

OPERATION OF A SOLIDS CONTACT TANK AT LOW DISSOLVED OXYGEN AND LOW TOTAL SUSPENDED SOLIDS CONCENTRATIONS

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ABSTRACT

Solids retention time (SRT) and dissolved oxygen concentration (DO) set points were optimized at the 32 MGD trickling filter-solids contact tank system. OPTImasterTM, on-line optimization software, was used for set points selection. Set points were maintained automatically using SRTmaster and DOMaster-sludge age and dissolved oxygen automatic control systems. Referenced above biological system was successfully operated at DO=0.5 mg/l and MLSS less than 900 mg/l. As a result of set points optimization and automatic control, airflow demand was decreased by 25% while water quality and sludge settleability continued to be excellent.

Tests performed at the first phase of optimization work showed an increase of total and non-settleable effluent TSS when DO at the end of the solids contact tank was reduced to 0.3 mg/l or less. SVI has decreased to 60 ml/g-70 ml/g during the same time. Reduction of DO at the beginning and the middle of the solids contact tank did not produce similar results. It can be preliminary concluded that DO concentration at the end of the tank is more important for flocculation than at the first part of the tank.

Despite absence of any flocculation baffles, rectangular clarifiers showed excellent flocculation ability reducing non-settleable solids concentration from 20 mg/l to 6 mg/l. Total effluent suspended solids concentration was only 1 mg/l higher than non-settleable fraction.

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KEY WORDS

Trickling filter-solids contact, SRT, sludge age, dissolved oxygen, optimization, automation, energy savings

INTRODUCTION

The Oxnard Wastewater Treatment Plant is the largest wastewater treatment plants in the geographical area located between Monterey, Ca and Los Angeles. The plant staff is continuously working on process improvements using advanced automation and optimization methods because this approach provides the largest return on investment. The paper discusses optimization of biological treatment processes using new optimization software.

METHODS AND MATERIALS

Plant description

The Oxnard Wastewater Treatment Plant is a 32 MGD facility that employs the following liquid treatment processes: primary clarification, biofiltration (trickling filters), activated sludge, secondary clarification and chlorination/dechlorination. Average flow is currently 23.5 MGD. The plant has the following NPDES requirements TSS <30 mg/l, BOD₅ <30 mg/l. Dimensions of the biological process units are provided in Table 1.

Table 1- Dimensions of biological process units

Unit process	Length	Width	Depth	Comments
Trickling filter	D = 140 ft	D = 140 ft	26 ft	Plastic media
Solids contact basin	3 passes, 460 ft each	16 ft	16.5 ft	3 grids of fine bubble ceramic diffusers per pass
Mixed Liquor Channel	480 ft	7 ft	6.5 ft	Coarse bubble diffusers
Clarifier	150 ft	22 ft	9.87 ft	No baffles

Optimization work prior to 2006

This section of the paper describes optimization and automation work that preceded current study.

Until 2003 the plant was experiencing incidents of high SVI during spring and summer time. Based on analysis of historical data using data mining methodology (Ekster, 2006) it was determined that lower SVI was observed when the sludge age was less than 2.5 days and MLSS was less than 1000 mg/l. It was also concluded that a decrease of SVI below 180 ml/g may lead to decrease of effluent TSS. Based on these conclusions target sludge age was decreased from 4.5 days to 2 days in 2003. Commissioned the same year an automatic sludge age control system (SRTmasterTM, Fremont, Ca) was able to maintain this value very precisely (standard deviation was less than 0.2 days) over the next four years. The same year a trickling filter flushing routine was implemented, and it has been used ever since. During early morning hours, the second recirculation pump is turned on for 2 to 3 hours.

In 2004 DO in the first pass and the beginning of the second pass was less than 0.5 mg/l, while DO at the end of the second pass and in the third pass was around 2 mg/l. Part of the day DO in the last pass was higher than 3 mg/l due to the fact that automatic DO control was not practiced. At the second part of 2004 an automatic DO control system (DOmasterTM, Fremont, Ca) was implemented. It was able to maintain individualized DO set points to each of nine aeration grids (three aeration passes, with serpentine flow, each pass with three aeration grids) with standard deviation less than 0.2 mg/l except for the time when airflow reached minimum value established by diffusers manufacturer.

