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TECHNICAL NOTE No. 4.

Dewatering Sewage Sludge by Centrifuge

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DEWATERING SEWAGE SLUDGE BY CENTRIFUGE

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DEWATERING SEWAGE BY CENTRIFUGE

1. INTRODUCTION

The sewage sludge from about a quarter of the population of this country is discharged to sea, and most of the remainder is still being disposed of on land, either as wet sludge or after dewatering on drying beds.

The drying of sludge on beds has always had a number of undesirable features, particularly its dependance on weather conditions, but until recent years it has provided a simple and economic means of dewatering.

Today there is an increasing trend away from drying beds, towards mechanical means of dewatering sludge for both new works and for replacing drying beds at existing works. Some of the factors contributing towards this trend are:-

a. The shortage of land and its steeply rising cost.

b. The difficulty of obtaining labour for lifting dried sludge and its cost.

c. The high capital cost of mechanical harvesting equipment.

d. The rising construction cost of properly designed drying beds.

e. The uneconomically low loadings on drying beds enforced by the increasing proportions of secondary sludge and trade wastes.

f. Intolerance of odour and fly nuisances as housing development progresses closer to drying bed areas, particularly those drying undigested sludge.

The mechanical methods commonly employed use either pressure or vacuum filtration following some form of sludge conditioning.

Centrifuging achieves water-solid separation by settlement and consolidation of solids under the influence of strong centrifugal forces generated in high speed rotating machines. The success of polyelectrolytes in flocculating sludge for this progress is largely responsible for a revival of interest in centrifuging which is now becoming accepted as an efficient and competitive means of producing a sludge cake with 20-25% solids.

2. EARLY CENTRIFUGE EXPERIENCE

Although the principle of centrifugal separation was known to early civilisations it was not until 1879 that Dr De Laval developed the first continuous centrifugal separator.

The first centrifuges to be used for sludge dewatering are believed to be those operating at Hamburg, Frankfurt, Hanover and Cologne between 1905 and 1908. They were batch operation machines built by G Egestorff of Hanover to Schaefer ter Meer design. Although they produced up to 40% solid cakes without chemicals, the effluents, or centrates, carried up to 3.7% solid. The poor solid recovery, and high capital and running costs made them uncompetitive with filter presses.

Further attempts to centrifuge sludge were made in Germany, the USA and the UK during the last 20 years, but good quality centrates were not achieved consistently

Improved results were obtained in Sweden with two stage centrifuging, using one type of machine to remove most of the solids and another to capture the remaining fine suspended matter. Initially two stage throughput rates were too low to be practical, and now with larger machines it is generally more economical to use single stage dewatering with sludge conditioning.

Inorganic conditioners such as copperas, ferric chloride and aluminium chlorohydrate have been used with varying success, but with most sludges they are not as effective as polyelectrolytes in flocculating the fine suspended solids.

Polyelectrolytes are long chain high molecular weight water soluble organic compounds which have the property of forming large, though delicate flocs, which can bridge between and capture fine suspended solids.

The development of polyelectrolytes and improvements in centrifuge design have enabled the achievement of solid recoveries comparable with filter performances.

3. TYPES OF CENTRIFUGE

The essential component of all centrifuges is a rotating bowl in which the solids or heavier fractions in a liquid are separated by centrifugal settlement. There are many variations in arrangement and design detail, but centrifuges may be classified broadly into four main groups:-

a. Simple bowl

b. Perforated bowl

c. Bowl with conical disc separator

d. Bowl with scroll sludge conveyor

3.1 Simple bowl – see Fig No 1

These are usually operated on a batch cycle, at least, for the removal of the sludge cake.

The sludge is fed through a pipe entering the open end of the vertical rotating imperforate bowl, and the solids are collected and compacted at the bowl circumference under the influence of centrifugal force. The clarified water which separates towards the cylindrical liquid surface may be discharged over a weir or removed intermittently by a scoop pipe. When the solids have built up to a pre-determined depth, the feed to the machine is stopped, and the bowl speed usually allowed to run down before a knife blade is inserted to remove the sludge cake from the bowl.

The batch operation makes these machines less suitable for handling large volumes of sludge than the solid bowl scroll centrifuge. Their particular application is in thickening activated sludge which is not abrasive and allows long runs between cake knife maintenance. They have been used for this in the USA for several years.

A machine is now on trial at a sewage works in this country where it is handling consolidated activated sludge with 2.5% solids. It is thickening this to about 6.5% solids and producing a centrate with 0.2% solids without any chemical coagulant at a feed throughput of 6.8 m^3/h. A concentration of this order represents a worthwhile saving in volume when sludge is pumped to a digester or tankered away for disposal.

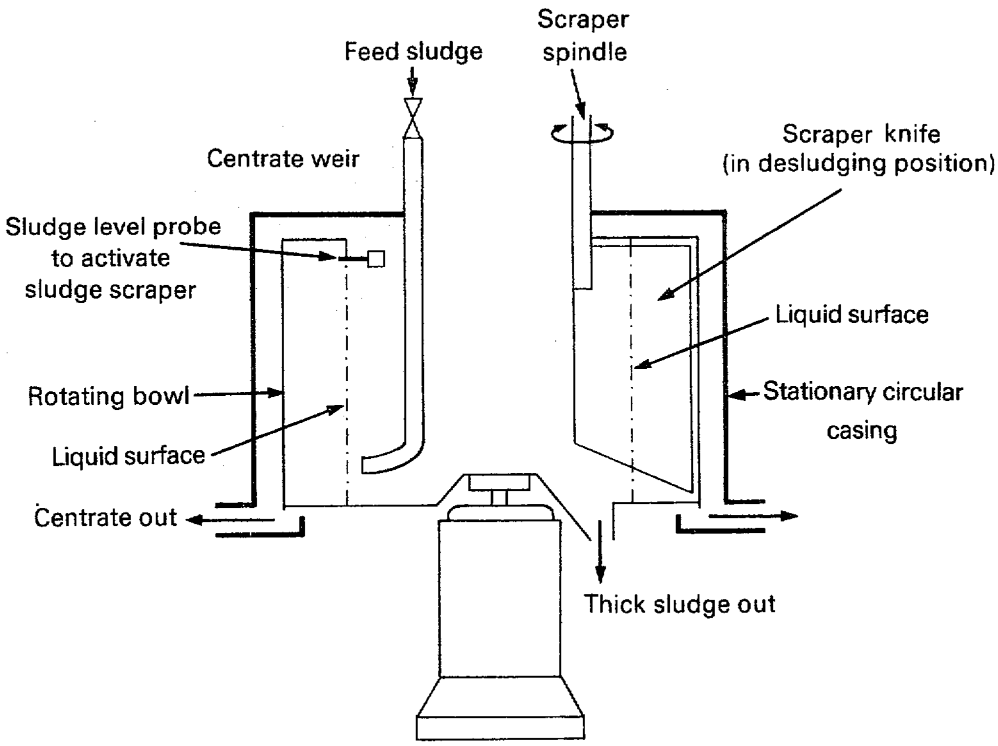


Fig. 1 Batch Bowl Centrifuge

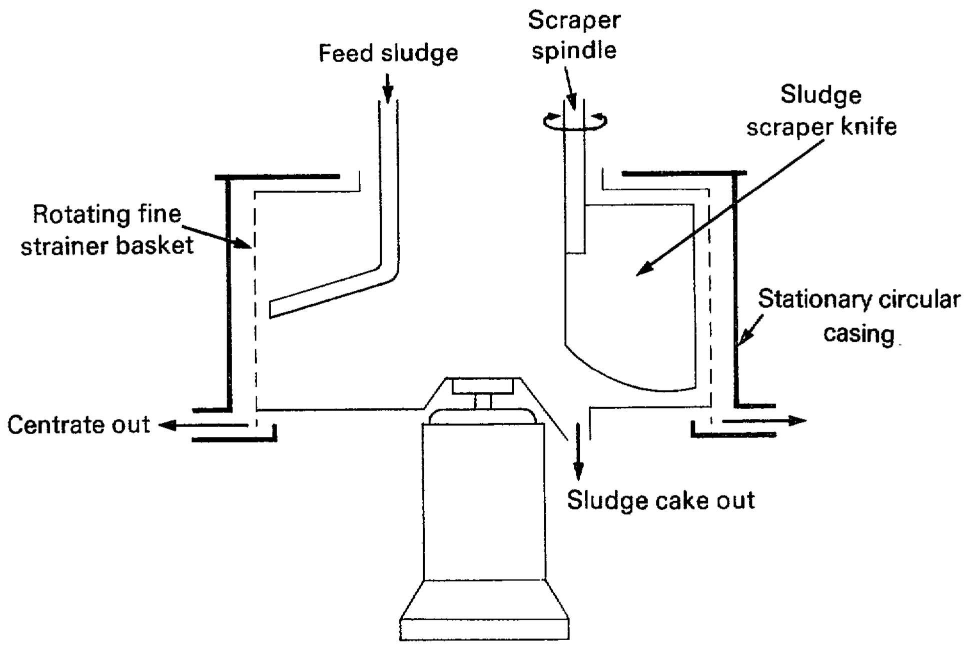


Fig. 2 Basket Centrifuge

The hydraulic motor on this model is powered by an electrically driven pump. This arrangement is particularly suited for driving by a single motor-pump, a battery of similar centrifuges operating on staggered time cycles, as the regular accelerating loads then amount to only a small fraction of the total driven load.

The present machine is noisy, but future refinements in design are expected to reduce this.

3.2 Perforated Bowl – see Fig No 2

These are industrial spin dryers. They comprise a fine mesh filter basket which rotates in a fixed outer casing. The sludge is fed to the inside of the basket and the water which is spun out through the basket mesh is collected in the outer casing from which it drains freely. The solids retained by the basket are removed periodically by a scraper. Operation is usually on automated batch cycling.

These machines were developed for the separation of crystals, and although widely used by the chemical and food industries, they are not suitable for handling soft insoluble solids which rapidly blind the screen pores, and cannot be used for dewatering or thickening sewage sludge.

3.3 Conical Disc Centrifuge – see Fig No 3

The sludge is fed through a central pipe into a rotating bowl in which the solids are thrown to the circumference and discharged from outlet ports. The partially clarified liquid passing radially inwards through a pack of conical shaped discs which rotates with the bowl, and flows through outlet ports or over a circular weir. The spaces between the discs function as efficient shallow settlement chambers, as do the channels in tilted plate or tube separators in sedimentation tanks.

Operation is usually continuous but in some designs the thickened sludge is discharged intermittently under time or depth control without reducing the machine speed.

These high speed machines are well suited to handling suspensions with low solid content say less than 2%. They have been used with success in Scandanavia as second stage units to clean the centrates from first stage machines. When operating as second stage units they will raise the overall suspended solid recovery to over 95% without the use of conditioning chemicals. They are not suitable for single stage sludge dewatering, because the high solid concentrations cause chokeages in the disc packs.

This type of centrifuge is also used in the USA for thickening activated sludge. Tests in this country have demonstrated that this may be thickened to over 5% solids without chemical coagulants. As with batch bowl centrifuges, solid recoveries depend on the characteristics of the activated sludge, and performances fall off with increase in feed Sludge Volume Index.

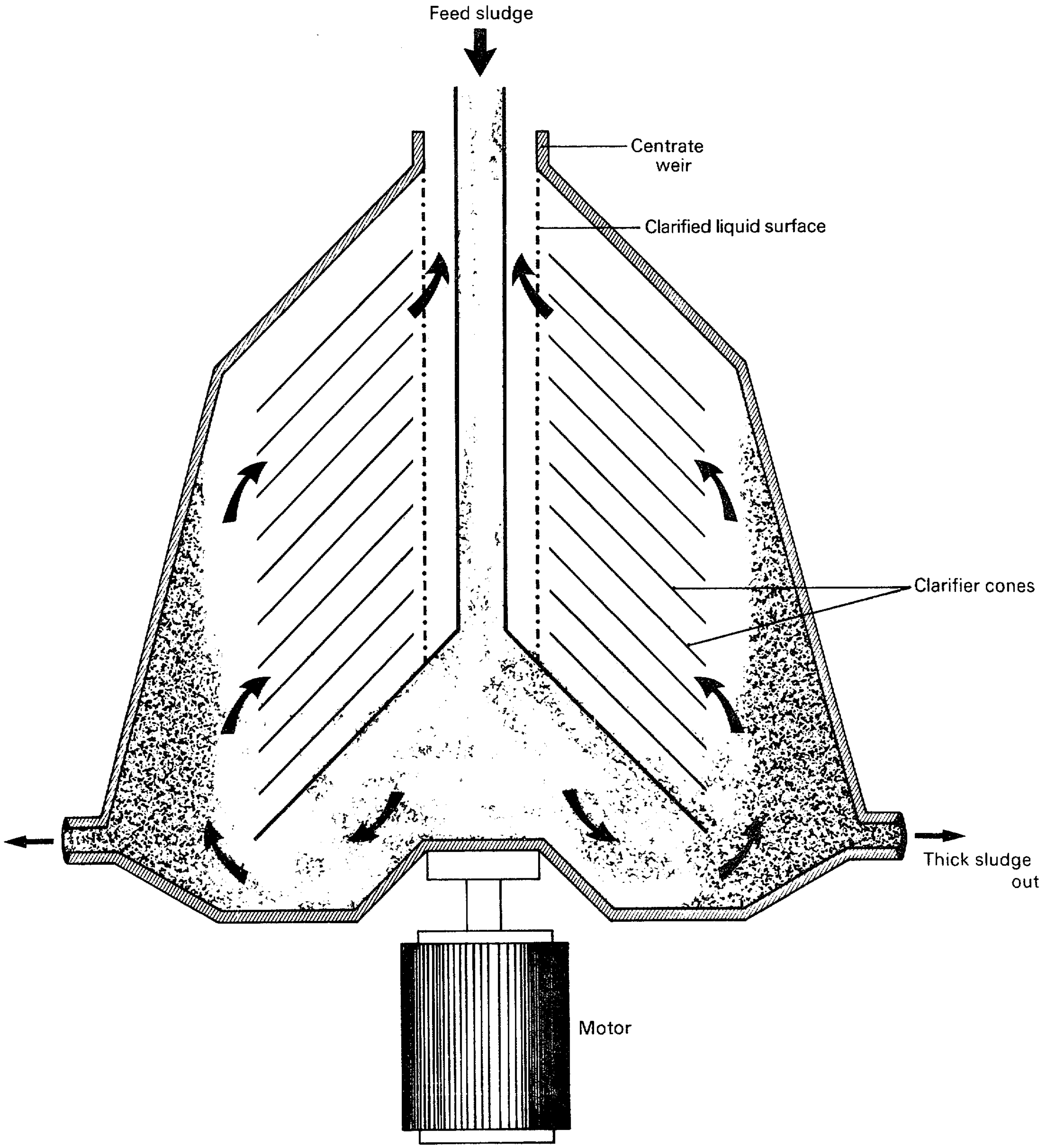


Fig. 3 Conical Disc Centrifuge

3.4 Bowl with Sludge Conveyor – see Fig No 4

Although this type of centrifuge has been employed in industrial applications for many years, it is only since polyelectrolytes have become available that it has been developed specifically for sewage sludge dewatering.

