505	45	162	91,9
DS	NIL	NIL	730	65	67	91,9
HTL+DW	DW	10	1287	136	94	89,4
HTL+DW	DW	20	730	111	92	84,8
HTL+DW	DW	25	566	80	141	85,9
HTL+DW	DW	30	498	86	92	82,7
HTL+DW	DW	40	418	44	112	89,4

HTL - heat treatment waste liquor
IS - raw industrial sewage
DS - raw domestic sewage
DW - distilled water

TABLE 1.2

BIODEGRADABILITY OF HEAT TREATMENT WASTE LIQUORS LABORATORY BATCH ACTIVATED SLUDGE METHOD

Sample	DILUTION		Feed Filtered COD mg/ℓ	Effluent Filtered COD mg/ℓ	Aeration Time, h.	Biodegradability %
	Diluent	No. of Dilutions				
HTL+IS	IS	5	2385	370	23	84,9
HTL+IS	IS	20	1134	169	23	85,1
HTL+IS	IS	40	733	114	23	84,4
IS	NIL	NIL	867	118	23	86,4
HTL+DS	DS	20	1142	102	23	91,1
HTL+DS	DS	20	1124	110	72	90,2
DS	NIL	NIL	469	54	23	88,5
HTL+DW	DW	10	1395	283	23	79,7
HTL+DW	DW	20	500	85	23	83,0
HTL+DW	DW	30	350	68	23	80,6
HTL+DW	DW	40	305	59	23	80,7

HTL - heat treatment waste liquor
IS - raw industrial sewage
DS - raw domestic sewage
DW - distilled water

APPENDIX A

AN EVALUATION OF THE COST OF THE ZIMPRO HEAT-TREATMENT PROCESS

1.0 INTRODUCTION

In order to arrive at a realistic cost for treating sludge by the Zimpro thermal conditioning process, actual operational data obtained from the Fishwater Flats plant during the 12 months of 1983 have been used.

Each operational parameter which contributes to the cost of treatment has been expressed in terms of units per metric ton of dry solids treated.

Costs are derived from actual prices paid in Port Elizabeth during 1983.

The Port Elizabeth Zimpro plant has a design capacity of 58 t of dry solids per day. Although the plant includes 50% standby of items such as compressors and high-pressure pumps, which reduces shut-down periods to a minimum, a 10% allowance has been made for plant shut-down. In view of the high proportion of standby equipment, this 10% allowance is a generous figure.

Total capacity of the plant = 58 x 365 t dry solids per annum.
Less 10% allowance for plant shut-down.
Therefore, total capacity = 19 053 t dry solids per annum.

The following evaluations are based on a plant treating this amount of sludge.

2.0 OPERATIONAL COSTS

2.1 OPERATIONAL STAFFING

Operating on a 24-hour per day basis, the plant requires one Senior Operator and one Plant Attendant per shift. This requires the provision of five of each of these categories of employee, working on a rotating shift system.

Working hours per annum = 2349
Total Senior Operator hours per annum = 2349 x 5 = 11745.

In addition the total overtime hours worked by the Senior Operators = 2625 hours per annum.

Therefore total Senior Operator hours per annum = 14370.

Total Plant Attendant hours per annum = 2349 x 5 = 11745
Total overtime hours worked by Plant Attendants = 1850

Therefore total Plant Attendant hours per annum = 13595.

Senior operating staffing = 0,754 hours per ton dry solids

Plant Attendant staffing = 0,713 hours per ton dry solids

2.2 MAINTENANCE STAFFING

The plant requires one qualified artisan, together with an assistant, working on day shift only.

Total maintenance staffing = 2 x 2349 hours per annum
= 4698 hours per annum
= 0,246 hours per ton dry solids

2.3 STEAM PRODUCTION

At the Fishwater Flats plant, steam used in the Zimpro process is available from two sources:-

(a) Supplied under contract by a neighbouring private industrial concern.
(b) Produced on site using heavy furnace oil (HFO) as a fuel.

