Dewaterability of municipal sludges 2: Sludge characterization and behaviour in terms of SRF and CST parameters

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Abstract

Development of economic and more efficient sludge handling methods require identification and understanding of the characteristics that control sludge dewatering behaviour. This paper attempts to identify some of the main factors that might be responsible for the dewatering characteristics of municipal sludges. Two well known laboratory sludge characterization techniques were used, i.e. specific resistance to filtration (SRF) and capillary suction time (CST). The study indicated that the SRF provides greater opportunity for identifying and investigating these factors. By studying the deviations of the recorded behaviour from that hypothesised in the SRF test it was found that the SRF parameter is a composite of filtration, blinding and compression characteristic.

Introduction

Sludge handling (i.e. treatment and disposal) is often a major problem at waste-water treatment plants both from technological and economic aspects. One would expect that with mechanical dewatering the water content of the sludge could be reduced, for example, from 85 to 55 per cent, but this in many instances is not achieved even with the aid of chemical conditioners. The cost of energy, plant depreciation and maintenance and in particular chemical additives often make sludge treatment and disposal a heavy financial burden. Usually these effects become apparent only after the plant is put into operation, when the sludge does not respond to treatment as predicted, and the operators are forced to apply crisis procedures, usually high and costly chemical addition. The major cause of these problems is that the character of the water-sludge matrix is not well understood.

The problems associated with sludge dewatering are widely appreciated and extensive research has been reported, but the data available in the literature tend to be of an *ad hoc* nature and difficult to relate to a common basis.

This second paper on dewaterability of municipal sludges attempts to identify some of the main factors that might be responsible for poor dewatering of municipal sludges. The first paper was also published by the author (Smollen, 1986a).

Filtration tests for sludge dewatering characterization

In the literature, characterization of sludge dewaterability has been attempted mainly in terms of the specific resistance to filtration (SRF) and capillary suction time (CST). Theoretical and experimental description of the two parameters is given in the first of the two papers on dewaterability of municipal sludges (Smollen, 1986a).

These two parameters are based on certain hypothetical properties of sludge dewatering, and will allow description of the dewatering behaviour only in so far as these hypothetical properties reflect reality. At present the two parameters are widely accepted as the basis for sludge dewatering characterization. However, by studying the deviations of the recorded behaviour from the behaviour indicated by employing these parameters it is possible to identify other factors that explain these deviations.

Of the two parameters, i.e. SRF and CST, the SRF is the more important, principally because it relates the rate of filtration to a number of parameters directly implicated in filtration, as described in the first paper. In the rest of this paper, the SRF test will feature prominently and the effects of a number of factors on the SRF and dewatering will be reported.

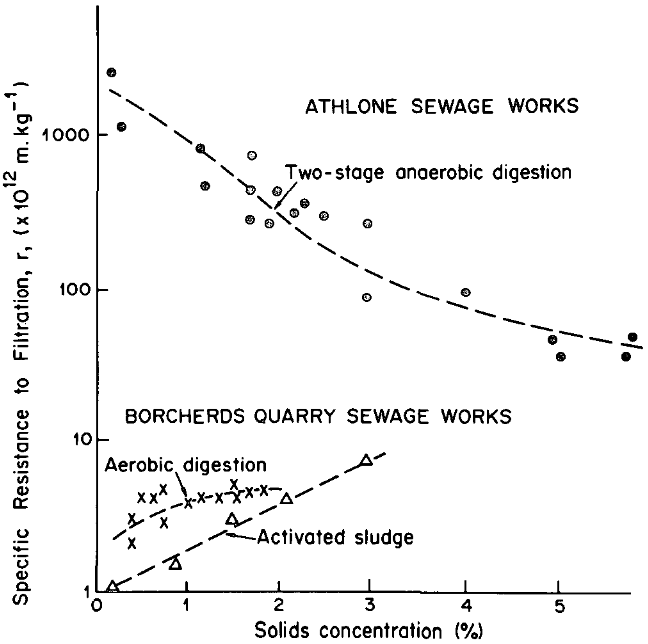

Figure 1
Relationship between specific resistance to filtration and solids concentration for various sludges.

