Plate Settler Capture Velocity Team

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Abstract

Through lab research we seek to understand the different influence of coagulant type, capture velocity, coagulant dose and raw water turbidity on the performance of the plate settler in AguaClara plants. We are using a tube settler to simulate those plate settlers in the full-scale plants. Through various changes in operating conditions, we expect to determine the best parameters, and this is of great significance in real practice. After that, we are going to pick out some of the best conditions and repeat the experiments with natural organics in order to see how humic acids affect overall performance.

Literature Review

The design of plate settlers plays an essential role in the performance of both the sedimentation tank and the whole plant, with the goal of removing the colloidal particles. Optimal plate settler capture velocity as well as spacing will lead to lower required height and smaller total required area of sedimentation tanks, which reduces construction costs.

The previous work was mainly focused on the floc roll-up failure mechanism and its effect on the required spacing of plate settlers. The traditional design told us that smaller spacing is always betterAdachi and Tanaka [1997], but this previous research demonstrated a failure mechanism of floc roll-up that sets the minimum spacing for the plates. In contrast, our research will generally look at how performance is affected by a number of different variables, including provision of hydraulic flocculation, raw water turbidity, coagulant dose, upflow velocity through the floc blanket, and bulk density and solids concentrations of the floc blanket.

Based on the research carried out by Hurst et al. [2010]on the evaluation of parameters affecting steady-state floc blanket performance, a bench-scale apparatus was used to simulate a water treatment process sequence of rapid mix, hydraulic flocculation, upflow clarification with a floc blanket, and lamellar sedimentation to accomplish removal of colloidal particles. The results show that overall particle removal efficiency improved with increasing hydraulic flocculator residence time and energy dissipation rate. Particle removal efficiency improved with increasing floc blanket depth for floc blanket depths between 15 and 75 cm. Lamellar sedimentation with a capture velocity of 0.12 mm/s is suggested in improving clarifier performance when utilizing a floc blanket in AguaClara facilities.

Another study on the implication of hydrodynamic drag force to free-settling tests numerically evaluates the hydrodynamic drag force exerted on an individual floc moving steadily over a wide range of Reynolds numbers.Wu and Lee [1998] A computational fluid dynamics software was used to solve the fluid field within and around the moving floc, from which the corresponding hydrodynamic drag force exerted on the floc is subsequently obtained. In this way, hydrodynamic drag force could be roughly predicted in our plate settling tests.

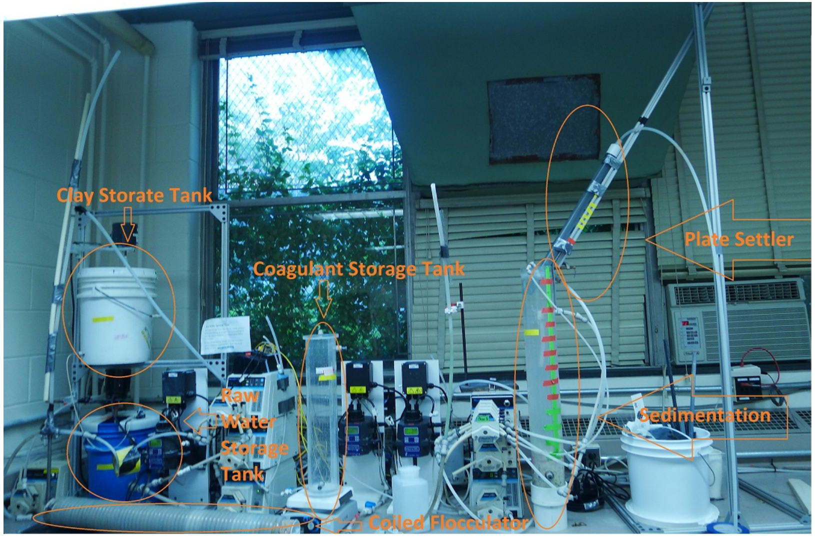
Our research, which is supported by the previous relevant research, is promising to contribute to the improvement of the performance of the sedimentation tank as well as the whole plant.

Methods

In general, we decide to vary coagulant type, capture velocity, coagulant dose and raw water turbidity to determine under which conditions the tube settler, which is the simulation of the full-scale AguaClara plate settler, shows the best performance of removing turbidity. This is of great significance in practice for the AguaClara plants.

Experimental Apparatus

Fig 1. Experiment Apparatus



For the whole procedure, tap water is filled into the raw water storage tank in which the water level is controlled by a pressure sensor and computer Process Controller software. Clay solution is added into the raw water to achieve a certain level of turbidity. A calculated amount of coagulant is pumped in and the mix passes through the coiled flocculator to form flocsLiu and Masliyah [1993]. After that, water with flocs flows into the sedimentation tank where flocs move downward and clarified water stays in the top part. Then clarified water is pumped into the plate settler for removal of smaller flocs.

As the AguaClara plant uses plate settlers of roughly 60 cm long with 2.5 cm space, we take 60 cm long tube settler with 2.5 cm diameter in our experiment inclined at a 60 degree angle.

Setup of Experimental Parameters

A) Coagulant Control: Since we use a pump to control the alum dose, we should calculate the alum flow rate first. For example, suppose the expected alum dose is 0.5 mg/L while the designed plant flow rate is 300 mL/min through our apparatus. Also, the coagulant we use is $Al_2(SO_4)_3.16H_2O$. So the coagulant dose expected is found by Equation 1:

$$\frac{0.5mg/L\times 300ml/min}{2MW_{Al}/MW_{Al_2(SO_4)_3.16H_2O}} = 1.75mg/min \quad (1)$$

So we use 1 g/L as the concentration of $Al_2(SO_4)_3.16H_2O$ in the stock tank of coagulant, and set the velocity of pump which controls the alum dose to be 1.75 mL/min.