The essential components are a rotating bowl usually mounted horizontally between bearings at either end, a central sludge feed pipe passing through one of the bearings, and a drive motor at the other end which also drives (through a gearbox) a sludge scroll conveyor inside the bowl. There are a number of variations of type and position of gearbox and drive.

The gearbox is designed to provide a small speed differential between the bowl and screw conveyor, so that the solids settled at the bowl perimeter are screwed along the bowl surface towards outlet ports at its smaller end. The clarified liquid or centrate overflows through ports at the larger end of the bowl which maintain a set liquid pond depth.

Machines of this type will dewater sewage sludge in a continuous single stage process to about 75% moisture with a solids recovery between 95% and 98% according to the nature of the sludge and the polyelectrolyte dose rate.

This paper is concerned with the dewatering of sewage sludge rather than its thickening, on which little information is yet available. As the scroll conveyor bowl centrifuge has proved reliable and the most successful type for dewatering, a more detailed description of its construction and performance is given in the following sections.

4. CONSTRUCTION OF THE SCROLL CONVEYOR BOWL CENTRIFUGE

4.1 Materials

When centrifuges have to withstand heavy corrosion as for example in certain chemical industries, the bowls are supplied in stainless steel, either spun cast or fabricated from plate.

Although sewage sludges are not generally corrosive, some manufacturers may supply standard stainless steel bowl sections for all applications to save production costs. Others offer bowls in mild steel since it is cheaper and has good resistance to surface erosion.

The clearance between the bowl and scroll allows the formation of a hard protective skin of sludge material on the inside of the bowl, but the sludge cake discharge ports are subject to heavy erosion and should be protected by hard surfacing or inserts.

The bowl sections should be assembled with stainless or coated steel bolts to permit easy dismantling.

The scroll conveyors are usually fabricated by welding a series of semi circular mild steel flight sections to the scroll shaft or drum, and finally machined to bowl profile. The leading faces and outer edges are surfaced with stellite or nickel carbide compounds. Most manufacturers offer a guarantee on scroll life between resurfacings, varying from 4000 to 7000 hours according to their experience with the type of sludge to be handled.

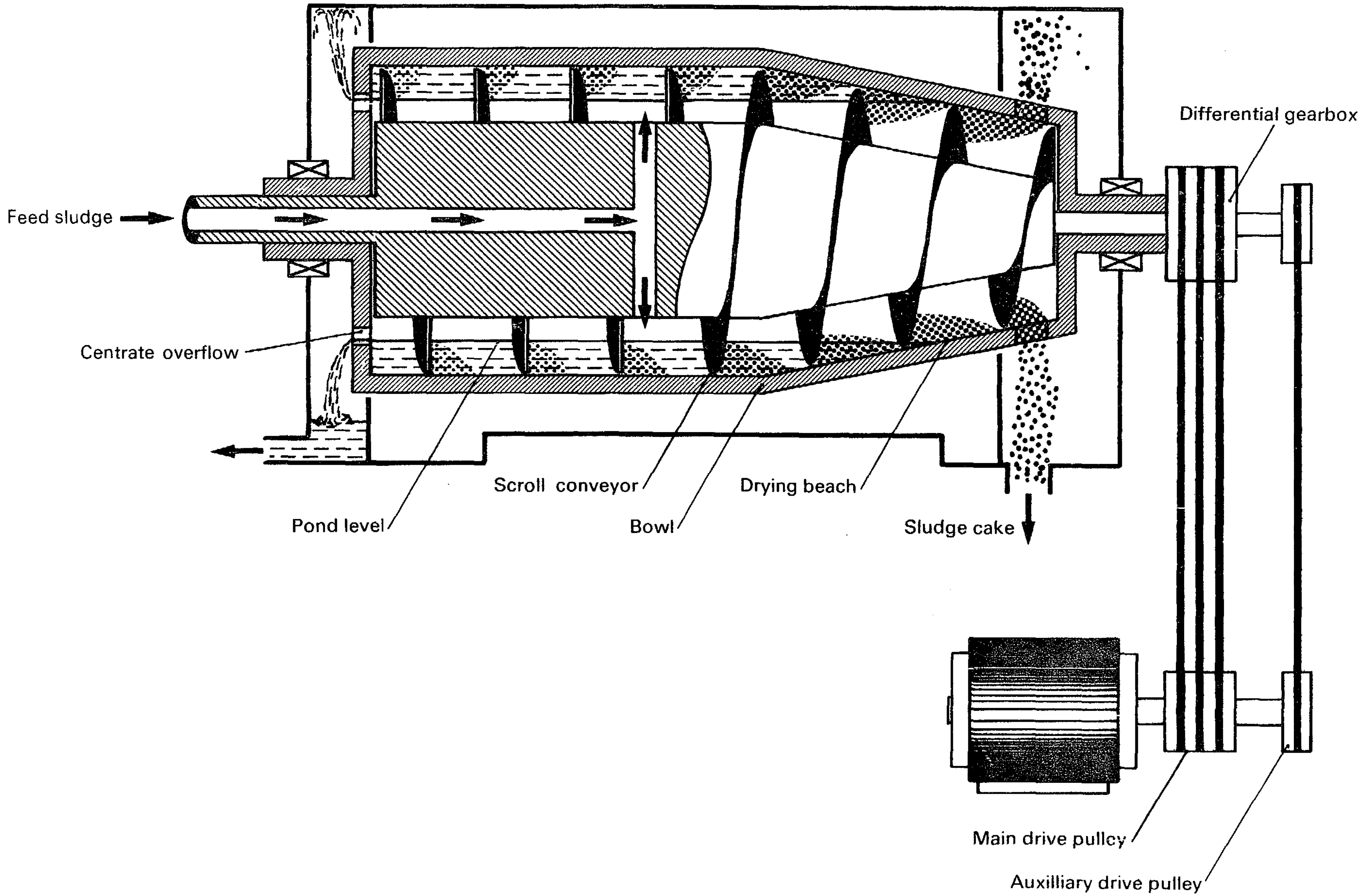


Fig. 4 Scroll Conveyor Bowl Centrifuge

4.2 Bowl Design

Bowls for sewage sludge centrifuges are usually cylindrical with a cone at one end, but there is one design which is shaped as one long cone and one short one placed base to base.

These bowls have a longer overall length to diameter ratio and a shallower cone angle than the original designs produced for industrial chemical applications. The length/diameter ratios are normally between 2 and 3 and the cone angles 5^0 to $7\frac{1}{2}^0$.

These proportions permit a dense sludge to be formed in the large diameter or cylindrical clarification section which can be conveyed up the cone slope without slipping back round the scroll or squeezing through the scroll tip clearance.

The cone angle is more critical than the length/diameter ratio which may be varied with the size of machine to maintain the best proportioning of cylindrical clarification and conical cake drainage sections. An increase in length increases the retention volume or liquid handling capacity, but not the sludge scrolling capacity. An increase in diameter increases both the retention volume and the sludge scrolling capacity.

As the sludge is screwed up the cone it emerges from the liquid, is drained and pushed up to discharge ports at the small end of the bowl. An over-dry cake may tend to rotate as a plug between the scroll flights, so some bowls have the cone surface roughened or rifled to reduce this possibility.

4.3 Pond Depth Adjustment

The depth of the cylindrical liquid pond created by the rotation of the bowl is controlled by the overflow of centrate from ports in the large end casing. To alter this it is necessary to stop the machine, open the light hinged outer casing and adjust the weir or eccentric cover plated bolted over the ports.

The centrate is collected in the outer casing and piped away to a convenient drain where the quality should be easily seen.

4.4 Sludge Feed

The feed sludge enters the cylindrical port of the bowl through a central pipe which may pass through either of the main end bearings. The point of discharge is selected to avoid disturbance of the sludge cake being conveyed up the cone and turbulence near the centrate overflow.

If unrestrained, the feed sludge falls radially outwards from the feed pipe to the pond surface creating turbulence which is detrimental to the formation of the weak sludge flocs. Some manufacturers fit vanes to accelerate the feed sludge in a circumferential direction. One incorporates a scroll conveyor in the large end of the bowl which gently accelerates and screws the feed sludge down an internal cone, formed in the large end of the main scroll hub, towards the clarification chamber. The sludge solids separated by this centrifuging stage are picked up by the main scroll conveyor and screwed along the bowl cone in the opposite direction towards the cake discharge ports.

Ram or other pulsating discharge pumps are not recommended for feeding centrifuges.

4.5 Conditioner Feed

Most centrifuges have connections which may feed the polyelectrolyte conditioner solution either into the sludge feed line before the machine, or at a point close to the sludge feed pipe discharge inside the bowl. The former position allows a longer mixing time, but the latter appears to be more suitable with most polyelectrolytes which form weak flocs, particularly the negatively charged anionic group.

Although the amount of polyelectrolyte normally used is well under half a per cent by weight, the volume of solution dosed may amount to 10% or 12% of the sludge volume handled.

4.6 Scroll Conveyor

The single start screw conveyor is shaped to the bowl contour and carried on a central shaft or drum. It rotates inside the bowl at a speed of 5 to 15 rpm faster or slower than the bowl according to the direction of the screw pitch. This differential speed causes the thickened sludge to be propelled along the bowl. The direction of travel is not, truly axial, because of the effects of pitch angle and friction of the scroll, and the slope of the conical section. The greater these effects, the greater is the degree of spiral travel.

Although a small pitch reduces the degree of spiral travel, it is usually kept to a minimum of about 100 mm (4") to prevent the bridging of the sludge cake between the flights.

The clearance between the bowl surface and screw tips is about 1 mm. As wear increases this clearance, the feed rate has to be reduced to maintain a reasonable concentration of suspended solids in the centrate.

4.7 Bowl and Scroll Drives

The rotational speed of sewage sludge dewatering centrifuges varies from 1200 to 2500 rpm: less than half that used in some chemical applications. The forces generated at greater speeds can cause the weak flocs formed by polyelectrolytes to break up, and slower speeds lead to wet cake. Some sludge centrifuges have been designed for higher speeds, which may be used when stronger floc forming polyelectrolytes are developed.

Some centrifuges have the bowl and scroll drive assembly at the small end of the bowl, others at the large end. The bowl is normally driven by V-belts from an electric motor, and the scroll conveyor by a central output shaft which passes through the bowl bearing from a differential gearbox built into or attached to the bowl pulley.

The differential speed, usually 5 to 15 rpm, is controlled by an auxiliary pulley on the gearbox driven by a separate belt from the main motor, and may be altered by changing the auxiliary drive pulley sizes. Some centrifuges have the refinement of on-load adjustment by controlling the auxiliary pulley from a separate low HP variable speed motor or eddy current brake.

British centrifuges are provided with planetary type differential gearboxes, but the manufacturers are considering the use of the epicyclic type on future models.

Continental manufacturers provide the epicyclic type. This has an ingenious but simple eccentric notching system connected to the auxiliary drive which permits the output shaft to the scroll conveyor to drop back or advance on the main drive by a small number of rpm. Since it has fewer working parts than the planetary gearbox which contains precision sun and planet gear trains, it is lighter, quieter in operation, quicker and cheaper to overhaul and its cost is less than half that of the planetary type.

The planetary gearbox is superior for transmitting large horsepowers, and the continental manufacturers still use this for scrolling high density chemical sludges.

Most centrifuge gearboxes incorporate shear pins to protect them against sudden overloads such as the jamming of a scroll conveyor.

To avoid excessive starting currents, small centrifuges are provided with star-delta starters and the larger units with hydraulic clutches. Some drive motors are provided with cut-out protection devices which operate if the starting current is not reduced within a pre-determined time limit.

4.8 Vibration and Noise

The bowls and scrolls are balanced individually both statically and dynamically, and although centrifuges in good order rotate very smoothly, they are mounted on springs or bonded rubber to steel feet to prevent vibration being transmitted to buildings or floors.

Light foundation blocks are adequate for supporting scroll conveyor centrifuges; massive concrete foundation slabs are not necessary.

The noise level in a centrifuge building is comparable with that in a large pump house. Building wall finish has a significant effect, and sound absorbent surfaces are preferable to glazed tiling.

Data from one manufacturer shows the following noise levels at 1 m horizontally from the centrifuge:

72 dBA at 200 Hz	
67 " " 1500 "	dBA = decibel measurement weighted
60 " " 4000 "	for frequency

Another manufacturer quotes an average of 80 dBA.

These noise levels are slightly below the general levels in industrial installations, London traffic noises vary from 60 to 85 dBA.

Although centrifuge installations may be weather proofed for outdoor operation, plants constructed close to residential areas should be enclosed to reduce noise nuisance.

