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Determination of the optimal dose of polyelectrolyte sludge conditioner considering particle sedimentation effects

Chih Chao Wu[a*], D.J. Lee[b], Chihpin Huang[c]

[a] Institute of Environmental Engineering & Science, Feng Chia University, Taichung, Taiwan, PR China
[b] Department of Chemical Engineering, National Taiwan University, Taipei, Taiwan, PR China
[c] Institute of Environmental Engineering, National Chiao Tung University, Hsinchu, Taiwan, PR China

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Abstract

The specific resistance to filtration (SRF) of sludge was determined using both a leaf filter and a Buncher funnel. The filterability of a kaolin suspension and an alum sludge were characterized using SRF data and capillary suction time (CST) measurements. Filter orientation during the leaf filter test and stirring during the Buncher funnel test affected the SRF values, and the optimal dosage of polyelectrolyte conditioner (defined as the dosage that yields the minimum resistance to filtration) varied depending on the type of test used. Therefore, the optimal dose of polyelectrolyte was an operationally defined value that depended on the geometry of the filter chamber and fluid/particle interactions, such as sedimentation.

Keywords: Sludge conditioning; Specific resistance to filtration; Particle sedimentation; Capillary suction time; De-waterability; Optimal dose

1. Introduction

A key process in sludge treatment is the removal of water. The characterization and quantification of sludge de-waterability are vital components of process design and operation. The specific resistance to filtration (SRF) has been widely used to evaluate sludge de-waterability. Two methods of determining the SRF are the Buncher funnel test and the leaf test. Christensen and Dick (1985) developed a computer-aided data acquisition system to enhance the reliability and accuracy of the Buncher funnel test.

The capillary suction apparatus (CSA) was originally proposed for the rapid determination of filterability. A CSA consists of a sludge cylinder that rests on a filter (Whatman No 17 chromatography paper), which serves as the slurry reservoir. The capillary suction of the filter paper sucks out the filtrate from the slurry while a cake is formed inside the cylinder. The filtrate moves outwards from the center of the filter. The time it takes for the wet front to travel between two concentric

* Corresponding author. Tel.: +886-4-4517250-5213; fax: +886-4-4517686.
E-mail address: ccwu@fcu.edu.tw (C.C. Wu).

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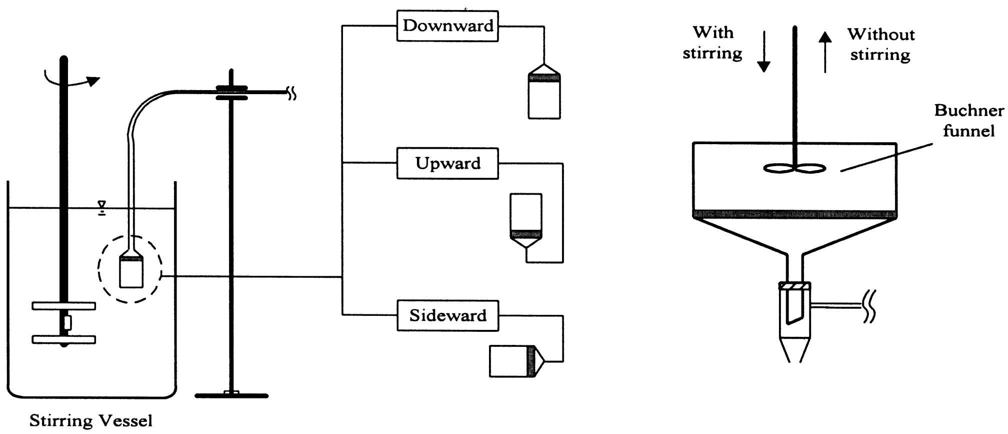

Fig. 1. Experimental setup: (left) leaf tester at three orientations; (right) Buncher funnel with stirrer.

circular rings is referred to as the capillary suction time (CST). Lee and Hsu (1992, 1993, 1994) have summarized some recent advancements in CST measurement.

