

A Simulation Method for Activated Sludge Systems

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Abstract— The aim of this paper is to develop a simulation method for activated sludge systems consisting of an aeration pond and settler. The importance of the study is to conduct the simulation of the system with an optimization algorithm so that the optimum design variables for a wastewater treatment system can be determined and the concentrations of activated sludge components in the ponds which are necessary during optimization can also be estimated concurrently. A serial-three-stage simulation is performed within a sequential quadratic optimization algorithm where the minimum cost (investment and operational) is defined as objective function. The optimum design variables can be defined using this method for a known inlet flow rate and composition as well as the desired outlet characteristics. Furthermore, the effect of initial guesses to the optimization results is considered. The simulations are executed in Matlab® and *fmincon* is used as optimization algorithm with some improvements.

Index Terms— *activated sludge, ASM3, design, optimization, simulation.*

1 INTRODUCTION

Activated sludge is one of the biological waste water treatment processes, which has been used since 1914, when Arden and Lockett first used repeatedly flocculent solids in aeration in order to increase treatment capacity. The process can be used in either domestic wastewater treatment, or the secondary treatment of industrial wastewater. The basic idea of the activated sludge process is to maintain 'active sludge' suspended in wastewater by means of stirring and aeration. The suspended material contains not only living biomass, that is, bacteria and other microorganisms, but also organic and inorganic particles. Some of the organic ones may be broken down into simpler components with a process known as 'hydrolysis', while other organic particles are not affected - also known as inert material. The biomass in the process uses the organic material as its energy source usually in combination with oxygen or another oxidation agent - that is, the organic material can be removed from the wastewater while more biomass is being produced. The amount of suspended material in the process is normally controlled by means of adding a sedimentation tank at the end of the process where the biomass is transported towards the bottom by gravity settling, and is either circulated back to the biological process or removed from the system as excess sludge; whereas, the purified wastewater is withdrawn from the top of the sedimentation tank and released either for further treatment or directly into a receiving water [1].

In order to understand how an activated sludge system operates, one of the best ways is to simulate the model of it. Performing any simulation whether it is complex or simple, one needs a model and the model parameters as the first step. Unless they are defined well and represent the actual situation, the simulation results cannot be used as a reference neither for

further researches nor in practical applications. In the simulation of an activated sludge model and a settler model in combined, there are many problems like the design variables for the treatment system and the concentrations of the model components in the ponds under normal operation conditions besides complex kinetics and dynamics. When the design variables are known, the simulation can be performed by one of the models in literature. However, in order to assign the design parameters, the best way is to apply an optimization algorithm. In the mean time, in order to apply the optimization algorithm, the concentrations of the model components under the steady flow conditions should be known. These concentrations can be determined by simulation of the dynamic model but at the same time during the simulation the design parameters of the treatment system should be required. So, such a simulation becomes a very complex problem because of dependence of concentrations in the ponds to the design variables. For this reason, the design variables used in the simulation model are determined by an optimization algorithm during the simulation of the activated sludge system starting from the inlet waste water characteristics in the present study. As a summary, a simulation method for activated sludge systems is proposed in the present study in which the design variables are optimized.

In optimization algorithm the objective function is the minimum cost of the investment. The cost of an investment can be divided into two categories: fixed capital investment and operational costs. The main investment cost in an activated sludge system consists of the sum of the construction cost (aeration pond and settler and as well as the piping system) and the equipment cost (pumps, aerators, scraper, control equipments etc.). As to the main operational costs, they are related to the electricity needed to operate the aerating devices in order to obtain the necessary aeration and mixing, pump-

ing, and sludge removing. Actually, all of the costs, either investment or operational, mostly depend on the quantity and quality of the inlet water and the treated water quality required by authorities. When one keeps inlet quantity and quality to be constant, the optimum design and operation parameters can be attained within the required limits. For such a design, one can determine the cost-related design parameters which define the minimum cost within the desired conditions.

