Activated Sludge Operation in the Extreme Conditions of MLSS, TDS, and Temperature

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ABSTRACT

Three case studies of activated sludge operating at extreme conditions are presented. In case study #1, MBR treats pharmaceutical manufacturing wastewater with COD of 25 000 mg/L, TDS of 23 000 mg/L and high temperatures. Complete nitrification is achieved as long as TDS is kept under 20 000 (preferably 15 000) mg/L. The most striking feature of this installation is that it operates at very high MLSS concentrations, reaching up to 40 000 mg/L. Case study #2 discusses an MBR which is treating leachate from a municipal landfill with complete nitrification and partial denitrification. It operates at MLSS levels of 15 000 to 20 000 mg/L, influent COD/NH_3-N of 4 000/1 000 mg/L and TDS of 15 000 to 20 000 mg/L. Elevated process temperatures (up to 108 deg F/ 42^o C) are observed due to high energy mechanical equipment and heat of the biological reactions. Despite very high substrate concentrations, salinity and operating temperatures, essentially full nitrification and significant denitrification is being achieved. Case study #3 involves a conventional activated sludge plant with a secondary clarifier, treating ammonia, phenol and thiocyanate-rich wastewater from a coke manufacturing facility. Full nitrification, complete removal of phenol and 75% COD removal efficiency were typically achieved. The plant maintains as low an F/M ratio (high MLSS) as practical by operating with the sludge blanket close to the clarifier weir and with the resulting MLSS reaching 10 000 mg/L.

KEYWORDS: Activated sludge, nitrification inhibition, limits of technology, high temperature, high TDS, high salinity, high MLSS

INTRODUCTION

This paper presents operating experience at three industrial activated sludge nitrifying plants operating under extreme temperature, TDS, and MLSS conditions.

CASE 1. CHEMICAL – PHARMACEUTICAL MANUFACTURING MBR PLANT

The first plant is a membrane bioreactor (MBR) plant which treats wastewater from a pharmaceutical production site, manufacturing active pharmaceutical ingredients and intermediate products. The source of the wastewater is the production process itself, equipment wash-down and stormwater runoff from areas surrounding the production facilities. The plant is located in a warm, dry climate zone; therefore, most of the wastewater treatment tankage and equipment (with the exception of the blowers) is located outdoors.

The treated wastewater is discharged to the sewer for treatment at a regional POTW. The primary objective of the pretreatment process is the removal of ammonia and VOC, in accordance with the SIU permit and as required by the applicable categorical pretreatment standards. The critical effluent goal is maintenance of the effluent ammonia mass loading limit below the target level equivalent to approximately 30 mg/L.

A treatment plant flow schematic shown in Figure 1 includes dual influent storage and equalization feed tanks, used alternatively in a batch mode. The aeration basin is equipped with submerged hollow fiber membrane modules with the discharge directed alternatively to two effluent storage tanks. The final effluent is discharged batch-wise from the off-line tank after confirming it is of acceptable quality. Due to the high strength of the wastewater (design TOC of 14 000 mg/L, typical TKN of approximately 1 000 mg/L), the hydraulic retention time (HRT) in the MBR averages 20 days.

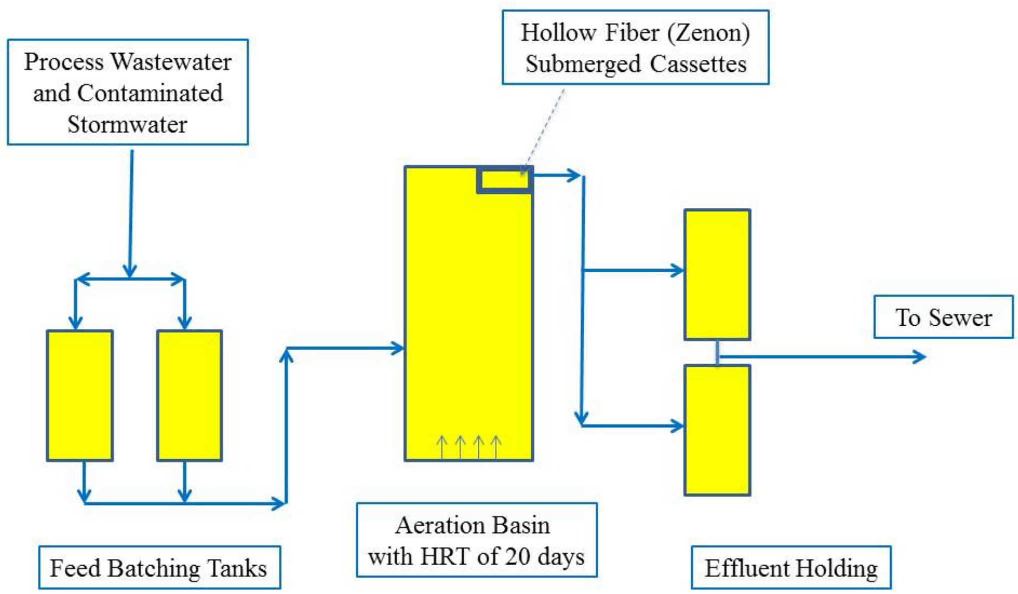

Figure 1. Pharmaceutical manufacturing facility pretreatment plant flow schematic

Following the start-up period, the plant performed adequately most of the time, with a single, temporary nitrification failure in 2009. The failure was thought to have been caused by an extended period of colder temperatures. However, in late May of 2011, the plant experienced another nitrification failure, the immediate cause of which was ostensibly a several-hour long power failure. Due to the elevated ammonia loadings during that time, the pretreatment plant was forced to go off-line and more detailed evaluations were performed.

