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Properties of Sludge Produced From the Pressurized Wastewater Treatment Process

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Abstract

The aim of this study was to investigate the effect of pressure on settleability and filterability of the sludge produced from a pressurized biological wastewater treatment unit in comparison with an equivalent unit held at atmospheric pressure but otherwise operating under identical conditions. The specific sludge volume index (SSVI) and the specific resistance to filtration (r) are described as standard parameters to expresss the sludge settleability and filterability properties.

For the sludge from the pressurized unit, the combination of air stripping and mechanical stirring produced SSVI results of as low as 60 ml/g and the specific resistance was discovered to be moderately stable with a mean 51.9×10^{12} m/kg at 49 kPa. Investigations filterability into sludge settleability and filterability revealed that realistic settlement of the sludge from the pressurized unit could only be achieved following aeration and stirring. The indications from filterability tests suggest that the pressurized unit sludge may be more readily dewatered than that from the unit open to atmosphere.

Key Words: Biological wastewater treatment, Sludge treatment, Settleability, Filterability, Pressure.

Basınçlı Biyolojik Atıksu Arıtımında Oluşan Çamurun Özellikleri

Özet

Bu çalışmanın amacı biyolojik atıksu arıtımında basınç kullanımının, bir basınçlı atıksu arıtım ünitesinden alınan çamurun çökelme ve filtreden geçirilme özellikleri üzerine etkisinin araştırılmasıdır. Elde edilen sonuçlar aynı ortam şartlarında işletilen atmosfere açık bir referans ünite sonuçları ile karşılaştırılmıştır. Spesifik çamur hacim indeksi (specific sludge volume index, SSVI) ve çamur özgül direnci (specific resistance to filtration), çamur çökelme ve filtrasyon özelliklerini belirlemede kullanılan standart parametreler olarak tarif edilir.

Basınçlı üniteden alınan çamur için bir ön havalandırma ve karıştırma işleminden sonra SSVI değerinin 60 ml/g'a kadar düştüğü ve spesifik özgül direnç değerinin oldukça stabil ve ortalama 51.9×10^{13} m/kg (49 kPa vakum altında) değerine eşit olduğu belirlenmiştir. Çamur çökelme ve susuzlaştırma özelliklerinin belirlenmesine yönelik yapılan çalışma sonucu, basınçlı ünitedne alınan çamurun çökelmesi ancak bir ön havalandırma ve karıştırma işleminden sonra olabilmektedir. Çamur susuzlaştırma deneylerinin sonucunda ise, basınçlı üniteden alınan çamurun referans üniteden alınan çamura göre daha kolay susuzlaştırılabileceği anlaşılmıştır.

Anahtar Sözcükler: Biyolojik atıksu arıtımı, Çamur arıtımı, Çöktürme, Filtrasyon, Basınç

1. Introduction

The treatment of wastewater is essentially a separation process, a method of concentrating and converting suspended and soluble substrates into a settleable form (sludge) that can be separated from the bulk of the liquid. Sludge separation, treatment and disposal represents a major capital and operational cost in wastewater treatment (Peavy et al. 1986). Dewatering and disposal costs for a medium-sized activated sludge plant represents as much as 50% of the initial capital and 65% of the operating costs (Calcutt and Moss, 1984).

All sludge produced during wastewater treatment must eventually be disposed of. The methods selected for pre-treatment, dewatering and disposal must depend not only on the availability and practicability of certain processes but also on the economics of the situations. The desing and operation of a sludge disposal system is based on the volume of the wet sludge as well dry solids weight. Most of the sludges from wastewater treatment works are relatively difficult to dewater, particularly the secondary sludge produced by biological treatment. This sludge contains fine solids and a high water content. There are various methods of sludge dewatering and these include lagoons, sludge drying beds, filter pressing, vacuum filtration and filter belt presses. A parameter used to express the ease of mechanical sludge dewatering is called the specific resistance to filtration (r). This parameter does not only make comparisons of sludge filterability between different sludges possible but also provides a design criteria or sludge dewatering methods.

Typical values of specific resistance are 4-12×10^{13} m/kg for the activated sludge, 3-30×10^{13} m/kg for digested sludge, 3-10×10^{11} m/kg for conditioned primary sludge and 2-20×10^{11} m/kg for conditioned digested sludge (Barnes et al., 1981). A sludge of high specific resistance is more difficult to dewater than one of low specific resistance.