Factors influencing filtration rate

The following factors are investigated:

- solids concentration
- particle distribution and behaviour
  Blinding phenomenon
  Medium and cake resistance
  Floc appearance
  Biopolymer formation

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- sludge compressibility

Solids concentration

In terms of the equation $\mu rc/(2\ PA^2)$ = constant = b (Smollen, 1986a) the value of r (specific resistance to filtration) should be independent of the solids concentration, c. However, this is not found to be so in practice. Figures 1 to 3 show that for anaerobically digested sludge there is an increase in SRF values with a decrease in solids concentration. The opposite appears to apply to activated sludge slurries where there is a decrease in SRF with a decrease in solids concentration (Figs. 1 to 3). It is clear that other factors not considered in the theoretical model affect the filterability of sludges. At present one has to take note of experience in this regard, because slurry concentration can be an important factor in determining the method of dewatering.

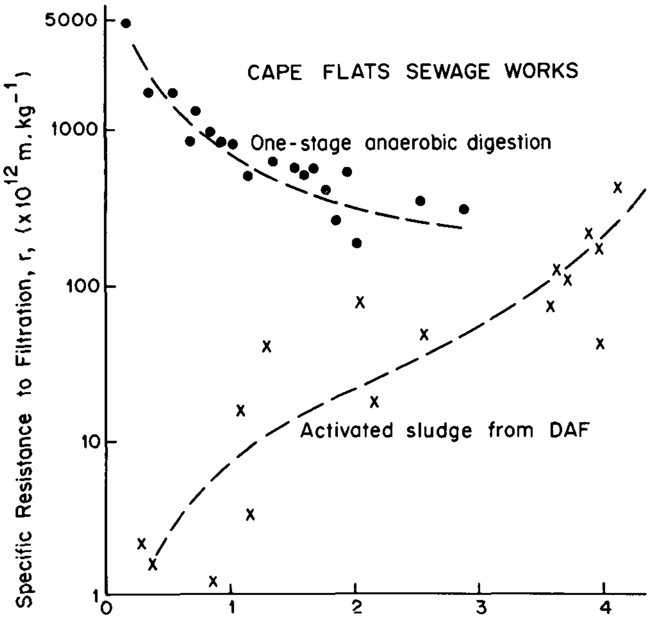

Figure 2
Relationship between specific resistance to filtration and solids concentration for various sludges.

TABLE 1
SOLIDS CONCENTRATION OF MUNICIPAL SLUDGES IN SOUTH AFRICA

Type of sludge	Solids Concentration (%)
Primary sludge:	
Thickened	2,3 – 5,6
Digested	2,5 – 6,7
Activated sludge:	
Returned	0,3 – 0,8
Thickened	2,4 – 4,4
Mixture of primary sludge and activated sludge:	
Digested	1,5 – 2,4

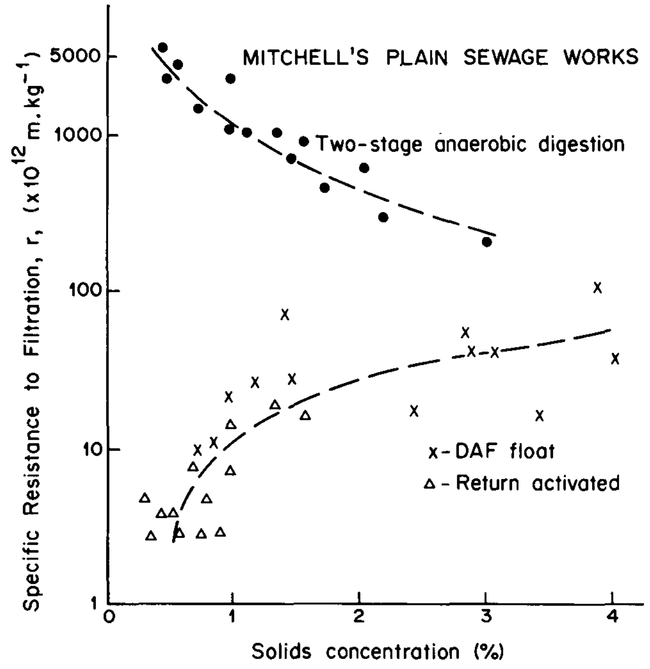

Figure 3
Relationship between specific resistance to filtration and solids concentration for various sludges.

Table 1 shows the range of solids concentrations in the various types of sludge obtained from different plants in South Africa (Smollen *et al.*, 1984).