Figure 2 provides a trend of critical operating parameters prior to the upset. Data indicated that the organic strength of the feed had been gradually increasing since the beginning of 2011 and at the time of the upset, the plant was operating at an F/M approximately double the typical. This resulted in an elevated process oxygen demand which occasionally exceeded the available aeration capacity, as the plant had intermittent problems in maintaining the desired residual dissolved oxygen (DO) of 2 mg/L. Even more notably, the effluent TDS, as measured by conductivity, was steadily increasing during that period (Figure 2). At the time of the upset, the TDS in the effluent (and in the reactor) exceeded 23 000 mg/L.

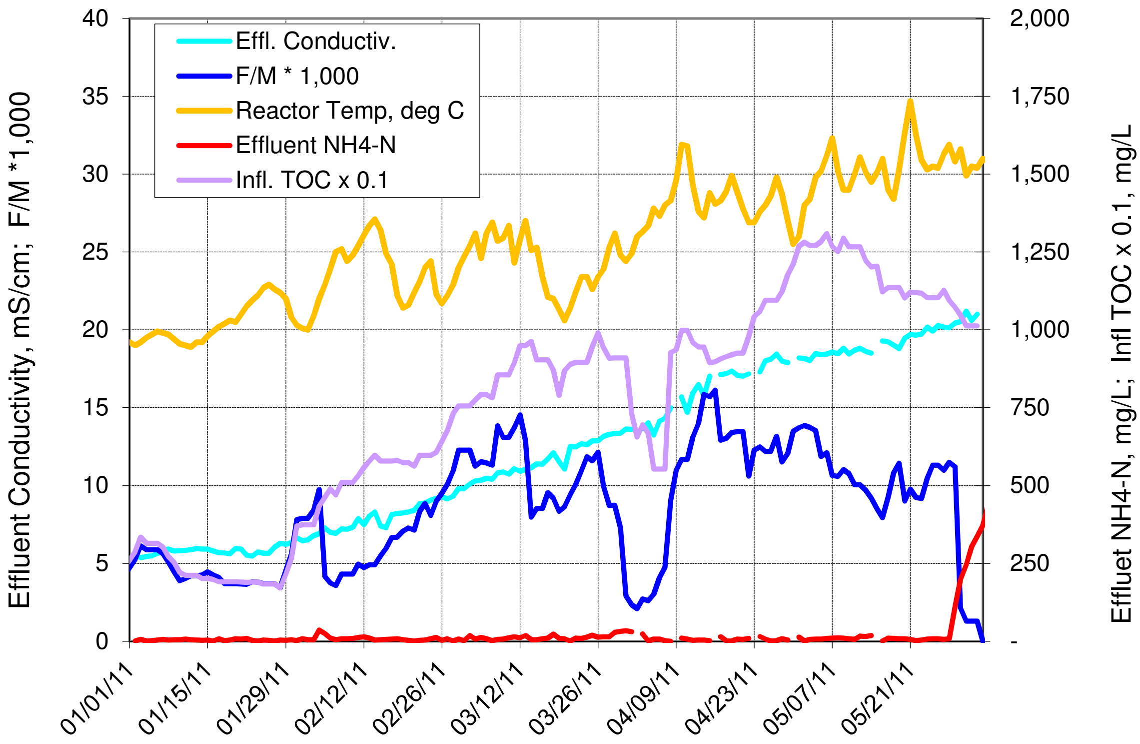

Figure 2. Summary of major operating parameters for the pharmaceutical site

There are literature reports of successful nitrification and denitrification at very high levels of salinity (34 and 45 gCl^-/L, respectively) (Vredenbregt *at al*., 1997). Other experiences (Ludzak, 1965) and our experience elsewhere (see Case Study 2) indicates that nitrification could be inhibited at a TDS concentration greater than 20 000 mg/L. Higher organic loading will exacerbate this effect, particularly when treating industrial, potentially inhibitory wastewater.

Due to extremely concentrated wastewater and associated high HRT (upwards of 30 days at lower flow rates), calculations indicated that evaporation due to aeration contributed a minor, but measurable, increase in the reactor TDS (about 4%). Figure 3 provides correlation between effluent conductivity and TDS levels.

