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Stage by stage design for primary, conventional activated sludge, SBR and MBBR units for residential wastewater treatment and reusing

Shuokr Qarani Aziz[*1], Imad Ali Omar[2a], Mohammed J.K. Bashir[3b] and Amin Mojiri[4c]

[1]Department of Civil Engineering, College of Engineering, Salahaddin University-Erbil, Erbil, Iraq
[2]Ministry of Municipality and Tourism, General Directorate of Water and Sewerage, Erbil, Iraq
[3]Department of Environmental Engineering, Faculty of Engineering and Green Technology, Universiti Tunku Abdul Rahman, 31900 Kampar, Perak, Malaysia
[4]Department of Civil and Environmental Engineering, Graduate School of Advanced Science and Engineering, Hiroshima University, 1-4-1 Kagamiyama, Higashihiroshima 739-8527, Japan

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Abstract. To date, there is no central wastewater (WW) treatment plant in Erbil city, Kurdistan region, Iraq. Therefore, raw WW disposes to the environment and sometimes it used directly for irrigation in some areas of Erbil city. Disposal of the untreated WW to the natural environment and using for irrigation it causes problems for the people and the environment. The aims of the current work were to study the characteristics, design of primary and different secondary treatment units and reusing of produced WW. Raw WW samples from Ashty city-Erbil city were collected and analyzed for twenty three quality parameters such as Total Suspended Solids (TSS), total dissolved solids, total volatile and non-volatile solids, total acidity, total alkalinity, total hardness, five-day Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), biodegradability ratio (BOD_5/COD), turbidity, etc. Results revealed that some parameters such as BOD_5 and TSS were exceeded the standards for disposal of WW. Design and calculations for primary and secondary treatment (biological treatment) processes were presented. Primary treatment units such as screening, grit chamber, and flow equalization tank were designed and detailed calculation were illustrated. While, Conventional Activated Sludge (CAS), Sequencing Batch Reactor (SBR) and Moving Bed Biofilm Reactors (MBBR) were applied for the biological treatment of WW. Results revealed that MBBR was the best and economic technique for the biological treatment of WW. Treated WW is suitable for reusing and there is no restriction on use for irrigation of green areas inside Ashty city campus.

Keywords: activated sludge; Erbil city; MBBR; primary units; reusing; SBR

1. Introduction

With increasing pressures on water resources, the possibility of the useful utilization of treated

*Corresponding author, Professor, E-mail: shuokr.aziz@su.edu.krd, shoker71@yahoo.com
[a]M.Sc., E-mail: Imad.omar@su.edu.krd
[b]Assistant Professor, E-mail: jkbashir@utar.edu.my
[c]Assistant Professor, E-mail: amin.mojiri@gmail.com

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wastewater (WW) has quickly gotten a basic for water associations around the globe. Water recovery, recycling, and reuse are presently recognized as key parts of water and WW the executives. Alongside the innovation advancements in WW treatment, the chance for water reuse has never been more applicable (Po *et al*. 2003).

The amount of freshwater available worldwide is decreasing, raising the requirements for more feasible use, one system of saving water is recycling greywater (GW) for irrigation purpose. Because of the considerable variance from there characteristics, separating GW and blackwater would supply for more active WW treatment plants (WWTP) permitting a huge amount of water to be effectively recycled (Lindstrom 2000). This is basically significant in arid areas, where water is deficient and recycling GW for irrigation could diminish drinkable water use by up to half (DHWA 2002).

The utilization of GW for watering private green areas is becoming common. In many nations, guidelines or explicit rules for GW reuse are not available, and it is accordingly utilized without any important pre-treatment, a practice wrongly regarded safe. In USA and Australia, they focus on issues related with public health but do not consider possible harmful environmental effects (Dixon *et al*. 1999).

