SCIENTIFIC OASIS

Decision Making: Applications in Management and Engineering

ISSN: 2560-6018, eISSN: 2620-0104

USING LAB SCALE SEQUENCING BATCH BIOFILM REACTOR (SBBR) FOR DOMESTIC WASTEWATER TREATMENT WITH OPERATION PHASES AND COST COMPARISONS

Zana Azeez Mohammed Ameen[1*], Shuokr Qarani Aziz [2]

[1] Department of Civil Engineering, College of Engineering, Salahaddin University-Erbil, Kurdistan Region, Iraq. Email: zanaaziz79@gmail.com, zanazana225@yahoo.com

[2] Department of Civil Engineering, College of Engineering, Salahaddin University-Erbil, Erbil, Kurdistan Region, Iraq. Email: shokr71@yahoo.com

* Corresponding Author: Zana Azeez Mohammed Ameen

Email: zanazana225@yahoo.com,

Abstract

Recently, modifying of conventional Sequencing Batch Reactor (SBR) treatment technology has been researched and developed extensively to enhance performance as well as to be cost effective. One of the most recent uses of modified SBR (MSBR) is sequencing batch biofilm reactor (SBBR) treatment technology. In this study, SBBR was applied as a modified version of SBR for domestic wastewater (DWW) treatment to achieve the effluent standards, cost effective and flexibility in operation. This study was carried out through the laboratory-scale tank which operated in both SBR and SBBR system for DWW treatment of residential apartments in Erbil city. Chemical oxygen demand (COD), total suspended solids (TSS), and ammonia-nitrogen (NH_3-N) for the real fresh DWW were 250 mg/L, 300 mg/L and 13 mg/L, respectively. The results of SBBR revealed that the removal efficiencies of TSS, COD, and NH_3-N were 88.2%, 95.5% and 81.7% respectively, for organic load 400 g COD/m^3.d, 17.42 g NH_3-N /m^3.d and hydraulic retention time (HRT) was 18 hrs. While, removal efficiencies for the TSS, COD, and NH_3-N in SBR were 89.5%, 92.8% and 82.5% correspondingly. Both SBR and SBBR effluent quality were meet discharge standards after comparison with Iraqi standard of effluent discharge. SBBR was more cost-effective comparing to SBR which, saving 5415 Iraqi Dinars (ID) for one kWh per annum. SBBR was superior than traditional SBR regarding cost effectiveness as well as start-up period which was slightly faster than SBR benefiting from biomedia plastic carrier. SBBR was applied due to their advantages in different residential projects as decentralized wastewater treatment plant (WWTP) in Erbil city.

Keywords: Biofilm, Cost effective, Domestic wastewater, Performance, SBBR.

1.0 Introduction

Erbil city has been largely developed and many large and small residential projects constructed, especially residential apartments. Still there is no centralized wastewater treatment plant (WWTP) in the city so far. The disposal of wastewater (WW) into environment without treatment is source of significant pollution problems threatening the communities, public health and environment. Also, treated WW can be reused for irrigation, carwash, landscape etc. (KOIKA and K-water, 2007). Currently, for this purposes Kurdistan Region Government (KRG) set new regulation and guidance about decentralized WWTP for these kinds of residential projects.

Using modified sequencing batch reactor (MSBR) in Erbil city as a new application technology or method for domestic WW (DWW) treatment. The modification of SBR has been made by using or adding moving bed biomedia (biofilms) inside SBR reactor. Active biomass grows in biofilms on the surfaces of plastic carrier elements which enhance performance, increase capacity and cost effective. This method would thus benefit WW utilities in Erbil. Especially for both medium and small-scale WWTPs.

In the recent years, due to their relative low cost biological treatment systems are widely used in wastewater treatment processes (Hibiya et al., 2000). Biological processes mainly can be classified as suspended growth and attached growth processes (Metacalf and Eddy, 2014). Generally, reactor is a vessel/tank in which a chemical or biochemical, physical separation process or any kind of biological activities takes place or happen. It may be operated either on a batch or continuous basis (Judd, 2013).

