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Proposing the Optimal Scenario for Treatment Wastewater Using Sequencing Batch Reactor System: Case Study Al Nasiriya City

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ABSTRACT

The overall task of this study is to determine an efficient control strategy and optimize the operation of the sequencing batch reactor (SBR) plant for treating the domestic wastewater of Al-Nasiriya City. During this research, a pilot-scale SBR unit was constructed to treat real domestic wastewater. The constructed SBR unit comprised: a collection tank of (250 L); an SBR reactor of (150 L); mixing and aeration units, PVC pipes, an Air flowmeter, influent pumps, effluent pumps, a programmable control panel (PCP), and other accessories. The raw wastewater characteristics of COD, TKN, NH_4-N, and NO3-N ranged between230-627mg/l, 29-55mg/l, 19-36mg/l, and 0.14-0.57mg/l, respectively. The results showed that the SBR system can be successfully used for treating domestic wastewater of Al-Nasiriya City and achieving high removal rates for pollutants which were 83%, 86%, and 66% for COD, NH_4-N, and TN, respectively, and the effluent matching with the Iraqi standard limitations for the effluent of WWTP. The results showed that the optimal scenario is three steps of Anoxic/Oxic/Anoxic. The reaction phase is achieved in 2/6/1 hr for Anoxic/Oxic/Anoxic conditions respectively, and a sludge age of 10 days to achieve an optimum removal rate for COD and TN components.

1. INTRODUCTION

Climatic changes and water pollution have caused water stress throughout the world [1]. For the past decades, the surface water was adversely affected in quality as a result of discharging untreated wastewater which contains high concentrations of pollutants to the aquatic surfaces. The discharge of untreated sewage has increased the pollution of fresh water and reduced the sources of clean water [2] Therefore, wastewater must be treated before entering the aquatic surfaces to protect the environment and human health from any harm or risk it may have on. Over the past years, many techniques have been applied to treat wastewater [3]. Most of these techniques rely on biological degradation namely the conventional method or biological wastewater treatment method [4]. A sequencing batch reactor system is a type of biological wastewater treatment by activated sludge process (ASP), composed of five sequence stages. These stages include fill, react, settle, draw, and, idle [5]. This system gets more attention after the 1980s onwards as a viable alternative for the constant flow aiming to dispose of the continuous flow method of ASP [6]. SBR offers several advantages comparing the conventional methods of activated sludge [7]. It requires single basin operation without the need for a secondary sedimentation basin which means there is no sludge return to the aeration basin [8]. Moreover, it is low cost and simple operation and energy consumption. SBR can be operated automatically with flexible configuration and easy installation [9, 10]. Another important feature of SBR shows high resistance to hydraulic and organic loading shocks, with effective bulking control, higher biomass retention, and endurance to toxicity [11-13]. Researchers around the world have worked on different operating SBR scales (bench, laboratory, pilot, and full-scale) to understand the mechanism of pollutant removal from wastewater in SBR systems to increase the efficiency of the used process. SBR systems are successfully applied to treat different types of wastewater such as dairy wastewater [14], real wastewater [15], and textile wastewater [16]. Previous studies demonstrated that SBR can remove a wide array of pollutants at different operational conditions. For instance, Leung and his teams [17] studied SBR performance by investigating different operation scenarios. They found that 4 hr of the aerobic phase, 3 hr of the anoxic phase, and 1 hr of the last aerobic react phase were suitable to remove N, C, and P, simultaneously with removal rates for COD and BOD nearby 94% and NH_4 N removal of 97%. Demuynck et al. [18] studied the performance of nutrient removal in a real SBR plant. He stated that short (Ox/Ax) sequencing phases are better than the usually used aerobic/anoxic sequencing phases. Approximately, total removal for nitrogen occurred by adding an extra COD to the anoxic phase for sufficient denitrification process. Baetens et al. [19] investigated the temperature effect on BPR in the SBR system. The experimental results showed that all the anaerobic and aerobic conversion rates were increasing due to temperature increases. The aerobic uptake rate of phosphorus showed a maximum value at temperatures between (15-20°C). Kargi and Uygur [20] investigated the relationship between wastewater composition and nutrient removal from synthetic wastewater in a five-step sequencing batch reactor. Wastewater composites of (COD/N/P: 100/3.33/0.69) were found to be the most suitable for optimum nutrient removal rates from wastewater using the SBR system. Kocyigit and Ugurla [21] studied the removal of reactive azo dye (Reactive Red 198) from wastewater in the SBR system in anaerobic/aerobic conditions. The removal efficiency of color was varied between 76-98% with an initial color concentration of (20-50) mg/l, the maximum removal rate was at (16/4) hours of (the anaerobic/aerobic) reaction phase. They also found that; the removal efficiency of dye is proportional to the anaerobic contact time. The dye removal efficiency improved with the increasing of organic loading rates from (500-1000) mg/COD.L.d. Based on the literature most studies aimed to improve SBR system efficiency via exploring the optimal performance of SBR systems and operational configurations, strategies, processes, materials, parameters, and the circumstance conditions. Based on the literature most studies aimed to improve SBR system efficiency by exploring the optimal performance of SBR systems and operational configurations, strategies, processes, materials, parameters, and circumstance conditions. However, most of the research reports optimal operating temperatures within a narrower range (e.g., 15-25°C). Meanwhile, Al-Nasiriya experiences a wide temperature range between 0°C in winter and can reach over 50°C in some cases during the extended summer months. Based on the best knowledge of the current research team, there is no research investigating the optimal performance of the SBR system based on southern Iraqi local conditions. Thus, the aims of this study are: to study the performance of the SBR system in treating domestic wastewater at Al Nasiriya City, Then Optimize the SBR operational parameters to get its best scenario which matches our local conditions to achieve the best removal rate of pollutants (COD, NH_4-N and Total nitrogen).

