Dewaterability of municipal sludges 1: A comparative study of specific resistance to filtration and capillary suction time as dewaterability parameters

Maryla Smollen
National Institute for Water Research, Bellville Branch Laboratory, Council for Scientific and Industrial Research, P.O. Box 109, Sanlamhof 7532, Cape Town, South Africa.

Abstract

The parameters specific resistance to filtration (SRF) and capillary suction time (CST) are used to compare the relative dewatering properties of different types of sludge. In terms of the results, anaerobically digested mixtures of primary and waste activated sludges display the poorest dewatering characteristics while sludge heated by the Zimpro process is recorded to have the best dewatering properties.

Introduction

The specific resistance to filtration (SRF) and capillary suction time (CST) are widely accepted measurements of sludge dewatering properties. The former derives its importance from the fact that it forms a parameter within a theoretical model of the filtration phenomenon (Carman, 1938). However, these parameters are not comprehensive in their description of dewatering behaviour, but are the only ones available at present and must serve of necessity as comparative measures until improved parameters are developed. Furthermore, differences in test procedures between laboratories have been found to influence the SRF results (Kempa and Fukas-Plonka, 1982). To eliminate these phenomena during this investigation, a set procedure with the same apparatus was used for all the measurements. This allowed comparison of dewatering properties of different types of sludge in a consistent manner.

SRF and CST of six categories of municipal sludge from eleven municipal waste-water treatment plants throughout South Africa are presented in this paper and analysed for the purpose of obtaining a comparative picture of the dewatering properties of the different types of municipal sludge. This is the first of two papers on dewaterability of municipal sludges in terms of SRF and CST parameters; the second paper is also published by the author (Smollen, 1986b).

Filtration parameters

The two well-known and generally used laboratory measurements for dewaterability of sludges are the following:

- specific resistance to filtration (SRF)
- capillary suction time (CST)

SRF measurement

In the SRF measurement a sludge sample is dewatered by filtering it in a Buchner funnel under vacuum differential (usually 49 kPa) through a filter paper (usually Whatman No. 1 and 541). Instead of vacuum, positive pressure may be applied. According to Kavanagh (1980), both methods should give results which agree within 3 per cent. The SRF derives its importance from the fact that it is a parameter based on a theoretical model of the filtration phenomenon. From Carman (1938) accepting D'Arcy's law and assuming (i) the cake form is incompressible and (ii) the filter media have a negligible resistance (Gale, 1967) the following equation is derived to describe the volume of slurry that deposits its solids onto the filter cake in time dt:

$$\frac{1}{A} \cdot \frac{dV}{dt} = \frac{PA}{\mu r c V} \qquad (1)$$

Where

V = volume of filtrate (m^3)
P = applied pressure differential ($N.m^{-2}$)
A = filter area (m^2)
c = concentration of slurry ($kg.m^{-3}$)
r = specific resistance of cake to filtration, i.e. SRF ($m.kg^{-1}$)
μ = filtrate viscosity ($N.s.m^{-2}$)

In a batch filtration test the solution is

$$t = \frac{\mu r c}{2PA^2} V^2 \qquad (2)$$

If μ, r, c, P and A are constant then

$$\mu rc/(2PA^2) = \text{constant} = b \qquad (3)(a)$$
$$\text{i.e.} \quad t = bV^2 \qquad (3)(b)$$
$$\text{or} \quad t/V = bV \qquad (3)(c)$$

A plot of t/V vs.V should give a straight line passing through the origin and the measured slope determines b, hence r can be calculated from Eq. (3)(a). Theoretically, values of r given by Eq. (3)(a) are expected to remain constant irrespective of the slurry concentration c, and therefore, by standardizing the pressure differential, all sludges can be compared directly.

