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Solids Movement within the ABR system

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Abstract

Solids are settled, suspended, and dissolved matters in the ABR system. Solids can be organic or inorganic matter. Analysing solids movement in the ABR system requires the classifications of solids into four groups. . [1] **Total Solids (TS)** – It is the sum of settled, suspended and dissolved solids. [2] **Volatile solids (VS)** is organic portion of the total solid that is lost during ignition. [3] **Total Suspended solids (TSS)** – is the sum of dissolved and suspended particles in the liquid portion of wastewater and [4] **Volatile Suspended Solids (VSS) –** is the organic portion of the Total Suspended Solids (TSS) lost during ignition. TS, VS, TSS, and VSS were analysed in all the three trains with respect to time, hydraulic loading and chamber size. according to the data there is a strong relation between TS and VS in all the three trains with strong correlation coefficient that are close to 0.98 for all three trains with statistical confidence interval test of p-value of ≤ 0.05 which suggests a valid and stronger correlation between TS and VS. TSS and VSS were analysed using two different methods: crucible and centrifuge. The result shows higher dissolved solids in the ABR system and the TSS value goes up at higher flow rate. Turbidity test also shows a high reading in turbidity in NTUs at high flow rate.

Introduction

According the pollution research group at the University of KwaZulu Natal, Anaerobic Baffled Reactors (ABR) have been implemented by the German NGO BORDA as a standard component of Decentralized Wastewater Treatment Plants (DEWATS) in Durban, South Africa to treat wastewater in a highly dense areas that are not close to the centralized network. According to SSWM, Anaerobic Baffled Reactors Is an improved septic tank with a series of baffles under which the grey, black and industrial wastewater is forced to flow under and offer the baffles from the inlet to the outlet. The increased contact time with the active microbial sludge slayer results in an improved treatment. ABRs are robust(strong and safe) and can treat a wide range of wastewater, but both remaining sludge and effluents still need further treatment in order to be reused or discharged properly.

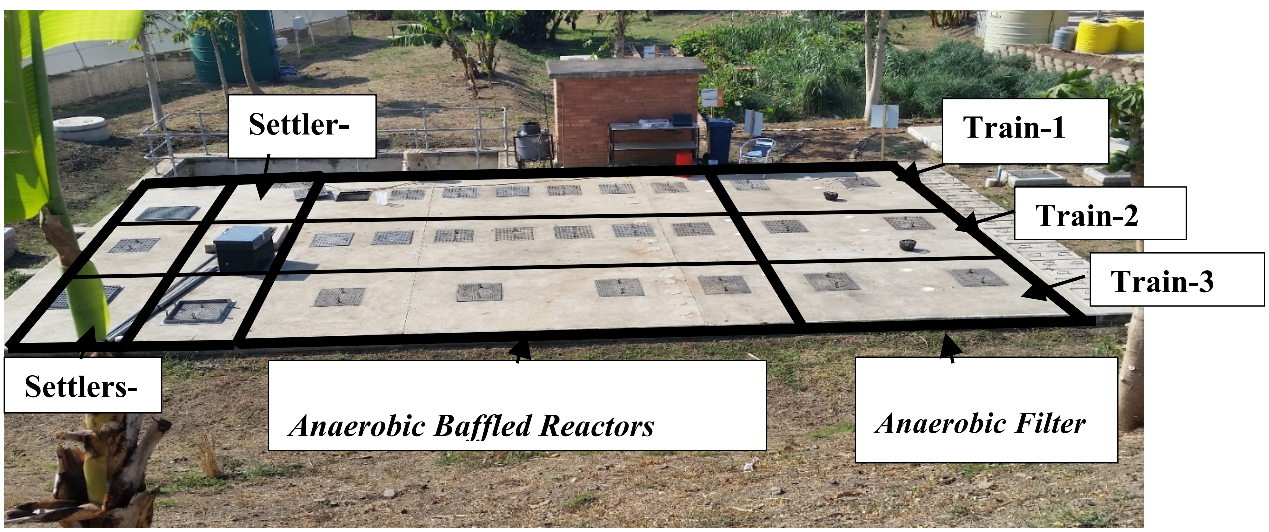


Figure 1-Newlands Mashu DEWATS Plant in Durban, South Africa

IRES summer research project was designed to analyse different parameters that affect the operation of ABRs such as flowrate, Solid movement, Chemical Oxygen Demand, and Volatile fatty Acid as a function of hydraulic loading and ABR size to determine the wastewater treatment quality and efficiency. The DEWAT plant was designed according to BORDA guidelines (Sasse, 1998) to treat domestic wastewater from around 80 households. THE Newlands Mashu DEWATS plant shown in figure-1 above consists of a settling Chamber/biogas collector, 3 parallel ABR trains and 2 anaerobic filter (AF) modules. ABR train 1 and 2 have seven identical chambers while ABR train 3 have 4 chambers shown below in figure 2 and 3.

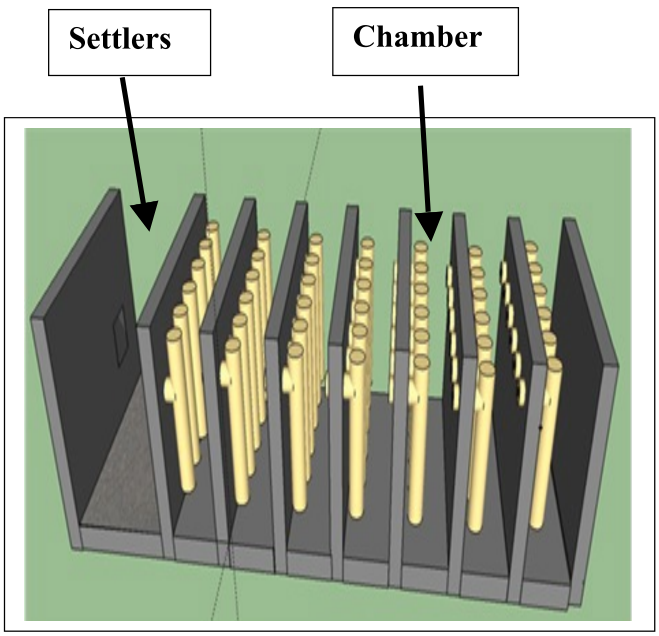


Figure 2 - Schematic representation of the seven Chambered ABR used in train 1 and 2.

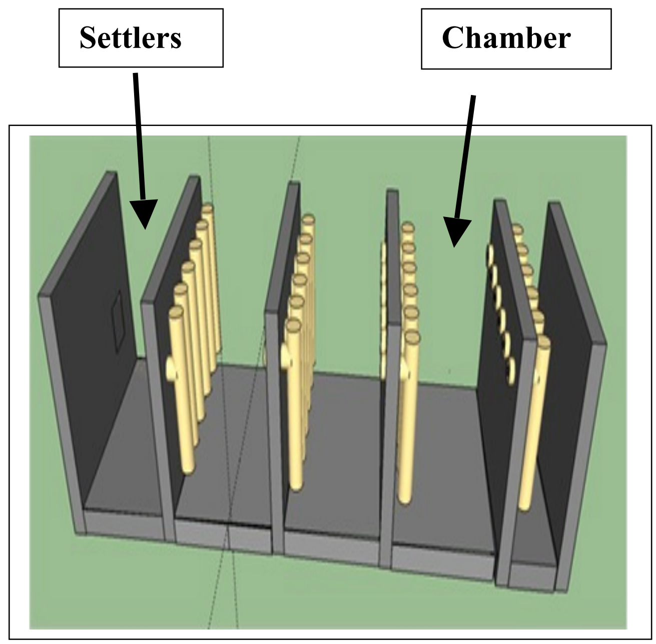


Figure 3 - Schematic representation of the Four Chambered ABR used in Train 3.

In this project, the movement of solids within the ABR system was analysed with respect to flowrate, hydraulic loading and chamber size. Solids are suspended, dissolved and settled matters within the ABR system. We can divided solids into two groups depending on their chemical properties: Organic and Inorganic solids. Organic solids are solids that made up of Carbon, hydrogen, oxygen, nitrogen, phosphorous and few other elements. The inert compounds that are not subjected to decaying are called inorganic. For this project, solids were classified into four to simplify scientific investigation on the movement of solids within the ABR system. [1] **Total Solids (TS)** – It is the sum of settled, suspended and dissolved solids. [2] **Volatile solids (VS)** is organic portion of the total solid that is lost during ignition. [3] **Total Suspended solids (TSS)** – is the sum of dissolved and suspended particles in the liquid portion of wastewater and [4] **Volatile Suspended Solids (VSS) –** is the organic portion of the Total Suspended Solids (TSS) lost during ignition.

Methodology

Solids movement within the ABR system involves analysis on total solids, volatile solids, total suspended solids, volatile suspended solids and turbidity testing. In order to meet our goals in a scientific manner, a control volume method was used to determine the gross characteristics of solids within and across the boundary layers. Two meter long tube (Di of 10cm) with a stainless steel hook was used to collect a total sample from Each ABR chambers. The sample height within the column was measured and 20ml of the sample from each ABR was transferred into a pre-dried and pre-weighted crucible and placed into an oven for 24 hours after the mass of the sample was recorded. The crucible with the sample was removed from the oven after the 24 hours period and the weight was recorded prior to igniting it in a furnace for 2 hours. The weight difference before and after the oven and furnace time was used to calculate the total and volatile solids with respect to each ABR chambers.

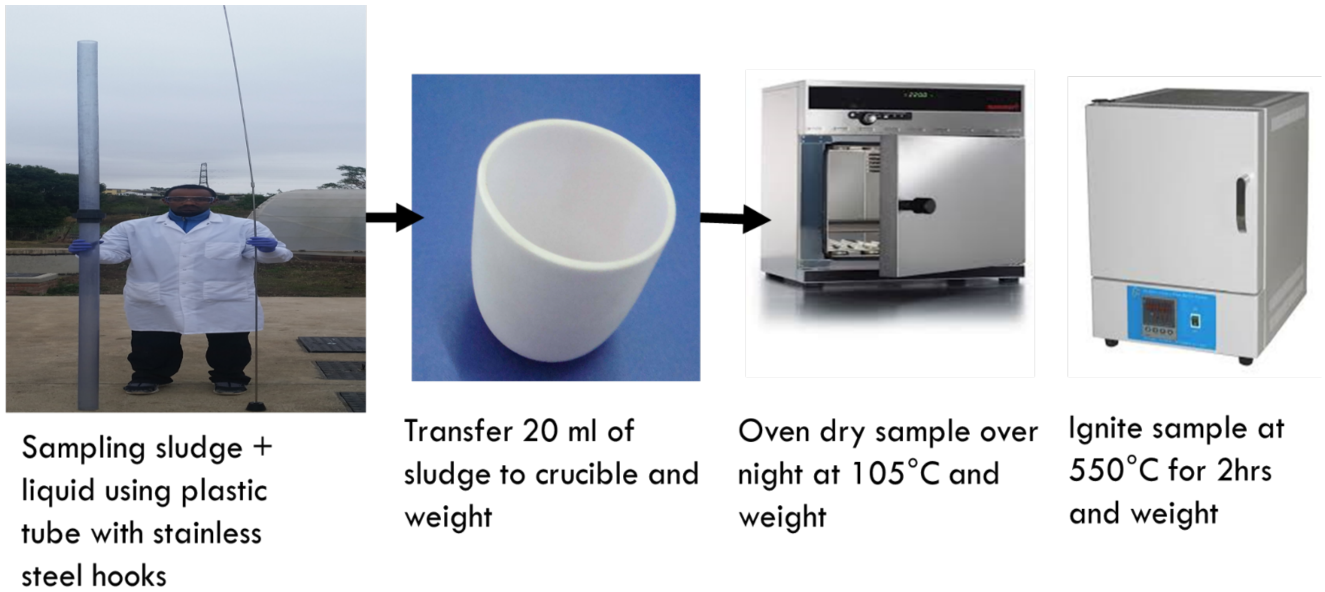


Figure 4 - Schematic Representation on Total and Volatile Solids experiment

Total suspended solids and volatile suspended solid was analysed using two different methods: centrifuge and Crucible. Sample was collected from each ABR at two different time in a single day using 1-litter bottle attached to an end of 1.5m long wood stick. Sample from each ABR chambers collected using 1-litter bottle attached to an end of stick was transferred into 1000 ml beakers. 30ml of the sample from each beakers was measured out using micro-pipet and transferred into a pre-dried and pre-weighted crucible. The crucible with sample was oven dried for 24 hours period and the mass difference before and after the oven time was used to calculate the total suspended solids in each ABR system and this method was named the Crucible method.