4.9 Ancillary Equipment

All centrifuges should be protected by local sludge screens, preferably mechanically cleaned.

Centrifuge manufacturers can offer complete installation packages including polyelectrolyte mixing tanks, dosing and feed pumps, pipework, sludge cake conveyor, electrical control gear and panel and a set of essential spares. European manufacturers can provide all ancillaries of British manufacture.

5. DESIGN AND OPERATION FACTORS
(Relating to the Scroll Conveyor Bowl Centrifuge)

The performance of a centrifuge is analogous to that of a settlement tank in respect of a number of design and operation factors.

The percentage solids removal depends on:

1. The liquid retention period or feed rate
2. The surface area to depth relationship
3. The efficiency of the design
4. The feed solids concentration
5. The characteristics of the solids
6. The quantity of flocculent dosed

Operational variables can be altered to produce either a good solid recovery or a good cake; or a compromise. As solid recovery is improved, more of the lighter less drainable solids are captured and the cake moisture usually increases.

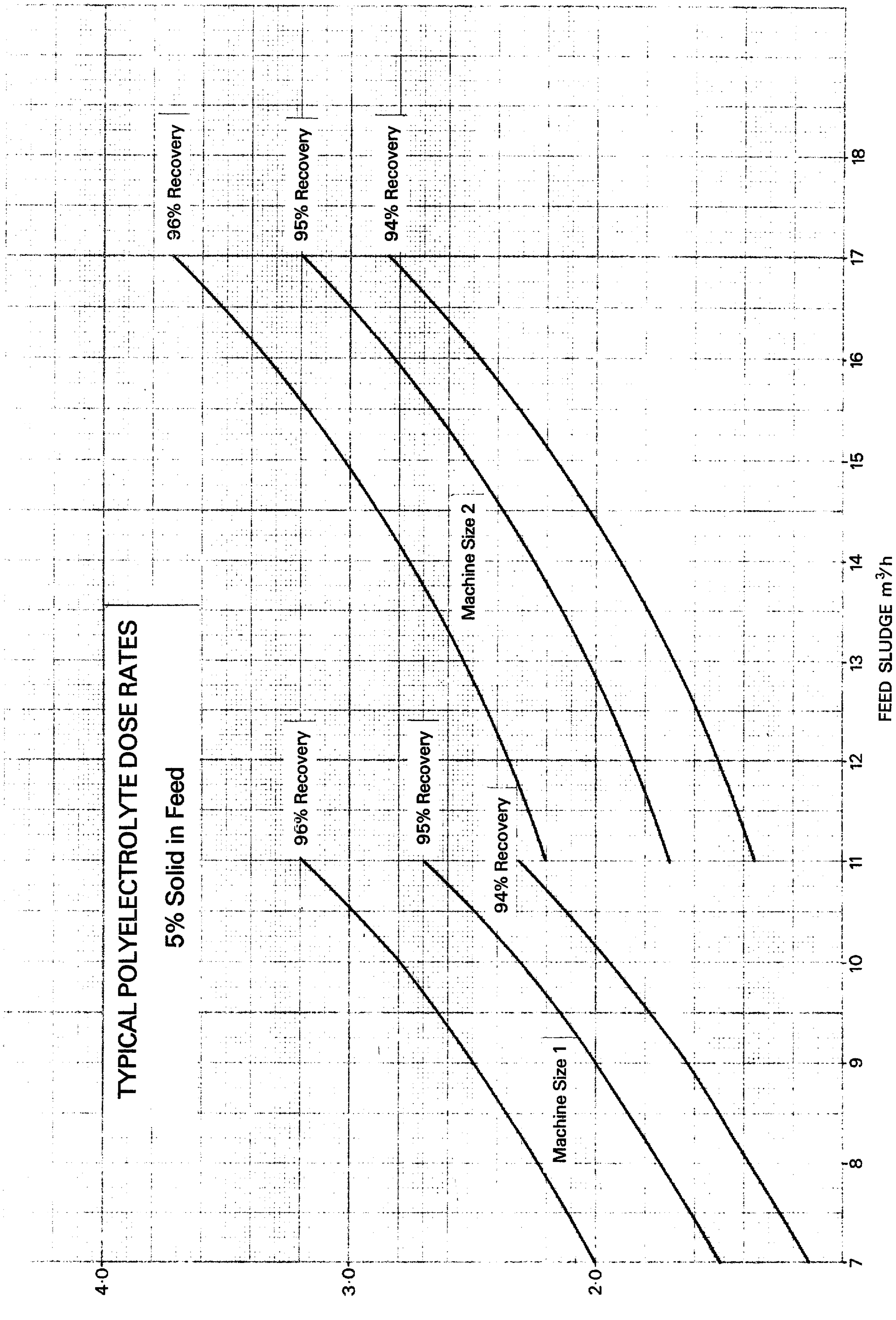
5.1 Feed Rate

Increasing the feed rate at constant polyelectrolyte dose in Kg/T.ds reduces the recovery of solids.

Figure No 5 shows that for a given centrifuge and constant solid recovery, the dose rate in Kg/T.ds at high sludge feed rates is substantially greater than at low feed rates.

The curves also illustrate the importance of selecting a machine capacity with a reasonable margin to deal with peak loads and batches of poor sludge, and to ensure that its normal operation is within an economic dose range.

FIGURE No 5


TYPICAL POLYELECTROLYTE DOSE RATES
5% Solid in Feed
96% Recovery
95% Recovery
94% Recovery
Machine Size 2
96% Recovery
95% Recovery
94% Recovery
Machine Size 1
FEED SLUDGE m³/h
7
8
9
10
11
12
13
14
15
16
17
18
2·0
3·0
4·0

5.2 Pond Depth

The mathematical theory developed by Hazen to prove that settleable solid removal in horizontal flow settlement tanks is dependent on free surface area and independent of depth can be applied to centrifuges. This theory postulates that depth is unimportant, but in both settlement tank and centrifuge practice it is found that as depth is reduced, flocculation of solids decreases, turbulence hinders clarification and ultimately sludge is scoured.

In centrifuge operation, the deeper the pond the better the retention period and centrate quality, but the resulting increased recovery of volatile matter and shortened drainage beach give a wetter cake (see figure No 6). The higher hydrostatic head on the sludge cake assists the scroll to convey the wet cake up the cone slope.

5.3 Design Efficiency

For given operating conditions, the efficiency of a centrifuge depends on good design of feed inlet, cake and centrate removal and proportioning of the bowl.

The performance may be measured by the quality of the centrate, cake dryness or both, but the usual way of expressing the efficiency is in the percentage recovery of solids. The exact relationship between the quantities is:

$$\% \text{ Solids Recovery} = \frac{\text{solids in cake} \times (\text{solids in feed} - \text{solids in centrate})}{\text{solids in feed} \times (\text{solids in cake} - \text{solids in centrate})} \times 100$$

An approximation of this formula is:-

$$\% \text{ Solids Recovery} = \frac{\text{solids in feed} - \text{solids in centrate}}{\text{solids in feed}} \times 100$$

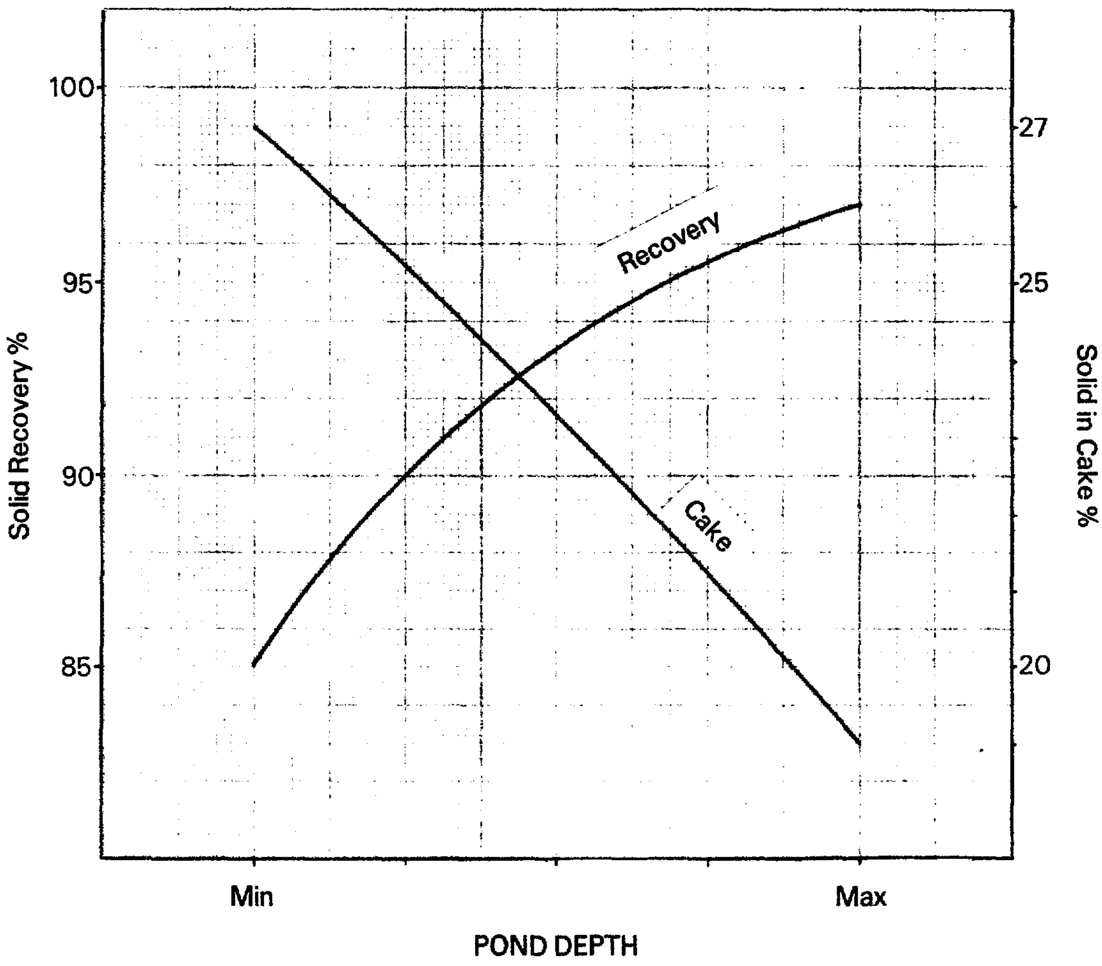
(all solids expressed as percentages by weight).

This simplified relationship is more easily visualised and commonly used for comparative purposes. Figure No 7 shows this graphically.

It does not account for the water carried away in the sludge cake, but the results obtained are less than 1% lower than the recoveries calculated by the exact formula.

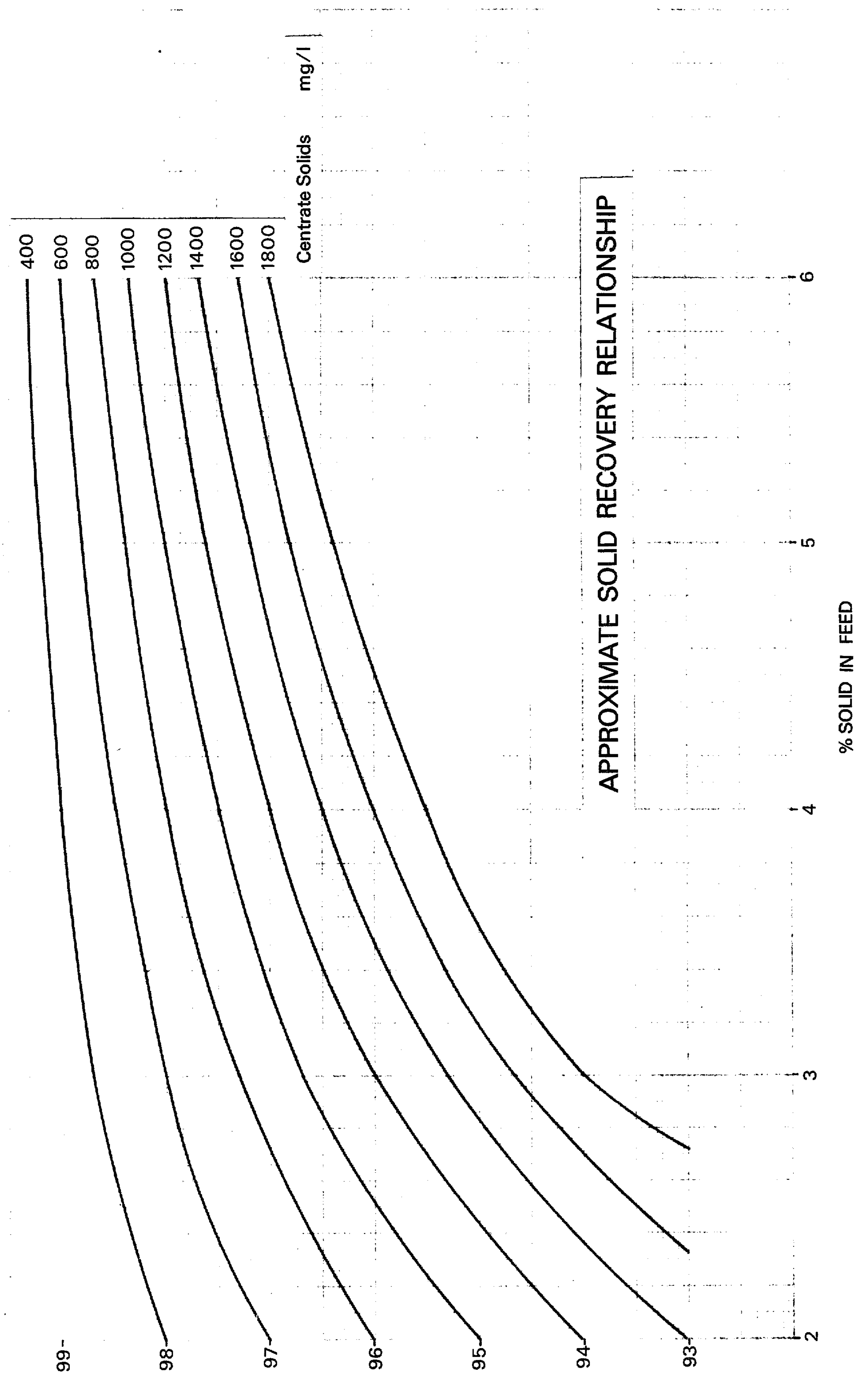
Solids in feed sludges are normally given as total solids, and those in centrates as suspended solids. The recoveries should be calculated in terms of either suspended or total solids.