Note that return activated sludge is the most diluted of all the sludges produced at municipal waste-water treatment plants and is the cause for the lower concentration when mixed with primary sludge in the anaerobic digestion process; usually sludges after anaerobic digestion are characterized by low solids concentrations.

The effect of solids concentration on CST is illustrated in Fig. 4 using aerobically and anaerobically digested sludge samples. As can be seen there is no apparent correlation between CST and solids concentration, especially in the case of anaerobically digested primary sludges. This is in contrast with what is so often postulated in the literature, viz. the dependence of CST measurements on solids concentration. This finding leads to the conclusion that parameters other than, or in addition to, solids concentration may be critical to the response of a sludge sample to CST measurement. Therefore, interference with dewaterability during full-scale plant operation of such parameter could be expected.

Particle distribution and behaviour

SRF data together with microscopic examination were employed to investigate the effect of particle distribution and behaviour on sludge dewaterability.

Blinding phenomenon

When a sludge contains fine particles, specific resistance measurement is affected by blinding, either of the passageways through the sludge (cake blinding), or of the filter medium during filtration (medium blinding). Karr and Keinath (1978) developed an expression which they called "blinding index" (BI). This index has a scale ranging from zero (unblinded) to 100

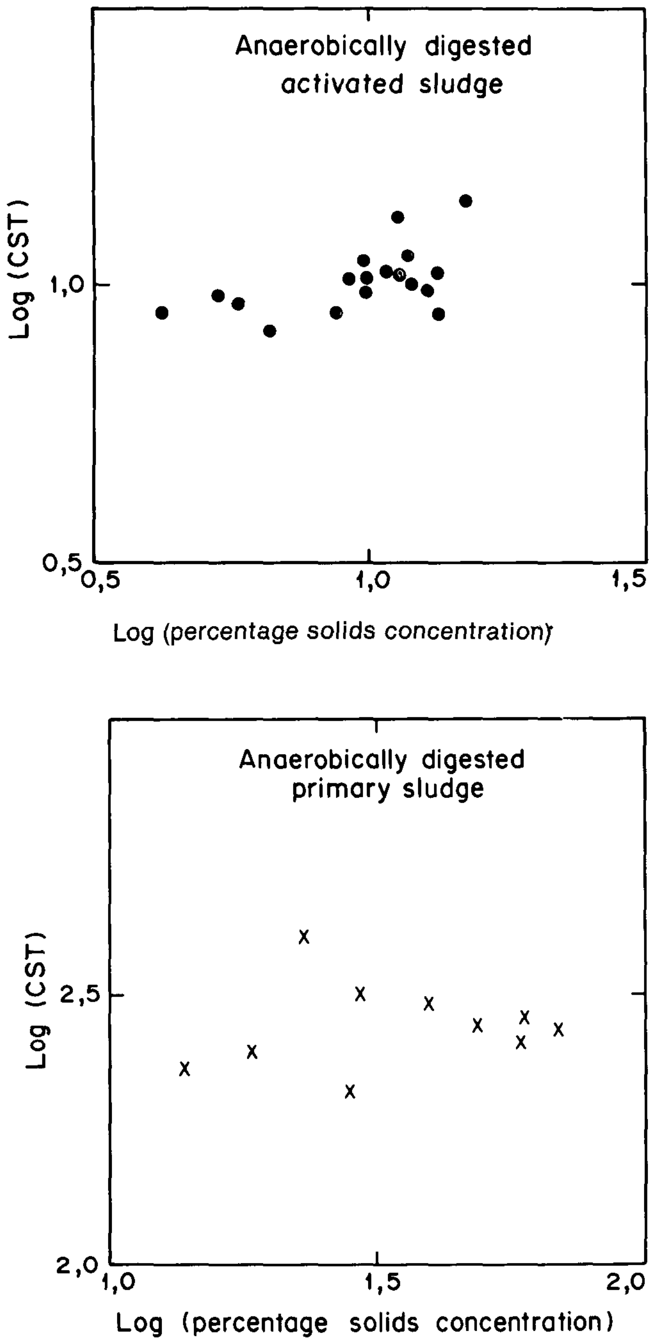

Figure 4
Effects of solids concentration on capillary suction time.

per cent (completely blinded), and is calculated from SRF measurements on a sludge at two different solids concentrations. The index is defined by the following relationship:

$$BI = \frac{r_1 - r_2}{r_1} \cdot \frac{c_2}{c_2 - c_1} \cdot 100\,(\%) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where:

r_1, r_2 = specific resistance value at two different concentrations
c_1, c_2 = mass of cake deposited per volume of filtrate collected for a sludge at two different solids concentrations.