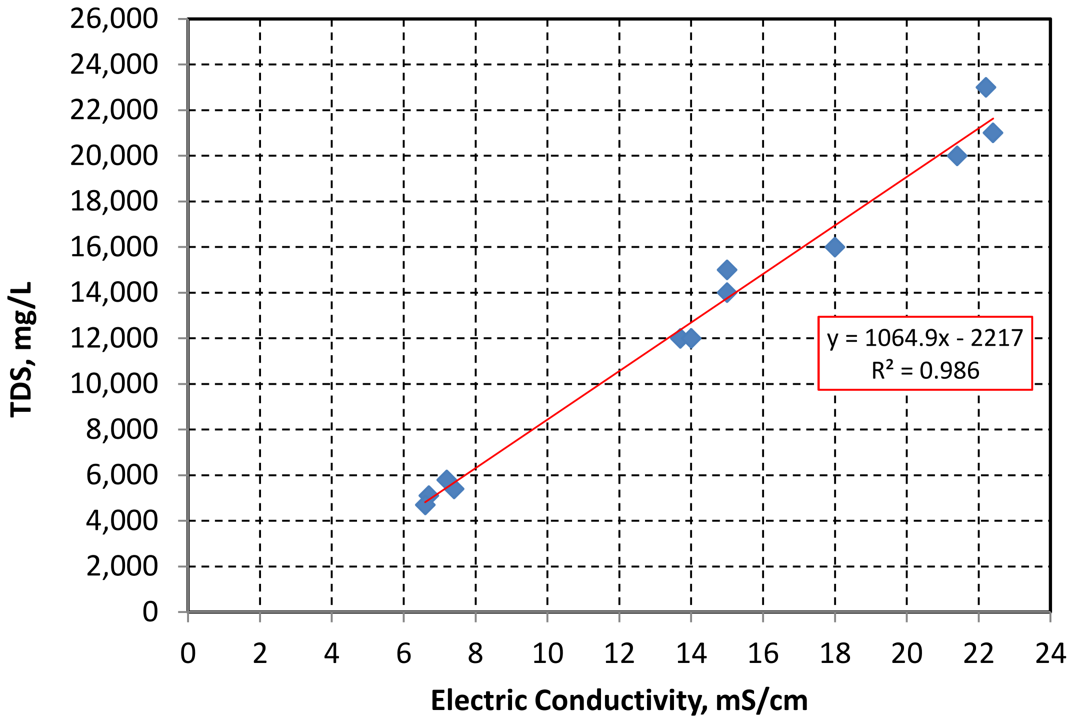

Figure 3. Correlation between effluent conductivity and TDS

While cause-response relationship for the upset cannot be firmly established, the preponderance of evidence indicates that, at the time of the upset, the nitrification process was operating at the limit of acceptable salinity. Thus, a temporary power failure caused a complete nitrification failure and initial attempts at re-establishing nitrification by aerating the reactor without additional feed were not successful.

Following the initial evaluations, a more diluted wastewater (the plant was storing wastewater from different sources in a number of temporary storage vessels) was pumped to the MBR reactor, which resulted in a gradual lowering of the TDS and restoration of full nitrification. Table 1 provides a summary of the major operating parameters measured immediately following the restoration of nitrification. The TDS in this period gradually decreased from above 20 000 mg/L to 17 000 mg/L with almost complete nitrification and a COD removal efficiency of better than 90%.

Perhaps the most noteworthy feature of this installation was operation at very high levels of MLSS, approaching 40,000 mg/L, with only a minor contribution of inert solids (Table 1). In our experience, this is the highest MLSS we have encountered in an operational activated sludge reactor. Adequate performance of the hollow fiber membranes was undoubtedly aided by a low design flux rate of 4.5 $L/m^2/h$. In laboratory tests, a decrease in the membrane flux rate of 30 $L/m^2/h$ were reported for MLSS levels higher than 16 000 mg/L (Trussell *et al.*, 2005) and the maximum MLSS tested was 27 000 mg/L. In earlier work (Trussell *et all*, 2000), severe membrane fouling was observed at an MLSS concentration of 25 000 mg/L and it was recommended to limit an MBR operating MLSS to no more than 20 000 mg/L.

Table 1. Summary of average testing results following restoration of nitrification

Parameter	Wastewater In	Permeate
TKN, mg/L	980	155
NH_3-N, mg/L	140	6
$NO_3 + NO_2$-N, mg/L	6	446
COD, mg/L	22,500	1,900
TDS, mg/L	-	20,000
MLSS/MLVSS, mg/L	37,750/31,000	
Summer Temperature, deg C	30 - 35	

High MLSS concentrations in an MBR are known to lower aeration efficiency (alpha coefficient) (Schwarz *et al*., 2006), which likely contributed to the oxygen deficiencies discussed above. For this reason it was recommended to maintain regular sludge wasting from the MBR and to maintain operational MLSS below 30 000 mg/L. This concentration is still significantly higher than typical design recommendations, which advocate MLSS levels of 10 000 mg/L to ensure reasonable oxygen transfer efficiency (WEF 2010).

Microscopic evaluations found that flocs were firm and round (Figure 4), indicating a degree of granulation, characteristic of some specialized applications (upflow sludge blanket reactors). Dispersed bacteria as well as a single species of filamentous bacteria (actinomycete) were present as well.

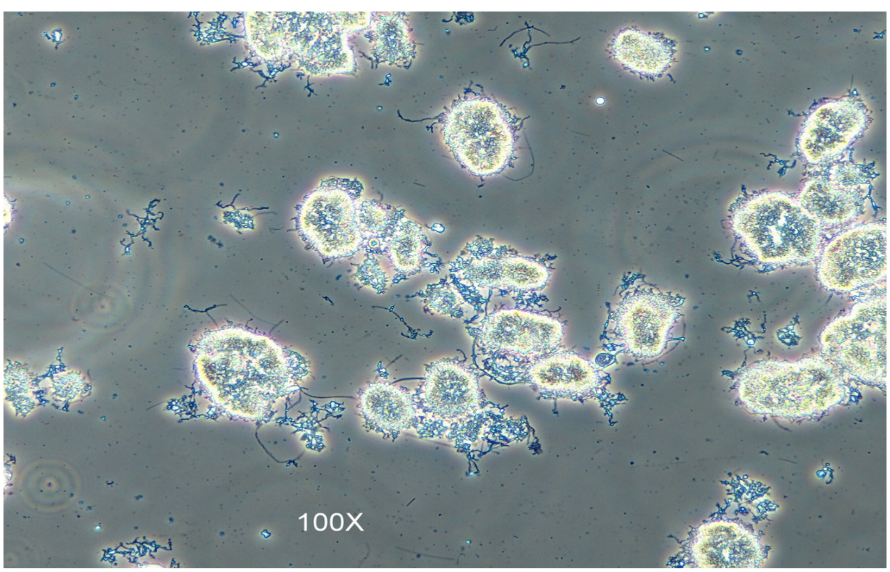

Figure 4. Microphotograph of activated sludge from pharmaceutical wastewater MBR plant