From the literature review, it was found that the SBR system is an effective way for biological removal of pollutants from wastewater but in the same time, it can't be used directly in our local conditions because it's a flexible process (accepted by a wide range of treatment steps with various conditions and time intervals) which depends on the type of raw wastewater, local characteristics of raw wastewater, sludge seeds, climate…etc. For instance, the local condition in Al Nasiriya city is characterized by hot weather during the summer months and the temperature degrees sometimes reach fifties which is indeed a relevant factor for SBR operation. Determining the operational parameters for the SBR could minimize the energy consumption and facilitate the utilization of the locally available resources to the wastewater treatment more feasible. Therefore, it is important to conduct this study to have a close insight into the mechanism of pollutant removal in the local conditions and to optimize the operation of the SBR plant for treating the domestic wastewater of Al-Nasiriya City.

2. MATERIALS AND METHODS

2.1 The Experimental Setup

The experimental setup included the construction of a pilot-scale SBR plant which mainly consisted of an SBR reactor (150 L), collection tank (250 L), air compressor, mechanical agitation mixers, two pumps, air flow meter, programmable control panel (PCP), connection PVC pipes and other parts as depicted in Figure 1.

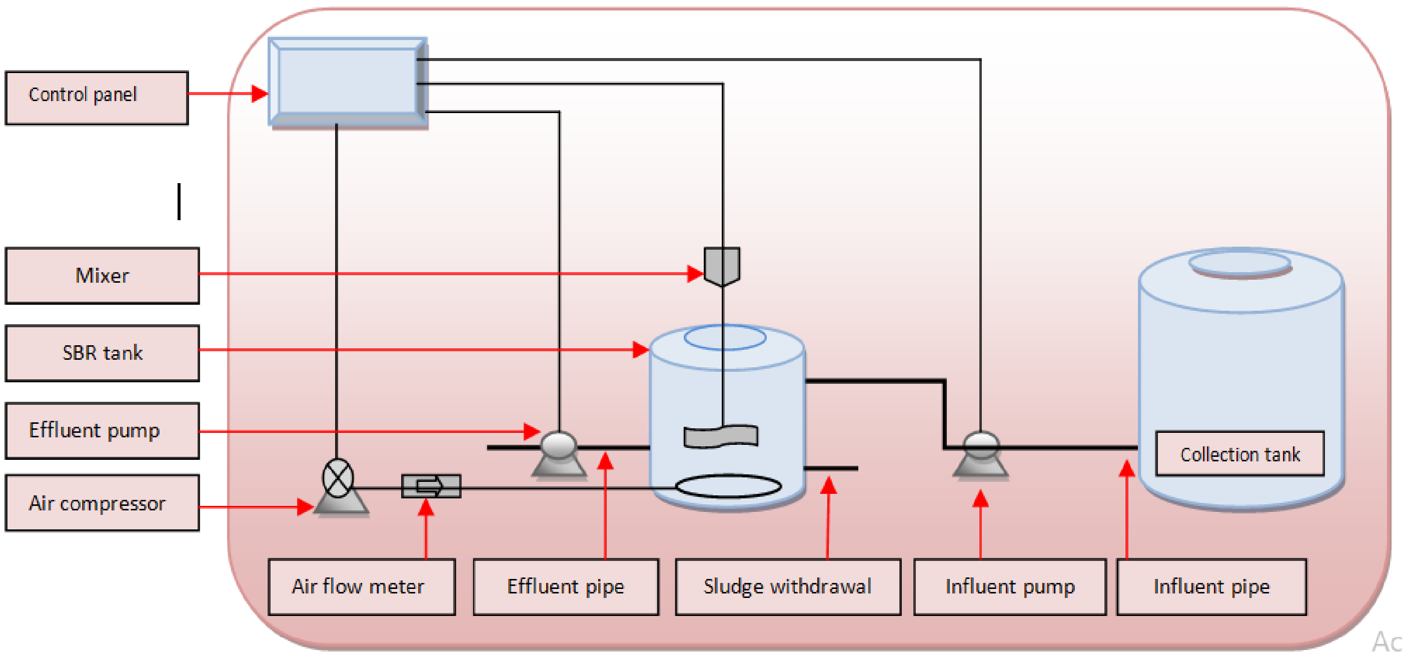

Figure 1. Schematic diagram of SBR unit

2.2 Wastewater characterization

The raw domestic wastewater was supplied from the main influent pipes in the main wastewater treatment plant at Al-Nasiriya City for nearly one year to be more representative to the characteristics of local conditions. The characterization of the wastewater was performed based on "Standard methods for water and wastewater examinations" [22].

2.3 Sludge seeds and startup period

The sludge seeds were taken from the main WWTP in Al-Nasiriya City. The initial concentration of MLSS was 2047 mg/l, therefore it was a suitable concentration for SBR systems which require the MLSS concentration of more than 2000 mg/l [23]. The sludge seeds were acclimated to the sequence of anoxic and aerobic conditions for 24 hours/day using an air blower and wastewater feeding at different times of the day.

MLSS concentration was continuously tested in this period which showed a noticeable increase. This period was extended for 40 days before starting the experimental work procedure.

2.4 Experimental work procedure

