# Sedimentation Tank Hydraulics Team

August 15, 2011

**Abstract**

A floc blanket is a dense fluidized blanket of flocs that helps to reduce effluent turbitidy in the sedimentation tank by trapping other flocs. The geometry of the sedimentation tank is crucial in determining the extent of floc resuspension by the jet and hence floc blanket formation. To improve tank bottom geometry, nine experiments were conducted, each testing a different tank bottom geometry. The experiments were run in a 1/2 inch wide tank to model a thin slice of the full scale sedimentation tank. The geometry that resulted in the least sludge accumulation and therefore best floc resuspension was two 60 degree inserts leading to a semicircular trench 10 cm in diameter. We also provided initial designs and calculations for a floc weir to maintain the height of the floc blanket. A preliminary experiment was also conducted to evaluate the feasibility of our initial floc weir design.

## 1 Introduction

The Sedimentation Tank Hydraulics Team seeks to incorporate a floc blanket into the AguaClara sedimentation tank by improving the tank bottom geometry. A floc blanket is a dense layer of suspended flocs that acts as a filter to trap particles before they reach the plate settlers, and one key condition for floc blanket formation is that the inlet jet continually resuspends settling flocs. Previous research done by Matthew Hurst has confirmed that floc blankets help to reduce effluent turbidity. In Spring 2011, the research team conducted experiments with a single insert and showed that the minimum angle of repose for the tank is around 24 degrees. In these experiments, the asymmetrical geometry of the experimental set up could be modified to model the actual sedimentation tank hydraulics more accurately. This summer, our team's objectives are to build on last semester's work by observing the sedimentation tank hydraulics with two inserts instead of one, to evaluate the effectiveness of a trench-shaped bottom geometry as compared to a flat bottom geometry, and to design a floc weir for the sedimentation tank.

Table 1: Inserts and tank bottom geometries used

| Experiment | No of Inserts | Angle of Incline | Tank Bottom Geometry | Tank Bottom Width | No of Sec |
|---|---|---|---|---|---|
| 1 | 1 | 60 degrees | Flat | 10cm | |
| 2 | 1 | 60 degrees | Flat | 10cm | |
| 3 | 2 | 60 degrees | Flat | 20cm | |
| 4 | 2 | 30 degrees | Flat | 20cm | |
| 5 | 2 | 60 degrees | Rectangular trench | 20cm | |
| 6 | 2 | 30 degrees | Rectangular trench | 20cm | |
| 7 | 2 | 60 degrees | Rectangular trench | 10cm | |
| 8 | 2 | 60 degrees | Semicircular trench | 20cm | |
| 9 | 2 | 60 degrees | Semicircular trench | 10cm | |
| 10 | 1 | 60 degrees | Flat | 10cm | |

## 2 Methods

We used the same experimental apparatus and procedure as with the experiment documented in the Sedimentation Tank Team's Research Report 1 (Spring 2011). A thin 1/2" wide tank was used to model a thin slice of the full scale sedimentation tank. Figure 1 in The Sedimentation Team Final Research Report shows AutoCAD renderings of the side view and front view setups for the 1/2" wide sedimentation tank and light panel system. A total flow of 456 mL/min of aerated raw water containing 45 mg/L of alum and an average influent turbidity of 100 NTU made from a concentrated kaolinite clay stock regulated by Process Controller was run through a tube flocculator before being expelled through a vertical downward-pointing jet suspended 10 cm from the bottom of the sedimentation tank. Images of the tank were acquired with a camera at fixed time intervals and recorded using the LabVIEW data acquisition software. The images were then compiled to make a video using 30 images per frame, thereby documenting the whole experiment. A schematic of turbid water flow through flocculator and sedimentation tank and data acquisition can be found as Figure 1 in the Sedimentation Tank Team's Research Report 1.

Our team ran ten experiments with either one or two inserts, with inserts of different angles of incline, and different widths of the tank bottom. For set ups with a single insert, the tank bottom width is defined as the distance between the inlet jet and the insert. For set ups with two inserts, the tank bottom width is the distance between the inserts, measured at where the inlet jet opening is located. Magnets were used to secure the position of the inserts. Images were acquired every 5 seconds in all experiments except in Experiment 2 where the rate was 30 seconds per image. Table 11 summarizes the number of inserts, angle of incline, tank bottom geometry and number of seconds per image taken for each of the five experiments that were run. Figure 1 shows diagrams of the tank in the five experimental set ups.

Figure 1: Diagrams of tank in the 10 experiments

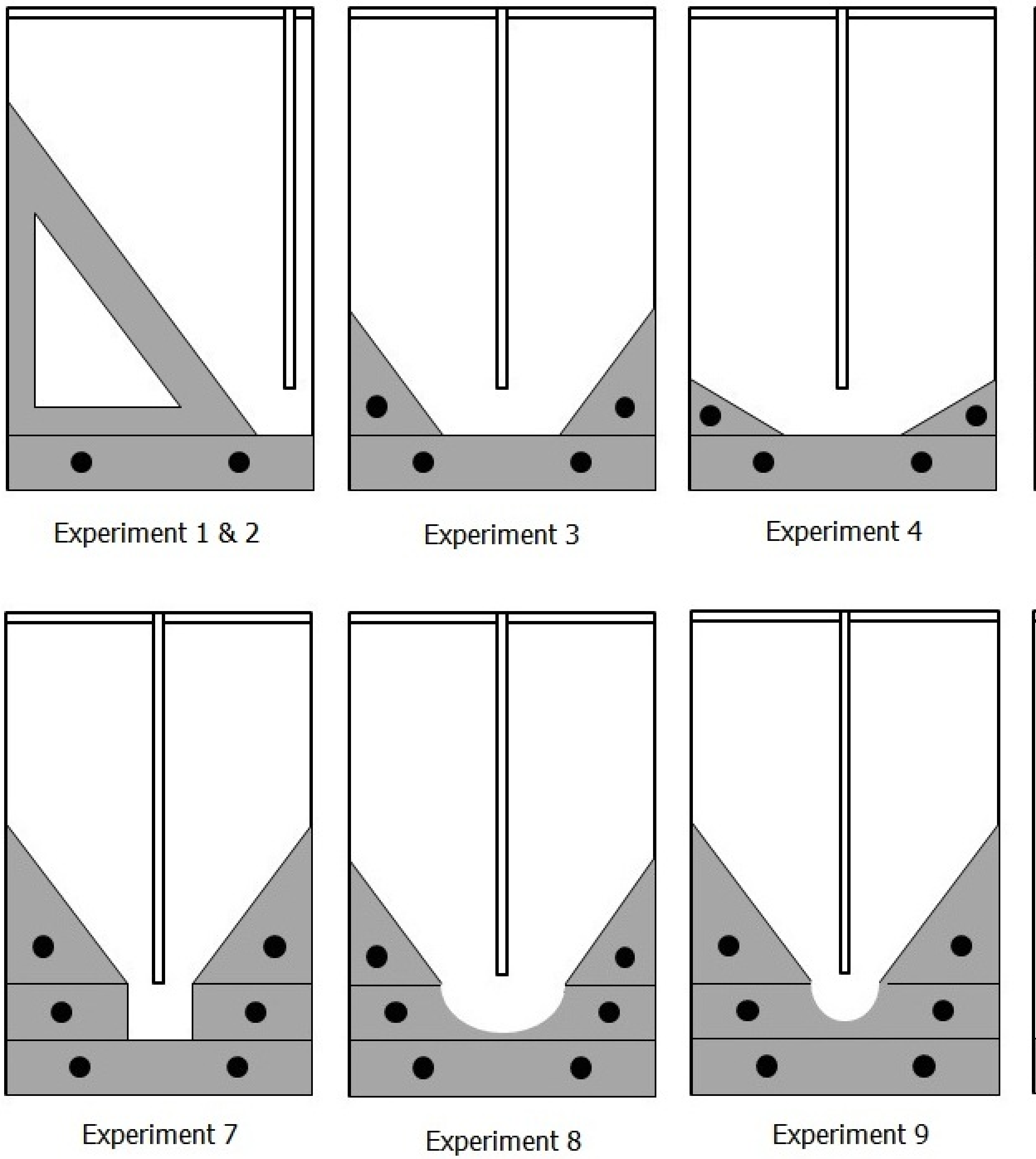

Figure 2: The tank before floc blanket formation. Flocs are much denser on the right hand side of the tank.

Figure 3: The tank close to floc blanket formation. Flocs immediately suspended by the jet no longer reach the top of the tank.

# 3 Results and Discussion

## 3.1 Experiment 1: One 60 degree insert, 10cm-wide flat bottom

We modeled the bottom geometry of half of the actual sedimentation tank using a 60 degree insert and a flat bottom geometry. Initially, there was differential settling where the jet resuspended the settling flocs, causing them to flow upwards to the top of the tank and subsequently settle down as discrete particles, where they were again resuspended. The flocs were spread out throughout the entire tank, but were much less dense on the left side of the tank2.We observed that the jet flowed horizontally along the flat bottom before moving at an angle upwards along the incline. About 1h into the experiment, the suspended flocs became denser and began to trap the upward flowing flocs that were resuspended by the jet3. This transition to flocculated settling marked the beginning of floc blanket formation. After about 1h 15min, a floc blanket had formed in the tank4. The floc blanket height was approximately 65cm, the same height as the tank insert. With a 60 degree angle of repose and a flat bottom, there was no sludge buildup either on the bottom or on the slope, which implies that 60 degrees is greater than the minimum angle of repose.

Previous experiments run with a 60 degree incline and a trench bottom resulted in a floc blanket forming at a much lower height and growing to the height of our experimental floc blanket. We suspect that a trench bottom allows for quicker formation of a stable floc blanket at a lower height because it causes vertical flow of jet water, allowing for immediate resuspension of flocs coming off the slope.

The actual AguaClara sedimentation tank bottom contains a 60 degree angle of repose and a flat bottom geometry, the same conditions that were tested in this experiment. While a floc blanket formed during our our experiment, a floc blanket does not currently form in the AguaClara sedimentation tanks. This may be due to the sludge drain located at the bottom of the current AguaClara sedimentation tanks, which is not contained in our experimental setup and can

Figure 4: The tank after floc blanket formation. The height of the floc blanket is approximately the same as the height of the insert.

drain some flocs before they become resuspended (check this). The formation of a floc blanket in our experimental apparatus may have also been affected by the simplifications used to model the actual plant. The experimental tank is only 1/2 inch thick, so the close proximity of the walls to the jet may have affected the motion of water and flocs in the tank. In an actual AguaClara tank, the jet is located at discrete points throughout the length of the tank, but since the experimental apparatus only contains half of the full bottom geometry, the jet is located on the side of the tank, which may affect the formation of a floc blanket.

### 3.2 Experiment 2: One 60 degree insert, 10cm-wide flat bottom, run till failure

Experiment 2 was run for an extended period of time to observe the failure in the sedimentation tank. We define failure to have occured when the floc blanket breaks due to large head loss through the dense blanket, or when the floc blanket reaches the top of the sedimentation tank, or when the accumulated sludge hinders the inlet jet from effectively resuspending flocs. It is undesirable for the floc blanket to break or to grow to the top of the tank as this implies that a high concentration of flocs will be present in the effluent water, contaminating the whole batch of clean treated water that was previously collected. On the other hand, if the inlet jet is hindered by the accumulated sludge, the floc blanket is unlikely to be maintained.

The floc blanket formed quickly in about 45 minutes at a height of 40 cm5. It then grew steadily and reached the top of the tank (90 cm) about 4h and 15 min later6. There was a significant amount of sludge accumulation at the base of the insert, which formed a smaller angle of repose of about 20 degrees. The side of the accumulated sludge that was in contact with the jet had formed a curved, almost vertical surface that resembled a trench bottom geometry, and served to redirect the horizontal jet upwards. The floc blanket maintained its height for about 24 hours, after which the alum stock was depleted and the floc blanket thinned out as flocs and water were continually being drained from the top of the tank7. After the alum stock was replenished, the floc blanket reformed and started to grow again8.

