Evaluation and Optimizing the Operating System of Aeration Tanks

Mohamed F. Soliman, Mohamed S. Dardear, Nashat A. Ali , S. A. Gutub, M. Bassyouni, and Mohamed A. Soltan

Abstract- In this work, practical and measuring data collected from plant of municipal wastewater treatment that follows the activated sludge operating system, with total capacity 35,000 m^3/day. The results of the steady-state simulation are discussed. Main target of this work is evaluate and optimize the plant operating system by achieving sufficient efficiency of organics degradation represented by COD removal, in additional to nitrogen removal with less consumption energy. (Activated Sludge Simulation Programme, Model No.1 - ASM1) has been applied after analysis the sensitivity, calibration, verification then validation checked. Different strategies of operating system based mainly on dissolved oxygen distribution have been tested and analysed. In terms of energy conservation that associated with aeration and recirculation, strategies (1 and 4), out of seven tested strategies in additional to original one, in sequence in aeration tanks will save around 50% of energy out, and results in same COD removal as that reached by original operating strategy, represents around 94.1 %. The percentage of N removal is 98.5% compared with 73.56 % that reached by original strategy.

Keywords—activated sludge, COD removal, modelling, operating strategies

I. INTRODUCTION

INCREASING urbanisation and industrialisation lead to increase in the quantity of wastewater produced all over the world and in turn increasing of the cost related to treatment and disposed by safe and environmentally friendly ways. Processes of wastewater treatment are described as complex with non-linear dynamics and strong interactions within the multivariable system [15]. Referring to references [10, 11, 19], many researchers discussed the necessity and importance of control target formulation and structure design control related to Wastewater Treatment Plant (WWTP) process control. The activated sludge (AS) process is a most treatment versatile biological process available to designer for the treatment of almost all types of wastewaters.

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Most treatment facilities use some kind of suspended growth system which represented by process of activated sludge. In this system, microorganisms are cultivated in the wastewater under conditions that improve its ability to consume the influent biodegradable organic matter [3]. Previous work has been carried out, concentrated on optimizing the period of aeration and non-aeration length in an intermittently aeration process [2, 5, 9]. Dissolved oxygen (DO) distribution and concentration in aeration tanks play the main role by activation the required type of microorganisms, which play the main role in this process.

Enhancing the treatment efficiency and minimizing consumed energy is main target. Dealing with full scale plant is so costly to gain this object. For this reason the trend is dealing with simulations that represented by modeling. Mathematical models implemented in several simulation platforms have been applied in different fields such as; design, optimization, control, and research of activated sludge systems. A model is always a simplification of reality [12]. Modelling can help to minimize the gap between lab-scale experiments and full-scale applications, and in turn is considered as a time and cost-saving tool for the optimization of treatment strategies [14]. Mathematical modelling is widespread now for design and control of wastewater treatment plants (WWTP's). For the description of activated sludge processes the Activated Sludge Model No.1 (ASM1) is still the most commonly applied model in practice. Generally this model has been developed for the numerical simulation of biokinetic degradation of organic compounds and for nitrogen elimination processes. ASM1 allows the simulation of the behavior of nitrifying and denitrifying activated sludge systems, which treat primarily domestic wastewater. ASM1 immediately gained wide acceptance and became a major reference for further research work as well as the basis for many software programs applied for design and operation of treatment plants [8]. The structure software that has been used in this paper so-called **A**ctivated Sludge **Si**mulation **P**rogram (ASIM) consists of files that in turn include variant components. For simplicity all the software units have been summarized and presented in Fig.1.