Hopwood and Downing (1965) investigated the effects of temperature, dissolved oxygen, strength of sewage and retention time on the sludge specific resistance to filtration. They reported that the specific resistance decreased with increasing retention time. As a result of the experiment, the specific resitance was increased to 33-45×10^{13} m/kg merely by increasing the stirring intensity of the conditioned sludge (Gale and Baskerville, 1970). According to Coackley (1958), although the specific resistance is used to describe the behaviour of sludges, little attention has been paid to studies of the compressibility coefficient of the sludge which mainly depends upon the relation between the filtration pressure and the specific resistance. The specific resistance can also be used to evaluate the effects of chemical conditioning materials on the sludge filterability (Vesilind, 1974).

The specific resistance to filtration may be defined as the resistance of sludge, having a unit weight of dry solids per unit area at a given pressure, to a unit rate of flow of liquid having unit viscosity. It is possible to analyse the filtration of sludge based on the flow of a liquid throught a porous medium. The work of Carman (1937) on filtration was developed by Coackley (1955) for the dewatering of sludges by filtration. The rate of filtration of a sludge is given by,

$$\frac{dV}{dt} = \frac{PA^2}{\mu(rcV + RA)}$$

where,

V	:	filtrate volume obtained after time t,
P	:	applied pressure,
A	:	filter area,
μ	:	absolute viscosity of filtrate,
r	:	specific resistance of sludge,
c	:	solids concentration of sludge,
R	:	resistance of clean filter medium.

and

$$r = M^{-1}L \qquad or \qquad r = m/kg$$

The higher value of (r) indicates a sludge which is more difficult to dewater. At lower values of (r), no further conditioning of sludge is required. Using a laboratory filtration apparatus it is possible to determine the specific resistance to filtration (r) by plotting t/V against V. In reporting a value of specific resistance to filtration, it is necessary to quote the pressure difference at which the measurement was carried out. A vacuum of 49 kN/m^2 is standard. The results of the specific resistance to filtration test are therefore reported as (10^{13}) m/kg.

The sludge volume index (SVI) may be used as a standard parametre for expressing sludge settleabilty and hence dewatering potential by simple settlement. The SVI is defined as the volume in millilitres occupied by one gram of dry solids after settling the mixed liquor for 30 minutes. The settlement is normally carried out in a one litre graduating cylinder. The SVI is then calculated as:

$$SVI = \frac{\text{Volume of settled sludge after 30 minutes}(ml/l)}{\text{Concentration of dry solids}(g/l)} = ml/g$$

Although widely and succesfully employed over a long period, the SVI possesess weaknesses with regard to reproducibility and comparability associated with the concentration of solids present and the size and geometry of the settling vessel. As a result, in 1975, the Water Research Centre (WRc) introduced the stirred specific volume index (SSVI) test as an improved method of measuring the settleability of sludge (WRc, 1975). For this test, a cylinder of specified dimensions is used and fitted with a specially designed stirrer which rotates at a rate of one rpm. The effect of the stirrer is to reduce the wall effect when concentrations of MLSS are high and the settleability of the sludge is poor. It also causes a consistent degree of flocculation in the sludge as it settles. This test either should be carried out with sludges of a 3.5% dried solids content or the results of other tests extrapolated to the standard 3.5% dry solids figure. The results are calculated in exactly the same manner as for the SVI. The SSVI test allows for a better simulation of conditions in a full-scale settling tank and allows for better comparability of the results from different treatment units. This parameter is also used in the desing of secondary sedimentation tank. Most plants suffer sporadic incidents of poor sludge settleabilty when the SSVI increases from an average value of <80 to > 120 (Horan, 1990).

2. Experimental Results And Discussion

The use of pressure is a relatively new technique in the field of biological wastewater treatment. An investigation was reported into the effect of pressures of up to 6 bars on the operation of laboratory-scale rotating biological contactors (Berktay and Aydın, 1996). In comparison with an identical reference unit held at atmospheric pressure, the pressurized unit demonstrated slightly improved BOD and COD removal efficiencies, a greatly improved capacity to nitrify and the development of a substantially lower sludge yield coefficient.

