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SENSITIVITY ANALYSIS OF ACTIVATED SLUDGE PROCESS

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ABSTRACT

This paper presents a sensitivity analysis of effluent variables in the activated sludge process. Sensitivity analysis is used to study the effluent variables such as Ammonium plus ammonia nitrogen ($S_{NH,e}$), Total Nitrogen ($N_{tot,e}$), Chemical Oxygen Demand (COD_e), Biochemical Oxygen Demand ($BOD_{5,e}$) and Total Suspended Solids (TSS_e) are sensitive towards the manipulated variables for various influent conditions (low, average and high influent conditions). No case studies have been discussed in the literature for the BSM1 activated sludge process using the municipal WWTP (wastewater treatment plant) located in India. In this study, simulations are performed using the influent variables data taken from the municipal WWTP, located in India. The outcomes of the sensitivity analysis indicate that the optimal values of the manipulated variables such as oxygen transfer coefficient (K_La), internal recycle flow rate (Q_a), external recycle flow rate (Q_r) and excess sludge flow rate (Q_w) are determined under various influent conditions and also used to keep the effluent concentration within the discharge limits and also used for the selection of control strategies in the activated sludge process.

KEY WORDS : Municipal WWTP, Activated sludge process, Benchmark Simulation Model No.1, Sensitivity analysis, Activated Sludge Model No.1, Nitrogen removal.

INTRODUCTION

Activated sludge process is the most commonly used technology for organic compounds and nitrogen removal from municipal wastewater treatment. Due to the variation of influent flow rate and wastewater composition in the activated sludge process, the operation is complex. Moreover, the strict regulations on discharge limits and increased focus on operational costs acted as a driving force for the implementation of process control and instrumentation in the municipal WWTP (O'Brien *et al.,* 2011).

The benchmark evaluation is performed based on effluent constraints, energy savings and magnitude of effluent violations (Gernaey *et al.*, 2006). The evaluation criteria compute the costs for aeration energy, mixing energy, pumping energy and sludge disposal cost (Gernaey *et al.,* 2014).

In this study, the sensitivity analysis is carried out to study the effect of influent flow variation on the performance of the activated sludge process. Cost-efficient operation and the search for optimal values of the manipulated variables that allow the achievement of the effluent concentration under specified constraints is the main target to be accomplished in the activated sludge process. The modeling and simulation software GPS-X is used for the simulation of BSM1 activated sludge process at steady state and dynamic conditions of municipal WWTP data.

MATERIALS AND METHODS

Plant description

The BSM1 activated sludge process (Figure 1) consists of five biological reactors and a secondary settler. The first two biological reactors are maintained under anoxic condition (1000 m^3 each) and next three biological reactors are kept at aerobic condition (1333 m^3 each) and followed by a settler (6000 m^3).

The nitrogen removal occurs in two steps. The first step is Nitrification, where ammonia is oxidized to nitrate under aerobic condition; and the second step is Denitrification, where nitrate is converted into nitrogen gas under anoxic conditions. The BSM1 activated sludge process combines denitrification takes place in the first two biological reactors followed by nitrification takes place in the last three biological reactors used for the removal of nitrogen and organic matter. The mixed liquor is recycled from the last aerobic zone to the first anoxic zone through internal recirculation flow (Q_a) to enhance nitrogen removal.The sludge is recycled from the settler to the anoxic zone through external recirculation flow (Q_r) to maintain the microbiological population in the biological reactors. Moreover, the waste sludge (Q_w) is continuously removed from the secondary settler underflow.

Process model

The biological reactors are modeled using ASM1 model (Henze *et al.*, 2000) and a secondary settler is modeled with 10 layers based on Takacs model (Takacs *et al.*, 1991) used for the simulation.

Influent loads

The influent composition data shown in Table 1 are taken from the municipal WWTP located in Tamilnadu, India. The influent load data are given in terms of fractions of ASM1 state variables. As the flow variations are considered in this study, simulations are performed at steady state condition using low, average and high influent conditions. The average influent condition is an average influent composition calculated from the municipal wastewater treatment plant data. The low and high influent conditions are selected from minimum and maximum influent flows with component concentrations respectively.

The simulation is carried out using 14 days of municipal WWTP data at 15 min sampling period and the performance is evaluated over the last 7 days of dynamic condition (Alex *et al.*, 2008).

The average values of effluent variables from BSM1 activated sludge process should comply with the effluent regulation limits shown in Table 2 (Alex *et al.*, 2008).