After reduction of sludge age set point and precise control of the sludge age and D.O. set points performance of the plant has improved. The foam observed from time to time during summer months has never been observed since 2004. SVI was reduced on average from 190 ml/g to 90 ml/g. No increase of SVI above 140 ml/g was ever observed since 2004. Energy use was reduced by 10%-15%. In addition, mass load on thickening facility has stabilized and as a result, polymer usage for thickening was reduced by 25%. Effluent TSS continues to be less than 10 mg/l most of the time. Detailed description of the referred above efforts and the results of these efforts can be found in (M.Moise et al., 2005). However, the plant staff felt that further reduction of energy usage can be achieved. The goal of the work performed in 2006 and beginning of 2007 was reduction of energy usage while continuing maintaining excellent water quality and reliability.

Current study

At the beginning of 2006 number of diffusers was reduced in all aeration grid zones. In addition, outdated Zullig (currently Rosemount, Irvine, Ca) type D.O. meters (were replaced with the fluorescence type (InsitIG, Slidell, La) in the winter of 2006. Starting 2006 composite effluent non-settleable and total TSS were determined daily using Standard Methods methodology. Turbidity was monitored on-line using Scatter 6 turbidity meter (HACH Inc.).

At the time of D.O. meters replacement, DO concentration varied while airflow was maintained constant. During that time several short-term studies have been performed. First, mixed liquor supernatant TSS was compared for a period of two weeks with effluent TSS.

Second, airflow was reduced in all passes to minimum values allowed by diffuser manufacturers i.e. airflow to each pass was reduced from 600 cfm to 170 cfm per grid in pass #1, from 450 cfm to 170 cfm per grid in pass #2 and from 300 cfm to 170 cfm per grid in pass #3. As a result of airflow change, DO concentration throughout the tank did not exceed 0.3 mg/l. Low airflow condition was maintained for a period of three weeks. Then airflow was returned to pre-testing values. During time of the test sludge age was maintained automatically at a set point equal to two days.

Third, to determine the influence of air supplied to the beginning and middle of the aeration tank on performance of activated sludge another test was performed. Airflow was reduced to 170 cfm per grid initially in pass 1 and two weeks later also in pass 2 for another week. DO in pass 3 was maintained at 1 mg/l. Results of SVI, ISV and effluent TSS were compared using Turkey's multiple t statistical test. (Berthouex et al., 1994).

Based on the results of these tests SRT and DO optimization software OPTImaster™ (Ekster and Associates, Fremont, Ca) was customized and placed in operation. The software utilizes a combination of data mining technique with activated sludge modeling. The algorithm automatically calculates set points for DO and SRT using historical and current data. SRTmaster and DOmaster maintained precisely set points recommended by OPTImaster.

Initially OPTImaster was used off-line and then it was operated on-line. DO readings observed as a result of set point changes are summarized in Table 2. DO in the first pass throughout 2006 and 2007 was less than 0.2 mg/l.

Table 2- Operating parameters during the optimization period

Time Period	MLSSave	SRTave	Minimum DO for longer than 4 hours, mg/l		
			Grid 1-4	Grid 5-6	Grid 7-9
A	850	2.0	<0.2	1	1
B	750	2.1	<0.2	0.75	0.7
C	530	1.9	<0.2	0.5	0.7
D	575	1.6	<0.2	0.5	0.4
A	650	2.4	<0.2	0.5	0.5

RESULTS

During normal operation average non-settleable TSS were 20 mg/l in mixed liquor supernatant and 6 mg/l in the clarifier effluent. Maintaining DO equal or less than 0.3 mg/l throughout the aeration tank led to effluent TSS increase from an average of 8 mg/l to 12-22 mg/l. Non-settleable TSS was increased from 6-7 mg/l to 10-18 mg/l. Effluent turbidity increased from 4NTU to 8-9 NTU. Average SVI was decreased from average 90 ml/g to 60-70 ml/g. When airflow was increased to pre-test values SVI and effluent TSS returned to pretest values. Effluent TSS changed within one day after changing airflow. It took 2-4 days for SVI to change.

Average and standard deviations of logarithm of SVI (lnSVI), calculated initial settling velocity (ISV), and logarithm of effluent TSS (lnTSSe) for reduced airflow rates at different part of the basin are depicted in Tables 3 and 4.