Newly, methods of enhancing of conventional SBR treatment technology have been researched and developed. Several modified versions of SBR are Sequencing Batch Biofilm Reactor (SBBR) (Gururaj and Kumar 2015; Abdelaziz et al., 2020; Al-Rekabi et al., 2021; Elhawary et ai., 2021; Al-Khafaji, et al., 2023), Intermittent Cycle Extended Aeration System (ICEAS) (Mahvi et al.,2004; Al-Rekabi et al., 2017), Powdered Activated Carbon SBR (PAC-SBR) (Aziz et al.,2011), Application of Anoxic phase in SBR (ASBR) and SBR retrofit with integrated fixed film activated sludge (SBR-IFAS) (Veolia - AnoxKaldnes Hybas, 2023), Multiple reactors that operate through a series of stages (Aqua MSBR) (Aqua- Aerobic System Inc., 2022) etc. However, there are many design and operation parameters can be improved and developed which lead increasing the overall capacity of conventical SBR such as aeration system, time of cycle etc. (Aziz and Fakhrey, 2017). Nowadays, MSBR plants have become more popular in the business, due to their advantages after improvement and upgrading., There are many different scale WWTPs around the world which based on MSBR treatment process ranging from large-full scale size to small scale size (package plant). According to Gururaj and Kumar (2015); Abdelaziz et al. (2020); Al-Rekabi et al. (2021); Elhawary et ai. (2021); Al-Khafaji, et al. (2023) the conventional SBR was upgraded by using attached growth methods (fixed film). The modification was done by adding biofilm carriers (moving bed bio media) with a specific surface area. SBBR was an innovative application technology, can increase the capacity of a SBR in the same footprint as a conventional SBR without the need for additional tankage or increasing footprint. Enhance performance to increase the removal of efficiency and cost effective. SBBR is an effective system / cost effective and has good and flexible operational stability (Aqua-Aerobic System Inc., 2022). One of the most recent uses of modified sequencing batch reactor (MSBR) is sequencing batch biofilm reactor (SBBR) treatment technology. (Al-Khafaji, et al., 2023). In this study SBBR was applied as a modified version of SBR for DWW treatment to achieve the discharge standard, cost effective and good operation.

2.0 Materials and Methods

2.1 Study Area

Central Park is one of the residential projects located on Gullan Street 40 m - Ronaki Quarter in Erbil city, Kurdistan Region-Iraq, Figure 1. It is approximately 3 km far from down town/city centre. The geographical coordinate is 36° 09’ 56” N and 44° 01’ 17” E. The real DWW was collected from Central Park Apartment No. 1 (CP1). The amount of produced WW was estimated around 85 m^3/day for only one apartment (CP1). When, estimated population is about 500 persons equivalent (PE) and water supply consumption is 200 litre per PE/day . Factor of WW generation from water supply is 0.85 (Metacalf and Eddy, 2014).

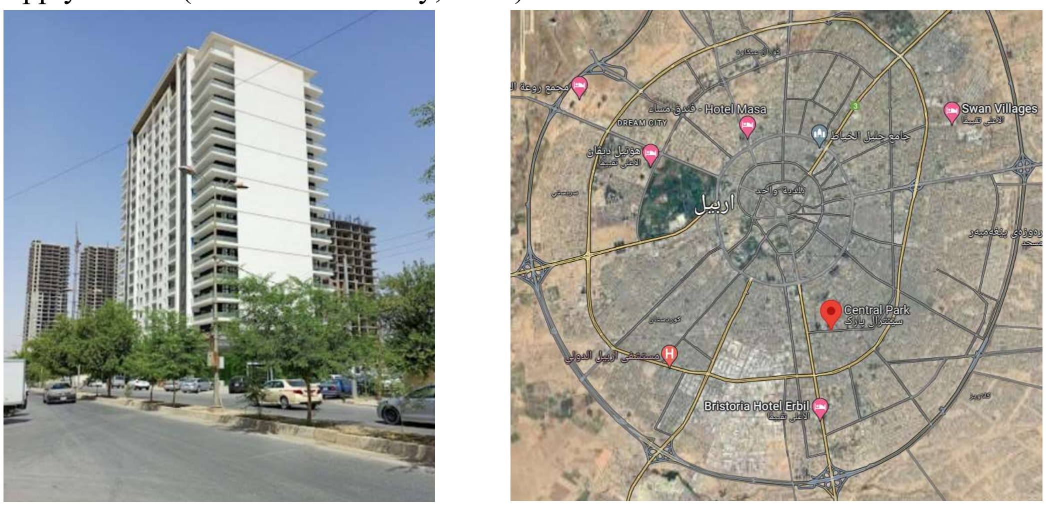

Figure 1. Photo and satellite image of study area

2.2 WW Sampling and Analysis

DWW collected from residential apartments of residentials area in Erbil city from equalization tank. The WW quality analysis was done for the pollutant parameters such as COD, TSS, and NH_3-N as well as pH and Temperature. Collection of samples and analysis were done according to (American Public Health Association APHA, 2005). All the experiments were carried out in the Erbil Directorate of Environment and laboratory of Civil Engineering Department, Salahaddin University-Erbil. The analytical methods which used in this study were followed Standard Methods for the Examination of Water and Wastewater (APHA,2005). The instruments used during the experimental work are; Lovibond MD 600, APEL PD-303UV and DR3900 HACH spectrophotometers, EUTECH pH700 and HANNA HI97715.