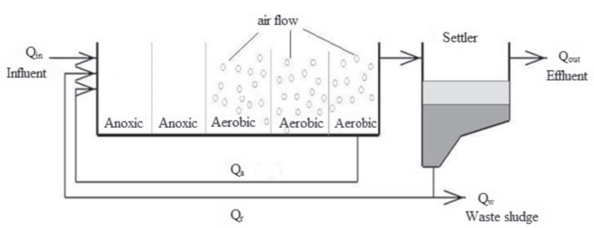

Fig. 1. BSM1 Activated sludge process

RESULTS AND DISCUSSION

Sensitivity analysis of steady state conditions

This study intends to analyze the influence of influent flow rates and manipulated variables on the sensitivity of effluent variables in order to determine the optimal values of the manipulated

Table 1. Values of influent composition in various influent conditions

Influent composition	Low influent conditions	Average influent conditions	High influent conditions
Influent flow rate, Q_0 (m^3/d)	10000	19328	32000
Readily biodegradable substrate, S_S(mg COD/L)	57	60.508	62.5
Soluble inert organic matter, S_I(mg COD/L)	30	30	30
Slowly biodegradable substrate, X_S (mg COD/L)	177.1	194.289	198.89
Particulate inert organic matter, X_I(mg COD/L)	50.22	51.489	52.04
Active heterotrophic biomass, X_{BH} (mg COD/L)	30	30	30
Active autotrophic biomass, X_{BA} (mg COD/L)	0	0	0
Particulate products arising from biomass decay, X_P (mg COD/l)	0	0	0
Dissolved oxygen, S_O(mg O_2/L)	0	0	0
Nitrate and nitrite nitrogen, S_{NO}(mg N/L)	0	0	0
Ammonia-nitrogen, S_{NH}(mg N/L)	21.5	24.3	25.03
Soluble biodegradable organic nitrogen, S_{ND} (mg N/L)	3.68	6.502	10.89
Particulate biodegradable organic nitrogen, X_{ND} (mg N/L)	4.91	8.517	11.47
Alkalinity, S_{ALK} (mol HCO_3^-/m^3)	7	7	7

Table 2. Effluent regulation limits

S. No.	Variable	Constraint (mg/L)
1	Ammonia ($S_{NH,e}$)	4
2	Total Nitrogen ($N_{tot,e}$)	18
3	COD_e	100
4	$BOD_{5,e}$	10
5	Total Suspended solids (TSS_e)	30

variables and also propose the control strategies for the activated sludge process.

The manipulated variables such as the oxygen transfer rate in reactor 5 (K_La_5), Q_a, Q_r and Q_w are set to the constant (default) values of 84 d^{-1}, 55338 m^3/d, 18446 m^3/d and 385 m^3/d respectively.

Sensitivity analysis is performed by varying one manipulated variable at a time during simulation, while the remaining manipulated variables are set to the default values defined by the benchmark (Vrecko *et al.,* 2001). The results are shown in Figures 2 to 12.

The influence of manipulated variable K_La_5 on the effluent variables is shown in Figures 2 -4 and it is clear that K_La_5 has a major influence on $S_{NH,e}$ (Figure 2), $N_{tot,e}$ (Figure 3), $S_{NO,e}$ (Figure 4) but a minor influence on COD_e, $BOD_{5,e}$ and TSS_e. It should be noted that the effluent concentration of $S_{NH,e}$ decreases and this shows that it is completely oxidized during nitrification in the aerobic tank while the effluent concentration of $S_{NO,e}$ increases in

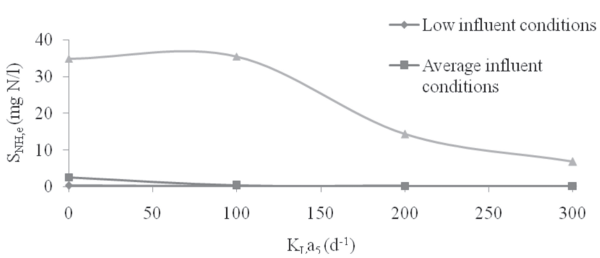

Fig. 2. Response of Ammonium plus ammonia nitrogen as a function of K_La_5 under different influent conditions

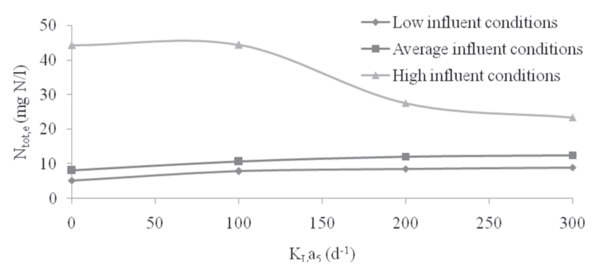

Fig. 3. Response of Total Nitrogen as a function of K_La_5 under different influent conditions