Figure - 5 - Schematic Representation on Total Suspend Solids (Crucible Method)

The exact same sample used to determine total suspended solids using the crucible method was used to analyse total suspended solids and suspended volatile solids in each ABR using centrifuge method. 180ml of sample from each beakers was transferred into equal amount of four separate 45ml centrifuge tubes. Each tube with the sample was centrifuged for 10 minutes at 10,000 relative centrifugal force (RCF) and the pellet that accumulate on the side of the tubes was carefully washed out of the tubes with about 5-7ml of the sample in each centrifuge tube and transferred into a pre-dried and pre-weighted crucibles. The weight before and after the 24 hour oven time and 2 hours furnace time was used to determine total suspended solids, and volatile suspended solids. Comparison used to analyse total suspend solids using the centrifuge and crucible method gives us an insight view of the amount of dissolved solids in our sample.

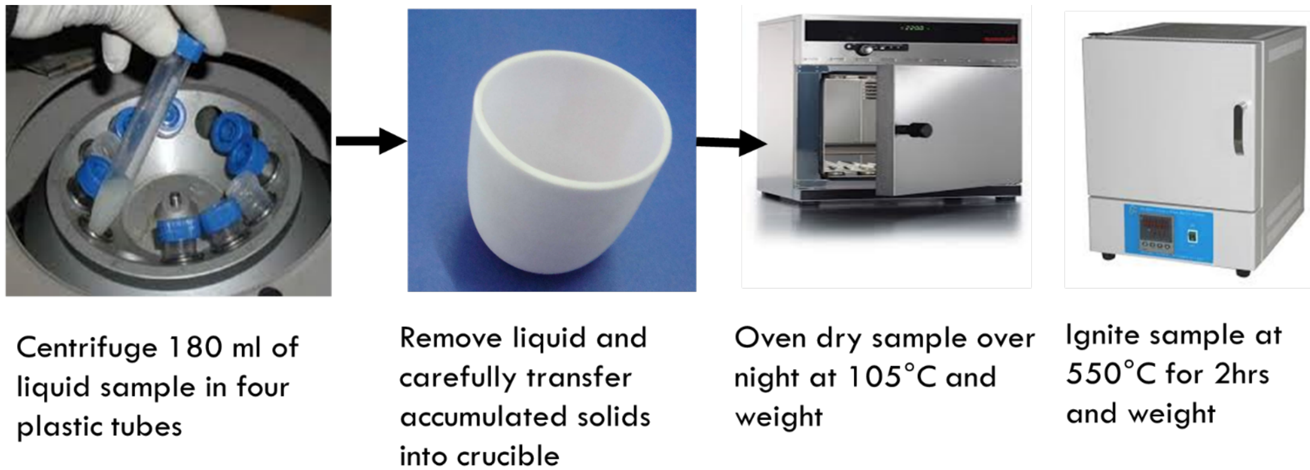


Figure - 6 - Schematic Representation on TSS and VSS (Centrifuge Method)

Finally, turbidity tube was used to measure the cloudiness of the sample. The quality of the treatment depend on the turbidity of the effluent. Sample was collected from each ABR chambers using 1-litter bottle attached to an end of 1.5m long wood stick and transferred into 1000ml beakers. These samples was pour into the turbidity tube in shaded area until the black and white triangle at the bottom of the turbidity tube is no longer seen by the individual taking the turbidity measurement. The height of sample is at this point is measured and used to calculate the turbidity of the sample in NTUs.

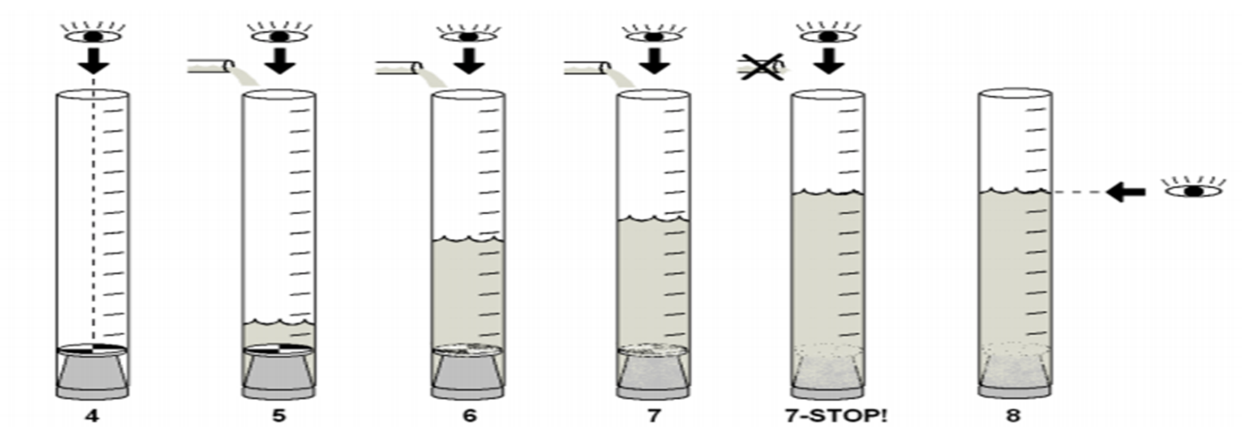
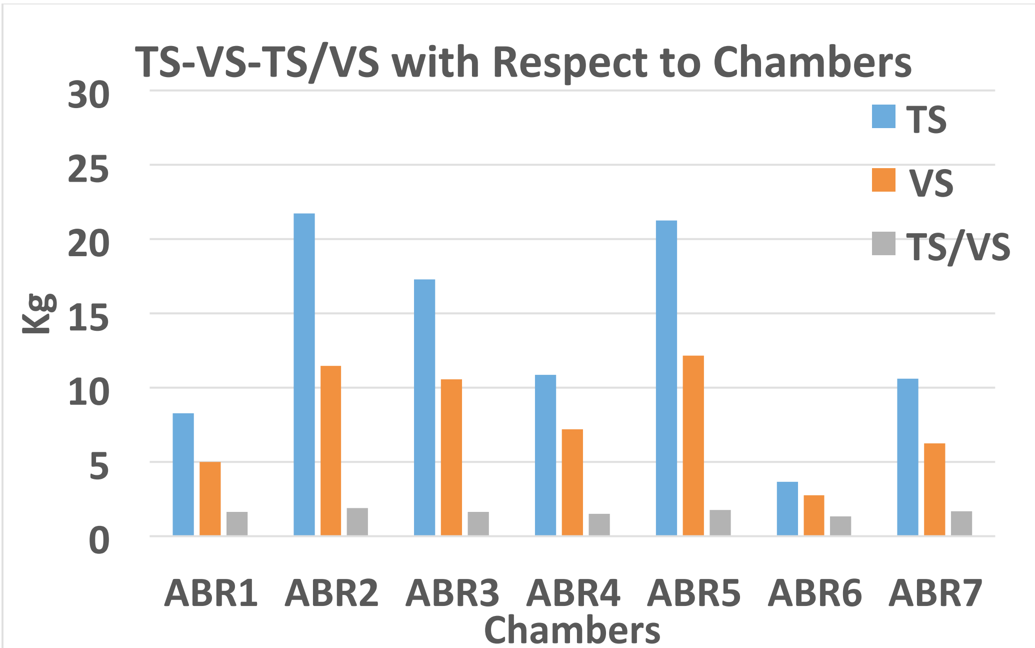


Figure - 7 – Turbidity testing

Results

Total and Volatile Solids on Train-1 (experiment date 07/15/15)



$\sum_1^7 TS$ = 93.7 Kg

$\sum_1^7 VS$ = 55.4 Kg

TS/VS = 1.7

$(TS/VS)^{-1}$ = 0.59

Figure 8 – TS - VS – TS/VS with Respect to Chambers-Train-1

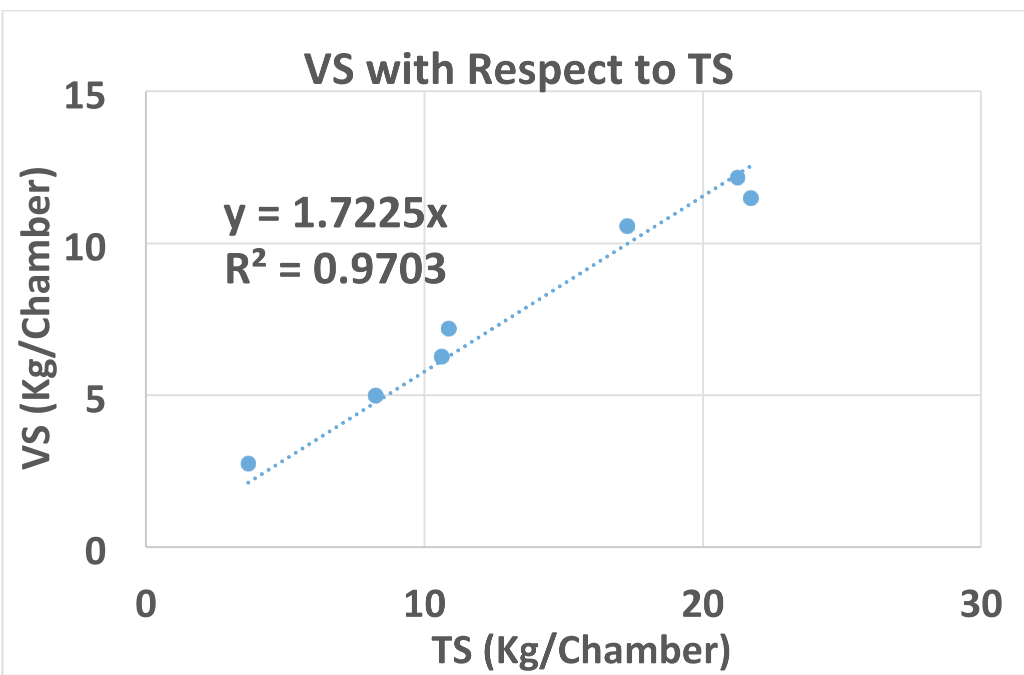


Figure 9 – VS with Respect to TS-Train-1

Summary Output-Train-1									
Regression Statistics									
Multiple R	0.990								
R Square	0.981								
Adjusted R Square	0.977								
Standard Error	0.542								
Observations	7.000								
ANOVA									
	df	*SS*	*MS*	*F*	*Significance F*				
Regression	1.000	74.811	74.811	254.194	0.000				
Residual	5.000	1.472	0.294						
Total	6.000	76.282							
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*	
Intercept	1.018	0.479	2.125	0.087	-0.213	2.249	-0.213	2.249	
X Variable 1	0.515	0.032	15.943	0.00002	0.432	0.598	0.432	0.598	