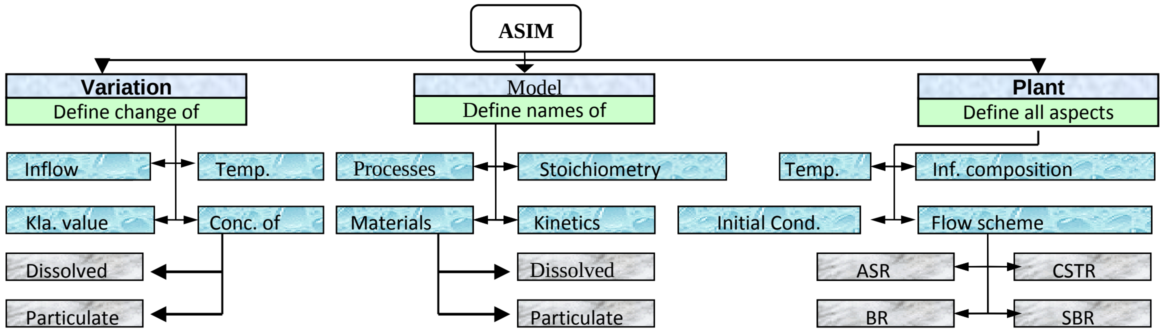

Fig. 1 Software structure model implementation

II. METHODOLOGY

Wastewater samples have been collected from aeration tank of Kima Wastewater Treatment Plant, Aswan, Egypt, coordinates 24°04'55.25" N and 32°55'40.58" E, that shown in Fig. 2.

Fig. 2 Kima Wastewater Treatment Plant-Aswan-Egypt

The main target was to study the removal of Nitrogen (N), and removal of organics that represented by degradation of Chemical Oxygen Demand (COD). The aeration tank has two lines, each has seven reactors in serious. Each reactor contains single mechanical surface aerator. The original operating system was keeping all mechanical aerators in work. This strategy leads to height efficiency in organics removal, but associated with height consumption of energy related to working of mechanical aerators. In the same time, working of aerators continuously leads to inhibition of anoxic conditions to take place. In other words, denitrification process will not occurs, and in turn no elimination of nitrogen, only conversion from form (NH_4) to another (NO_3) in nitrification process that takes place in aerobic condition. Nitrification and Denitrification biological processes are commonly used for purpose of nitrogen elimination from wastewater [7]. As reported by previous studies, disposal of wastewater that contains nitrogen components has detrimental effects in different manner like; contribution to eutrophication, oxygen depletion, aquatic environment toxicity and public health concerns [1].

Temperature (T), Dissolved oxygen (DO), Chemical oxygen demand (COD), Total suspended solids TSS, Ammonium-Nitrogen (NH_4-N), Nitrate-Nitrogen (NO_3-N), Sludge age (SA), Alkalinity (pH), all have been measured to be used as input data for ASM No.1. Measurements of parameters have been taken three times a day, then average used, as shown in table 1.

TABLE 1
MEASURED CONCENTRATIONS OF DIFFERENT PARAMETERS IN REACTORS

Parameters	influent	Reactor (1)	Reactor (2)	Reactor (3)	Reactor (4)	Reactor (5)	Reactor (6)	Reactor (7)	effluent
DO (mg/l)	NM	0.98	0.39	1.53	2.92	4.12	4.60	4.18	NM
pH	7.12	7.19	7.18	7.09	7.22	7.31	7.36	7.33	7.33
COD (mgO_2/l)	395	361	228	170	130	96	63	30	23.33
TSS (mg/l)	107	1787	1266	1611	1117	1067	1000	1183	NM
NO_3-N (mg/l)	1.43	1.13	4.67	4.80	4.93	4.63	2.50	2.93	7.81

- NM: Not measured

Samples were collected from ten different points as follows: Inlet of aeration tank; In each reactor (seven reactors) of the aeration tank No.1; The outlet of aeration tank; The final sedimentation tank. Fig. 3 shows the flow scheme of the seven aerators supported by their volumes and original dissolved oxygen concentration in each reactor, in additional to influent, sludge age and return sludge flow.