As the consolidation and dewatering characteristics of sludge reflect appreciably on the cost and ease of its disposal, a research strategy was developed to test the hypothesis that the sludge dewatering properties would improve with increasing pressure. For this, a series of settleability and filterability tests were carried out on the sludge produced by the pressurized treatment unit and by the reference unit open to atmophere. This proposal immediately created difficulties as a result of the relatively small amounts of sludge produced by the pressurized unit. For the settleabilty tests used was made of a 250 ml measuring cylinder fitted with a 1 rpm stirrer. When a sufficient mass could be assembled of the rather more abundant sludge from the reference unit, settleability tests were also carried out using a standard one-litre cylinder, also with a 1 rpm stirrer, so as to investigate the comparability of the results from the two different sized settlement cylinders.

With the sludge obtained from the pressurized unit a further problem appeared to have been overcome. As this sludge was withdrawn from the pressurized unit, gas bubbles were released from the solution and became attached to the sludge particles, effectively reducing the density of the solids and preventing settlement. Various techniques were investigated to overcome this problem. The application of a thermal shock to the sludge by rapid cooling was found to be totally ineffective. The application of a vacuum was found to be rather more effective but not to a significant extent. Air stripping by the aplication of diffused air was discovered to be rather better but only became appreciably successful when applied to the sludge which had already been subjected to vacuum treatment. Mechanical agitation by means of slow stirring by hand had some beneficial effects on settlement but in the end the technique which was found to be most effective with the pressurized unit sludge, was a combination of air stripping and slow stirring by hand.

The average amount of surplus sludge withdrawn from the pressurized and the reference units were found to be 270 ml per day (3.93% dry solids) and 628 ml per day (5.37% dry solids) respectively. The average percentage of volatile solids of the sludge samples were 92% and 88% for the pressurized and the reference units, respectively.

The sludge yield coefficient is defined as the total dry weight of sludge produced per unit weight of BOD_5 removed. The sludge production was calculated from the amount of surplus sludge removed from the reaction vessel plus the amount of suspended solids discharged in the effluent.

In this study, the production of biological sludge by the pressurized unit, in terms of sludge (dry solids) produced per unit mass of BOD_5 removed, was as low as 0.38 kg (dry solids)/kg (BOD_5 removed) even with an applied pressure of only 1 bar. As the pressure was increased by 1 bar increments up to 6 bars the sludge yield coefficient decreased further to 0.22 kg/kg through 0.11 kg/kg to 0.10 kg/kg and finally with a slight upturn to 0.14 kg/kg at 5 bars and 0.13 kg/kg at 6 bars (Figure 1). For the reference unit, the sludge yield coefficient ranged from 0.39 kg/kg to 0.74 kg/kg with an average value of 0.51 kg/kg.