Table 1-Regression Analysis on Train-1

Total and Volatile Solids on Train-2

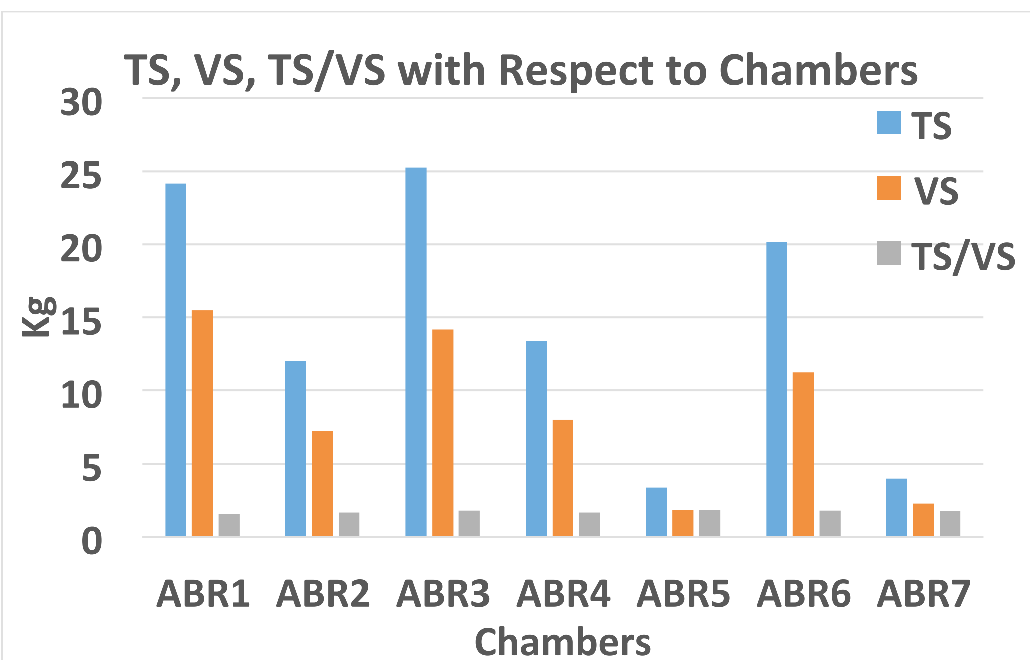


Figure 10 – TS - VS – TS/VS with Respect to Chambers-Train-2

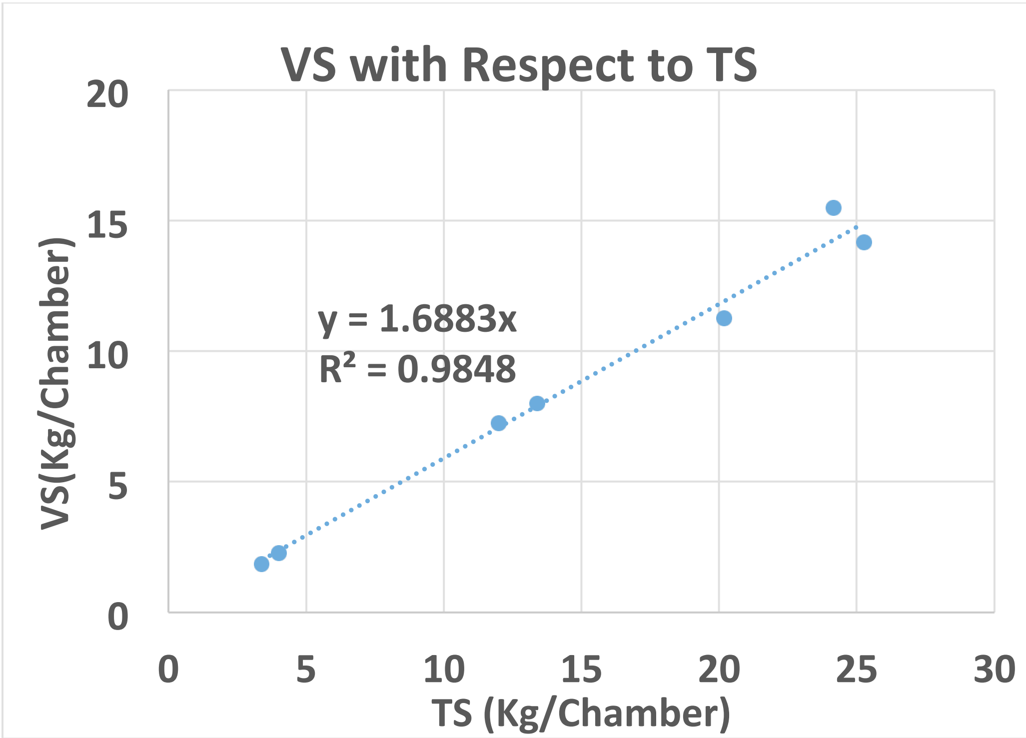


Figure 11 – VS with Respect to TS-Train-2

Summary Output-Train-2								
Regression Statistics								
Multiple R	0.975							
R Square	0.950							
Adjusted R Square	0.940							
Standard Error	1.924							
Observations	7.000							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1.000	351.233	351.233	94.836	0.000			
Residual	5.000	18.518	3.704					
Total	6.000	369.751						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-2.110	1.617	-1.305	0.249	-6.267	2.046	-6.267	2.046
X Variable 1	0.715	0.073	9.738	0.0002	0.526	0.904	0.526	0.904

Table-2 Regression Analysis on Train-2

Total and Volatile Solids on Train-3 (experiment date – 07/15/14)

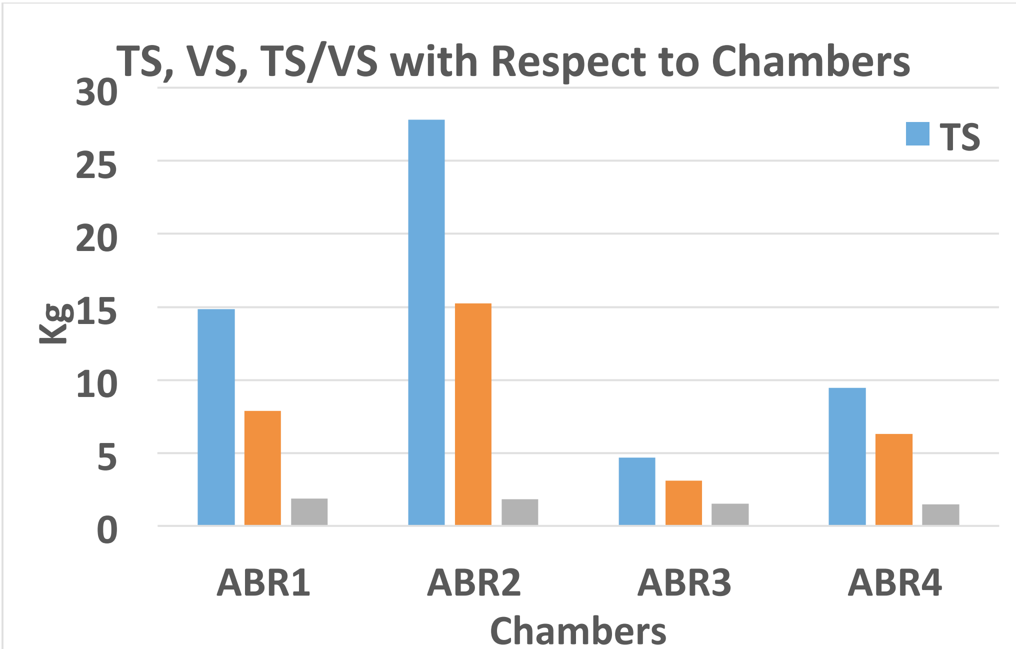


Figure 12 – TS - VS – TS/VS with Respect to Chambers-Train-3

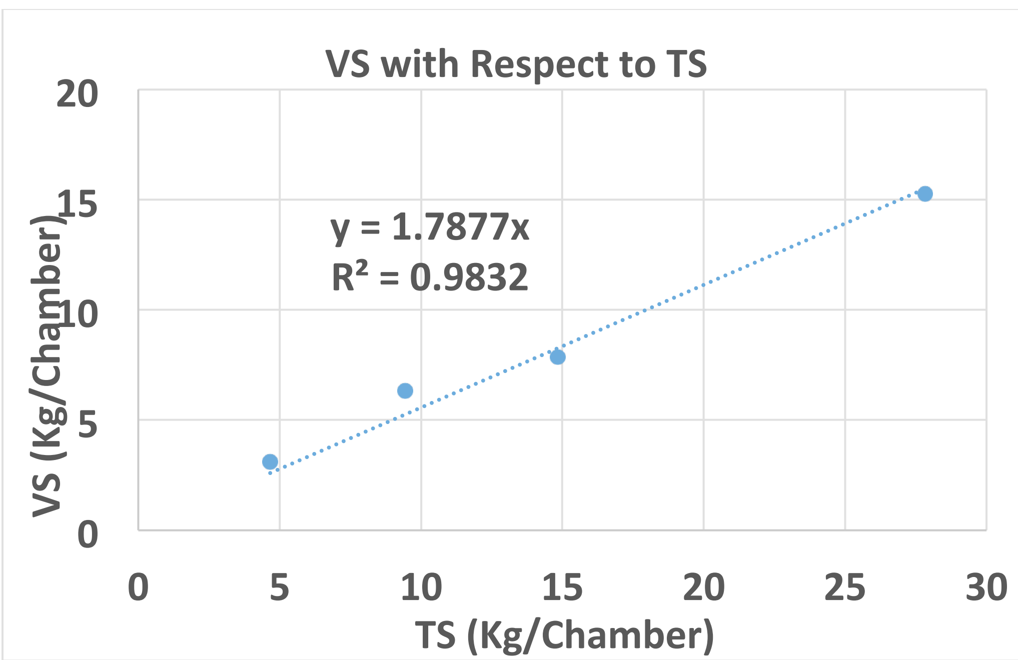


Figure 13 – VS with Respect to TS-Train-3

Summary Outpput-Train-3								
Regression Statistics								
Multiple R	0.9951							
R Square	0.9902							
Adjusted R Square	0.9853							
Standard Error	0.6251							
Observations	4.0000							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1.0000	78.8786	78.8786	201.8626	0.0049			
Residual	2.0000	0.7815	0.3908					
Total	3.0000	79.6601						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.8538	0.6002	1.4225	0.2908	-1.7287	3.4364	-1.7287	3.4364
X Variable 1	0.5130	0.0361	14.2078	0.0049	0.3576	0.6683	0.3576	0.6683