In recent years' dozens of residential campuses and factories are opening in Erbil city, Kurdistan region-Iraq, these projects are producing a high quantity discharge to valley and depression land causing: 1) The pollution of shallow wells of the farmers which are used for irrigation and domestic purposes; 2) in separate parts the water is used for irrigation purposes using pumps, so it forms great health problems; 3) the swampy area is formed in the region which leads to creating health problems; 4) odour spreading, this causes air pollution; 5) affects the beauty of the environment, and 6) causes pollution surface water sources such as Greater-Zab river water (Aziz and Fakhry 2016).

Disposal of produced WW directly to the natural environment causes problems to the people, animals and environment. So, appropriate treatment WW prior disposing to the environment is essential. Ashty city in Erbil city (near Kasnazan sub-district) is one of the new residential areas in Erbil city. To date, there are no any treatment processes for the produced WW of Ashty city and is discharged to the environment directly (as shown in Section 2.4), which causes problems for the surrounding environment for Ashty city.

WWTP process consists of primary, secondary (biological) and advanced treatment processes. Biological treatment processes including generally trickling filter, rotating biological contactor, Sequence Batch Reactor (SBR), Moving Bed Biofilm Reactors (MBBR), etc (Metcalf and Eddy Inc 2014, Qasim 2017). These were used as an alternative for Conventional Activated Sludge (CAS) and suspended growth systems due to its low operational and maintenance cost, less energy and space required as well as more reliable removal efficiency for contaminants (Shahot *et al*. 2014).

In literature, a number of works have been published on WW treatment processes (Balku 2007, Fontenot *et al*. 2007, Tandukar *et al*. 2007, Aziz 2020, Aziz *et al*. 2011, 2013, 2019, Lackner and Horn 2013, Mojiri *et al*. 2014, Thakur and Khedikar 2015, Kawan *et al*. 2016, Khan *et al*. 2019, Showkat and Najar 2019, Alagh *et al*. 2020, Wei *et al*. 2020, Yang *et al*. 2020). But, to date, there is no a stage by stage design, detailed calculations, using various scenarios for biological WW treatment processes, economic issues and reusing in one research. Consequently, the current study aimed to: 1) Characterize of produced WW from Ashty city, Erbil city; 2) design and calculations for WW treatment units using various treatment scenarios, and 3) suitability of reusing treated WW for irrigation purpose for the green areas inside Ashty city. To date, this type of research has

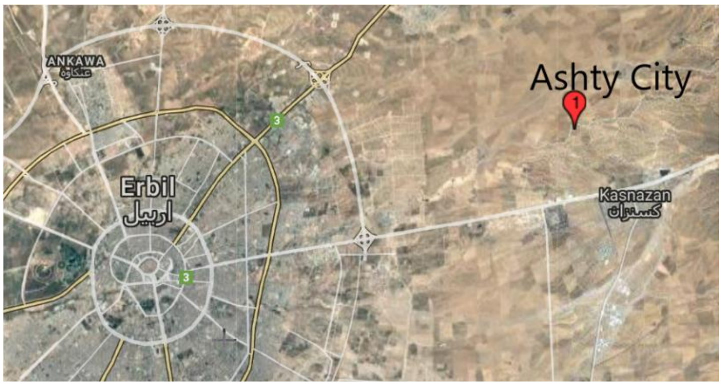

Fig. 1 Satellite image for Ashty city in Erbil

(a) 25th February 2018

(b) 27th March 2018

Fig. 2 WW produced in Ashty city

not been documented in the extant literature.

2. Materials and methods

2.1 Study area

Ashty city is located on the left side of the Erbil-Koya main road (near Kasnazan sub-district) in Erbil city, Kurdistan region-Iraq. Ashty city is approximately 12 km far from Erbil city center (Fig. 1). The geographical coordinates are 36° 13’ 19” N and 44° 07’ 32” E. Ashty city which is proposed to finish all the works in this project in 2020, has a total number of 940 houses. Discharge of produced WW ranged between 30 to 40 m^3/h. The WW consist of GW from baths, washing, hand wash basins and sinks. The total green area in the studied area is about 50000 m^2.

