ADDITION OF LIME TO IMPROVE SLUDGE SETTLING HELPS DEFER CAPITAL SPENDING

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ABSTRACT

New Zealand drinking water tends to lack alkalinity. Bad sludge settleability is a common problem in New Zealand waste water treatment plants. Both have one in common: dependency on cations.

The application of basic water chemistry and the addition of lime can drastically improve sedimentation characteristic of biomass. The article explains how well founded theory proves to be successful in practice in a trial plant.

Sludge structure, zone settling velocity and dewaterability improved dramatically.

First results showed that addition of lime can 10 fold the sedimentation velocity of sludge.

KEYWORDS

Activated sludge sedimentation, lime addition, zone settling velocity, state point analysis, divalent cation bridging theory

1 INTRODUCTION

The activated sludge method is superior to other biological wastewater treatment options through its ability to produce biologically active flocs. These flocs can –when well-handled - reflect the waste water plant operator's craftsmanship and art as they are the functional cell of all activities. Carbon reduction, nitrification, denitrification or even biological phosphorous removal are the key benefits of good floc handling. The flocculation process strongly influences sludge sedimentation which is sensitive to high hydraulic loads and consequently could cause loss of precious sludge volumes if not managed properly. Not only does this affect the biological treatment capacity of the plant, it also negatively impacts on energy costs at the sludge drying stage.

The Activated Sludge System (AS) typically uses gravity fed Secondary Settling Tanks (SST) to separate flocs from water. AS and SST act as one unit and the overall performance of the set up depends on a well-designed SST unit just as much as on the overall design efforts that go into the AS. It is even fair to say that a failing SST with poor floc settlement can cause total plant failure driving the effluent stream towards non-compliance.

Putting too much emphasis on the process dynamics of the AS system without detailed understanding of the SST dynamics can result in poor design putting the environment and public health at risk.

The target of best practice AS plant operation is to discharge as little Total Suspended Solids (TSS) as possible. A wide range of interactions between AS and SST are known, and a variety of factors within AS operation and control affect the final TSS concentration. Aeration strategy, provision of food, nutrients and minerals for the operating bacteria, inhibiting substances, mechanical equipment and tank design are common and well understood factors when it comes to evaluate plant performance.

A lot of emphasis has been put on the microbiological side of things, with detailed investigations into organism species and environmental conditions of floc bacteria. Much less effort has been put into investigating the interrelationship between water chemistry and sludge characteristics.

Successful wastewater operation is based on the application of detailed knowledge of water chemistry. At the operational level problems can arise as most operators are not trained in water chemistry in any great detail. It is the aim of this paper to build the bridge between the skills of the knowledgeable operator and the theories behind improved sludge handling, applying basic chemical processes.

2 SLUDGE SETTLEABILITY AND THE DIVALENT CATION BRIDGING THEORY

Divalent cation induced bioflocculation is assumed to have a pivotal influence on sludge settleability (Tandoi et al, 2006; Murphy 1998). According to Sobeck and Higgins (2002) there are three major theories which describe bioflocculation processes: the Alginate Theory, the Derjaguin, Landau, Verwey, and Overbeek (DLVO) theory and the Divalent Cation Bridging Theory (DCBT). Overall the DCBT was found to best describe the interaction of cations and sludge bioflocculation.

One of the first researches highlighting that Calcium and Magnesium were important for the bioflocculation process was Tezuka (1969). Novak and Higgins (1997) finally established the DCBT, which was frequently tested over the years confirming its fundamental role in the understanding of bioflocculation. According to the DCBT, divalent cations bridge negatively charged functional groups within the exocellular poly-meric substances (EPS) and this bridging helps to aggregate and stabilize the biopolymer and microbes matrix thus promoting bioflocculation.

The basic application of the DCBT is linked to the following conditions:

- The ratio of monovalent to divalent cations (M/D ratio should be less than 2), expressed in meq/l
- DCBT is essentially a slow reaction process. It is important to allow the system to achieve steady state over approximately three times the sludge retention time (SRT)

It is important to understand that the DCBT does not constitute a precipitation mechanism. Traditionally the addition of lime was used foremost as coagulant for organic matter (Demel & Moebius, 1998). Piirtola at al (1999) found that addition of cations (one of them Calcium) did not improve the sedimentation velocity of activated sludge. His study was solely based on the instantaneous effects of chemical assisted settling.