CASE 2. MUNICIPAL LEACHATE MBR PLANT

The second plant is also an MBR which treats leachate from a municipal landfill with complete nitrification and partial denitrification. The facility's main treatment units include one anoxic and two aerobic reactors, housed in a building. Effluent separation is provided by two batteries of cross-flow ultrafiltration (UF) membranes through which mixed liquor from the aerobic reactors is pumped at a high rate (more than 15 times the forward flow) by high-pressure recirculation pumps. As indicated on the plant flow schematic (Figure 5), extensive flow equalization and off-line storage facilities were provided to accommodate highly variable, rain-driven leachate generation rates.

Additional details about the facility design, start-up and initial operation were provided elsewhere (Patoczka, 2011).

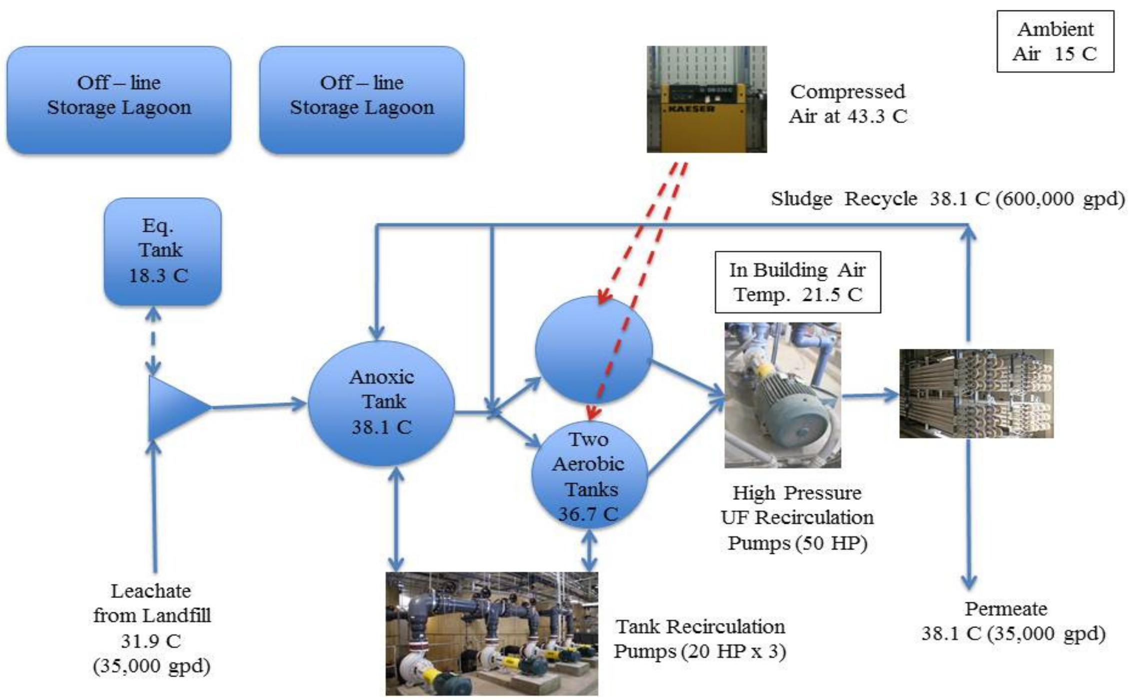

Figure 5. Municipal leachate MBR plant flow schematics.

Initial start-up problems, including the MBR reactor foaming and elevated effluent color were overcome; the former by addition of an antifoaming agent and the latter by ferric dosing. Figure 6 illustrates the effect of ferric chloride addition on the effluent color.

Despite the influent COD and NH_3-N concentrations having increased over the years to the levels 2-3 times higher than the design assumptions, the plant operates with almost complete nitrification and partial denitrification. A summary of the typical operating parameters is given in Table 2.

MBR reactors are housed in a building; hence, heat exchange with the ambient air is minimized. Due to the substantial energy input from the high pressure recirculation pumps and other mechanical equipment and heat generated by biological reactions (removal of COD, nitrification and denitrification of high strength wastewater at high MLSS), the MBR operates at elevated temperatures. A more detailed energy balance for this plant was previously provided (Patoczka, 2011).

The operating temperatures in the aerobic reactor are typically above 80^o F (27^o C) in the winter and have reached up to 108^o F (42^o C) during a summer heat wave (Figure 7). The EPA Manual on Nitrogen Control (US EPA, 1993) indicates that the nitrification process occurs over a range of temperatures from 4 to 45^o C (39-117^o F), with the nitritation step (generation of NO_2) peaking at 35^o C. Sabalowsky (1999) determined that temperatures higher than 40^o C suppress nitrification activity. Despite the fact that the leachate MBR plant sometimes operates at the high end of acceptable temperatures for nitrification, no detrimental impacts on the process performance have been observed.