The following steps are followed during the optimizing stage to get the optimum operational parameters of the SBR system.

1. Recording the number of the test, time, and date.
2. Setting the required time intervals for each phase (filling, reaction, settling, decanting, and idle) using the programmable control panel by connecting the ARDUINO board to the computer and setting them.
3. Automatically, the raw wastewater is transported from the collection tank to the SBR reactor.
4. Collect samples from the influent raw wastewater for COD, NH_4-N, NO_3-N, TKN, and pH analyses.
5. At the end of the fill phase, samples were taken from the SBR reactor for MLSS concentration and sludge volume tests.
6. The reaction phase automatically started when the fill phase ended. It may be anoxic or aerobic according to the available conditions (anoxic with only the mixer operating or aerobic with both the mixer and aerator operating).
7. At the end of the reaction phase and before sedimentation, a part of the mixed liquor was removed from the SBR reactor every day to adjust the sludge age to the required level [24-26].
8. The settling phase starts immediately after the reaction phase. The mixed liquor is allowed to settle under quiet conditions for (30 min) [26]. During this phase, the activated sludge settles in a flocculent mass forming an identified interface with the clear supernatant. The settled sludge mass is called a sludge blanket. It's a critical phase because insufficient settling leads to decanting a part of the activated sludge during the decanting phase causing poor effluent quality.
9. After the settling phase ends, the drawing (decant) phase starts, in which the clear supernatant is decanted and samples are collected from the supernatant for COD, NH_4-N, NO_3-N, TKN, and pH analyses.
10. The last phase is the idle phase which is defined as the time between cycles used to adjust phases' time in the next cycles, excess sludge wasting can occur during this phase [27].

2.5 Analytical methods

COD, NH_4-N, NO_3-N, and TKN were analyzed according to "Standard methods for water and wastewater examinations" [22], NH_4-N concentration is measured according to 4500-NH_4-C Titrimetric method, Nitrate-Nitrogen concentration is measured according to 4500-NO_3-B, ultraviolet spectro-photometric screening method and TKN was measured according to 4500-Norg, Kjeldahl method while the concentration of dissolved oxygen (DO), sewage temperature (T) and (pH) were measured using a digital device.

3. RESULTS AND DISCUSSION

The chemical characteristics of raw wastewater are tabulated in Table 1.