Nguyen et al (2008) found a relationship between an increase in cation ions in the infeed concentration to a reactor with a decrease of polysaccharide in the supernatant. Polysaccharides are understood to influence flocculation characteristics of sludges.

Higgins et al, (2004) summarises the effect of the addition of divalent cations as follows:

(1) Improved SSVI (stirred sludge volume index) and ZSV (zone settling velocity)

(2) Decreased effluent COD (Chemical Oxygen Demand) and TSS (Total Suspended Solids)

(3) Faster recovery from filamentous episodes

(4) Lower optimum polymer dose

(5) Increased concentration of cake solids in a belt filter press and at the specific resistance to filtration test

(6) Increased floc-strength

(7) Potential significant costs savings from reduced polymer demand and fuel for incineration

For the beneficial use of the effects of the DCBT on sludge from AS plants especially in combination with the addition of lime it is fundamental to test the performance of the sedimentation unit. The best test to mirror the ability of sludge to settle is the Zone Settling Velocity test (ZSV). This test needs to be well understood to enable wastewater treatment plant staff to execute it appropriately.

2.1 ZONE SETTLING VELOCITY (ZSV)

During the process of a batch settling test, with or without stirring, four phases of sedimentation can be described (see figure 1). From these four phases – lag, zone settling, transition and compression phase – only the compression phase is of interest for flux related design considerations. According to Henze et al (2008), there is a unique relationship between settling velocity in the zone settling phase and concentration of activated sludge (MLSS) with reduction of velocity at increasing MLSS concentrations. This is caused by the equilibrium which is created by gravitational forces and hydraulic friction of the particles sinking down. The zone settling phase is characterized by a linear relationship of sludge volume (the volume represented by the sludge blanket in the test cylinder at the time of reading) versus time. The velocity at which sludge settles at this stage is called Zone Settling Velocity (ZSV).

Reading the sludge blanket level at different times allows calculating the settling velocity for a certain MLSS. The result is based on physically real sludge conditions and can be used for further design considerations which are necessary for the State Point Analysis that will be described below.

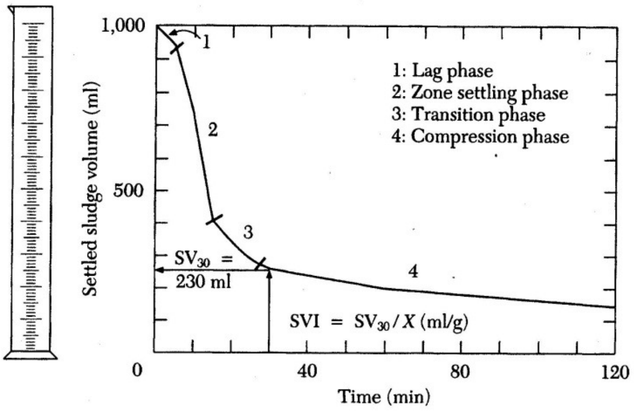
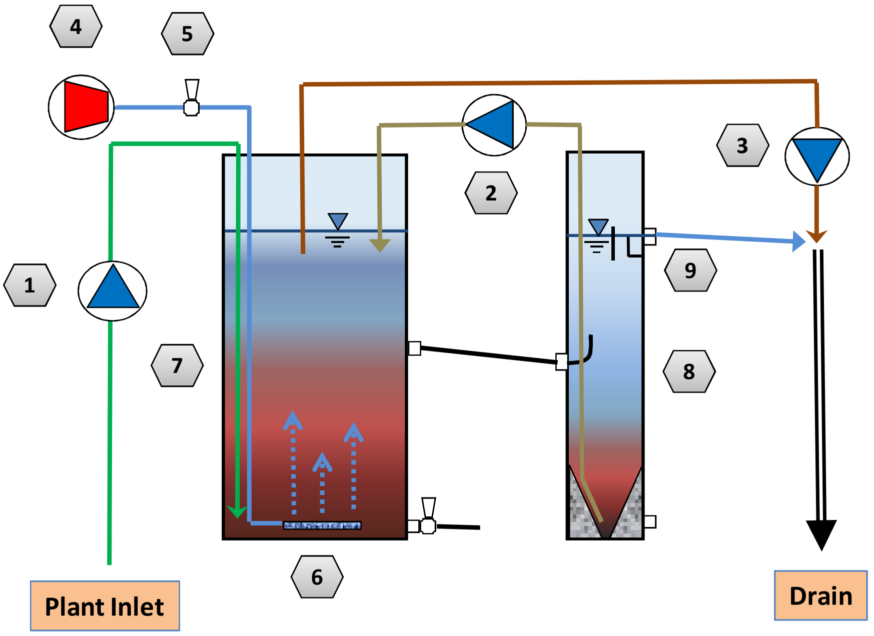


