WATER TREATMENT USING SLUDGE BLANKET CLARIFIERS

T. A. S. Nithini,
Department of Civil Engineering, University of Moratuwa
(email: tasnithini@gmail.com)
N. Ratnayake
Senior Professor, Department of Civil Engineering, University of Moratuwa
(email: niranjanieratnayake@gmail.com)

Abstract: A sludge blanket clarifier is a treatment unit combining flocculation and upward flow sedimentation, which is more efficient compared to the conventional sedimentation tank. It has the ability to treat water at a faster rate, resulting in less space requirement. The removal of suspended particles takes place by a combination of flocculation, sedimentation and straining as the water passes upwards through the blanket of sludge formed within the clarifier. The performance of the blanket appears to directly depend on the raw water quality, coagulant concentration, temperature and up flow velocity. However, there are no direct relationships available to help the operators to adjust these variables to obtain satisfactory performance of the clarifier. Hence it is essential to identify a characteristic that can be used as an indicator to monitor the sludge blanket. A study of literature showed that a parameter called "sludge cohesion coefficient (SCC)" of sludge has been used in France (Degremont, 1991) to characterize the sludge blanket. However, the procedure given was not clear, and parameters to characterize performance of sludge blanket clarifiers in the tropical environments could not be found in the literature studied. Therefore this research was conducted to study the behaviour of a sludge blanket using the parameter SCC, which was done in two stages. During first stage development of a standard test procedure and introduction of cohesion coefficient ranges which can be expected under tropical climatic condition were done. Under this stage several laboratory tests were conducted and a test procedure was finalized. In the second stage, using the developed test procedure, SCC of synthetic raw water samples was measured to develop relations between the SCC and other variables. Results showed that there is an optimum range of alum dose that produced the sludge blanket with the highest SCC under controlled raw water conditions.

Keywords: Sludge blanket clarifier, Cohesion coefficient, Coagulant concentration

---

1. Introduction

In pulsator technology raw water mixed with coagulant is injected through a matrix of inlet diffusers situated above the bottom of the clarifier by means of pumping action. Then the flow impacts with the bottom surface of the tank and is directed in an upward direction. Flocculation takes place during this stage and formed flocs are captured by the already formed sludge blanket clarifier which is in suspension. A pulsator is a special kind of sludge blanket clarifier in which the middle portion of the bulk liquid in the tank is raised using a vacuum arrangement, and released suddenly (causing a pulse), creating a vertical (up and down) motion in the bulk liquid, which helps the sludge blanket to remain suspended. .("cityofsteubenville").The upward velocity of flow is controlled by the pump, and the speed at which the pulsator is being operated is important because it isdirectly related to the maintaining of sludge blanket. If the speed is higher, sludge blanket can be disturbed and the performance of the pulsator can be reduced.

Stability of the sludge blanket depends on sludge composition and its characteristics. Cohesivity is one of the major factors which can be considered to characterise the sludge blanket behaviour. Hence the research was conducted to study about the cohesion coefficient of the sludge to understand the blanket behaviour and performance.

2. Background Study

When suspended solids are removing by means of sedimentation, two governing factors are taken into account,

- Particle size

- Specific weight (ρ_S/ρ_L)

Particle settling velocity can be measured using Stokes' Law,

$$V_s = \frac{g\,(\rho_S - \rho_L)\,d^2}{8\mu} \text{...... } \textit{equation 1}$$

V_s - Particle settling velocity
d - Particle diameter
g - Acceleration of gravity
ρ_S - Density of particle
ρ_L - Density of medium
μ - Viscosity of medium

Table 1 shows typical settling time for colloidal particles.("Water board")

Table 1: Relationship between Particle Size and Settling Time

Particle diameter (mm)	Particle Type	Settling Time (through 1m)
0.001(1 μm)	Bacteria	8 days
0.0001(0.1 μm)	Colloidal Particles	2 years
0.00001(0.01 μm)	Colloidal Particles	20 years

According to above details it is required to apply advanced techniques to settle colloidal particles from raw water. Normally coagulation and flocculation is used to combine micro size particles into flocs and then allove to settle under gravity. Sludge blanket clarifier is a technique which is used to remove those flocs in an effective way.

2.1.1. Coagulation and Flocculation

Normally colloidal particles have higher surface area compared to self weight. Hence it is difficult to settle those by means of gravity.