In order to improve wastewater treatment performance, several optimization studies have been carried out in the recent years for the optimal design and operation of the activated sludge unit. In most cases, objective functions are based on economic criteria. Iqbal and Guria [2] review various studies in this regard, and their optimization problems are formulated according to the present construction and on the operation of a domestic wastewater treatment plant using an elitist non-dominated sorting genetic algorithm. Various studies in the literature deal with different design parameters in activated sludge systems. Holanda et. al. [3] apply a model predictive control for the dissolved oxygen concentration in an aerobic reactor of a wastewater treatment plant. They have used two different kinds of design parameters: The first one is from the COST 682 Working Group No.2 [4], which is a benchmark for evaluating by simulation and control strategies for activated sludge plants. The second one is the treatment plant described by Chachuat et al. [5]. In their optimization studies, Balku and Berber [6] use a set of different parameters which describe a wastewater treatment system using a general approach and trial - error - method. Simulations are performed in a simplified kinetics and MATLAB version R2011a with Simulink (MathWorks) in the optimal aeration control in a nitrifying activated sludge process by Amand and Carlsson [7]. Li et al. [8] simulate a full-scale oxidation ditch process for treating sewage with the ASM2d model and optimized for minimal cost with acceptable performance in terms of ammonium and phosphorus removal. However, only the operational costs related with aeration energy and sludge production are considered. Rojas and Zhelev [9] study on energy efficiency optimization of wastewater treatment of thermophilic aerobic digestion, a dynamic model is presented, global sensitivity analysis is performed, and the problem is implemented in MATLAB® (*fmincon*). Gernaey et.al. [10] review and focus on the modeling of wastewater treatment plants, white-box modeling, and the introduction of the ASM model family by the IWA (International Water Association) task group.

In the present study, a simulation method is developed in which an activated sludge treatment model together with the settler model is used with the design variables determined by an optimization algorithm embedded in. The optimization problem is formulated to define the design variables for a simple activated sludge system that involve the minimum cost (both investment and operational), while other necessary requirements are considered as well. In order to reach its aim,

the present work uses the Activated Sludge Model No.3 [11] amongst the other models [12] and a standard optimization algorithm included in MATLAB® (*fmincon*) based on sequential quadratic programming, together with an optimization technique proposed by Biegler and Grossmann [13].

Many optimization problems arising from engineering applications have been described by complex mathematical models (e.g., sets of differential-algebraic equations). A general complex process optimization problem may be formulated as follows:

Find x to minimize:

$$C = \phi(\dot{x}, x, y) \quad (1)$$

$$\text{subject to } f(\dot{x}, x, y) = 0 \quad (2)$$

$$x(t_0) = x_0 \quad (3)$$

$$h(x, y) = 0 \quad (4)$$

$$g(x, y) \leq 0 \quad (5)$$

$$y^L \leq y \leq y^U \quad (6)$$

where y is the vector of decision variables; C is the cost (objective function) to minimize;

f is a function describing the complex process model (e.g., a system of differential algebraic equations); x is the vector of the states (and \dot{x} is its derivative); t_0 the initial time for the integration of the system of differential algebraic equations (and, consequently, x_0 is the vector of the states at that initial time); h and g are possible equality and inequality constraint functions, which express the additional requirements for the process performance; and, finally, y^L and y^U are the upper and lower bounds for the decision variables [14].

2 SIMULATION METHOD FOR ACTIVATED SLUDGE SYSTEMS

The simulation method consists of mainly four stages:

1. Optimization algorithm: The flow rate and composition of waste water entering the treatment system, composition of the waste water initially present in the aeration tank and settler, and optimization algorithm are defined with the constraints and boundaries.
2. Serial simulation: The program is referred by the optimization algorithm as a 'sub-program'. In the algorithm, the activated sludge system is operated in three consecutive periods; start-up, conditioning, and normal operation. The inlet and initial data are used first during the start-up period with the initial guesses of the design variables. The wastewater treatment algorithm is called in each period, and the results achieved from one period are used as the initial values for the next period.
3. Wastewater treatment plant model: All the mass balances, microbiological processes in aeration tank, and the settling tank expressions are involved in this subroutine.
4. Constraints file: All the inequality constraints are given under this algorithm. When the serial simulation is completed once, all the constraints are controlled and, if complied, the program is completed; otherwise new initial guesses for the

system variables are assigned by the optimization algorithm, and all the computations are repeated until all the constraints are met.

