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Modeling and Simulation of a Two-Step SBR Wastewater Treatment Plant

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Abstract—the most important purpose of wastewater treatment is to reduce pollution of the raw water and reclaim wastewater for reuse. Modeling and optimization of wastewater treatment processes were applied in this study to improve the efficiency of a wastewater treatment model. The model was applied on wastewater characterized by high organic loading and suspended solids concentrations. The approach was applied to optimize a treatment process of a two-step sequencing batch reactors SBR model. Also in this research we investigated the rule of denitrification process via anoxic conditions to remove nitrogenous compounds. Based on the results, it shows that two-step SBR model operates with removal efficiencies higher than 96% for biological oxygen demand (BOD), total suspended solids (TSS) and total kjeldahl nitrogen (TKN) were established. This modeling analysis applied to define a performance measuring plan based on the most important parameters that can be reliable and applicable for any waste water treatment plant.

Index Terms— Modeling, simulation, SBR, Biological Treatment, Aerobic, nitrification, denitrification, activated sludge

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1 Introduction

ACTIVATED sludge process has been modified to a sequencing batch reactor SBR to improve the treatment of various types of wastewater such as domestic, industrial and landfill leachate. The main benefits of using the SPR are flexibility in operations, low capital and maintenance cost and the simultaneous removal of both nitrogen and phosphorus.
SBRs have shown great success in achieving nitrite accumulation at high nitrogen loading rates due to its discontinuous feeding which allows the reactor to maintain high ammonia concentration as well as the sequencing of the feeding phase would help to control possible free ammonia FA and free nitrous acid FNA accumulations inside the reactor and by consequence inhibiting nitrite oxidizing bacteria NOB. In a SBR operated with a stepwise increase in influent ammonium concentration, an ammonia removal efficiency ARE of 98.6 ± 2.8% with Nitrite accumulation rate NAR of 93.0 ± 0.7% was achieved at a nitrogen loading rate NLR of 1.2 kg/(m3 day) through a novel dissolved oxygen DO control strategy depending on the mixing regime [1].

The biological nitrogen removal BNR process is an economically feasible alternative for the treatment of wastewater with high concentrations of nitrogen. BNR is divided into two subprocesses: nitrification and denitrification. Its implementation offers high conversion efficiency, reduced consumption of chemical products, and a low biomass generation [2]. Removal of nitrates and nitrites from wastewater that is achieved via microbial denitrification under anoxic conditions, whereby the nitrates and nitrites are utilized as final electron acceptors for cellular respiration in place of oxygen with resultant production of gaseous nitrogen accompanied by concurrent COD removal [3]. The Anoxic process in very essential in operation of SBR to prevent filamentous sludge bulking that is considered a major problem in the operation of WWTPs.

In terms of technology, SBRs are often applied to the refractory wastewater treatment [4], for industries such as those from food processing [5], coal gasification [6], oil extraction [7], chemical [8] and papermaking [9]. In spite of these success cases, there is still a need to improve the modeling and control strategies applied to these fields, which are subject to larger disturbances in composition and volume of industrial wastewater to be treated [10] than those reactors treating municipal wastewater [11].

Modeling of wastewater treatment processes has been of great importance due to the need for a full understanding of complex treatment systems and the optimization of their practical applications. Numerous modeling techniques, such as reaction kinetics and equilibrium [12] [13], computational fluid dynamics [14] [15] and artificial neural networks [16] can be applied on wastewater modeling.

2 Methods

2.1 Wastewater Treatment Modeling

WWTP modeling is an essential tool for the process of engineering design of modern water resource. It is very important for recovery facilities that are experiencing increasing demands on wastewater effluent quality. The aim of this research is to identify how the model selection, the data collection and the WWTP model calibration all relate to the modeling purpose.
The mathematical model of a WWTP usually depends on analyzing a group of mathematical equations that represent the biological and chemical reactions, physical properties the can affect the treatment process, and the rates of the different reactions. The existence of modeling software can help to facilitate

the solving of the equations without long substitution analysis process.