 

Figure 2. Domestic Wastewater (DWW) samples for the study

2.3 Lab scale SBR and SBBR system configuration

In this study, the laboratory-scale SBBR vessel of total volume was 62.5 L with rectangular geometric shape length (L) 50 cm, width (W) 25 cm which L=2W, a height (H) of 50 cm, effective depth (D) of WW 36 cm and working volume was 45 L, Figure 2. Air blower (Type: MiT, B1TT-102, 0.25 Kw, 220-240 V, 50 Hz, Turkey) was used for supplying the air to the reactor. The airflow rate used was ≈100 L /min discharged through the disc diffuser (Aquaflex Disc Diffuser, ADD80-3”, EPDM diffuser membrane) network arrangement located at a height of 4 cm from the reactor bottom. The disc diffuser in 7.5 cm dimeter with air flow capacity about (3000 L/hr). Control electrical board on/off manual and auto, with timer. Correspondingly, using barometer gauge mm bar Aterma type small scale, with gate valve, control valve, flow meter, electrical pump, mixer, UPVC pipes and fittings etc.

Feeding, sludge wasting and withdrawing were accomplished by both pumping and gravity (gravitational force). Dissolved Oxygen (DO) concentration was kept always ≥ 3.0 mg/L within the aerobic process. Using/adding fixed biofilm (attached growth) carriers with a specific surface 650 m^2/m^3 as detailed in table 1. Without increasing in area (tank) all process will be in the same tank. Amount of %38 of working volume was selected and used for this specific type of moving bed media as shown in Table 1 and Figure 4 which, give approximately 11.115 m^2 of surface area inside the SBBR reactor (nearly 2166 NO.)

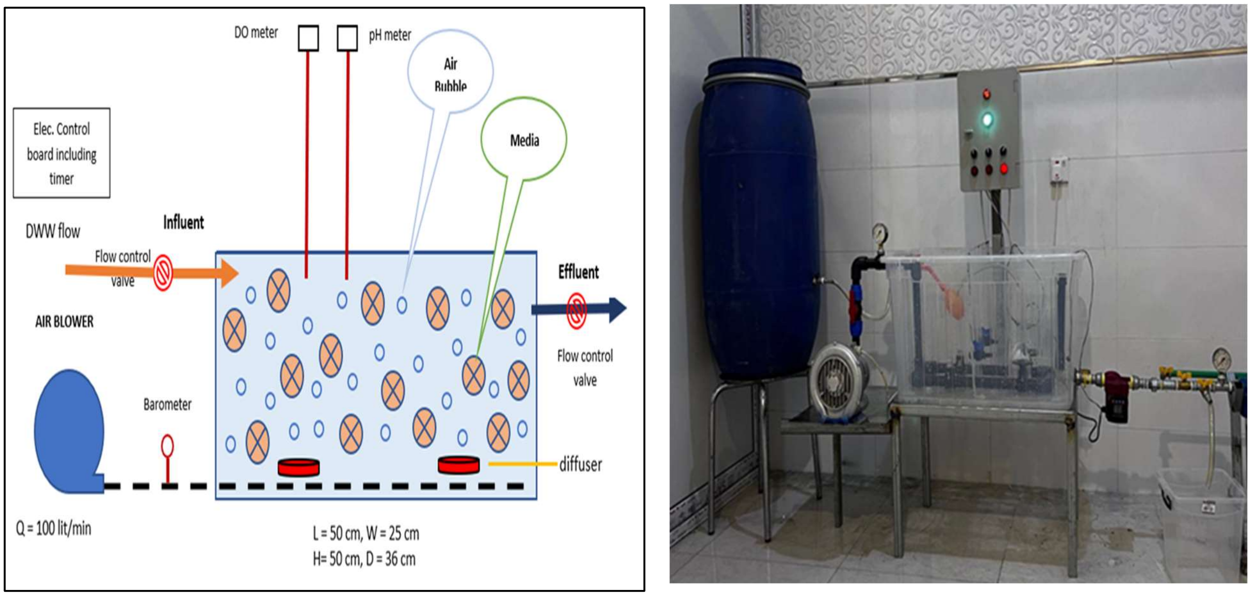

Figure 3. Sequencing Batch Biofilm Reactor (SBBR) Lab Scale Plant

Table 1. Biomedia plastic carrier (moving bed biomedia) description

Bio Media Plastic Carrier Description	
Diameter	26 mm
Width	10 mm
Effective Surface Area	5133 mm^2
Surface Area of	650 m^2/m^3
Approximate dia. and No. of inner departments	4-5 mm and 19 mm
Specific Gravity	< 1
Density	(bulk density) 0.92-0.96 g/cm^3
Material , colour and Structure type (shape)	PE Virgin, White and Cylindric Type
Max operation temp	5-60 °C
Number per m^3	100000 (approximately)
Efficiency of Nitrification	400-1200 (gNH_4-N/m^3.d)
COD (oxidation efficiency)	2000-15000 ($gCOD/m^3$.d)
% of Media fill range rate	%30-50 Fill of Volume

