

## Effect of Variation of $K_LA$ in Aeration Tanks

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### Abstract

The Benchmark Simulation Model No 1 (BSM 1), as a part of its layout has three aeration tanks preceded by two anoxic tanks. In this study, steady state sensitivity analysis has been carried out in the BSM 1 plant layout which is composed of two models i.e. Activated Sludge Model No.1 (ASM1) for simulation of activated sludge process and simple 1-D Takacs model for simulation of settling processes. With aeration being the energy intensive step in activated sludge process, it is important to understand how sensitive the effluent variables are to the aeration in tanks. Here,  $K_LA$  is identified as the manipulated variable. Sensitivity analysis is used here to understand how the effects of aeration is propagated across the system in order to undertake decisions regarding the levels of aeration required to meet the effluent limits.

**Keywords:** Aeration, Activated Sludge Process, Activated Sludge Model No 1, Benchmark Simulation Model 1, Sensitivity Analysis.

### 1. Introduction

The aeration tank is the biological reactor where relatively large number of bacteria is provided with aeration. Carbonaceous oxidation and nitrification are the two reactions that are taking place in the aeration tank. In the presence of adequate dissolved oxygen, optimal microbial growth and hence pollutant removal can take place. Bacteria hence formed contribute to the solids that are present in the tank and it is called sludge. In presence of oxygen, a significant percentage of bacteria gets metabolically active and hence the name 'Activated Sludge'. With respect to dissolved oxygen, low levels of dissolved oxygen may lead to nitrite accumulation due to incomplete nitrification

process. The optimal DO concentration to achieve nitrification is relatively low and it is around 2 to 3 mg/L. But many activated sludge process based plants are over aerated based on the assumption that higher DO levels would result in reduction of competition between microorganisms for the oxygen and more nitrification which in turn leads to increase in the power consumption. (Gerardi, 2002)

The operational costs of a wastewater treatment plant depends on the type of wastewater treatment process employed which determines the amount that is spent on energy, maintenance, chemical usage, manpower and allied activities such as sludge treatment and disposal. In this study, we are focusing upon aeration which consumes energy during operation along with pumping and mixing. In Alex et al. (2008), the aeration energy is defined as the function of oxygen saturation concentration, bioreactor volume and  $K_LA$  i.e. mass transfer co-efficient of oxygen. In this study the effect of variation of  $K_LA$  on effluent parameters are studied by sensitivity analysis and this can give cues regarding the aeration energy for there is a direct proportionality between  $K_LA$  and aeration energy.

The findings here are specific to the given layout with specific set of conditions and may not extend to real world cases, for the analysis is done on the mathematical model which may not replicate real time field conditions. So as specified in Araujo et al. (2013), these could be taken as thumb rule for testing it in waste water treatment plants. Bifurcation analysis of a large scale wastewater treatment plant was undertaken in Tlacuahuac et al (2009) and it gave cues regarding the link between aeration and effluent parameters.

In this work, our aim is to understand the sensitivity of the effluent parameters like COD, BOD, ammonia and nitrites/nitrates with respect to  $K_LA$  in every tank as individual varying parameters. This in turn could result in identifying the operable regions of the system and developing control strategies to result in lowering of pollutant levels. To carry out this work, we have used BSM 1 layout which is implemented in GPS-X environment after validating the constructed BSM 1 layout according to the protocol given by COST Simulation benchmark.

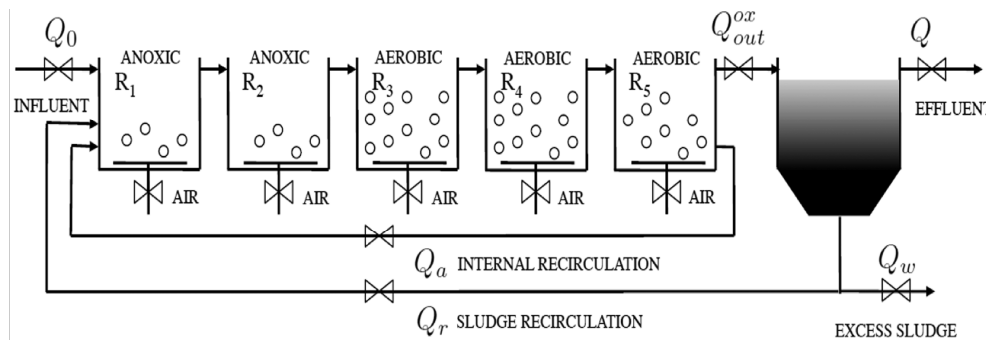
## 2. Sections

### 2.1 Plant Description and Models

Wastewater treatment plants are large non-linear systems subject to large perturbations in influent flow, pollutant load, together with uncertainty concerned with composition of incoming wastewater.