Table 3-Regression Analysis on Train-3

Standard Error analysis in Sludge Sample						
sample	**weight of crucible (g)**	**weight of 20ml sample (g)**	**weight after oven (g)**	**weight after ignition(g)**	**Total Solids (KG/Chambers)**	**Volatile Solids (Kg/Chamber)**
1	45.843	20.055	45.96	45.893	17.916	10.259
2	35.306	20.211	35.417	35.352	16.997	9.953
3	30.964	20.612	31.07	31.009	16.231	9.341
4	56.471	20.424	56.583	56.515	17.150	10.412
5	50.715	20.532	50.808	50.755	14.241	8.116
6	48.605	20.311	48.718	48.653	17.303	9.953
7	36.843	20.792	36.96	36.895	17.916	9.953
8	38.839	20.71	38.957	38.891	18.069	10.106
9	36.586	20.006	36.694	36.64	16.538	8.269
STDV TS (Kg/chamber)	1.121	Std. Error (Kg/chamber)	0.373617			
STDV VS (Kg/chamber)	0.801	Std. Error (Kg/chamber)	0.266852			

Table 4 – Standard Error analysis in sludge sample

Total Suspended Solids and Volatile suspended Solids using Crucible and Centrifuge Method

Train-1 (experiment date 07/07/2015)