Table2. Summary of typical operating parameters for the leachate MBR

Parameter, mg/L	Raw Leachate	Permeate
Flow, gpd	35,000	
NH3-N, mg/L	887	5
NO3-N, mg/L	<2	50
COD, mg/L	3,750	1,520
BOD5, mg/L	782	<10
TDS, mg/L	14,800	13,400

In September of 2012 the plant experienced a nitrification failure, which coincided with an increase in wastewater TDS to above 22 000 mg/L (Figure 8). Similarly, as in the Case Study No. 1, once the reactor's TDS was lowered to below 20 000 mg/L, by addition of a low-TDS water to the reactor, nitrification was restored.

Another noteworthy feature of this MBR is its operation at very high MLSS concentrations, which have reached 30 000 mg/L on some occasions, without any detrimental effect on the reactors' performance or pressure loss at the UF membranes. However, most of the time, the MBR operates at MLSS levels closer to the recommended 15 000 mg/L.

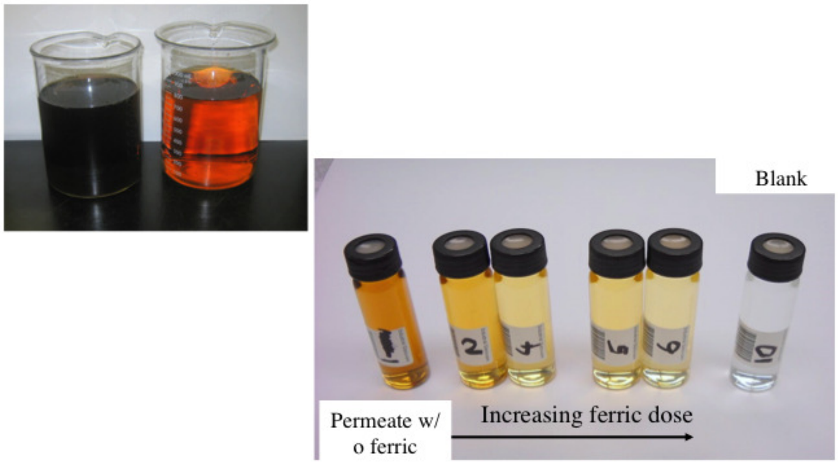

Figure 6. Effect of ferric addition on leachate color

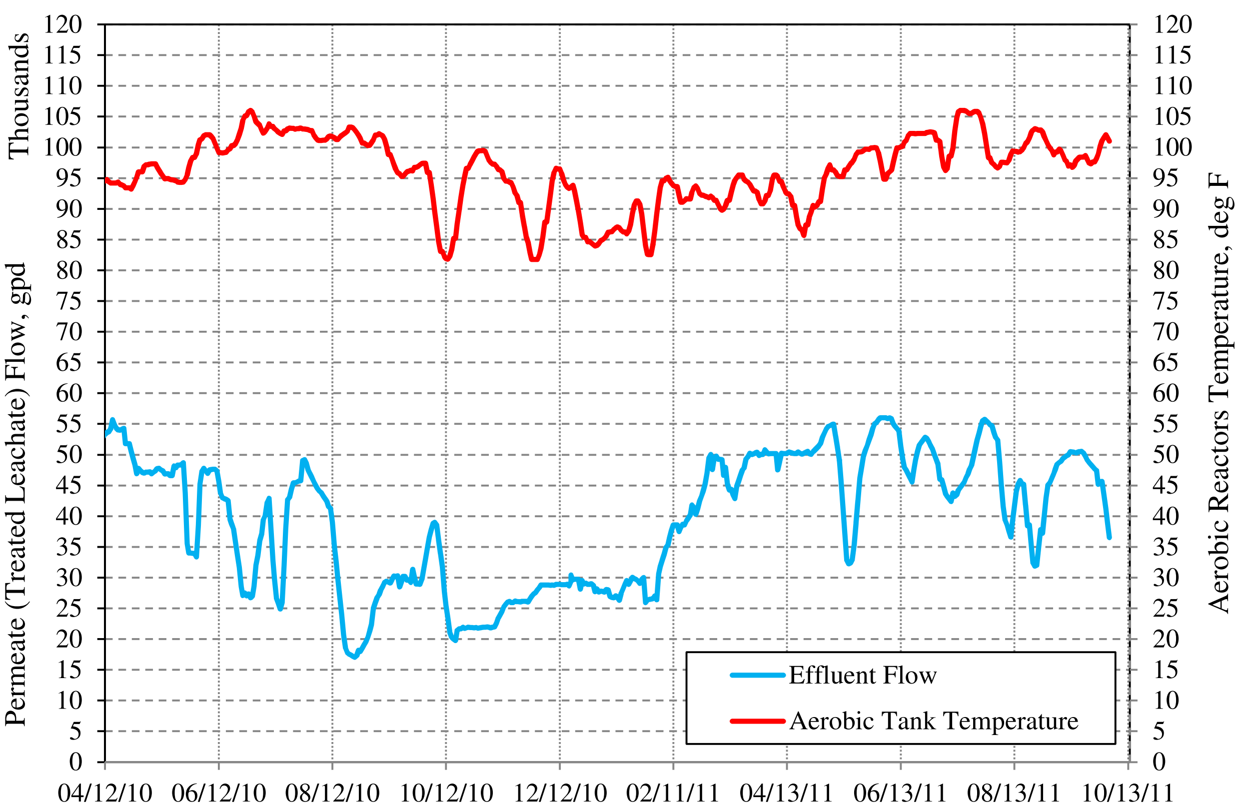

Figure 7. Record of plant operating temperature (and flow)