In the video of Experiment 2, 1 second in the movie corresponds to 15 minutes of experiment time. We calculated the the average growth rate of the floc blanket to be about 0.2cm per minute. Assuming that the height of the plate settlers above the tank bottom in the actual sedimentation tank is about 70cm and that the floc blanket forms at an initial height of 40cm, this means that without a floc weir, failure will occur in about 2.5h after the formation of the floc blanket, or about 3h 15min from the start of flow into the tank. The floc blanket maintained its height for about 24 hours, after which the alum stock was depleted and the floc blanket thinned out as flocs and water were continually being drained from the top of the tank.

Although Experiments 1 and 2 were run under the same experimental conditions, the floc blanket in Experiment 2 formed at a lower height than that in

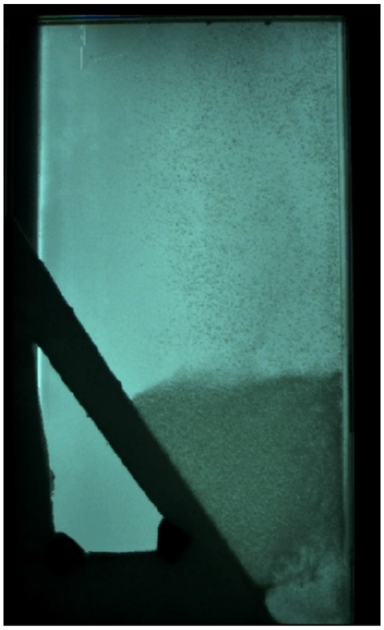

Figure 5: Formation of floc blanket

Figure 6: Floc blanket reaches top of tank 5h into the experiment

Figure 7: Floc blanket thins out after alum stock runs out

Figure 8: Floc blanket reforms after alum stock is replenished

Experiment 1. This is possibly due to errors in alum stock concentration. The tube flocculator was also not cleaned out after Experiment 1, which may have caused residue sludge to be pumped into the tank during Experiment 2.

### 3.3 Experiment 3: Two 60 degree inserts, 20cm-wide flat bottom

Experiment 3 modeled the bottom of the sedimentation tank more accurately by placing the inlet pipe in the middle of a pair of symmetrical 60 degree inserts. Initially, flocs were more concentrated on the right side of the tank9. They were unable to flow by the inlet pipe to the left side, which is a source of error in this experiment. About 50 minutes into the experiment, a small 30cm high floc blanket is formed but never really grows in height 10. Sludge continues to build up on the tank bottom to form a smaller angle of repose of about 25 degrees leading into a trench11. After 5h, a circular trench is formed in the region surrounding the jet12.

### 3.4 Experiment 4: Two 30 degree inserts, 20cm-wide flat bottom

No clear floc blanket was formed in this experiment and most of the sludge accumulated on the inserts. The initial flocs that were pumped into the tank were very large13, which is probably the result of a dirty tube flocculator that was discharging large flocs and sludge into the tank. This is a significant source of error in this experiment and could be the cause for the absence of a floc blanket because the jet is not strong enough to keep large flocs in suspension. Flocs accumulated unevenly on both inserts, forming two separate angles of repose leading up to a trench1415. It was only at 5h into the experiment that there was a slight hint of a floc blanket forming16.

### 3.5 Experiment 5: Two 60 degree inserts, 20cm-wide trench bottom

The distribution of flocs in this experiment was more even as compared to Experiment 317, and this gave rise to the formation of an even floc blanket about 45min into the experiment18. In contrast to Experiment 3, there was little sludge accumulation at the bottom of the trench for the first 2h 15min because the upward flowing jet was able to resuspend the flocs as they reached the tip of the insert. However after 2h 15min, the jet was no longer able to resuspend the flocs that were sliding down the incline and a second smaller trench was formed within the larger trench19. The floc blanket grew slowly at a rate of about 0.8cm per minute and had not reached the top of the tank after 5h. More sludge accumulated in the trench, and it is likely that a circular trench encompassing the jet (as in Experiment 3) would be observed if the experiment was left to run20.

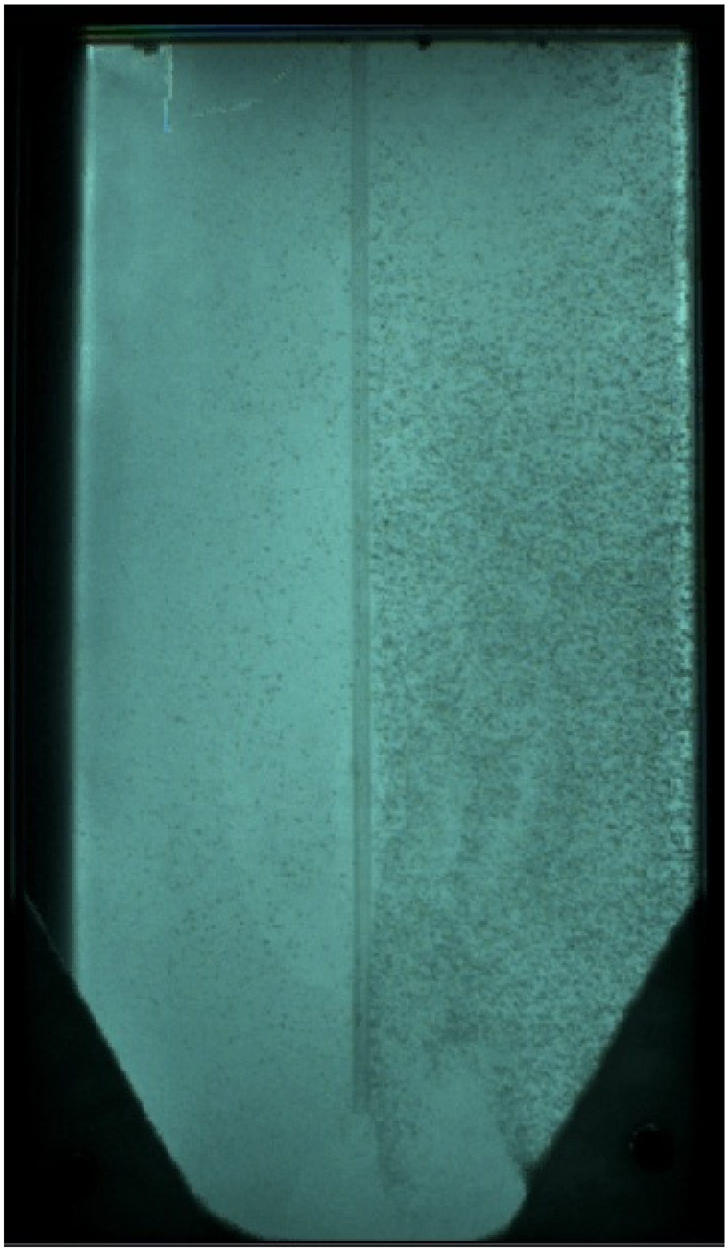

Figure 9: Differential settling predominantly on right side of tank

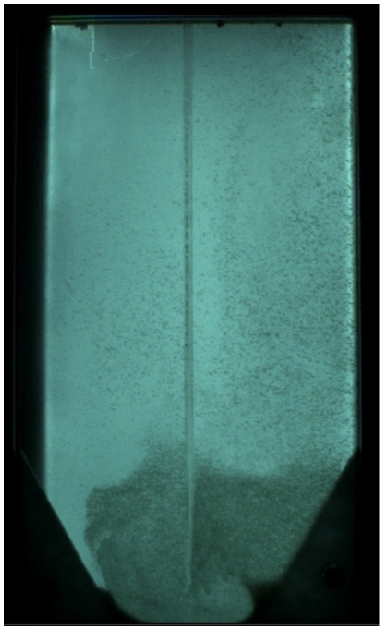

Figure 10: Formation of small floc blanket

From our experiments with two inserts, the trench bottom geometry is more efficient in forming and maintaining a floc blanket as compared to a flat bottom geometry. However, sludge still accumulated within the trench, suggesting that the current spacing between the inserts (20cm) is too wide for the jet to resuspend larger flocs when the floc blanket increases in density.

### 3.6 Experiment 6: Two 30 degree inserts, 20cm-wide trench bottom

A tank with 30 degree inserts resulted in the formation of a small floc blanket in about an hour21. Similar to Experiment 5, there was significant sludge accumulation that formed a smaller semicircular trench within the existing rectangular trench. However, about 15 minutes after formation of the floc blanket, there was a sudden increase in the density of the floc blanket22, followed by a violent eruption of flocs when the blanket broke23. This is likely due to an error with the apparatus, such as the raw water tank running out of water. The momentary pause in the inlet jet allows the flocs to settle, and then when bubbles are pumped into the tank, they generate turbulence and large eddies cause flocs to drain out at the top of the tank. Even though the floc blanket reformed at about 2.5h into the experiment24, there was minimal growth over the next 2.5h, and most of the flocs settled as sludge, forming an angle of repose of about 30 degree on the left insert25. The results from this experiment and

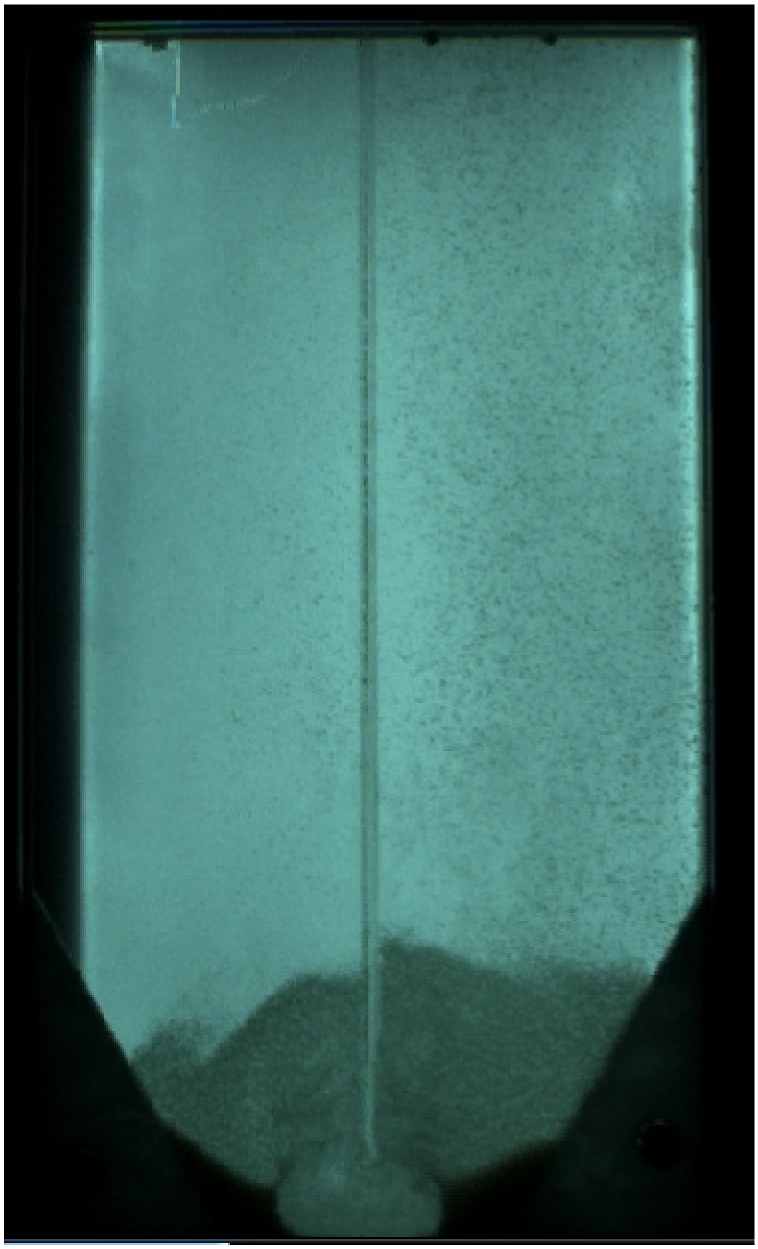

Figure 11: Sludge continues to build up forming a smaller angle of repose and trench bottom geometry