CST measurement

Another method for the determination of dewaterability is the CST measurement. The method is most commonly used for rapid determination of flocculation dosages. The CST is determined by pouring a sample of sludge into a standard reservoir (18 mm diameter) resting on absorbent filter paper. The filtrate is drawn from the reservoir by the capillary suction of the paper. The liquid saturates the paper and spreads outwards in a circular pat-

Received 9 January 1986.

tern at a rate determined by the properties of the paper, the viscosity of the filtrate and the filterability of the sludge. The time taken for the liquid front to move a specified radial distance is recorded in seconds and defines the capillary suction time. Complete details concerning equipment and procedures are available in the literature (Baskerville and Gale, 1968).

Experimental

The SRF was determined by pouring a 250 mℓ sludge sample into a Buchner funnel lined with No. 541 Whatman filter paper. The funnel was then sealed on top by means of a locking ring (Fig. 1) and a positive differential pressure of 4,9 × 10^4 Pa (the standard pressure differential used during vacuum filtration process) was applied. A pressure regulating system maintained the pressure within one per cent of the set value. The volume of filtrate collected during the period in which the apparatus was brought to full pressure was disregarded; thereafter the filtrate volume was recorded every 30 s using an electronic balance connected to a timer. The use of an electronic balance rather than a graduated cylinder for measuring the filtrate volume improves precision. Pressure filtration, instead of the commonly used vacuum procedure, also allows for more accurate control of the pressure differential during the test. Both the pressure and the vacuum methods should give the same results within the same range of pressure differentials (Chemical Engineer's Handbook, 1973).

The capillary suction time (CST) was determined in a standard CST apparatus, using an 18 mm diameter reservoir resting on standard CST filter paper.

The sludges from eleven plants were categorised into six different types, i.e. primary, returned activated, waste activated thickened by dissolved air flotation (DAF), anaerobically digested primary, anaerobically digested mixture of primary and activated, and sludges heat-treated by the Zimpro process. The SRF and CST tests were done on each batch of the different sludges investigated.

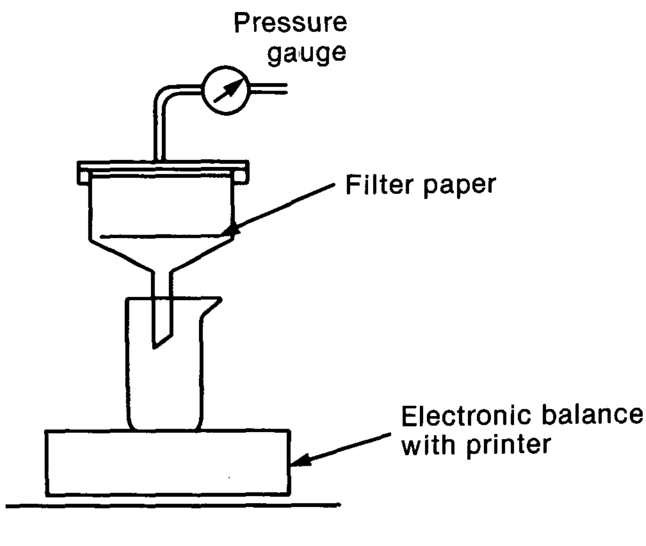

Figure 1
Apparatus for measuring specific resistance to filtration.

Results and discussion

Using apparatus shown in Fig. 1, the ratio (time)/(volume of filtrate) was obtained and plotted against the volume of filtrate. A typical plot is illustrated in Fig. 2.

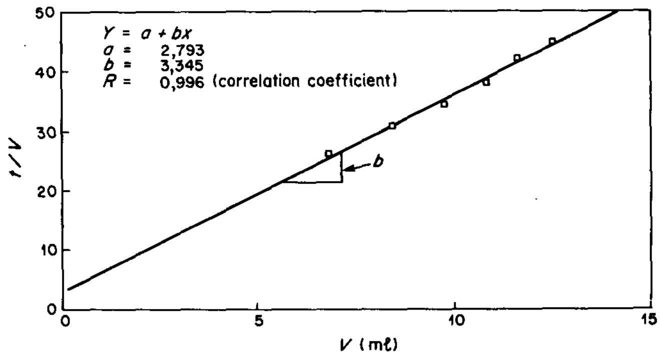

Figure 2
Determination of slope b for specific resistance to filtration calculation.

