Influence of Temperature on Activated Sludge Systems

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Abstract

The present study aims to determine the influence of temperature in the treatment efficiency of the activated sludge systems. To reach this aim, a simulation study is performed using Matlab® programming language. A biological tank is modelled by the ASM3 (activated sludge model No. 3) and a settling tank is modelled by Takács settling velocity model. For a defined inflow rate and inlet waste water characteristics with the predefined design and operational parameters, the treatment model is simulated. The changes in the kinetic parameters by temperature are estimated from the values given in ASM3 and the dissolved oxygen saturation concentration in water is also concerned as a function of temperature. All the other design and the operational conditions are kept constant during simulations. The simulation algorithm is executed for the temperatures 0°C, 10°C, 20°C, and 30°C. The results show that chemical oxygen demand and total suspended solids reduce slightly with increasing temperature, however, the total nitrogen content in the effluent is changing, first increases for the temperatures 10°C, 20°C, and then decreases for 30°C when it is compared to that of at 0°C. The change in temperature affects mostly the ammonium concentration in the waste water treatment systems.

Keywords: ASM3, temperature effect, simulation, nitrogen removal

1. Introduction

Activated sludge is one of the commonly used processes in the biological treatment of waste water. Arden and Lockett first applied this process in 1914 and it has been used since then. The main idea of the active sludge is to increase bacteria growth by means of stirring and aeration as well as recycling the active sludge settled in a sedimentation tank. At the end of the process, a settling tank is placed where the biomass and the treated water is separated by gravity, and some part of the biomass is recirculated to the biological tank and the excess amount is taken for drying, stabilization or land fill. The treated wastewater is discharged or if necessary, sent for an advanced treatment.

The activated sludge models have become an important part of the design and operation of the waste water treatment plants. An international task group was established in 1982 in order to create a common platform for activated sludge processes. The Activated Sludge Model No.1 (ASM1) was developed first and published in 1987. It is a model for the microbiological processes occur in the aeration tank and in the same time, it is also a guideline for the development of computer codes with a set of default values for wastewater characterization. ASM1 has widely been used as a basis for further model development also. Another model ASM2 with nitrogen removal and biological phosphorus removal was published in 1995. The Activated Sludge Model No.3 (ASM3) model [1, 10] was published in 1999, in which the growth and decay processes of nitrifiers and heterotrophs were entirely separated. Therefore nitrogen removal in the activated sludge systems could be modelled better than ASM1. In the same year, ASM3 was calibrated and validated for Swiss municipal wastewater. Kinetic and stoichiometric parameters were reviewed. Koch et al concluded that ASM3 results were better than ASM1 especially for industrial waste water with high chemical oxygen demand and for the systems having non-aerated zone also [2]. The ASM3 model has also been studied by Ni, Yu and Sun [3] to develop a mathematical model for the simultaneous dynamic growth of autotrophic and heterotrophic bacteria. They reported that the heterotrophic bacteria consumed more oxygen than the autotrophic bacteria. When the sludge residence time increases, the amount of biomass increases, however the active biomass in it lowers. The total biomass content is affected by the heterotrophs, while the autotrophs have significant effect on nitrogen removal. The heterotrophs are located in the center of granules and also occupy the outer layers, however autotrophs take place on the outer layers. There are many studies in the literature on the simulation and optimization of activated sludge systems. Chachuat et al. [4] modelled an activated sludge plant by ASM1 and developed an optimization algorithm to determine the optimal aeration for an alternating system. Balku and Berber [5] determined the durations of aerated and non-aerated periods for an alternating activated sludge system which was modelled by ASM3. The alternating system was compared to a conventional system from the viewpoint of the oxygen need and concluded that the alternating system had some advantages [6]. However, there are very limited studies on the effect of temperature in activated sludge systems, although biological processes are influenced by the temperature changes considerably. Kreuk et.al [7] studied on the influence of temperature on biological processes occurred in aeration tank. They considered a reactor exposed to temperature changes from 20˚C to 8˚C and concluded the nitrifying capacity decreased with the reducing temperature, and so nitrogen removal. Wanner et al. [8] investigated the effect of changing temperature on nitrification when a heat recovery system was present before the treatment. They concluded that the decrease in temperature caused decrease in nitrification capacity and increase in ammonium concentration in the effluent stream. However, the reduced temperatures for a couple of hours did not affect the nitrification. Their analysis under steady state conditions showed 1ºC permanent decrease in temperature resulted a decrease of 10% in the maximum specific growth rate of nitrifiers.

In the present study, a waste water treatment system which consists of an aeration tank modelled by the Activated Sludge Model No.3 [1] and the settling tank modelled by Takács et al. [9] are utilized in order to perform a simulation study. The temperature of the treatment system is changed and its effects on the bacteria growth and the treated water characteristics are determined at the end of the simulations. The simulation algorithm is written by MATLAB® software package [12].