Figure 1: The four sedimentation phases during the sedimentation test

3 SET UP OF THE TEST PLANT IN NEW PLYMOUTH

The pilot plant for the trial was set up as a bench top model of the big AS plant in New Plymouth. The 'big brother' is equipped with 2 aeration tanks, each 9,500 m3 volume, and 3 clarifiers with 39 m diameter each. The model was built so that specific relevant design criteria could be suitably mirrored. These parameters were inflow, MLSS, sludge waste rate and clarifier overflow rate.



1: raw wastewater pump
2: recircluation pump
3: waste sludge pump
4: plant air compressor
5: solenoid valve, air control
6: ceramic diffusor
7: aeration tank, pipe NB 380 mm, H = 1000 mm
8: sedimentation tank, NB 150 mm, H = 1000 mm
9: effluent weir and baffle

Figure 2: Schematic of the trial plant

The plant was built as a 100 l model aeration tank. To simplify construction the aeration tank was built from 380 mm NB plastic pipe 1,000 mm high, and the clarifier was modeled as 150 mm NB plastic pipe of the same height. A lot of effort was put into design and construction of the piping between the reactors and the bottom shape of the clarifier. It turned out that even under the small geometric conditions of the model the shape of the clarifier bottom was instrumental for successful sludge recirculation (see figure 2).

The raw-wastewater was taken out of the inflow channel before the entrance to the grit trap. A special strainer was used to prevent big particles and fibers from being sucked into the inflow piping. Inflow to the trial plant, sludge recirculation and waste sludge pumping was achieved with one peristaltic pump each, one model for all three types of media. All three pumps were installed in a weatherproof switchbox together with the timers for the pump run times. Aeration was provided from the plant process air using a pressure reduction valve and a solenoid valve to simulate on/off cycles of the diffusers (aquarium style ceramic filter stones). A photograph of the set up and site is shown in photograph 1.

Key to operating the plant at a steady state was denitrification, as nitrified conditions caused massive sludge bulking and equally massive loss of biomass out of the clarifier. A proper effluent weir had to be installed to reduce horizontal flow velocities to prevent removal of sludge particles floating close to the surface. Occasional cleaning of the 6 mm tubing and greasing of the peristaltic pumps were part of plant maintenance. That and the daily addition of lime in the second phase of the trial was all that was needed for safe operation. Proper design and testing of the trial plant for optimal working conditions took about 3 months.

Photograph 1: The trial site at the New Plymouth Wastewater Treatment Plant

3.1 METHODS OF ANALYSIS

All tests were performed in the laboratory of the NPWWTP.

The basic tests performed for this trial were total suspended solids (TSS), zone settling velocity (ZSV), sludge volume (SV) and sludge volume index (SVI). The sludge volume index was calculated as DSVI or diluted sludge volume index.

The sedimentation tests were performed in standard 1000 ml plastic cylinders.

The laboratory of the NPWWTP executed standard chemical analysis of the inflow and the outflow of the pilot plant. Periodical quality checks were undertaken on the DO and pH levels of the reactor to allow optimum adjustment of the timed solenoid valve.

Microscopic analysis was undertaken at the NPWWTP laboratory by Graham Morris.

3.2 TRIAL RUNS

The plant was operated from October 2011 to mid-February 2012 to optimize plant configuration and to achieve steady state conditions at the biological reactor. Operation was set up in a semi batch mode, where denitrification was achieved by switching off the air supply with the solenoid valve. Plant feeding, aeration, and recirculation was just timer controlled, no lock outs or sequencing was programmed.

On the 7th of March 2012 addition of lime was started. The lime used was standard quick lime from local building supplies. The dose of lime was 10 g/d on normal working days. During the trial period (ending 4th of April 2012), which covered 28 days, lime was dosed on 19 days. The inflow to the plant was metered at 130 l/d. The lime dose can be calculated as 52 mg/l inflow.

4 RESULTS

First big improvements were noticed when the trial plant was operated at steady state with nitrification / denitrification. The NPWWTP performed at about 0.45 m/h at 2,000 mg/l MLSS. This reflected under-aeration and insufficient denitrification rates. By adjusting the air supply this figure went up to 1.11 m/h. before lime dosing started. The partial anoxic conditions obviously improved environmental conditions for non-filamentous bacteria.