Table 1. Raw wastewater characteristics

Parameter	Unit	Min.	Max.
COD	$mg.l^{-1}$	230	627
TKN	$mg.l^{-1}$	29	55
NH_4-N	$mg.l^{-1}$	19	36
NO_3-N	$mg.l^{-1}$	0.14	0.57
pH	-----	6.4	7.15

3.1 Startup stage

During the startup stage, the mixed liquor-suspended solids (MLSS) of raw wastewater were continuously monitored. Figure 2 depicts the growth of biomass concentration in terms of MLSS during this period. The MLSS concentration reached around 3683 mg/L after 40 days of acclimation period with HRT of 14.2 hr.

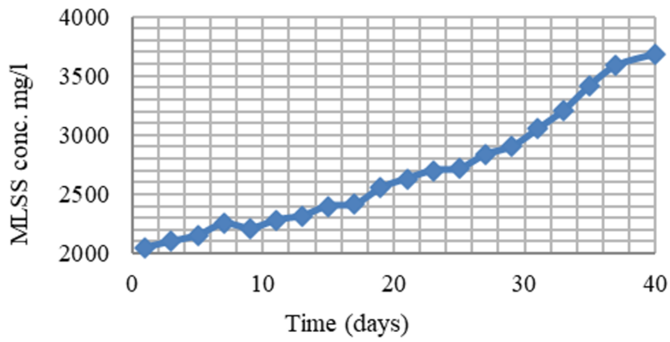

Figure 2. Variation of MLSS Conc. during the startup period

The removal rate of COD, NH_4-N, and TN were tested daily during this step. It showed an oscillating increase due to the oscillating increase in the MLSS concentration and other affecting factors such as temperature, pH, influent nutrient concentrations, etc. The startup period was finished when the removal rate of the pollutants became stable and that occurred after approximately 40 days of startup and acclimation process. The low removal rate for TN is noticeable during this period due to the following reaction steps (Anoxic/Oxic) in which the inhibition in TN concentration by the nitrification process was compensated by conversion of the ammonia-nitrogen to nitrate nitrogen without final anoxic conditions to achieve a denitrification process.

3.2 Optimization process

First of all, the MLSS concentration is reduced from 3683 to 2410 mg/L before starting the optimization experiments in order to avoid losing the ability of sludge to settle into distinct layers at high MLSS concentration [28]. Then the effect of reaction step number, Reaction phase time, and sludge age were investigated to determine the optimum removal rate for pollutants. The applied operational conditions during the optimization stage are listed in Table 2.

3.2.1 Effect of reaction steps number

Two scenarios with different numbers of reaction steps were experimented with using similar operation conditions except for the time. The reaction phase in the first scenario consists of two steps 1/3 hr of Ax/Ox conditions, respectively while the second scenario consists of three steps1/3/3 hr of Ax/Ox/Ax conditions respectively. Each scenario was repeated three times and the average removal rate of pollutants was measured. Figure 3 depicts the removal rates of pollutants as an average of three cycles for the tested scenarios.

Table 2. The applied operational conditions

Description	Symbol	Unit	Value	Notes
Influent flow	Q	m^3/d	37	Based on influent wastewater velocity and SBR tank volume
Fill time	tf	min	2.7	Based on the influent flow and effective volume of the SBR tank
Reaction time	tr	min	investigated	Research subject
Settling time	ts	min	30	Based on the study [25]
Draw time	td	min	2.7	Based on effluent flow and effective volume of the SBR tank

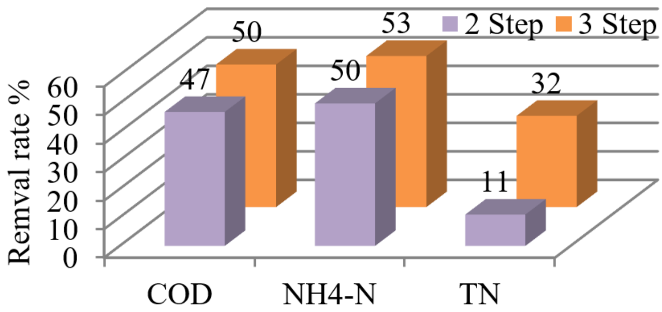

Figure 3. Overall pollutant removal rates using different reaction steps

Experimentally:

The results revealed that the average COD removal rates were 47% and 50% for the first and second scenarios, respectively. Based on these outcomes, the three reaction-steps operation Ax/Ox/Ax seems to be slightly more advantageous depending on the COD removal rate due to the extra COD consumption that might occur due to the denitrification process in the second anoxic step [7].