B) Raw Water Turbidity Control: In order to maintain the raw water turbidity to be 5 NTU, we use the Process Controller. Since 5 NTU is a comparatively low turbidity, we dilute the suspension of clay, and shorten the "on time" for the pinch valve while extend the time for the pinch valve to wait until the clay and raw water mix well and the turbidity of the raw water to be more stable. On the contrary, when we need to maintain the raw water turbidity to be 500NTU, we add more clay in the clay storage tank and thus increase the concentration of the clay, in case of using up the clay before the experiment cycle ends. By observing the deviation of raw water turbidity from 500 NTU and how many times the pinch valve will open before turbidity reaching 500 NTU, we adjust the "on time" as 1.5s and "off time" as 5s for the pinch valve to increase the frequency of adding clay in the raw water storage tank.

C)Tube Settler Pump Control: In order to get expected capture velocity, we use Equation 2 Weber-Shirk [2011]to calculate the capture velocity:

$$\frac{V_{Plate\uparrow}}{V_c}=\frac{L}{S}\cos\alpha\sin\alpha+\sin^2\alpha \quad (2)$$

Thus we can change the roation veloctiy of the pump to get different $V_{Plate\uparrow}$. Therefore, through changing the capture velocity value in the Process Controller, we get the capture velocity we need. For example, when using the capture velocity of 0.05mm/s, and under the design that $\alpha = 60 degree, L = 60cm, S = D = 2.5cm$, we find the plate upflow velocity component and the tube settler flow rate using Equation 3-4:

$$V_{Plate\uparrow} = 0.05mm/s * (\frac{60cm}{2.5cm} * \sin 60 \cos 60 + \sin^2 60) = 0.557mm/s \quad (3)$$

$$Q_{tube} = \frac{\pi V_{Plate\uparrow} D^2}{4\sin 60} = \frac{\pi * 0.557mm/s * (2.5cm)^2}{4\sin 60} = 0.273ml/s = 18.95ml/min \quad (4)$$

Experimental Procedure

First we determined the time period for each single condition, as it takes some time for the device to run steadily after we make a change to the conditions. We must observe and collect the data to demonstrate how much time is needed for each condition. Therefore we are able to set the running time "t" for each condition before sampling and analyzing once steady state is reached.

We then conduct the experiments by the time order shown in the following table.

Parameters\ Time Order	1	2	3	4	5	6	7
Raw Water Turbidity, NTU	5	5	5	5	5	5	5
Coagulant Dose, mg/L	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

Parameters\ Time Order	8	9	10	11	12	13	14
Raw Water Turbidity, NTU	5	5	5	5	5	5	5
Coagulant Dose, mg/L	1	1	1	1	1	1	1
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

Parameters\ Time Order	15	16	17	18	19	20	21
Raw Water Turbidity, NTU	5	5	5	5	5	5	5
Coagulant Dose, mg/L	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

Parameters\ Time Order	22	23	24	25	26	27	28
Raw Water Turbidity, NTU	5	5	5	5	5	5	5
Coagulant Dose, mg/L	2	2	2	2	2	2	2
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

Parameters\ Time Order	29	30	31	32	33	34	35
Raw Water Turbidity, NTU	5	5	5	5	5	5	5
Coagulant Dose, mg/L	3	3	3	3	3	3	3
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

Parameters\ Time Order	36	37	38	39	40	41	42
Raw Water Turbidity, NTU	500	500	500	500	500	500	500
Coagulant Dose, mg/L	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

Parameters\ Time Order	43	44	45	46	47	48	49
Raw Water Turbidity, NTU	500	500	500	500	500	500	500
Coagulant Dose, mg/L	1	1	1	1	1	1	1
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

Parameters\ Time Order	50	51	52	53	54	55	56
Raw Water Turbidity, NTU	500	500	500	500	500	500	500
Coagulant Dose, mg/L	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

Parameters\ Time Order	57	58	59	60	61	62	63
Raw Water Turbidity, NTU	500	500	500	500	500	500	500
Coagulant Dose, mg/L	2	2	2	2	2	2	2
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

Parameters\ Time Order	64	65	66	67	68	69	70
Raw Water Turbidity, NTU	500	500	500	500	500	500	500
Coagulant Dose, mg/L	3	3	3	3	3	3	3
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

Parameters\ Time Order	71	72	73	74	75	76	77
Raw Water Turbidity, NTU	50	50	50	50	50	50	50
Coagulant Dose, mg/L	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

Parameters\ Time Order	78	79	80	81	82	83	84
Raw Water Turbidity, NTU	50	50	50	50	50	50	50
Coagulant Dose, mg/L	1	1	1	1	1	1	1
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

Parameters\ Time Order	85	86	87	88	89	90	91
Raw Water Turbidity, NTU	50	50	50	50	50	50	50
Coagulant Dose, mg/L	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

Parameters\ Time Order	92	93	94	95	96	97	98
Raw Water Turbidity, NTU	50	50	50	50	50	50	50
Coagulant Dose, mg/L	2	2	2	2	2	2	2
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

Parameters\ Time Order	99	100	101	102	103	104	105
Raw Water Turbidity, NTU	50	50	50	50	50	50	50
Coagulant Dose, mg/L	3	3	3	3	3	3	3
Capture Velocity, mm/s	0.05	0.075	0.1	0.125	0.15	0.2	0.3

After this, we will change the coagulant from Alum to PACl, and re-do the whole set of procedures. Afterwards, we will select the best performance conditions and add some natural organics, which contains humid acids, and repeat the experiments to see how the humic acids affect tube settler performance.