4.1 ZONE SETTLING VELOCITY IN PRACTICE

Zone settling velocity increased dramatically. As ZSV is a function versus MLSS, a simple way of comparing the various stages of the test is to look at just one single MLSS figure. As the currently upgraded plant is likely to operate at about 3,000 mg/l MLSS this number was used for the purpose of comparison.

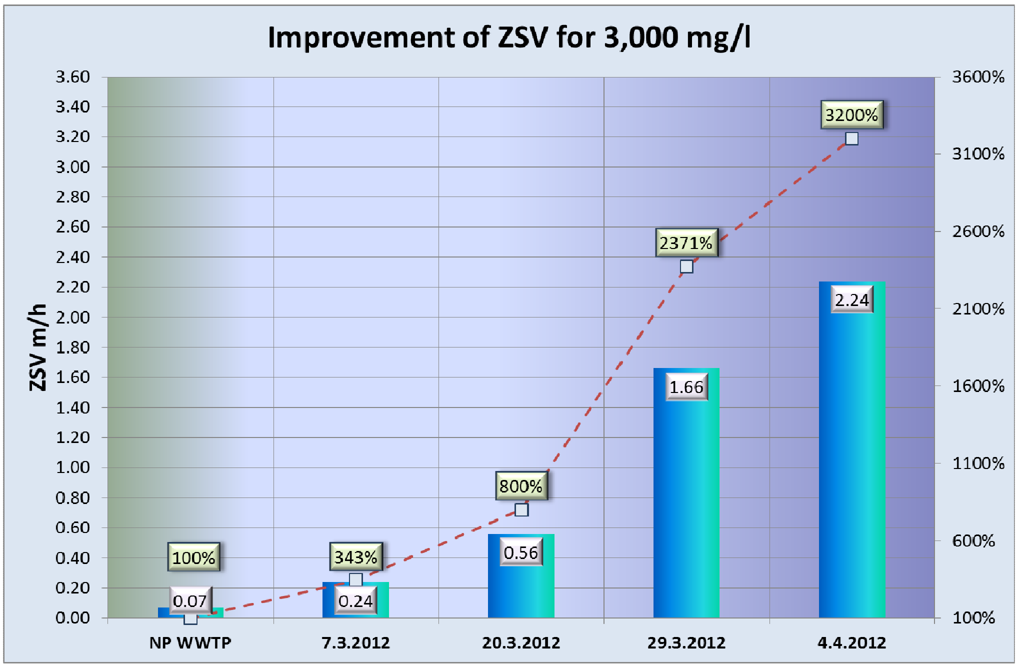


Figure 3: Improvement of ZSV over the trials

As is shown in figure 3 the improvement in ZSV compared to the base conditions of the NPWWTP was from 0.07 m/h to 2.24 m/h, or an increase of 3,100 %. The first step was monitored after the set-up of the trial plant, with an increase from 0.07 to 0.24 m/h or plus 243%. This increase was caused by a change in bacteria population which occurred during the set up phase. The second step, which can be primarily attributed to the

DCBT, was a tenfold increase in sedimentation velocity. A full summary of the relevant charts over the duration of the trials is shown in figure 4.