Particle sedimentation could profoundly affect gravity filtration tests (Bockstal et al., 1985). Nevertheless, related information is still limited. Ju (1982) compared the performance of filtration surfaces with different orientations. Leu (1981) demonstrated that the CST was affected when tiny air bubbles were added to the inner cylinder to agitate the slurry, which implied that particle sedimentation did occur. Christensen and Dick (1985) found that sludge particle sedimentation markedly affected the determination of the SRF value. Tiller et al. (1995) discussed the role of sedimentation in filtration processes. Lee et al. (1995) discussed its effects on CST tests.

The purpose of both the SRF and CST tests is the evaluation of slurry filterability. Using SRF or CST vs. dosage curves, the optimal dose of a sludge conditioner (defined as the dosage that yields minimal resistance to filtration) can be estimated. However, the effect of particle sedimentation on the determination of the optimal dose has not yet been properly addressed. Sedimentation effects may became more apparent when conditioning close to the optimal dose, since the flocs produced will be large and will settle easily. The purpose of this work was to determine the optimal dose of a cationic polyelectrolyte based on SRF and CST measurements, and to investigate the effects of particle sedimentation on the determination of optimal polyelectrolyte dose.

2. Experimental

Two sludges were tested in this study: a kaolin suspension and an alum sludge. The alum sludge was sampled from the Fung–Yuan Water Treatment Works (Taichung, Taiwan). The 0.5% w/w kaolin suspension was made in our laboratory by mixing pre-weighed kaolin powders with DI water for 6 h prior to the test.

The Taiwan Polymer Company supplied the cationic polyelectrolyte (PC-320), which was a co-polyelectrolyte of acrylamide and diallyldimethyl-ammonium chloride with an average molecular weight of $1.1–1.2 \times 10^7$ and a 20% charge density. The mixing unit was a 500-ml baffled mixing chamber. The stirring device worked in conjunction with a variable speed motor that was directly connected to a torquemeter. A 250-ml sludge sample was poured into the chamber and mixed with the polyelectrolyte at a paddle rotation speed of 125 rev./min for 60 s. After conditioning, all of the sludge was then immediately withdrawn for testing.

A Triton CST (Capillary Suction Time) apparatus model 200 with a 1.8-cm diameter cylinder and Whatman No 17 filter paper were used to measure the CST.

The pressure difference used in the Buncher funnel test and the leaf test was 15 cmHg. Fig. 1 depicts the

Table 1
Measured SRF in leaf tester and in Buncher funnel. All numerical values are in 10 Tm/kg

	Leaf test Downward	Sideward	Upward	SRF^S (Eq. (5))	Buncher test
Kaolin slurry	0.41 ± 0.03	0.57 ± 0.08	1.70 ± 0.09	0.65	0.80 ± 0.07
Alum slurry	1.06 ± 0.10	1.87 ± 0.14	2.82 ± 0.18	1.40	2.38 ± 0.15

leaf filter at three filter orientations: upside down, right side up and sideways. During the Buncher funnel test, a stirring device with a speed of 50 rev./min was activated within the funnel to avoid sludge sedimentation. The filtrates were then collected and weighed as functions of time by a balance connected to a computer. The SRF data were calculated according to the methods described by Christensen and Dick (1985).

All data were compiled in triplicate and the average values were then taken. The maximum relative error of the data was, typically, less than 10%.

3. Results and discussion

3.1. Particle sedimentation effects

Table 1 presents the SRF data for the original sludges. The highest SRF values were obtained with the leaf test when the filter was facing upward. For the kaolin slurry tests, the results obtained using downward- and sideward-facing filters differed by approximately 20%. However, for the alum sludge, the SRF, when measured on the sideward-facing filter, was approximately 43% higher than when measured on the downward-facing filter. The SRF values obtained using the Buncher test, in which stirring occurred to homogenize the slurry, were situated between those obtained with the sideward- and upward-facing leaf filters.

In practice, the SRF values measured using downward-facing filters could be considered to be representative of the de-watering resistance of rotary-drum filters, the while upward- and sideward-facing filters were representative of belt filter presses and plate and frame filter presses, respectively. The differences in the SRF values, as indicated in Table 1, were as high as 50–60%. This indicated that filterability data based on a specific test (fixed configuration or setup) could either over- or under-estimate the filterability of a practical filter, depending upon the intended application. The differences in the SRF values could be attributed to the effects of particle sedimentation.