Mathematical models representing activated sludge processes were borne out of the efforts of the International Association on Water Quality (IAWQ, formerly IAWPRC). In 1987, Activated Sludge Model 1 was first presented and since then substantial additions were effected to make the models represent the new experimental observations that described the growth and population dynamics of the microorganisms involved in pollutant removal and the enhanced biological phosphorus removal. BSM (Benchmark Simulation Model) 1 is a defined model that includes plant layout, influent loads during different weather namely dry, wet and storm, modeling

and test procedure with evaluation criteria. Once the user has validated the simulation, any control strategy can be applied and the performance can be evaluated according to a defined set of criteria. The layout is shown in Figure 1 which consists of 5 reactors of combined volume of  $6000 \text{ m}^3$  followed by a settler of 10 layers with a volume of  $6000 \text{ m}^3$ . The three aerobic reactors are preceded by two anoxic reactors to aid denitrification. The plant thus combines nitrification with predenitrification in a configuration that is commonly used for achieving biological nitrogen removal in full scale plants. The plant is assumed to operate at a dry weather inflow of  $18446 \text{ m}^3/\text{d}$ , recirculated activated sludge (RAS) rate of  $18446 \text{ m}^3/\text{d}$  and wasted activated sludge (WAS) rate of  $385 \text{ m}^3/\text{d}$ . The sludge recycle from settler to first anoxic tank is done to maintain microbial population in biological reactors and internal recycle from last aerobic reactor to first anoxic tank is done to enhance nitrogen removal through denitrification. BSM 1 layout is based on two models i.e. Activated Sludge Model No.1 to model the biological process and non-reactive Takacs one-dimensional settling model to model the secondary settling process. The BSM 1 layout is defined with extensive ordinary differential equations for every tank that include kinetic and stoichiometric parameters. The ASM 1 model is used for it is reliable and extensively used in modeling studies. The BSM 1 layout is platform independent and the information regarding the implementation of the layout can be found at the COST/IWA 624 Web site (<http://www.benchmarkwwtp.org>). The platform used in this study for simulation is GPS-X, which is developed by Hydromantis Environmental Software Solutions, Inc for modeling and designing municipal and industrial wastewater treatment plants.



**Figure 1:** BSM 1 Layout.

The default parameters in the GPS-X simulation environment are changed accordingly during tuning of the simulator. Duplicating the steady state and dynamic results is an essential first step in the evaluation procedure. By synchronizing the simulation tool, the tuning of the simulator can be ensured and that in turn can ensure the consistent comparison of process behavior and the consistent comparison of implemented control strategies. The simulation done in this study is preceded by appropriate tuning of the simulator according to the protocol specified in the COST simulation benchmark.

GPS-X provides a more convenient way to predict the changes in configuration as well as the operational conditions. Hence the parameters of the simulation can be deftly changed in order to create new scenarios for testing the control strategies.

## 2.2 Results and Discussion

We perform sensitivity analysis to understand how the changes in  $K_LA$  in an aeration tank propagate across the system and to identify the limits of operation with respect to violations of effluent limits. The effluent quality is defined by composite variables which are composed of various effluent fractions.

$$\text{COD}_e = S_{S,e} + S_{I,e} + X_{S,e} + X_{BH,e} + X_{BA,e} + X_{P,e} + X_{I,e} \quad (1)$$

$$\text{BOD}_e = 0.25 (S_{S,e} + X_{S,e} + (1 - fp) (X_{BH,e} + X_{BA,e})) \quad (2)$$

$$\text{TKN}_e = S_{NH,e} + S_{ND,e} + X_{ND,e} + iXB (X_{BH,e} + X_{BA,e}) + iXP (X_{P,e} + X_{I,e}) \quad (3)$$