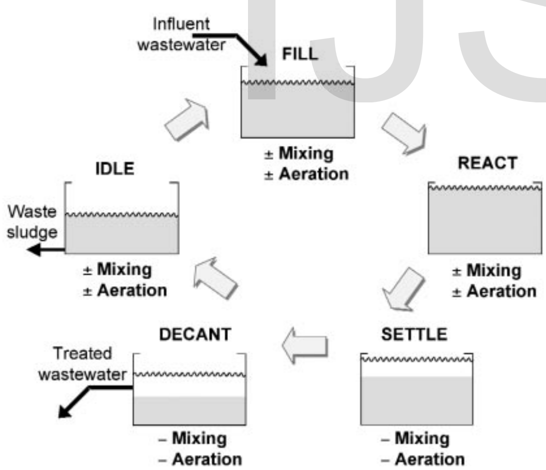
A WWTP usually consists of a set of activated sludge tanks, combined with a sedimentation tank, with a range of electron acceptor conditions occurring in the tanks. Depending on the concentrations of dissolved oxygen (DO) and nitrate present in the tanks, aerobic (oxygen present), anoxic (nitrate present, no oxygen) or anaerobic (no oxygen, no nitrate) tanks can be distinguished [17].

2.2 Sequencing batch reactor (SBR)

A Sequencing batch reactor SBR is a modified type of activated sludge process for wastewater treatment. SBR reactors treat wastewater such as sewage or output from anaerobic digesters or mechanical biological treatment facilities in batches.

The SBR presents the advantage of carrying out biological nitrogen removal BNR in only one reactor, through the sequential development of aerobic (nitrification) and anoxic (denitrification) phases. A SBR cycle is characterized by a series of phases: fill, react, settle and draw, each with a defined duration [18]. The different stages of the SPR Process are shown in Figure.1. The most effective factors that help to distinguish the sequencing batch reactor SBR is the flexibility in operation and its low cost.

Figure.1 SBR Cycle



Source (University of Florida SBR's Manual)

A remarkable feature of SBR processes is its batch mode operation, which enables control of the reaction time (aeration/mixing) to be adjusted in response to the wastewater quality. This improves the operational efficiency and energy savings of WWTPs, but it also brings more complex operation modes that require highly reliable automation methods [19]. For a normal design of the SBR, each phase has a prescribed duration regardless of the process dynamics and the nitrogen concentration in the wastewater influent. This may result in a highly inefficient operation in terms of energy consumption costs [20].

2.3 working model

This research focuses on investigating the action of anoxic/aerobic phases of treatment Model composed of two step SBR units in order to improve the treatment efficiency. The Percent of maximum volume and cycle time among the steps of SPR are shown in table.1.

Phase	maximum volume %	cycle time %
Fill	25-100	25
React	100	35
Settle	100	20
Decant	100-35	15
Idle	35-25	5

Table.1 Percent of maximum volume and cycle time of SBR Steps

The Two-step SBR model shown in Figure.2 was developed by using the SBR unit process object in the GPSX Hydromantis program. This program use an advanced graphical user interface GUI that let the dynamic modeling and simulation become easier. The layout of the SBRs unit model used in this project includes the influent passed through the first SBR unit followed by a Second SBR unit.

The proposed influent characteristics that pass through the two-step SBR model are shown in table.2. The reason for estimating the high concentration value influent was to investigate the efficiency of the two-step SBR model on dealing with high contaminated wastewater to meet the governmental law requirement after the treatment process

Influent parameter	Value
Q (m^3/d)	10000
BOD (mg/l)	1000
TSS (mg/l)	1200
TKN (mg/l)	70

Table.2 Two Step SBR influent characteristics

The research objective were to study the effect of the batch cycle time of different phases of the SBR process (Fill, React, settle,..) on the performance of the two-step SBR Model. The specifications of different runs are shown in Table 3. The operation variables of the two SBR reactors were the same because we considered the investigation of the performance of the two-step SBR reactors are done under similar working conditions for both SBR units.