The average NH_4-N removal rates were 50% and 51% for the first and second scenarios, respectively. These results are close to each of them because NH_4-N consumption was carried out during the aerobic condition, so adding a second anoxic reaction step doesn't affect the rate of ammonia-nitrogen consumption [7].

TN removal rates as the average of three cycles for the first and second scenarios were 11% and 32% respectively. Obviously, there is a clear variance in the results of the implemented scenarios. This difference is returned to NO_3-N removal in the second scenario which is generated due to the nitrification process in the aerobic reaction phase, so adding the second anoxic reaction step is important to NO_3-N removal (denitrification process) which leads to raising the rate of total nitrogen removal [7], so the second scenario of Ax/Ox/Ax reaction steps seems to be a logical choice depending on the results of TN removal rate.

Theoretical explanation:

When using two stages (anoxic and aerobic), In the anoxic stage, due to the lack of oxygen, Nitrate-Nitrogen (NO_3-N) acts as an electron acceptor in decomposing and removing the existing organic matter. When oxygen is depleted, the removal process stops until the aerobic stage begins, where oxygen acts as an electron acceptor in the process of removing pollutants. During this stage, Nitrate-Nitrogen (NO_3-N) is produced as a result of the nitrification process, in the presence of oxygen. This is the reason for the high final total nitrogen content (Nitrate-N + Nitrite+TKN) when using only two reaction stages. Therefore, it is necessary to use a third stage with (anoxic condition) to consume the nitrate-N produced in the aerobic stage, thus reducing the final total nitrogen concentration in the effluent wastewater [7].

3.2.2 Effect of reaction phase time

The SBR unit is operated with three reaction steps Ax/Ox/Ax. The time of each step varied at 4 levels, while the time of other cycle phases are remained constant. The most appropriate time for optimum pollutant removal rate is determined for each step.

<u>First step (anoxic)</u>

Theoretically:

The main functions of the anoxic step are the removal of COD and the de-nitrification process which is carried out in the lack of DO using the Nitrate-Nitrogen as an electron acceptor in the anoxic growth of heterotrophic bacteria [7].

De-nitrification process involves the conversion of Nitrate-Nitrogen or Nitrite-Nitrogen (found in raw wastewater) to Nitrogen gas (N_2) in the conditions of dissolved oxygen (DO) lack as shown in the following expression [7].

$$NO_3 \rightarrow NO_2 \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

The de-nitrification is also known as anoxic respiration whereas (NO_3-N or NO_2-N) is became the oxidizing agent (i.e. electron acceptor). Most of the de-nitrifiers are facultative (capable of utilizing DO or NO_3-N as an electron acceptor) such as Pseudomonas, Bacillus, Methanomonas, Paracoccus, Spirillum … etc. A lot of microorganisms are capable of changing their metabolism and using nitrate-N instead of DO as an electron acceptor [7].

Generally, the time of the 1st Ax reaction period affects the decomposition of organic compounds by microorganisms and thus easily dissolves through the next oxic step.

Experimentally:

The variation of COD, NH_4-N, and TN removal rates with the time of the first anoxic step is represented in Figure 4 as an average of three cycles for each experiment. The time of the first anoxic step is varied between 0.5-3 hr while the other times of aerobic and second anoxic reaction steps are kept constant at 3 and 3 hr respectively. The used anoxic times are 0.5-1.0-2.0-3.0 hr. Each time is investigated for three cycles and the results are obtained as an average of the three cycles. The overall percentage of COD, NH_4-N, and TN removal rates ranged from 35 to 67, 37 to 65, and 29 to 42% respectively.

Experimentally:

From Figure 4, the removal rates of pollutants were increased till two hours. It's also noticed that the final removal rate for TN increased slightly (not proportional to the added time) when the time increased by more than two hours.

Theoretically, that means NO_3-N concentration which represents the electron acceptor in the anoxic conditions was close to zero after 2 hours of the anoxic condition. So, 2 hr is suitable for the first anoxic reaction step since the process requires lower operating time and results in acceptable removal rates for the tested pollutants.