$$\text{NO}_e = S_{NOe} \quad (4)$$

$$\text{TN}_e = \text{TKN}_e + \text{NO}_e \quad (5)$$

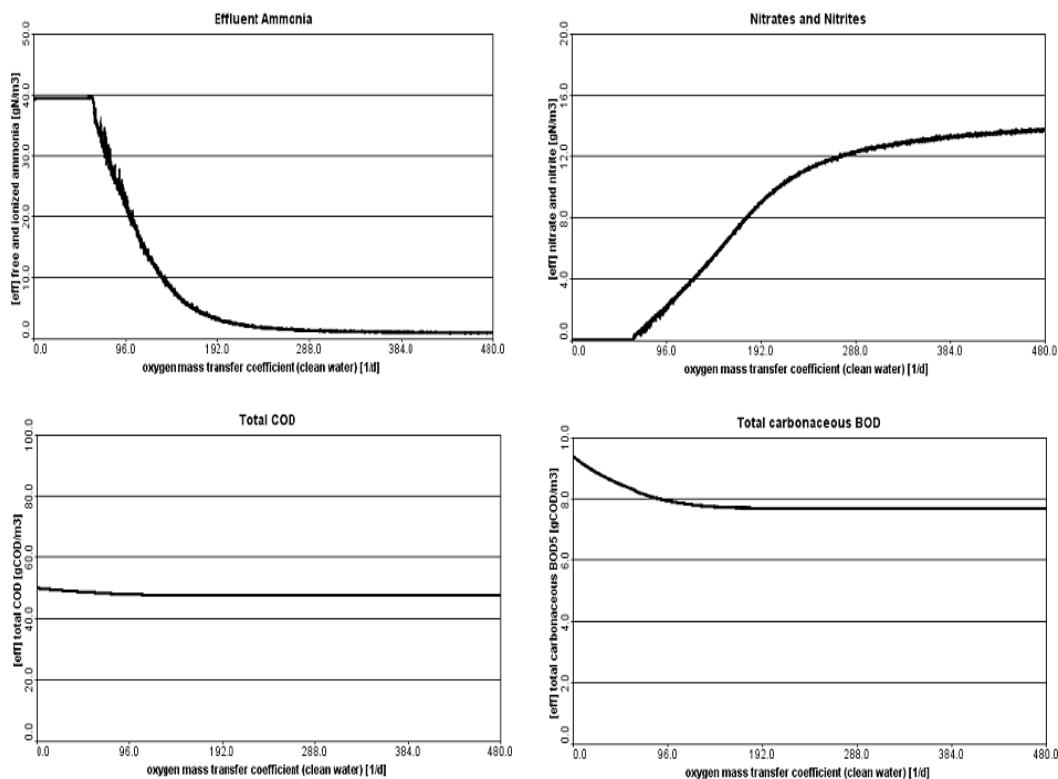
(Effluent Chemical Oxygen Demand-COD<sub>e</sub>, Effluent Biological Oxygen Demand-BOD<sub>e</sub>, Effluent Total Kjeldahl Nitrogen- TKN<sub>e</sub>, Effluent Nitrates/Nitrites- NO<sub>e</sub>, Effluent Total Nitrogen- TN<sub>e</sub>, fraction of biomass to particulate products-fp, fraction nitrogen in biomass -iXB, fraction nitrogen in particulate products-iXP)

The influent stream used here for the simulation is characterized as in Table 1. This data is attributed to dry weather and this is defined as the influent stream characterization throughout the simulation. The composite variables of the influent stream is COD of 381.19 g COD m<sup>-3</sup>, TN of 54.425 g N m<sup>-3</sup>, TSS of 211.27 g SS m<sup>-3</sup> and BOD<sub>5</sub> of 68.518 g COD m<sup>-3</sup>. The default flow rate during dry weather is 18446 m<sup>3</sup>/d. The default  $K_LA$  value for the first and second aerobic tanks is 240 d<sup>-1</sup> and the third tank is 84 d<sup>-1</sup>. The nitrate/nitrite levels and Active autotrophic biomass is assumed to be zero in the influent stream.