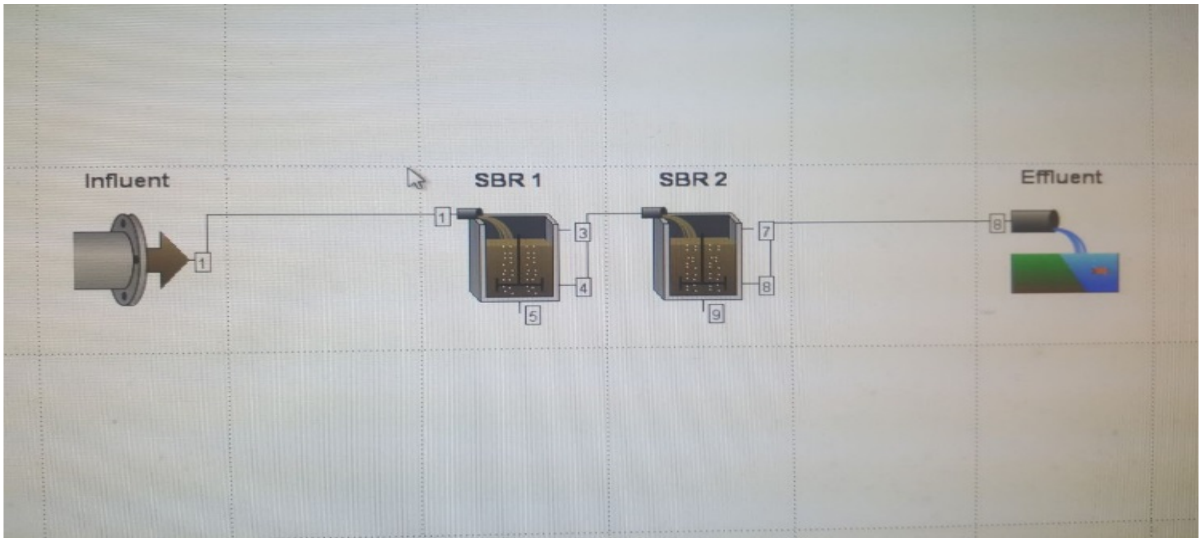


Figure.2 Two-Step SBR model

	Phase	Fill		React		Settle	Decant	De-sludge
		Mixed	Aerated	Mixed	Aerated			
Run1	SBR 1&2	0 min	120 min	0 min	300 min	75 min	60 min	25 min
Run 2		120 min	0 min	300 min	0 min	75 min	60 min	25 min
Run 3		60 min	60 min	150 min	150 min	75 min	60 min	25 min
Run 3		80 min	40 min	250 min	50 min	75 min	60 min	25 min

Table.3 Two Step SBR influent characteristics

3 Results and Discussions

The following results of the four Two-step SBR run model were obtained after modeling and simulation of all runs. (Table 4). According to the proposed scenarios of the two-step SBR model, the results were discussed as follow.

The biological oxygen demand BOD removal efficiency were ranged from 96.51% to 97.12% with mean value of 96.84% regarding to an average concentration of 31.65 mg/l. The total suspended solids TSS removal efficiency were ranged from 96.66% to 97.03% with mean value of 96.85% regarding to an average concentration of 37.82 mg/l. The total kjeldahl nitrogen TKN removal efficiency were ranged from 97.16% to 97.86 % with mean value of 97.48% regarding to an average concentration of 1.765 mg/l.

3.1 Run No.1

The verification of the model was done through this first run. In this run the fill and react phases were aided by aeration to achieve aerobic condition, therefore no anoxic condition can be attained through this run. In the first run at fill phase, volume and substrate were added to each SBR reactor under aerobic condition for 120 min. Then that through the react phase the flow were aerated for 300 min to continue the aeration action started at the fill phase. During this aeration period, the organic carbon and ammonia must be oxidized and the nitrification process took place.

3.2 Run No.2

During the fill phase after the first run was ended the run stat by mixing fill time 120 min without aeration. Also the cycle time is transformed in the react phase to 300 min mixing without aeration.

Effluent	Run 1		Run 2		Run 3		Run 4	
	SBR 1	SBR 2	SBR 1	SBR 2	SBR 1	SBR 2	SBR 1	SBR 2
BOD (mg/l)	150	28.8	168	32.3	159	30.6	172	34.9
TSS (mg/l)	199	35.6	205	38.5	202	37.1	208	40.08
TKN (mg/l)	11.4	1.5	11.98	1.89	11.77	1.68	12.42	1.99

Table.4 wastewater effluent characteristics

In this run influent flow were mixed with the biomass that was left in the tank from the previous run. The mass of nitrate remaining after decant could be reduced during the fill period if sufficient BOD and time were available. [21]

3.3 Run No.3

After the end of the two previous run, we began to distribute the cycle time equally between mixed and aerated in both phases fill and react. This distribution represents the running of the two-step SBR model under the anoxic and aerobic conditions.

A simultaneous denitrification/nitrification processes were achieved, then the react phase achieved denitrification so that the oxidized nitrogen species were denitrified by heterotrophs depending on the amount of biodegradable COD available.