The pressure drop across the filter cake was stated as follows (Leu, 1981):

$$\Delta P_{\text{cake}} = \text{SRF}\varpi_c \mu \nu \tag{1}$$

where ϖ_c, μ, and ν represent the specific cake weight on the filter medium (kg/m^2), the filtrate viscosity (Pa-s), and the superficial velocity of the filtrate (m/s), respectively. If particle sedimentation is neglected and the solid concentration in the slurry is assumed to be low, then the specific volume of the cake can be expressed as $\varpi_c = C_0 V/A$, where C_0 is the suspension concentration (kg/m^3), V, the filtrate volume (m^3) and A, the filter medium area (m^2). Eq. (1) can, therefore, be arranged as follows (Leu, 1981):

$$\text{SRF} = \frac{\Delta P_{\text{cake}}}{C_0(V/A)\nu\mu} \tag{2}$$

Conversely, when the particle sedimentation effect is significant, as it would be when conditioning the slurry close to its optimal dose, particles (aggregates) would move faster than the bulk flow by a velocity of ν^*, which would yield a cake specific volume of $\varpi_c = C_0[V/A + \nu^* t\cos(\theta)]$, where θ denotes the orientation (degree) angle, and t is the filtration time (s). For upward, downward and sideward facing surfaces, $\theta = 0°$ and $\cos(\theta) = 1.0$; $\theta = 180°$ and $\cos(\theta) = -1.0$; and $\theta = 90°$ and $\cos(\theta) = 0$, respectively. Hence, Eq. (1) is restated as follows:

$$\text{SRF}^* = \frac{\Delta P_{\text{cake}}}{\frac{1}{A}\mu C_0[V + \nu^* A t\cos(\theta)]\nu} \tag{3}$$

where SRF* is the corrected SRF.

The ratio between the true SRF (Eq. (3)) and the apparent SRF (Eq. (2)) is:

$$\frac{\text{SRF}^*}{\text{SRF}} = 1\Big/\left(1 + \frac{\nu^* t\cos(\theta)}{V/A}\right) \tag{4}$$

Clearly, the SRF values measured on upward-facing surfaces were higher than those measured on downward-facing surfaces. SRF^U, SRF^S, and SRF^D represent the SRF values measured on upward, sideward and downward-facing filters. Based on Eq. (4), and assuming that all tests were conducted for the same period of time and that the same amount of filtrate was obtained, the following equation can be written:

$$\frac{1}{\text{SRF}^U} + \frac{1}{\text{SRF}^D} = \frac{2}{\text{SRF}^S} \tag{5}$$

Table 1 also lists the calculated SRF^S values for both slurries, based on SRF^U, SRF^D and Eq. (5). Notably, the calculated SRF^S values were similar to those obtained experimentally. Certain differences existed, however, which could be attributed to the assumption that V, ν^* and t were the same for all tests. This would not be the case in practice. Furthermore, other factors involved in the filtration process, such as medium clogging, fine migration, and cake compactibility, make a direct comparison of Eq. (5) with experimental data impractical. However, Eq. (5) does successfully describe the discrepancies between the SRF data observed herein. We could, therefore, conclude that particle sedimentation was significant in determining the SRF values. The comparisons between the calcu-

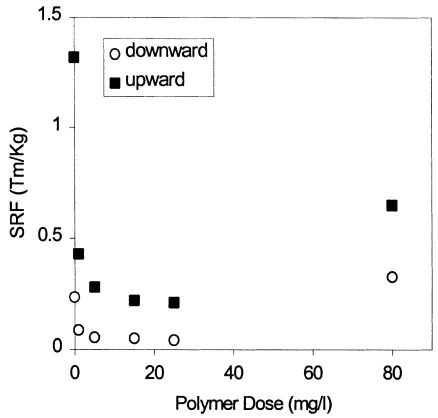

Fig. 2. SRF vs. polyelectrolyte dose plot from leaf test (Kaolin slurry).

lated SRF results based on Eq. (5) and those from the Buncher funnel tests revealed that, despite stirring, there was a definite sedimentation effect on the latter.

3.2. Polyelectrolyte flocculation

In subsequent tests to determine the effects of sedimentation, only upward and downward filter orientations were used.