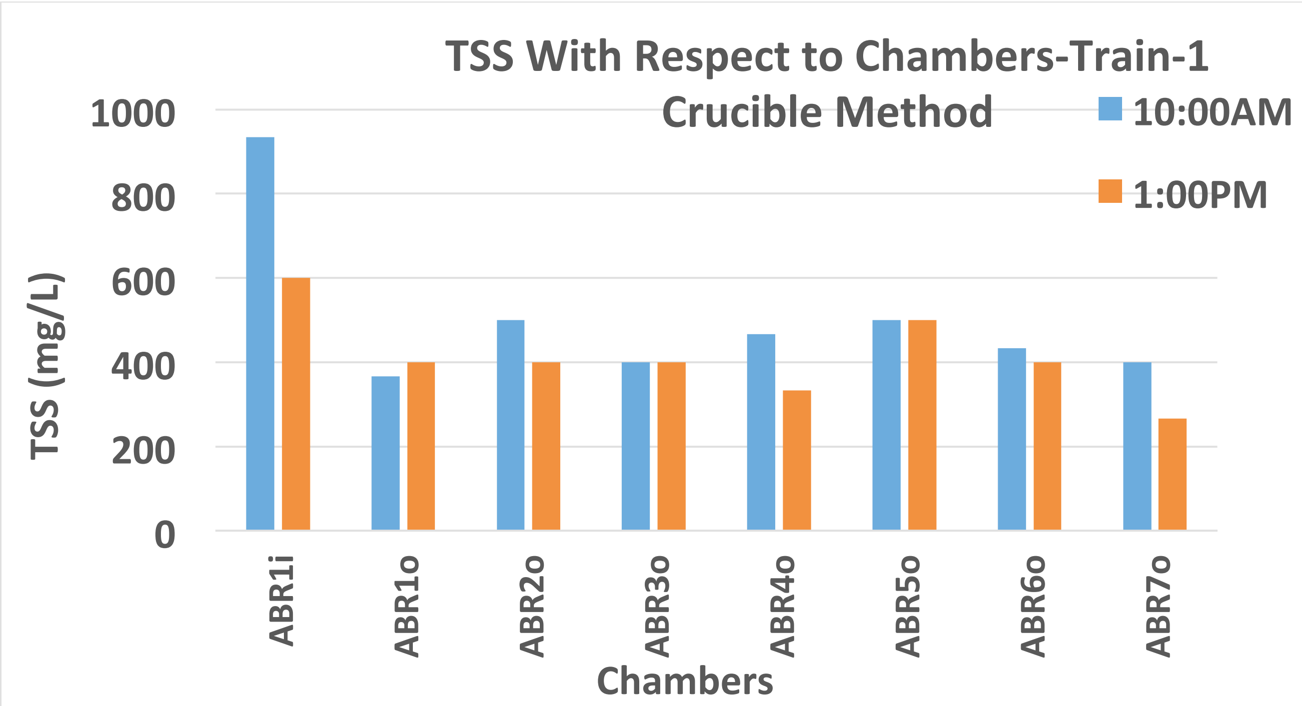


Figure 14 – TSS with Respect to Chambers and Time – Crucible method

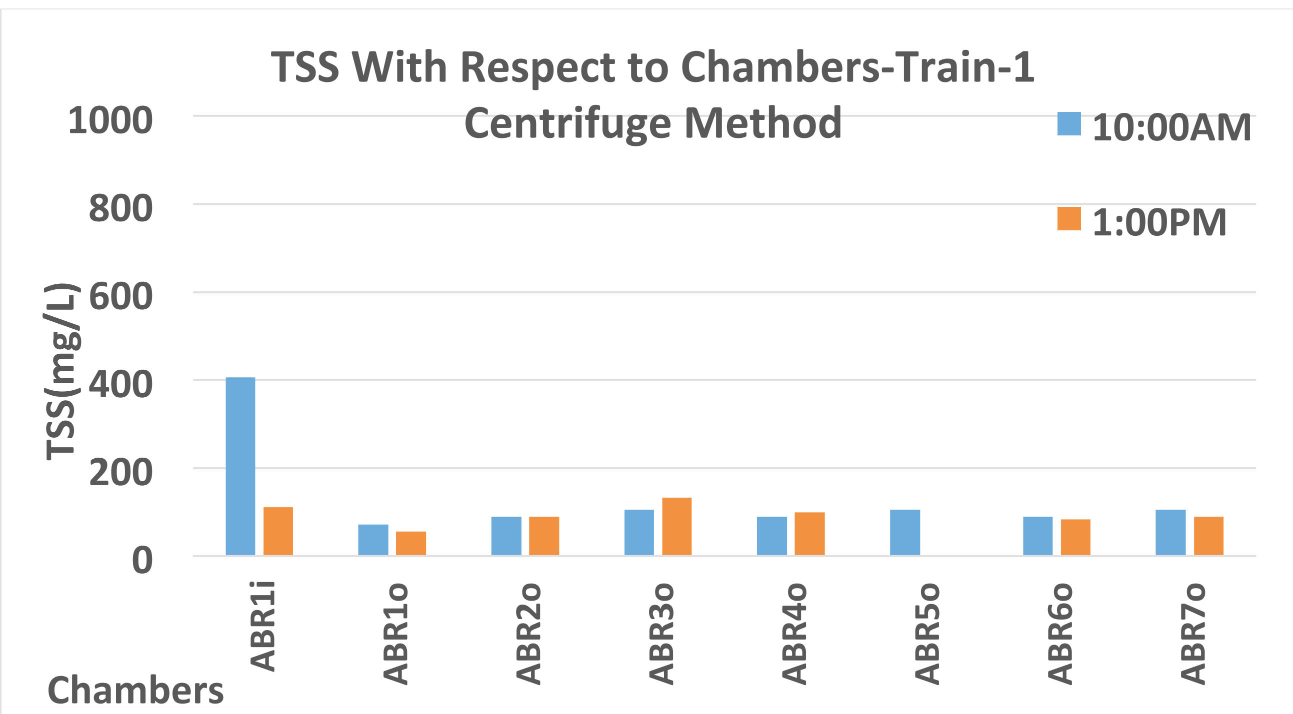


Figure 15 – TSS with Respect to Chambers and Time--centrifuge method

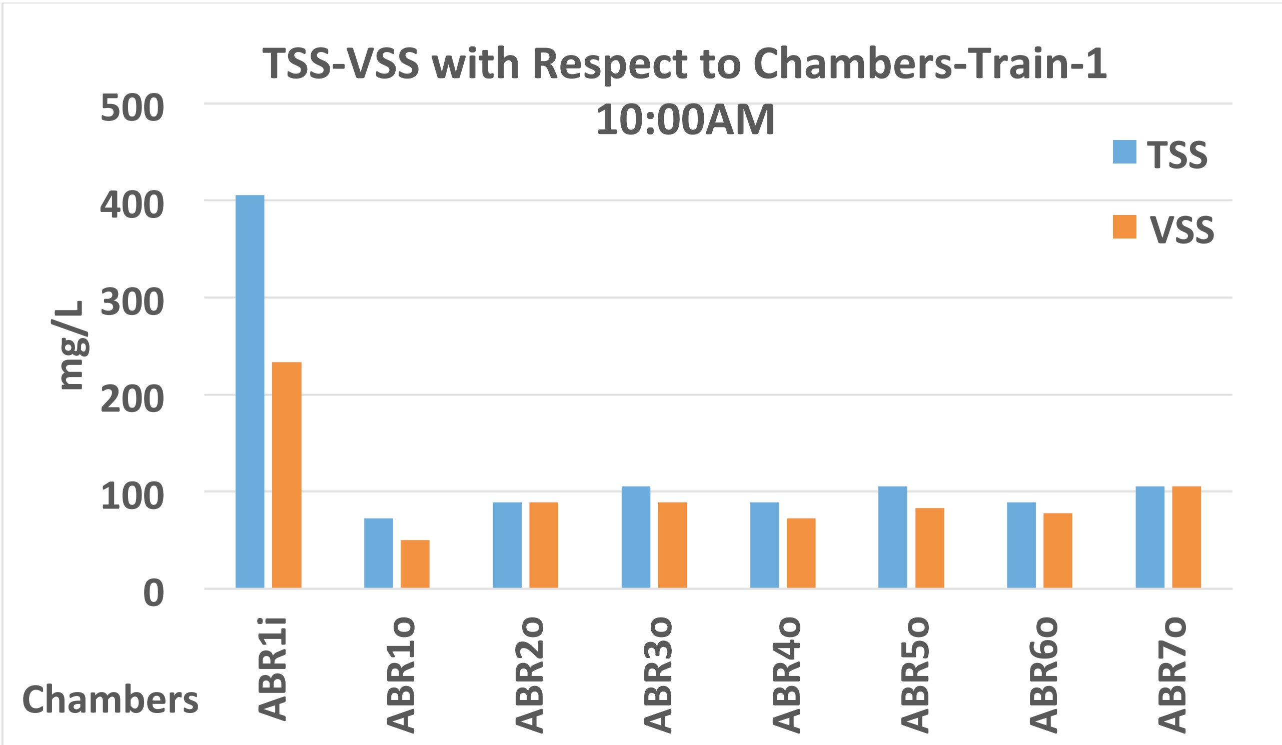


Figure 16 – TSS-VSS with Respect to Chambers at 10:00AM

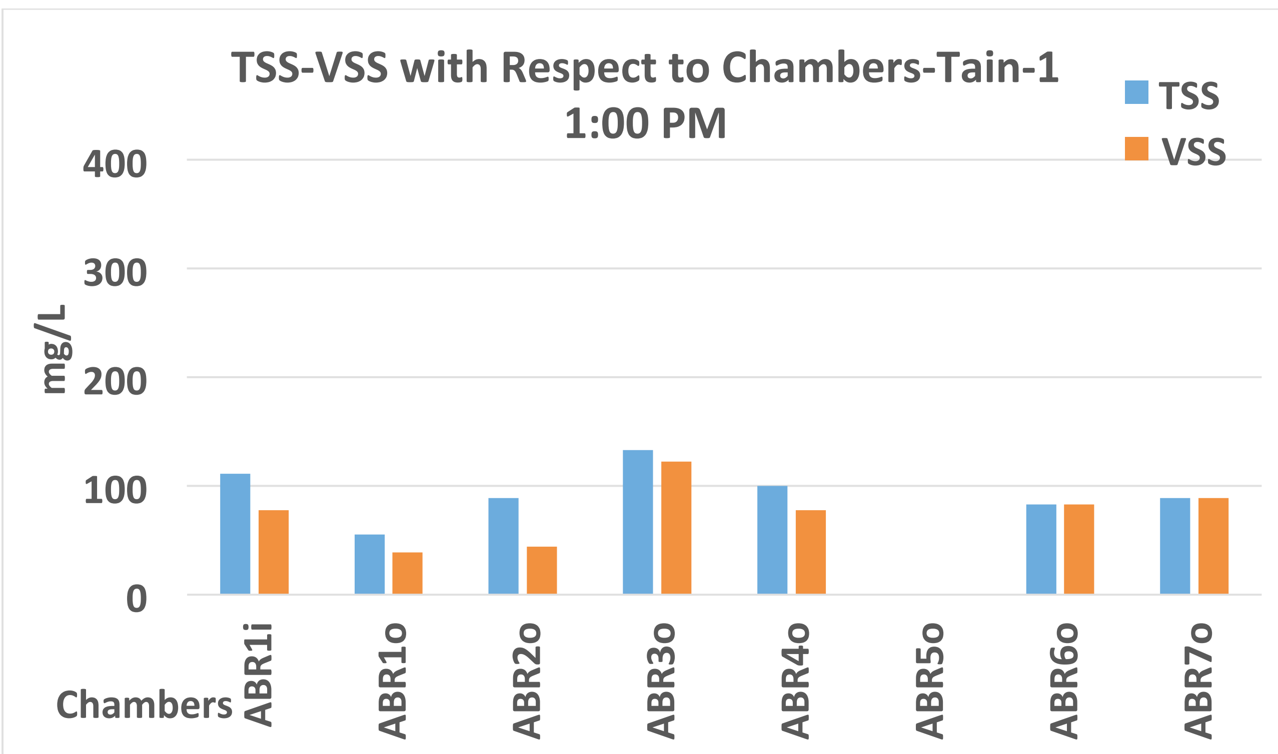
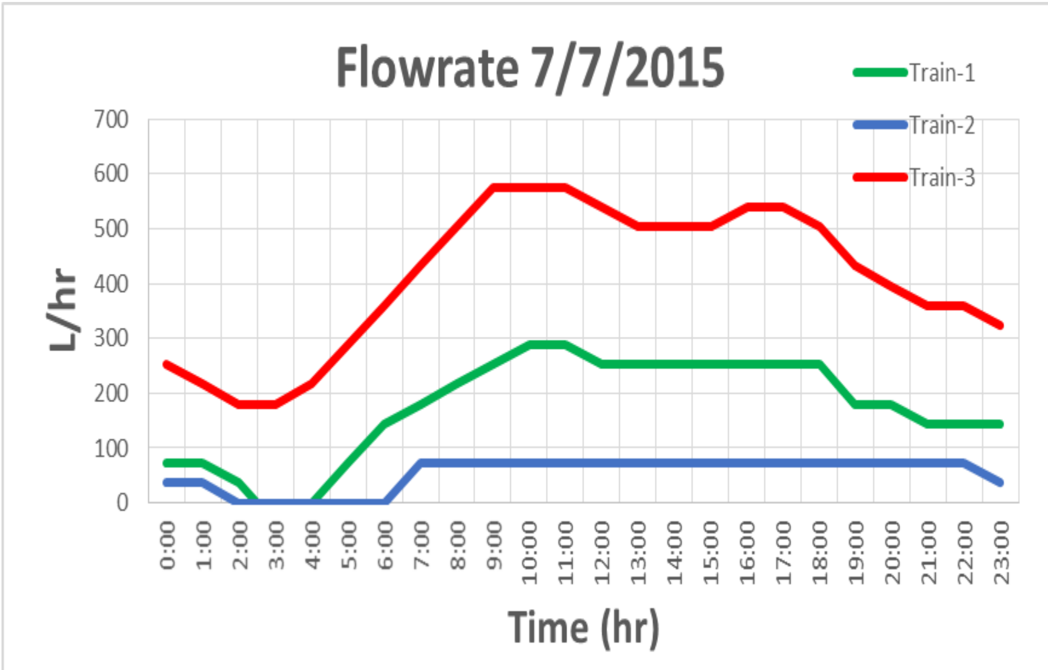


Figure 17 – TSS-VSS with Respect to Chambers at 1:00PM



Flowrate data

9:00AM = 252 L/hr

10:00AM = 288 L/hr

1:00PM = 252 L/hr

Figure 18 – Flow rate with Respect to time

Total Suspended Solids and Volatile suspended Solids using Crucible and Centrifuge Method

Train-2 (experiment date 07/14/15)