Dewaterability measurement in terms of CST and SRF

The waste-water treatment works from which the sludge samples were obtained and the individual test results are shown in Table 1. The range of results for each category of sludges is shown in the diagrams in Figs. 3 and 4.

Figure 5 illustrates the same general tendency of SRF and CST data. However, a scatter of the results, especially in the higher range of SRF values indicates, that although there are common factors affecting both SRF and CST such as sludge solids content, and temperature, these two parameters are also dependent on other factors which are not common. The main reason that has led researchers to expect a linear relationship between SRF and CST is that both tests provide a measure of the resistance offered by a sludge to the withdrawal of water. The more difficult the sludge is to dewater, the higher the SRF and CST values should be and vice versa. However, the differences in particle properties between sludges such as compressibility, particle size distribution, particularly the presence of fines and fragile settleable solids fraction (Karr and Keinath, 1978) give rise to deviations from the expected relationship.

The data indicate the lack of quantitative relationship between SRF and CST. Therefore these two parameters should not be treated as substitutes for each other for control and other purposes, as is often reported in the literature.

SRF, CST measurements related to dewatering experience

Theoretically, high SRF and CST values indicate inferior dewatering properties while low SRF and CST values indicate superior dewatering properties.

It is generally accepted that the laboratory filtration test can successfully predict dewaterability on drying beds, however, it cannot do it so accurately for mechanical dewatering (Slim *et al.*, 1984). This is because neither of the laboratory tests provide a

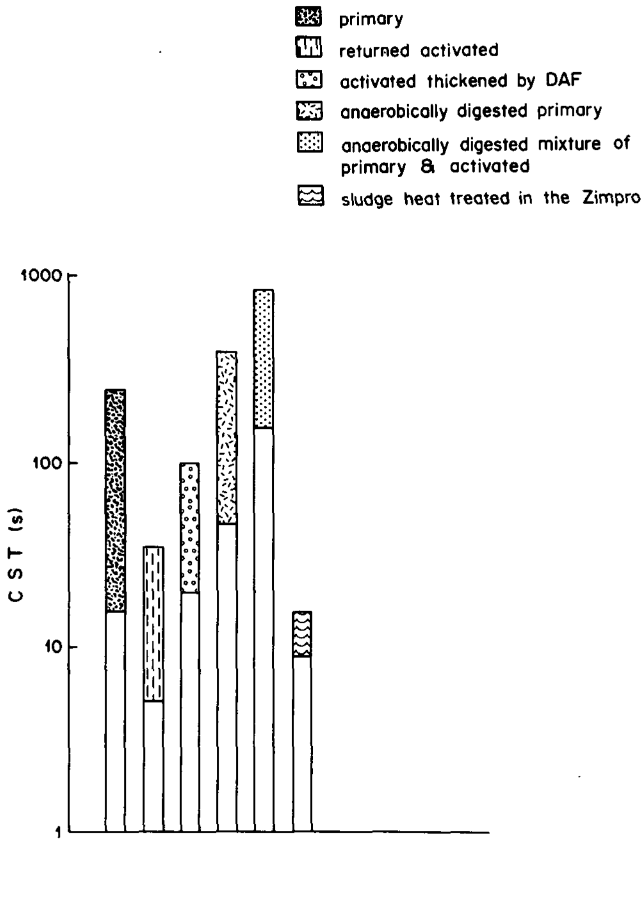

Figure 3
Range of capillary suction times for various sludges.

comprehensive measure of all properties that influence sludge dewatering behaviour during mechanical dewatering. Despite these inadequacies and owing to lack of alternative measurements, CST and SRF are used for making general qualitative statements on dewaterability of sludges. For example, it is accepted that sludges conditioned to values of SRF and CST below 10×10^{12} $m.kg^{-1}$ and 50 s respectively, can be satisfactorily dewatered by mechanical equipment.

Typical SRF values for some types of sludges reported by the US Environmental Protection Agency (USEPA, 1974) are illustrated in Fig. 4. As can be seen, results obtained on the same types of sludges in South Africa, fall within the range of typical values reported by the USEPA.