Results and Analysis

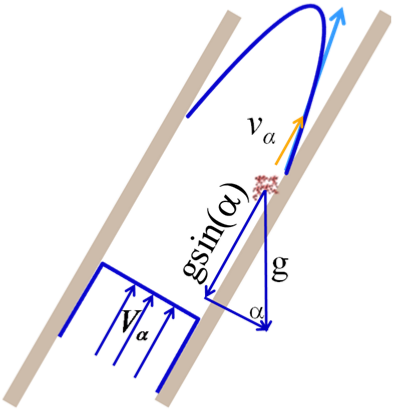
Tube Flocculator Perfomance

In this experiment, we use coiled tube which takes in the flow of both raw water and coagulant and functions as a flocculator. Through this coagulation and flocculation process, we can see that flocs form and move with the flow of water into the sedimentation tank. In the sedimentation tank, flocs with larger particle size will settle, and the water in the upper of part of the tank becomes much clearer.

Selection of Tube Settler Diameter

In the first week's experiment, we used a tube settler with diameter of 1/4 inch. However, the turbidity of water passing through the plate settler was higher than that of water coming out directly from the sedimentation tank. That means that the plate settler did not act as we have expected. On the contrary, it made the quality of water even worse. So we think that the problem may have been caused by floc rollup.

Fig 2. The movement of flocs in the plate settler tube



In order to get the velocity of flocs in the tube settler, we use Equation 5:

$$u \approx \left(\frac{6V_{\uparrow Plate}}{S sin\alpha}\right) d_{floc} \qquad (5)$$

In the equation, u refers to the velocity of flocs, while α represents the angle between plate settler and the horizontal. We use 60° in this experiment. $V_{\uparrow Plate}$ means the velocity of upflow between the plates, d_{floc} is the size of flocs, and S is the space between plate settlers, which is the diameter of plate settler tube in our experiment. Since the size of floc is comparatively constant, when the diameter of tube (which is defined as S in the equation) is small, the velocity of floc goes up. As a result, time for flocs to settle down decreases. Chances are that flocs will roll out of the plate setter directly, rather than settle down and slide back to the sedimentation tank.

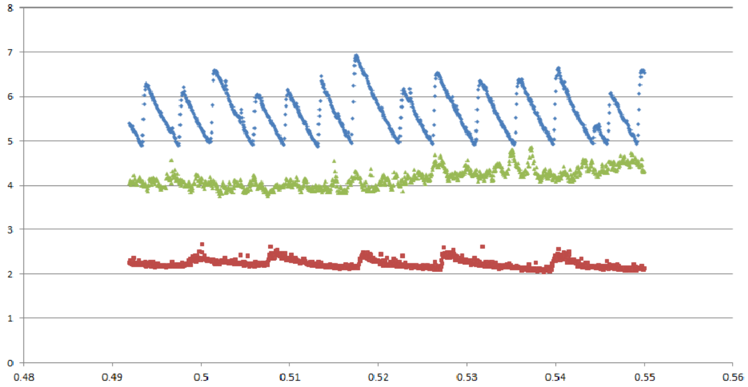
To solve this problem, we use another tube with 2.5 cm diameter as plate settler, which is the same as the design value for AguaClara plants. And for the length of the plate setter tube, we chose 60 cm. Then we restarted the system again, and flocs were observed to slide along the plate settler tube smoothly. The turbidity of water going through the plate settler decreased, observed to be around 6 NTU.

Results with 5 NTU Influent

In this week's experiment, we changed the capture velocity from 0.05 mm/s to 0.3 mm/s with constant alum dose of 0.5 mg/L and raw water turbidity of 5 NTU. And also we re-calibrated every pump to make the pumps run accurately in response to the flow rate set by the Process Controller.

After setting all the parameters in the Process Controller, we set different modes for the same alum dose with different capture velocity. Each mode runs for 2 hours and a half. The Process Controller will collect data every 5 seconds. Also, through our observation, the system will go steady 30 minutes after we change the caputure velocity. So we choose 1000 data points 30 minutes after the new loading and 30 minutes before the loading ends, to be sure that the data which we collect reflect the stable steady-state condition of the system. The following picture shows the turbidity of raw water, water in sedimentation tank and treated water after going through the plate settler over time, with capture velocity of 0.05 mm/s, alum dose of 0.5 mg/L and raw water turbidity of 5 NTU.

Fig 3. Typical Data



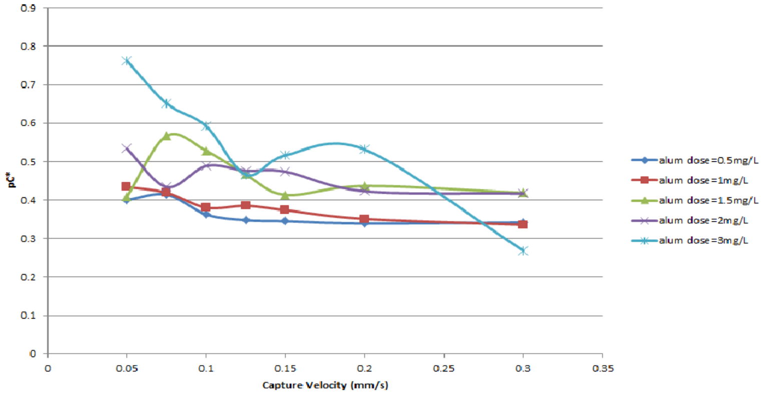
As we can see in Figure 3, raw water generally maintains a turbidity of 5 NTU (the blue dots), which proves that our pinch valve control works well. Also, the water in the sedimentation tank has turbidity which is generally lower than the raw water. This proves that under most conditions, some clay in the water will be removed through forming flocs in the flocculator and settle down at the bottom of sedimentation tank. However, we can see that sometimes the turbidity goes even higher than raw water. Reasons may be that the properties of flocs in the sedimentation tank vary and some flocs go into the turbidity meter. Finally, we can see that water coming through the plate settler has apparently lower turbidity and has a trend of continuously going down, which means that our treatment system works.

Through analyzing every 1000 data points under each capture velocity situation, we can get the average raw water turbidity, average turbidity of water in the sedimentation tank, and average water turbidity after going through the plate settler. We use overall removal efficiency as the criterion to evaluate the performance of the system. It is obtained as shown in Equation 6:

$$OverallRemovalEfficiency = \frac{RawWaterTurbidity - TurbidityafterTubeSettler}{RawWaterTurbidity} \times 100\% \quad (6)$$

Now compare the performance of turbidity removal under different capture velocity.