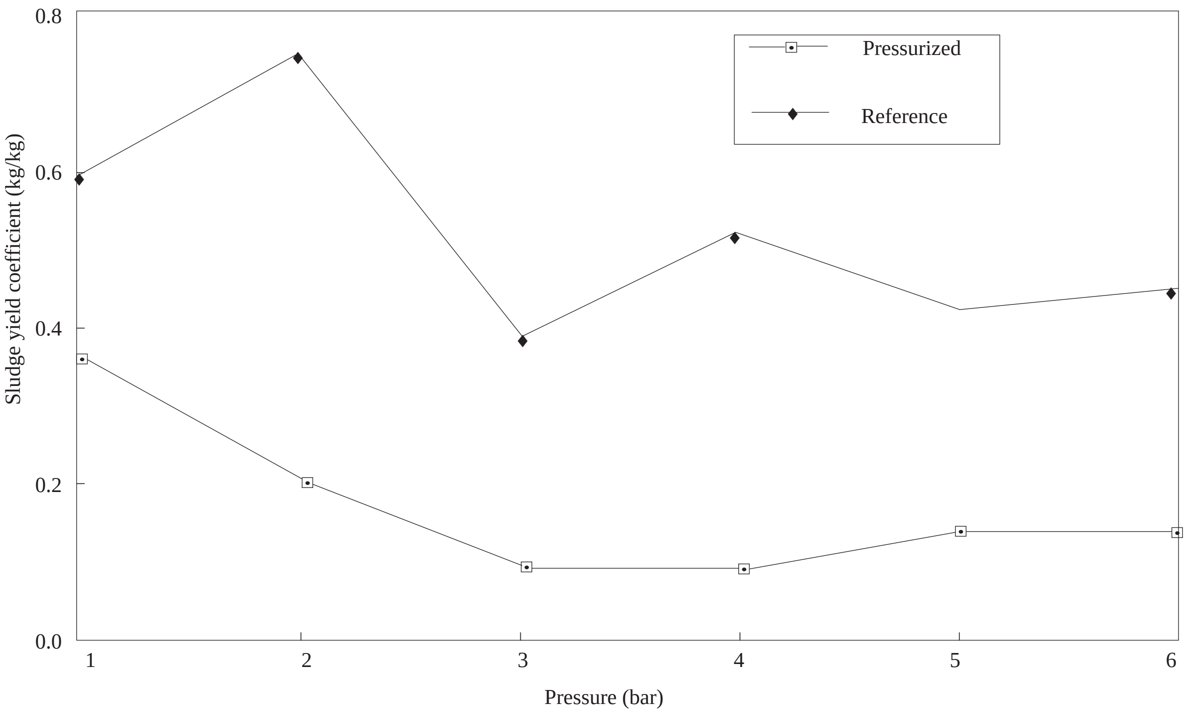

Figure 1. Sludge yield coefficients as a function of increasing pressure

The results for the sludge yield coefficient at a pressure of 5 bars are shown in Figure 2 as a function of organic loading. In general, the sludge yield coefficient tended to increase as the substrate loading increased. With the pressurized unit, a yield coefficient of 0.14 kg/kg was observed at a lower organic loading (13.3 g BOD_5/m^2. day). The yield coefficient increased to 0.16 kg/kg at a substrate loading of 20.9 g BOD_5/m^2. day, then to 0.21 kg/kg at the highest organic loading (27.0 g BOD_5/m^2. day). On the other hand, for the reference unit, the sludge yield coefficients were 0.41 kg/kg, 0.51 kg/kg and 0.55 kg/kg at the same level of organic loadings of those for the pressurized unit. In comparison, the increases in the sludge yield coefficients for the pressurized unit were found to be much lower than that for the reference unit as the organic loading increased.

The results given above demonstrated that an important feature of the use of pressure in the biodegradation of organic subsrate would be the much lower production of sludge. The sludge yield coefficient was always significantly lower than anticipated and compared very well even with the sludge production rates of a low rate anaerobic digester (Metcalf and Eddy, 1991). As difficultices with the disposal of sludge from municipal and industrial wastewater treatment plants increase, this must be a very significant result for the possible full-scale application of a pressurized treatment unit of this type.

The laboratory equipment used for the determination of the specific sludge volume index is shown in Figure 3. The results are shown in Table 1. It can be seen that initially there was no settlement at all with the sludges from the pressurized unit. No settlement was achieved with these sludges even following the application of thermal shock or the application of a vacuum. However, following the air stripping, SSVI's of between 109 ml/g and 222 ml/g were obtained while stirring alone produced a figure of 147 ml/g. The combination of air stripping an mechanical stirring procuded an SSVI result of only 60 ml/g. SSVI's for sludge from the reference unit were found to vary from 33 ml/g to 133 ml/g.

