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Assessment of Recirculation Ratio Impacts on Mixed Liquor Suspended Solids in the Activated Sludge Process

S. Mohan and S.T. Ramesh

Department of Civil Engineering,
Environmental and Water Resources Engineering Division
Indian Institute of Technology Madras, Chennai-36, India
smohan@iitm.ac.in

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Abstract: Control of the bacterial environment through efficient solid/liquid separation and operation of the biological processes with high biomass concentrations are likely to affect cell metabolism and limit the bacterial growth, and in turn the sludge production. This paper presents a simulation study with the objective to study the effect of recirculation ratio on Mixed Liquor Suspended Solids (MLSS) in plant design and operation strategy of activated sludge process. The simulation results indicated that an optimal combination of recirculation ratio and operation strategy, the performance in terms of MLSS and efficiency improves significantly when compared to current operational practice. The use of simulations, rather than experiments, to compare combinations of plant design and operation strategy excludes erroneous conclusions due to arbitrary events. Moreover, it would be practically impossible to make a fair experimental comparison between all the combinations of design and operation, which are compared in these simulations. The simulation results were verified by operating a bench scale reactor in the laboratory operated in the continuous mode with the recirculation ratio (R) varied in the range of 0.25 to 1.

Key words: Activated sludge process, mixed liquor suspended solids, biological solids retention time.

Introduction

During the past decades, an increasing number of investigations resulted in the improved knowledge of the bioreactors and the interactions between biological wastewater treatment processes. Research activities were mainly directed towards the optimization of process efficiency in terms of effluent quality, plant configurations and operational practices. Less attention has been devoted to the peculiarities of biological processes and microbial consortia developed through the application of activated sludge process. Control of the bacterial environment through efficient solid/liquid separation and operation of the biological processes with high biomass concentrations are likely to affect cell metabolism and limit the bacterial growth, and thus the sludge production. The biomass of an activated sludge tank is normally expressed through the concentration of volatile suspended

Nomenclature

θ_c	=	Biological solids retention time
V	=	Volume of the reactor
X	=	Biomass concentration in the Aeration tank
Q	=	Rate of wastewater flow into the aeration tank
Q_w	=	Sludge wasting rate from the sludge return line
Q_r	=	Recycle sludge rate
X_r	=	Biomass concentration in the underflow from the sedimentation tank
R	=	Recirculation ratio
S_0	=	Influent substrate concentration in the wastewater
S_e	=	Steady state substrate concentration after treatment
Y_{obs}	=	Observed yield
Y_T	=	True yield
k_d	=	Microbial decay coefficient

solids (VSS); it is quite obvious that the mere measurement of VSS is not adequate to express the active biomass. The volatile suspended solids of the mixed liquor contain, besides active microorganisms, biodegradable, endogenous and inert particulate substrate. Numerous factors which influence the performance of the activated sludge process, also called the "parameters" of the process, are variability in the wastewater flow, wastewater quality, aeration time, characteristics of aeration tank loadings, food to micro organism ratio, maintained levels of mixed liquor suspended solids and influent substrate concentration. In addition to that, an optimum sludge return rate is dependent upon a number of factors such as influent flow rate, influent BOD, cell growth rate, temperature, mixed liquor suspended solids, and recycle suspended solids. However, the operator has little or no control over many of these factors. Although the ideal sludge return rate will be dependent upon the factors noted above, optimum return rates can be determined based on operational requirements. The aim of this research is to determine the effect of recirculation ratio on the performance of activated sludge process in terms of mixed liquor suspended solids.