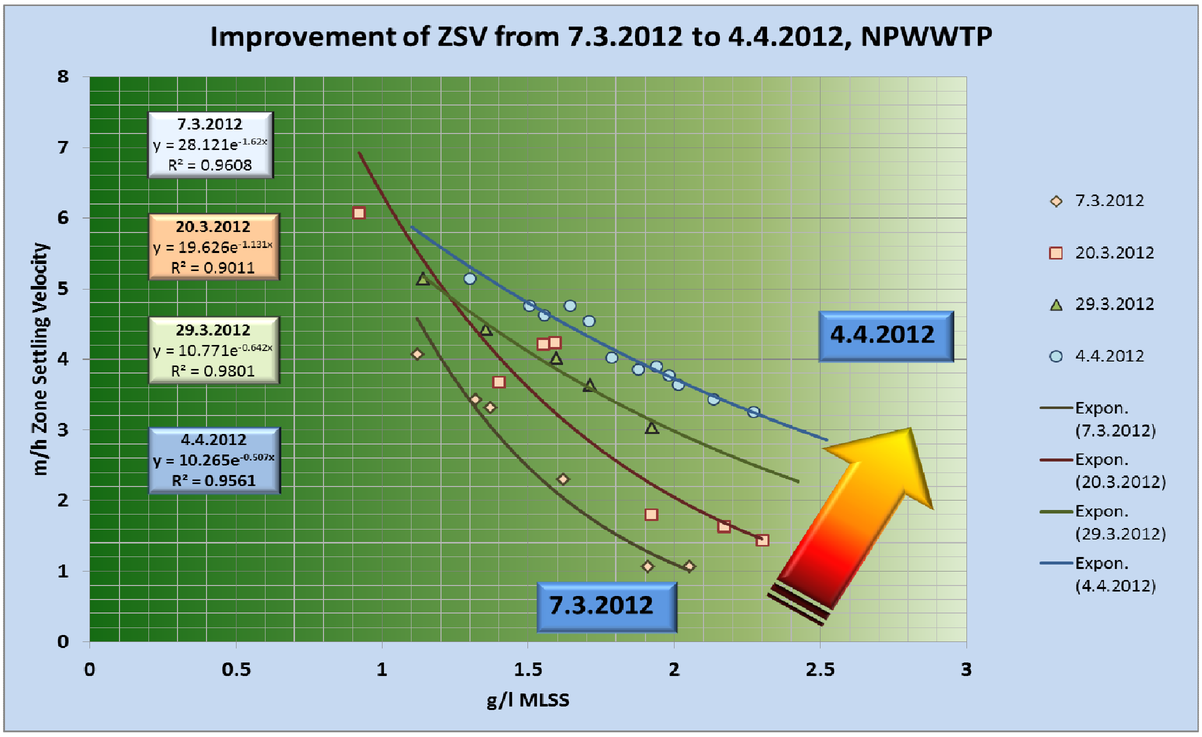


Figure 4: ZSV vs. MLSS charts over the trial period and improvements of sedimentation

4.2 VESELIND SETTLING FUNCTION / FLUX CURVES / STATE POINT ANALYSIS IN PRACTICE

If the settling test described above is executed for various MLSS concentrations a chart can be plotted with ZSV versus MLSS. The exponential approximation of this plot is called Veselind Function, a method to describe the relationship between MLSS and ZSV. The function describing ZSV is ZSV=Vo exp (-nX). The two parameters describing the function are v0 and n. V0 is the initial settling velocity derived from the extension of the curve to zero concentration intercept, and n is the hindered settling parameter in liter per gram or m^3/kg (Ekama et al, 2006).

Based on these parameters it is possible to calculate the flux balance for the clarifier, expressed as gravity and bulk flux. Both flux functions can be combined to create the State Point Analysis diagram (see figure 5).

The method described above was used to up-scale the effect of the lime treatment at the NPWWTP. The advantage of this method is that it is based on real physical experiments combined with well proven sedimentation models. It is interesting to note that the modified Veselind functions are also used in state of the art numerical dynamic simulation models.

These simulations however are usually not based on actual physical experiments, but on traditional parameter estimates for municipal wastewater plants. Considering the variation in the data obtained from various tests it is easy to imagine that the confidence belt for such simulation is huge.