2.2 Sample collection

WW samples were collected from Ashty city on 25 February 2018 and 27 March 2018 (Fig. 2). The WW samples were collected in plastic containers and instantly transported to the

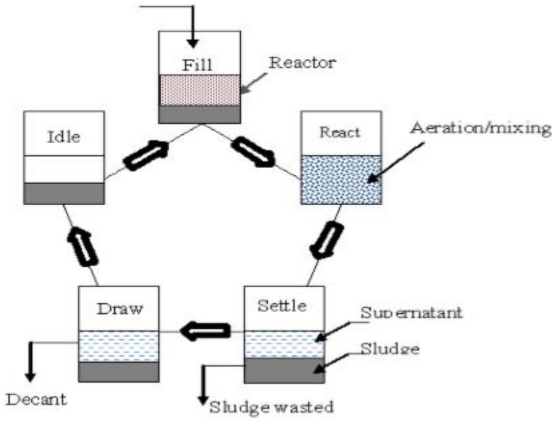

Fig. 3 SBR operation for one cycle (Aziz *et al*. 2011)

laboratory. Collection, transportation and storage of the WW samples were carried out according to APHA (2005). The collected samples were analyzed for 23 WW quality parameters. Experiments of pH, oxidation-reduction potential (ORP), temperature, total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), total volatile solids (TVS), total non-volatile solids (TnVS), total acidity, total alkalinity, total hardness, five day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), BOD_5/COD, turbidity, chloride, colour, ammonia (NH_3-N), dissolved oxygen (DO), electrical conductivity (EC), nitrite (NO_2), nitrate (NO_3) were conducted on the collected WW samples. The tests were carried out in the Sanitary and Environmental Engineering Laboratory, Department of Civil Engineering, College of Engineering, Salahaddin University-Erbil, Erbil, Iraq.

2.3 Quantity of WW

The total quantity of the WW that produced from the city is between 30 to 40 m^3/h, as it measured in a different season of the year (Fig. 2). The method which used to measure the discharge of WW was by collecting a volume of WW in a moment, then calculate the total amount of the WW in an hour. The total amount of the green area is about 50000 m^2.

2.4 Methods of treatment

Proposed WW treatment units for Ashty city WW were primary plus secondary treatment units. Biological WW treatment techniques such as CAS, SBR and MBBR, were proposed to overcome the problems of disposed of WW from Ashty city on the environment and for reusing for irrigation of green areas inside Ashty city project. The details for designing and calculations are given in results and discussions part. The proposed WW treatment units (i.e., primary plus secondary treatment units) in Ashty city is designed for treatment of residential WW produced from 940 houses in the city.

2.4.1 CAS (Conventional Activated Sludge)

Municipal WWTP was intended to eliminate pathogens and organic and inorganic suspended and flocculated matter. The most generally utilized biological treatment process for domestic and industrial WWs is the CAS process. However, the disadvantage of this process is high sludge production. The expense of handling, treatment, and removal of the excess sludge is about 40-60% of the costs of WW treatment (Metcalf and Eddy Inc 2014). Normal CAS comprises of aeration tank, settling basin and sludge recycling technique (Raji *et al*. 2017). A part of TSS, BOD_5 and NH_3-N remove in the CAS.

2.4.2 SBR (Sequencing Batch Reactor)

SBR technique comprises of fill, react, settle, draw and idle phases (Fig. 3). All stages are carried out in one tank; while, in CAS the processes conducted in two different basins with sludge recycling system. A great part of pollutants such TSS, BOD_5, NH_3-N, etc remove in WWs using SBR. It used widely for eliminating of contaminates in WWs (Aziz *et al*. 2013, Mojiri *et al*. 2014, Dutta and Sarkar 2015, Alagha *et al*. 2020). SBR augmented adsorption process enhanced removal of pollutants in landfill leachate and wastewater treatment (Aziz *et al*. 2011, Mojiri *et al*. 2014).