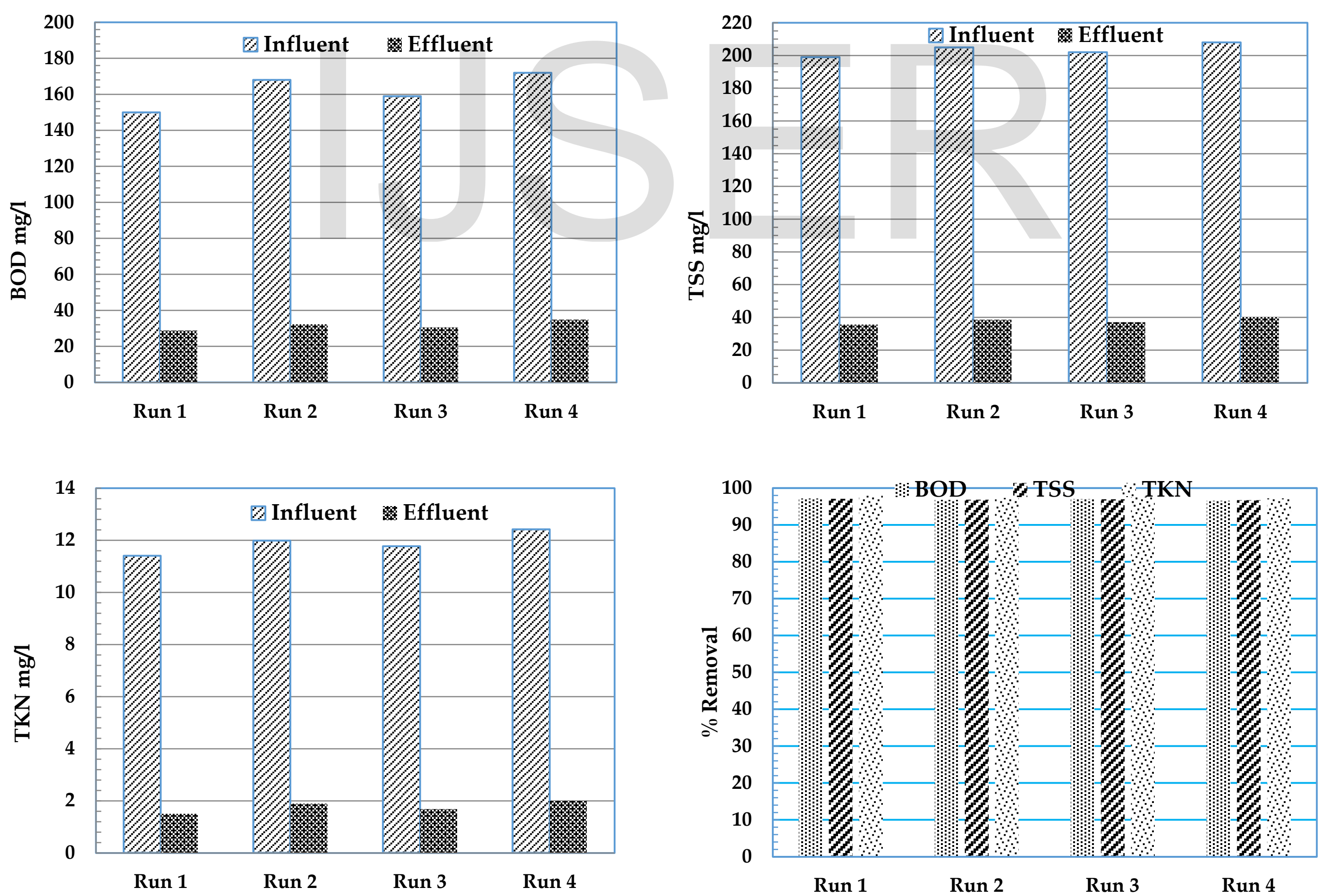


Figure 3 Influent and Effluent concentration and Removal Efficiencies

3.4 Run No.4

At the final run, we checked the performance of the two-step SBR model at decreasing the aeration period in the cycle time. The fill phase is partially aerated, while react phase is increased the mixing time under anoxic condition.

The aeration time was not sufficient for complete oxidization of ammonia, while in the react period, anoxic condition was achieved by mixing to complete the denitrification of the remaining oxidized ammonia

4 Conclusions

The objective of this study is to make an evaluation of the performance of a two-step SBR model dealing with wastewater characterized by high organic loadings. Conclusions are depending on the results from the modeling and simulation of four different scenarios. The main conclusions points of the study can be interpreted into the following points (1) the removal efficiencies of COD, TSS and TKN were acceptable according to the process guide lines; (2) All the effluents from each of the four runs are agreed with the Egyptian law No. 93/62 and its modifications at Decree No. 44/2000. The removals of nitrogenous compounds from wastewater were achieved via microbial denitrification.

It is Recommended for operation of Sequencing batch reactor a fully control of the factors which affect the system efficiency such as temperature, organic loading rates, pH and oxidation reduction potential.

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