In the solid recovery calculation, the chemical dose should be included in the percentage solid in the feed, but in practice this has negligible effect on the result.



100
95
90
85
27
25
20
Recovery
Cake
Solid Recovery %
Solid in Cake %
Min
Max
POND DEPTH

FIGURE No 7



APPROXIMATE SOLID RECOVERY RELATIONSHIP
Centrate Solids mg/l
400
600
800
1000
1200
1400
1600
1800
% SOLID IN FEED
2
3
4
5
6
93
94
95
96
97
98
99

5.4 Sludge Concentration

For a given feed flow the percentage solid recovery increases with solids concentration in the feed sludge but the solids in centrate also increase unless the polyelectrolyte dose per m^3 of feed sludge is increased. See figure No 8.

The benefit of sludge concentration before dewatering by centrifuge is that it permits a lower volumetric feed rate to a centrifuge of given capacity, and a lower polyelectrolyte dose in terms of Kg/T.ds, although higher per m^3 of sludge feed. In some cases thickening may allow the installation of a smaller unit.

5.5 Sludge Types

It is impossible to predict precisely the behaviour of a particular sludge in a centrifuge. Attempts have been made to compare results of trials on similar types of sludge carried out at different places with different machines and polyelectrolytes, but the number of variables involved makes conclusions from these limited trials unreliable.

It is reasonable to expect that with sludges of the same percentage solid matter, those with lower Organic and Volatile content should be more amenable to centrifuging.

The following is a probable order of amenability to dewatering:

	Sludge Type	Cake % Solid
1.	Heat conditioned	38 – 42
2.	Digested primary	22 – 26
3.	Primary	21 – 26
4.	Digested mixed	20 – 25
5.	Primary + Humus	19 – 22
6.	Primary + Activated	18 – 21
7.	Activated	6 – 8

Under carefully controlled test conditions, better cake moisture contents can be achieved.

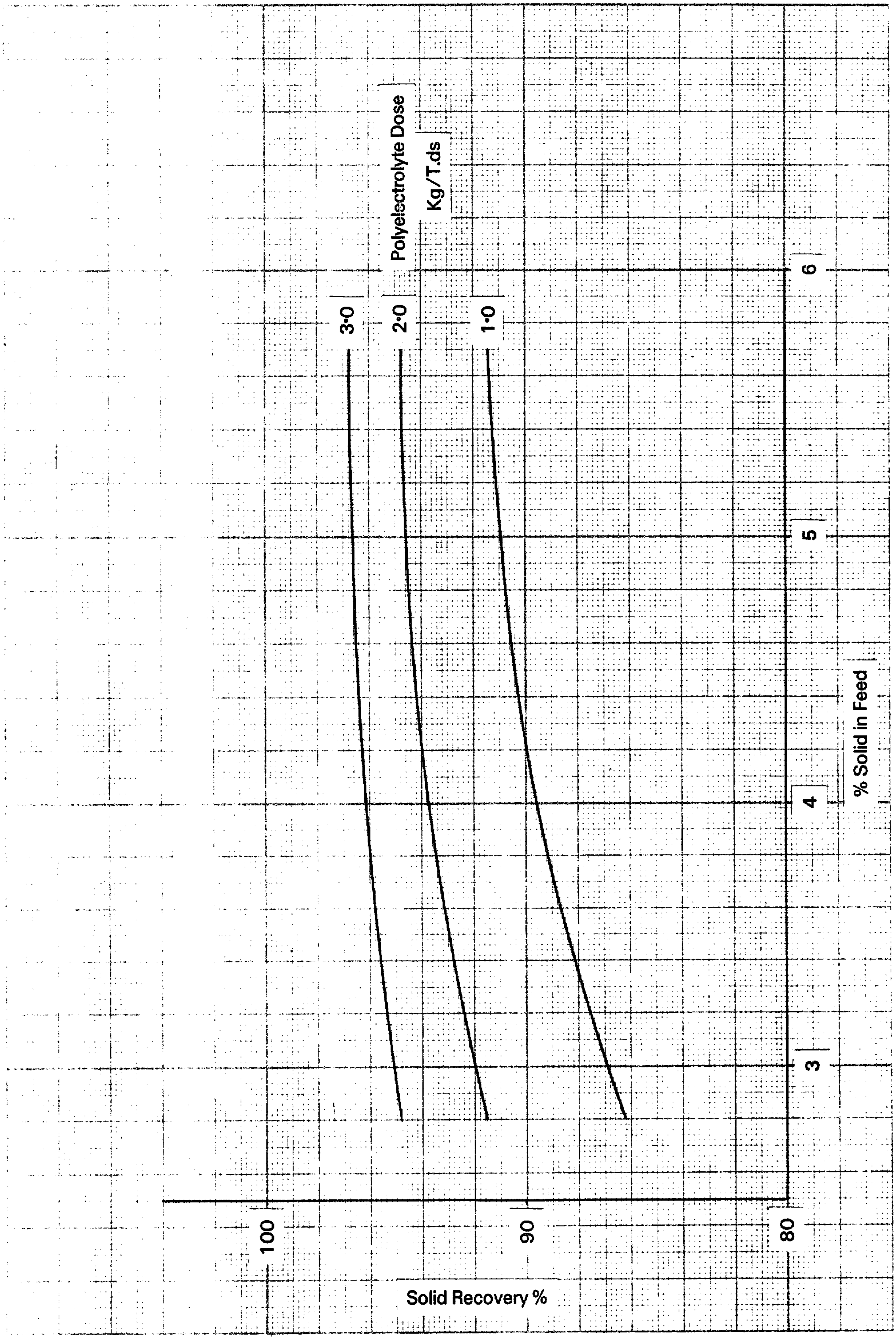
Factors influencing this order are the feed sludge origin, solid content, mixture proportions and degree of digestion.

Although activated sludge may be effectively thickened by batch and conical disc centrifuges, dewatering in scroll conveyor bowl machines is uneconomic owing to the high chemical dose rate required.

Greasy primary sludges are probably the most difficult to handle, because the grease tends to separate out and choke restricted passages in a centrifuge. There is also a tendency for floating grease with entrained solids to be rejected with the centrate.

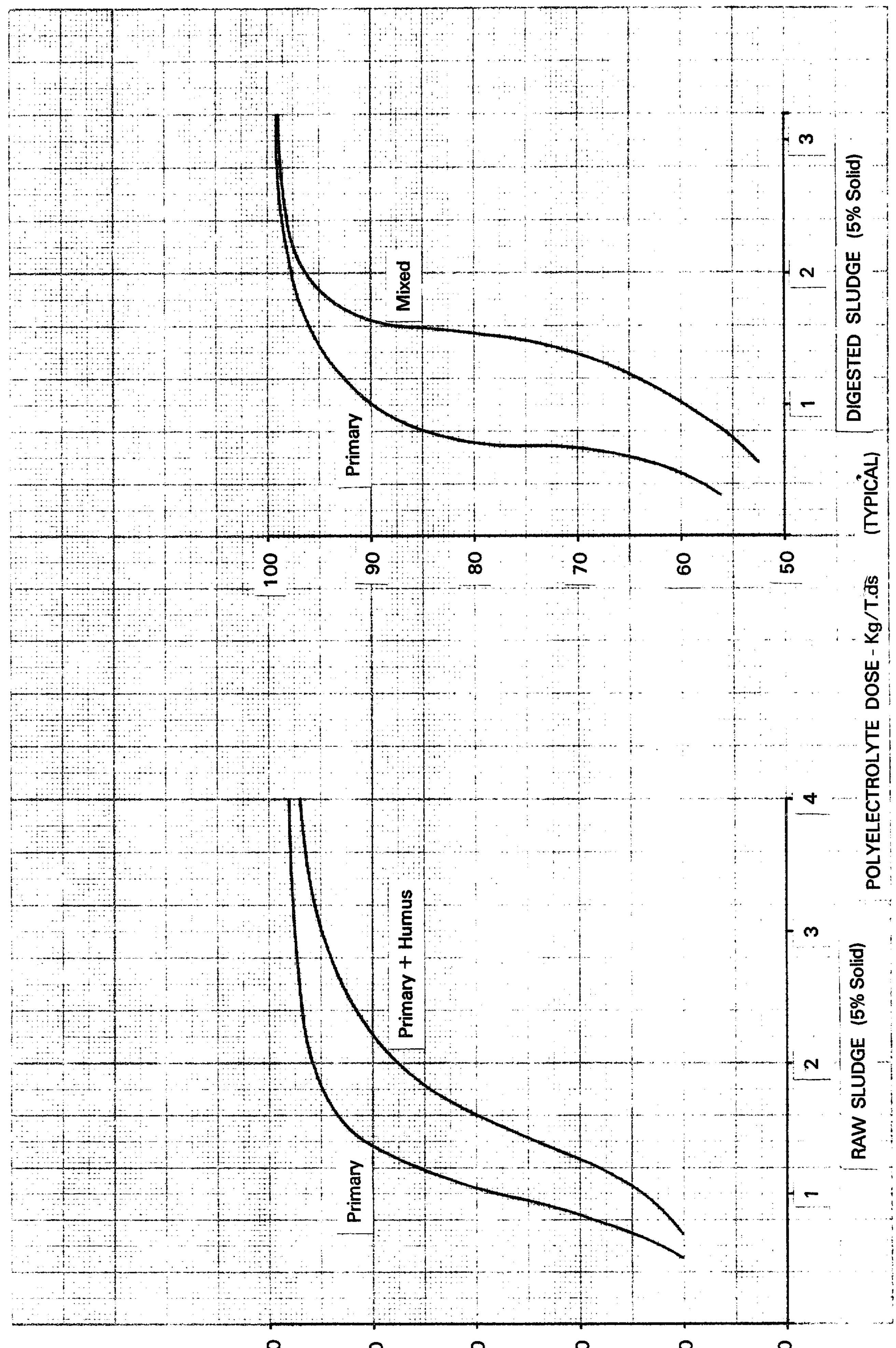
Typical solid removal curves are shown in Figure No 9.

FIGURE No 8



Polyelectrolyte Dose
Kg/T.ds
3·0
2·0
1·0
6
5
4
3
% Solid in Feed
100
90
80
Solid Recovery %

FIGURE No 9



RAW SLUDGE (5% Solid)
Primary
Primary + Humus
DIGESTED SLUDGE (5% Solid)
Primary
Mixed
POLYELECTROLYTE DOSE - Kg/T.ds
(TYPICAL)
100
90
80
70
60
50
1
2
3
4

Suspended solids in centrates are usually marginally lower with digested than with raw sludges, but values of 500 to 900 mg/l are easily achieved with most sludges. This range may be extended from 250 mg/l upwards according to operational requirements. It is a characteristic of centrifuging that the fine inorganic high density particles are thrown out with the sludge cake, and the centrate solids are mainly organics which can be removed by secondary sewage treatment processes when recirculated.

Wash water is not used during centrifuging, so the volume of centrate is increased only by the polyelectrolyte solution.

5.6 Polyelectrolyte Dosing

Sludge solids being negatively charged are flocculated by positively charged cationic polyelectrolytes. Anionic polyelectrolytes normally form weaker flocs which are liable to destruction by the shear forces generated in centrifuging.

Figure No 5 shows the influence of polyelectrolyte dose rate on the permissible sludge feed rate to a centrifuge.

Figure No 9 shows how the polyelectrolyte dose rate affects the solid recovery for a number of sludges. The normal dose for most sludges is 2.0 to 3.0 Kg/T.ds, above this the benefits diminish rapidly. With activated sludge the dose rate is so high and the cake product so wet that centrifugal dewatering is not feasible.

A polyelectrolyte dose rate may be expressed in terms of sludge feed or dry solids treated, for example:

100 g/m^3 wet sludge at 5% solid

or 2.0 Kg/T dry solid

or 0.2 % by weight.

Polyelectrolytes are supplied either in powder or liquid form. The powder must be stored in a dry atmosphere. The powder is dissolved in water or the liquid diluted to give a solution usually of 0.1% strength (1 kg dry polymer to 1000 l. water). At a dose rate of 2.0 kg per T.ds, the volume of feed sludge is increased by 10%.

The dilute solutions should be stirred gently for several hours before use and as they tend to deteriorate after 2 to 3 days they should then be discarded.

As the dry solid content of polyelectrolytes supplied in liquid form has been found to vary significantly from the labelled nominal strengths, it is more realistic to use cost per T.ds than the calculated Kg per T.ds when comparing performances of polyelectrolytes.

The inorganic flocculents used for conditioning in sludge filtration can add substantially to the final mass of solids and reduce the calorific value of the sludge cake, but the quantity of polyelectrolyte solid required has negligible effect.

As far as is known, none of the well established polyelectrolytes used for sewage sludge centrifuging are toxic.

5.7 Centrifuge Speeds

The settling velocity of a particle is directly dependent on the force of gravity acting upon it. Centrifuges generate gravitational fields many times greater than the earth's natural pull, the 'G' value being proportional to the bowl diameter and the square of the rotational speed.

$$\text{'G' No} = \frac{5.5\,N^2 d}{10^7} \qquad \text{where } N = \text{bowl rpm}, \quad d = \text{bowl dia mm}$$

A large centrifuge of 900 mm dia need rotate at only 1000 rpm to create about the same 'G' value as a machine of 350 mm dia rotating at 1750 rpm.