Figure 4. Bio Media Plastic carrier (moving bed biomedia)

2.4 Start-up and Operation

During the start-up phase, SBBR was operated at 4 cycle times during a day (6 hrs per each cycle) that was composed (fill 0.5 hr., react time 4.0 hr., settle 1.0 hr., and discharge 0.5 hr.), a total of 6 hours. After 23 days for the biofilm was grown in the reactor. While, SBR was operated at 3 cycle times during a day (8 hrs) that was composed (fill 0.5 hr., react time 5.5 hrs., settle 1.5 hr., and discharge 0.5 hr.), a total of 8 hours, Table 2. After 28 days for the biofilm growth in the reactor for SBR, then the test period started run for approximately 10 working days to get the results for different system operations after ensure that the biological treatment systems were mature and that the start-up requirements were reached. DO concentration is kept more than 3.0 mg/L within the aerobic process. Hydraulic retention time (HRT) was calculated as the ratio of cycle time to volumetric exchange rate applied. The organic loading rate (OLR) was determined by the following equation:

OLR = S*Q/V

Where S was the influent concentration, Q was the wastewater flow per day and V was the working volume of the reactor.

Table 2. Operation of SBR and SBBR

System	Time (Hour) 8 hrs					Cycle time	Operated Cycle/ Day	Flow L/Cycle	H.R.T Hrs	OLR COD g/m3.d	OLR NH3 g/m3.d
SBBR	**F**	**R**	**S**	**D**		6	4	15	18	400	17.42

SBR	**F**	**R**	**S**	**D**	8	3	15	24	400	17.42

Cycle		**SBBR**	**SBR**
F	**Fill**	0.5 hr	0.5 hr
R	**React**	4.0 hrs	5.5 hrs
S	**Settle**	1.0 hr	1.5 hrs
D	**Decant**	0.5 hr	0.5 hr

The operational conditions were used HRT of 18 - 24 hrs, aeration time varied from 4 to 5.5 hrs, operated cycle of 3 to 4 cycles per day. Influent concentration prepared of COD, TSS and NH_3-N were about 300, 250 and 13 mg/l respectively. The organic loading rates were 400 g COD /m^3.d, and 13.5 g NH^3-N /m^3.d. In addition, monitoring of pH and temperature were around 7.5 and 25 C^o . DO controlled by DO meter to maintain within the range for experiment.

3.0 Results and Discussions

3.1. DWW Characteristics

The wastewater quality analysis was done for the pollutant parameters such as COD, TSS, and NH_3-N as well as pH and Temperature. The results were shown and summarized in Table 3.

Table 3. The characteristic of domestic wastewater samples

No	Parameter	Unit	Sample week1	Sample week 2	Sample week3	Sample week4	Average	*Effluent Sewage (mg\L) Iraqi Standard
1	TEMP.	C^0	25.2	25.5	24.8	26.1	25.4	35^0 >
2	PH	-	7.8	7.5	7.4	7.9	7.6	6.4-8.5
3	COD	mg/l	285	310	296	338	307.3	100
4	NH3-N	mg/l	12.8	13.4	11.7	12.4	12.56	5
5	TSS	mg/l	225	265	278	238	251.1	40

*(Al-Khafaji, et al., 2023)

Generally, pH has slightly alkaline maximum was 7.9 and minimum was 7.4 of the samples which were within the Iraqi standard. The pH is a critical parameter that needs to be measured because of bacterial growth and culture of microorganisms. Regarding temperature, biological and chemical reaction are affected by temperature. The temperature was stable because collection basin or equalization tank of WWTP was under ground in the basement of apartment. It was within the Iraqi standard. TSS, COD and NH_3-N were slight fluctuations during the period, see table 3.
When the used domestic sewage characteristics were compared to the untreated domestic wastewater typical characteristics of, TSS (250mg/L), COD (300 mg/L), were considered to be in the medium strength range, while Ammonia NH_3-N (13 mg/L) was found to be in the low (weak) range as shown in Table 4.

Table 4. Comparison domestic wastewater with raw domestic sewage, (Metcalf and Eddy,

2003)

Pollutant in (mg\L)	Raw Wastewater Mean Value in (mg\L)	The Concentrations of International Domestic Wastewater		
		Low	Medium	High
COD	300	250	430	800
Ammonia NH_3-N	13	12	25	45
TSS	250	120	210	400

3.2. Performance of SBR and SBBR

Firstly, in SBR system, the filling was 30 min, the reacting was 5.5 hrs, the settling was 90 min, and the drawing(decant) was 30 min. Subsequently, total cycle was 8 hrs with 3 cycles/day. HRT was 24 hrs the removal rates of TSS, COD, and NH_3-N reached about 89.5%, 92.8% and 82.5%, respectively, Figure 5 and Table 6.