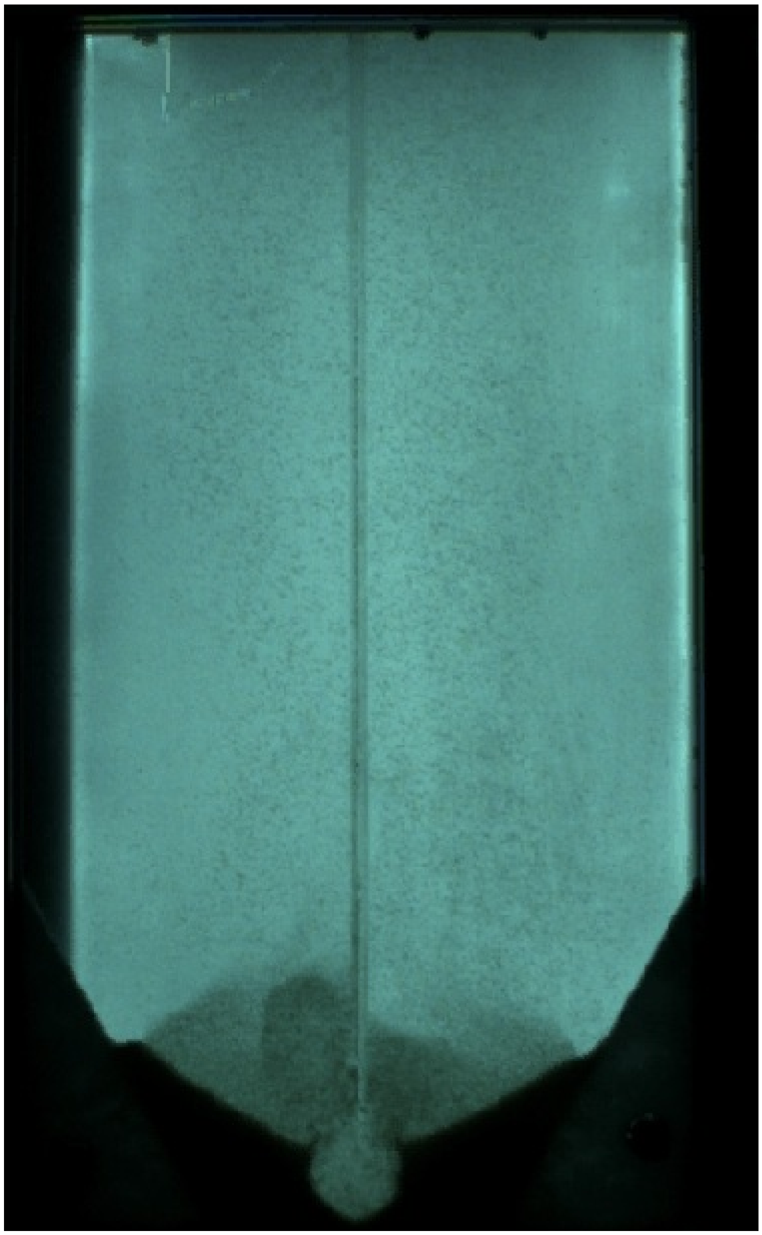

Figure 12: Circular trench forms around jet

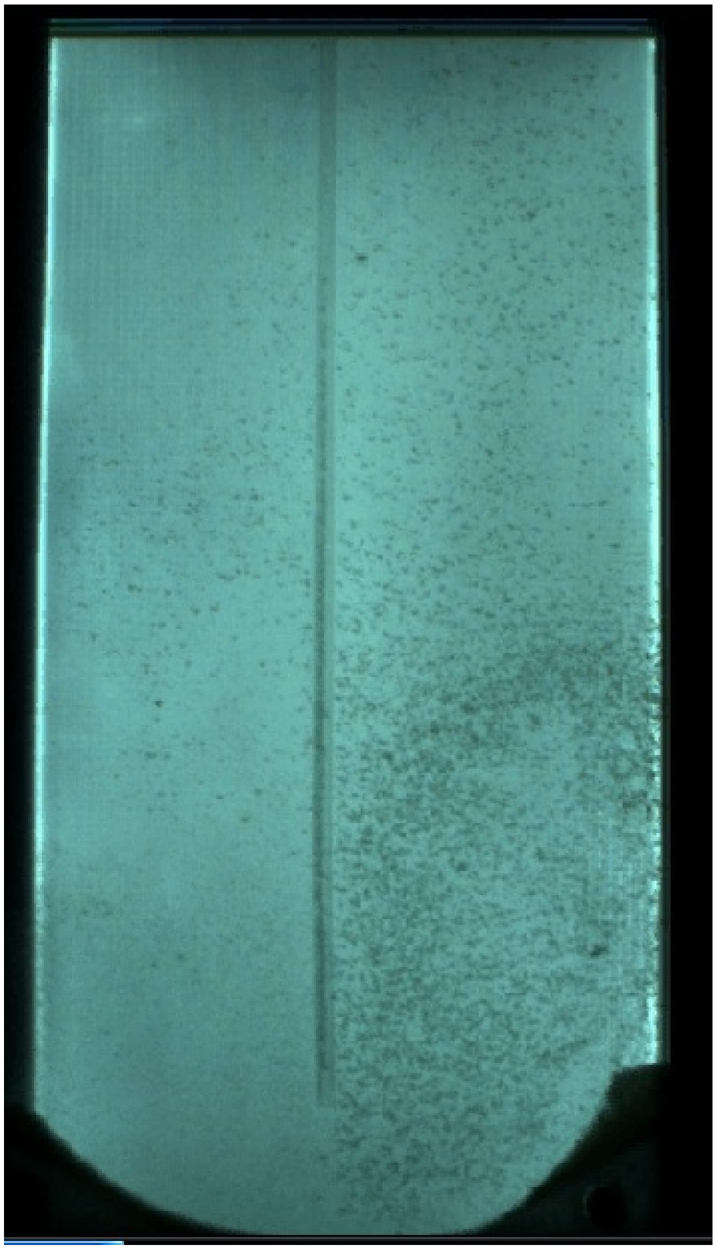

Figure 13: Very large initial flocs

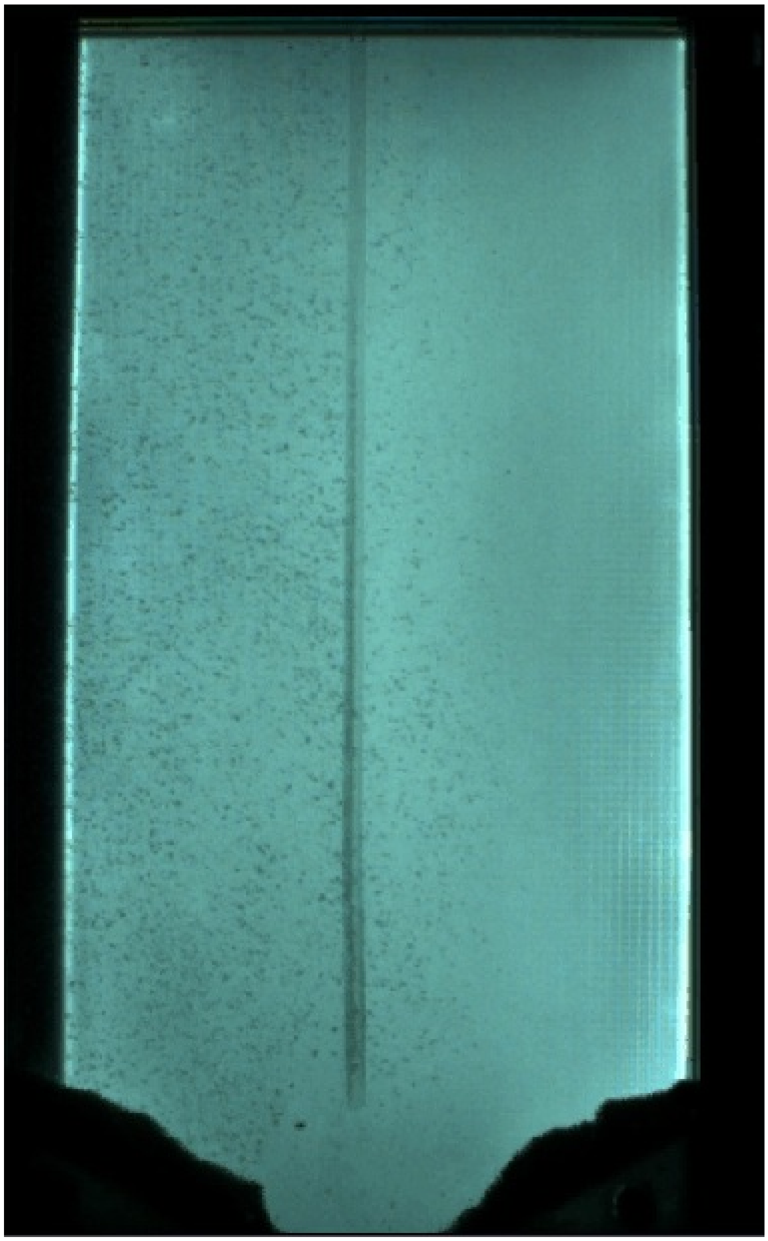

Figure 14: Sludge accumulation but no floc blanket formed

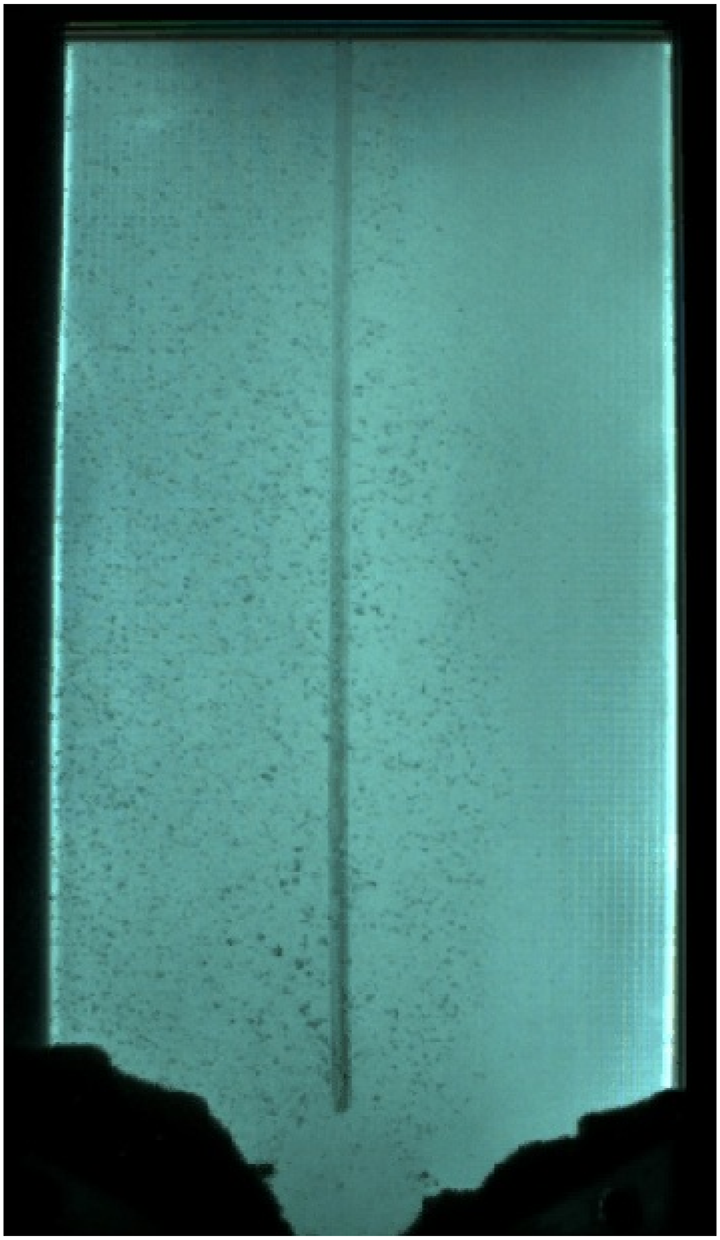

Figure 15: No clear angle of repose after 4h

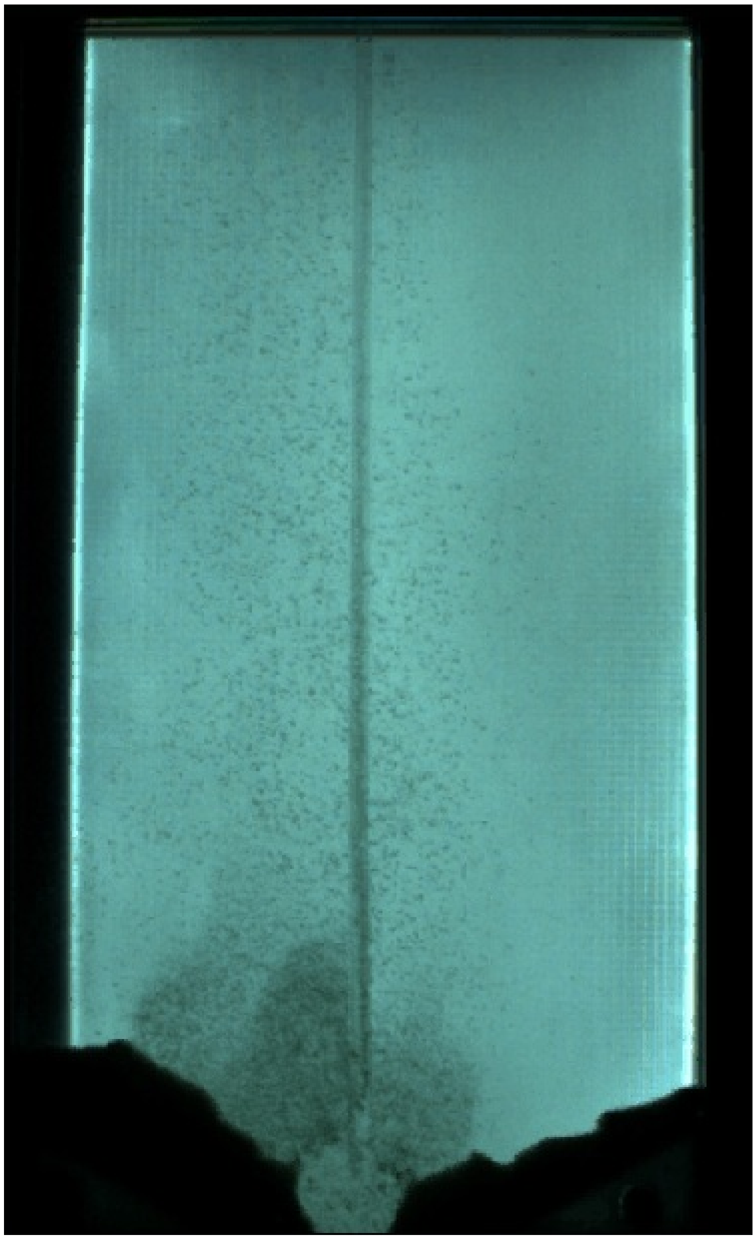