The higher the G No the better the clarification and drier the cake, but the greater the scroll conveyor friction HP and wear. G Nos up to 25000 may be used for dewatering sludges without polyelectrolyte dosing when poor quality centrates are acceptable. Polyelectrolyte dosing is essential to achieve the high standard of centrate normally required, and to avoid the break up of the weak sludge flocs formed by the polyelectrolytes, the G Nos are usually kept below 10000 to limit the generated shear forces.

Scroll conveyor differential speed, usually between 5 and 15 rpm controls sludge cake retention time and therefore cake moisture. A high differential speed can cause excessive turbulence and a low differential will reduce the rate of removal of sludge cake.

The influence of the differential speed of the bowl and conveyor on cake dryness is illustrated by Figure No 10.

5.8 Power Consumption

Total power cost is less than 20% of the polyelectrolyte cost and not a major item in the annual cost. The auxiliaries consume up to one quarter of the total power.

Bowl speed, scroll differential speed, feed rate and pond depth all affect power consumption, but the feed solid content has the greatest influence on kWh/T.ds.

Figure No 11 shows how the total power consumption may vary over a range of feed sludge solid contents.

6. OPERATION

The operation of a centrifuge plant is relatively simple and unskilled labour may be quickly trained for this, but for efficient and trouble free operation an unskilled grade attendant should be supervised by a superior who is familiar with the principles of centrifuge operation.

Operator attendance time should not exceed 2 or 3 hours per day shift, and the greater part of this will be in the preparation of the chemical dosing solution. When a centrifuge is installed for continuous service over two or three shifts, the storage tanks should be of sufficient size for the solution preparation to be confined to one shift.

FIGURE No 10

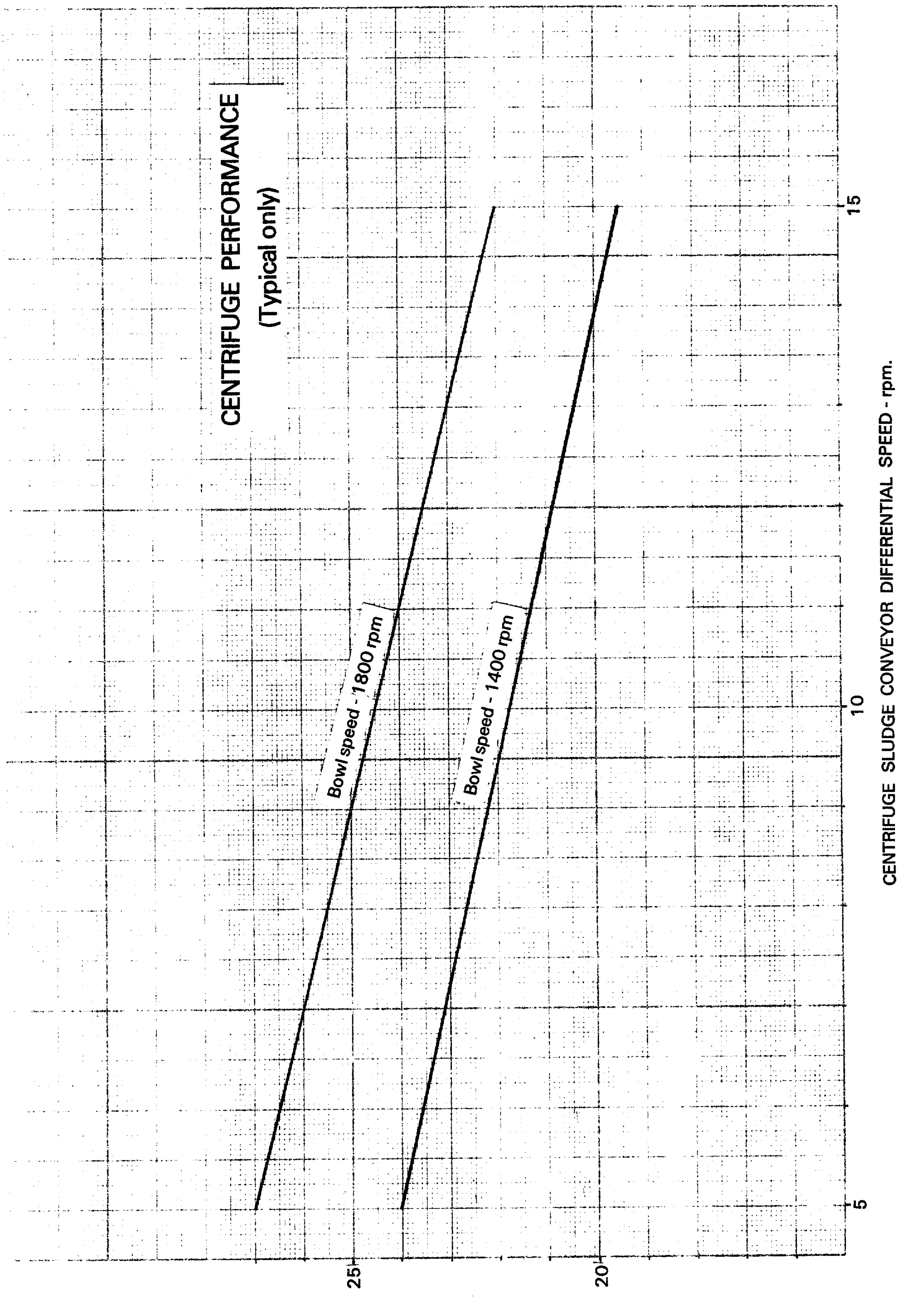
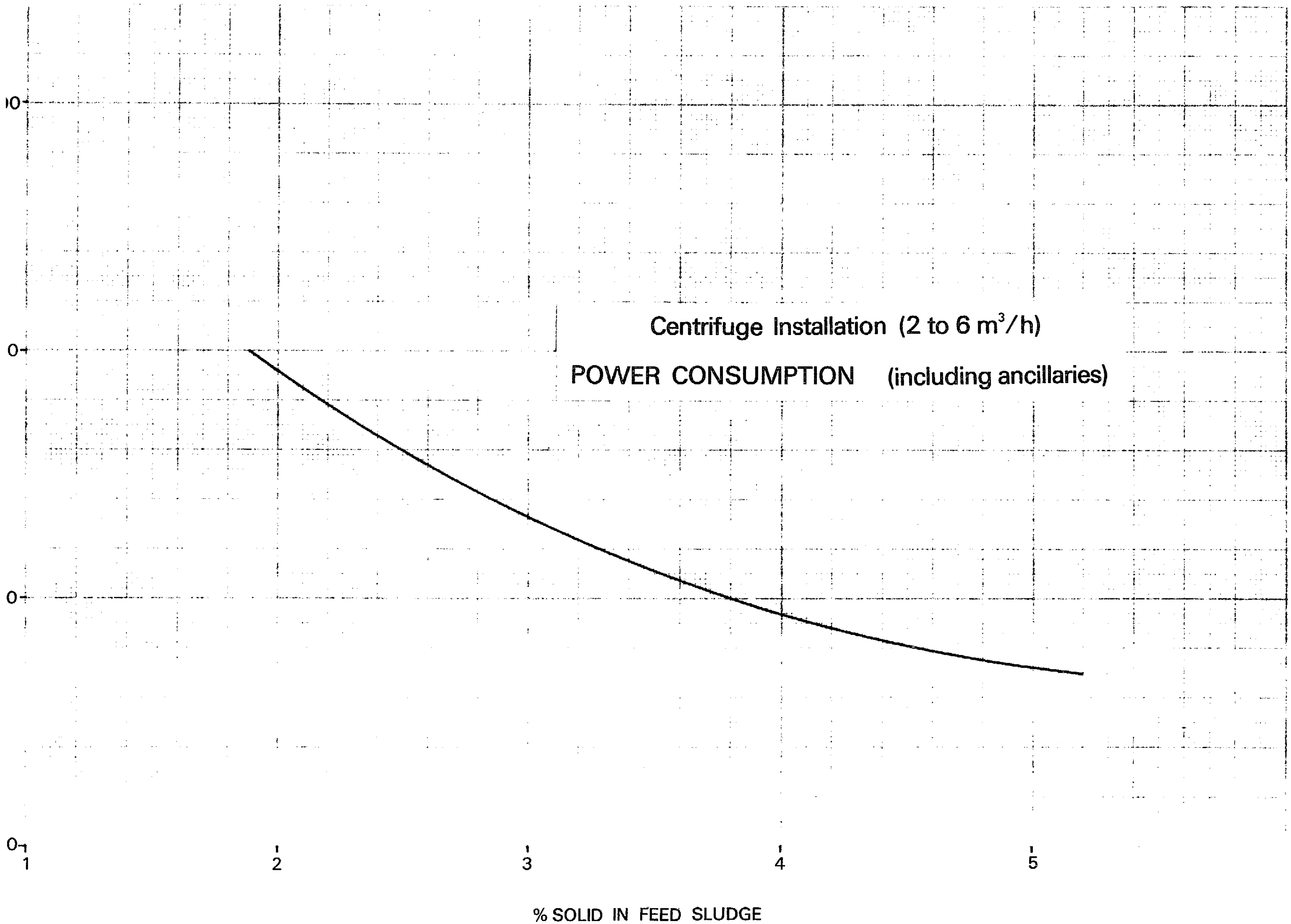

CENTRIFUGE PERFORMANCE
(Typical only)
Bowl speed - 1800 rpm
Bowl speed - 1400 rpm
5
10
15
CENTRIFUGE SLUDGE CONVEYOR DIFFERENTIAL SPEED - rpm.
25
20

FIGURE No 11



Centrifuge Installation (2 to 6 m³/h)
POWER CONSUMPTION (including ancillaries)
00
0
0
0
1
2
3
4
5
% SOLID IN FEED SLUDGE

The plant attendant's duties may include logging instrument panel readings, taking samples of sludge cake and centrate, keeping a watch on lubricating oil pressure, bearing temperatures and the quality of the sludge cake and centrate. These duties should leave time for other work even though he may be in charge of a group of machines.

The procedure for starting up a centrifuge plant follows a recommended procedure, such as starting the sludge cake disposal conveyor first, then the centrifuge lubricating oil pump, the seal and bearing water supplies if fitted, the centrifuge, the chemical dose and sludge feed pumps in that order. The larger installations may have the start-up steps electrically interlocked to prevent incorrect sequence, and some may have provision for automatic start-up under time-clock control while unattended. Some centrifuges are supplied with a lubricating oil pressure switch which will shut down the plant in the event of oil pressure failure.

The rate of sludge feed and chemical dosing, the scroll conveyor differential speed and the pond depth will be established during commissioning and should not require alteration during normal operation with constant feed quality. If a machine is to operate unattended for an extended period during which the feed quality may vary, the chemical dose rate may be increased temporarily as an insurance against deterioration of the centrate quality.

It is essential for a centrifuge to be flushed out thoroughly with clean water before shut down at the end of the shift.

7. MAINTENANCE

Although sludge centrifuges operate at speeds between 1200 and 2500 rpm, that is, rather higher than most mechanical equipment found on sewage treatment works, they are designed for this duty and have established a good record of mechanical reliability on the continent. Chemical centrifuges frequently run at even higher speeds, and are used with confidence in industrial processes.

Routine maintenance requirements are similar to those for sewage or sludge pumping stations, and if the services of a fitter and electrician can be provided and essential spares are carried, no serious problems need be expected. Corrosion problems in the chemical mixing and dosing equipment have been almost eliminated by the use of plastic materials.

The larger Authorities with the expertise and facilities should be capable of major overhauls and even the resurfacing of scroll conveyors, providing this is done before wear has become so severe that dynamic balancing is necessary. Some centrifuge manufacturers carry stocks of standard scrolls and all offer a prompt servicing arrangement, but it could be expedient to hold one spare.

The life of the scroll hard surfacing may vary from 6000 to 12000 hours according to the type of sludge handled and the efficiency of the sewage works grit removal plant. An inspection of the scroll condition after the first 3000 hours operation is advisable, with further inspections made at regular intervals to establish the pattern of wear.

An overhead or mobile crane capable of handling the heaviest lift must be available.

8. COSTS

8.1 Capital Costs

It is difficult to quote reliable capital costs for sludge centrifuges owing to the current inflation which affects all plant costs, and because their prices are influenced by continental competition and currency exchange variations.

Sludge dewatering by centrifuge is new in this country and present prices may be low to gain orders from other dewatering processes, and because too many manufacturers may have entered the field for the business available. If this is unprofitable some firms may withdraw and prices should stabilise at a more economic level.

The breakdown of capital costs will vary from one situation to another, but the following is a guide:-

Centrifuge	–	60%
Ancillaries	–	15%
Foundations and simple building	–	25%

With a multiple centrifuge installation, the centrifuge percentage cost will be higher.

Figure No 12 indicates the probable present costs of complete single machine installations.

8.2 Annual Costs

Centrifuges have not been in operation on sewage works in this country long enough for reliable running costs to be available. It may be misleading to convert continental costs into English equivalents, because of differences in sludge characteristics, interest rates, labour, power and chemical costs.

The DGWE is setting up a series of projects to investigate the performance and running costs of a number of centrifuges.

Some tentative annual costs for single machine installations are given in the table in Appendix 2. These are based on performance test data and estimated unit costs, and range from £6.5/T.ds for large machines to £15/T.ds for small machines.