Fig 4. Remove Efficiency vs. Capture Velocity



This figure shows that with raw water turbidity of about 5 NTU, after treatment through the apparatus, water with turbidity of about 2 NTU is obtained, which means about 60% removal efficiency. On one hand, there is a general downward trend in the overall removal efficiency with the increase in capture velocity for each alum dose. It might be explained by the definition that capture velocity is the slowest velocity of settling particle that the sedimentation tank can reliably capture. When the capture velocity is large, the flocs with small velocity can not be captured, so they will instead stay in the water. Also, the residence time for flocs is short due to the large capture velocity. As a result, flocs have limited time to settle down in the plate settler. However, the decrease in pC* is not that apparent when capture velocity is larger than 0.125 mm/s. This means that by increasing capture velocity within this range, we won't suffer much removal efficiency loss.

On the other hand, it is illustrated that a higher alum dosage leads to a higher overall removal efficiency. The relationship can help us to understand the effect of coagulant dose on the performance of a sedimentation tank. To quantify the performance, please see the following graph which shows the relationship of pC - alum dose graph, where pC is defined as:

$$pC = -log\frac{EffluentTurbidity}{RawWaterTurbidity} \quad (7)$$

The pC (or log removal) parameter acts as an indicator of particle removal performance.

Fig 5. Removal Efficiency vs. Alum Dose

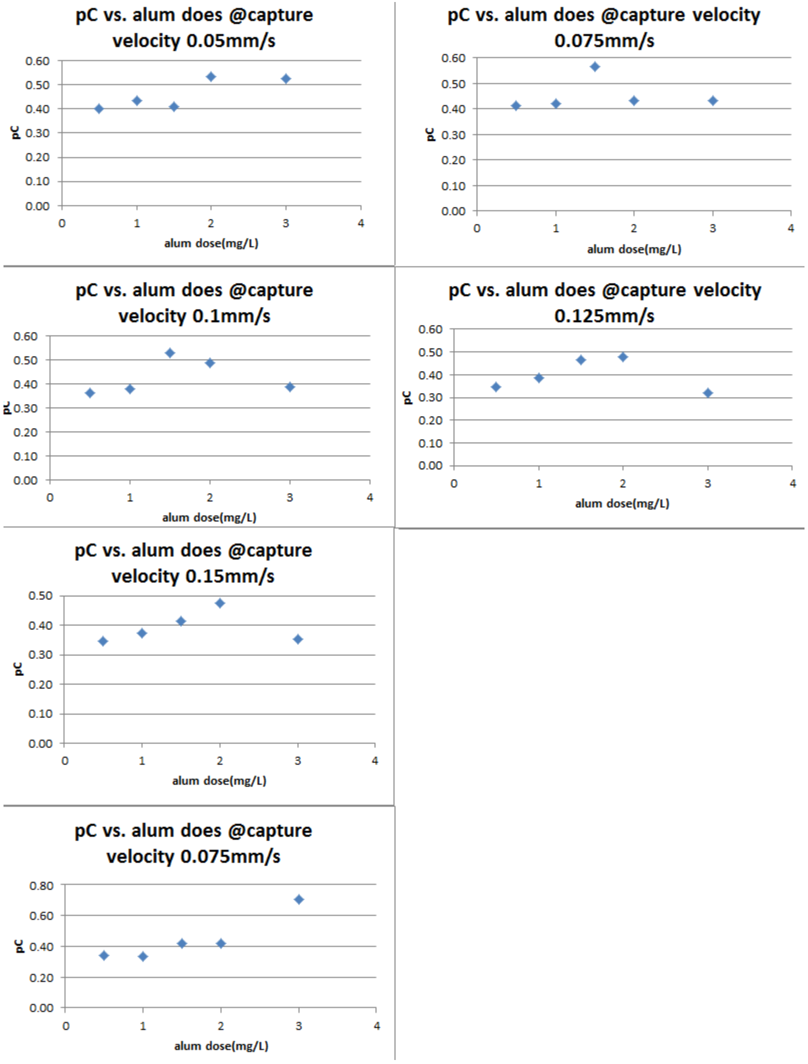
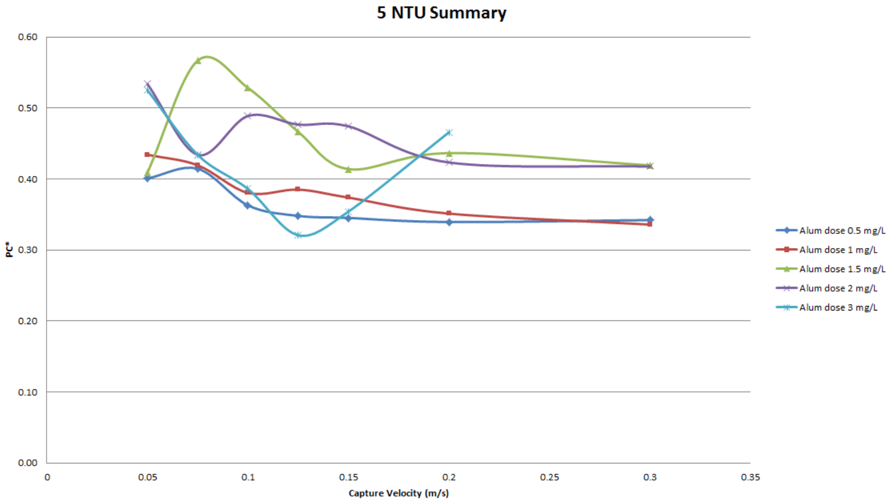


Fig 6. Removal Efficiency vs. Alum Dose (summary)



The graph shows that the pC* has the trend of increaseing (which means removal efficiency tends to grow higher) with increasing alum dose under fixed capture velocity. This is because the more coagulant added, the more particles are coated and the more sticky the particles become. As a result, more clay particles are aggregated to form more and larger flocs. However, this is not a linear increase. The reason may be that the system is not stable enough. Also, we can see that under the same dose of coagulant, lower capture velocity helps to get better removal efficiency, for lower capture velocity allows longer residence time for flocs to form and grow and then settle down.