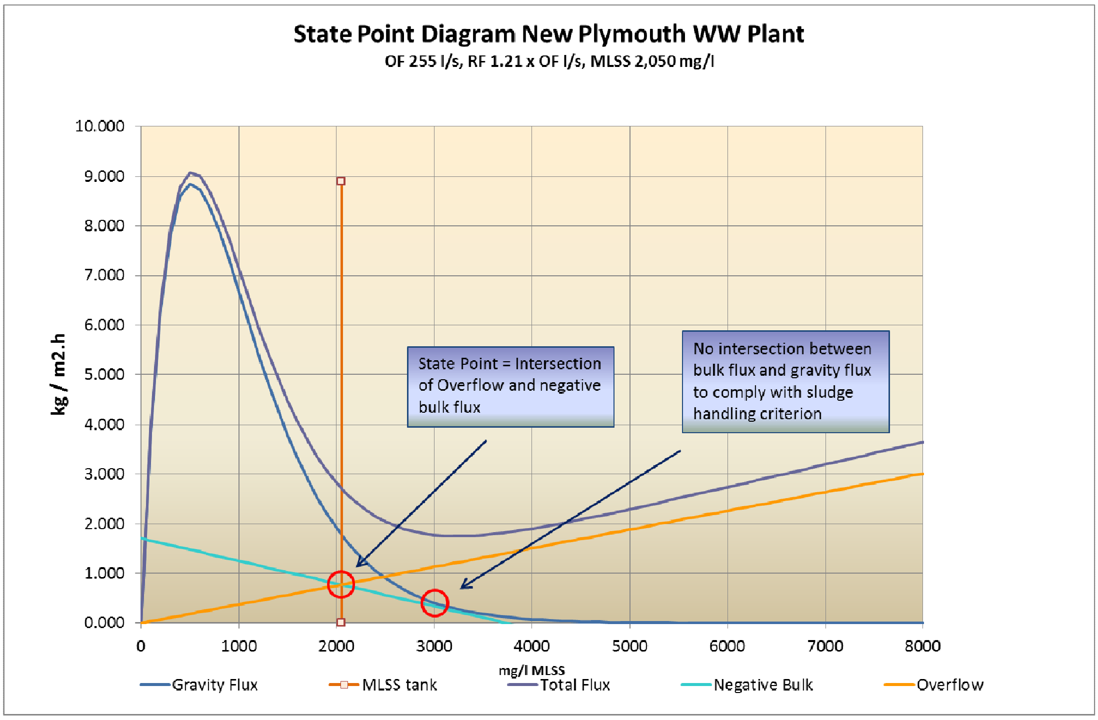


Figure 5: Plot of state point analysis

4.3 STATE POINT ANALYSIS (SPA) IN PRACTICE

The data obtained from the trials was further used in state point analysis charts to show the effects on the NPWWTP. Using this technique it was possible to calculate the maximum MLSS which can be kept safely in the system for processing in the aeration tanks (see summary in table 1).

	NP WWTP	7.3.2012 [m/h]	20.3.2012 [m/h]	29.3.2012 [m/h]	4.4.2012 [m/h]
1000 [mg/l]	3.05	5.09	5.04	5.77	6.18
2000 [mg/l]	0.45	1.11	1.68	3.09	3.72
3000 [mg/l]	0.07	0.24	0.56	1.66	2.24
	100%	343%	800%	2371%	3200%
max MLSS at 880 l/s	1,600	2,100	2,550	3,300	4,750
	100%	131%	159%	206%	297%
		100%	121%	157%	226%
corresponding RAS rate [%]	159	239	222	88	136

Table 1: Operating Parameter over the trial period, up-scaling for the NP WWTP

The calculation needs to satisfy the criteria of the state point analysis (solids handling criterion I and II – Takacs & Ekama in Henze at al (2008)) and the maximum hydraulic flow to the plant which in this case is 880 l/s.

The maximum MLSS which the clarifiers could potentially handle at the various sludge conditions was 1,600 mg/l for the NPWWTP without sludge improvement and 4,750 mg/l after 28 days of lime addition. This was an increase of 197 % (see figure 6). Reduced Nitrogen loads and safe solids operation would be the key environmental benefits.