No typical SRF values for anaerobically digested mixtures of primary and waste activated sludges could be found in the literature. These sludges display the highest SRF and CST values (Figs. 3, 4 and 5) and are also characterized as difficult to very difficult to dewater by sewage plant personnel.

Effect of anaerobic digestion on sludge dewaterability

Owing to the lack of information on the influence of anaerobic digestion on sludge dewaterability, the behaviour of sludge particles undergoing anaerobic digestion was examined more intensively than that of other sludges. The three photographs of the microscopic appearance of different sludge samples from the same sewage works shown in Fig. 6 represent: activated sludge, anaerobic sludge after first stage digestion and anaerobic sludge after second stage digestion respectively. The floc structure of activated sludge differs significantly from that of anaerobically digested sludge. The visual differences appear to reflect the differences in the SRF, CST values (Table 2). The SRF and CST values increase significantly after both primary and activated sludges have been subjected to the anaerobic digestion process.

TABLE 1
SRF AND CST FOR VARIOUS TYPES OF SLUDGES FROM DIFFERENT SOURCES IN SOUTH AFRICA (WITHOUT CHEMICAL CONDITIONING)

Waste-water treatment works	Primary		Waste activated		DAF Waste activated		Anaerobically digested primary		Anaerobically digested primary and activated		Anaerobically digested humus		Aerobically digested activated		Heat treatment (Zimpro)	
	CST[18] (s)	SRF*	CST[18] (s)	SRF*	CST[18] (s)	SRF*	CST[18] (s)	SRF*	CST[18] (s)	SRF*	CST[18] (s)	SRF*	CST[18] (s)	SRF*	CST[18] (s)	SRF*
Borcherd's Quarry			6–13	1,0– 8,0									9–14	2,2–5,5		
Athlone	52–105	100–150					220–400	32–388								
Mitchell's Plain	70–198	6–230	7–10	3,0–20	22–96	10–124			310–860	400–2 600						
Cape Flats	90–130	60–200	8	2,6–28	100–70	77–420			300–460	200– 620						
Milnerton	240	215													9–16	0,2–1,4
Bellville			5– 8	0,6–13,4												
Northern Sewage Works, Johannesburg					20–50	18– 42					205	64				
Northern Sewage Works, Durban	37	14			30	29	48	38								
Kwa Mashu	150	174					175	58								
Kwa Dabeka															70	6,2
New Germany	22	19	8	4,3					152	138						
Fish Water Flats			35	40											11–14	0,1–0,3
U.S. EPA data (1974)		100–300				40–120		30–300								

*SRF – $\times 10^{12}$ $m.kg^{-1}$
Note: CST[18] denotes the use of an 18 mm funnel

This is confirmed by photograph (a) in Fig. 6 where well defined flocs surrounded by clear supernatant can be seen. The liquid phase of the sludge which was subjected to anaerobic digestion differs significantly from that of activated sludge. It shows a very high turbidity after both first and second stage digestion. This observation confirms recent findings (Lawler and Singer, 1984) that digested supernatant returned to the process can account for as much as 71% of the suspended solids load on an activated sludge plant.

Conclusions

There is no quantitative relationship between SRF and CST. For this reason SRF and CST should not be used substitutionally for describing sludge dewatering behaviour.

The SRF can be used for measurement of the relative dewatering quality of sludges from various waste-water treatment plants, provided the test is conducted in a consistent manner.

Anaerobically digested mixtures of primary and activated sludge show the highest SRF and CST values which range from 138 × 10^{12} to 2 600 × 10^{12} m.kg^{-1} and from 152 s to 860 s respectively.

Sludges heat treated by means of the Zimpro process display the lowest values of SRF and CST, i.e. 0,1 to 1,4 × 10^{12} m.kg^{-1} and 9 to 16 s respectively.

Good intermediate filtration properties of waste activated sludges, specially those produced by extended aeration plants are indicated.

Acknowledgements

The financial support of the Water Research Commission, who sponsored the research, is gratefully acknowledged.