Figure 16: Slight hint of a floc blanket after 5h

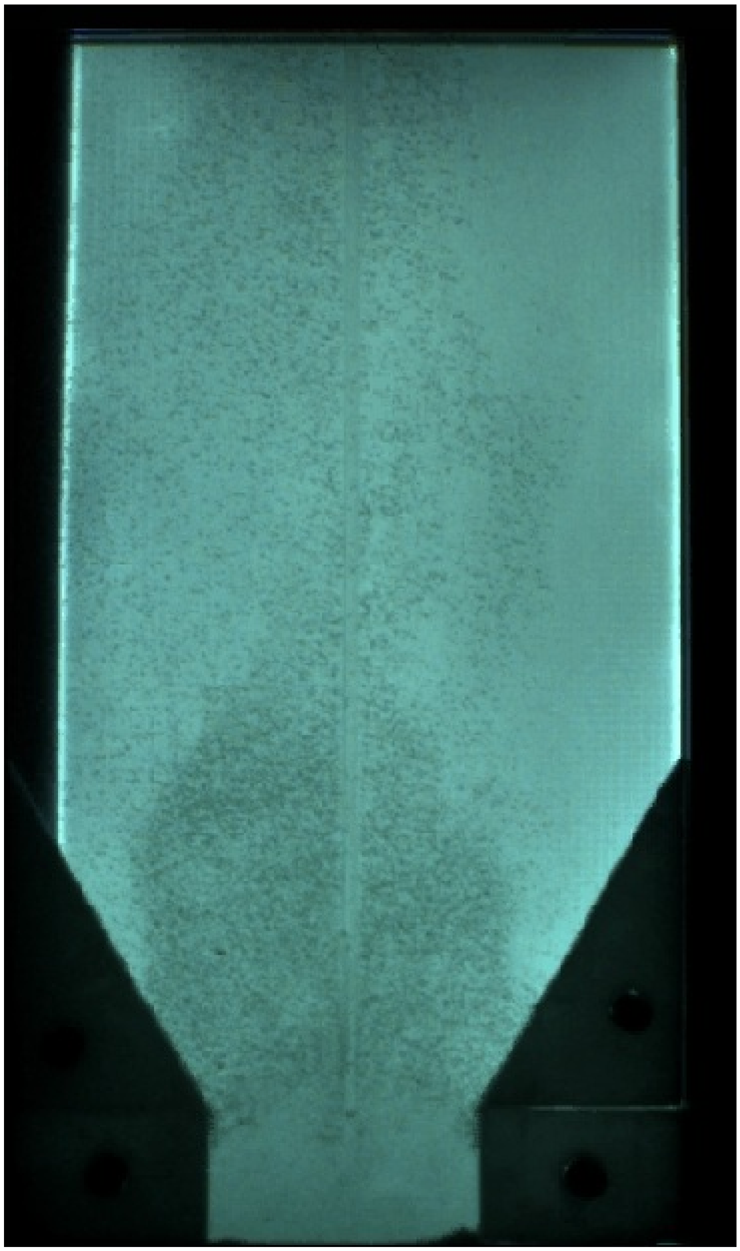

Figure 17: Even distribution of flocs on both sides of inlet pipe

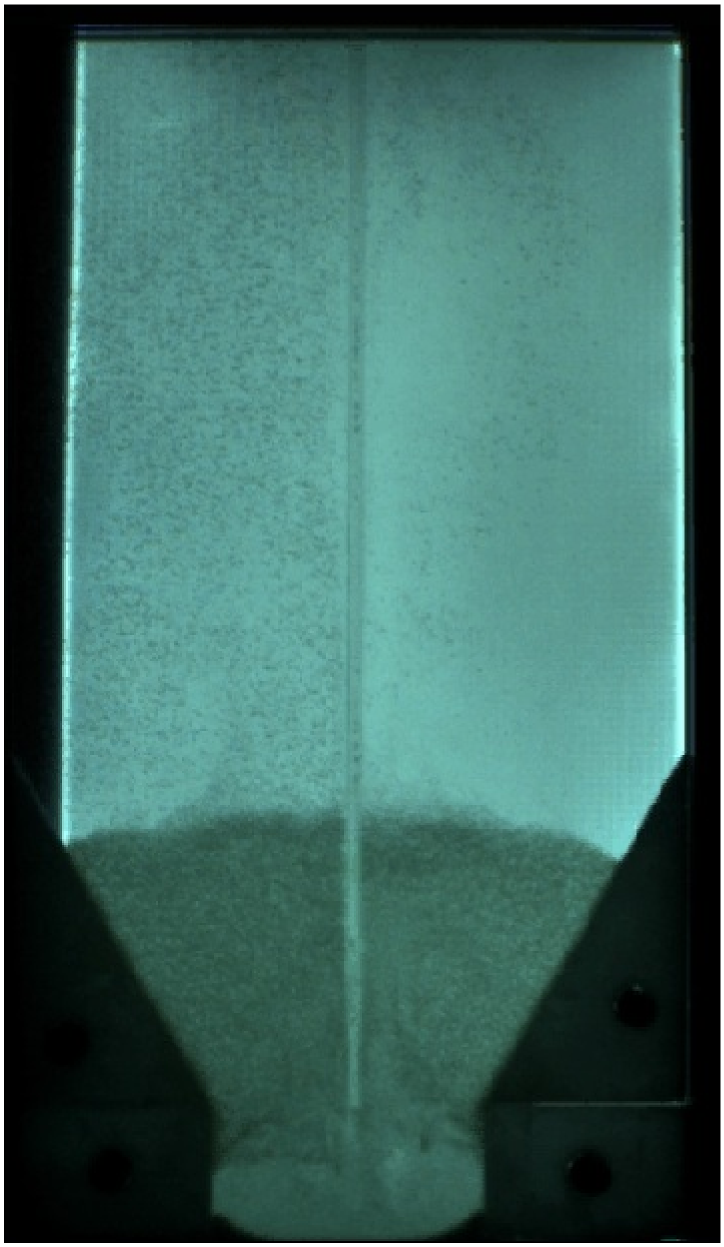

Figure 18: Even formation of floc blanket

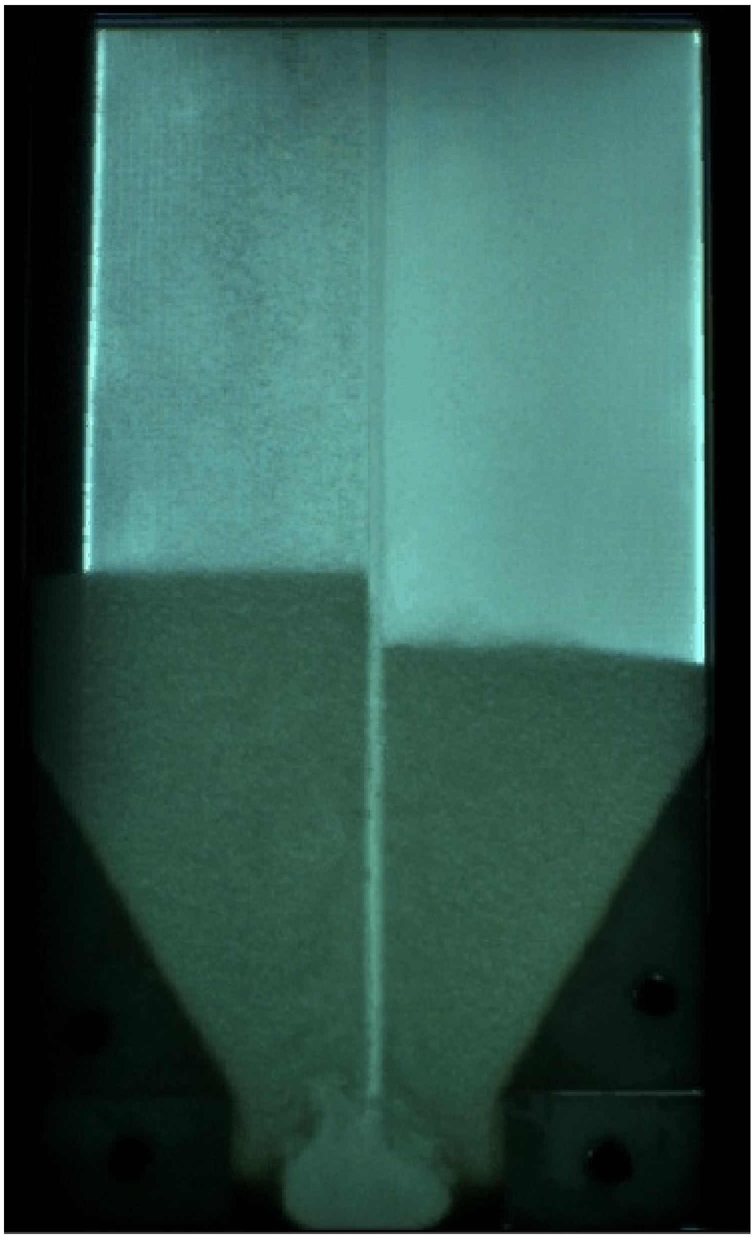

Figure 19: Slight accumulation of sludge, forming a smaller trench within the existing trench bottom