Secondly, in SBBR system, the filling was 30 min, the reacting was 4 hrs, the settling was 60 min, the drawing was 30 min, So, total cycle was 6 hrs with 4 cycles/day. The HRT was 18 hrs the removal rates of TSS, COD, and NH_3- N reached 88.2%, 95.5% and 81.7% respectively, Figure 5 and Table 6.

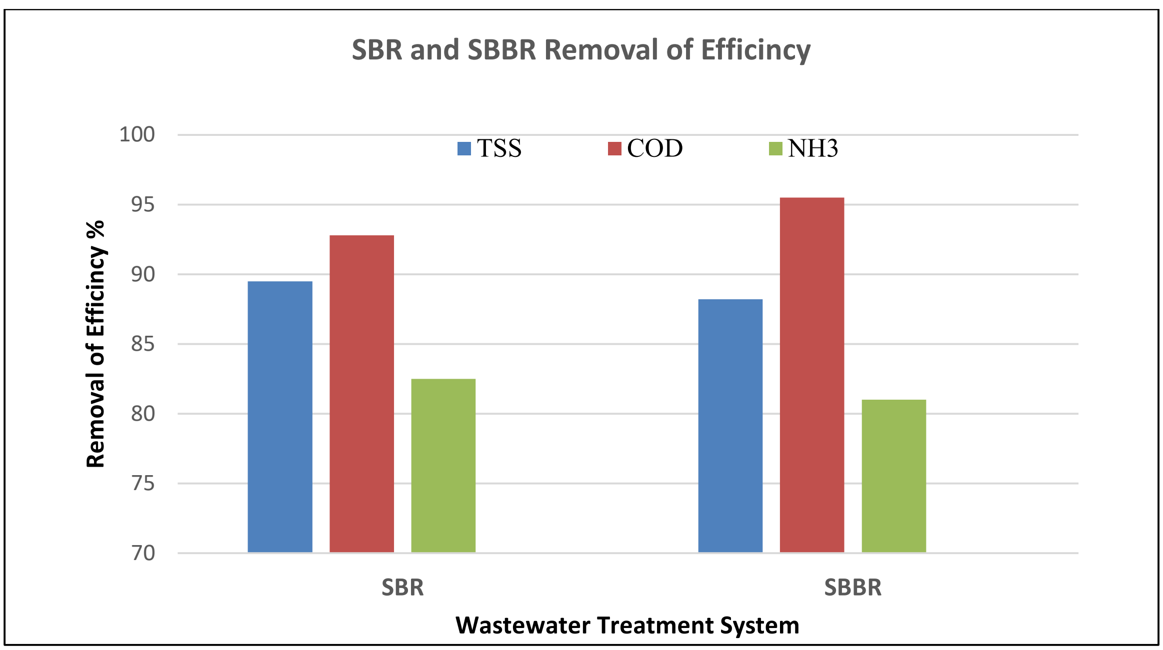

Figure 5. SBR and SBBR Removal of Efficiency

Regarding affluent quality, when comparing both SBBR and SBR effluent to the Iraqi standards. it was noticed that TSS, COD and NH_3-N concentration (mg/L) met these standards, Table 5.

Table 5. The comparison of SBR and SBBR effluent with Iraqi standard of effluent discharge

Parameters	SBR Effluent in	SBBR Effluent in	Standards of Effluent Sewage (mg\L) Iraqi Standard (MOHE, 2012), (Al-Khafaji, et

	(mg\L)	(mg\L)	al., 2023)
COD	21.6	13.5	100*
Ammonia	2.275	2.47	5**
TSS	26.25	29.5	40*

* (Aziz and Ali, 2018), ** (Al-Khafaji, et al., 2023)

The results of experiments show that, TSS, COD and NH_3-N removal of efficiencies for both SBR and SBBR in same operation condition was follow:

In SBBR system, the removal efficiency of COD, TSS and NH_3-N was around 95.5%, 88.2% and 81.7%, respectively. But, in SBR system the removal rates of TSS, COD, and NH_3- N reached 89.5%, 92.8% and 82.5%, respectively, Table 6 and Figure 5. HRT was 18 hrs. and The organic loading rate were 400 g COD /m^3.d, and 13.5 g NH_3-N /m^3.d.

The outcomes were compared to SBR which has very little differences in percentage for TSS and NH_3-N removal and slightly increasing in COD removal from SBBR due to presences of bio-media.

Table 6. SBR and SBBR Average Removal of Efficiency %

System	TSS		COD		NH3-N	
	%Removal	Effluent	%Removal	Effluent	%Removal	Effluent
SBR	89.5	26.25	92.8	21.6	82.5	2.275
SBBR	88.2	29.5	95.5	13.5	81.7	2.47

* Removal of Efficiency in (%) = (C1 – C2)/C1 × 100

where C2 and C1 were the effluent and influent concentrations of the parameters

Moreover, the outcomes were compared to other SBBR studies as shown in Table 7.