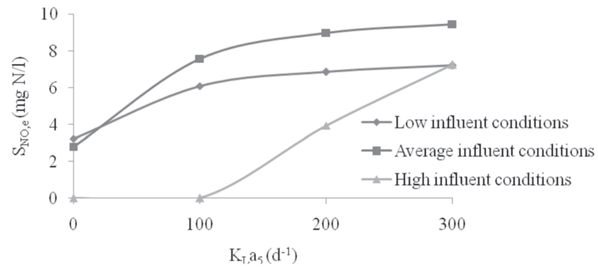

Fig. 4. Response of Nitrate and nitrite nitrogen as a function of K_La_5 under different influent conditions

the entire operating range. On the other hand, the concentration of $N_{tot,e}$ increases with increasing K_La_5 in a low and average influent conditions and decreases in the case of high influent conditions.

In this analysis, it is possible to control the effluent concentration of $S_{NH,e}$ through the dissolved oxygen controlled variable with a feedback controller and K_La_5 is considered as a manipulated variable.

Figures 5-7 indicates that Q_a has a major influence on $S_{NH,e}$ (Figure 5), $N_{tot,e}$ (Figure 6) and $S_{NO,e}$(Figure 7) but a minor influence on COD_e, $BOD_{5,e}$ and TSS_e. The concentration of $S_{NO,e}$ and $N_{tot,e}$ varies with respect to increase in Q_a in the entire operating range.

From this analysis, it is possible to implement the feedback controller in order to control the

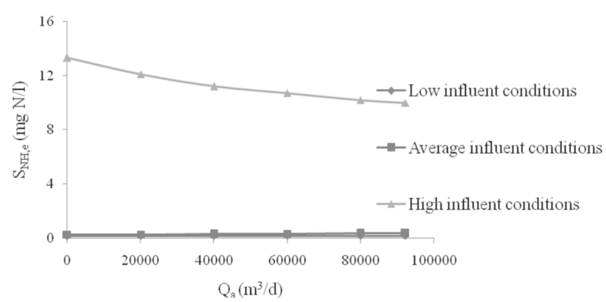

Fig. 5. Response of Ammonium plus ammonia nitrogen as a function of Q_a under different influent conditions

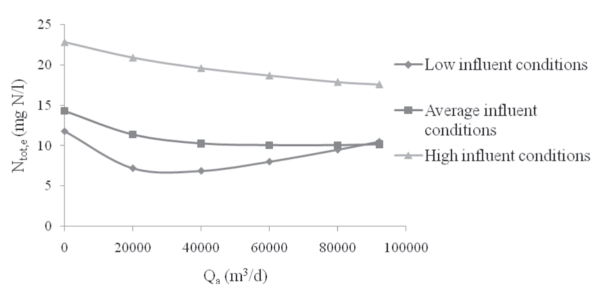

Fig. 6. Response of Total Nitrogen as a function of Q_a under different influent conditions

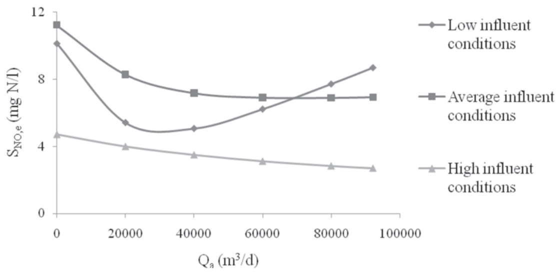

Fig. 7. Response of Nitrate and nitrite nitrogen as a function of Q_a under different influent conditions

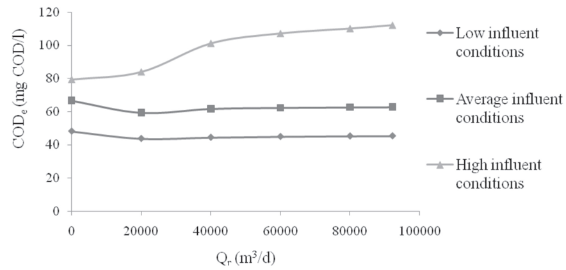

Fig. 10. Response of Chemical Oxygen Demand as a function of Q_r under different influent conditions

concentration of $S_{NO,e}$ and $N_{tot,e}$, where Q_a is taken as the manipulated variable.