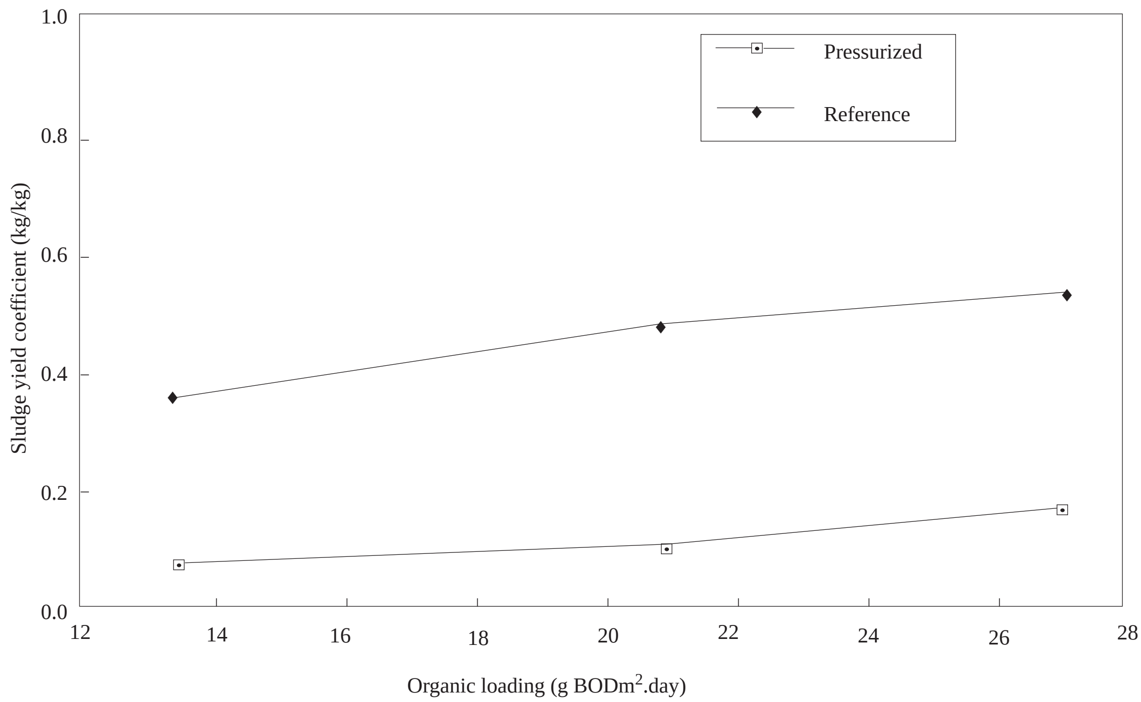

Figure 2. Sludge yield coefficients as a function of organic loading

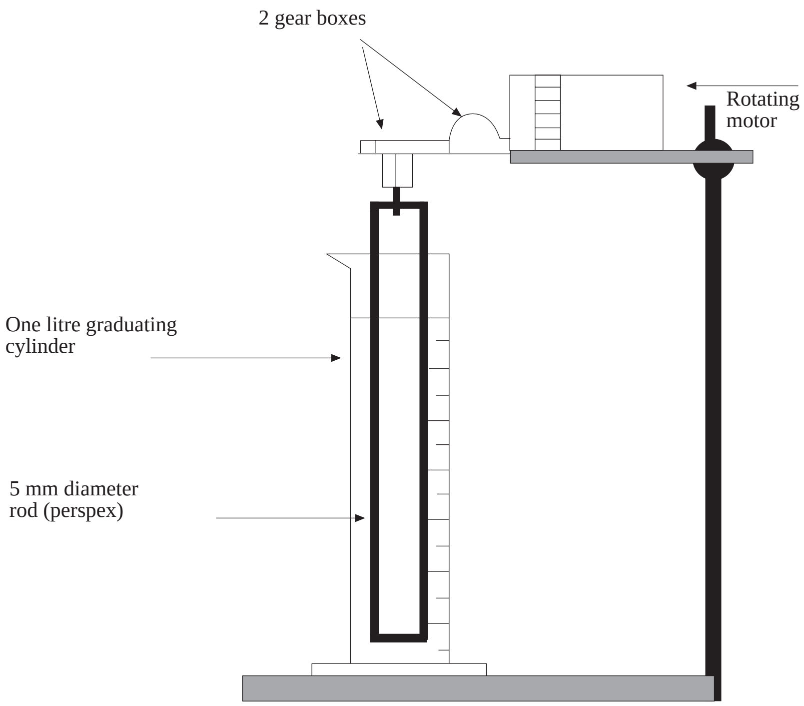

Figure 3. The settling apparatus

Similar problems related to the association of gas bubbles with sludge particles found in this investigation also caused some difficulties with the deep shaft activated sludge process. With the deep shaft process it was usually found to be necessary, to have a special installation for the separation of the gases from water at the top of the shaft. In order to achieve this, Hemming et al. (1977) and Collins and Elder (1980) have suggested the use of a vacuum degasser whereas Irwin et al. (1989) reported on the use of secondary aeration in the process of degassing.

Sludge dewatering characteristics were determined as the specific resistance to filtration of the sludges. The methods employed for the determination of specific resistance to filtration are visual observation by beaker test, gravity drainage test, capillary suction time (CST) test, standard shear test and Buchner funnel test. In this study, the Buchner funnel test was used to determine the specific resistance to filtration of the sludges. The laboratory equipment used is shown in Figure 4.

The results obtained are shown in Table 1. The specific resistance to filtration was determined following the methods described by Coackly (1955), Gal (1967) and Tebbutt (1970). For the sludge from the pressurized unit, the specific resistance to filtration was found to be moderately stable with a variation of between 31×10^{13} m/kg and 87×10^{13} m/kg (mean 51.9×10^{13} m/kg) at 49 kN/m^2. For the sludge tested from the reference unit with the same vacuum gave figures from 51×10^{13} m/kg to as high as 217×10^{13} m/kg (mean 123×10^{13} m/kg). The indications from the tests carried out were that the sludge from the pressurized unit would be rather more readily dewatered than that from the reference unit.