2.1 Optimization Algorithm

A standard SQP (Sequencing Quadratic Programming) algorithm imbedded in the Optimization Toolbox of Matlab® is used to implement the solution [15]. With such improvements, the suggested algorithm is easy to implement and allows the entering of all the required constraints. In the SQP method, a Quadratic Programming (QP) sub-problem is solved, and an estimate of the Hessian of the Lagrangian is updated at each iteration until some predefined ending criteria are met. A developed dynamic model is used for the simulation of the treatment plant, and *ode15s* integration routine in Matlab® is executed with an adjustable step size under an optimization sub-program of *fmincon* [15]. *Fmincon* is a deterministic gradient-based method which uses sequential quadratic programming, which is utilized by some other studies [16], [9].

The inlet wastewater composition, stoichiometric matrix, and kinetic parameters (at 20 °C) were taken from ASM3 (Activated sludge model 3) as they were without making any changes [11]. The parameters involved in the settling velocity model were used as given by Takács et al. [17]) for low-load feeding. The feed to the settler was at the 7th layer from the top. In the recycling stream, the concentrations of S_O and S_{N2} were assumed to be equal to zero. The threshold concentration X_t was equal to 3000 g m⁻³. The inlet wastewater flow rate is taken as Q_{in} : 1000 m³ day⁻¹

The objective function is formulated such that the most important design variables which affect the investment and the operational costs of an activated sludge system are taken into account. The investment cost is the total of purchasing, construction, and other related costs for the aeration tank, settler tank, recycling pump, waste sludge pump, aerators, and piping. The operation cost involves the energy used for aeration and pumping, and other operational costs related with the sludge disposal.

The design variables related to an activated sludge plant are decided according to the basic principles of the wastewater treatment plant design and operation as follows:

1. Size of the aeration tank;
2. Area of the settler;
3. Recycle ratio;
4. Waste sludge ratio; and
5. Liquid phase volumetric mass transfer coefficient.

When one designer decides the above variables, the activated sludge system is easy to shape. It has to be mentioned that these design variables should be in accordance with the influent quality and quantity as well as the required effluent quality.

The sizes of the aeration tank and the settler affect the investment costs, while the recycle flow rate and the waste sludge flow rate impact both the investment and operational costs. Also, the liquid phase volumetric mass transfer coefficient ($k_L a$) affects the investment cost (aerator capacity) along with operational cost (energy).

Under these conditions, the optimization problem can be defined as a minimum cost problem as:

$$\min f = \alpha \times V_{at} + \beta \times A_c + \theta * (\delta \times Q_{rs} + \varepsilon \times Q_w + \phi \times k_L a3) \quad (7)$$

where $\alpha, \beta, \theta, \delta, \varepsilon,$ and ϕ are the cost functions related with either fixed capital investment or operational cost, or both of them; θ is a weighing factor between the fixed capital investment, the miscellaneous investments, and the operational costs. Also, where:

- V_{at} : volume of the aeration tank (fixed capital investment);
- A_c : cross sectional area of the settler (fixed capital investment);
- Q_{rs} : recycle flowrate (fixed capital investment and operational cost);
- Q_w : waste sludge flowrate (fixed capital investment and operational cost);
- $k_L a3$: liquid phase volumetric mass transfer coefficient during the normal operation period (fixed capital investment and operational cost).

The objective function is subjected to the general model given in Eq. (8), where X is a 74-dimensional vector which is described in section 2.3.

Waste water treatment plant model:

$$\frac{dX}{dt} = f(X) \quad (8)$$

The system variables which affect the operation of the waste water treatment system are;

$$[V_{at}, A_c, Q_{rs}, Q_w, k_L a1, k_L a2, k_L a3, tp1, tp2, tp3].$$

These ten system variables are determined by the optimization algorithm. Those which do not appear in the objective function but are still determined in the course of optimization algorithm are as follows:

- $k_L a1$: liquid phase volumetric mass transfer coefficient for the start-up period;
- $k_L a2$: liquid phase volumetric mass transfer coefficient for conditioning period;
- $tp1$: length of start-up period (h);
- $tp2$: length of conditioning period (h);
- $tp3$: sample length of normal operation period (h).