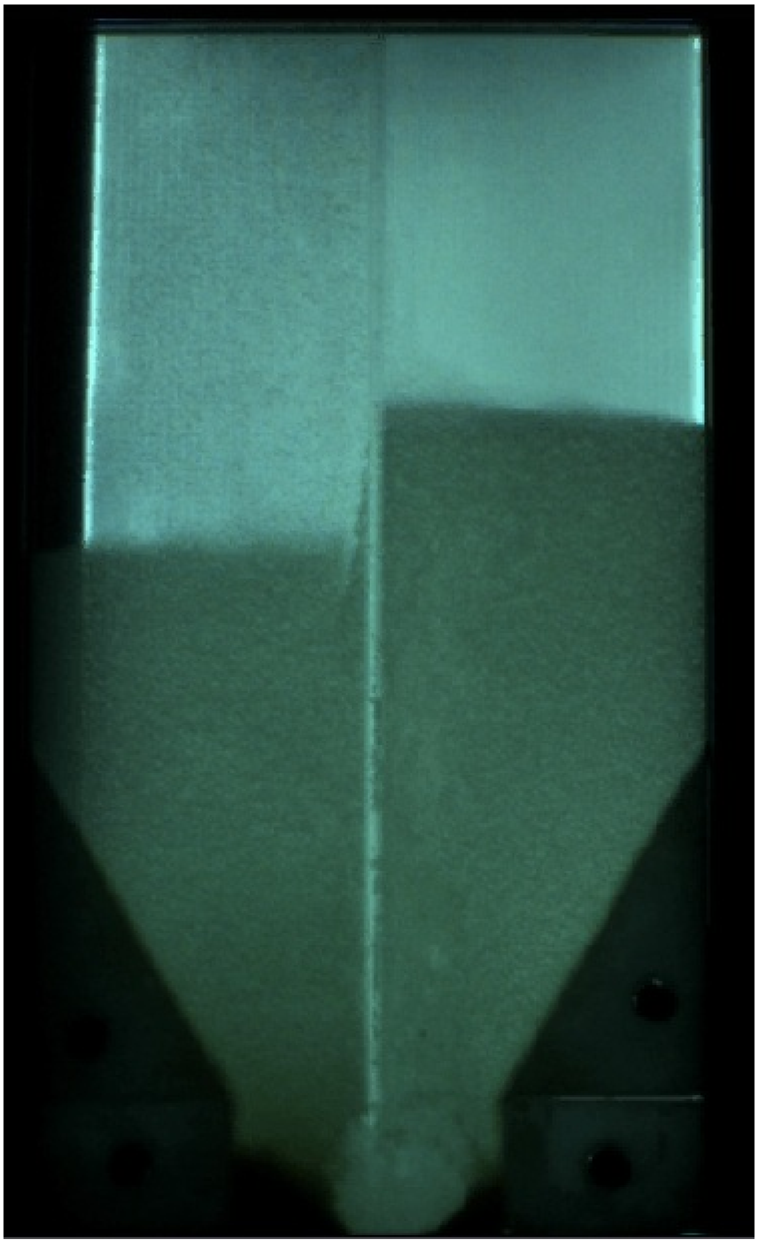

Figure 20: More sludge accumulation and floc blanket growth after 5h

Experiment 4 show that an angle of incline of 30 degrees is less desirable than an angle of 60 degrees, because only a small floc blanket is formed and does not grow significantly.

### 3.7 Experiment 7: Two 60 degree inserts, 10cm-wide trench bottom

In this experiment we halved the width of the trench from 20cm to 10 cm. The floc blanket formed at about 40 minutes and grew steadily in height and density until it reached the top of the tank26. There was less sludge accumulation in the trench as compared to Experiment 5 where the trench was 20cm wide, and the sludge formed a slighly curved surface beneath the pipe27. Therefore, a narrower trench bottom allows for better floc blanket formation because more flocs are resuspended and less end up settling on the tank bottom.

### 3.8 Experiment 8: Two 60 degree inserts, 20cm-wide semicircular trench bottom

In this experiment, we changed the rectangular trench bottom to a semicircular one because this is the geometry that is consistently formed in previous experiments. We expected that a semicircular trench would result in better floc resuspension because less energy is lost by the jet when it changes direction. The floc blanket formed in about 50 minutes28. For the next hour, there was minimal growth and significant sludge accumulation on the left side of the trench, such that the width of the trench was narrowed to about 10cm and the jet was essentially diverted to the right side of the tank29. After that, the floc blanket started to grow steadily. This result suggests that the width of the tank is too wide for the current jet diameter and velocity.

### 3.9 Experiment 9: Two 60 degree inserts, 10cm-wide semicircular trench bottom

With a narrower semicircular trench geometry, a floc blanket formed quickly and steadily grew to the top of the tank30. Throughout the experiment, there was hardly any sludge accumulation and flocs were continually being resuspended. Therefore, this was the best bottom geometry out of all the experiments we conducted thus far.

## 4 Floc Weir and Hopper Design

The purpose of a floc weir and floc hopper is to maintain the height of the floc blanket in the sedimentation tank. Ideally, the floc blanket will be located in the lower part of the sedimentation tank below the plate settlers. It is undesirable for the floc blanket to grow in height until it reaches the plate settlers, as this is likely to result in poorer effluent quality.