**Table 1:** Influent Stream.

State Variables	Description	Value with Units
Ss	Readily biodegradable Substrate	69.5 g COD m-3
XB,H	Active Heterotrophic Biomass	28.17 g COD m-3
Xs	Slowly biodegradable substrate	202.32 g COD m-3
XI	Particulate inert organic substrate	51.2 g COD m-3
SNH	Ammoniacal Nitrogen	31.56 g COD m-3
SI	Soluble inert organic substrate	30 g COD m-3
SND	Soluble biodegradable organic substrate	6.95 g N m-3
XND	Particulate biodegradable organic substrate	10.59 g N m-3

In this study, the aeration is provided by mechanical surface aerators and the degree of aeration is specified by the oxygen transfer co-efficient  $K_{LA}$ . Aeration is energy intensive step and lower aeration may lead to reduction of effluent quality. Hence propagation of the effect of aeration across the system is analyzed by varying the  $K_{LA}$  value from  $0 \text{ d}^{-1}$  to  $480 \text{ d}^{-1}$ . In all tanks, the variations led to the same final steady state as in Tlacuahuac et al (2009). As seen in Figure 2 and Figure 3, the effluent parameters response to the changes in first and second aeration tank is nearly similar with the response to the changes in the first tank showing a lag where in reduction in effluent ammonia levels happen at lesser  $K_{LA}$ . Hence this shows a link between the location of the aerator and the performance of the wastewater treatment system. In this system, with increase in  $K_{LA}$ , the effluent ammonia levels show a steady decrease with the otherwise happening with effluent nitrate/nitrite levels. This may be due to excessive nitrification due to increased aeration and with it getting carried over to anoxic tank due to internal recirculation from third aeration tank to first anoxic tank, therein resulting in reduction of efficiency of denitrification. With respect to effluent COD and BOD, they are not sensitive to aeration. Hence it becomes clear that aeration play a role in polishing of effluent wastewater for it removes ammonia and results in reduction of nitrogenous pollutants. Taking the effluent constraint for ammonia at  $4 \text{ mg/l}$  from Alex et al., the constraint is met at  $K_{LA}$  of around  $170 \text{ d}^{-1}$  in both first and second tank.



**Figure 2:** Effect of variation of KLA in first aerobic tank.

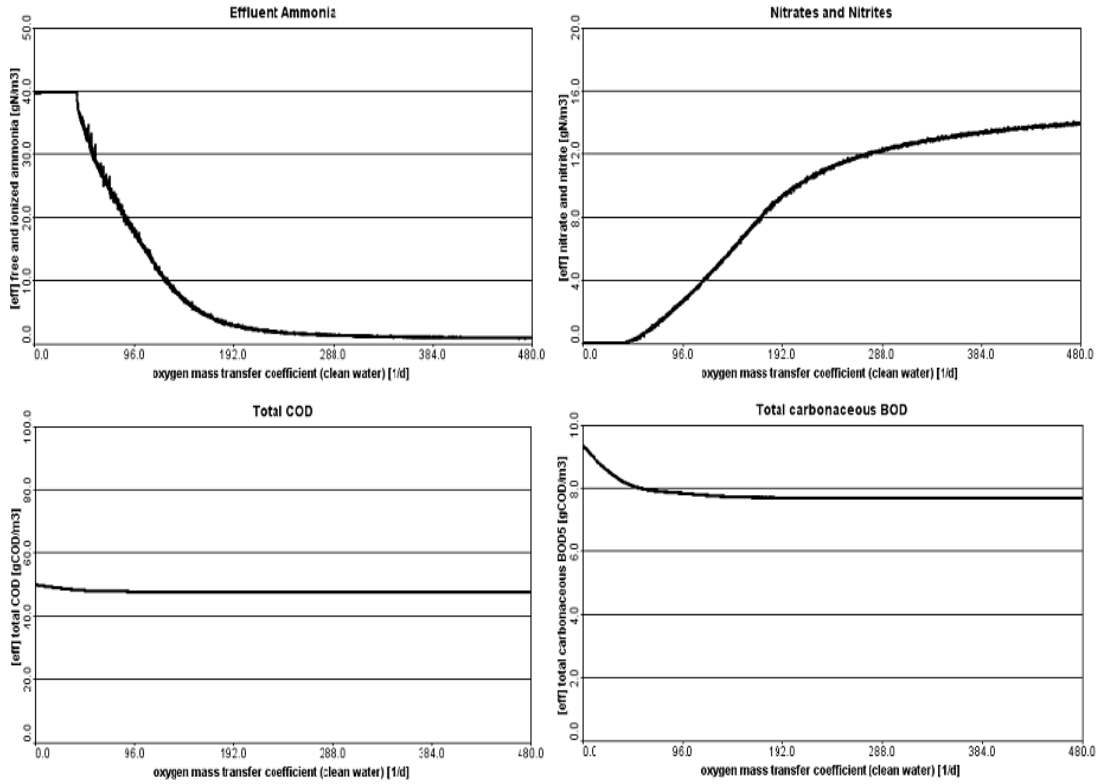


Figure 3: Effect of variation of KLA in second aerobic tank.