Fig. 2 depicts SRF data for a polyelectrolyte-flocculated kaolin suspension. Regardless of the filter's orientation, the SRF values initially decreased when a cationic polyelectrolyte was added. After a polyelectrolyte dose of 25 mg/l was reached, however, the SRF values increased again. The upward-oriented filters yielded SRF values that were greater than those obtained with the downward orientation. If the optimal dose of polyelectrolyte is defined as the dose at which the SRF value is at a minimum, then the optimal dose was 25 mg/l both in the upward and the downward filtration. Restated, in the leaf test, the filter orientation affected the absolute value of the SRF, but not the optimal dose of polyelectrolyte.

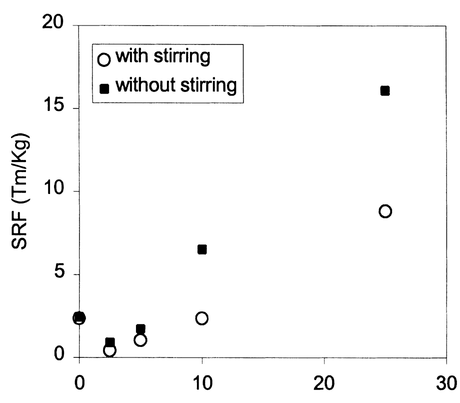

Fig. 3. SRF vs. polyelectrolyte dose plot from Buncher funnel test (Alum sludge).

Table 2
The SRF values for kaolin suspension. All numerical values are in Tm/kg

Dose (mg/l)	Buncher funnel test SRF value	Filter leaf test SRF value	
		Downward	Upward
0	0.80 ± 0.06	0.23 ± 0.02	1.32 ± 0.10
1	0.40 ± 0.03	0.09 ± 0.006	0.44 ± 0.09
5	0.32 ± 0.03	0.05 ± 0.004	0.28 ± 0.05
15	2.20 ± 0.29	0.04 ± 0.005	0.23 ± 0.05
25	4.16 ± 0.51	0.33 ± 0.04	0.21 ± 0.04

Fig. 3 illustrates two SRF data sets from the Buncher funnel test for the alum sludge with stirring (represented by squares) and without stirring (represented by circles). The optimal dosage was identified as 7.5 mg/l for alum sludge. The SRF values were similar, regardless of stirring at doses < 7.5 mg/l, i.e. near the optimal point. Based on naked-eye observation, the alum flocs were relatively small at these dosages, thereby exhibiting minimal sedimentation effects. During the overdosing regime, however, the floc size markedly increased. Notably, there was an increasing discrepancy between $SRF_{stirring}$ and $SRF_{non\text{-}stirring}$, as illustrated in Fig. 3. Thus, the mild stirring rate (50 rev./min) affected the absolute value of the SRF but not the optimal dose of polyelectrolyte.

3.3. Optimal dose of polyelectrolyte

Table 2 lists the SRF values for unconditioned and conditioned kaolin suspensions. Fig. 4 also depicts the SRF values measured using the leaf test and the

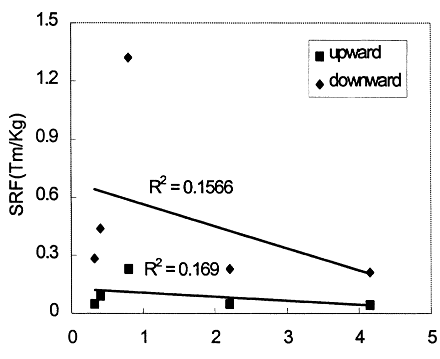

Fig. 4. SRF of kaolin suspension measured from leaf test vs. SRF measured from Buncher funnel test (with stirring).