Due to their negative charge, particles repel each other and coagulant agents like Alum and Ferric chloride are used to destabilize the charge of those particles. With the presence of coagulant agent, colloidal particles tend to agglomerate into larger flocs which are heavy enough to settle by gravity, provided they are brought together by some means. In a pulsator, flocculation takes place during the pulsation action, and when flowing through the blanket in the upward direction. When the sludge blanket is subjected to upward flow, it tends to expand and occupy an apparent volume greater than the volume under quiescent conditions. According to Degremont (1991), this apparent volume is roughly proportionalto the up flow velocity.Therefore, by analysing the variation between apparent volume expansions versus operating speed, the SCC of the sludge sample can be determined. In Degremont (1991), Equation 2 shown below is used to develop a mathematical relationship between apparent volume expansion and upflow velocity.

$$v = K\left(\frac{V}{V_0} - 1\right) \text{ ...... } \textit{equation 2}$$

v	- Upward velocity in the cylinder necessary to obtain the volume V
V	- Apparent volume of the sludge in expansion
V_0	- Volume of the settled sludge corresponding to a zero velocity and measured on the graph. Normally this is maintained as 50ml at the initial step.

The Coefficient K is a characteristic of the cohesion of the sludge and it is known as the sludge cohesion coefficient (SCC). It depends on the temperature, water quality and Alum concentration.

Equation 2 shows that the SCC is the negative of the intercept of the graph of $v$vs. V/V_0. Thus, the physical interpretation of the coefficient SCC is that it is the upward velocity required to double the apparent volume of a sample of 50 ml of sludge in the blanket.

3. Objectives

The main objective of this research was to study about the behavior and performance of up flow sludge blanket clarifiers. Hence it was necessary to identify a characteristic of the sludgeblanket as an indicator to be studied and the test procedure for that characteristic, and then use that indicator to study the effects of variables on the behavior of the blanket.

Two specific objectives were:
- To set up a standard test procedure for testing cohesion coefficient of sludge from sludge blanket of upward flow clarifier

- To study the effect of varying Alum dose on the cohesivity of the sludge produced from synthetic raw water.

4. Materials and Methods

4.1 Set up for the standard test procedure for testing cohesion coefficient of sludge

When developing the standard test procedure, a laboratory experimental model apparatus was used to create upward flow at the environment laboratory. For these experiments, sludge prepared with synthetic sample was used instead of raw water sample due to varying consistency of raw water.

According to Degremont (1991), the proposed test procedure is as follows:

i. Conduct a Jar Test and identify the optimum coagulant dose for raw water sample.
ii. Conduct another Jar Test using identified optimum coagulant dose and collect settled sludge, or use coagulant concentration which is used at the treatment plant to do the Jar Test. Or else directly use sludge from the sludge blanket.
iii. Collect settled sludge to a 250ml measuring cylinder and allow settling for 10 minutes.
iv. After a 10minute period, siphon off the excess sludge introduced to get an apparent volume of 50 ml.
v. Then fill the cylinder up to 250ml level with supernatant, which is collected after conducting the Jar Test.
vi. Arrange the apparatus as shown in figure 1, and pour 100 ml of the supernatant to the funnel at a constant flow rate.
vii. Measure the time T (s) and apparent volume increase A (ml) at the end of delivering 100ml of the supernatant, and record it. Continue same procedure several times by adjusting the valve in separatory funnel to operate under different flow velocities and record the readings.
viii. Then measure the flow velocity using equation 2 and plot the graph, apparent volume versus flow velocity. The intersection of the graph illustrates the Cohesion coefficient of the sludge blanket.

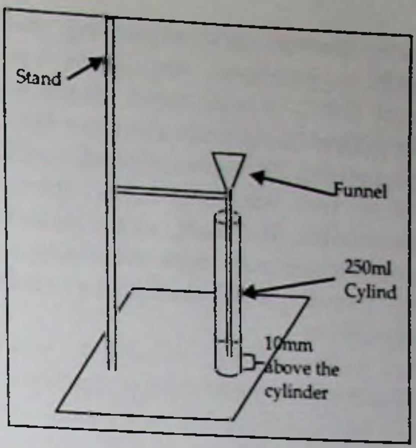

Figure 1: The experimental set up according to Degremont (1991)

- During the test, push funnel lightly into cylinder to avoid air bubble drawing along with the water.
- Limit test trials to below 15 to prevent change in physical properties of the sludge blanket.

$$V = \frac{\underline{3.6A}}{T}\ \text{mhr}^{-1} \quad \text{.......}\textit{equation 2}$$

$$\underset{\underset{Y}{\uparrow}}{\frac{V}{V_0}} = \underset{\underset{m}{\uparrow}}{\underline{(K)}}\underset{\underset{x}{\uparrow}}{V} - \underset{\underset{C}{\uparrow}}{K}$$

A - Distance between the 100 and 200ml marks on the 250ml cylinder.
K- Cohesion Coefficient

Figure 2 illustrates the shape of graph which canbe expected with the results.