However, dose of alum added may have diminishing effect in increasing removal efficiency. That is, as additional alum is added, performance increases at a decreasing rate. So we need to find the dose which is most economical. So we calculate the marginal effect of alum on the removal efficiency. For example, under capture velocity of 0.05 mm/s and raw water turbidity 5 NTU,

Alum dose(mg/L)	0.5	1	1.5	2	3
PC*	0.40	0.43	0.41	0.53	0.76
Marginal	/	0.07	-0.05	0.25	0.23

Marginal effect of increasing alum dose from 0.5 mg/L to 1 mg/L is calculated as $\frac{0.43-0.40}{1-0.5} = 0.07$. We can see that under this capture velocity, the largest marginal effect occurs when we increase the alum dose from 1.5 mg/L to 2 mg/L. This means that 1 mg/L alum dose is the most economical and effective.

So we can get the optimal alum dose under different capture velocity at raw water turbidity equals 5 NTU:

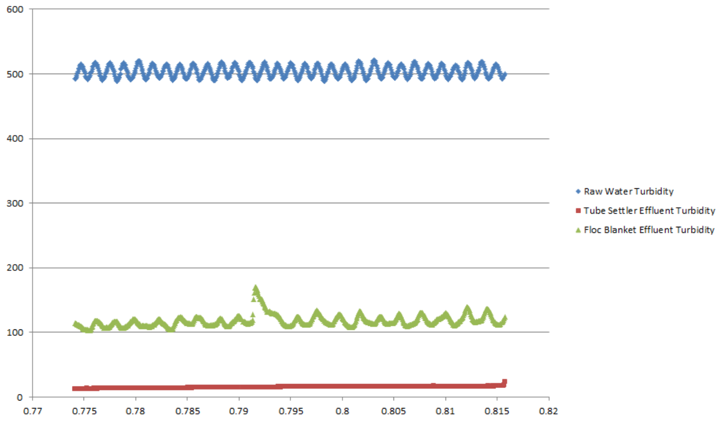
Capture Velocity(mm/s)	0.05	0.075	0.1	0.125	0.15	0.2	0.3
Alum Dose(mg/L)	2	1.5	1.5	1.5	2	1.5	1.5

Results with 500 NTU Influent

Here we increased the raw water turbidity to 500 NTU and re-did the cycle. Since 500 NTU is a high turbidity, the raw water turbidity tended to change violently. In order to control the raw water turbidity within a comparatively steady condition, we increased the concentration of clay and adjusted the on and off time of the pinch valve. Through our observation, the turbidity of raw water varied from about 488 NTU to 510 NTU.

Also, since 500 NTU influent consumes lots of clay, to prevent running out of clay and thereby affecting the result of the experiment, we shortened the experiment time of each state from 2.5 hour to 2 hour. And in order to get the steady state data, we remove the data of the first hour and analyze the data collected during the second hour. So we get 720 data points in each state. The following picture shows typical data of 500 NTU under steady state:

Fig.7 500 NTU & 0.05 mm/s & 1.5 mg/L



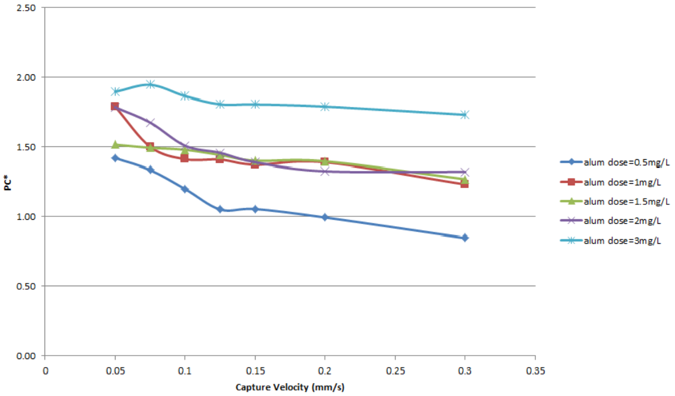
We can see a dramatic drop of turbidity from this picture. This proves that with raw water turbidity as high as 500 NTU, we can get a high removal efficiency, although the final effluent turbidity may not be low enough for the water to be potable. Also, under such a high raw water turbidity, we observe the appearance of a floc blanket.

However, the series of data under 0.5 mg/L alum shows very high turbidity in the floc blanket effluent, though the final effluent turbidity after the tube settler is satisfactory. Reasons for the appearance of this phenomenon may be that due to the low capture velocity, the upflow velocity is also very low. The position where floc blanket forms is higher than the tube which sucks excess flocs and controls the height of the floc blanket. This might have something to do with the lower alum dose since 0.5mg/L alum dose is very low for 500 NTU influent. Thus, some sucked flocs enter the turbidity meter and cause the abnormal high result. Then when we changed the alum dose and switched into new state, the former floc blanket is broken and reformed in a lower position. As a result, not so many flocs are sucked into the turbidity meter. Thus data after that is quite normal.

Generally, the removal efficiency is above 90% after treatment, which is much higher than that of the 5 NTU experiments. This is because with higher raw water turbidity, more flocs exist in the water, and chances for them to collide with each other increase largely. Apart from that, there is enough turbidity to form a floc blanket under steady state. The combination function of filtration and flocculation of floc blanket contribute to the removal of turbidity.

Now compare the performance of turbidity removal under different capture velocity.