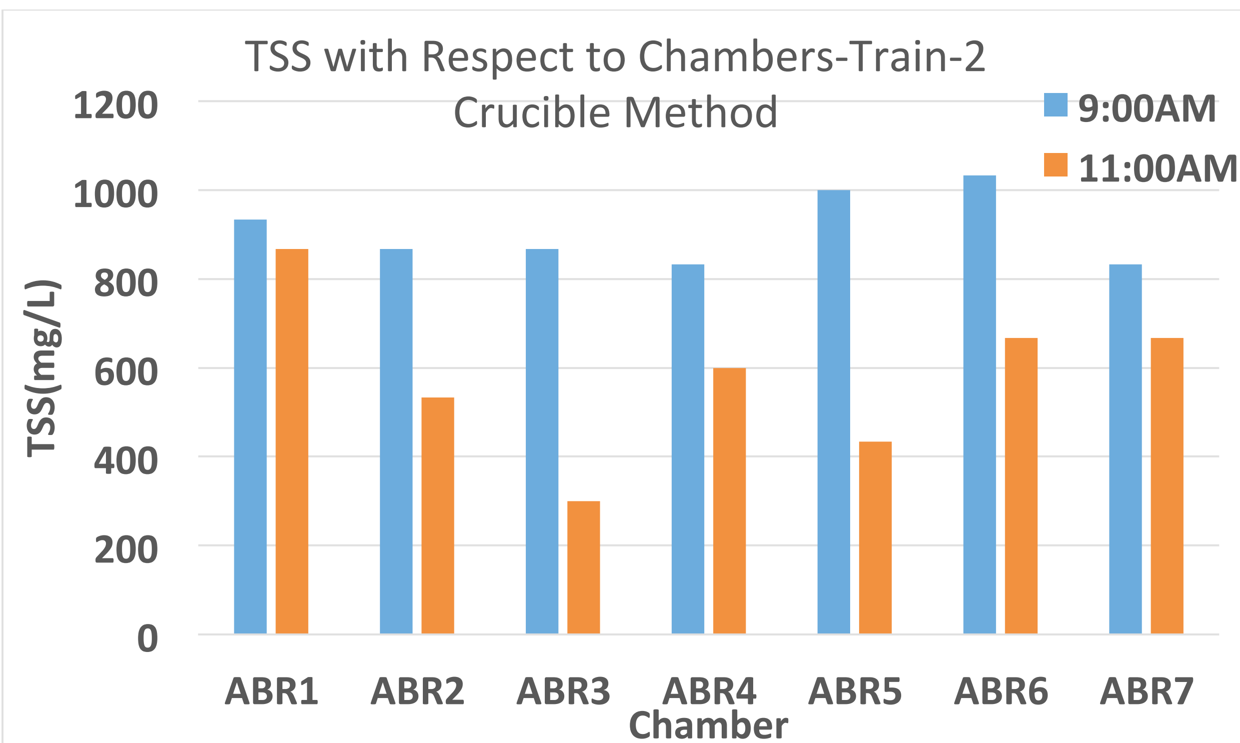


Figure 19 – TSS with Respect to Chambers and time – Crucible Method

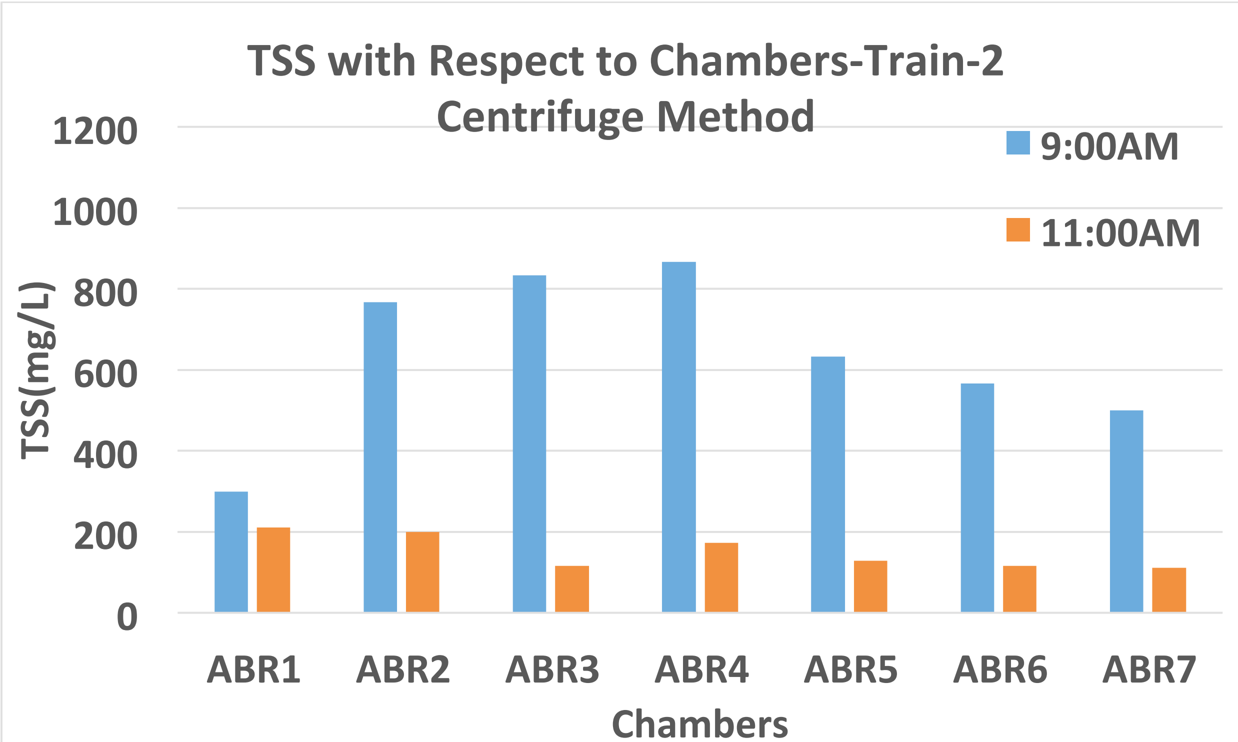


Figure 20 – TSS with Respect to Chambers and time – Centrifuge Method

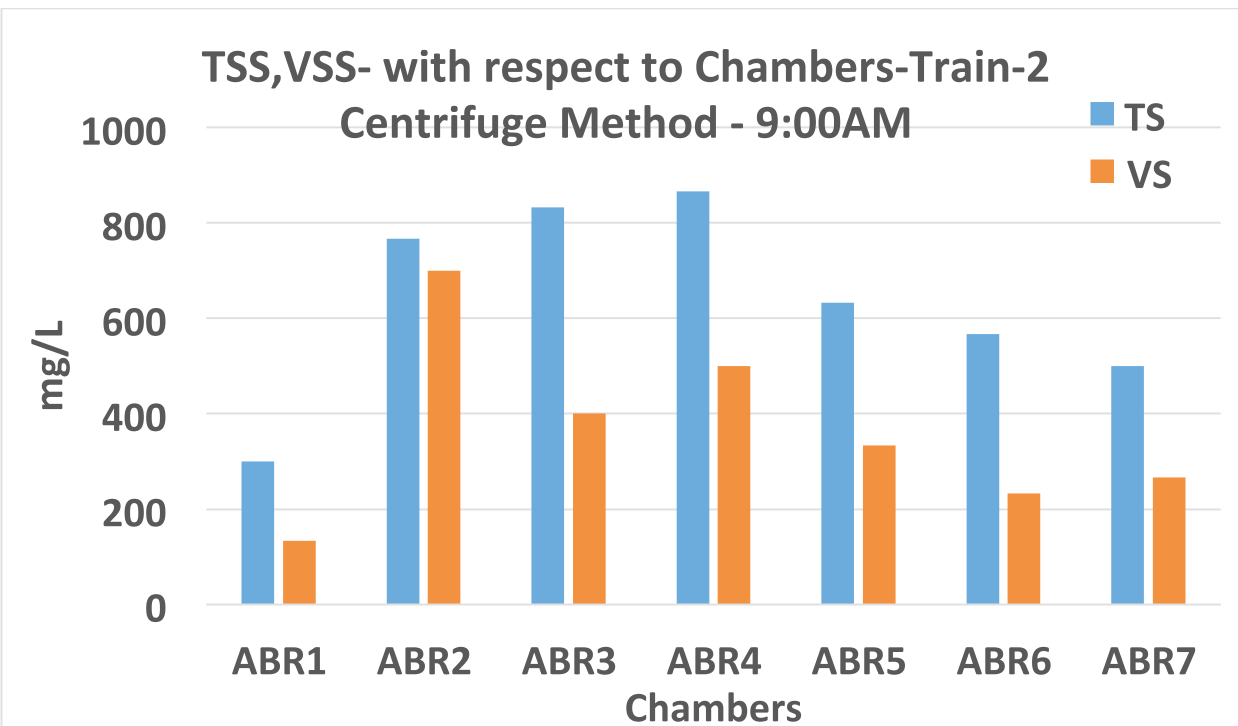


Figure 21 – TSS-VSS with Respect to Chambers at 9:00AM

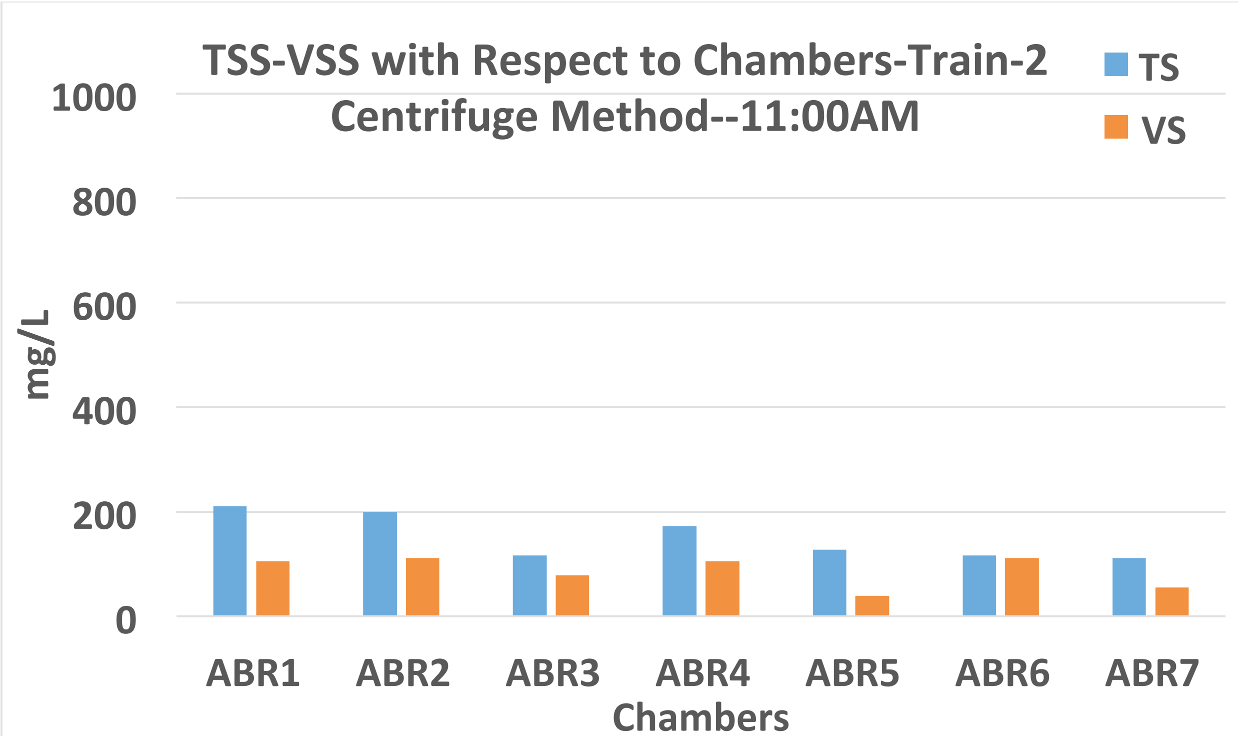


Figure 22 – TSS-VSS with Respect to Chambers at 11:00AM

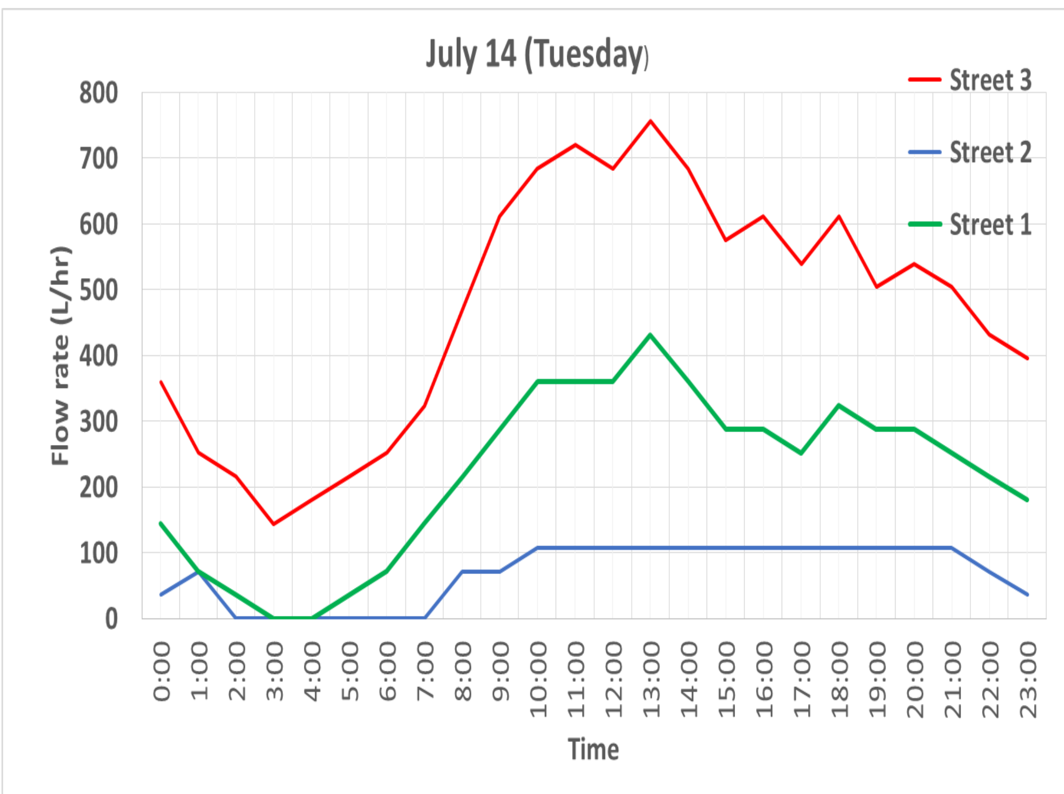


Figure 23 – Flowrate with Respect to time

Total Suspended Solids and Volatile suspended Solids using Crucible and Centrifuge Method

Train-3 (experiment date 07/15/15)