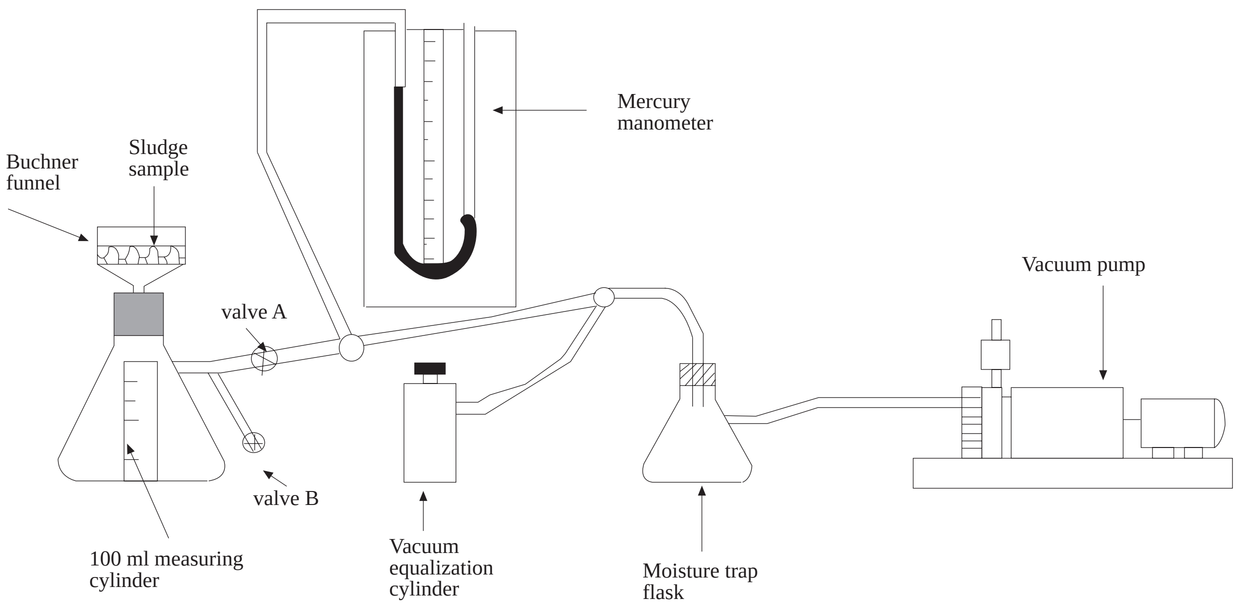

Figure 4. Buchner funnel apparatus for sludge filtration test

The test results of filtrate volume (V) measured at time interval (t) for the pressurized unit were calculated and the results of t/V and V are plotted in Figure 5. The value of b is the slope of the line or (t/V)/V and is equal to 0.38139 sec/ml^2. The value of the specific resistance of filtration (r) is then calculated below,

$$r = \frac{2 \times P \times A^2}{\mu \times c} \times b \qquad (1)$$

where,

$$P = 49 \times 10^3 N/m^2$$
$$A = 6.361 \times 10^{-3} m^2$$
$$\mu = 1 \times 10^3 N.s/m^2 \qquad (20°C)$$
$$c = 2.34 kg/m^3$$
$$b = 0.38139 s/ml^2 = 0.38139 \times 10^{12} s/(m^3)^2$$

Therefore,

$$r = 65 \times 10^{13} m/kg$$

The value of the specific resistance to filtration (r) is usually expessed as 10^{13} m/kg at a standard pressure of 49 kN/m^2. It has been reported by Swanwick et. al. (1962) that sludge with a specific resistance of 0.13×10^{13} m/kg at a standard pressure of 49 kN/m^2 could be dewatered on a pilot scale rotary vacuum filter without further conditioning. However the (r) values obtained during this study were appreciably higher than that figure. The indication is that chemical conditioning would be required for all the sludges prior to dewatering by mechanical means, i.e. by vacuum filter or filter press, but a lower dosage of chemical would be required for sludges produced by the pressurized unit.