Table 3- Average values

Reduced airflow to pass 1			Reduced airflow to passes 1,2			Airflow is not reduced		
lnSVI	ISV,ft/hr	lnTSSe	lnSVI	ISV, ft/hr	lnTSSe	lnSVI	ISV, ft/hr	lnTSSe
4.75	4.6	1.85	4.6	4.70	1.95	4.89	4.4	1.82

Table 4- Standard deviations values

Reduced airflow to pass 1			Reduced airflow to passes 1,2			Airflow is not reduced		
lnSVI	ISV,ft/hr	lnTSSe	lnSVI	ISV, ft/hr	lnTSSe	lnSVI	ISV, ft/hr	lnTSSe
0.15	0.21	0.31	0.11	0.25	0.45	0.17	0.32	0.28

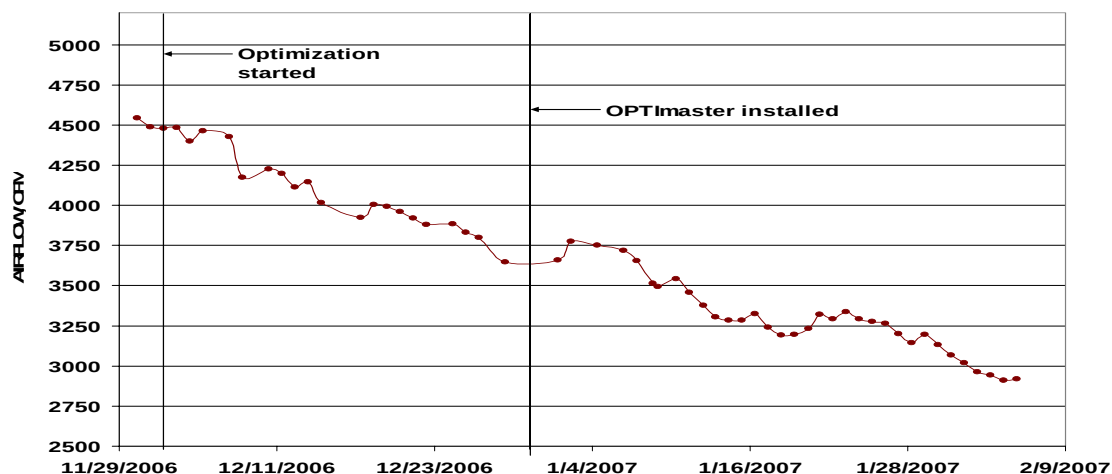
Median and 95 percentile of sludge volume index (SVI), total TSS (TSS) and non-settleable TSS (TSS)ns during OPTImaster off-line and on-line operation are provided in table 5.

Table 5-SVI and effluent TSS during optimization

Time period	SVI ⁵⁰	SVI ⁹⁵	TSS ⁵⁰	TSS ⁹⁵	TSS ⁹⁵ _{ns}	TSS ⁹⁵ _{ns}
A	85	111	9	13	7	12
B	92	114	7	9	6	7
C	87	100	7	10	6	7
D	80	120	8	9	6	7

Reduction of airflow as result of optimization is shown on Fig.1

Figure 1- Airflow change due to optimization



DISCUSSIONS

When D.O. within the entire basin did not exceed 0.3mg/l for longer than 4 hours, effluent TSS has significantly increased. Most of the TSS increase can be attributed to an increase of non-settleable solids. These results are in line with results obtained on a pilot scale level (La Motte et al., 2003).

At the same time, results of Turkey's multiple t statistical tests showed that reduction of airflow to the beginning and the middle of the tank did not cause an increase of non-settleable solids. The following discussions are intended to explain this phenomenon observed by Willen's et al., 1998 as well.

Li et al., 2004 showed that the amount of unoxidized material within the floc is reduced when floc travels through an aeration basin. It is also a well-known fact that concentration of non-settleable solids is higher at the end of the aeration tank than at the beginning. Based on these facts we hypothesize that reduction of unoxidized material within the floc improves flocculation. The amount of unoxidised material is a function of DO and aeration SRT. Due to the fact that some oxidation takes place in the trickling filter, additional oxidation in the third pass of the solids contact tank, apparently, was adequate for proper flocculation. We hypothesize that as long as oxygen gradient in the third pass exceeded minimum value, presence of DO in the first and second passes was not necessary for proper flocculation. That is why, in our opinion, non-settleable solids were affected by DO only at the end of contact solids tank.