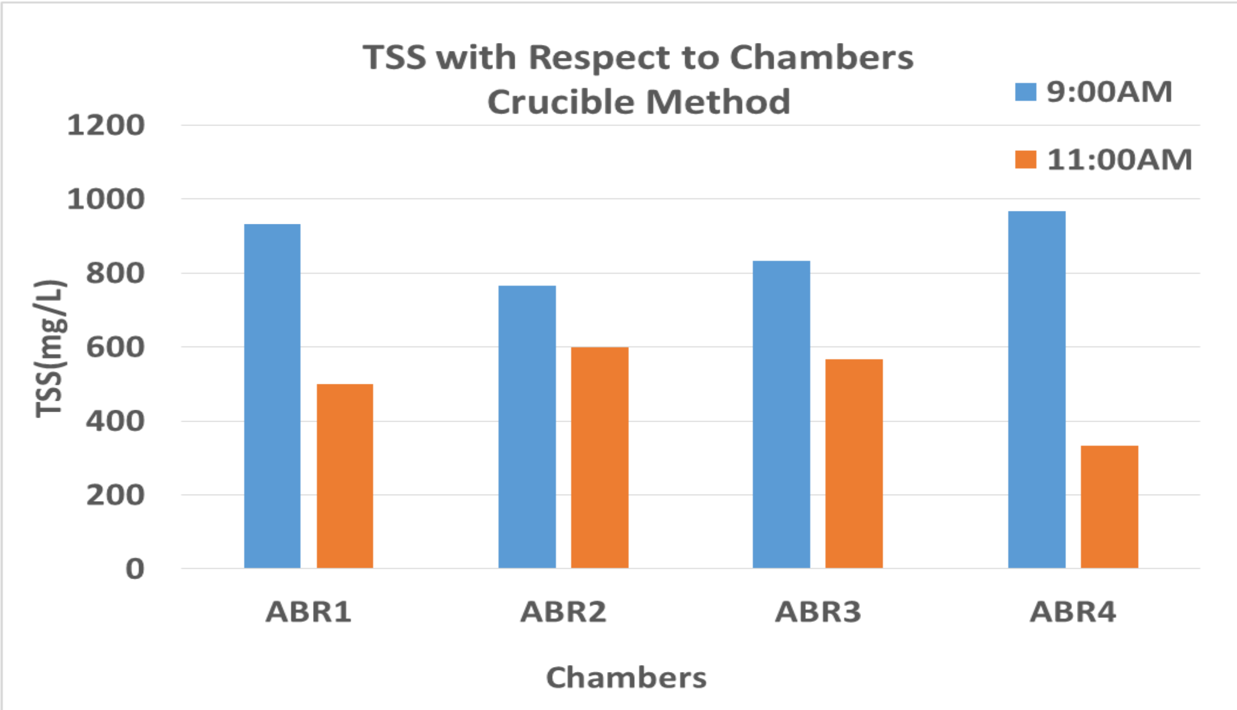


Figure 24 – TSS with Respect to Chambers and time – Crucible Method

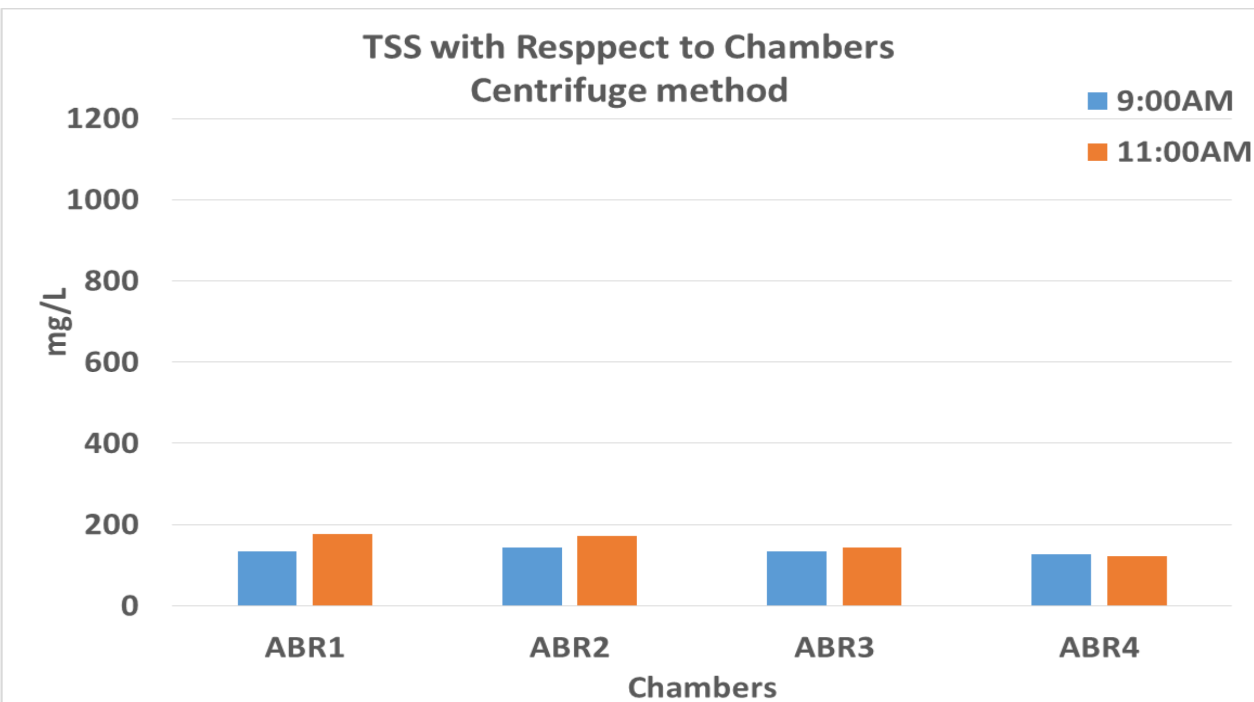


Figure 25 – TSS with Respect to Chambers and time – Centrifuge Method

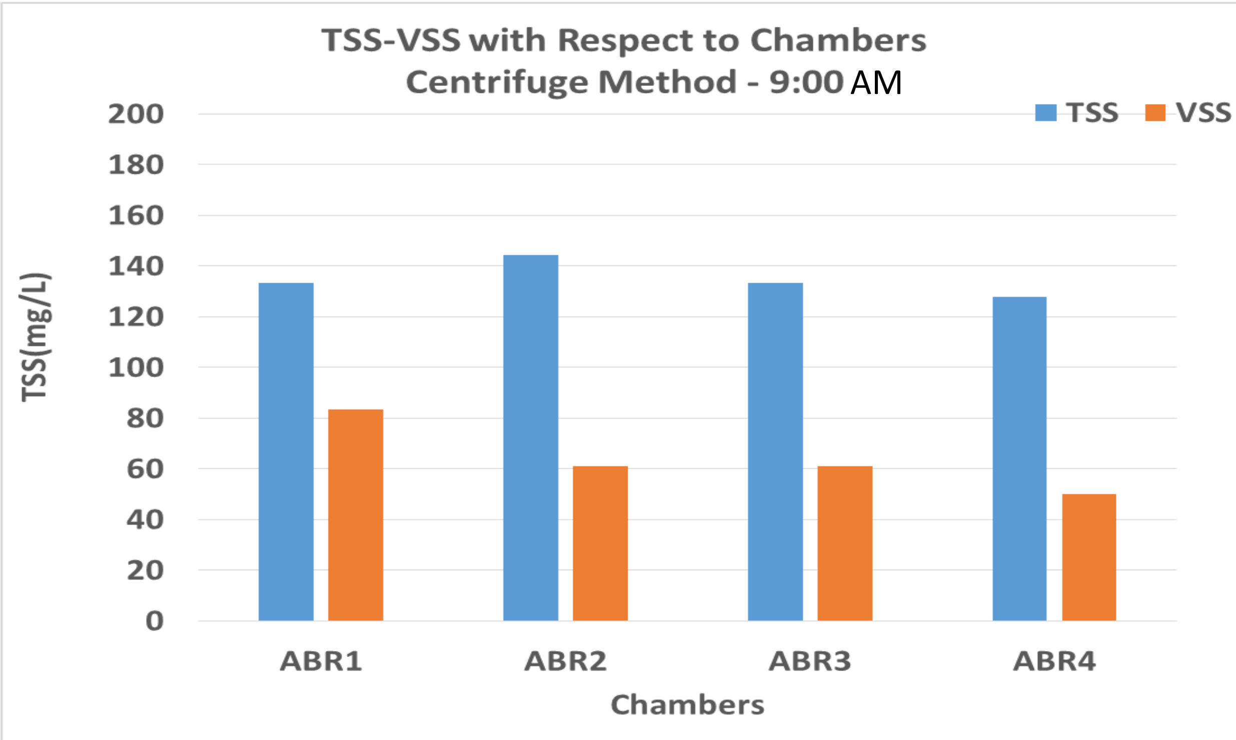


Figure 26 – TSS-VSS with Respect to Chambers at 9:00AM

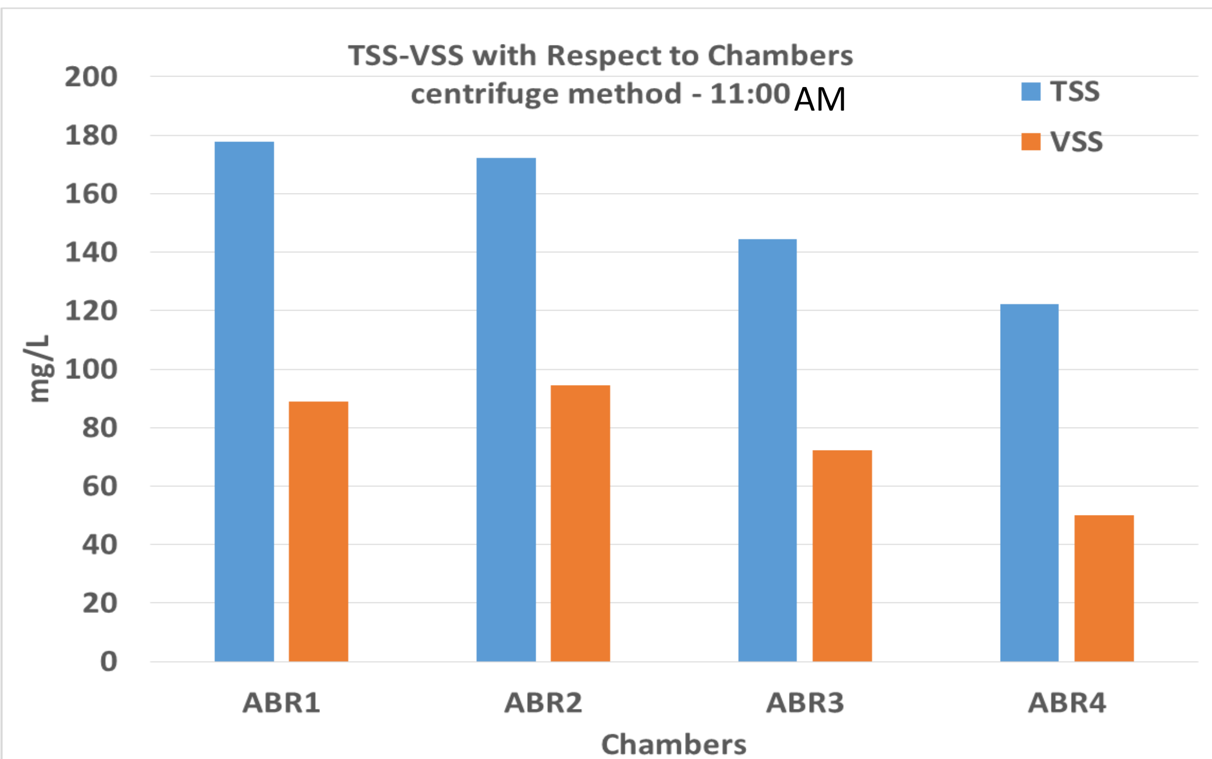


Figure 27 – TSS-VSS with Respect to Chambers at 11:00AM

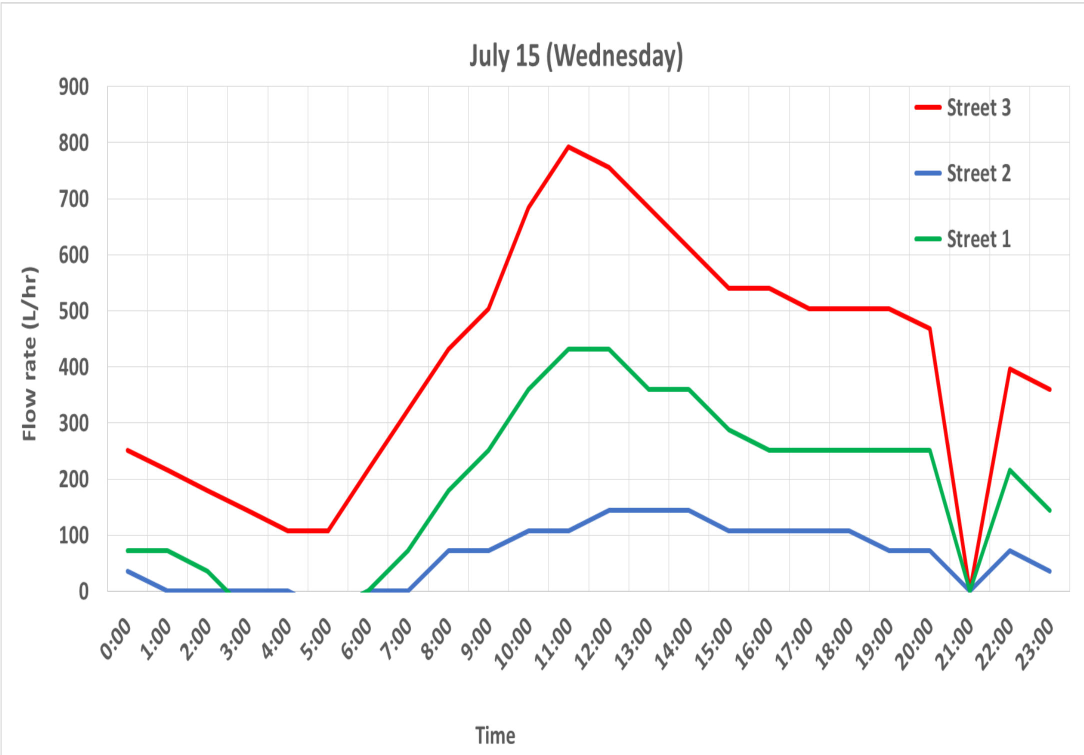


Figure 28 – Flowrate with Respect to time

Standard Error is the sludge sample				
sample	weight of crucible (g)	weight of 30ml sample (g)	weight after oven (g)	**Total Suspended Solids(mg/L)**
1	39.63	31.653	39.650	666.667
2	45.495	31.252	45.513	600.000
3	46.405	31.390	46.418	433.333
4	50.388	31.396	50.412	800.000
5	53.861	31.356	53.880	633.333
6	50.003	31.487	50.017	466.667
7	34.408	31.476	34.425	566.667
8	54.223	30.707	54.238	500.000
STDV TSS (mg/L)	111.803	Std. Error (mg/L)	39.528	

Table 5 – Standard Error analysis in liquid sample

Turbidity on train-1 (experiment date – 07/07/2015)

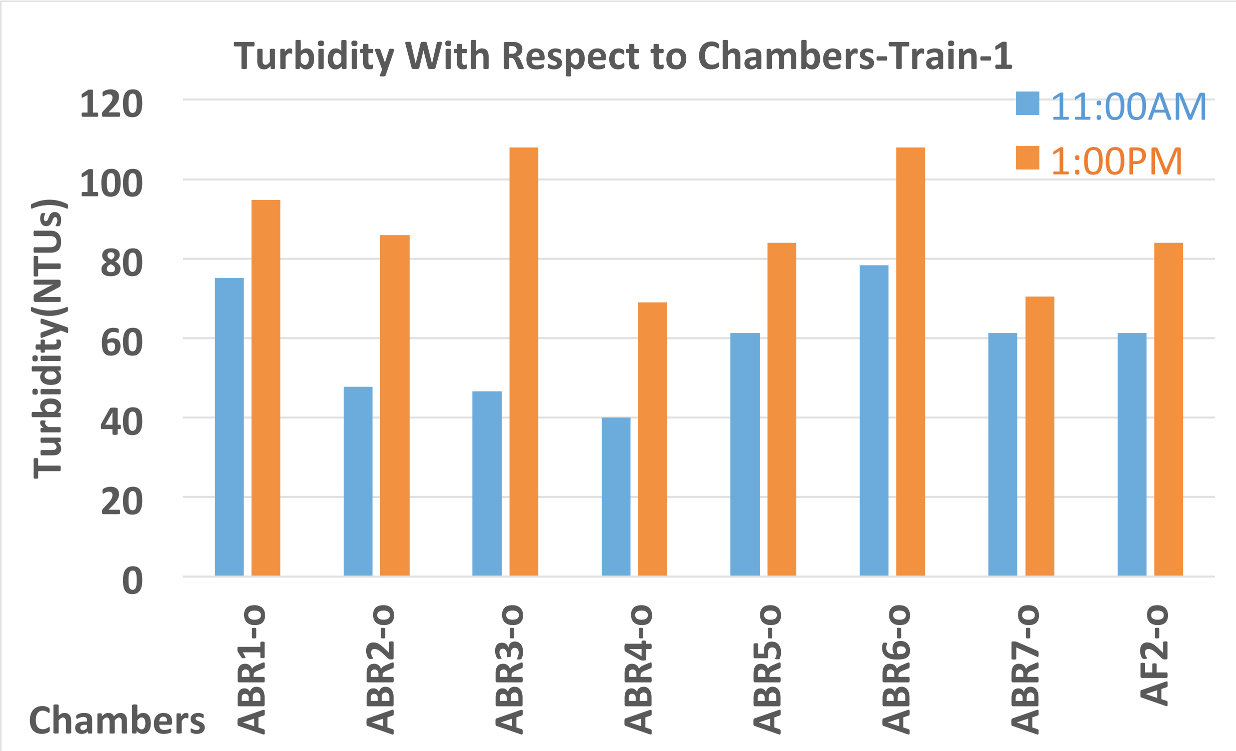


Figure 29 – Turbidity with Respect to chambers and time – Train-1

Discussion

Total and Volatile Solids

Prior to the scientific investigations of solids movement within the ABR system, it was assumed to observe a linear tread in total and volatile settled, suspended, and dissolved matter with negative slop across all the chambers in all three trains; however, Total and volatile solids do not show any linear trend with respect to chambers in all three trains according to the data. The ratio TS/VS stays roughly constant throughout all the three trains. In train-1, the sum of all the total and volatile solids in all chambers adds up to 93.7Kg and 55.4Kg respectively. The ratio TS/VS is 1.7. Graph of VS with respect to TS shows a strong relationship between VS and TS with correlation coefficient of 0.9703 which gives an idea that VS can accurately be calculate if the amount of total solids in each chambers were determined experimentally. Ninety-five percent statistical confident interval test was used to determine the strength of the correlation between VS and TS. It yield a p-value of 0.00002 which is ≤ 0.05 so the correlation observed was valid and can be used to calculate volatile solids theoretically if total solids is determined experimentally.

In train-2, the sum of the total and volatile solids is 102.4 kg and 60.2 kg respectively. The ratio of the two is 1.7 which is similar to the value observed in train-1. Graphed Vs with Respect to TS shows a strong relation with correlation coefficient of 0.9848. Ninety-five percent statistical confident interval test yield a p-value of 0.0002 that is ≤ 0.05 which suggests that the relation observed between VS and TS is strong and can be used to determine VS mathematically if TS is determined experimentally.

In Train -3, the sum of the total and volatile solids is 56.8 Kg and 32.5 kg respectively. The ration of TS/VS is 1.74 and when it is rounded up to the same significant figure as the rest of the trains, it will end up 1.7. In all the three trains, the TS/VS ratio stays constant at 1.7. When VS was plotted with respect to TS, strong relation was once again observed with correlation coefficient of 0.9832. Ninety-five percent statistical confident interval test gives a p-value of 0.0049 which is ≤ 0.05 and it confirms that the relation between VS and TS is valid and strong. VS can be calculated if TS is known.

Train 1 and Train 2 are identical except train 2 has twice the hydraulic loading compare to train -1 and the chambers in train 3 are twice as much as the chambers in trains 1 and 2. According to the data, chamber size and hydraulic loading does not affect TS/VS ratio. In all the three trains, strong relation was observed between VS and TS. VS can be calculated with fair accuracy from known TS value.

Sludge sample was obtained from train-1, chamber 4. Nine replicate from the same sample was analysed to determine stand error and the variation in the sludge study. The results gives a standard deviation of 1.11 kg/chamber in TS and 0.801 Kg/chamber in VS. Stand error was calculated to be 0.374 in TS and 0.267 in VS.