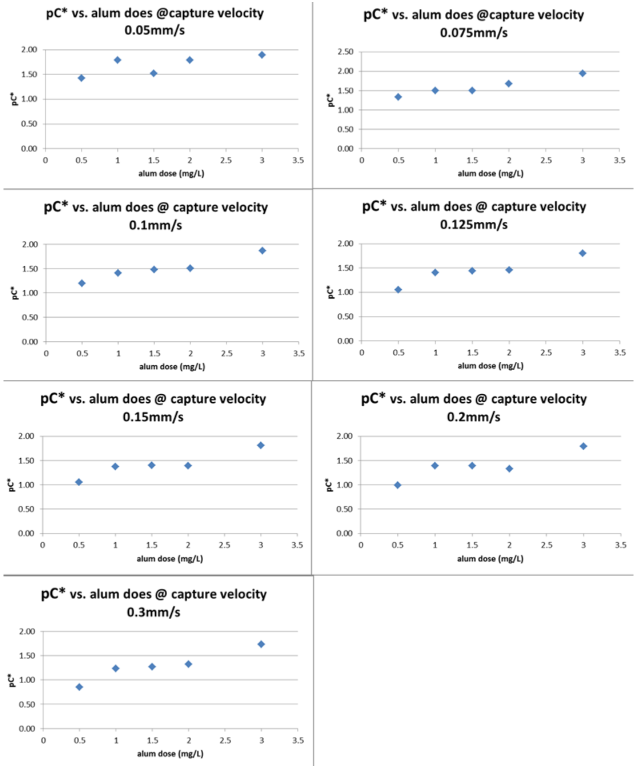
Fig.8 PC* vs. Capture Velocity under 500 NTU



We can see the similar trend as the 5 NTU. Slower capture velocity tends to have better removal efficiency, because lower capture velocity will capture smaller flocs and give more time for flocs to settle down. Again, we can see a comparatively flat slope of decrease in pC* when capture velocity is larger than 0.125 mm/s.

Now compare the performance of turbidity removal under different alum dose.

Fig.9 PC* vs. Alum Dose under 500 NTU



pC* vs. alum does @capture velocity 0.05mm/s

pC* vs. alum does @capture velocity 0.075mm/s

pC* vs. alum does @ capture velocity 0.1mm/s

pC* vs. alum does @ capture velocity 0.125mm/s

pC* vs. alum does @ capture velocity 0.15mm/s

pC* vs. alum does @ capture velocity 0.2mm/s

pC* vs. alum does @ capture velocity 0.3mm/s

Higher alum dose contributes to higher removal efficiency. Again, we calculate the marginal effect of alum on the removal efficiency. For example, under capture velocity of 0.05 mm/s and raw water turbidity 500 NTU,

Alum dose(mg/L)	0.5	1	1.5	2	3
PC*	1.42	1.79	1.52	1.79	1.90
Marginal	/	0.74	-0.55	0.54	0.11

Marginal effect of increasing alum dose from 0.5 mg/L to 1 mg/L is calculated as $\frac{1.79-1,42}{1-0.5} = 0.74$. We can see that under this capture velocity, the largest marginal effect occurs when we increase the alum dose from 0.5 mg/L to 1 mg/L. This means that 1 mg/L alum dose is the most economical and effective.

So we can get the optimal alum dose under different capture velocity at raw water turbidity equals to 500 NTU:

Capture Velocity(mm/s)	0.05	0.075	0.1	0.125	0.15	0.2	0.3
Alum Dose(mg/L)	1	2	1	1	1	1	1

Results with 50 NTU Influent

We now adjust the influent with turbidity of 50 NTU, which is closer to the actual conditions typically observed in AguaClara Plants.

In this experiment, it shows two distinct types of data shown as in the following figures:

Fig. 10 50 NTU & 0.05 mm/s & 0.5 mg/L

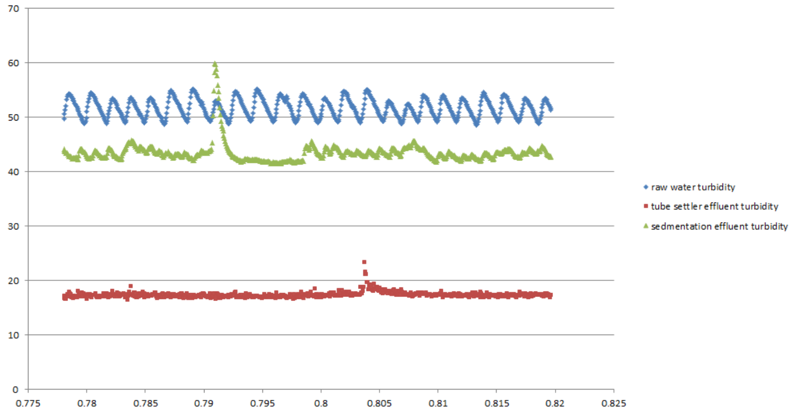
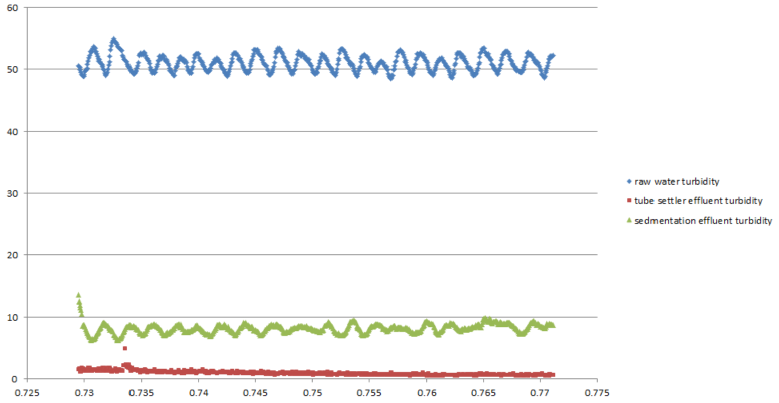