2.4.3 MBBR (Moving Bed Biofilm Reactors)

MBBR is an attached growth process; it uses plastic carriers to provide a surface on which biofilm grows. Sludge recycle in an MBBR process is not required. Required reactor volume is typically considerably smaller than for a CAS treating the same WW flow. The MBBR process is effective for BOD removal and nitrification process (Bengtson 2010).

MBBR has extensively applied technology used to treat not only the domestic WW but also the industrial WW. The process incorporates the better efficiency to treat the WW ranging from lower concentration to the higher concentration. The small carrier (Fig. 4) elements with a density close to water so that it tends to be kept in in suspension with lowest mixing energy supplied by aeration or mechanical blending inside the reactor will continuously mix in terms of suspension with the WW either in aerobic or anaerobic basins (Burghate and Ingole 2013). Fig. 5 shows the mechanism operation of two ideal system design of MBBR.

The MBBR method has numerous advantages over any other secondary treatment systems used to treat WW. MBBR has the positive feature of both the suspended and attached growth processes (Thakur and Khedikar 2015). One significant advantage of the MBBR is that the filling division of biofilm carriers in the reactor might be dependent on preferences, to be able to move the carrier

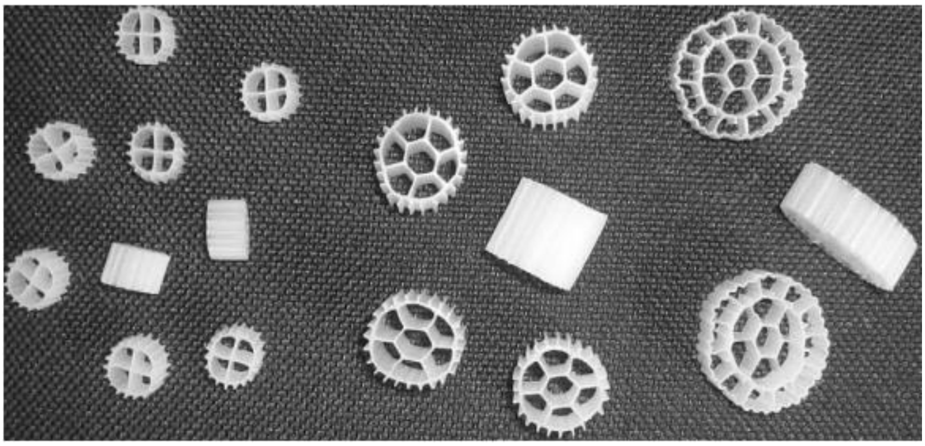

Fig. 4 Photo of (from left to right) Kaldnes type K1, K2 and K3 biofilm carriers

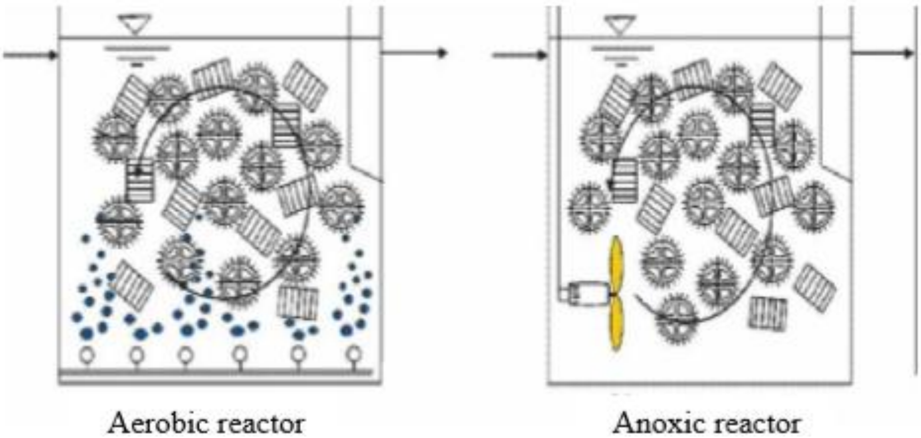

Fig. 5 Typical reactors of MBBRs with submerged and suspended packing material (Metcalf and Eddy Inc 2014)

suspension freely, it suggested that filling parts ought to be underneath 70%.