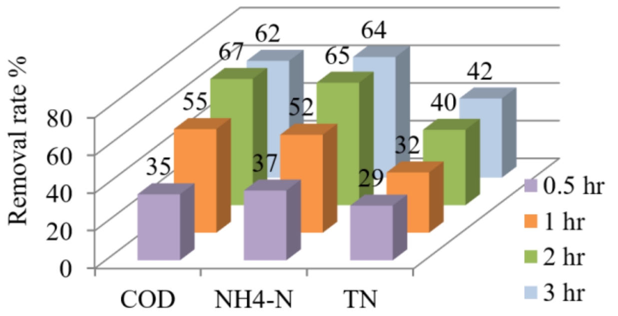

Figure 4. Overall pollutant removal rates at different 1st anoxic time

The overall percent of COD, NH_4-N, and TN removal rates at anoxic time of 2 hr were 67%, 65%, and 40%, respectively as an average of three cycles.

<u>The second step (oxic)</u>

Theoretically:

The major functions of the oxic reaction step are COD removal and the nitrification process

The expression "nitrification" refers to the biological oxidation of ammonia-nitrogen carried out by autotrophic bacteria (Nitrifiers) which exist in wastewater treatment plants (WWTPs). The process involves two steps; The first one includes the transformation of ammonia-nitrogen (NH_4^+-N) to Nitrate-Nitrogen (NO_2-N) by a group of "Nitrosomonas" Bactria, then the transformation of Nitrate-Nitrogen to Nitrate-Nitrogen (NO_3-N) by a group of "Nitrobacter", as shown in the following equations [7]:

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H+ + \text{Energy}$$
$$2NO_2^- + O_2 \rightarrow 2NO_2^- + \text{Energy}$$

The dissolved oxygen represents the electron acceptor in this process. NH_4-nitrogen is utilized as a source of nitrogen for the synthesis of cell mass in the nitrification process.

Experimentally:

The time of the second step, oxic reaction (aerobic reaction step) is varied from 2-8 hr while the other times of the first and second anoxic reaction steps remained constant at 2 and 3 hr respectively. The used aerobic times are 2.0-4.0-6.0-8.0hr, each time is investigated for three cycles. The removal rate of (COD, NH_4-Nitrogen, and total Nitrogen) using different times for aerobic steps is represented in Fig.5 as an average of three cycles for each time. The overall percentage of COD, NH_4-N, and TN removal rates ranged from (40 to 92, 45 to 93, and 30 to 63) % respectively for aerobic times varied between (2-8) hrs.

From Figure 5, it's clear that the percentage of COD removal increases with the increase in the aerobic time till 6 hr, then the removal rate shows a slight increase with time.

The ammonia-N removal rate is directly proportional to the aerobic reaction time due to the nitrification process and aerobic growth of heterotrophic bacteria.

For the Total nitrogen removal rate, the results show that; it increases with time till 6 hr to reach 63% then it decreases to 40% at 8 hr because of the accumulation of Nitrate-Nitrogen resulting from the nitrification process which isn't removed during the second anoxic reaction phase due to the consumption of all biodegradable COD entirely during the long aerobic reaction phase (the availability of biodegradable COD is essential for denitrification process).

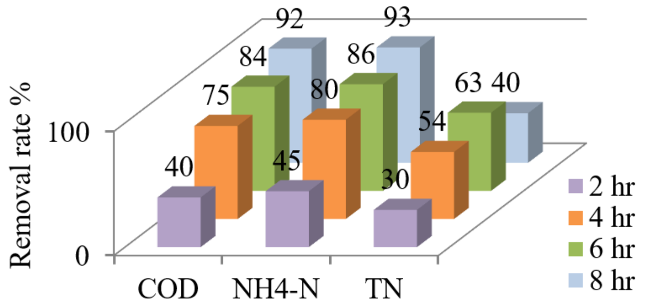

Figure 5. Overall pollutant removal rates at different times of aerobic step

So according to the above results, 6 hrs is the most suitable choice for the aerobic reaction step. The overall percent of COD, Ammonia-N, and Total-N removal rates at aerobic intervals of 6 hr was (84, 86 and 63) % respectively as an average of three cycles.

<u>Third step (anoxic)</u>

Theoretically:

The main functions of the second anoxic reaction step are COD removal, de-nitrification of Nitrate-N produced during the aerobic step as a result of the nitrification process, reducing the acidity of the SBR reactor contents, and enhancement of the settling ability by preventing the growth of filamentous bacteria which causing sludge bulking problem which is considered as a common problem in the suspended growth systems [7].