Most of the steam is taken from the local industry, (a) above, with option (b) used only when this supply is not available. Allowance is normally made for the use of steam produced on site for thirty days per annum only.

Steam required for process = 1215 kg per ton dry solids

Calorific value of steam = 2,8 MJ/kg

Therefore energy requirement = 3402 MJ per ton dry solids

For 335 days per annum this energy is supplied using steam from the local industry and for the remaining 30 days per annum from the use of HFO which has a calorific value of 38,2 MJ/ℓ.

HFO required for steam production = 89 ℓ per ton dry solids

(Both the steam and HFO requirement have been included in the calculation of the cost per unit of energy - see table).

2.4 ELECTRICITY

Electricity consumption by the process = 186 units per ton dry solids

2.5 NITRIC ACID

It is necessary to wash the system regularly with nitric acid to remove any scale which may have formed. Acid washing is normally carried out at intervals of approximately 1200 running hours.

Total stream running hours = 15768 per annum (365 less 10% = 328,5 days/annum/stream)

Therefore a total of 13 washes per annum at an acid requirement of 1110 kg of 93% nitric acid per wash.

Therefore acid required = 0,76 kg per ton dry solids

2.6 WATER

Water is required for washing of heat exchangers and reactors as necessary, for cooling compressors, pumps and macerators and for on-site steam generation. Actual volumes have not been measured but estimated consumption of water is equivalent to 3,5 kℓ per ton dry solids.

2.7 SUMMARY OF OPERATIONAL COSTS

Item	Units per t DS	Cost per unit R	Cost per t DS R
Operator staffing	0,754 hours	4,79	3,61
Attendant staffing	0,713 hours	2,08	1,48
Maintenance staffing	0,246 hours	8,50	2,09
Steam	3402 MJ	0,00473	16,09
Electricity	186 units	0,0421	7,83
Acid	0,76 kg	1,20	0,91
Water	3,5 kℓ	0,09225*	0,32
TOTAL	-	-	32,33

* reclaimed water

From the table above it can be seen that the total operational cost based on 1983 prices in Port Elizabeth amounted to R32,33 per ton of dry solids.

The cost of spares has not been included as it is not available; however a figure of R0,5 per ton of dry solids would be a reasonable estimate.

Therefore total operational cost of conditioning sludge by the Zimpro process = R32,8 per ton dry solids

3.0 CAPITAL COSTS

The capital cost will obviously depend on such factors as the size of the plant, the materials used in its manufacture, the amount of standby equipment included and the degree of instrumentation and automation built into the control system. The interest paid on a capital loan will also depend on the cost of borrowing money at any time.

The following figures, therefore, which apply to the Port Elizabeth plant can only be taken as an illustration.

Total cost of plant: R1,5 million (1976)
Interest and redemption at 17,1% per annum = R256 500 p.a.

Therefore, capital costs = R13,46 per ton dry solids

4.0 OTHER FACTORS AFFECTING COSTS

Comparing the cost of any sludge treatment and disposal system that includes Zimpro heat-treatment with one that does not, there are two important considerations to be taken into account in addition to the costs outlined in the previous paragraphs. The first of these is the 30% solubilisation of solids that takes place during the heat-treatment process. In the example given in this section, in which the total sludge processed is taken as 19053 tDS per annum, the amount of sludge requiring dewatering and disposal would be 5716 t per annum less in a system using heat treatment than in a system not using heat-treatment. This represents a significant reduction in the comparative cost of the Zimpro process.

The second factor is the treatment of the highly-polluted waste liquors. As the trend is now towards anaerobic digestion, in which the methane produced is used as fuel in the heat-treatment process and the digestion costs are fully recovered (see previous sections of Part II), it seems unlikely that the treatment of the waste liquors will add significantly to the total cost of sludge processing.