Theoretically, the value of BI must remain within the range of zero to 100 per cent (Karr and Keinath, 1978). This arises from the criterion that as the SRF of an unblinded sludge is independent from solids concentration, the term ($r_1 - r_2$) is equal to zero, and therefore BI must also equal zero per cent. But when blinding occurs, SRF becomes dependent on solids concentration. The net effect on the BI equation is that the first group of variables becomes the exact inverse of the second. These, therefore, cancel and yield a BI of 100 for a completely blinded sludge. In practice, however, some of the BI values exceed 100 per cent going as high as 290 per cent (see Table 2), with some results giving negative BI. This inconsistency is most likely due to an inadequate theoretical model, which does not incorporate all the characteristics influencing the behaviour of compressible sludges.

TABLE 2
BLINDING CHARACTERISTICS AND CORRESPONDING SRF AND CST

Type of Sludge	Blinding		SRF	CST^{18}*
	β (slope)	BI (%)	($\times 10^{12}$m.kg^{-1})	(s)
Primary	8,26	290	44	70
Activated	2,00	– 20	5	8
Anaerobically digested				
– primary	3,39	110	36	270
– primary and activated	3,20	80	267	470
Aerobically digested				
– activated	2,00	0	5	10
Heat treatment	1,46	10	0,5	9

*CST^{18} denotes the use of an 18 mm funnel.

Medium and cake resistance

The blinding index does not distinguish between medium and cake resistance. Christensen and Sipe (1982), however, consider that it is vital to distinguish between these two effects when it comes to media selection for sludge filtration processes. They suggest that, by proper interpretation of Buchner funnel sludge filtration data, refinement in the media selection process can be achieved. To this end, they suggest plotting filtration data according to a rearranged form of Eq. 3(b) given in the first of these two papers.

$$\log t = \log b + 2 \log V \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where:

t = filtration time,
V = volume of filtrate and
b = slope of the plot of t/V vs. V

According to Eq. (2) the data should plot as a straight line with a slope $\beta = 2$ when plotted log t versus log V. If the medium is being blinded, the slope β will be less than 2 (resistance decreasing). If the cake is being blinded, the slope β will be greater than 2 (resistance increasing). If the slope is equal to 2, there is no blinding.

According to Fig. 5, high cake blinding was recorded with primary and anaerobically digested sludges, medium or no blinding with activated sludges, and medium blinding with Zimpro heat-treated sludge. Owing to changeability in the nature and behavioural patterns of biological sludges, the data shown in Fig.

5 cannot be taken as typical. However, the measurements in Fig. 5 were obtained by using a Buchner funnel with *pressure* instead of traditional *vacuum* application, which may affect the blinding pattern. Even though the Chemical Engineer's Handbook (1973) reported that vacuum test data are approximately the same as pressure test data, "bleeding" of fine particles at the beginning of the test was found to occur under pressure. Bleeding only terminates after a small thickness of cake has formed on the medium, with fine particles caught in the cake. In contrast the "bleeding" phenomenon has not been observed under vacuum filtration. This might be due to a slow increase in vacuum at the start of application, as opposed to a more rapid application of pressure. Pressure and vacuum testing, in consequence, may give rise to different behavioural characteristics and should be investigated in greater detail.

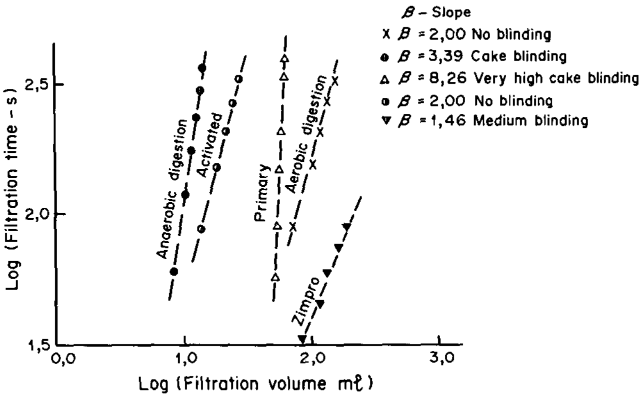

Figure 5
Blinding characteristics of various biological sludges.