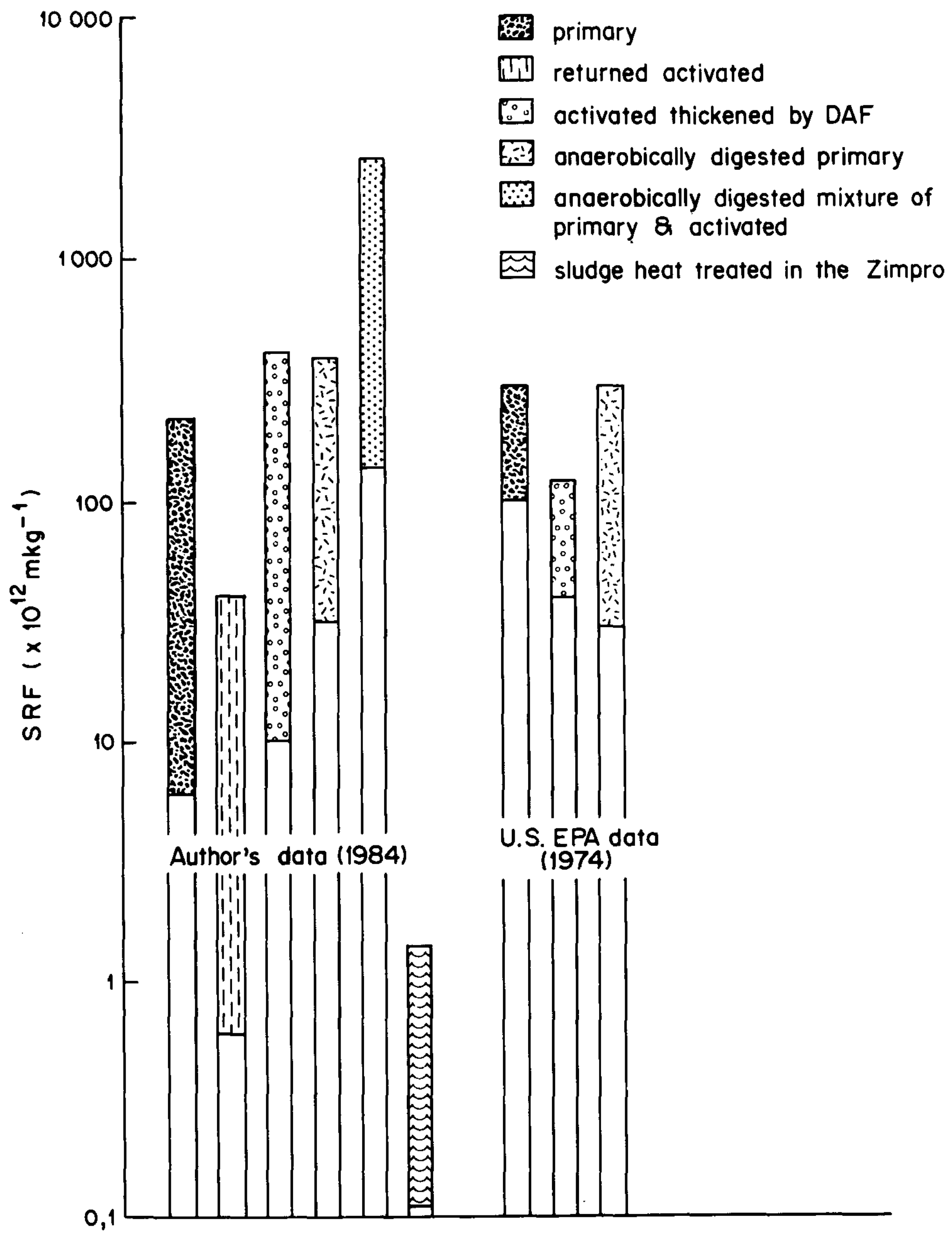

Figure 4
Range of specific resistance to filtration for various sludges.