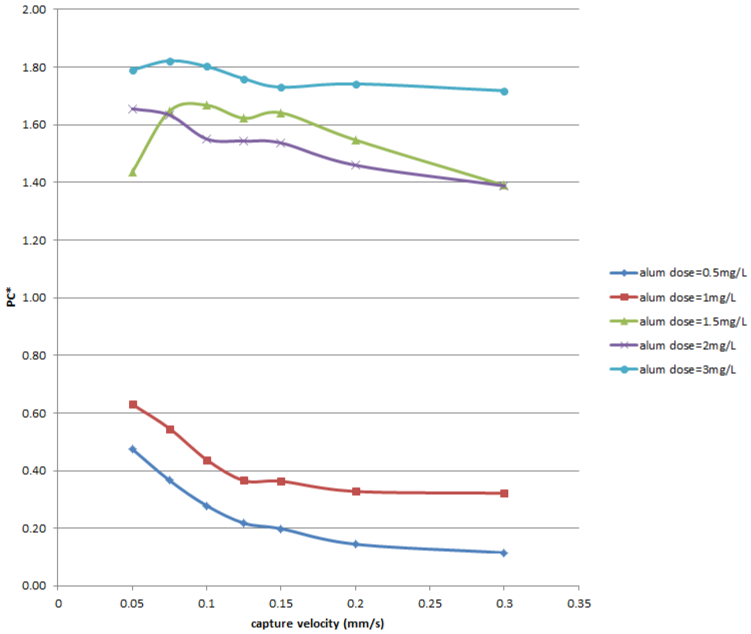
Fig. 11 50 NTU & 0.05 mm/s &3 mg/L



From the above pictures, we can see a significant difference in turbidity removal capacity.

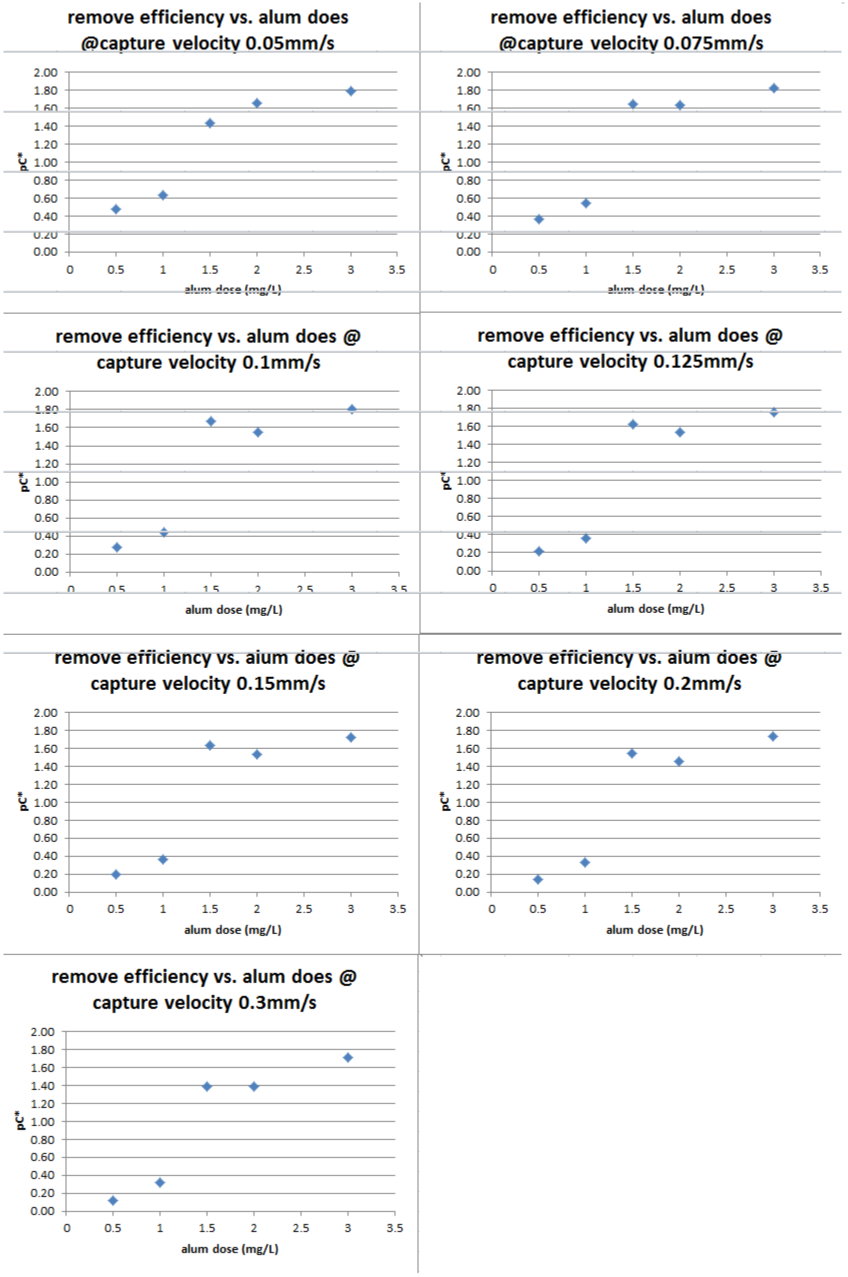
However, the trend that with increasing capture velocity, removal efficieny decreases is simlar to the result under the condition of 5 NTU and 500 NTU raw water turbidity. Also, the decrease is slight after the capture velocity reaching 0.125 mm/s. But the rate of decrease of pC* with higher capture velocity decreases when we increase the alum dose.

Fig.12 pC* vs. Capture Velocity under 50 NTU



This picture shows that there is a big jump of pC* after between 1.0mg/L and 1.5mg/L alum. With the assumption that it might be caused by apparatus failure, we tested these groups for the second time, but got similar results. So we are considering that this jump of removal efficiency is due to the formation of floc blanket. Furthermore, we suppose that floc blanket will form only when enough alum is present with influent turbidity of 50 NTU. For the 5 NTU group, increasing alum does not help form big and enough flocs. Thus floc blanket can't be expected, either. On the contrary, in the 500 NTU group, sufficient clay particles provide considerably larger chance of floc formation. Once the system is runing steady, floc blanket is likely to form. But these assumptions are not verified.