2. Materials and Methods

2.1 The model for treatment

The waste water enters into the aeration tank together with the recirculated sludge. The aeration and mixing are performed by aerators. The microbiological processes and the bacteria growth take place in the aeration tank. The wastewater leaving the aeration tank enters a settler where gravity settling is possible. A definite amount of sludge from the bottom of the settler is recycled and excess of it is removed from the system. The treated water from the upper side of the settler is discharged to any receiving medium like river, lake or sea or if it is necessary it is sent for a tertiary treatment. The overall treatment plant is modeled by dynamic mass balances for ASM3 components. The mass balances for each ASM3 component are written around the aeration tank as follows:

$$input - output + generation - consumption = accumulation$$

$$\dot{V}_{in} S_i^{in} + \dot{V}_{rs} S_i^{rs} - (\dot{V}_{in} + \dot{V}_{rs}) S_i^{at} + R_i V_{at} = V_{at} \frac{dS_i^{at}}{dt}$$

However in order to determine the recycled sludge concentrations, a settler model is needed and Takács’ 10 layer model is preferred. The dynamic mass balances for ASM3 particulate components are written for ten layers of the settling tank. The velocity for settling is calculated simultaneously during the course of simulation with the Takács formula [9]. The time change of the concentrations of ASM3 components then can be determined by both the aeration tank and settling tank mass balances solve simultaneously.

2.2. Simulation Studies

The model of the activated sludge system consisted of mass balances is simulated with the predefined design parameters and the operational conditions which are kept constant during each run. The system is designed for a 1000 m^3/day waste water flow rate, the volume of aeration tank, the liquid phase mass transfer coefficient, the settler area, recycle and waste ratios are taken as 450 m^3, 4,5 1/h, 113 m^2, 0,8 and 0,012 respectively. Simulations are executed in MATLAB® programming language for inlet waste water characteristics given in ASM3 [1]. In order to satisfy the necessary bacteria growth, the system is simulated for 20 days without sludge disposal. In other words all the sludge is recycled to the aeration tank. This period is called start-up period. Then, in the other consecutive period which is called conditioning period, the sludge removal is started from the system for an additional 20 days. After the operation becomes approximately steady, the simulation is executed an extra 100 hours in normal operation period. The concentrations of ASM3 components determined at the end of each period are used as the initial values of the subsequent period. The simulations are performed at four different temperatures of the waste water which are 0˚C, 10˚C, 20˚C, and 30˚C. The changes in kinetic parameters by temperature are estimated from the values given in ASM3 and dissolved oxygen saturation concentration in water is taken into account as a function of temperature [11].

3. Results and Discussion

The simulation algorithm is run consecutively for three periods and it is executed also at four different temperatures of the waste water. The changes in ASM3 components with respect to time for each three consecutive periods at different temperatures can be followed from Figure 1 in the aeration tank. During the start- up period which is 480 hours the bacteria growth is continuously increasing which is achieved by recycling all the sludge to the aeration pond. Then, the sludge is removed from the settling tank continuously in a definite amount. At the beginning of the removal, the bacteria concentrations are decreasing in the conditioning period to the some extent, but then they remain constant during the normal operation period.

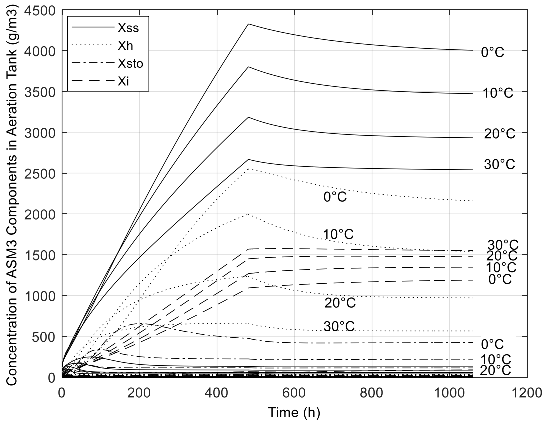

Figure 1. Changes in ASM3 components with time at various temperatures

The changes in total suspended solids, inert particulate organics, organic stored by heterotrophic bacteria and heterotrophic biomass concentration with respect to time and at different temperatures can be followed in Fig.1. The other ASM3 components are present in Fig. 1, however they cannot be seen on the figure since their concentrations are smaller when compared to above concentrations. In order to indicate the changes in heterotrophic bacteria and autotrophic bacteria in details Figures 2 and 3 are drawn. Figure 2 shows the changes in heterotrophic bacteria with time at various temperatures and it can be followed that it decreases in considerable amounts at 30°C which can also be seen from Table 1. The profiles for the heterotrophic bacteria are similar, growth in the start-up period, decrease in the conditioning period and nearly constant in normal operation.

The changes in autotrophic bacteria concentration with time at various temperatures can be followed in Fig.3. The concentration of it changes with increasing temperatures in considerable amounts which can be seen also in Table 1. The profiles are similar for 20°C and 30°C when they are compared to general tendency which is increasing in start-up then decreasing and lastly goes constant. However, they differ for 0°C and 10°C, the autotrophic bacteria concentration is increasing continuously for these temperatures. The maximum concentration is reached at 10°C. So it cannot be said anything about the autotrophic bacteria either increasing or decreasing with temperature under the specified conditions. The dissolved oxygen concentration in the aeration tank decreases with increasing temperature as Table 1 indicates, the inert soluble organic material concentration remains unchanged as expected. All the particulate materials decrease except inerts and autotrophs. Ammonium plus ammonia nitrogen, S_{NH} decreases with increasing temperature. This leads that the oxidation of ammonia will be better as temperature increases.