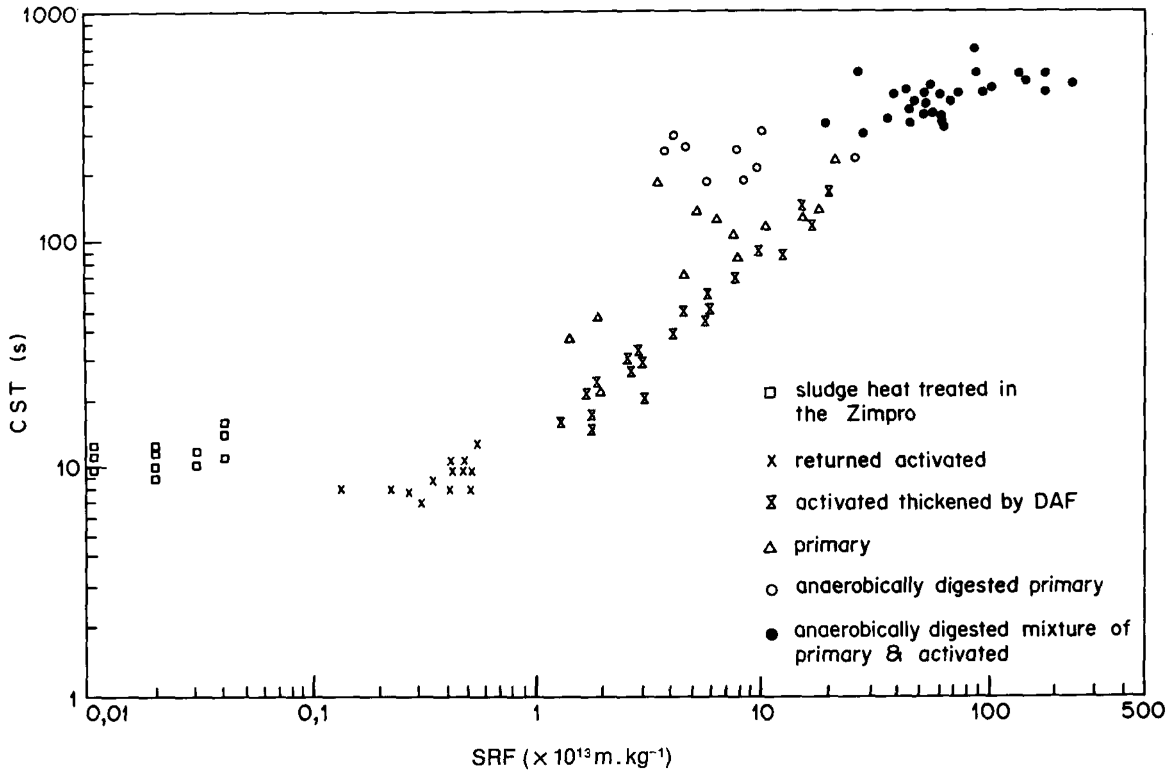

Figure 5
Relationship between specific resistance to filtration and capillary suction time for various types of sludges.