Experimentally:

The time of the second anoxic reaction step varied between (0.5-3 hr), while the other times of the first anoxic and aerobic reaction steps remained constant at (2 and 6) hr respectively. The times used for 2nd anoxic step are (0.5-1.0-2.0-3.0) hr.

Figure 6 shows the variability of (COD, NH_4-nitrogen, and Total-nitrogen) removal rate with time in this step as an average of three cycles for each experiment. The overall percentage of (COD, Ammonia-N, and Total-N) removal rate is varied from (83 to 86, 85 to 87and 50 to 63) % respectively.

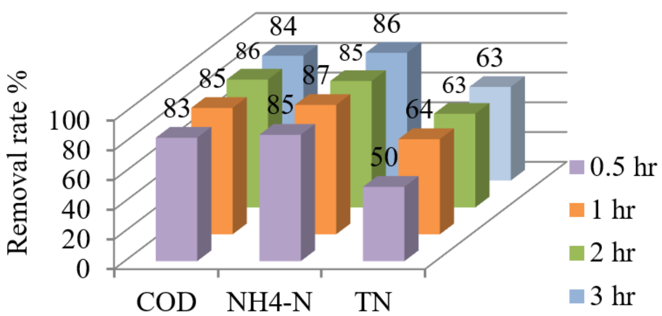

Figure 6. Overall pollutant removal rates at different times for 2nd Ax step

The above results mean that; the available biodegradable

COD is consumed within approximately one hour of anoxic conditions; therefore, there is no significant difference in pollutant removal rate results by increasing the time of 2nd anoxic conditions by more than one hour.

So, the enough time for this step is 1 hr. The overall percent of COD, NH_4-N, and TN removal rates at 2nd anoxic time of 1 hr was 85, 87, and 64 % respectively as an average of three cycles.

3.2.3 Effect of sludge age

Sludge ages ranging between (5-30) days were investigated, while the time of reaction steps remained constant at the optimum values (2/6/1) hr for (Ax/Ox/Ax) conditions respectively which were discovered previously. The used sludge ages are (5-10-20-30) days. The process is done by removing a portion of the mixed liquor from the SBR reactor before settling every day to adjust the age of the sludge to the required level [24, 25]. Then the effect of sludge age on pollutant removal rate, MLSS concentration, and sludge volume index is investigated.

<u>Relationship between sludge age and Pollutants Removal Rates:</u>

The overall percent of (COD, ammonia-nitrogen, and Total-nitrogen) removal rate with various values of sludge age is shown in Figure 7, as an average of three cycles for each experiment.

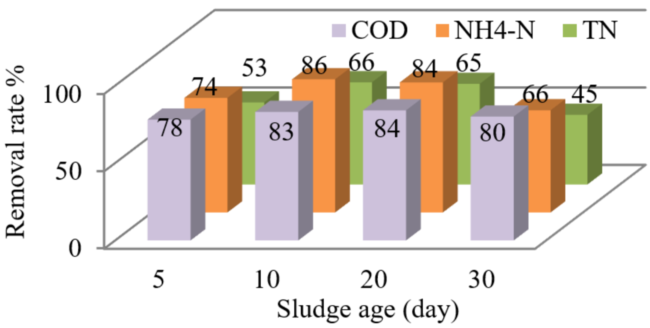

Figure 7. Overall pollutant removal rates at different sludge ages

Maximum COD removal rates are determined at (10 and 20) day of sludge age, which were (83&84) % respectively.

The maximum removal rate for NH_4-N is (86%) which is obtained at 10 days of sludge age. The ammonia-N removal rate is noticed to be relatively low (53%) at 5 days of sludge age, that's maybe the result of nitrifiers washout under low sludge ages. Also, Poor nitrification is noticed at 30 day of sludge age, the reason may be the return to the old population of nitrification micro-organisms [24].

For TN removal rate, the optimum sludge age is 10 days which gave a maximum removal rate of 66%.

From Figure 7, it's clear that the removal rate of TN is decreased at 30 days of sludge age, due to the low nitrification rate at that sludge age which is reflected in the Total nitrogen removal rate because of that; ammonia nitrogen represents the main part of the Total nitrogen.

<u>Relationship among sludge age, MLSS concentration, and SVI:</u>

The relationship between sludge age and MLSS concentration is investigated too. Figure 8 shows the results of this part of the investigation.

The Figure 8 shows that MLSS concentration increases with the increase in sludge age due to the settling process and transferring of the biomass to the following cycle. MLSS concentration is increased from (2288 mg/l) at the sludge age equals 5 days to 3255 mg/l at the sludge age of 30 days.