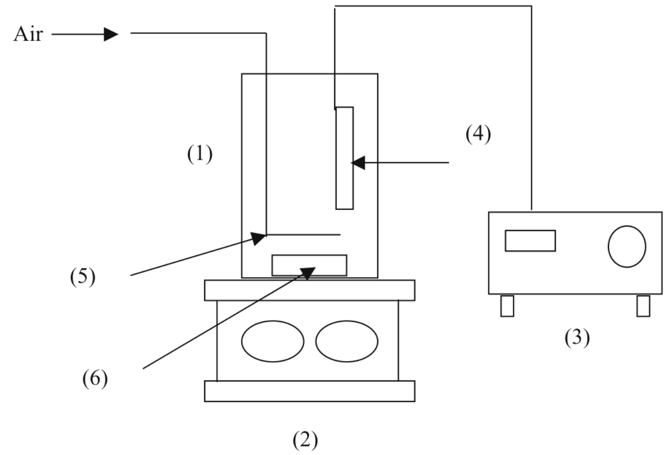
Material and Methods

Batch Study

Batch studies for activated sludge process were carried out with the wastewater collected from a collection well of municipal sewage pumping station at Velachery, Chennai. Experiments were conducted with Biological Solids Retention Time (BSRT) of two days, 2.5 days, five days and ten days and nutrient broth and dextrose spiked water as feed. After the attainment of steady state, experiments were continued to study the substrate removal rate and the sludge growth rate. The experimental setup for the batch system is shown in Figure 1. The bio kinetic constants for the wastewater operated with four different BSRT values were determined from the kinetic study. The evaluated bio kinetic parameters are given in Table 1.

Activated Sludge Process Modelling

The modelling of the activated sludge process is based on food balance i.e. there is no accumulation of food in the aeration tank and micro organism balance i.e. there is no accumulation of micro organisms in the aeration tank and the micro organism concentration in the influent is zero. In the complete mix system with recycle, cell wastage can be accomplished by wasting from the reactor



(1) 1 L bio reactor (2) Magnetic Stirrer (3) DO meter (4) DO probe (5) Air diffuser (6) Mixing bar

Figure 1: Laboratory scale batch study activated sludge process.

Table 1: Bio Kinetic Coefficients for Chennai Municipal Wastewater

BSRT in days	*Observed yield Y_{obs}*	*True yield Y_T*	*Decay coefficient (k_d) day $^{-1}$*	*Substrate utilisation rate constant (K) l/mg.day*
2	0.45	0.44	0.058	0.0363
2.5	0.27	0.27	0.072	0.0497
5	0.38	0.39	0.1	0.039
10	0.34	0.35	0.058	0.0489

or from mixed liquor return line. The mean cell residence time (the wastage from the recycle line) is given by the following expression.

$$\theta_c = \frac{VX}{Q_w\ X_r + (Q - Q_w) X_e} \tag{1}$$

Assuming that X_e is very small, the modified value of mean cell residence time is given by

$$\theta_c = \frac{VX}{Q_w\ X_r} \tag{2}$$

From the equation (2), the ratio of $\frac{X_r}{X}$ is found to be

$$\frac{X_r}{X} = \frac{V}{Q_w\ \theta_c} \tag{3}$$

A relationship between the recycle ratio R and θ_c can be developed from a material balance equation for biomass entering and leaving the aeration tank.

$$\frac{1}{\theta_c} = \frac{Q}{V}\left(1 + R - R\frac{X_r}{X}\right) \tag{4}$$

Substitute the value of $\frac{X_r}{X}$ in the equation (4); the value of θ_c can be determined. Substrate utilization rate q is given by

$$q = \frac{1 + k_d\,\theta_c}{Y_T\,\theta_c} \tag{5}$$

Based on the substrate utilisation rate, the effluent substrate concentration (S_e) is calculated from

$$S_e = \frac{q}{K} \tag{6}$$

The mixed liquor suspended solids in the aeration tank and the recycle line are determined by

$$X = \frac{Q\theta_c Y_T (S_0 - S_e)}{V(1 + K_d\,\theta_c)} \text{ or } X = \frac{Q(S_0 - S_e)}{Vq} \tag{7}$$

$$X_r = \frac{XV}{Q_w\,\theta_c} \tag{8}$$

The sludge volume index (SVI) is calculated from

$$\text{SVI} = \frac{10^6}{X_r} \tag{9}$$

The process efficiency is determined by

$$E = \frac{S_0 - S_e}{S_0} \times 100 \tag{10}$$

A simulation programme has been developed to study the effect of recirculation ratio on mixed liquor suspended solids in the system, and the simulation runs were made using the following parameters as input to the programme.