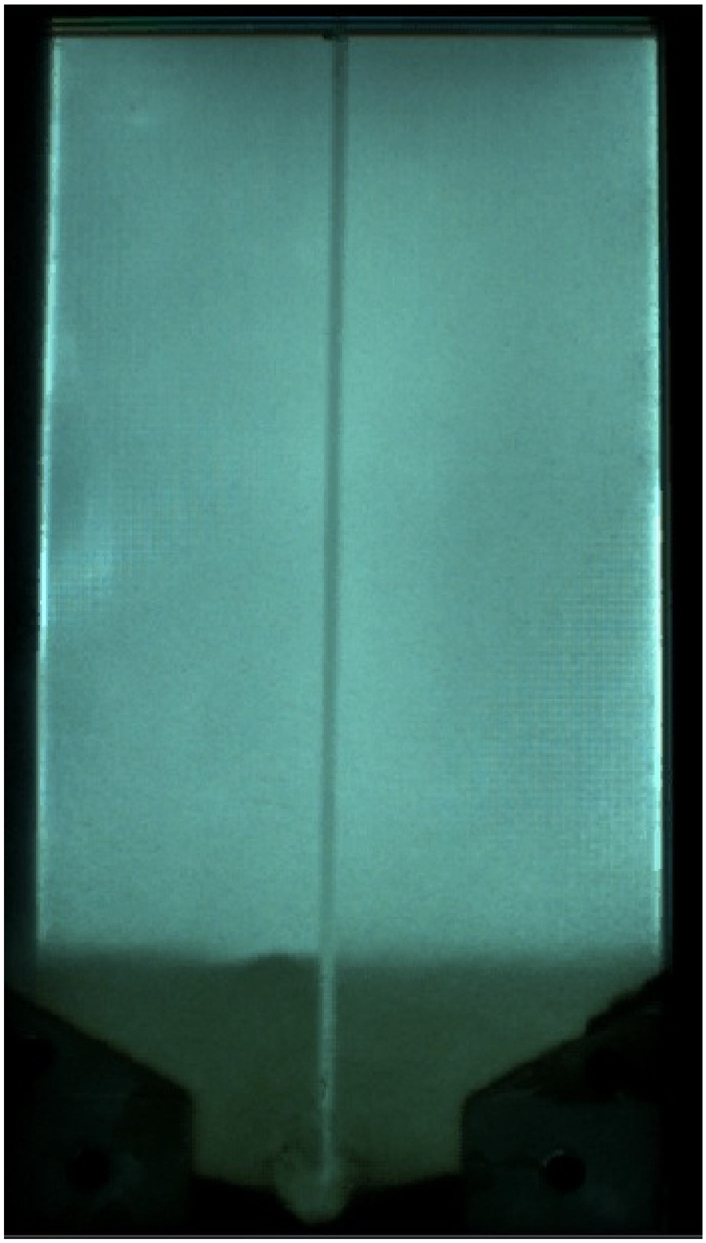

Figure 21: Inital formation of the floc blanket

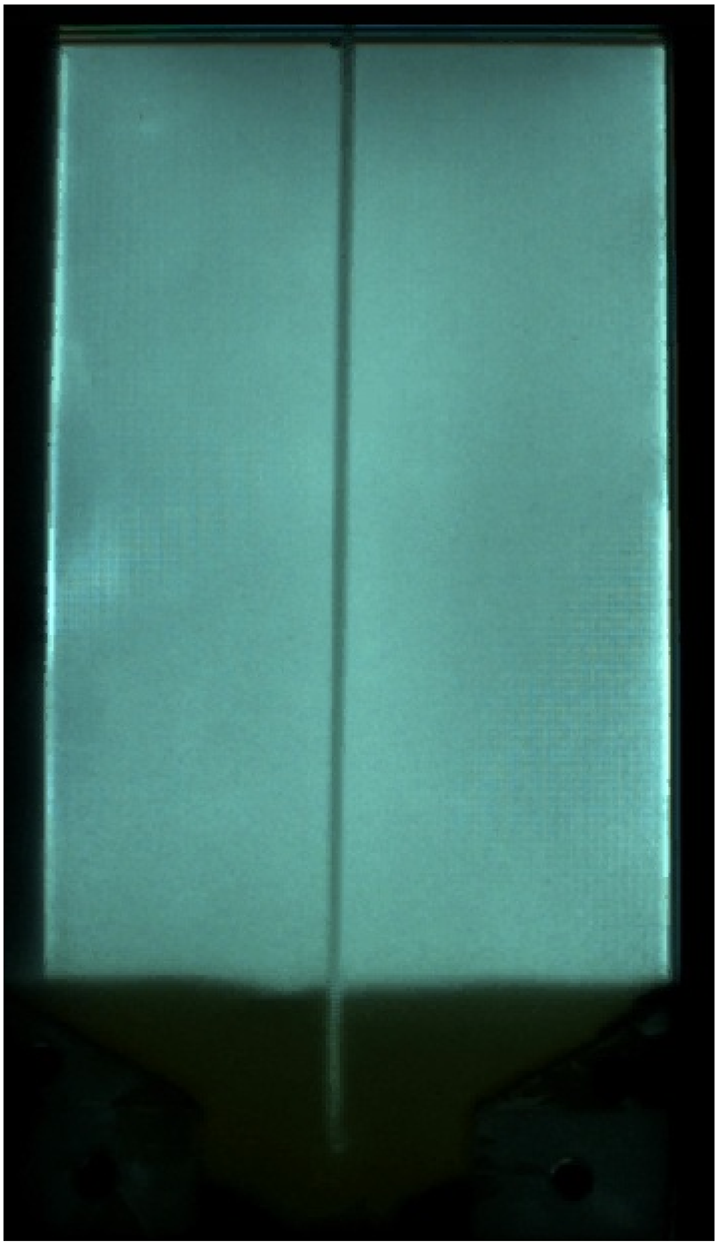

Figure 22: Sudden increase in density of the floc blanket

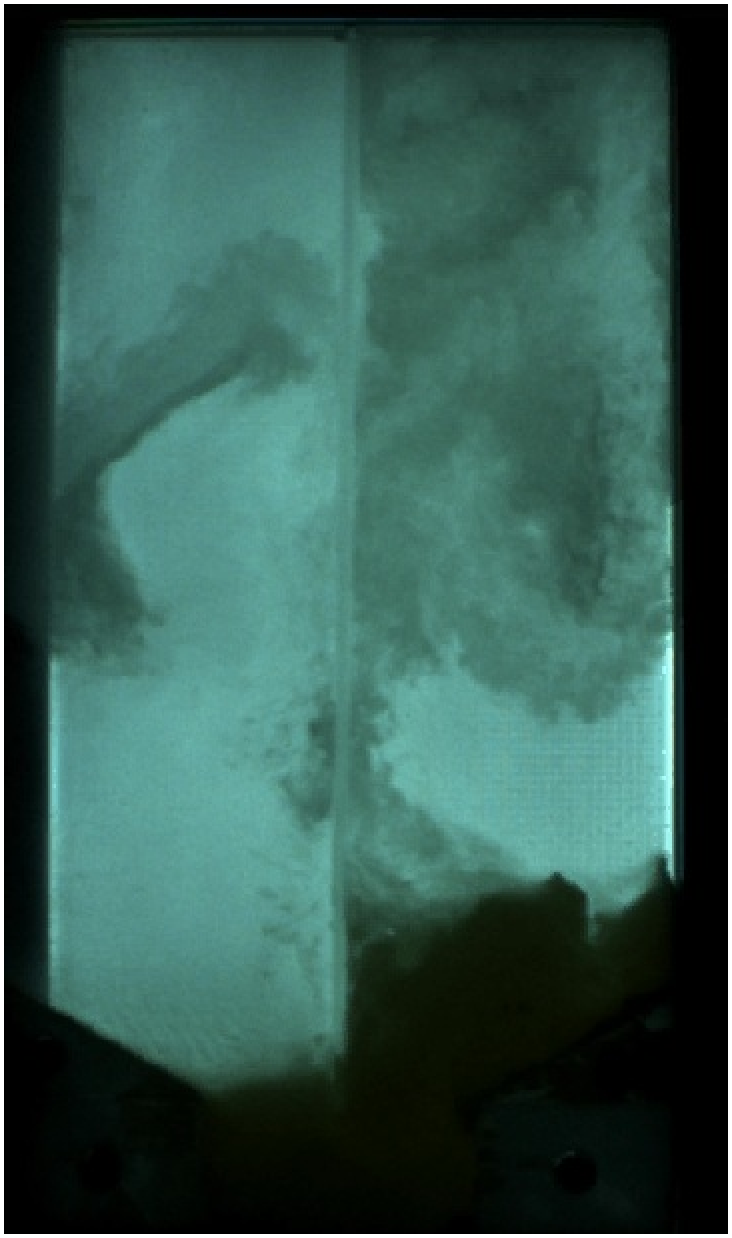

Figure 23: Breaking of the floc blanket

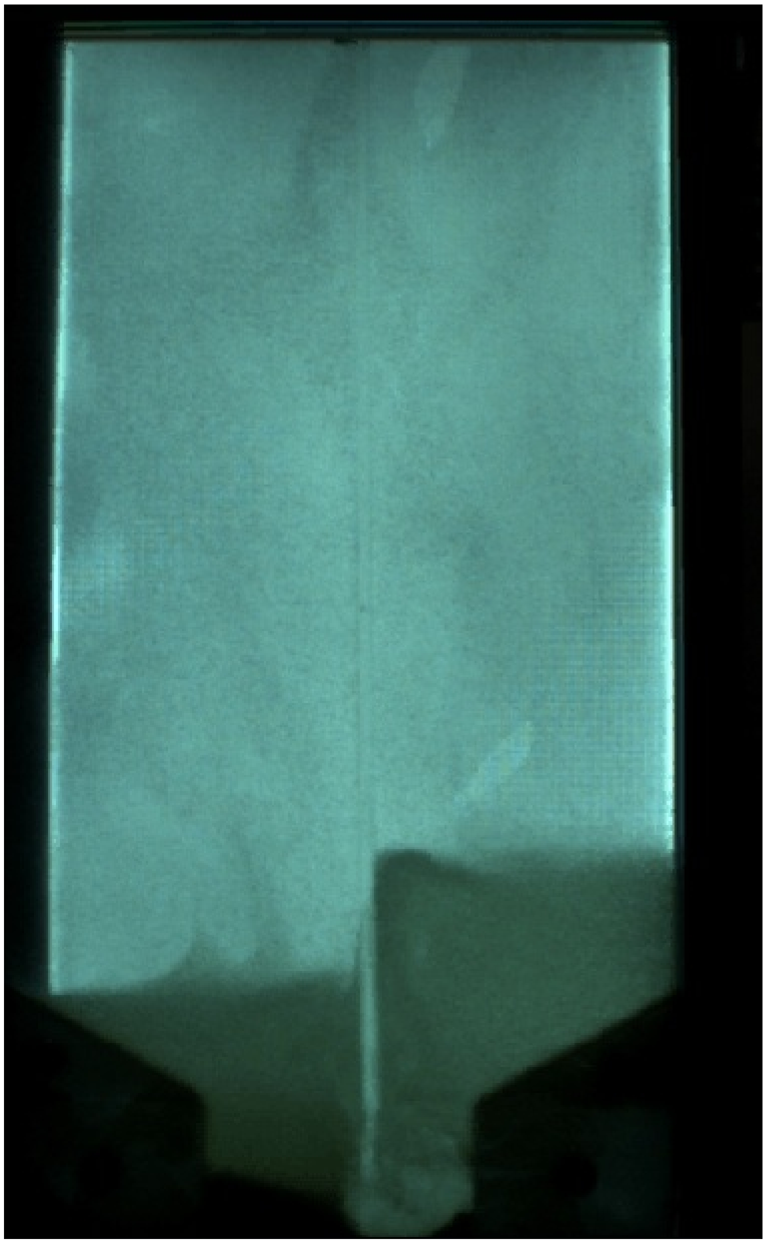