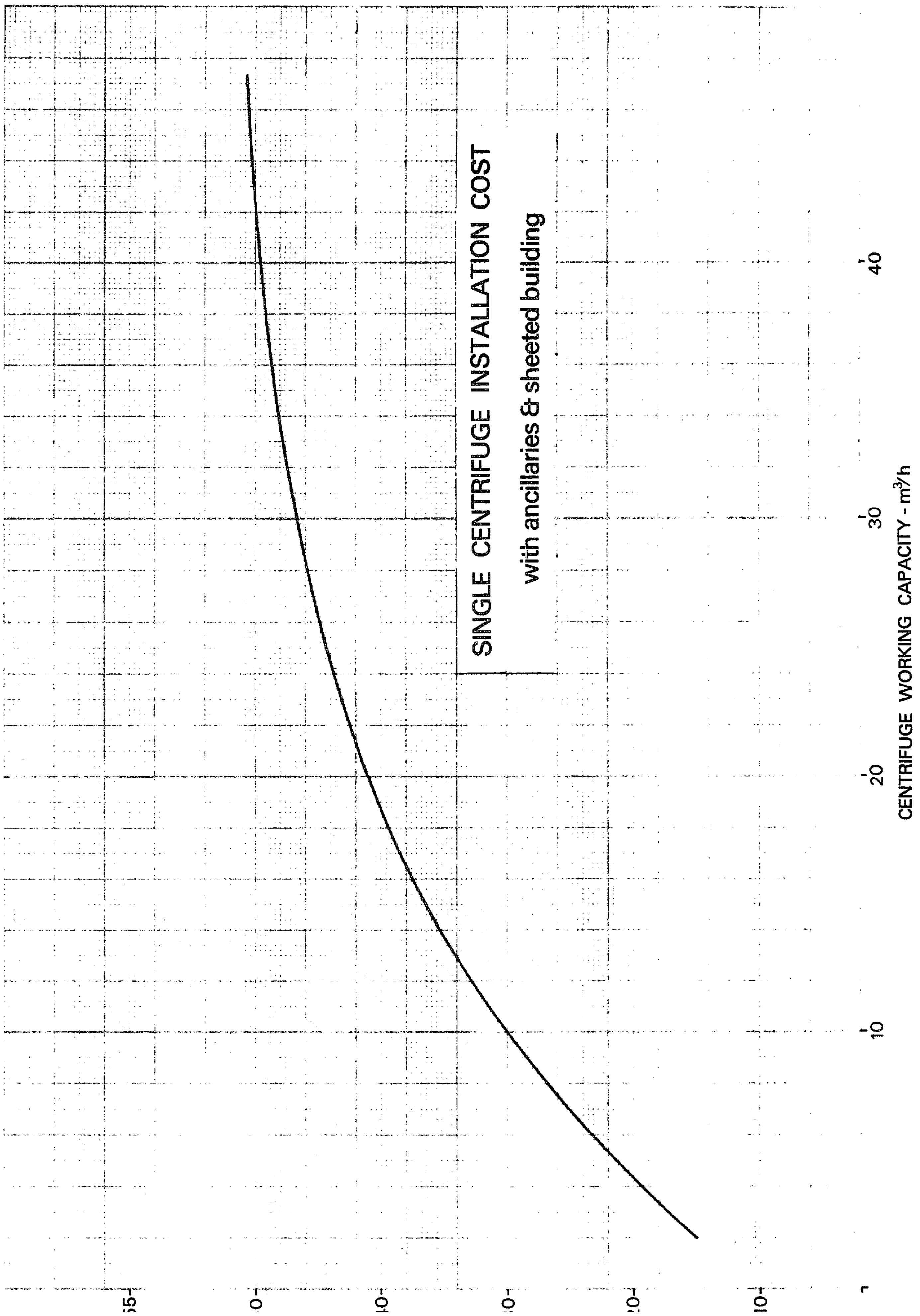
Operating labour cost is a significant item in the total costs for small installations operating for one shift per day. Three shift operation is less economical because the labour element then becomes the major item.

Even with large installations the gain from operating 3 shifts per 24 hours is small, because the saving in capital costs is small relative to the chemical conditioning cost which may be as much as half the total annual cost.

When a single machine is installed to handle a given sludge flow, and this flow subsequently increases, it is then more economical to increase the running hours than to incur the additional capital charges on a second machine.

The running hours used in the cost table allow ample time for routine maintenance, but an alternative means of sludge disposal should be available in case of a major breakdown of a single centrifuge.

FIGURE No 12



SINGLE CENTRIFUGE INSTALLATION COST
with ancillaries & sheeted building
CENTRIFUGE WORKING CAPACITY - m^3/h
10
20
30
40

Standby centrifuge capacity may be provided by installing either 3-50% duty or 2-100% duty machines. The former arrangement may cost slightly more to install and to run but it does provide greater flexibility.

9. SUMMARY

Experience on the continent and trials in the UK since the introduction of polyelectrolytes suggest that centrifuging is now a practical and economical method of dewatering raw or digested sewage sludges.

The scroll conveyor bowl centrifuge is the most suitable type for dewatering sewage sludge.

Activated sludge cannot be dewatered economically by centrifuge unless mixed with primary sludge, but the batch and conical disc types show promise for thickening it.

The scroll conveyor bowl centrifuge is mechanically reliable, but the hard surfacing on the scroll has to be refurbished at intervals depending on the nature of the sludge.

The performance of a centrifuge depends on a number of operational variables, each of which may influence the effects of the others. The number of possible combinations of settings makes it difficult to predict accurately the performance on a given sludge.

Preliminary trials should be conducted to establish the optimum throughout, chemical consumption, cake and centrate qualities. From these trials the performance of larger machines of similar design can be predicted with sufficient accuracy for setting guarantees.

The effects of the operation variables are summarised below:-

VARIABLE	—	CHANGE	PERFORMANCE IMPROVEMENT
Feed Rate	—	decrease	recovery and centrate
Feed solids	—	increase	recovery
	—	decrease	centrate
Pond depth	—	increase	recovery and centrate or throughput
	—	decrease	cake
Chem. dose	—	increase	recovery and centrate or throughput
Bowl speed	—	increase	cake, recovery and centrate, or throughput
Conveyor speed	—	decrease	cake and centrate

The present reasonable cost of dewatering sewage sludge by centrifuge, including capital charges and all running costs, is probably between £7 and £15 per T.ds according to the type of sludge and size of installation.

Although the cost of chemical conditioning per T.ds will not vary much with size of installation, the percentage of the total annual cost will be about 20% for small installations and up to 50% for large installations.

10. COMPARISON WITH OTHER DEWATERING EQUIPMENT

10.1 Capital costs

From available cost data, the total cost of a centrifuge installation compares favourably with plate filter presses and vacuum filters of equivalent capacity and is less than drying beds of adequate area. Below $2m^3/h$ capacity centrifuges may cost more than plate filter presses or filter belt presses.

Local or special conditions can influence capital costs significantly.

10.2 Annual costs

Estimated annual costs suggest parity with plate filter presses and vacuum filters, but higher rates than those for small filter belt presses. They are lower than the majority of drying bed costs (which vary widely).

10.3 Buildings

Centrifuges require slightly less floor area than other mechanical dewatering plants and a single storey building. Plate filter press houses usually have heavily constructed first floors, but today most press manufacturers recommend the supporting of presses by steelwork from the ground floor to save on building costs.

10.4 Chemicals

Sludge conditioning with polyelectrolytes is recommended for centrifuges. The dose rates are higher than for vacuum filters and filter belt presses. Plate filter presses normally use inorganic conditioners which give rise to higher ash contents in the cake.

10.5 Power

Consumption is similar to that of vacuum filter installations, but higher than that of plate filters and filter belt presses.

10.6 Sludge Cake

The solid content is similar to that in vacuum filter and belt press cakes, ie 20—25%, but the cake is of a more crumbly nature and more easily spread.

When the object is dewatering to low moisture content, centrifuges cannot compete with plate filter presses, and when the dewatering stage is to be followed by thermal drying or a reliable autothermic incineration process centrifuging may not be the most economical choice.

10.7 Effluent

The quality of centrate from a centrifuge is inferior to that of the filtrate from a plate filter press, similar to that from a cloth covered vacuum filter, and usually better than those from metal coil covered vacuum filters and filter belt presses. The solids in the centrate from a greasy primary sludge may comprise a large percentage of light floating matter.

The volume of centrate is not increased by wash water, or by elutriation liquors associated with some inorganic chemical conditioning processes.

10.8 Operating Labour

Total manhours are similar for centrifuges, vacuum filters and automatic filter presses.

10.9 Standby Capacity

Standby is more essential with centrifuges than with slower moving or static mechanical plant.

11. PROBABLE FUTURE DEVELOPMENTS

Currently there are eight centrifuge suppliers in this country. Although the number of orders will continue to grow, the competition and low profit margins may persuade a number of suppliers to withdraw from the sewage market.

The lower dewatering costs in £/T.ds of large centrifuges may encourage manufacturers to extend their range of machine capacities.

The lower unit cost of large machines may be attractive in situations where sludge can be transported to and dewatered at central stations.

With increased useage, polyelectrolyte costs should fall relative to the other annual costs.

Polyelectrolytes forming stronger flocs may be developed which will permit higher bowl speeds and drier cake product.

Automated process control and data logging will be adopted in some of the larger centrifuge installations.

When sludge is to be disposed of as a solid residue, the preliminary stages of disposal – thickening, digestion, conditioning and dewatering – will tend to be selected with greater regard to the ultimate stage, which may be application to the land as wet cake, crushed dry cake or thermally dried powder, incineration or tipping.

The nature of the sludge and the method of final disposal may indicate which of the intermediate stages should be used, the requirements of these and whether the centrifuge or any other equipment is appropriate.

A number of integrated centrifuge and dryer or incinerator schemes are under construction or consideration.

APPENDIX 1

References on Sewage Sludge Centrifuging

C M Ambler – Chem Eng Prog 1952 48 150

G A Frampton – Chem & Process Eng Aug 1963 p 402

Sludge dewatering by centrifuges – Recent operating experiences

– 37th Annual Conf Wtr Poll Cont Assn 1965

Sludge dewatering – WPCF Manual of Practice No 20 1969

Albertson & Guidi – Jour Wtr Poll Cont Fed April 1969 41.4.607

Some aspects of sludge technology including new data on centrifugation

– Swanwick, Fischer & Foulkes – Wtr Poll Manual 1972

Estimated Capital and Annual Costs
Single Centrifuge Installations

Sludge production	m^3/h	1		4		10	
Sludge per annum	m^3/a	8,760		35,040		87,600	
1 shift operation	h/a	2,000		2,000		2,000	
3 shift operation	h/a		6,000		6,000		6,000
Centrifuge rate	m^3/h	4.38	1.46	17.52	5.84	43.80	14.60
Additional sludge storage	£	1,920	–	7,680	–	19,200	–
Single installation, complete	£	17,800	14,000	39,000	23,000	51,000	36,500
	£	19,720	14,000	46,680	23,000	70,200	36,500
Annual Costs:	£						
Loan repayment & interest		2,760	1,960	6,550	3,220	9,850	5,110
Operating labour		1,000	3,000	1,000	3,000	1,000	3,000
Polyelectrolyte		1,400	1,400	5,600	5,600	14,000	14,000
Power		306	306	1,225	1,225	3,060	3,060
Maintenance – running		494	700	1,165	1,150	1,760	1,830
– scroll		300	700	650	1,150	850	1,825
Supervision, stores, rates		300	300	400	400	500	500
Total	£	6,560	8,336	16,590	15,745	31,020	29,325
	£/m^3	0.75	0.95	0.47	0.45	0.35	0.33
	£/T.ds	15.0	19.0	9.4	9.0	7.0	6.6

Notes:

Sludge solids – 5%
Storage tank costs – £40/m^3
Capital costs – Figure No 12
Repayment and interest – 14%
Polyelectrolyte cost – 16p/m^3
Power cost – 3½p/m^3
Maintenance general – 2½% of capital (2000 hrs pa)
5% of capital (6000 hrs pa)
scroll – 5% of capital every 6000 hrs

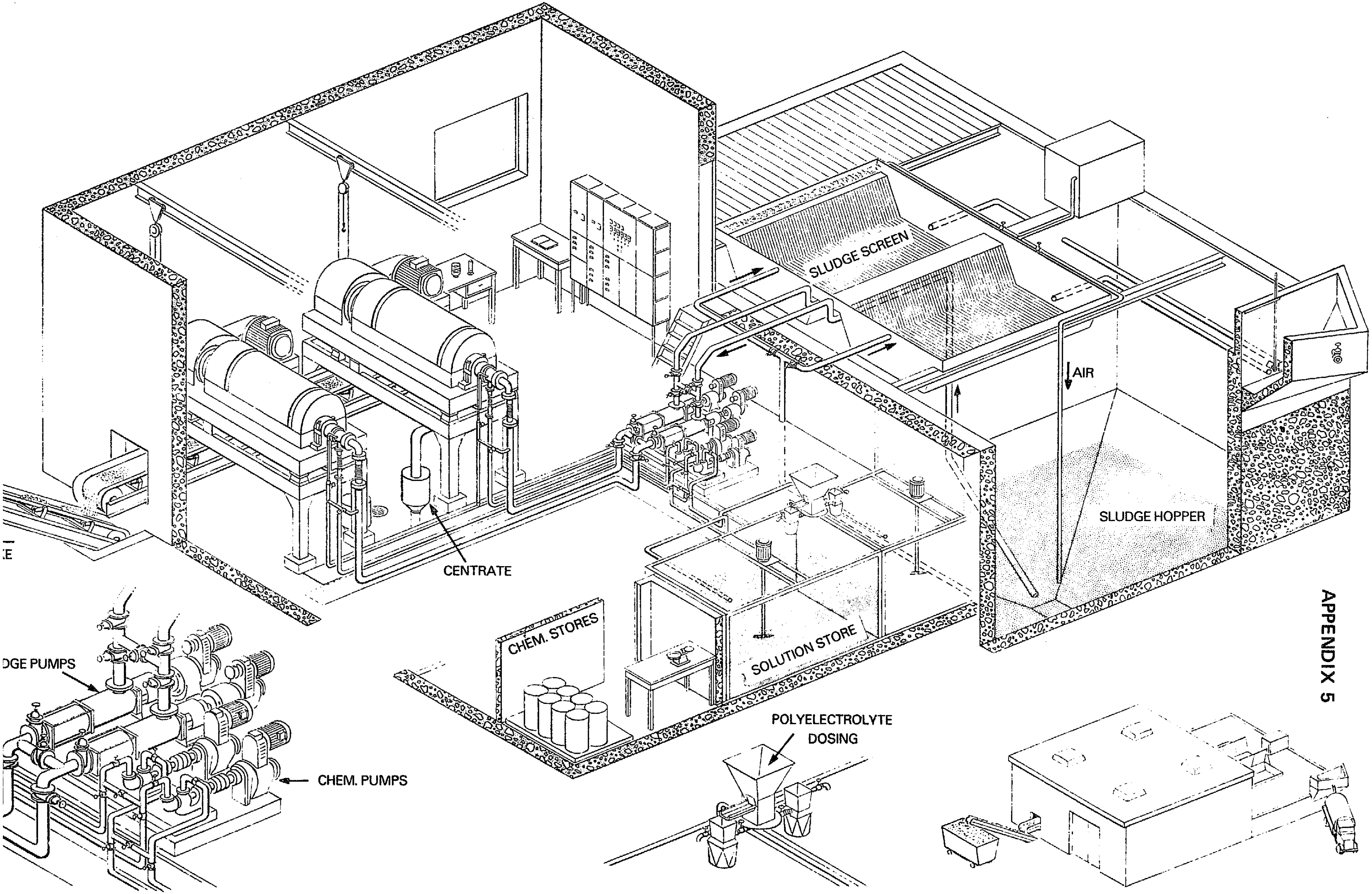
CONVEYOR BOWL CENTRIFUGES AVAILABLE IN THE UK
(There may be others of which DGWE has no details)