Volume of aeration tank	:	6 litres
Influent BOD_5 (S_o)	:	240 mg/l
Influent COD	:	320 mg/l
Flow rate (Q)	:	28.8 l/day
Yield co-efficient (Y_T)	:	0.45
Decay co-efficient (k_d)	:	0.05/day

Substrate utilization rate constant (K): 0.018 l/mg.day

The constants yield co-efficient (Y_T) and decay co-efficient (k_d) were obtained from the batch experimental studies. Simulation studies were carried out with different recirculation ratio of 0.25 to 1 by varying the sludge wastage rate from 0.08 l/day to 0.34 l/day.

Continuous Study

The experimental bioreactor employed in the laboratory tests is illustrated in Figure 2. It consists of two units: a six-litre capacity aeration tank and a 1.8 litre capacity sedimentation tank. The sterile feed was pumped continuously into the reactor by peristaltic pump (MicLins model) and an air compressor provided the aeration and homogenization of the reactor contents. Normally in conventional activated sludge process, for better performance of the system the MLSS should be maintained in between 1500 mg/l and 4000 mg/l. From the simulation study, it was observed that the sludge wastage rate of 0.2 l/day gave better MLSS variation as of conventional activated sludge process with different recirculation ratio 0.25 to 1. So, all experimental works have been performed with synthetic wastewater (a constant COD of 320 mg/l) with constant sludge wastage of 0.2 l/day. For start-up of the reactor, an activated sludge sample was taken from the sludge return line (from secondary sedimentation tank) in Nesappakam sewage treatment plant (Chennai). A quantity of 3.5 litre sludge and 2.5 litre volume of wastewater was placed in the unit. The activated sludge process system was loaded with synthetic wastewater, and it was operated for various recirculation ratio 0.25 to 1 with constant wastage of 0.2 l/day from sludge return line. MLSS in the aeration tank and COD of the effluent were determined daily until a steady state was attained.

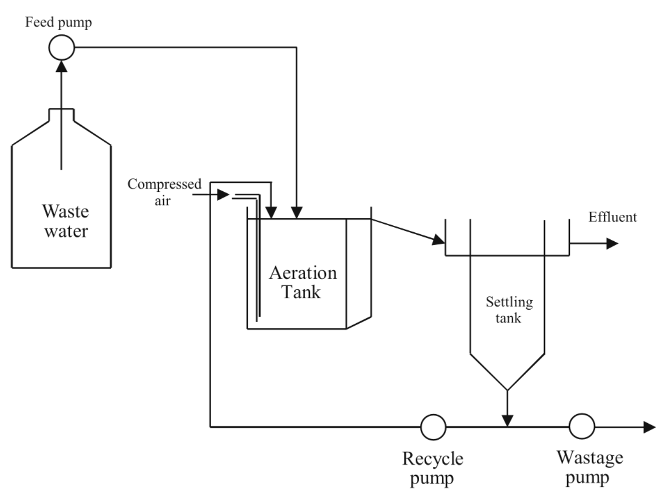


Figure 2: Laboratory scale activated sludge process.

Results and Discussion

Sludge recycling from the secondary clarifier to the aeration basin is an important part of the activated sludge process. Inadequate sludge recycle rates may reduce the MLSS concentration in the aeration tank. Also, the proper sludge recycle rate can be estimated based on the desired MLSS to achieve the required effluent concentration. The variation of MLSS with recirculation ratio for different sludge wasting rate are shown in Figure 3. The MLSS concentration increases with increase in recirculation ratio; correspondingly the MLSS concentration decreases with increasing sludge wastage rate. From Figure 3, for a constant recirculation ratio, the MLSS concentration decreases with increasing the sludge wastage rate. At the same time, for constant sludge wasting rate slight increase of MLSS has been observed with increase of recirculation ratio. For the minimum sludge-wasting rate of 0.08 l/day, the MLSS increases from 4686 mg/l to 7238 mg/l with increase in recirculation ratio from 0.25 to 1. More MLSS concentration in aeration tank will deplete the food supply in short period of time and start of auto oxidation of cellular materials takes place. This leads to endogenous respiration resulting in a higher fraction of non-active biological solids in the sludge and a resultant loss of fine solids in the effluent. For a minimum recirculation ratio of 0.25, microbial concentration decreases from 4686 mg/l to 1515 mg/l with the wastage rate increase from 0.08 l/day to 0.34 l/day and also for the sludge-wasting rate of 0.34 l/day, the MLSS varies from 1515 mg/l to 3273 mg/l with increasing the recirculation ratio from 0.25 to 1.