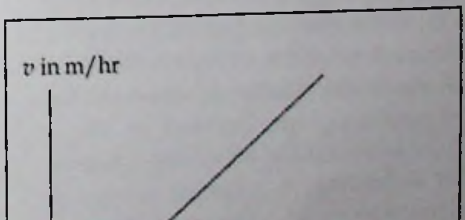

Figure 2: Apparent volume vs up flow velocity

During the study, while conducting the experimental procedure as given in Degremeont (1991), it was found that it is practically difficult to maintain a constant flow rate when pouring the supernatant by hand, and thus it was not possible to obtain consistent results. Therefore, after several attempts at modifying the apparatus, using a separating funnel proved to be the most satisfactory device.

Figure 3 illustrates the modified test apparatus which was used during the laboratory tests.

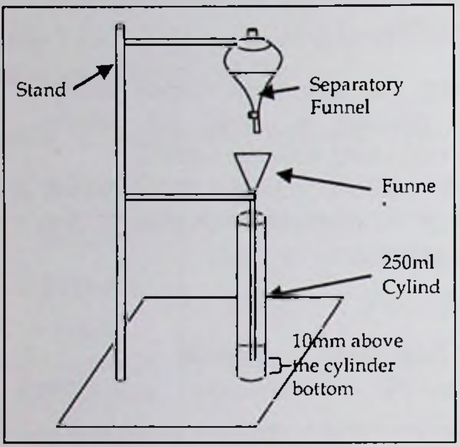

Figure 3: Modified test apparatus

4.2 Synthetic raw water sample and coagulant description

Due to varying consistency of raw water in natural water source, a synthetic raw water sample was used for laboratory experiment. It was required to maintain all the parameters similar for every test procedure except characteristic which are to be changed (Alum dose). Normally coagulation and flocculation is done to remove colloidal particles in raw water. However, since it is difficult to find raw water of consistent quality to conduct the series of studies, it was decided to use a synthetic sample prepared by mixing a known weight of Bentonite with a known volume of tap water as the sample. Main reason to select Bentonite is the colloidal effect which can be achieved with it.

The Synthetic Raw WaterSample was prepared using 3g of Bentonite mixed with 1*l* of tap water. The coagulant used was 14ml of Aluminium Sulphate at 0.5%concentration.

5. Results

5.1 Determination of SCC for sludge samples

According to the test procedure, apparent volume increases versus time taken to introduce 100m*l* of supernatant were recorded. Results are shown in Table 2.

Table 2: Apparent volume increase according to time consumed for 100ml introduction

Distance	A (m)	T (s)	*V* = 3.6A/T(m/hr)	V (ml)
100	0.1	75	4.8	110
100	0.1	82	4.390244	100
100	0.1	43	8.372093	136
100	0.1	54	6.666667	146
		0	0	50

After conducting the test, variation of apparent volume and inflow velocity was plotted and Figure 4 depicts the graph. From the intersection of the graph the cohesion coefficient of the sludge sample was determined.

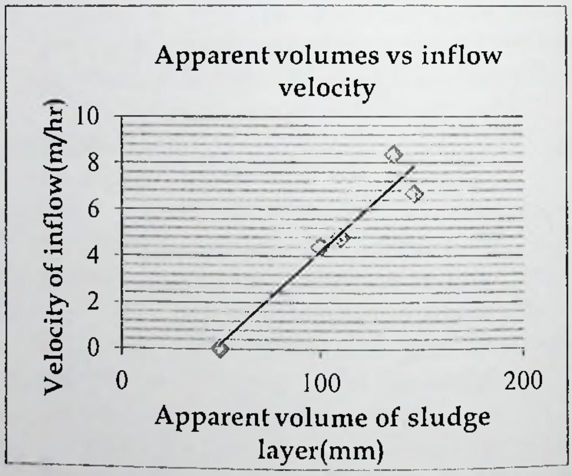

Figure 4: Apparent volume vs inflow velocity

Y=0.08x-3.822
$R^2 = 0.917$
SCC : K = 3.822

Following the above test procedure, several tests were conducted. Table 3 illustrates the summary of those test results.

Table 3: Test results summary - calculated cohesion coefficient for several sludge samples.