System variables are converted into dimensionless figures by dividing them by the predefined values given in the previous studies [18] as follows:

Predefined values: Q_{rs} : 800 m³ day⁻¹; Q_w : 12 m³ day⁻¹; V_{at} : 450 m³; A_{set} : 113 m²;

$k_L a1$: 4.5 h⁻¹; $k_L a2$: 4.5 h⁻¹; $k_L a3$: 4.5 h⁻¹; $tp1$: 480 h; $tp2$: 480 h; $tp3$: 100 h.

Dimensionless figures: A sample conversion is as follows:

$$y1 = \frac{V_{at,opt}}{V_{at}} = \frac{V_{at,opt}}{450} \quad (9)$$

Therefore, the system variables can be expressed in a dimensionless form as below:

$$y = [y1; y2; y3; y4; y5; y6; y7; y8; y9; y10]$$

The objective function (Eq. 7) can be defined in dimension-

less form as follows;

$$\min f = \alpha \times y1 + \beta \times y2 + \theta * (\delta \times y3 + \varepsilon \times y4 + \phi \times y7) \quad (10)$$

The lower and upper boundaries for the system variables are assigned for the dimensionless numbers as follows:

Lower Boundaries: 0.5;

Upper Boundaries: 3.0

2.2 Serial Simulation

In the simulation algorithm, there are three periods: start-up, conditioning, and normal operation periods. The first and second periods are unsteady, but the third one is tried to be kept steady.

The simulation for the start-up period of the plant is accomplished by starting with an aeration tank and a settler filled with by the incoming wastewater. In this period, no sludge is removed from the system and the aim is to reach the required microorganism concentration in the aeration pond to provide convenient treatment and proper settling characteristics.

The inlet wastewater composition, stoichiometric matrix, and kinetic parameters (at 20 °C) were taken from ASM3 as they were. The parameters involved in the settling velocity model were used as given by Takács et al. [17] for low-load feeding. The feed to the settler was at the 7th layer from the top. In the recycling stream, the concentrations of S_{O_2} and S_{N_2} were assumed to be equal to zero. The threshold concentration X_t was equal to 3000 g m⁻³. The inlet wastewater flow rate was taken as Q_{in} : 1000 m³ day⁻¹.

In the conditioning period with sludge disposal, the sludge is started to be removed from the system. At the beginning of the sludge disposal, the concentration of the suspended solids and the related particulates in the aeration tank start to decrease to such an extent that is not required in the normal operation period, where it is preferred to be steady in terms of particulates as much as possible. For this reason, this period can be considered as a transient stage.

As a third stage, a normal operation period is simulated with a continuous sludge disposal, and both DO concentration and percent change of concentration of mixed liquor volatile suspended solids are controlled.

2.3 Wastewater Treatment Plant Model

The treatment plant model consists of an aeration tank model, in which the microbiological processes take place, along with a settling tank model where the settling velocity of activated sludge is considered.

In the aeration tank, ASM3 is considered for the modeling of microbiological processes in a single tank. The mass balances in this tank result in:

$$\frac{dX_i^{at}}{dt} = \frac{Q_{in}X_i^{in} + Q_{rs}X_i^{rs} - (Q_{in} + Q_{rs})X_i^{at}}{V_{at}} + R_i \quad (11)$$

where X^{at} , X^{rs} , and X^{in} are 13-dimensional vectors consisting of ASM3 components in the activated sludge tank (at), recycle (rs), and inlet waste water (in), respectively. The mass balance

related to the dissolved oxygen (S_o) includes an additional term on the right-hand side $+ k_L a (S_o^{sat} - S_o^{at})$ representing the oxygen transfer, and the mass balance results in:

$$\frac{dS_o^{at}}{dt} = \frac{Q_{in}S_o^{in} + Q_{rs}S_o^{rs} - (Q_{in} + Q_{rs})S_o^{at}}{V_{at}} + R_{S_o} + k_L a (S_o^{sat} - S_o^{at}) \quad (12)$$

where $k_L a$ and sat represent liquid phase volumetric mass transfer coefficient and saturation, respectively.