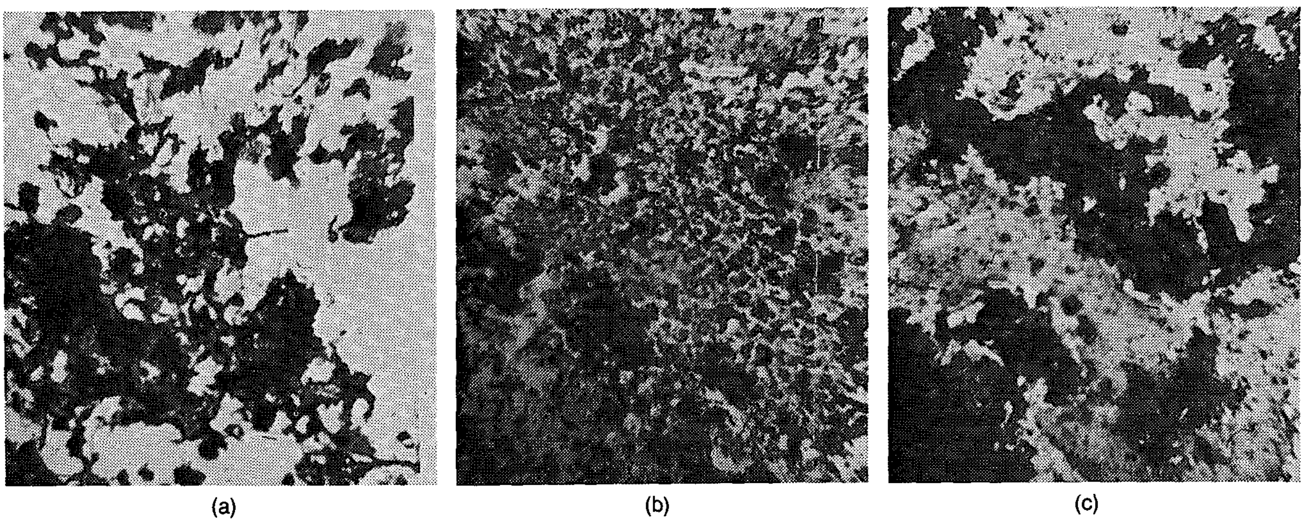

Figure 6
Microscopic appearance of (a) activated sludge (b) anaerobic sludge after 1st stage digestion (c) anaerobic sludge after 2nd stage digestion.

A special word of thanks for the assistance given during site visits is extended to the following: Sewage Branch of the Cape Town and Milnerton Municipalities, City Engineer's Department of the Port Elizabeth Municipality, City Engineer's Department of the Durban Corporation and the City Health Department of the Johannesburg Municipality.

This paper is published with the permission of the National Institute for Water Research, CSIR.

TABLE 2
SLUDGE DEWATERABILITY (SAMPLES FROM MITCHELL'S PLAIN WASTE-WATER TREATMENT WORKS – 1983/03/17)

Type of sludge	Solids concentration g/ℓ	SRF × 10^{13}m.kg^{-1}	CST[18] (s)
Primary sludge	54,3	35,5	198
Activated sludge	4,6	0,4	9
Anaerobically digested 1st stage	16,9	166	750
Anaerobically digested 2nd stage	17,9	68	600

References

BASKERVILLE, R.C. and GALE, R.S. (1968) A simple automated instrument for determining the filterability of sewage sludges. *Wat. Pollut. Contr.* **67** 233.

CARMAN, P.C. (1938) A study of the mechanism of filtration. *Trans. Inst. Chem. Engrs.* **16** 168.

CHEMICAL ENGINEER'S HANDBOOK (1973) 5th Edition McGraw-Hill – Ed. Robert H. Perry/Cecil H. Chilton.

GALE, R.S. (1967) Filtration theory with special references to sewage sludges. *Wat. Pollut. Contr.* **66** 622-631.

KARR, P.R. and KEINATH, J.M. (1978) Influence of particle size on sludge dewaterability. *J. Wat. Pollut. Control Fed.* **50** 1911-1930.

KAVANAGH, B.V. (1980) The dewatering of activated sludge. Measurements of specific resistance to filtration and capillary suction time. *Wat. Pollut. Contr.* **80** (1).

KEMPA, E.S. and FUKAS-PLONKA, L. (1982) Determination of the specific resistance: A critical review. Flemish Chapter of the Filtration Society, London.

LAWLER, D.F. and SINGER, Ph.C. (1984) Return flows from sludge treatment. *J. Wat. Pollut. Control Fed.* **56** (2).

SLIM, J.A., DEVEY, D.G. and VAIL, J.W. (1984) Mechanical dewatering of Zimpro heat-treatment and untreated sewage sludges: The treatment of waste liquors from the Zimpro heat-treatment of sewage sludges. City Engineer's Department, Port Elizabeth. Final contract report to the Water Research Commission.

SMOLLEN, M. (1986b) Dewaterability of municipal sludges 2: Sludge characterization and behaviour. *Water SA* **12**(3) 133-138.

U.S. ENVIRONMENTAL PROTECTION AGENCY (1974) Process design manual for sludge treatment and disposal. EPA Report No. 625/1 – 74 – 006.