The external recycle flow rate, Q_r has a major influence on all effluent variables (Figures 8 -12). From these Figures, it should be noted that the concentration of $S_{NH,e}$ (Figure 8) and $N_{tot,e}$ (Figure 9) decreases in the entire operating range.

It can also be seen that Q_r should not be increased highly, otherwise the concentration of COD_e (Figure 10), $BOD_{5,e}$ (Figure 11) and TSS_e (Figure 12) largely deteriorate for high influent conditions. In this analysis, the controller for Q_r should be a feed-forward control to reduce the concentration of $S_{NH,e}$.

Sensitivity analysis of dynamic influent conditions

The results of the effluent variables are obtained by simulating the activated sludge process for 14 days

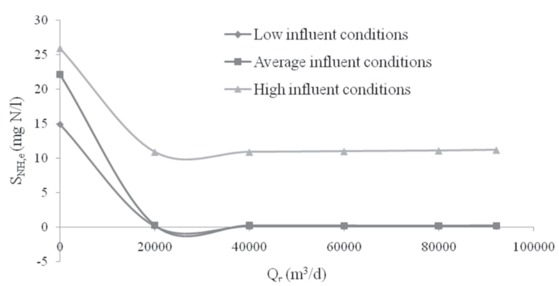

Fig. 8. Response of Ammonium plus ammonia nitrogen as a function of Q_r under different influent conditions

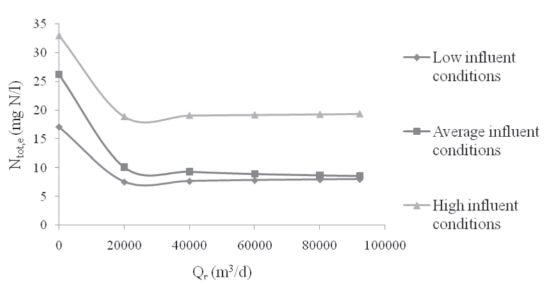

Fig. 9. Response of Total Nitrogen as a function of Q_r under different influent conditions

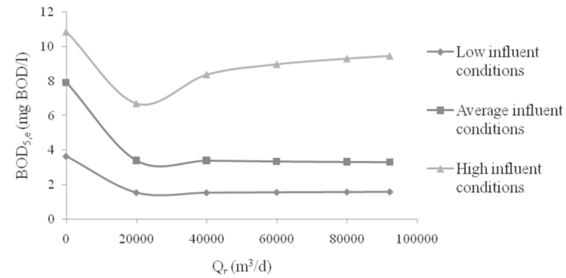

Fig. 11. Response of Biological Oxygen Demand as a function of Q_r under different influent conditions

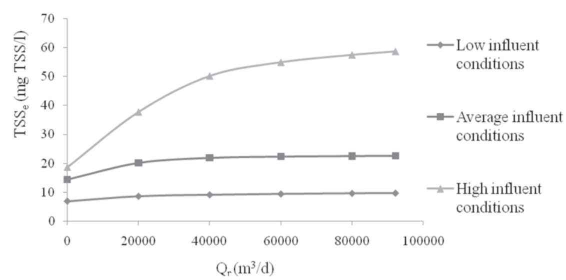

Fig. 12. Response of Total Suspended Solids as a function of Q_r under different influent conditions

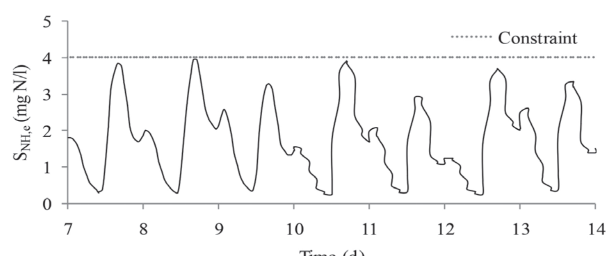

Fig. 13. Response of Ammonium plus ammonia nitrogen under dynamic influent conditions

of STP data. The simulation results of the effluent variables under dynamic condition are shown in Figures 13-17. The horizontal solid line represents the constraint. The concentration of effluent variables are maintained well within the constraint by using the optimum values of manipulated variables.