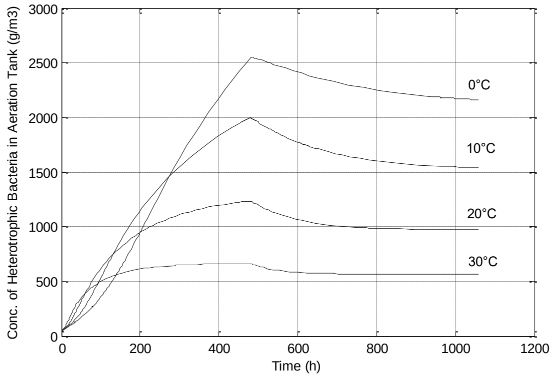

Figure 2. Changes in heterotrophic bacteria with time at various temperatures

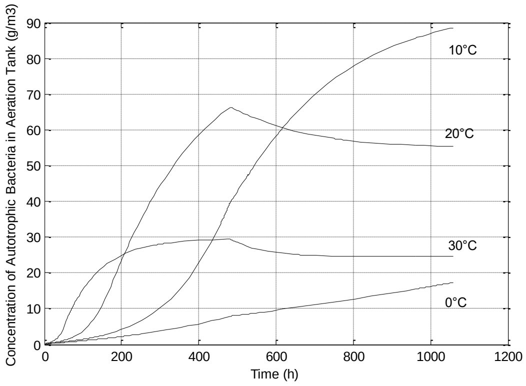

Figure 3. Changes in autotrophic bacteria with time at various temperatures

Table 1. Concentrations of ASM3 Components in Aeration Pond at Various Temperatures

Concentration (g/m^3)	**Initial**	**After Simulation**			
		T=0°C	**T=10°C**	**T=20°C**	**T=30°C**
S_O	0	11,5	6,5	3,9	2,2
S_I	30	30	30	30	30
S_S	100	0,3	0,2	0,2	0,2
S_{NH}	16	16,3	0,8	0,4	0,3
S_{N_2}	0	0,2	0,5	1	1,8
S_{NO}	0	2,8	18,8	19,5	18,9
S_{HCO}	5	4,8	2,6	2,5	2,6
X_I	25	1188,2	1346,9	1474,4	1550,1
X_S	75	125,9	85,1	57,5	39
X_H	30	2159,1	1539,3	970	565,3
X_{STO}	0	422,6	219,5	112,4	57,1
X_A	0,1	17,3	88,6	55,3	24,6
X_{SS}	125	4004,7	3472,5	2932,4	2539,9

During the simulations, the effluent characteristics are also determined at the above mentioned temperatures and given in Table 2. The chemical oxygen demand (COD) in the effluent is decreasing with increasing temperature in small amounts and the total suspended solids (SS) also show the similar tendency. However, the most important change is seen in total nitrogen (TN) content in the effluent. It is increasing with increasing temperature between 0°C and 20°C, but it is decreasing for 30°C.

According to those results achieved by simulations, the increase in temperature affects COD and SS removal positively. However, its effect changes for TN removal, up to 20°C, TN content in the effluent increases, but it reduces at 30°C.

Table 2. Effluent Characteristics with Temperature

Conc.	**Temperature**			
(g/m^3)	0°C	10°C	20°C	30°C
COD_{eff}	38,5427	37,8607	37,3371	37,0170
TN_{eff}	19,8325	20,1697	20,4310	19,7498
SS_{eff}	8,4042	8,0865	7,8658	7,7977

4. Conclusion

The world's demand is increasing continuously and new resources have being searched for energy. The energy which can be recovered from sewerage systems before the waste water treatment may be a possible additive source. When some amount of energy is recovered from the sewerage system, the temperature of waste water will lower as expected and if its effect on the biological treatment system is known then the decision makers can use this knowledge. In the present study, a waste water treatment system modeled for the municipality waste water is simulated for four different temperatures in order to see the effect of temperature change on the treatment efficiency. At the end of the simulations studies, it can be concluded that COD and SS removal will be better with increasing temperature. The total nitrogen removal is fluctuating with respect to temperature changes. However, the results for the ammonium plus ammonia nitrogen, S_{NH} decrease with increasing temperature confirm the conclusion derived by Wanner et al. [8] for the wastewater treatment plant (WWTP) in Zurich Switzerland. For the decision makers, it can be said that the energy recovery from sewerage system before biological treatment will show no harm to the bacteria growth and so, the treatment performance at the temperature range between 0-30°C.

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Activated Sludge Model 3 (ASM3) Components:

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

S_i : concentration of ith component of ASM3

R_i : generation/consumption rate of ith component of ASM3

$\dot{V}$: volumetric flow rate (m^3/h); V_{at} : volume of aeration tank

at: aeration tank; in: inlet flow; rs: recycle flow