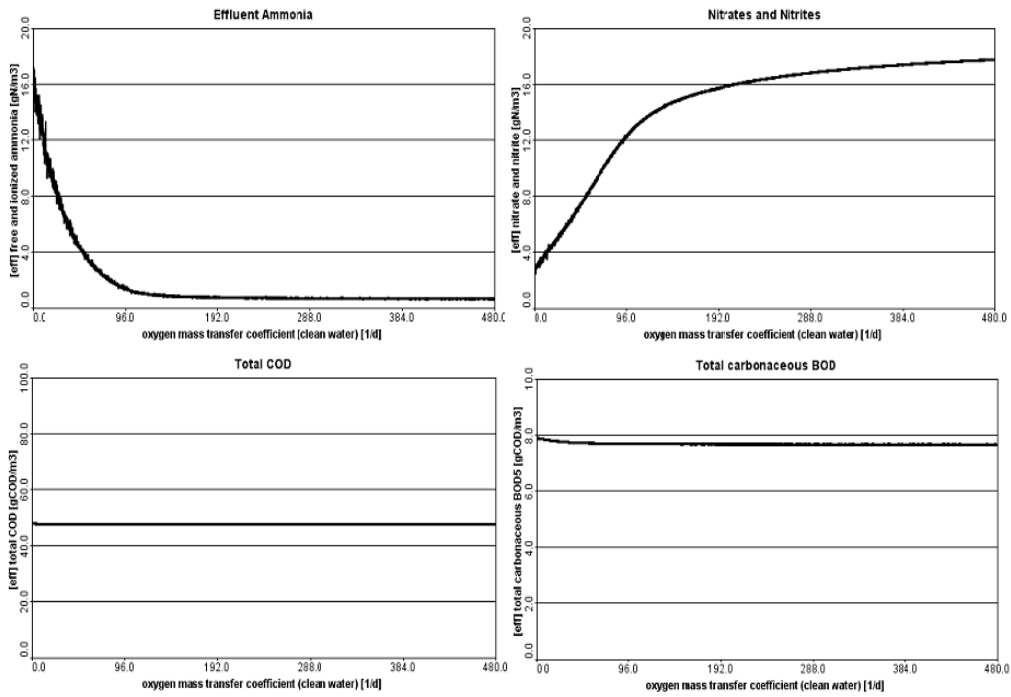


Figure 4: Effect of variation of KLA in third aerobic tank.

As seen in Figure 4, the response to the changes in third tank differs from the above as the constraint with respect to ammonia is met when the  $K_{LA}$  is around  $50 \text{ d}^{-1}$ . The effluent ammonia is very sensitive to the changes in the  $K_{LA}$  of third tank and hence it could be used in control strategies. At  $K_{LA}$  values above  $75 \text{ d}^{-1}$ , the nitrate/nitrite values steadily increases and hence the total nitrogen (TN) increases at higher  $K_{LA}$  values. Along with this, higher  $K_{LA}$  values cannot be applied in this tank as higher dissolved oxygen in the internal recycle would affect the performance of the anoxic tank which receives it. Hence, it can be understood that  $K_{LA}$  values around  $50 \text{ d}^{-1}$  would be optimal to achieve the constraints.

The above results show us that aeration in first and second tank should not be considered for control strategies because they evoke lower sensitivity in effluent variables in comparison to the third tank in comparison to the actions in third tank which directly impacts the performance of the first anoxic tank.

### **3. Conclusion**

This paper discussed the application of sensitivity analysis to understand the propagation of changes in  $K_{LA}$  in aeration tanks and it is found that effluent variables are sensitive to the aeration in third tank. Effluent ammonia and Effluent nitrate/nitrite levels are sensitive to the aeration and hence it could be used to polish the effluent in order to achieve constraints imposed. In this paper, the study is limited to datasets from dry season and hence the findings are applicable to the BSM 1 layout and dry season. Future work would include effect of variation of  $K_{LA}$  in aerobic tanks during wet and storm weather conditions.

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