There have been many studies referred in Ekama *et. al.* [19] which focused on the modeling of the settling tank in details. In the light of those studies, the settler is modeled as a cylindrical tank with 10 horizontal layers and the settling velocity model [17] has been applied to it, and adapted to the ASM3 components [6], [18], [20].

The general model is as follows;

$$\frac{dx}{dt} = f(x) \quad (13)$$

where X is a 74-dimensional vector, 13 aeration tank variables, and 60 settling tank variables. The last variable is related to the deviation from the constraints for the effluent

$$\frac{dX^j}{dt} = \max(0, COD_{eff} - COD_{max}) + \max(0, SS_{eff} - SS_{max}) \quad (14)$$

where j is the index representing the 74th state variable. COD_{eff} is calculated by its definition in ASM3. In the course of integration, this differential equation represents the cumulative deviation from the constraints related to COD and SS . However, no constraint is assigned to the total nitrogen concentration in the effluent since denitrification is not an aim of this system.

2.4. Constraints

2.4.1. The inequality constraints

a. The maximum constraints on the effluent are taken as given in EU Commission Directives[21], [22]:

$$COD_{max} : 125 \text{ g m}^{-3}$$

$$SS_{max} : 35 \text{ g m}^{-3}$$

and the effluent discharge criteria can definitely be controlled with the given differential equation (14). The maximum total deviation from the given constraint will be 0.01.

b. The dissolved oxygen concentrations in each period (start-up, conditioning, and normal operation) should be greater than 1.9 g m⁻³ and less than 3.0 for the normal operation period.

c. The objective function should be positive.

d. The MLVSS (mixed liquor volatile suspended solids) change in the conditioning period should be less than 12 percent.

$$\% \text{ change in } MLVSS_{\text{conditioning}} = \frac{MLVSS_{\text{conditioning}} - MLVSS_{\text{start-up}}}{MLVSS_{\text{conditioning}}} \quad (15)$$

e. The MLVSS change in the normal operation period should be less than 3 percent

$$\% \text{ change in } MLVSS_{\text{normal}} = \frac{MLVSS_{\text{normal}} - MLVSS_{\text{conditioning}}}{MLVSS_{\text{normal}}} \quad (16)$$

- f. At the end of the start-up period, MLVSS should be between 2300 g m⁻³ and 4000 g m⁻³.
- g. The maximum change in heterotrophic bacteria concentration should be less than 1 % in normal operation period in order to keep the period steady.
- h. The overflow rate for settler should be between 0.5 and 2 m³/m².h.

2.4.2. The equality constraints

In the optimization problem, there are no equality constraints on the system. The flow diagram of the proposed simulation algorithm is given in Fig.1.

All computations have been performed by an Intel(R) Core(TM)2 Duo CPU E8400 @ 3.00 GHz 2.67 GHz, RAM 4,00 GB computer, 64-bit. For the simulations MATLAB 7.10.0 software package and the 'ode15s' integrating routine of MATLAB with maximum step size of 0.1 h and 'fmincon' optimization subroutine have been used.

3 RESULTS

The improved dynamic model is simulated in order to find the optimum design parameters in the activated sludge model. The most important design parameters which affect the cost of a treatment system are considered to be the volume of the aeration tank, the area and height of the settler tank, the recycle and waste sludge, and the aeration. For this reason, these design parameters are taken into account in the objective function. The cost functions and weighing factors are regarded as 1 for simplicity. The other system variables in the start-up and conditioning periods-e.g., the time elapsed during these periods, and the liquid phase volumetric mass transfer coefficients- are considered as not so important in the optimization problem since the processes at those periods take place only once during long periods of operation. Also, the operational cost in these periods is not accounted as significant as that of the normal operation period, which is continuous and regarded as steady. The DO concentration and MLVSS are not taken as design variables since DO can be controlled during the simulation by k_{LA} , and the MLVSS can also be controlled by the constraints on it. The DO constraint is necessary in order not to allow the growth of undesirable filamentous bacteria, and MLVSS constraint is necessary in order to keep the system operating for a long time without being washed-out. Obviously, the most important constraint on the optimization problem is the deviation from the effluent discharge criteria. In the previous study [18], the inlet waste water flow rate was taken as Q_{in} : 1000 m³ day⁻¹, and the sys