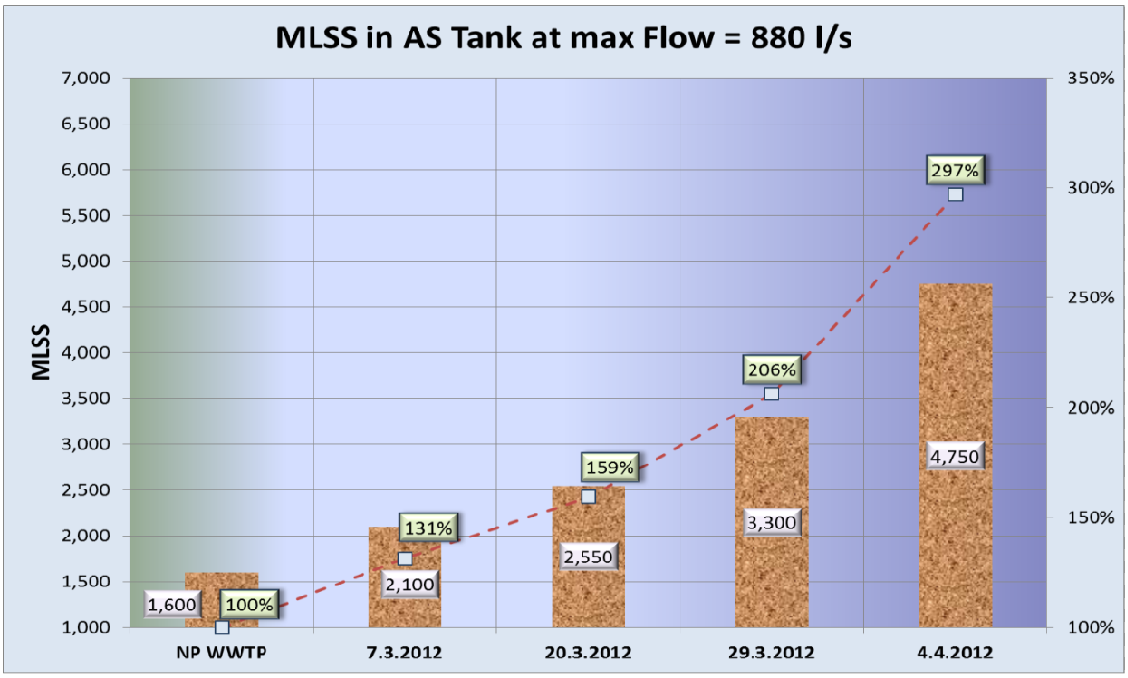


Figure 6: Maximum MLSS which can be operated at max flow without sludge drift

A second outcome of the SPA is a minimum Recirculating Activated Sludge (RAS) rate for a specific operating scenario. Each flow can be modeled so that the negative bulk flux curve, which is determined by the RAS rate, does not intersect with the gravity flux curve. The calculation of this RAS rate for several discrete inflows creates a RAS rate versus inflow chart. Based on this chart a control strategy for the RAS rate can be populated (specifying % of RAS rate versus l/s inflow). This chart could be updated after every ZSV test to avoid unnecessary sludge drift under varying sludge settling behavior (see figure 7).

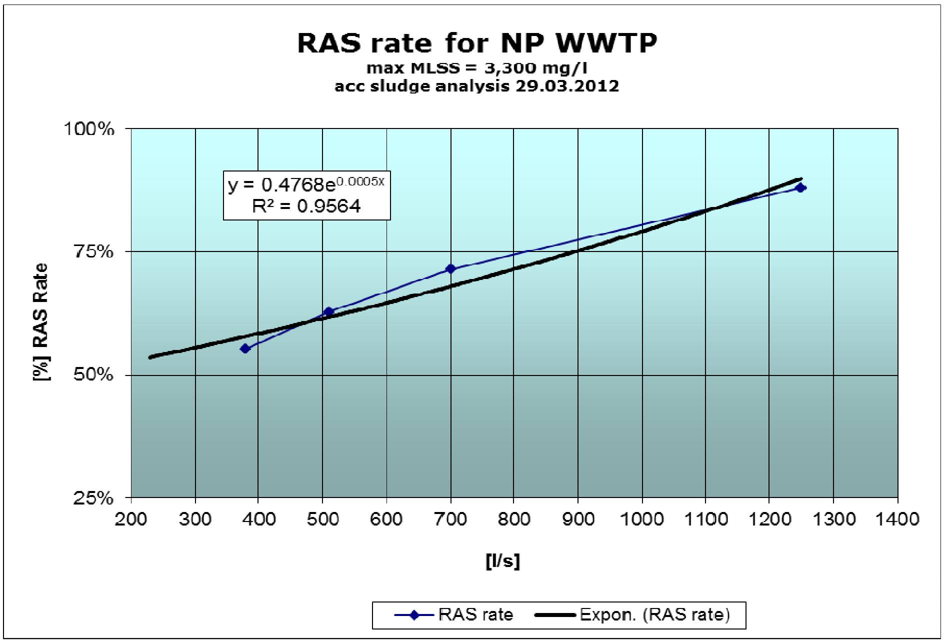
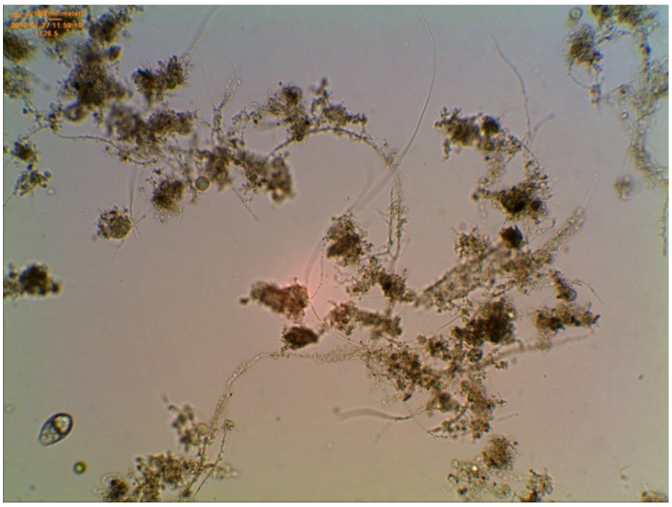