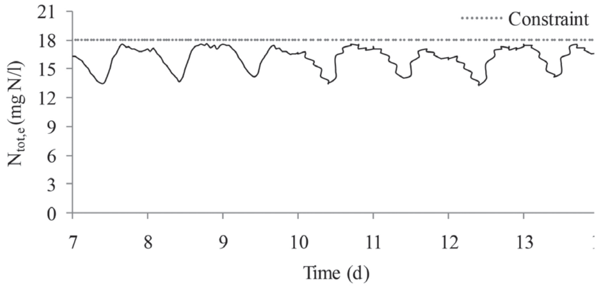

Fig. 14. Response of Total Nitrogen under dynamic influent conditions

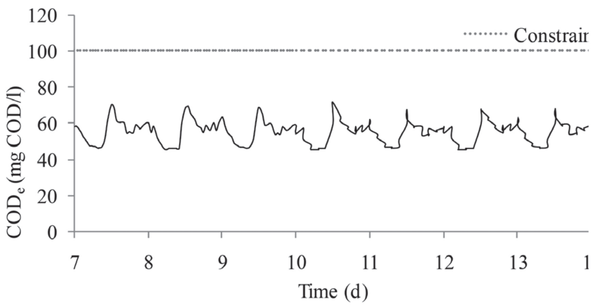

Fig. 15. Response of Chemical Oxygen Demand under dynamic influent conditions

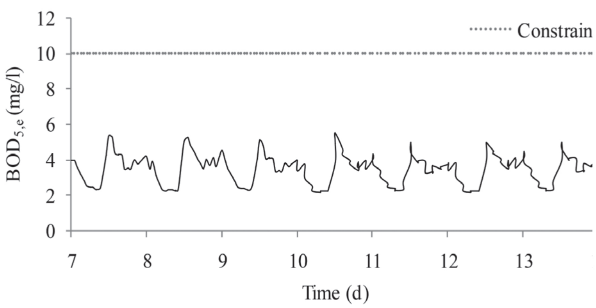

Fig. 16. Response of Biochemical Oxygen Demand under dynamic influent conditions

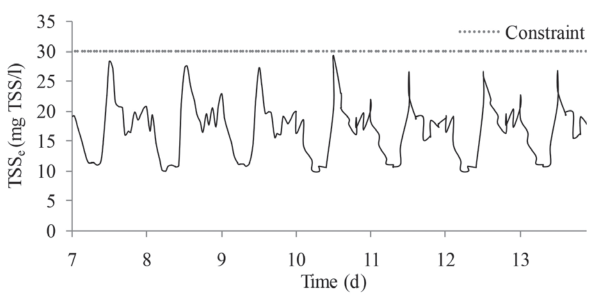

Fig. 17. Response of Total Suspended Solids under dynamic influent conditions

The simulation results obtained from the dynamic influent condition in the activated sludge process are presented in Table 3, 4 and 5.

The optimal values of manipulated variables determined for dynamic influent condition are shown in Table 4.

Table 3. Effluent discharge values using dynamic conditions

Variable	Values
Effluent average S_{NH} (mg/L)	1.72
Effluent average Total Nitrogen (mg/L)	16.10
Effluent average COD (mg/L)	55.39
Effluent average BOD (mg/L)	3.49
Effluent average TSS (mg/L)	17.07

Table 4. Optimal values of manipulated variables under dynamic conditions

Manipulated variable	Optimal values
Oxygen transfer rate in reactor 3, K_La_3 (d^{-1})	240
Oxygen transfer rate in reactor 4, K_La_4 (d^{-1})	240
Oxygen transfer rate in reactor 5, K_La_5 (d^{-1})	200
Internal recycle flow rate, Q_a(m^3/d)	40000
External recycle flow rate, Q_r(m^3/d)	6400
Excess sludge flow rate, Q_w(m^3/d)	385

The simulation results indicate that the optimal values of the manipulated variables under dynamic condition are used to maintain the effluent variables under the constraints (Table 3).

The evaluation criteria described in Pons et al. (1999) and Alex *et al.* (1999) are used to estimate the performance of activated sludge process under dynamic influent condition and the calculated values are given in Table 5.

Table 5. Evaluation criteria

Variable	Values
Aeration Energy (kWh/d)	4028.62
Pumping Energy (kWh/d)	230.45
Mixing Energy (kWh/d)	240
Sludge production for disposal (ton/d)	2.379
Operating costs (Per day)	37407

The operating costs evaluated in the activated sludge process by using the optimal values of manipulated variable under dynamic influent condition are estimated as 37407 per day.

CONCLUSION

The sensitivity analysis discussed the effluent variables are sensitive towards the manipulated variables for various influent conditions (low, average and high influent conditions). The simulation results of the sensitivity analysis in the activated sludge process indicated that the optimal values of the manipulated variables under dynamic influent condition are used to maintain the effluent concentration within the discharge limits. The outcomes of the sensitivity analysis will be used for the design of control strategies in the activated sludge process.

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