Fig 13. pC* vs. Alum Dose (50 NTU)



These seven graphs illustrate that the higher the alum dose, the better the performance. This relation help us understand the effect of coagulant dose on the performance of a sedimentation tank, as well as the plate settlers. Please see the above graphs which show the relation of pC* and alum dose.

The interesting point is though a similar trend along increasing alum dose is maintained in different capture velocity groups, they all indicate a nice jump-up of pC* from 1mg/L to 1.5 mg/L alum, which is consistent with what is mentioned above. This single increase about 1 unit of pC* means a roughly nine times higher removal efficiency, which should be attractive to AguaClara engineers and operators.

Again, we calculate the marginal effect of alum on the removal efficiency. For example, under capture velocity of 0.05 mm/s and raw water turbidity 50 NTU,

Alum dose(mg/L)	0.5	1	1.5	2	3
PC*	0.47	0.63	1.44	1.66	1.79
Marginal	/	0.31	1.61	0.44	0.13

Marginal effect of increasing alum dose from 0.5 mg/L to 1 mg/L is calculated as $\frac{0.63-0.47}{1-0.5} = 0.31$. We can see that under this capture velocity, the largest marginal effect occurs when we increase the alum dose from 1 mg/L to 1.5 mg/L. This means that 1.5 mg/L alum dose is the most economical and effective.

So we can get the optimal alum dose under different capture velocity at raw water turbidity equal to 50 NTU:

Capture Velocity(mm/s)	0.05	0.075	0.1	0.125	0.15	0.2	0.3
Alum Dose(mg/L)	1.5	1.5	1.5	1.5	1.5	1.5	1.5

Comparation with Data from Cuatro Comunidades

Comparing our result to the actual operation conditon of Cuatro Comunidades, we find that when the influent turbidity is as low as 5 NTU with coagulant dose 10 mg/L, the effluent turbidity is around 2 NTU, which is a acceptable but not perfect removal efficiency the same as our result.

For the influent turbidity which is about 40-60 NTU, the effluent turbidity is around 4 NTU, which is a very good performance. And the removal efficiency dose not change much using coagulant dose 20 mg/L or 15 mg/L.

For high influent turbidity, which is very unsteady, the measure adopted is to increase the alum dose immediately in order to get stable effluent.

To sum up, the result which we get from the lab is quite close to the actual conditons. So the current appatuas is a good simulation of the AguaClara Plant in the reality.

Conclusions

1. The coiled tube flocculator works well. Flocs with enough size to sink in the sedimentation tank can form moving through the coiled tube. Plate settler tube with small diameter will cause of problem of flocs rolling up. Through setting a 60 cm long plate setter tube with diameter of 2.5 cm in an angle of 60°, we can solve

the problem. After going through the whole system, particles in raw water with turbidity of 100 NTU can be removed effectively.

2. The removal of turbidity in the water is acceptable but not very good when raw water turbidity is as low as 5 NTU. Chances for clay particles to collide and combine together are not very large.

3. At a given dose of alum, the slower the capture velocity the higher removal efficiency can be achieved; while at a given capture velocity, the more alum added the better the performance. However, the dose of alum added may have diminishing effect on increasing removal efficiency. So we should find the dose with largest marginal effect.

4. Within the range tested, the operating point with highest removal efficiency is at 5 NTU raw water, 3 mg/L alum and 0.05 mm/s capture velocity. But taking coagulant cost into consideration, 2 mg/L alum may be the optimal choice.

5. Within the range tested, the operating point with highest removal efficiency is at 500 NTU raw water, 3 mg/L alum and 0.075 mm/s capture velocity. Also taking coagulant cost into consideration, 1 mg/L under capture velocity of 0.05 mm/s, or 2 mg/L under capture velocity of 0.075 mm/s may be optimal choice, although capture velocity depends on the design requirement of the plant.

6. Within the range tested, the operating point with highest removal efficiency is at 50 NTU raw water, 3 mg/L alum and 0.075 mm/s capture velocity. Also taking coagulant cost into consideration, 1.5 mg/L under capture velocity of 0.075 mm/s may be optimal choice.

7. We observed the formation of floc blanket with 500 NTU influent. And we suppose that the formation is due to steady state and high turbidity influent. And the reason for the jump of removal efficiency when increasing alum dose from 1 mg/L to 1.5 mg/L in the 50 NTU tests may be the formation of floc blanket, too. However, we did not observe this formation since it might took place when we were absent. But we suppose that, when the influent turbidity is 50 NTU, floc blanket may form under the situation that the system reaches steady state and the dose of alum is large enough.

8. Comparing our result with the real data derived from Cuatro Comunidades, we can say that the current appatuas can reflect the actual conditions well. So we can offer some suggestions to the actual operation:

Firstly, since the size of sedimentation tank is closely related to capture velocity, if we increase capture velocity within this range, we will effectively reduce the size of sedimentation tank and thus reduce the cost while suffering just a little decrease in removal efficiency.

Secondly, for influent around 50 NTU, we should try to maintain steady state and use alum dose of 1.5 mg/L, though right now we are not sure whether floc blanket is necessarily to form under this situation.

Thirdly, 5 NTU and 500 NTU influent turbidity can be considered sudden occation in actual operation. For low turbidity influent, there is no need to worry about it much, since it won't upset the effluent turbidity though the removel efficiency of turbidity is not very high. For very high turbidity influent, though the removal efficiency is very high, the effluent may be bad in a short period of time.

Future work

Limited by time, we do not do the research on the impact of different coagulant, such as PACl, on the performance of this treatment method. More work is expected to be done on the research of coagulation and economic effect of PACl and other coagulants.

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