Floc appearance

Slides of the different sludge samples under investigation were prepared, according to the Gram-stain technique, and photographs were taken of the microscopic appearance. Figure 6 shows photographs of primary and anaerobically digested sludges, which are characterised by a high degree of cake blinding (Fig. 5). The floc appearance in Fig. 6 is not clearly defined, owing to a great number of dispersed particles in the liquid phase. In contrast, activated and heat treated sludges, shown in Fig. 7, display well defined flocs and the surrounding liquid shows few dispersed particles. According to the visual observations emerging from the microscopic examinations, it would appear that sludges with a high degree of blinding described by β and BI factors contain high proportions of fines and dispersed particles. However, from examination of Table 2 such an interrelation is not necessarily indicated by SRF/CST measurements; this finding is supported by observations of similar significance made by Knocke and Wakeland (1982). In view of the above, the suggestion made by Karr and Keinath (1978) that "particle size distribution seems to be the property of sludge that mostly affects its dewaterability" has to be taken with caution; there may be some other parameter more appropriate for dewaterability assessment.

Biopolymer formation

A study of Novak and Moore (1982) has shown that thickening

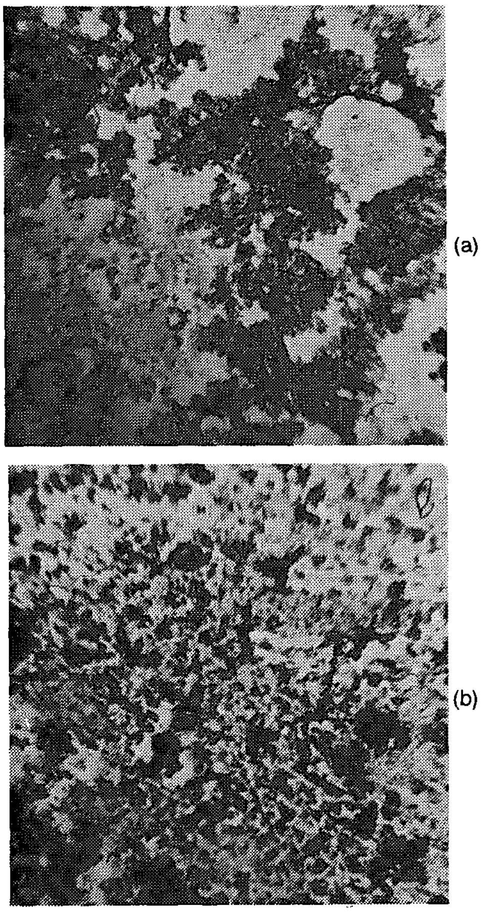

Figure 6
Microscopic appearance: (a) primary sludge (b) anaerobically digested mixtures of primary and activated sludge.

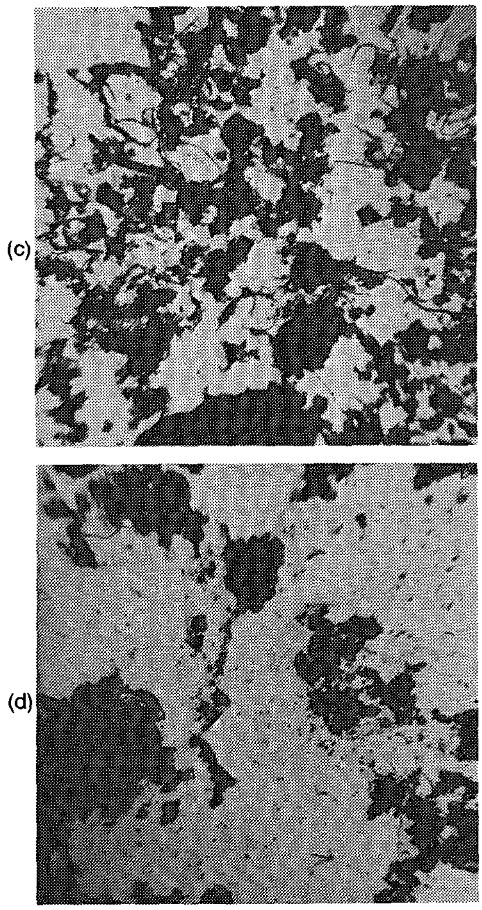

Figure 7
Microscopic appearance: (c) activated sludge (d) heat treated by the Zimpro process.

and dewatering properties of sludge are influenced by the presence of biopolymers. Specifically, organic material of high molecular size, appearing as extracellular polymers in solution, interferes with filtration. The quantity of high molecular size polymers was found to correlate with dewatering characteristics in that dewatering improves when the biopolymers are removed from the solution phase.