Table 7. Removal efficiency of other SBBR studies, (Al-Rekabi et al., 2021).

References	Year	Removal of Efficiency (%)	
		Ammonia	COD
Ding et al. (2010)	2010	90	95
Ding et al. (2011)	2011	90	90
Jin et al. (2012)	2012	92	85
Cai et al. (2013)	2013	---	86
Wang et al. (2015)	2015	85	93
Al-Rekabi et al. (2021)	2021	86.24	90.23

Both COD and NH_3-N removal were benefitting from Bio-media as shown in table 7. Adding moving bed biomedia (biofilms) inside SBR reactor. Active biomass grows in biofilms on the surfaces of plastic carrier elements which enhance performance, increase capacity and cost effective. According to the operation and design of biofilm reactor in SBBR system which is a single vessel (tank) reactor with activated sludge system. It operates in time rather than in space as a batch reactor for wastewater treatment. In SBBR capacity of treatment can be increased without increasing of area (foot print) or any other tank because all processes still in the same tank. Cycle time increased mainly due to decreasing of react time (aeration) from 3 to 4 cycles/day.

3.3 Cost Effective

Aeration is the main parameter that affect operational cost which, lead to high operational expenditure (OPEX) in WWTPs. Accordingly, decreasing aeration time is very important to achieve cost- efficient (Aziz and Fakhrey, 2017). It is clear that, SBBR has less aeration compare to SBR which has 5.5 hrs aeration. At the same time both of them achieved the consent of discharge effluent. However, removal of efficiencies has very little differences in percentage for TSS and NH_3-N removal and slightly increasing in COD removal from SBBR due to presences of biomedia, Figure 5 and Table 5.

On the other side, adding or using moving bed biomedia in SBBR lead to increase capital expenditure (CAPEX). But fortunately, it is very cheap compare to the cost of aeration (OPEX) which can be neglecting. As a result, SBBR is more cost-effective compare to SBR. Furthermore, decreasing react period (aeration time) led to increasing cycle time period per day. Subsequently, increasing capacity without increasing foot print or add another tank (extra land). For instance, one piece of plastic biomedia that used for this study is about 3 Iraqi Dinars (ID) compare to the cost of aeration which done by air blower through a network of pipes including fittings and diffusers as well as more aeration more energy (electricity kWh) as OPEX. According to the ministry of electricity in KRG, price of electricity in kWh for industrial purposes is 120 ID as shown in table 8.

Table 8. Cost comparative for SBBR and SBR system

System	Cost of electricity for operation (OPEX)				Cost of biomedia as Investment cost (CAPEX)		
	Price kWh ID	Aeration kWh/day	Amount ID/day	Amount ID/year	Pieces (pcs) of biomedia	ID/Pcs	ID
*SBBR	120	4	480	175200	2166	2.5	5415
**SBR	120	4.125	495	180675	-	-	-
Difference in cost of electricity for operation in ID per one year as (OPEX) between SBR and SBBR				5475	Difference in CAPEX between SBBR and SBR		5415

* SBBR
Air Blower (Aeration)
0.25 kW x 4 h / cycle = 1 kWh/cycle
1 kWh/cycle x 4 cycle /day = 4 kWh/day
** SBR
Air Blower (Aeration)
0.25 kW x 5.5 h / cycle = 1.375 kWh/cycle

1.375 kWh/cycle x 3 cycle /day = 4.125 kWh/day

3.4 Operation Conditions

SBBRs system are a single vessel (tank) reactor with activated sludge system. It operates in time rather than in space as a batch reactor for wastewater treatment. In SBBR capacity of treatment can be increased without increasing of area (foot print) or any other tank because all processes still in the same tank. Cycle time was increased mainly due to decreasing of react time (aeration) from 3 to 4 cycles/day.

Generally, SBR and SBBR were operated for different operating conditions. Nowadays, automation by programmed logic controller (PLC), and supervisory control and data acquisition (SCADA) make SBR and SBBR are more easy and very simple in operation for various conditions and allows to adjust the work parameters to the various conditions. In the past, WWTP that based on SBR known as complex in operation due to more complicated process which need skill operators (Water Environment Federation,1996) and suffering from supporting by technologies in operation. But currently, well known as highly flexible, modular wastewater treatment system. Easy installation. simple, intuitive operation, due to developments and improvements in technologies in recent years that related to operation of WWTPs. Therefore, around the world MSBR plants have become more popular over the last years. According to Ding et al. (2011), to optimize the operation of traditional SBBR and reduce the aeration phase, a newly developed intelligent controlling system was adopted to control the SBBR. Lab-scale SBBR operation condition was compared to common full-scale range in treatment processes based on SBR, Table 8. Because of existing moving bed biomedia (biofilm), SBBR was robustness in the process and resisting loading rate (shock load) (Wilderer et al.,1993). As well as, start-up period for SBBR was slightly faster than SBR.