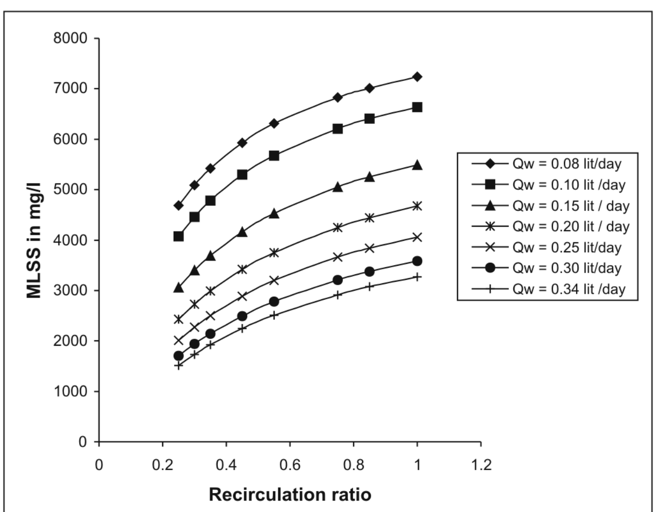


Figure 3: Variation of MLSS with recirculation ratio.

The reduction of MLSS concentration beyond certain value such as 2000 mg/l decreases the BSRT value. If there is not enough MLSS concentration available to assimilate the incoming BOD (food) in the wastewater, some of the BOD will pass through the system, resulting in a poor quality of effluent. Optimum food to microorganism ratio should be maintained in order to assure an adequate MLSS concentration in the system to degrade the entire incoming BOD. Operational adjustment to increase the MLSS concentration can be accomplished by decreasing the wasting rate and increasing the recycle rate, thereby maintaining a higher MLSS concentration in the aeration basins. The simulation results are also verified with the experimental values, and the values are presented in Figure 4. It was found that there might be lot of variation in the MLSS concentration by varying the recirculation ratio.

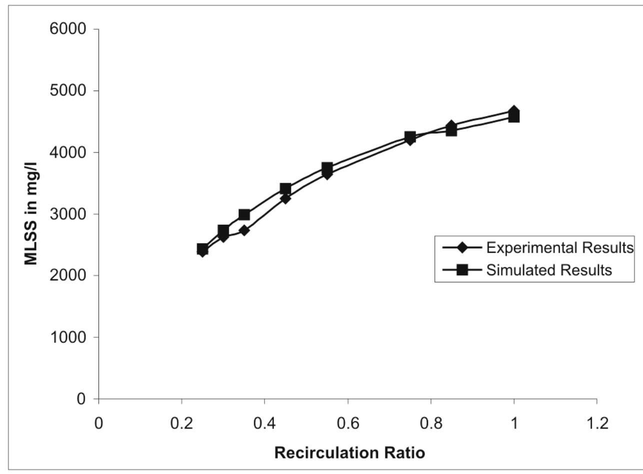


Figure 4: Comparison of MLSS.

Conclusions

Significant developments have taken place in both the engineering and technology and the microbiology and biochemistry areas of the activated sludge system for treating mainly domestic wastewater. Within the engineering and technology, the activated sludge system has become well established, with systems implemented worldwide for the biological removal of carbon, nitrogen and phosphorus. This implementation has been aided by the development of a suite of steady state and kinetic simulation models, which have facilitated optimization of design and operation. Parallel to this development, significant advances have been made in the microbiological and biochemical areas of activated sludge. These advances have been driven by the development of new analytical techniques that allow microorganisms to be studied in situ in the activated sludge environment. However, there has been little cross-linking and overlap between the engineering and technology and microbiology and biochemistry paradigms. In particular, the information from the microbiology and biochemistry has not been integrated into the engineering and technology paradigm, to enable improved design and optimization. One area that can form a starting point to build bridges between the two paradigm sets is active biomass. It is hoped that this paper will facilitate the development of links and overlap between the two paradigms.

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