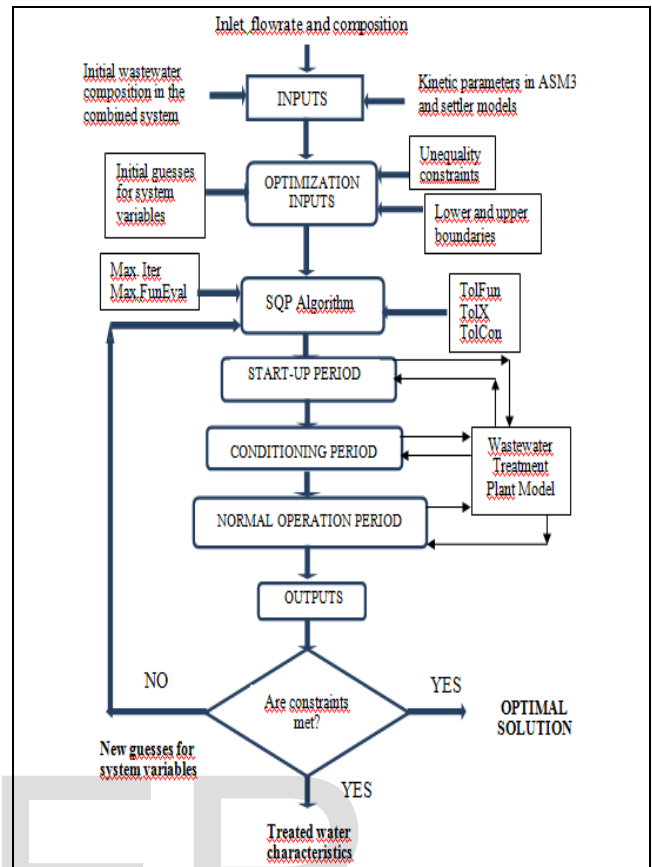


Fig. 1. Flow diagram of simulation algorithm

tem variables were predefined according to the basic principles of waste water treatment system design [23]. In the present study, the predefined system variables are determined by an optimization algorithm given in the previous sections and initial guesses are assigned as 1.0. The comparisons of the results are shown in Table 1. From the viewpoint of the operating an activated sludge system, both results are acceptable. In terms of economic perspective, the predefined system has an objective function of 6, whereas the optimized system has a value of 4.6. This means that, when the system design variables are selected according to the optimized ones, the wastewater treatment systems become more economical.

The changes in ASM3 components with respect to time during the simulations are shown in Fig. 2 when the system is operated by optimized system parameters at a 1000 m³/day flow rate. The changes in the concentrations of inert particulates, heterotrophic bacteria and suspended solids in the aeration tank can be traced based on the elapsed time. As usual, the concentrations of these three components all increase during the start-up period, and then the concentrations of heterotrophs and suspended solids in the aeration tank start to decrease due to waste disposal during the conditioning period. In the last period (normal operation), they are tried to be kept constant within the given constraints.

TABLE 1
SIMULATION RESULTS OF ASM3 PARAMETERS IN AERATION TANK

Components	Initial	After simulation	
		Pre-defined system (*)	Optimized system
S_o (g/m ³)	0.00	3.5	2.8
S_i (g/m ³)	30.00	30.0	30.0
S_s (g/m ³)	100.00	0.2	0.2
S_{NH} (g/m ³)	16.00	0.4	0.4
S_{N_2} (g/m ³)	0.00	1.1	1.3
S_{NO} (g/m ³)	0.00	19.3	19.0
S_{HCO} (gmole/m ³)	5.00	2.5	2.6
X_i (g/m ³)	25.00	1473.6	2380.3
X_s (g/m ³)	75.00	57.5	84.5
X_H (g/m ³)	30.00	971.5	1478.7
X_{STO} (g/m ³)	0.00	112.5	165.9
X_A (g/m ³)	0.10	55.4	85.2
X_{SS} (g/m ³)	125.00	2933.2	4625.2

(*) Pre-defined in the previous study [18]