In the end, SBBR is found as flexible technology which can be atomized in treating DWW which allows to adjust the work parameters to the various conditions for different residential projects.

Table 9. Operation of SBBR in Lab and common SBR Full-scale range.

…m …R	Cycle Time hr	Fill Time hr	React Time hr	Settle Time hr	Decant Time hr	Operated Cyc/Day	DO mg /l	pH	T C°	H.R.T Hrs	SRT day	Media % vol. SBBR	OLR COD Kg/m3.d	Control	tr…
…l …e …TP)	6-12	0.5-2	4-8	1-2	0.5-2	4-2	>2	6 - 8.5	40>	6-36	14-30	25 - 50%	0.15-9	PLC	0…
…o …e	6	0.5	4	1	0.5	4	≈3	≈7.5	25^0	18	25	38%	0.4	A/M	0…

A=Auto, M=Manual, PLC= programmed logic controller

4.0 Conclusions

The DWW characteristics of residential area (apartments) was medium strength range for COD (300 mg/l) and TSS (250 mg/l), while NH_3-N (13 mg/l) was low range. SBBR was able to treat domestic sewage in good performance. It has good removal efficiencies of TSS, COD, and NH_3-N were 95.5%, 88.2%, and 81.7% respectively and achieved the required effluent quality of TSS, COD, and NH_3-N were 29.5, 13.5, and 2.47 mg/l respectively. SBBR is more cost-effective comparing to SBR saving 5415 Iraqi Dinars per one kWh per annum. It has low OPEX due to lower react period (time of aeration) (differences of electricity consumption kWh) which is one of the main parameters that affect the operational cost in WWTPs. While, using moving bed biomedia in SBBR. But it is very cheap compare to the cost of aeration which can be neglecting. Start-up period for SBBR was slightly faster than SBR. Comparing SBBR to SBR, capacity of treatment can be increased about (33 %) without increasing of area (foot print) or any other tank because all processes still in the same tank. Cycle time increased mainly due to decreasing of react time (aeration) from 3 to 4 cycles/day. Over all, SBBR was an effective treatment technology. It has good performance, robustness in the process, flexibility in operation for various conditions as well as it is cost effective.

REFERENCES

Abdelaziz, H. A. , Moharram Fouad , Mohamed Mossad (2021), “Upgrading sequencing batch reactor using attached biofilm”, Water Environment Federation, Water Environment Research, pp1700–1713.

Abdelaziz, H. A. , Fouad, M., Mossad, M., (2020),” Effect of increasing organic loading rate on the performance of conventional and modified sequencing batch reactors “, Mansoura Engineering Journal, (Mej), Vol. 45, Issue 4.

Al-Khafaji, S. A., Al-Rekabi, W.S., Al-Saad, Z. A., Al-Shmailawi, A. H., (2023), “Sequencing Batch Biofilm reactor (SBBR) Performace in Domestic Sewage Treatment: Mini Review”, Eurasian Journal of Engineering and Technology, vol 15, pp96-105.

Al-Rekabi, W.S., Abbas, A. A., Abbas, S. A. (2017), “Municipal Wastewater Treatment Of Basrah City Using Intermittent Cycle Extended Aeration System (ICEAS) ”, Journal of Engineering and Sustainable Development Vol. 21, No. 02, March 2017, ISSN 2520-0917.

Al-Rekabi, W.S., Al-Khafaji, S. A., Hassan, A. H., Janna H., (2021), “ Effectiveness of Sequencing Batch Biofilm Reactor Technology to Treat Domestic Wastewater in Basrah City”, Journal of Ecological Engineering 2021, 22(8), pp 234–242.

APHA, (American Public Health Association), (2005),” Standard Methods for the Examination of Water and Wastewater, 21st ed., American public health association”, Washington DC.

Aziz S. Q., Ali S. M. (2018), Characteristics and Potential Treatment Technologies for Different, Kinds of Wastewaters, Zanco Journal of Pure and Applied Science, 30(s1), pp 122-134.