Total Suspended solids and volatile suspended solids

Total Suspended solids were analysed using two different methods: crucible and centrifuge method. Crucible method allows to obtain both suspended and dissolved solids in the ABR system using small amount of the wastewater; however, the amount of solids obtain from this method is not enough to ignite. On the other hand, the centrifuge method captures all the suspended solids in the sample from a large amount of wastewater. This method generates enough solids and it allows to investigate the behaviour of volatile suspended solids in the system.

Centrifuge method does not precipitate out the dissolved solids in the sample, so the compares between the two methods in terms of total suspended solids gives an idea on the amount of solids that are dissolved and suspended in the wastewater. In train-1, there isn't any significant change in total suspended solids obtained using both methods at 10:00 AM and 1:00PM. TSS and VSS also seem constant with respect to time. The flow rate of the system during the sampling frame of time was in fact the same right around 10:00AM and 1:00PM which explains why no change was observed In TSS and VSS using both method of analysis. Comparison between figure 14 and 15 gives an idea on how much dissolved solids are present in the system. Figure 15 is a representation of total suspended solids obtained using centrifuge method and the numerical value of TSS is around 100 mg/L in all chambers. Figure 14 shows TSS with respect to chambers obtained using the crucible method and the numerical values of TSS is around 400 mg/L in all the chambers. The concentration difference seen in these two methods is a result of total dissolved solids in the system. High amount of dissolved solids was present throughout the system which contributes to the turbidity of the wastewater in the system.

Figure 19 and 20 shows the profile of TSS in train-2. Notable change was observed in TSS using both methods at 9:00AM and 11:00AM. High amount of TSS was seen at 9:00AM in both centrifuge and crucible method. The flow rate at 9:00AM is 72L/HR meanwhile the flow rate at 11:00AM is 108 L/HR. At lower flow rate, the contact time of the solids with the microbial layer is higher and as a result more solids are break down and suspended in the wastewater. Once again, high amount of dissolved solids were seen in the system. There are more dissolved solids at high flow rate. TS and VS obtained using centrifuge method were higher at lower flow rate and lower at higher flow rate as represented in figure 21 and 22.

Train-3 shows the exact same behaviours seen in train 2. Figure 24 and 25 is a representation of the profile of TSS with respect to time using crucible and centrifuge method. Figure 24 shows a higher TSS concentration at lower flow rate. Figure 25 shows a constant TSS concentration with respect to flow rate using the centrifuge method. Higher TSS and VSS concentration was observed at higher flow rate in figure 26 and 27.

Conclusion

In all three trains, there is a strong relation between volatile solids and total solids with correlation coefficient of around 0.98. This value is tested for its validity using ninety five percent statistical confidence interval test, it yield p-value ≤ 0.05 for all the three trains which confirms the reliability of the result. If total solids are experimentally determined, volatile solids can be calculated mathematically with precision. According to data, Hydraulic loading, and chamber size does not any effect on the total and volatile solids in the ABR system. Total suspend solids and volatile suspended solids stays roughly constant at constant flow rate. At higher flow rate, Both TSS and VSS go up as a result of it. The difference between the crucible and centrifuge method used to study the profile of TSS and VSS give insight view of the distribution of dissolved solids with the ABR system. According to data, there is high amount of dissolved solids in the ABR system which contributes to the turbidity of the fluid. Turbidity of the wastewater go up at high flow rate.

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