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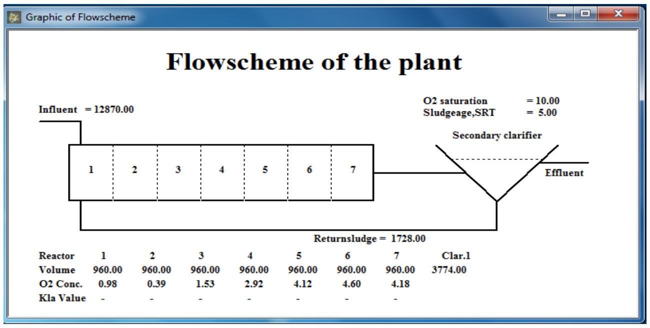

Fig. 3 Flow scheme of the plant

For the purpose of finding the optimum operating strategy, different seven cases of DO distributions in the seven reactors of aeration tank by switch off mechanical aerators have been tested. Table 2 shows the aeration tanks flow scheme with different strategies that have been tested.

TABLE II
STRATEGIES OF TESTED OPERAING SYSTEMS

Case No.	DO concentration in diff. reactors (mg/l) (by switching on and off the aerators)						
	R_1	R_2	R_3	R_4	R_5	R_6	R_7
1	2	0	2	0	2	0	2
2	2	2	0	2	2	0	2
3	2	2	2	0	2	2	0
4	0	2	0	2	0	2	0
5	2	0	0	2	0	0	2
6	0	2	0	0	2	0	0
7	0	0	2	0	0	2	0
Original case	on	Off*	on	on	on	on	on

*Aerator in R_2 was out of work

As known that high aeration rates and high concentration of oxygen not recommended, because it will be lead to oxygen transfer and in turn decreased aeration efficiency [13, 17]. Operation of aeration tanks with concentration of DO around 1.5 mg/l was shown to be successful for deamonification, [4, 20]. According to reference [6], DO concentration between 2 and 3 mg/l, is sufficient to achieve a satisfactory level of solids degradation. For this reason the concentration of DO in all strategies that have been tested, was adjusted to be 2 mg/l. Distribution and rearrangement of DO in aeration tank based mainly on keeping Nitrification and Denitrification processes to take place. As pointed by [18], the implementation of biological Nitrification and Denitrification is successfully used in highly loaded side stream processes. Referring to experiment work carried out by [16], it has found that quantity of generated NO_3-N during Nitrification process can be consumed in one forth to one third time in Denitrification process, which represented in this work by cases No. 2 and No. 3.

III. RESULTS AND DISCUSSIONS

This paper contains two main parts, the first related to practical and laboratory part, and the second related to simulation model and apply ASM No.1. Fig. 5 indicates the measured degradation of COD during the biological process in aeration tank. The percentage of COD removal was around 94 % under applying of original operating system.

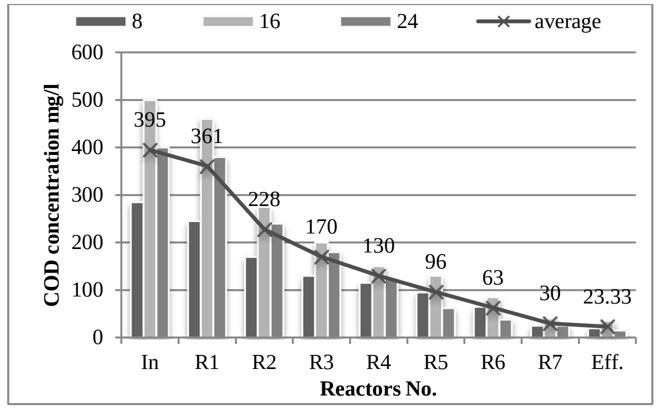

Fig. 4 Degradation of COD in different reactors

In original case concentrations of measured DO "shown in figure (3)" in different bioreactors not the same, which can be explained by quantity of consumed organics. In other word, oxygen uptake rate was higher in first reactors then decreased by the order of reactors. PH value was around 7.2, and nearly did not change in all reactors. Biochemical Oxygen Demand (BOD_5) measured too and the ratio of BOD_5 to COD was 0.56. Nitrification process takes place in all bioreactors due to aerobic condition, and in turn depletion of NH_4-N and generation of NO_3-N has observed by measurements. The removal of nitrogen components was around only 73.56 %. The explanation of low percentage of N removal related to run of all aerators in all reactors, which prevents anoxic condition. In turn denitrification process was not available that helps to convert NO_3-N generated by nitrification to nitrogen gas, and consequently decrease the nitrogen removal efficiency.