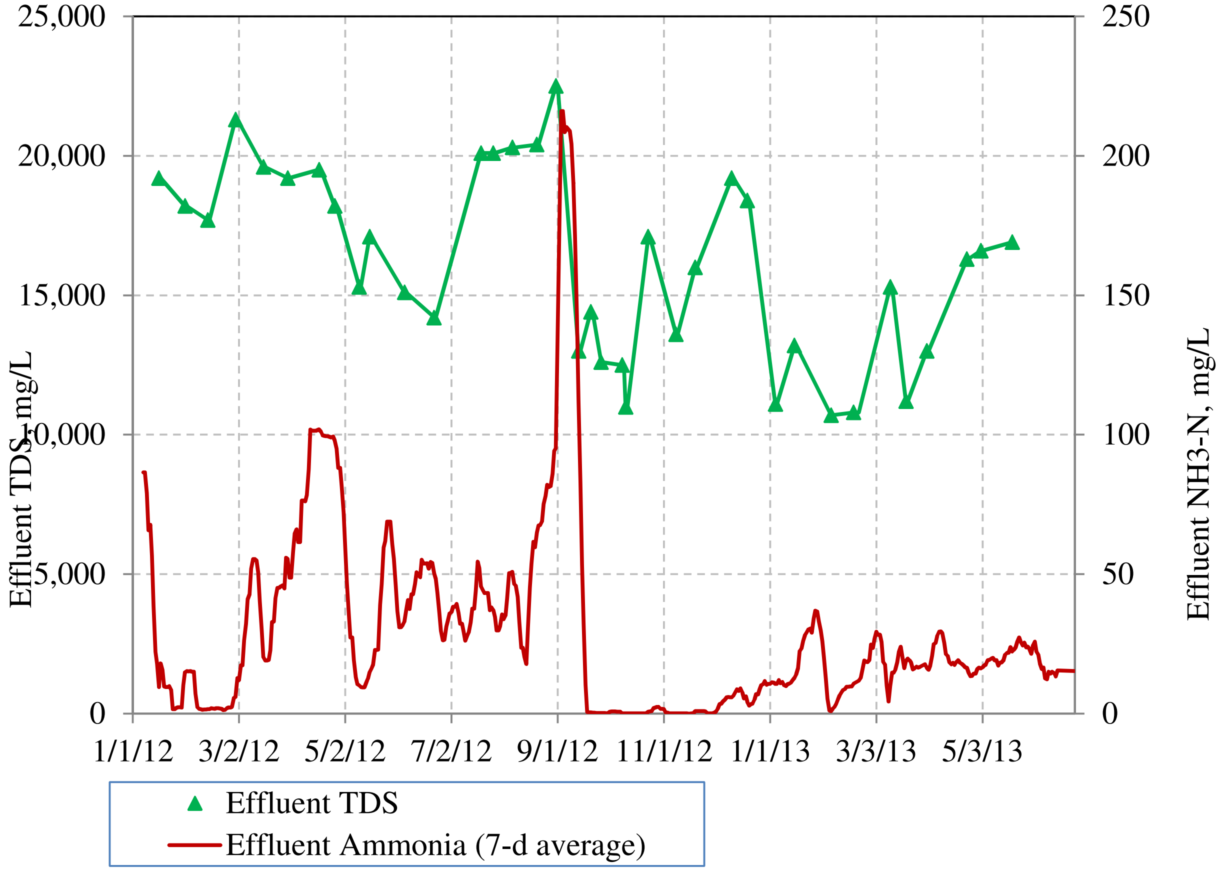

Figure 8. Impact of TDS on nitrification

CASE 3. COKE MANUFACTURING PLANT

The third plant is a conventional activated sludge plant with a secondary clarifier which treats ammonia, phenol, and thiocyanate-rich wastewater from a metallurgical coke manufacturing facility. The primary pretreatment objective is ammonia removal (35 mg/L effluent goal), with TSS and COD removal required to avoid surcharges.

The plant typically achieves full nitrification, complete removal of phenol, and 75% COD removal efficiency as shown in Table 3. However, periodically the plant experiences periods of nitrification failure, which have been correlated with spikes in influent conductivity. The absolute values of TDS levels observed at the plant were well below 10 000 mg/L, thus conductivity spikes are most likely associated with presence of elevated levels of constituents inhibitory to nitrification.

As shown in Table 3, the typical operating F/M is 0.27/d (COD, MLVSS-based), which is higher than 0.13/d recommended for another industrial facility with occasional nitrification problems (Patoczka, 2004).

Table 3. Typical operating parameters of the coke facility wastewater treatment plant

Parameter	Influent	Effluent
COD, mg/L	3,280	846
Phenol, mg/L	432	< 1
TKN (estimated)	200	-
NH3-N, mg/L	64	16.6
SCN, mg/L	468	2.0
F/M, # COD/# MLVSS-d	0.27	
SVI, mL/g	96	
Clarifier overflow rate, m/h (gpd/sq ft)	0.47 (275)	
Clarifier solids loading, $kg/m^2/h$ (lb/day/sq ft)	7.7 (38)	
Conductivity, mS/cm	4.56	

The plant strived to maintain as low an F/M ratio (high MLSS) as practical by operating with a sludge blanket close to the clarifier weir. This practice maximized the MLSS inventory in the system, but resulted in periodic discharges of elevated levels of TSS to the sewer (Figure 9). This practice, in conjunction with a well-settling, non-bulking sludge, and a low clarifier overflow rate, allowed the plant to operate with record-breaking MLSS and MLVSS concentrations of up to 10 000 and 9 000 mg/L, respectively. This is higher than the upper range of MLSS concentration (8 000 mg/L) recommended for pure oxygen plants (WEF, 2010).