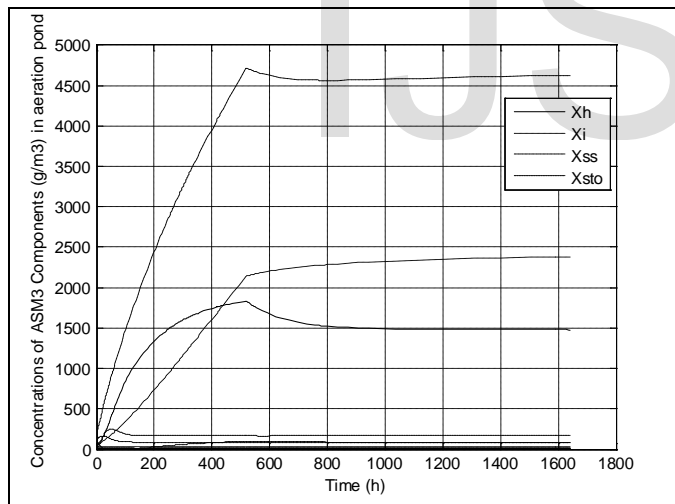


Fig. 2. Changes in ASM3 components of an optimized activated sludge system

The comparisons of the system design variables are shown in Tables 2, 3, and 4 where the simulation algorithm is also run for wastewater inlet flow rates of 500 m³/day, 1000 m³/day and 2000 m³/day and the objective functions are 3.01919, 4.55406, and 5.99271, respectively. As a result, it can be stated that in order to have a more economical system, these optimal system design variables provide better solution.

TABLE 2
SIMULATION RESULTS OF OPTIMIZATION VARIABLES

Design variables/ Inlet wastewater (m ³ /day)	Predefined(*)	Optimized	Optimized	Optimized
	1000	500	1000	2000
Aeration tank (m ³)	450	225.3755	306.3039	847.7189
Settler area (m ²)	113	86.1337	95.1271	97.0076
Recycle ratio (Q_{rs}/Q_{in})	0.8	0.4000	0.8861	1.4878
Waste ratio (Q_w/Q_{in})	0.012	0.0060	0.0074	0.0060
$k_{L,a3}$ (h ⁻¹)	4.5	3.3988	5.8851	4.0073

TABLE 3
SIMULATION RESULTS OF OTHER PARAMETERS

Other Parameters Inlet Wastewater (m ³ /day)	Predefined(*)	Optimized	Optimized	Optimized
	1000	500	1000	2000
$k_{L,a1}$ (h ⁻¹)	4.5	5.1016	5.0869	12.2350
$k_{L,a2}$ (h ⁻¹)	4.5	4.1738	4.9998	7.6698
Start-up period (h)	480	565.0979	518.6262	1013.4
Conditioning period (h)	480	540.5516	1071.2	1010.1
Normal Operation Period (h)	100	63.1491	50	98.1812
S_o (g/m ³) start-up	2.99	4.5808	2.8738	6.4891
S_o (g/m ³) conditioning	2	2.9165	1.8982	5.0959
S_o (g/m ³) normal operation period	2.1	1.9200	2.8185	2.2574
MLVSS (g/m ³)	2140.1	2397.3	3355.7	3814.9
COD _{eff} (g/m ³)	37.3375	36.3986	40.675	46.9899
TN _{eff} (g/m ³)	20.2217	18.8725	20.0261	20.0651
SS _{eff} (g/m ³)	7.8653	6.8916	10.9147	19.1569

4. DISCUSSION

The simulation method proposed in the present study is executed first for various incoming wastewater volumetric flow rates (500, 1000, 2000 m³/day). The results are satisfactory and reasonable. All simulations in the present study are performed under the same conditions: maximum iteration number is set to 50; maximum function evaluation is 750; and maximum constraints are 0.01 for the objective function, design variables, and the optimization problem constraints. However, the optimization algorithm used in the present study is seen to be very dependent on the initial guesses of the system variables. Hence, the simulations are performed for 1000 m³/day flow rate for various initial guesses. In spite of the system variables being in a dimensionless and similar form, the initial guesses affect the results which are shown in Table 4.