Name Ref	Supplier Bowl dia x Len mm	Country of Manufacture Capacity Range m^3/h
Alfa Laval	Alfa Laval Ltd, Brentford	England
AVNX 314	350 short	4 – 6
AVNX 418	350 long	6 – 12
AVNX 225	500 long	15 – 20
Broadbent	Thos. Broadbent & Sons Ltd Huddersfield	England
18.44	450 x 1130	3 – 5
24.60	600 x 1530	14 – 21
36.72	915 x 1830	22 – 34
Dynocone	International Combustion Ltd Derby	England
1840	450 x 1015	3 – 5
3060	760 x 1520	Details not available
4080	1015 x 2030	
Flottweg	Simpson Sales Associates Ltd Edinburgh	Germany
Z1.L	230 x 690	1 – 2
Z2.L	320 x 960	3 – 4
Z3.L	420 x 1260	6 – 9
Z5.L	620 x 1860	15 – 25
Humboldt	British Deutz Ltd, London	Germany
S1.1	350 x 950	2 – 4
S2.1	450 x 1350	5 – 8
S3.1	600 x 1400	15 – 20
S3.2	600 x 1800	17 – 30
S3.3	600 x 2500	30 – 40
S4.0	900 x 1800	35 – 50
S4.1	900 x 2500	40 – 60
Monofuge	Mono Pumps Ltd, London	Italy
2	Details not available	– 2
5		2 – 5
Sharples	Penwalt Ltd Camberley	England
P 3000 S	350 x 760	2 – 8
P 3400 S	350 x 1220	6 – 10
P 5000 S	630 x 1650	15 – 25
P 5400 S	630 x 2340	20 – 30
Total	Kruger (GB) Slough	Denmark
	350	1 – 3
	500	3 – 7
	500L	7 – 14
	600	7 – 14
	670L	10 – 27
	800	10 – 27
	800L	20 – 40

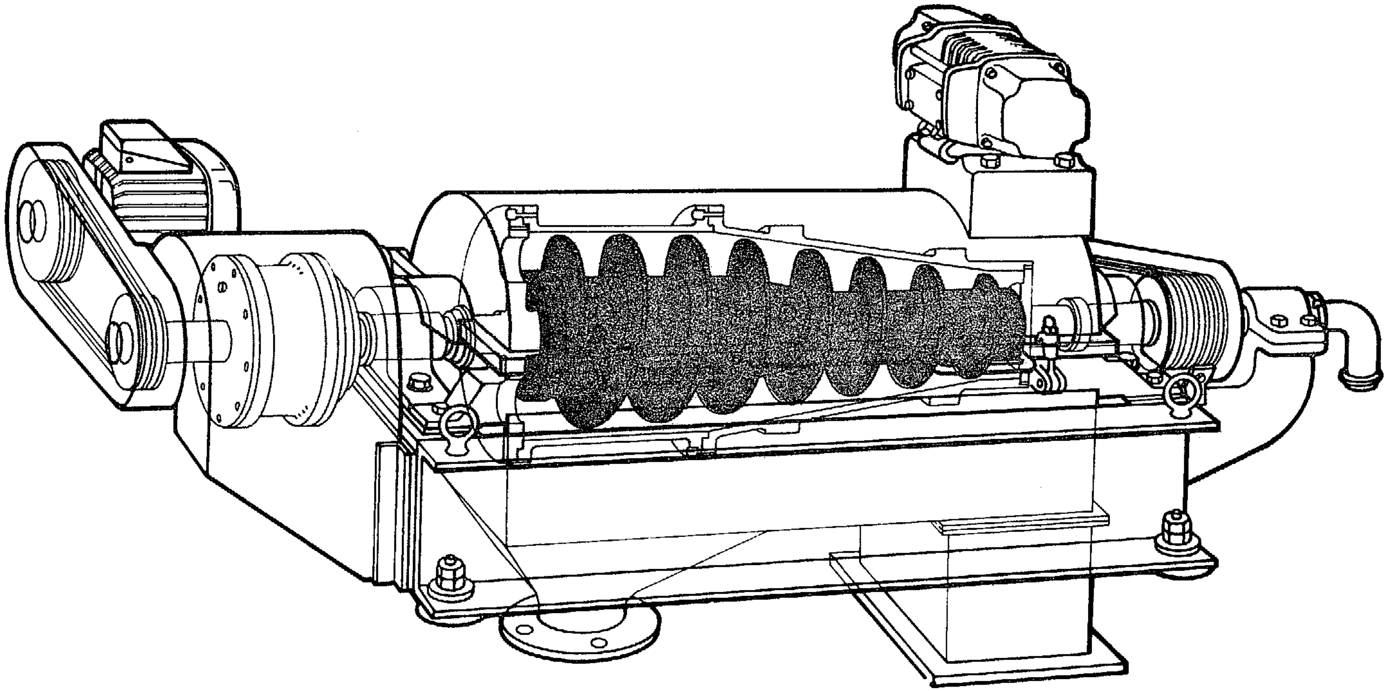
Conveyor Bowl Centrifuges Installed or Ordered in UK for Sewage Sludge Dewatering (February 1974)

Alfa Laval:	On site testing – one AVNX 314	
Broadbent:	On site testing – two	
Dynocone:	On site testing – one	
Flottweg:	Stranraer – one Z3.L	
	St. Andrews – one Z3.L	
	Whitburn – one Z3.L	
	Rothes – one Z3.L	
Humboldt:	On hire – one S3.1	
	Wigan – four S3.2	
Sharples:	Basingstoke RDC	One – P 3000 S
	Dumfries	One – P 3400 S
	Irlam	Two – P 3400 S
	Wallyford	One – P 3400 S
	Docking	One – P 3400 S
	On hire	Three
Total:	Milton Keynes	2 – 600
	Southend	3 – 670L
	Caernavon	2 – 500L
	Dunmow RDC	1 – 500L (mobile)
	On hire	four

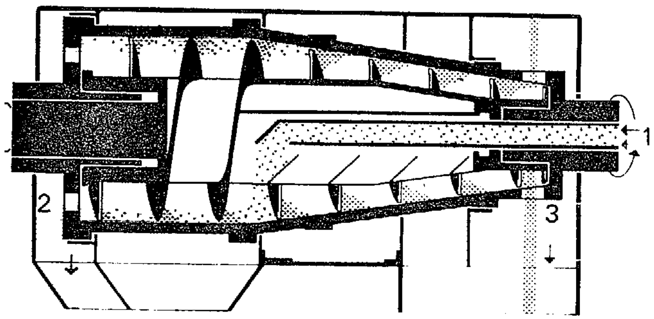
APPENDIX 5


SLUDGE SCREEN
AIR
SLUDGE HOPPER
CENTRATE
CHEM. STORES
SOLUTION STORE
POLYELECTROLYTE
DOSING
CHEM. PUMPS
DGE PUMPS

APPENDIX 6/1

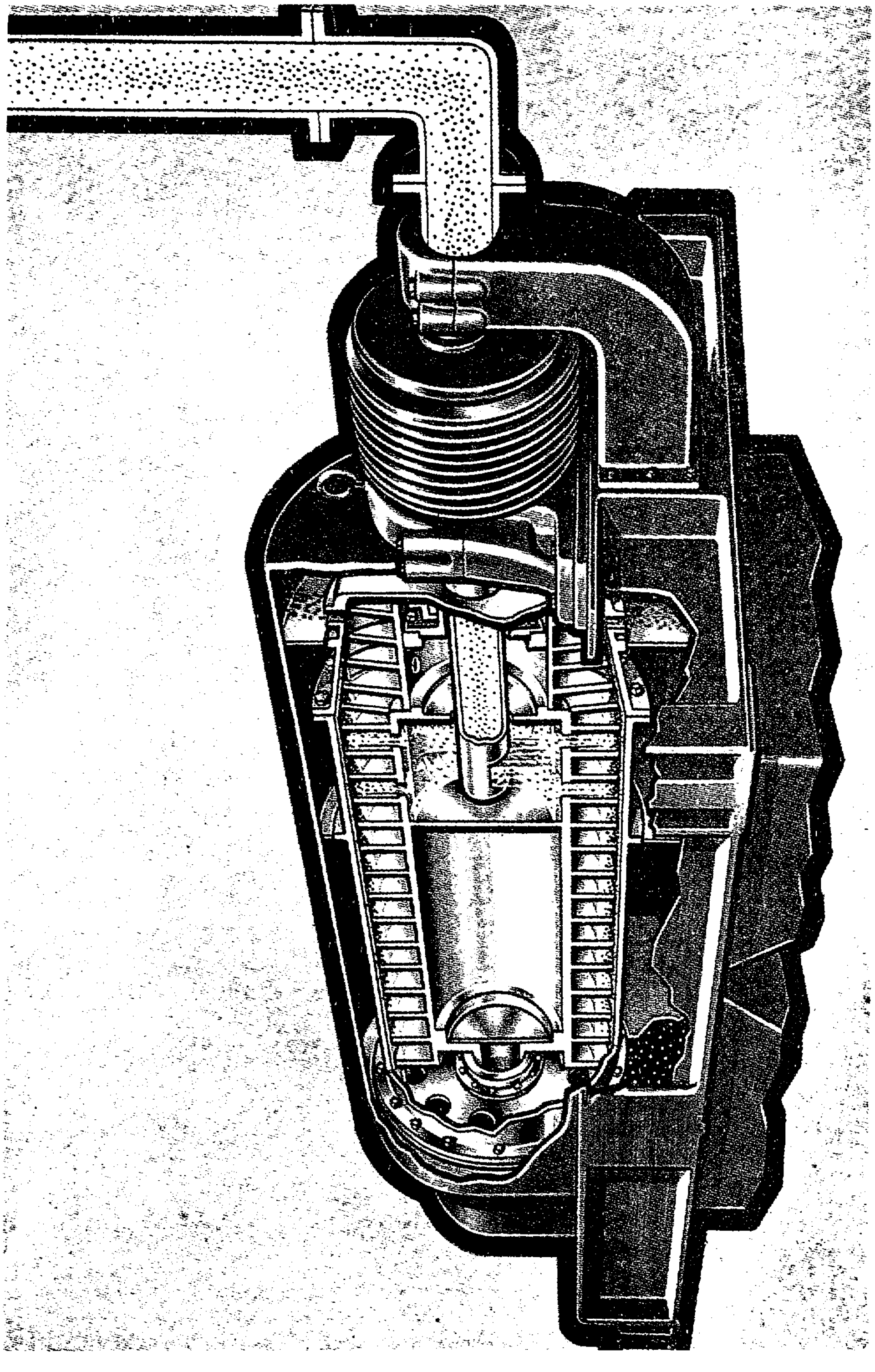


1 Feed
2 Outlet for liquid phase
3 Outlet for solids phase



ALFA LAVAL LTD.