As indicated in Table 3, a relatively large secondary clarifier allowed for operation at a surface overflow rate (SOR) of only 0.47 m/h (275 gpd/sq ft), which undoubtedly facilitated maintenance of very high MLSS. Another factor was good sludge settleability with SVI averaging below 100 mL/g and dense, compact sludge with few filamentous bacteria. It is interesting to note that the only filamentous species present in this case, as well as in the two previously discussed cases, were actinomycete (i.e. gram positive, filamentous bacteria) (Figure 10), which seem to be associated with difficult to biodegrade, industrial wastewater.

Jar tests performed on samples of mixed liquor demonstrated that even at high MLSS levels, polymer addition could significantly increase the initial zone settling velocity (ZSV) of activated sludge (Figure 11).

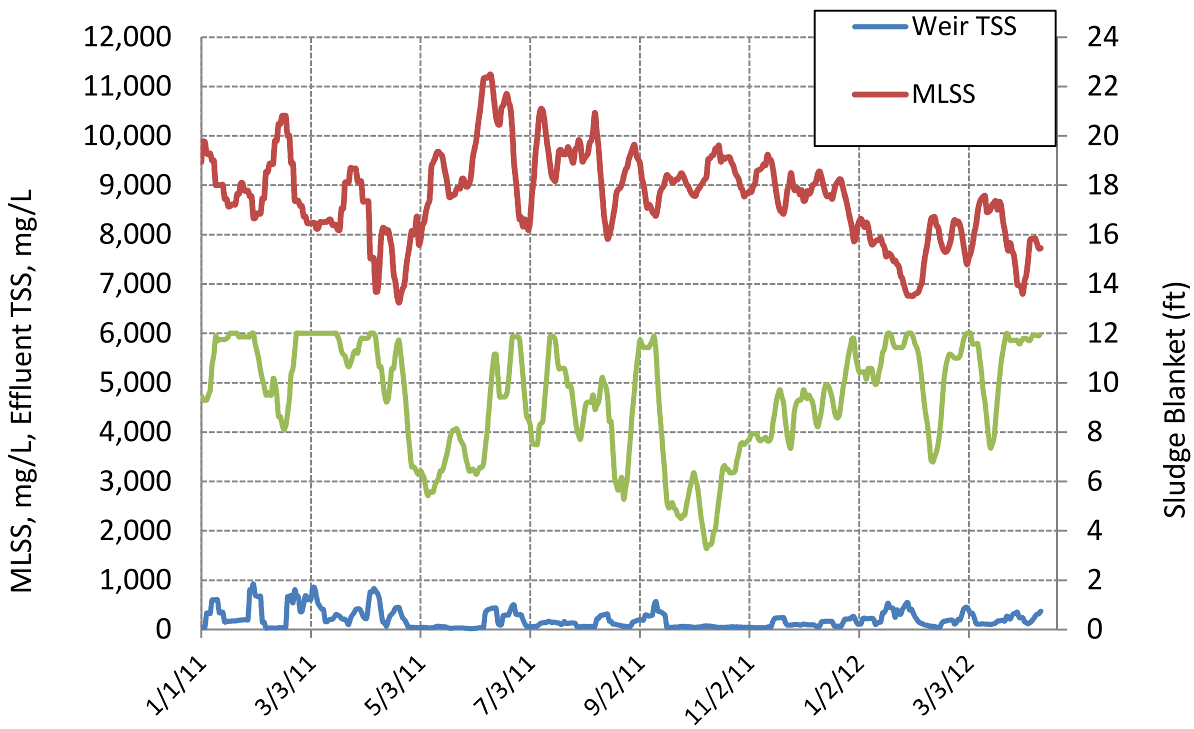

Figure 9. Coke plant self-regulating MLSS control

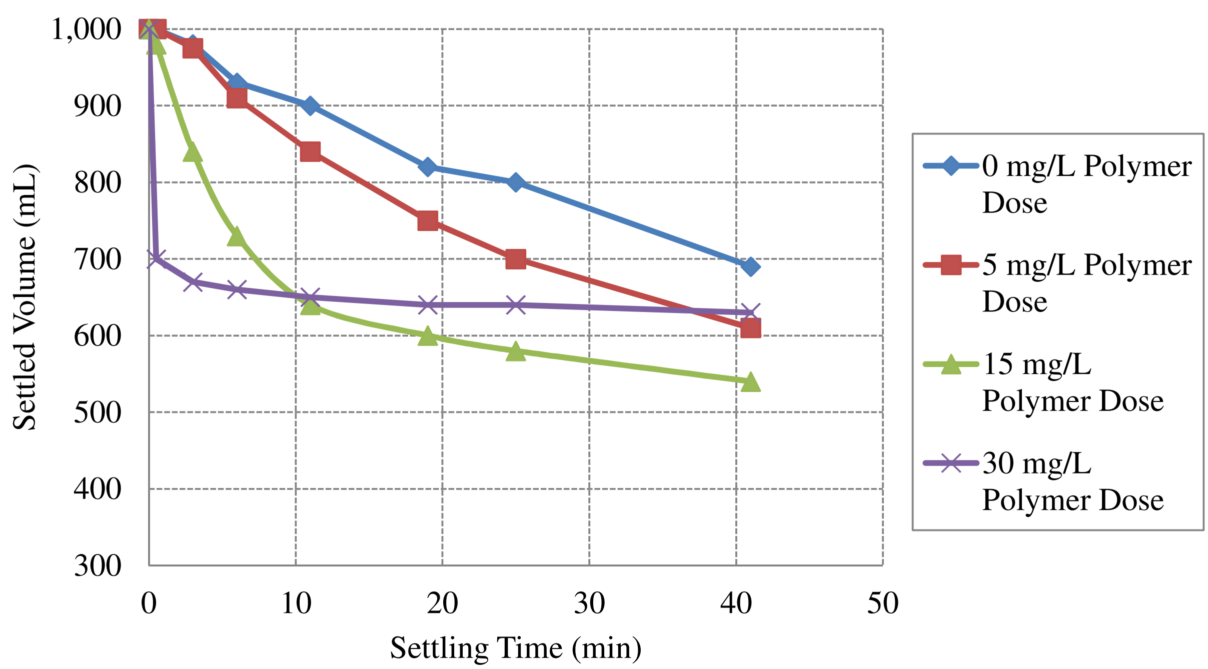