Aziz, S. Q., and Fakhrey, E. S., (2017), “Optimization of Aeration Style and Cycle Time for Treatment of Oil Refinery Wastewater Using Powdered Activated Carbon and Sequential Batch Reactor” , ZANCO Journal of Pure and Applied Sciences , Salahaddin University-Erbil ZJPAS (2017), 29 (1); pp 140-153 . (http://dx.doi.org/10.21271/ZJPAS.29.4.15).
Aziz, S.Q., Aziz, H.A., Mojiri, A., Bashir, M.J. and Abu Amr, S. (2013), “Landfill leachate treatment using sequencing batch reactor (SBR) process: Limitation of operational parameters and performance”, Int. J. Sci. Res. Knowl., 1(3), pp 34-43.
Aziz SQ, Aziz HA, Yusoff MS, Bashir MJK (2011). Landfill leachate treatment using powdered activated carbon augmented sequencing batch reactor (SBR) process: Optimization by response surface methodology. J. Hazard. Mater., 189: pp 404–413.
Aziz SQ (2011). Landfill Leachate Treatment Using Powdered Activated Carbon Augmented Sequencing Batch Reactor (SBR). Process Unpublished, PhD thesis, School of Civil Engineering, University Sains Malaysia.
Aziz S. Q., Omar I. A., Bashir M. J. K., Mojiri A. (2020), Stage by stage design for primary, conventional activated sludge, SBR and MBBR units for residential wastewater treatment and reusing, Advances in Environmental Research, 9, pp233-249.
Boon, A. G, (2003). “Sequencing batch reactors: a review”. Water and Environment Journal, vol.17, no. (2), PP 68-73.
Cho, B.-C.; Chang, C.-N.; Liaw, S.-L.; Huang, P.-T., (2001) “The feasible sequential control strategy of treating high strength organic nitrogen wastewater with sequencing batch biofilm reactor”. Water Sci Tech 2001, 43, p115-122.
Ding, D., Feng, C., Jin, Y., Hao, C., Zhao, Y., Suemura, T., (2011). “Domestic sewage treatment in a sequencing batch biofilm reactor (SBBR) with an intelligent controlling system”. Desalination 276 (1–3), pp260–265. https://doi.org/10.1016/j.desal.2011.03.059
EPA, U.S. (1986), “Summary report Sequencing Batch Reactor” United States Environmental Protection Agency EPA/625/8-86/011. Washington D.C.,Summary report Sequencing Batch Reactor.
Elhawary A.S., Rozaik E.H., Zaher K., (2019),” Effect Of Biofilm Filling Rates , Various Cycles Duration And Organic Loading Rates On Organic And Nutrients Removal In Sequencing Batch Biofilm Reactor (SBBR)”,International Research Journal of Engineering and Technology (IRJET), Volume: 06 Issue: 02, www.irjet.net
Gururaj A, Kumar BM, (2015), “Comparison of Performance Sequencing Batch Biofilm Reactor (SBBR) For The Treatment OF DOMESTIC. International Journal of Current Research. Vol. 7, Issue, 07, pp.18147-18150.
Hibiya, K., Tsuneda, S. and Hirata, A. (2000), "Formation and characteristics of nitrifying biofilm on a membrane modified with positively-charged polymer chains", Colloids and Surfaces B: Biointerfaces, vol. 18, no. 2, pp. 105-112.
KOIKA and K-water.(2007), “The Erbil water supply and sewerage system improvement project”, Final report, Erbil-KRG.

Mahvi, A. H. (2008). “Sequencing Batch Reactor: A promising technology in waste water”, Iranian Journal of Environmental Health and Science Engineering, 5(2), pp79- 90.

Mahvi, A.H., Mesdaghinia, A.R. and Karakani, F. (2004). “Feasibility of continuous flow sequencing batch reactor in domestic wastewater treatment”, American Journal of Applied Sciences, 1 (4), pp 348-353.

Metcalf & Eddy (revised by Tchobanoglous, G., Burton, F.L. & Stensel, H.D. (2003), (2014). "Wastewater Engineering, Treatment and Reuse". 4th edition, McGrawHill, New York.

Modified Sequencing Batch Reactor, Aqua MSBR, (2022) “Aqua MSBR®”, available at: Aqua MSBR® - Aqua-Aerobic Systems | Activated Sludge System https://www.aqua-aerobic.com/downloads/MSBR-Brochure-2012_web.pdf, (accessed 1st Sept. 2023).

MOHE, (2012), The Iraqi National Environment Wastewater Standards for Agricultural Irrigation Quality standard for water sources according to regulations issued by Iraqi government. Iraqi government

Simon Judd. (2013), “Watermaths” process fundamentals for the design and operation of water and wastewater treatment technologies, text book, Second Edition.

Singh, M., and Srivastava, R. K. (2011). Sequencing batch reactor technology for biological wastewater treatment: a review. Asia-pacific journal of chemical engineering, vol. 6 no. (1), pp 3-13.

Veolia, AnoxKaldnes Hybas™, (2023), “Krüger Kaldnes Technology:,Introduction” available at: https://www.krugerkaldnes.no/en/technologies/anoxkaldnes-hybas (accessed 25th Oct.2023).

Water Environment Federation, (1996). “Operation of Municipal Wastewater Treatment Plants.” (Manual of Practice—MOP 11. 5th ed. Volume 2. Alexandria, Virginia: Water Environment Federation, 1996.)

Wilderer, P. A., Röske, I., Ueberschär, A., & Davids, L., (1993), “Continuous flow and sequenced batch operation of biofilm reactors: a comparative study of shock loading responses”, Biofouling, 6 (4), pp295– 304.