High MLSS concentration reduces the ability of sludge to settle into distinct layers, so it's undesirable [24]. The variation of SVI with the age of sludge is shown in Figure 9. The results show that SVI increases with the increase of sludge age due to the increase of settled sludge volume.

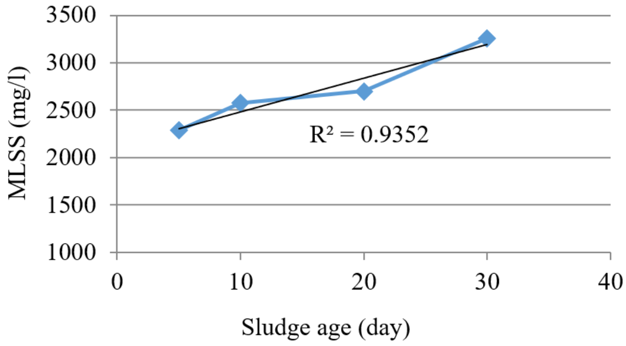

Figure 8. Variation of MLSS with sludge age

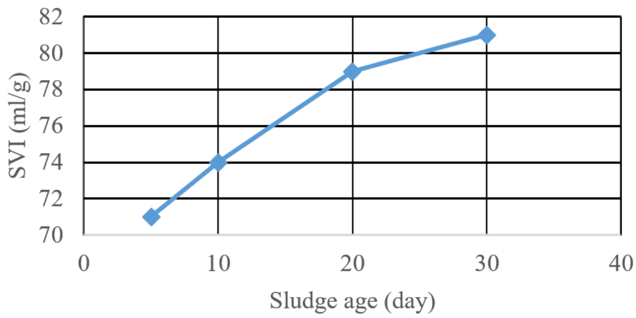

Figure 9. The variation of SVI with sludge age

SVI is an effective parameter for process performance. Low SVI (less than 100 ml/g) leads to good settling properties of the sludge while high SVI (greater than 100 ml/g) leads to a sludge bulking problem [24].

So according to the above results; a sludge age of 10 days is a suitable choice for optimum nutrient removal rates, optimum MLSS, and SVI.

The overall removal rate for COD, NH_4-N, and TN at a sludge age of 10 days are (83, 86 and 66) % respectively with MLSS concentration of 2578 mg/l and SVI 74 ml/g and that matches with the typical range of design parameters for SBR systems which limits MLSS concentration with (2000-5000 mg/l) and sludge age (10-30 day) [23].

4. CONCLUSIONS

According to all experimental results, it's clear that:

Sequencing batch reactor system can be used successfully for treating the real domestic wastewater in Al-Nasiriya City and achieving high removal rate for pollutants which were 83, 86 and 66 % for COD, NH_4-N, and TN, respectively, and the effluent matching with the local standard limitations. The following values for operational parameters can be considered as the optimum for local conditions in Al-Nasiriya City.

•Using three reaction steps of (anoxic/aerobic/ anoxic) conditions respectively.

•The optimum times for reaction phase steps are 2/6/1hr for Ax/Ox/Ax reaction steps respectively.

•A sludge age of 10 days represents the optimum value for sufficient pollutant removal rates, MLSS, and SVI.

As a future study, it is recommended to perform:

•Using a large-scale of SBR model to compare the results with the pilot scale results which used in this study.

•Studying the phosphorus removal rate using the SBR process.

•Investigate the performance of the SBR process in treating other types of raw wastewater such as industrial wastewater.

•Finding a cost analysis of wastewater treatment by SBR process.

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NOMENCLATURE

SBR	Sequencing batch reactor
PVC	Polyvinyl chloride
PCP	Programmable control panel
COD	Chemical oxygen demand
TKN	Total Kjeldahl nitrogen
NH_4-N	Ammonia nitrogen
NO_3-N	Nitrate nitrogen
TN	Total nitrogen
WWTP	Wastewater treatment plant
ASP	Activated sludge process
N	Nitrogen
C	Carbon
P	Phosphorous
BOD	Biological oxygen demand
OX	Oxic
AX	An oxic
BPR	Biological phosphorus removal
MLSS	Mixed liquor suspended solids
DO	Dissolved oxygen
T	Temperature
HRT	Hydraulic retention time
Q	Influent flow
tf	Fill time
tr	Reaction time
ts	Settling time
td	Draw time
SVI	Sludge volume index