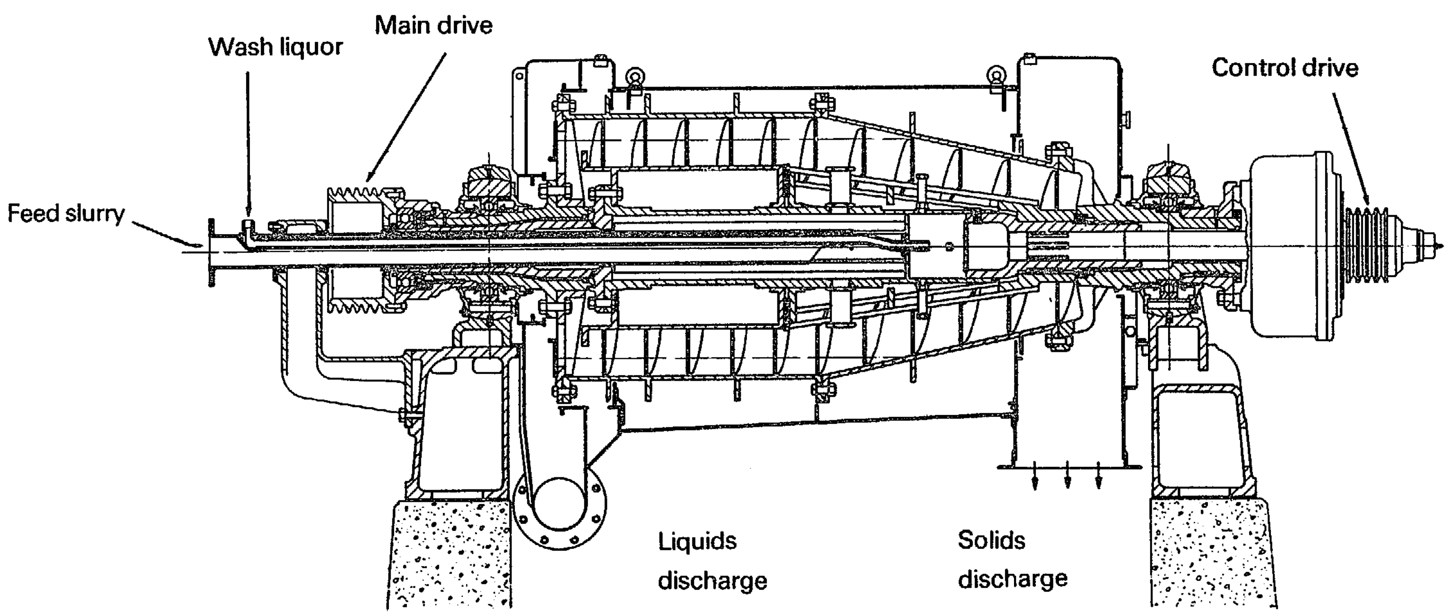
(with acknowledgement to Alfa Laval Ltd.)



SCROLL SEDIMENTATION CENTRIFUGE (Heavy duty type)-THOMAS BROADBENT & SONS. LTD.

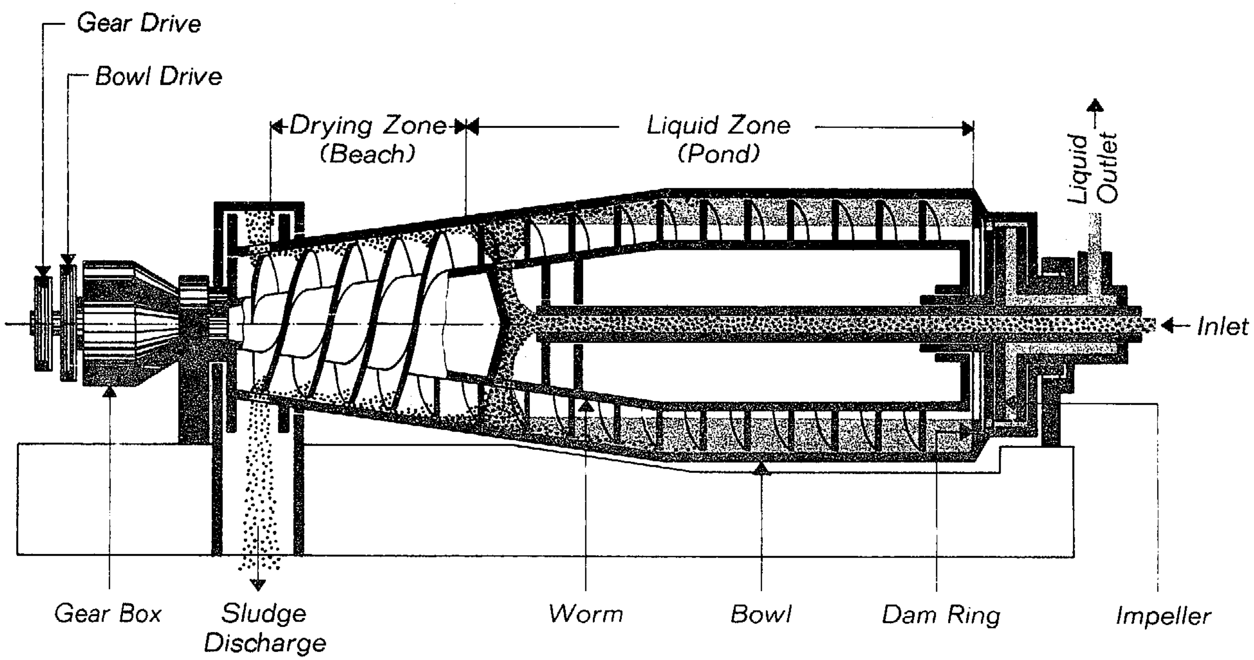
(with acknowledgement to Thomas Broadbent & Sons Ltd.)

APPENDIX 6/3



THE DYNACONE – INTERNATIONAL COMBUSTION PRODUCTS LTD.

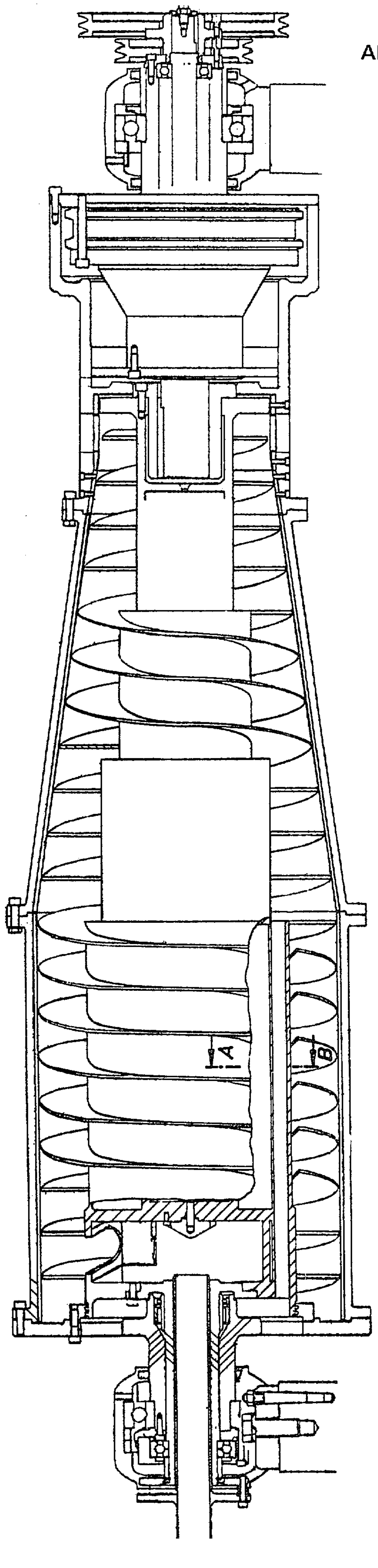
(with acknowledgement to International Combustion Products Ltd)



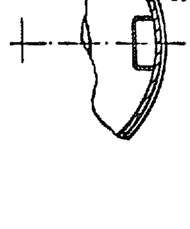
FLOTTWEG WERK

(with acknowledgement to Flottweg Werk)

APPENDIX 6/5



HUMBOLDT-BRITISH DEUTZ LTD.

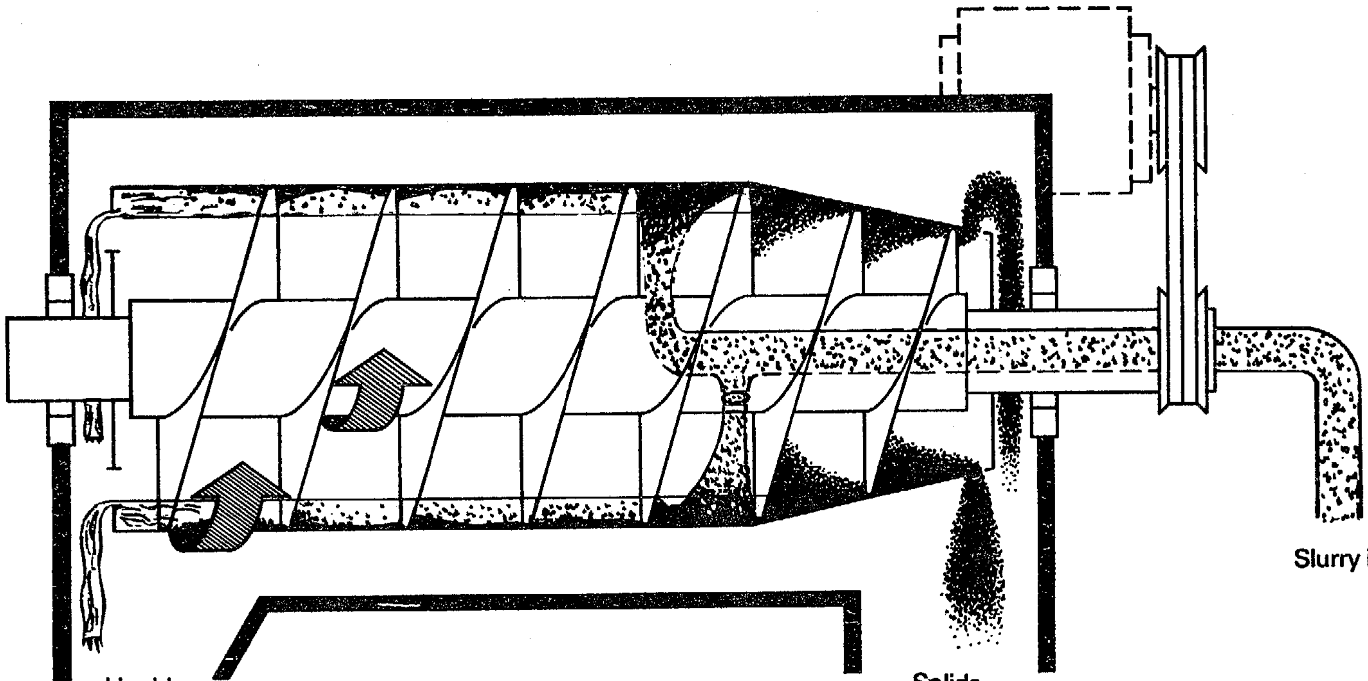


Section A-B

(with acknowledgement to British Deutz Ltd.)

MONOFUGE – MONO PUMPS (ENG) LTD.

(with acknowledgement to Mono Pumps (Eng.) Ltd.)



THE SHARPLES SDC CENTRIFUGES FOR SEWAGE SLUDGES - PENNWALT LTD.

(with acknowledgement to Pennwalt Ltd.)

1 Inlet for sludge

2 Inlet for chemicals

3 Inner screw conveyor

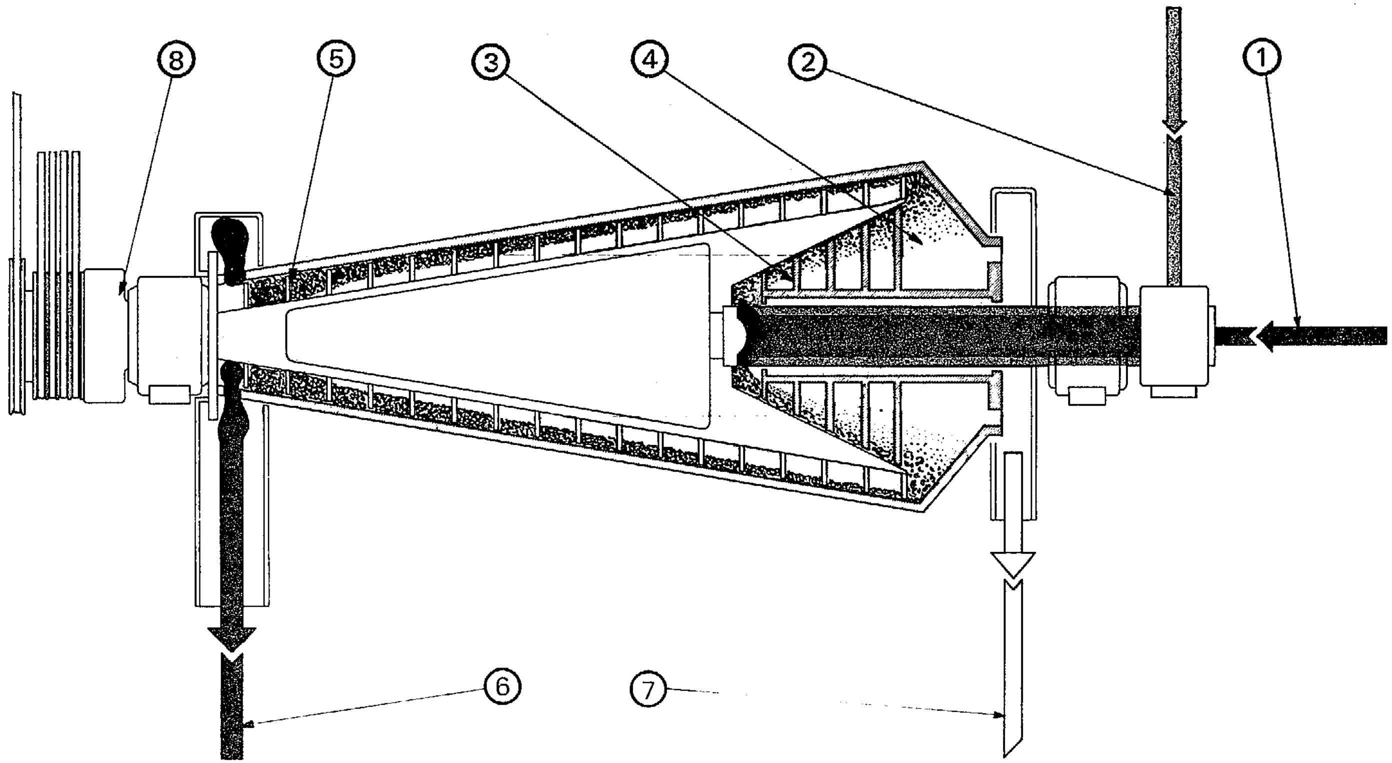
4 Sludge separating chamber

5 Sludge screw conveyor

6 Outlet for sludge cake

7 Outlet for reject water

8 Cyclo-gear



TOTAL-KRUGER (GB).

(with acknowledgement to Kruger (G.B.).