Figure 24: Floc blanket reforms 1h after breaking

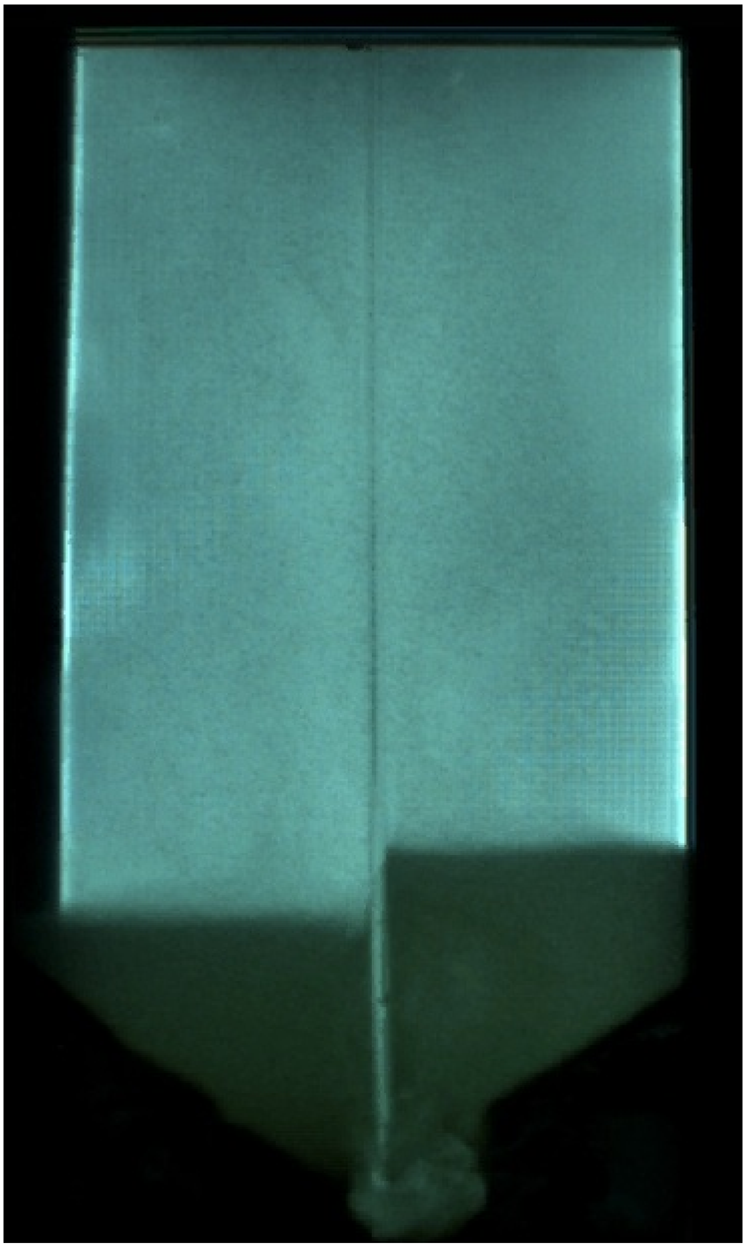

Figure 25: A smaller trench formed

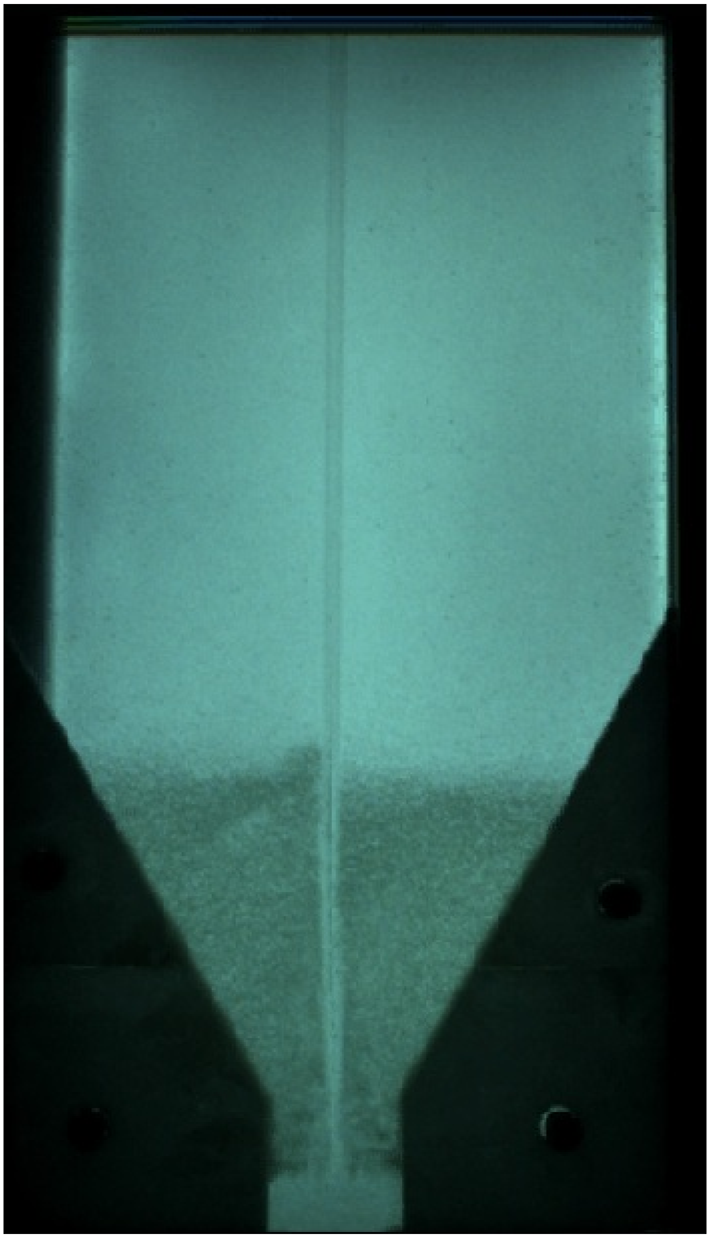

Figure 26: Floc blanket formed in about 40 minutes

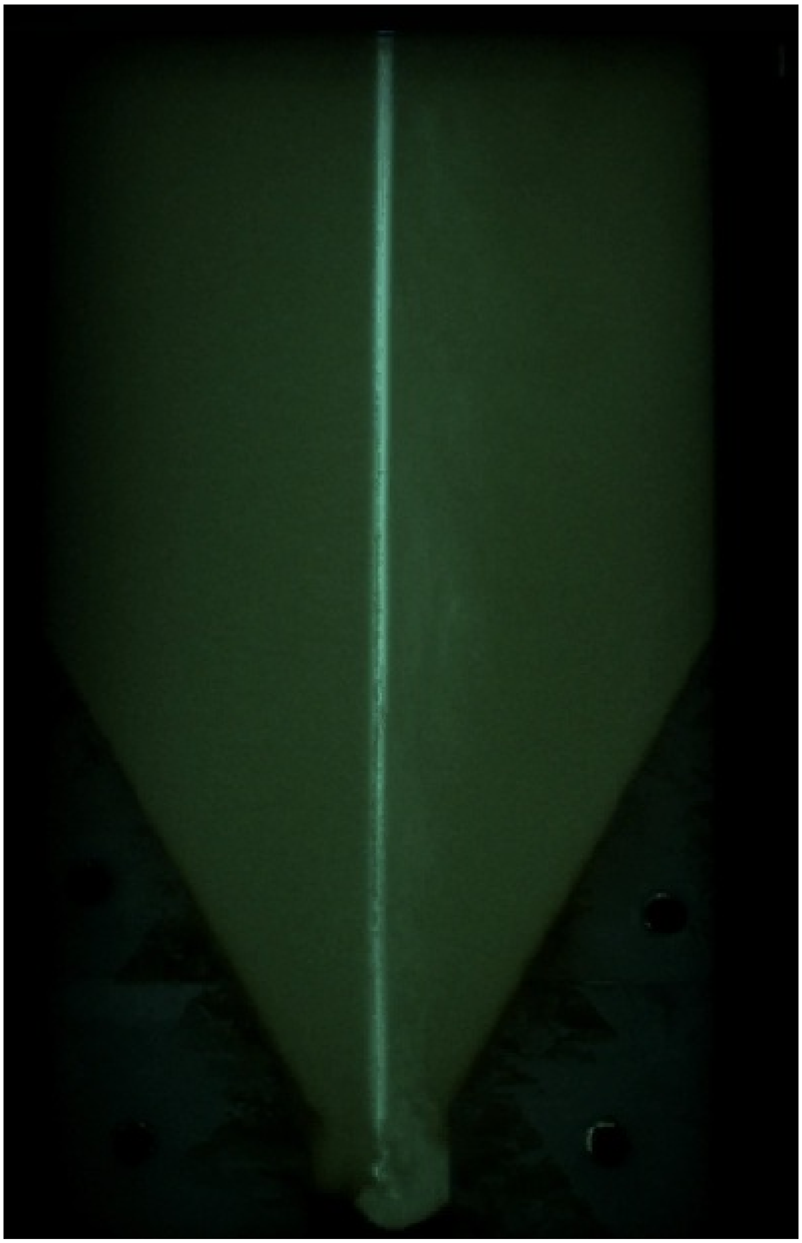

Figure 27: Very thick floc blanket 5h into experiment, some sludge accumulation in trench