SVI decreased rather than increased when airflow was decreased in the aerobic compartments. These results contradict results of frequently referenced work (Palm et al., 1980) that showed that a decrease of DO below a certain value causes low DO bulking. Comparing conditions for Palm et al., 1980 tests and the current study, we found three main differences. First, there was no upstream treatment in the referenced studies, while bio filters are located upstream of the Oxnard activated sludge system. Second, Palm et al., conducted tests with mixed reactors at high influent soluble BOD while soluble BOD concentration in the Oxnard trickling filter effluent was only 10-20 mg/l. Third, aeration tank configurations were different: mixed reactor in the referenced study vs. plug flow reactor with an anaerobic selector equal to 1/3 of an aeration basin volume in the current study. It is unknown whether the described SVI reduction phenomenon will take place in a conventional activated sludge system with anaerobic selector in the absence of trickling filters upstream. Additional bench scale and full-scale studies to make this determination are recommended.

Optimization of sludge age and DO using OPTImaster recommendations led to a 25% decrease of airflow. The biological system produced excellent effluent quality and good sludge settleability when DO in the second part of the solids contact basin was as low as 0.5 mg/l. In the first 40% of the solids contact basin DO was 0.2 mg/l or less most of the day. These results are different than La Motte et al. 2003 full-scale results that showed that good effluent quality can be achieved only at DO concentration 1 mg/l and higher.

Several site specific details could be the reason for excellent performance of the Oxnard plant at unusually low DO. First, operation of the Oxnard facility is tightly controlled due to high level of automation. For example, total airflow demand in the second pass changes from less than 540 cfm in the morning to more than 1600 cfm in the evening. Changes of airflow demand are caused by diurnal influent flow and BOD concentration variations. Because of precise performance of D.O. master (D.O. standard deviation was 0.12 mg/l) and multiple control points there were no periods when D.O. in the second part of the basin was below 0.4 mg/l even when D.O. set point was 0.5 mg/l.

Second, the Oxnard solids contact basin and mixed liquor channel have “perfect” plug flow properties and a fairly long hydraulic retention time. As a result combined aerobic hydraulic retention time (HRT) in the pass#3 and mixed liquor channel is longer than an hour.

Third possible reason is an excellent performance of the Oxnard secondary clarifiers. Rectangular clarifiers installed in Oxnard exhibit not only excellent hydrodynamic performance (effluent TSS concentration is higher than non-settleable effluent TSS concentration by just 1-2 mg/l) but also remarkable flocculation capabilities reducing non-settleable TSS from 20 mg/l in mixed liquor supernatant to 6 mg/l. Interestingly enough, clarifiers do not have any special influent baffles.

Low MLSS (400mg/l-1200mg/l) is another interesting feature of the Oxnard system. When in the past the solids contact tank was operated at MLSS concentration traditionally recommended for similar facilities (2000-3000 mg/l), bulking has been observed from time to time. SVI is maintained within an optimum range 70-130 ml/g at the current MLSS level.

Because automatic wastage control is based on constant sludge age criterion, MLSS concentration varies within 600 mg/l-1100 mg/l range. The lowest effluent TSS was observed when MLSS was at the 700-900 mg/l range. It can be speculated that inorganic material that causes MLSS increase contains large fraction of non-settleable solids, and as a result effluent TSS increases when MLSS increases.

CONCLUSIONS

1. A trickling filters/solids contact system is capable of consistent production of excellent effluent quality at DO= 0.5 mg/l and MLSS =700mg/l-900mg/l.
2. Optimization of DO and SRT using OPTImaster led to 25% reduction in airflow demand.
3. DOmaster and SRTmaster controlled sludge age and DO precisely contributing to good effluent quality and energy savings.
4. DO concentration at the end of the solids contract tank was more important for flocculation than at the beginning of the tank.
5. Reduction of DO below 0.5 mg/l led to reduction of SVI below 70 ml/g. Further studies are needed to explain this phenomenon.
6. Despite absence of any flocculation baffles designed in the 80s rectangular clarifiers showed excellent flocculation ability reducing non-settleable solids concentration from 20 mg/l to 6 mg/l. Total effluent suspended solids concentration was only 1 mg/l higher than non-settleable fraction.

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