According to Pitman (1975), deterioration in dewaterability of activated sludges is caused by mobile micro-organisms that maintain fine particles in the liquid phase. In conclusion, he suggests that effluent suspended solids content gives a good indication of sludge dewaterability.

In this investigation there is evidence supporting the above finding: if anaerobically digested sludge is diluted by adding the turbid supernatant from the digester to the sludge, both SRF and CST increase, whereas if clear water is used for dilution, the opposite happens. The question then arises as to what is the main cause of poor dewatering. Is it due to fines which are created by disintegration of the parent particles and which block the filter medium, or is it the high molecular size polymers which interfere with filtration by blinding the small channel in the cake structure? A line of research prompted by these questions appears to hold some promise in contributing to a better understanding of sludge particle water-bonding mechanisms.

Sludge compressibility

The applied pressure differential across the sludge cake is an operational parameter that may be varied to produce an optimum sludge dewatering rate. To accomplish such an optimisation, a relationship between pressure differential and SRF must be established (Eckenfelder and Ford, 1970). This relationship is described by a coefficient of compressibility, s, given by the slope of the straight line which is obtained by plotting log r versus log P, according to the equation:

$$r = r_1(P)^s \qquad (3)$$

where

r_1 = SRF when P = 1
s = coefficient of compressibility

A knowledge of the compressibility of a sludge is useful in determining the pressure to be used in a process such as pressure filtration. High pressures are normally avoided when pressing a highly compressible sludge, since the sludge tends to compress or compact to the point where liquid flow through the cake is no longer possible.

Figure 8 illustrates changes in SRF with pressure variation for three different types of sludges. As can be seen, anaerobically digested sludge displays the lowest coefficient of compressibility; s = 0,5, while activated sludge the highest; s = 1,4. Compressibility coefficient is usually determined under pressure differences ranging from 20 to 100 kPa. Information on behaviour of sludges subjected to higher pressures is limited. According to the Chemical Engineer's Handbook (1973) an increase in pressure causes a nearly proportionate increase in the flow rate during filtration of granular or crystalline solids. This principle is not equally applicable to highly compressible biological sludges, such as activated sludge. This observation is supported by Baskerville *et al.* (1978) who compare dry solids content of filter cake produced by a piston press operating for two minutes at pressures of 70 and 700 kPa (Table 3).

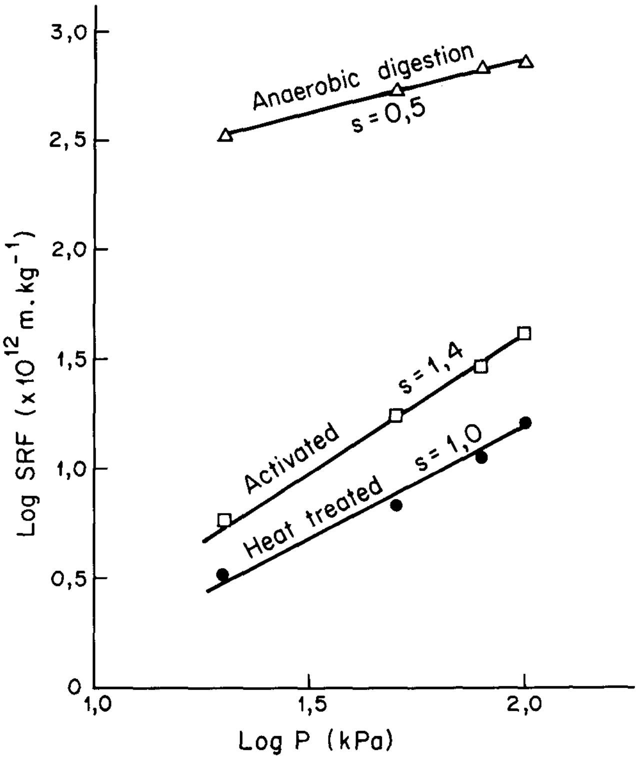

Figure 8
Changes in specific resistance to filtration with pressure difference.