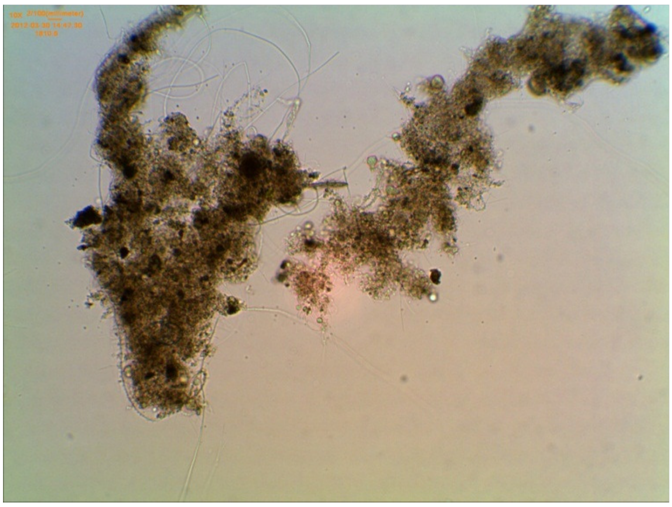
Figure 7: RAS rate profile for return sludge near completion of lime addition trial

4.4 MICROSCOPIC ANALYSIS

Microscopic Analysis was undertaken before and during the lime dosing trial. Before the trial the sludge was heavily infested with filamentous organisms and unable to produce substantial flocs (photograph 2). It was obvious that the sludge flocs would not release water which gets entrapped between the flocs during sedimentation. After 3 weeks of lime addition the flocs showed only a small number of filaments and strong clusters of solids (photograph 3).



Photograph 2: Microscopic analysis of sludge before trial, x100



Photograph 3: Microscopic analysis of sludge during trial, week3, x100

4.5 SLUDGE DEWATERING

On the 4 April 2012 simple sludge filtration tests were conducted in the laboratory of the NPWWTP. The tests were done without any polymer screening for the sludge from the trial plant. The simple non standardized test was to filter a sludge polymer mix through a piece of belt filter fabric. The duration of this drainage process was timed and some qualitative specifications of the filtrate and sludge cake were noted. A good relationship of free drainage and flocculation was achieved for a specific polymer to dry substance ratio of 1.5 (g/kg) for both sludge materials. The drainage time for the unconditioned sludge was timed at 84 sec whereas the lime conditioned sludge was timed at 63 sec. The increase in dewaterability was about 26 % reduction in filtration time. Lime conditioned sludge produced a very stable floc which showed only little signs of weakness after prolonged stirring; the sludge cake was solid with signs of good drainage canals. By way of comparison sludge from the NPWWTP was prone to over-mixing and produced soft cake with a gel-like structure.

5 PRACTICAL IMPLEMENTATION

The results of the trial plant are very promising. In order to use the methodology at a commercial level all components of a given system would need to be analysed to undertake a proper cost benefit analysis. A separate risk-analysis would afford additional confidence before implementation. For CAPEX and OPEX purposes it is useful to look at all the process units which are affected by the application of lime (table 2).

UNIT	ACTIVITY	EFFECT
Clarifier	utilization, size, numbers	CAPEX
Sludge recirculation equipment	power savings to run the pumps as less sludge is pumped because sludge thickens better in the sedimentation tanks	OPEX
Dewatering Equipment	reduced utilization,	CAPEX (deferred spending), OPEX, Levels of Service (increased reliability)
Polymer Equipment	Consumption	OPEX
Fuel for drying	Consumption	OPEX
Drier	Run Time	OPEX, CAPEX
Consent	compliance	Levels of Service

Table 2: Activity / Effect matrix for WWTP units

6 CONCLUSIONS

The addition of lime resulted in dramatic improvement of sludge sedimentation at the NPWWTP trial run. Plant performance was successfully stabilized and high quality effluent was produced. Further trial cycles would optimise the lime dose to ensure best OPEX spend. Lime treatment utilising the processes based on the DCBT dramatically reduce operational and even more so capital expenses. Secondary clarifiers which tend to be bottlenecks get their capacity back and there is time for optimization work. Improvements in sludge structure resulting in better dewatering and drying capability of sludge cakes provide for greater solids loading capabilities and overall efficiency gains.

ACKNOWLEDGEMENTS

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