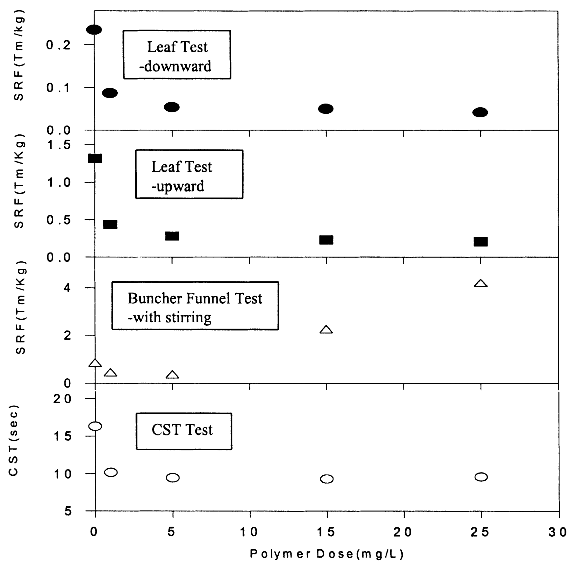

Fig. 5. SRF and CST vs. polyelectrolyte dose plot (0.5% kaolin suspension).

Buncher funnel test. Linear regression analysis yielded a low correlation coefficient, indicating a poor correlation between these two sets of experimental data. For the Buncher funnel test, the minimum SRF occurred at a polyelectrolyte dose of 5 mg/l, whereas the minimum SRF occurred at higher dosages during the leaf tests. The optimal polyelectrolyte dosage determined using the different tests could be very different. Although the determination of the optimal dose was not affected by the filter orientation or by stirring when using the same testing apparatus (as previously discussed), the optimal doses could vary when different tests were adopted.

Fig. 5 displays the SRF values measured using the leaf and Buncher funnel tests, as well as the corresponding CST data for the kaolin suspension. Notably, the optimal dose based on the leaf test was 25 mg/l, whereas it was 5 mg/l for the Buncher funnel and the CST tests. Considering the distinct geometry and the fluid flow/particle packing features of the various tests, different optimal doses were to be expected. Therefore, the optimal dose of a conditioner is an operationally defined value; that is, it varies with testing procedures. To determine the optimal dosage, the test that most adequately reflects the fluid flow and packing features of the de-watering equipment (such as the sedimentation effects discussed herein) should be adopted. It is unlikely that there exists a universal index for the determination of the optimal dose.

4. Conclusions

This work elucidated the filterability of a kaolin suspension and an alum sludge using leaf and Buncher funnel tests and CST measurements. Filter orientation during the leaf tests and stirring during the Buncher funnel tests affected the SRF. The SRF values for the original sludge yielded the following sequence: leaf test with downward-facing filter < leaf test with sideways-facing filter < Buncher funnel test < leaf test with upward-facing filter. The optimal dosage of the polyelectrolyte sludge conditioner, as determined by the leaf test, was not affected by filter orientation, and the optimal dosage as determined by the Buncher funnel test was not affected by stirring. However, the optimal dosage was found to vary depending on the type of test used. The optimal dose of a conditioner is, therefore, an operationally defined value, and depends on the geometry of the filter chamber and fluid/particle interactions, such as particle sedimentation.

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References

Bockstal, F., Fouarge, L., Hermia, J., Rahier, G., 1985. Constant pressure cake filtration with simultaneous sedimentation. Fil. Sep. 255.

Christensen, G.L., Dick, R.I., 1985. Specific resistance measurement: non parabolic data. J. Environ. Eng. ASCE 111, 243–257.

Ju, S.C., 1982. A study on the batch gravitational filtration. Master Thesis, National Taiwan University, Taipei, Taiwan.

Lee, D.J., Hsu, Y.H., 1992. Fluid flow in capillary suction apparatus. Ind. Eng. Chem. Res. 31, 2379–2384.

Lee, D.J., Hsu, Y.H., 1993. Cake formation in capillary suction apparatus. Ind. Eng. Chem. Res. 32, 1180–1185.

Lee, D.J., Hsu, Y.H., 1994. A rectangular capillary suction apparatus. Ind. Eng. Chem. Res. 33, 1593–1599.

Lee, D.J., Chen, G.W., Lin, W.W., 1995. Particle sedimentation effects on capillary suction time. J. Ch. I. Ch. E. 26, 371–378.

Leu, W.F., 1981. Cake filtration. Ph.D. Dissertation. University of Houston, Texas.

Tiller, F.M., Hsyung, N.B., Cong, D.Z., 1995. The role of porosity in filtration XII: filtration with sedimentation. AIChE J. 41, 1153–1164.