Referring to the second part that related to the mathematical simulation, sensitivity analysis, calibration, and verification by comparing measured and simulated data has been done.

The validation of the model checked, and then the model ASM No. 1 has been applied to find the best operating strategy.

By applying strategies represent by Case (1) and (4), the nitrification and denitrefication processes will take place. In turn the generated NO_3-N in nitrification process by Nitrosomonas and Nitrobacter bacteria, will consumed in denitrification process. In final, much removal of Nitrogen will occur (98.5%) comparing with the original operating strategy. Input concentrations of COD, NH_4-N, and NO_3-N were 395, 30, and 1.43 mg/l respectively. Table 3 contains the outputs of validated ASM No.1 for the effluent of COD and N of aeration tank for different cases.

TABLE III
COMPARING REMOVAL PERCENTAGE BY ASIM1 FOR DIFFERENT CASES.

Case No.	COD_{out} (mg\l)	N_{out} (mg\l)
case1	24.12	0.323
case2	29.80	1.295
case3	22.78	1.508
case4	22.70	0.6
case5	22.81	2.044
case6	23.23	13.31
case7	23.25	13.1
Original case	23.94	7.86

According to previous table, we can investigate that nearly all cases can achieve sufficient removal of COD, but the difference is related to efficiency of nitrogen removal. Case 1 and case 4 show the higher efficiency of nitrogen removal, which can be illustrated by occurring of nitrification and denitrification process consequently. In the same time applying of these two cases consequently allow working of half number of aerators, which save around 50 % of energy required for operation.

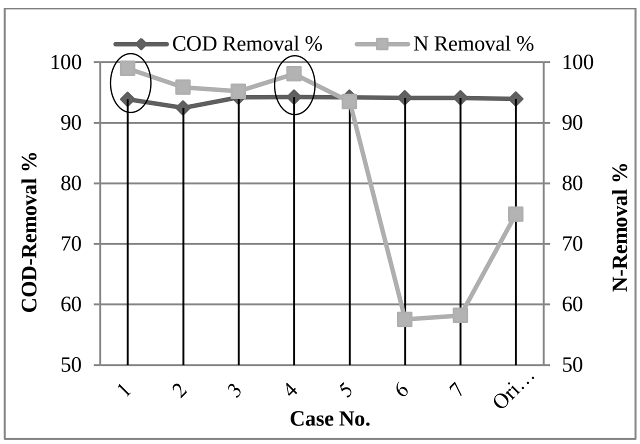

Fig. 5 Removal persentage of COD & N in different operating strategies

Referring to Fig. 5, we can observe that cases 1 and 4, can Work interchangeably, with saving energy and achieving height efficiencies in COD and N removal, represented by 93.89, 94.25, 98.97, and 98.09 % respectively. Cases (2) and (7), can too work interchangeably but the efficiency of nitrogen removal in case 7 was very low, around only 58.32 %, which can be explained by the quantity of NO_3-N generated was so limited because the aerobic condition exist only in two reactors out of seven.

IV. CONCLUSIONS

Based on the measured data and the results that have been obtained from this work by applying activated sludge simulation program, the following conclusions can be drawn:

Activated sludge simulation program (ASM No.1) that has been evaluated and calibrated can describe the processes of activated sludge system in Kima WWTP.

It has been concluded that by changing some operating conditions focuses on the effect of DO distributions in aeration tank, applying ASM No.1, we can get the optimum operating system for Kima WWTP to give the maximum degradation of COD and removal of nitrogen in the same time.

By applying those two strategies refers as case (1) and case (4) consequently, nearly the same percentage of COD removal (94.1%) can be achieved comparing with original operating system, and Kima WWTP can save around 50% of energy consumed for surface mechanical aerators.

Applying the tested strategies, represented by case (1) and case (4) consequently, can improve the nitrogen removal to be around (98.5%).

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