Synthetic water sample – Bentonite concentration in 1*l* of raw water	0.5% Alum concentration	SCC
5 g	14ml	2.823 1.970 2.236 3.099 2.069 3.938 2.772
3 g	14ml	3.846 3.822
2 g	8 ml	5.7130
2 g	16ml	7.667
2 g	38ml	6.356
2 g	46ml	7.473
2 g	20ml	9.592
2 g	24 ml	9.551
2 g	32 ml	12.05
2 g	24 ml	11.72
2 g	6 ml	12.93
2 g	28 ml	13.00
2 g	32 ml	10.03
2 g	34 ml	8.126
2 g	36 ml	7.993

According to Table 3, cohesion coefficient has varied according to the quality of synthetic raw water sample and Alum concentration. It is preferable to have a higher cohesivity under tropical climatic condition. The recommended Cohesion coefficient range varied between 2 and 13. For actual raw water sample cohesivity can be lower than the synthetic raw water sample. Therefore cohesion coefficient higher than 2, can be accepted as a better performing condition of sludge blanket.

5.2 Effect of varying alum dose on the cohesion of the sludge product

Another set of laboratory tests were conducted to measure SCC according to the varying Alum doses. Finally a relationship between Alum doses and behaviour of SCC was developed.

5.2.1 Results

Table 4 bellow, illustrates the summary of cohesion coefficient variation according to Alum concentration.

Table 4: Result summary / Cohesion coefficient variation with Alum concentration

Alum Dose (ml)	Cohesion Coefficient
8	5.7130
16	7.667
38	6.356
46	7.473
20	9.592
24	9.551
32	12.05
24	11.72
26	12.93
28	13.00
32	10.03
34	8.126
36	7.993

Cohesion coefficient variation with Alum concentration was plotted and then the behaviour was observed. According to the graph, the cohesivity could be observed to increase with increasing alum at low coagulant doses, but after reaching a peak value of SCC, it appears to reduce with increasing alum dose, indicating that there is an optimum Alum dose to achieve a highly cohesive sludge. Figure 5 shows the variation of Alum concentration and cohesivity variation. This is an important finding not available in literature studied.

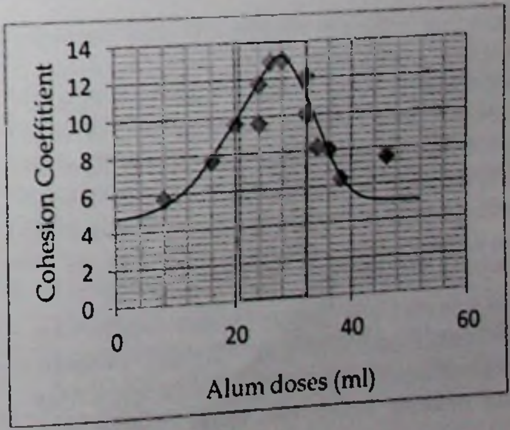

Figure 5: Cohesion variation according to the Alum concentration

According to the Figure 5, we can observe that when Alum dose is varying between 20ml and 32 ml, cohesion coefficient is greater than 10.

It is preferable to have higher cohesivity. Otherwise the sludge blanket is more vulnerable for small disturbances. Hence it is recommended to maintain higher cohesion coefficient in the sludge blanket.

Figure 5 shows that we can maintain a higher cohesion region if we use Alum content between 20ml and 32 ml, when using this raw water. However, further studies are needed to establish this relationship for other sources of water, and under other environmental conditions.

5. Conclusions

In this study, the apparatus for determining the SCC was modified to obtain more consistent results.

According to the physical meaning of SCC, it is the velocity required to increase the apparent volume by 100%. Hence, the stability of the blanket is increasing with the SCC. But sludge blanket should have enough inter-particle spaces to provide the path for the upward flow. Therefore there is a limit for higher SCC also.

By understanding the cohesion coefficient, we can predict the performance level of the clarifier. We can observe higher cohesivity range for Alum doses of 20 to 32m*l*. Higher as well as lower alum doses seem to produce sludge that are less cohesive, and hence less stable sludge blankets would result.

According to the test results, it is clear that the cohesion coefficient varies with Bentonite concentration and Alum dose applied. Therefore identifying a range of SCC which can be directly applied for the real condition is difficult. The above results are only for a synthetic raw water sample and the situation in a water treatment plant can differ from it.

It is reported that Sludge blanket clarifier can be disturbed due to higher ambient temperature, raw water quality or higher up flow velocity which can cause reduction of cohesivity. These aspects need to be studied further.

Reference

Water Treatment Handbook. (*6th ed.*). (1991). Paris: Degroment.

cityofsteubenville. (n.d.). Retrieved August 2013, from www.cityofsteubenville.us/water/superpulsator.pdf

S, W. (n.d.). *Step to Conventional Water Treatment.* Retrieved December 2013, from waterboard: http://www.waterboard.lk/Scripts/ASP/pic/WC/Presentations/Water_Treatment.pdf