The best result which gives the minimum objective function

is provided with the assignment of 1.5 as initial guesses for ten system variables. The objective function is 3.80089 which is the lowest amongst the five simulations. The design variables determined by the proposed simulation method can be seen in Fig. 3.

TABLE 4
COMPARISON OF RESULTS FROM VARIOUS INITIAL GUESSES FOR 1000 M³/DAY INLET WASTEWATER

Initial guesses	0.6	1.0	1.5	1.8	2.3
Iteration number	20	18	26	9	15
F-count	287	258	367	137	194
Objective func.	3.87	4.55406	3.80089	7.22993	8.13695
Max. constraint	0	0.001806	-.0001176	5.551e-017	0
Processing time(h)	0.6444	0.9771	0.9811	0.8583	0.8222

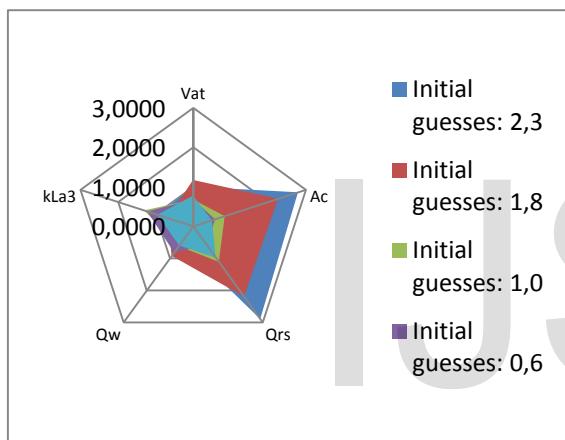


Fig. 3: Optimized design parameters (dimensionless) for 1000 m³/day inlet wastewater for various initial guesses

5 CONCLUSION

In the study, a simulation method involving an optimization algorithm is proposed for activated sludge systems. The continuously changing conditions such as growing or reducing bacteria concentrations and the dissolved oxygen concentration which varies accordingly with respect to time for an activated sludge system make the estimation of the design variables difficult in the optimization studies. Combining an activated sludge model with a settler model in optimization especially related with the complex kinetics and dynamics, the main problem is to determine the initial conditions for the optimization. In this study, initial conditions for a normal operating period of an activated sludge system are also determined during the optimization of the design variables. In other words, the initial conditions and the design variables are calculated in the same algorithm. In order to achieve that, a simulation method has been developed for an activated sludge system. Firstly, the incoming waste water is filled in the ponds. Following that, the bacteria growth required for proper set-

ling is maintained in the start-up period. The steady-flow operation is ensured after the conditioning period. All the processes run under an optimization algorithm. When the optimization algorithm is completed, the most important design variables for an activated sludge system can be determined, such as aeration pond volume, aerator power to be used in activated sludge, settler tank area, and recycle and waste ratios. In the analysis of the results, one can conclude that once we optimize the design variables according to the inlet waste water flow rate and composition and the required discharge criteria, we can design and know the operational conditions for the most economical system, prior to construction of the treatment system. Thus, the proposed simulation method, which includes an optimization algorithm, can be utilized as a good choice and optimization can be used as a design tool for an activated sludge system. In the present study, the figures for the cost functions related to the investment and the operational costs and the weighing factor between them have not been dealt with due to the continuously changing prices which may result in misinterpretation of results. The results achieved in the study are local optimums. As a further study, another optimization algorithm which allows inequality constraints embedded in the algorithm like the SQP may be improved and global optimum results may be reached.

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S_{NH} ammonium plus ammonia nitrogen
 S_{N_2} dinitrogen
 S_{NO} nitrate plus nitrite nitrogen
 S_{HCO} alkalinity
 X_I inert particulate organics
 X_S slowly biodegradable substrates
 x_H heterotrophic biomass
 X_{STO} organics stored by heterotrophs
 X_A autotrophic, nitrifying biomass
 X_{SS} total suspended solids

Nomenclature

$MLVSS$ mixed liquor volatile suspended solids
 COD chemical oxygen demand
 TN total nitrogen
 SS suspended solids

Activated Sludge Model 3 (ASM3) Components:

S_O dissolved oxygen concentration
 S_I inert soluble organic material
 S_S readily biodegradable organic substrate