Figure 11. Effect of Zetag 7563 polymer addition on settling of high MLSS sludge

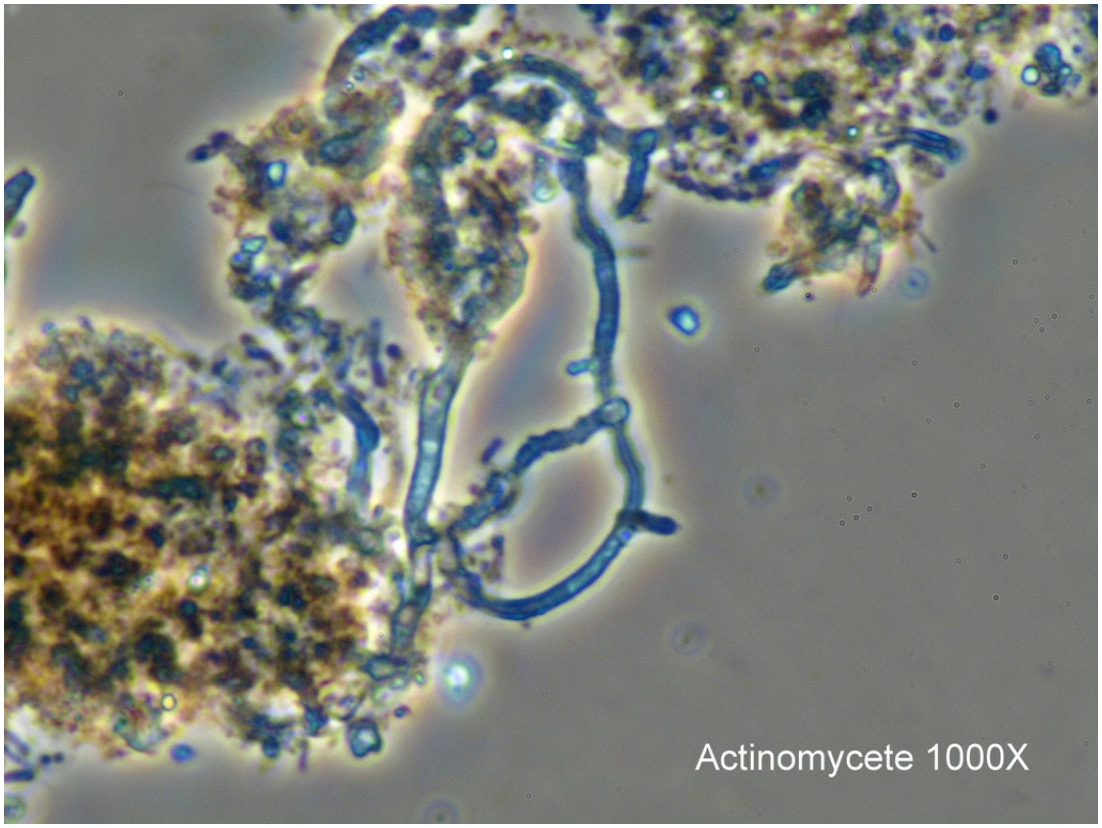

Figure 10. Actinomycete present in coke plant activated sludge

SUMMARY AND CONCLUSIONS

In summary, the nitrifying activated sludge plants evaluated in this study demonstrated successful operation at the limits of activated sludge technology:

- MLSS concentrations of up to 40 000 mg/L for an MBR and up to 10 000 mg/L for a plant with a conventional clarifier could be acceptable,
- Nitrification was maintained at temperatures of up to 108 deg F (42.2 deg C),
- Full nitrification was observed at TDS levels of up to 20 000 mg/L; however, there are consistent indications that, at higher TDS levels, nitrification will become less robust and could be more readily inhibited by other environmental factors (high organic loading, presence of other inhibitory compounds),
- Actinomycete type of filamentous bacteria seems to thrive in difficult industrial wastewater.

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