TABLE 3
COMPARISON OF DRY SOLIDS CONTENT OBTAINED FROM SAMPLES AT LOW AND HIGH PRESSURE DIFFERENTIAL APPLICATIONS (BASKERVILLE *ET AL.*, 1978)

Type of sludge	Dry solids content (%)			Increase in solids content (%)
	Initial	At 70 kPa	At 700 kPa	
Primary	4,4	22	36	63
Activated	2,0	8,2	11	34
Anaerobically digested	2,7	15	26	73

From Table 3 it can be seen that increase in dry solids content is not proportionate to increase in pressure differential. For instance, tenfold increase in pressure, i.e. from 70 to 700 kPa resulted in 34 per cent increase in solids content, in the case of activated sludge. The best response to pressure increase is shown by anaerobically digested sludge, which is characterised by the lowest coefficient of compressibility (Fig. 8). An interesting observation is that plotting the SRF versus pressure often shows functional discontinuity (Fig. 9), i.e. different factors appear to govern filterability in different pressure regions. Thus, it would seem that for a particular sludge a low β value, in the low differential pressure region, indicates blinding of the medium as the governing factor, but above a certain critical pressure differential, high β value indicates cake resistance as the governing factor.

Conclusions

The SRF parameter as a measure of the filtration (dewatering)

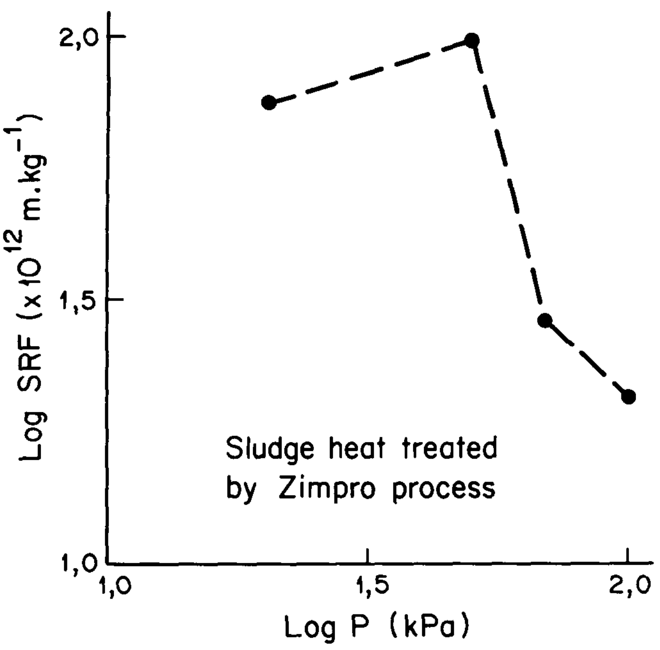

Figure 9
Functional discontinuity of log (P) vs. log (SRF).

behaviour of different types of sludges is a composite of solids concentration, blinding and compression characteristics as follows:

- sludge solids concentration affects SRF measurement, depending on the type of sludge; for example, anaerobically digested sludge displays a decrease, while activated sludge displays an increase in SRF values with increase in solids concentration.

- blinding interferes with the filtration rate and hence with the SRF by creating either cake or filter medium resistance. The SRF measurement is influenced differently by the two types of blinding. By appropriate interpretation of the results, cake resistance can be distinguished from medium resistance.

- owing to high compressibility generally displayed by biological sludges, increase in pressure differential does not result in proportionate improvement in filtration. High pressures should be avoided when handling activated sludges, while anaerobically digested sludges appear to be not so much affected by the compressibility factor. In addition, our data often exhibited a functional discontinuity in the log P vs. log SRF plots (to determine s); this might indicate that different factors govern the SRF values in the low and the high pressure regions.

- the method of differential pressure application in the SRF test, i.e. whether the measurement of SRF is made under pressure or under suction, appears to be an important factor in creating either cake or medium resistance.

- microscopic examination shows that sludge characterized by high proportions of colloids and fines in the supernatant creates cake blinding during filtration. This suggests that the liquid phase characteristics might be the reason for some of the poor dewaterabilities observed.

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