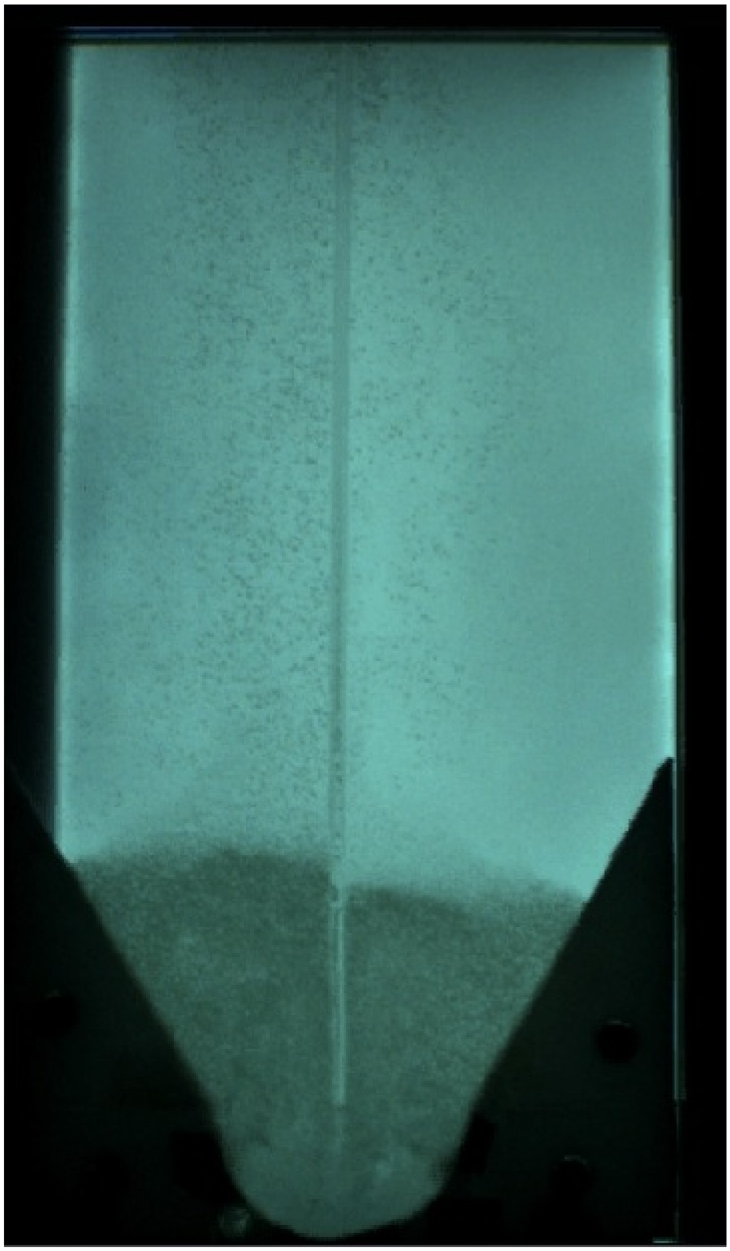

Figure 28: Floc blanket formed in about 50 minutes

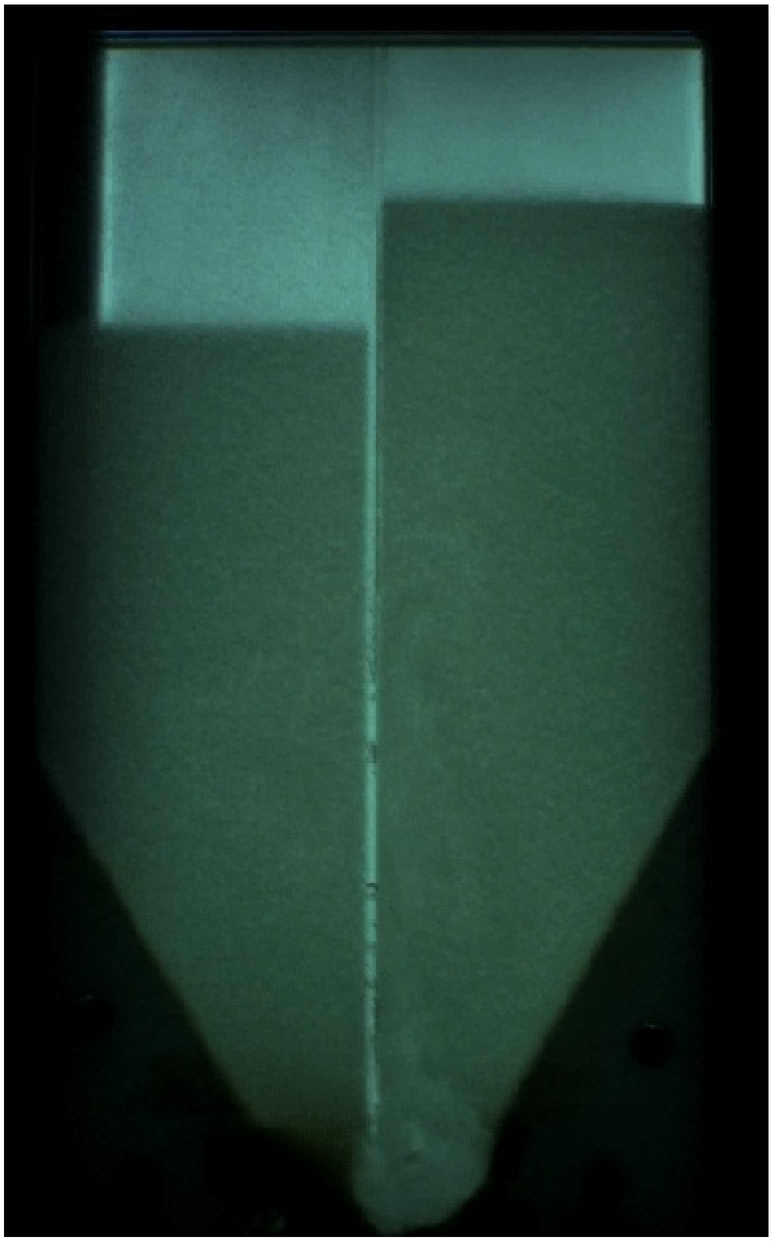

Figure 29: Jet was diverted to the right side of the tank

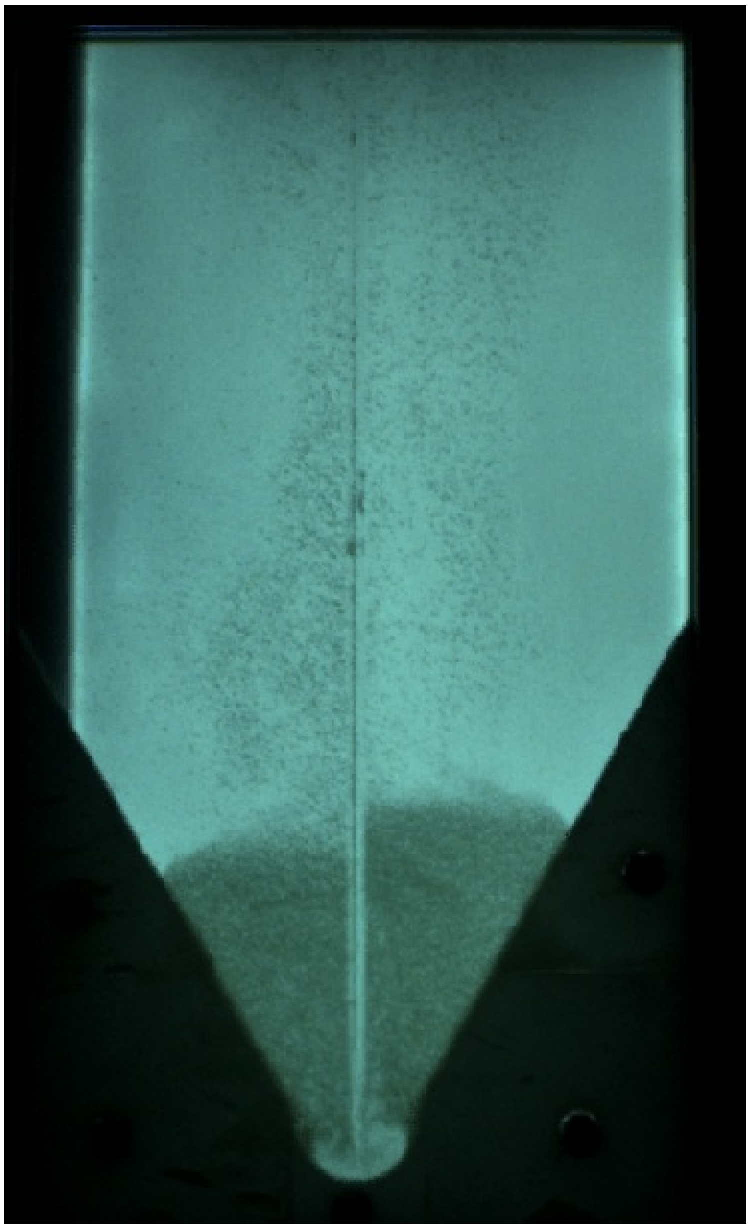

Figure 30: Floc blanket forms within 40 minutes

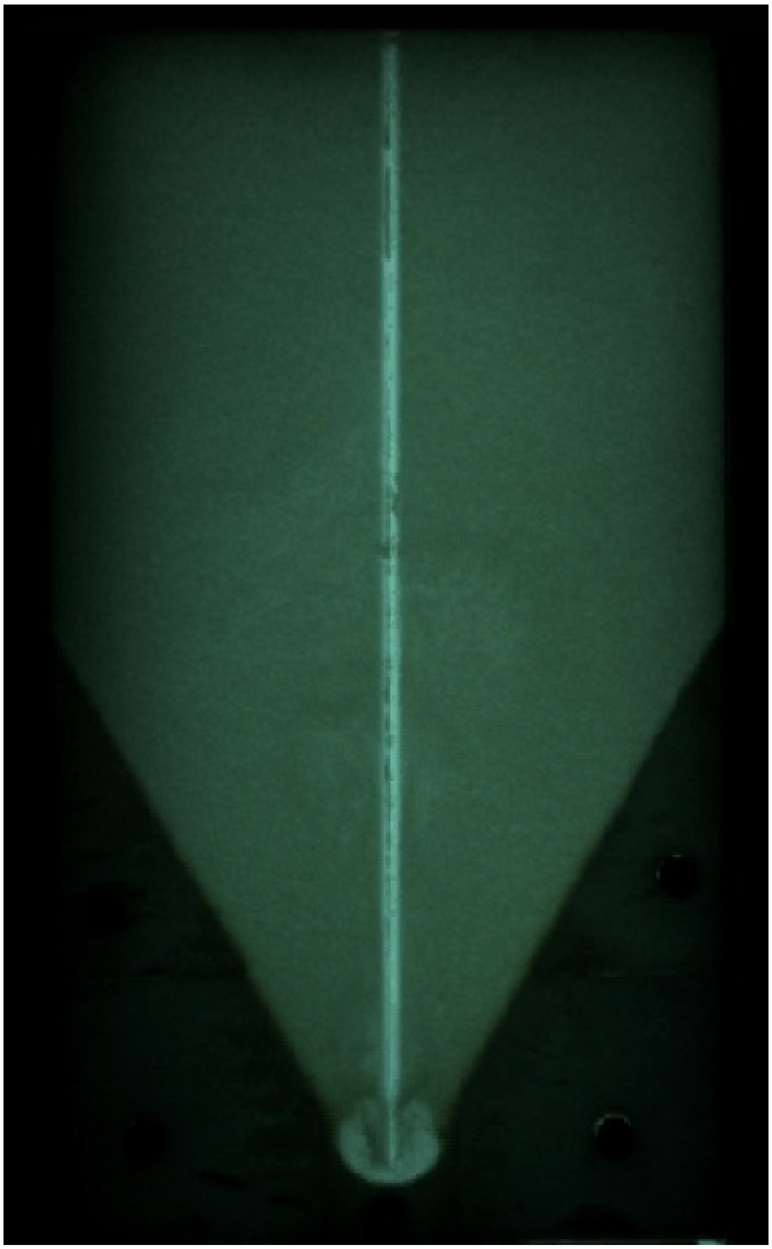

Figure 31: After 5h there is hardly any sludge accumulation

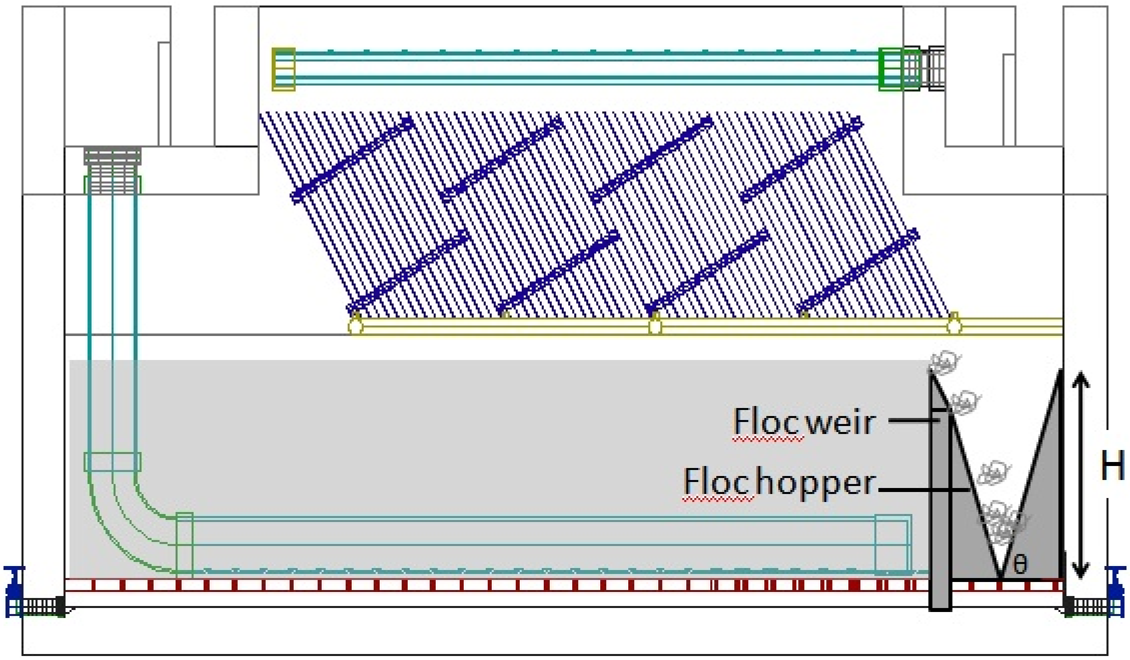


Figure 32: Proposed floc weir and floc hopper in full size sedimentation tank

Our current design is a sharp crested weir placed at the far end of the sedimentation tank with an adjacent V-shaped floc hopper to collect the excess flocs32. When the height of the floc blanket exceeds the height of the weir, excess flocs will be collected in the hopper, and the accumulated sludge can be removed by opening the sludge drain.

As we assume the floc blanket to be uniform in all directions, we have come up with a similar design for a floc weir in our experimental tank33.The tank is set up with either one or two inserts such that there is a small gap next to the leftmost insert to collect excess flocs. The insert itself acts as the floc weir and the empty space a simplified floc hopper. Once a floc blanket has formed and grows to the height of the insert, excess flocs are expected to spill over into the hopper because they are denser than water. The collected flocs can be removed via an outlet pipe at a rate Qout.

## 4.1 Experiment 10: One 60 degree insert, 10cm flat bottom

We tested the concept of using the insert as a floc weir by running an experiment with a single 60 degree insert spaced 5 cm apart from the left wall to create a floc hopper. No outlet pipe was used in this experiment. As expected, the

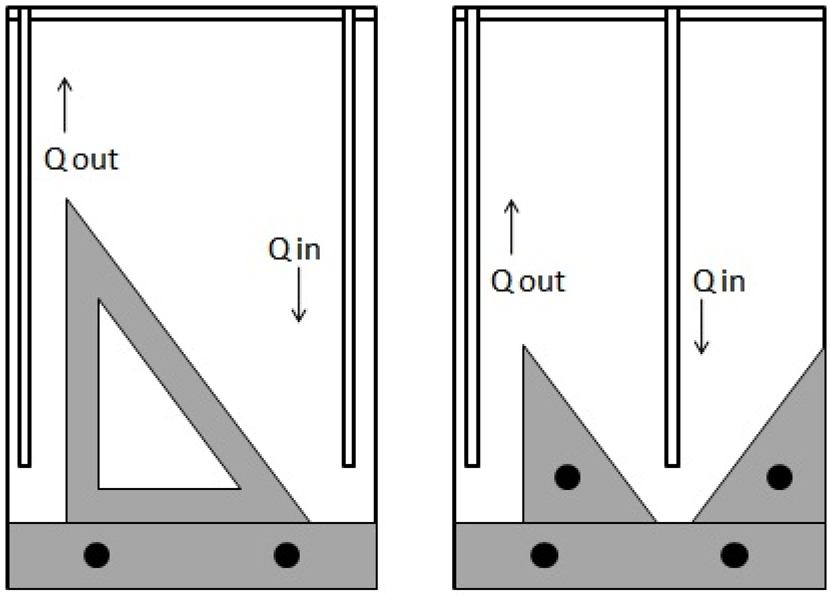


Figure 33: Proposed floc weir and hopper in experimental set up

floc blanket formed and grew to the height of the insert34, after which the flocs spilled over the tip of the insert into the space behind and the height of the floc blanket remained constant35. Sludge accumulated slowly in the floc hopper, but this rate of accumulation was slower than expected because there was also a significant loss of flocs to the hole in the middle of the insert36. Nevertheless, the results show that this design for a floc weir is feasible, and further experiments can be conducted without having to greatly modify our current apparatus.

## 4.2 Parameters of Floc Weir and Hopper

### Height of Floc Weir

Based on previous research by Hurst et al[1], the overall particle removal efficiency improves with increasing floc blanket depth up to 45cm. This can be the initial height of our floc weir, which will ensure the highest possible removal efficiency for the smallest floc blanket, thereby saving space in the sedimentation tank. The floc weir should also be higher than the height of the floc blanket when it first forms.

Figure 34: Floc blanket forms and slowly grows to the top of the insert

Figure 35: Flocs spill over the top of the insert into the hopper

Figure 36: Sludge accumulates slowly in the hopper, but mass is not conserved due to flocs leaking into the hole within the insert

**Volume of Floc Hopper**

The volume of sludge collected in 1 day can be estimated by $V_{sludge} = \frac{C_{flocblanket} \cdot Q_{weir} \cdot t}{\rho_{sludge}}$, where $Q_{weir}$ is the flow rate of flocs over the weir and can be estimated by the growth rate of the floc blanket, and $\rho_{sludge}$ is the density of sludge. To determine the appropriate size of the floc hopper, we impose the constraint that the hopper needs to be emptied at most once a day. Assuming that the walls of the hopper (in the full sized tank32)are at an angle $\theta$ and runs the breadth of the sedimentation tank, and W is the width of the hopper, the maximum volume of sludge that can be collected in one day is

$V_{max} = \frac{H^2}{tan\theta} W$ or $H = \sqrt{\frac{V_{max} \cdot tan\theta}{W}}$

Therefore, an additional height constraint on the floc weir is $H = \sqrt{\frac{C_{flocblanket} \cdot Q_{weir} \cdot t \cdot tan\theta}{W \cdot \rho_{sludge}}}$.

# 5 Future Work

- Determine the effects of further reducing the diameter of the semicircular trench on sludge accumulation and floc blanket formation.
- Change the size of the inlet pipe to more accurately reflect the diameter of the actual drop tube, and so that flocs are able to easily pass from one side of the tank to the other.
- Come up with an empirical relationship between the ideal diameter of the semicircular trench to the diamter of the inlet pipe.
- Determine the flow rate needed to drain sludge from the floc hopper in order to keep the system running at steady state without any sludge accumulation on the tank bottom.

# References

[1] Hurst et al. (2010) Parameters affecting steady-state floc blanket performance.