Table 1. The results of sludge settleabilty and filterability

Pretreatment Applied	Specific resistance ($\times10^{13}$m/kg)	SSVI (ml/g)	Sludge dry Solids (%)
None	-	**No settlement**	**5.6**
-	-	68	3.9
None	-	**No settlement**	**8.8**
-	-	83	3.2
None	-	**No settlement**	**2.9**
-	-	-	-
Thermal shock	**39**	**No settlement**	**2.9**
-	120	-	4.1
Thermal shock	**-**	**No settlement**	**2.9**
-	54	76	3.9
Vacuum	**57**	**No settlement**	**2.4**
-	67	-	4.2
Vacuum	**-**	**No settlement**	**7.0**
-	-	133	4.5
Air stripping	**58**	**144**	**3.3**
-	51	123	4.8
Air stripping	**-**	**130**	**6.4**
-	-	76	5.5
Air stripping	**57**	**208**	**3.8**
-	86	54	4.6
Air stripping	**31**	**222**	**1.3**
-	136	56	4.4
Stirring	**65**	**147**	**2.3**
-	173	50	5.4
Stirring	**87**	**147**	**4.1**
-	121	33	9.4
Air Stirring and stripping	**31**	**109**	**1.8**
-	217	56	9.6
Air stripping and stirring	**42**	**60**	**3.5**
-	206	48	7.7
*** Results of the pressurized unit shown in bold figures.**			

3. Conclusions

The sludge yield coefficient was always significantly lower for the unit operated under pressure than for the reference unit, and results such as 0.11 kg/kg at 3 bars 0.1 kg/kg at 4 bars 0.14 kg/kg at 5 bars and 0.13 kg/kg at 6 bars were far lower than anticipated and compared very well even with the sludge production rates of a low rate anaerobic digester. The increase in the sludge yield coefficient for the pressurized unit was found to be much lower than that for the reference unit as the organic loading increased. As difficulties with the disposal of sludge from municipal and industrial wastewater treatment plants increase, this must be a very significant result.

The indications from a number of tests carried out were that the sludge from the biological wastewater treatment unit under pressure would be rather more readily dewatered than that from the unit open to atmosphere. Chemical conditioning would be required for all the sludges prior to dewatering by mechanical means, i.e. by vacuum filter or filter press, but a lower dosage of chemical is required for sludges produced by the biological wastewater treatment unit under the influence of pressure.

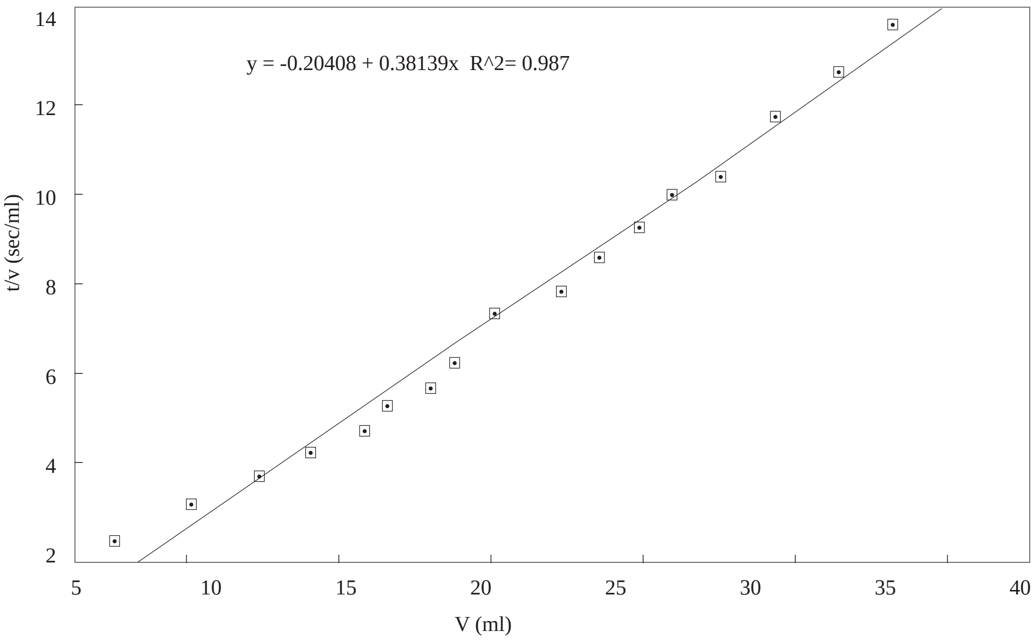

Figure 5. t/V and V to obtain b value for specific resistance

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