3. Results and discussions

3.1 Characterization of Ashty city WW

Table 1 illustrates the Ashty city WW sample test results. Obtained results were compared with Iraqi disposal standards and Environmental Protection Agency (EPA) regulations to recognize the environmental risks posed by Ashty city WW. Results revealed that organic matter is the major EMWW pollutant. BOD_5 for all Ashty city WW samples were exceeded the WW disposal standards. Ashty city WW can be classified as low strength WW. The BOD_5 values demonstrated that Ashty city WW contains common contaminants and requires biological treatment. Biodegradability ratios (BOD_5/COD) for all Ashty city WW samples were higher than 0.50. Thus, biological treatment process is more efficient and applicable for Ashty city WW treatment (Aziz *et al*. 2011). WW composition fluctuates with time even for a given area (Qteishat *et al*. 2011).

The TSS are particles of various materials that remain in suspension in water. Moreover, it gives adsorption sites for chemicals and biological agent (Ntengwe 2006).

Wilén *et al*. (2000) commented that increase in suspended solids and particles in WW could be returned to the content of the organic materials, phosphorus and sometimes nitrogen that discharged from effluent sludge. TDS originated from natural sources, sewage effluent discharges, urban runoff or industrial waste discharge (Ntengwe 2006). The physical characteristics of Ashty city WW, such as pH, temperature, color and turbidity were remained within Iraqi Environmental Standards (Standards 2011).

3.2 Design of WWTP units

WWTP consists of primary, secondary and advanced treatment processes. Characteristics of WW and purpose of treatment process led to choosing suitable treatment processes. The purposes

Table 1 Ashty city WW characteristics

No.	Parameter	Unit	Value: Feb. 25, 2018	Value: Mar. 27, 2018	Disposing standards
1	pH		8.2	8.6	6.5-9.6*
2	Temperature	°C	14	14.9	< 35*, 40**
3	EC	µs/cm	500	417.2	
4	Turbidity	FTU	18	20	
5	Total acidity	mg/L	20	20	
6	Total alkalinity	mg/L	200	212	
7	Total hardness	mg/L	116	136	
8	Chloride	mg/L	26	24	750**
9	Colour	Pt. Co	157	103	Nil*
10	Total salts	mg/L	300	267	
11	Total solids	mg/L	300	600	
12	TDS	mg/L	100	200	
13	Total suspended solids	mg/L	200	200	60*, 35**
14	Total non-volatile solids	mg/L	200	500	
15	Total non-volatile solids	mg/L	100	100	
16	BOD_5	mg/L	100	95	< 40*
17	COD	mg/L	200	196	< 100*
18	BOD_5/COD		0.5	0.48	
19	ORP	mv	−111.2	−131.3	
20	Ammonia	mg/L	7	7.2	Nil*, 1**
21	DO	mg/L	5.6	5.3	
22	Nitrate (NO_3-N)	mg/L	4.1	3.5	50*, 10**
23	Nitrite (NO_2-N)	mg/L	8	9	1**

* Iraqi Environmental Standards (2011)
** Environmental protection regulations (EPA) (2003)

of treating Ashty city WW is for reusing and irrigating green areas in Ashty city. Therefore, applying primary and secondary treatment techniques fulfill the requirement of irrigation quality (Aziz *et al*. 2019). The details of WW treatment units are shown below.

3.2.1 Screening

Designing parameters and criteria for bar screen.
Bar size (Tchobanoglous *et al*. 2003);
Width = 13 mm (Fig. 6);
Thickness = 50 mm;
Bar clear spacing = 30 mm;
Slope from vertical degree = 30˚;
Approach velocity = 0.6 m/s

$$hl = 1/C(V^2 - v^2)/2g \tag{1}$$

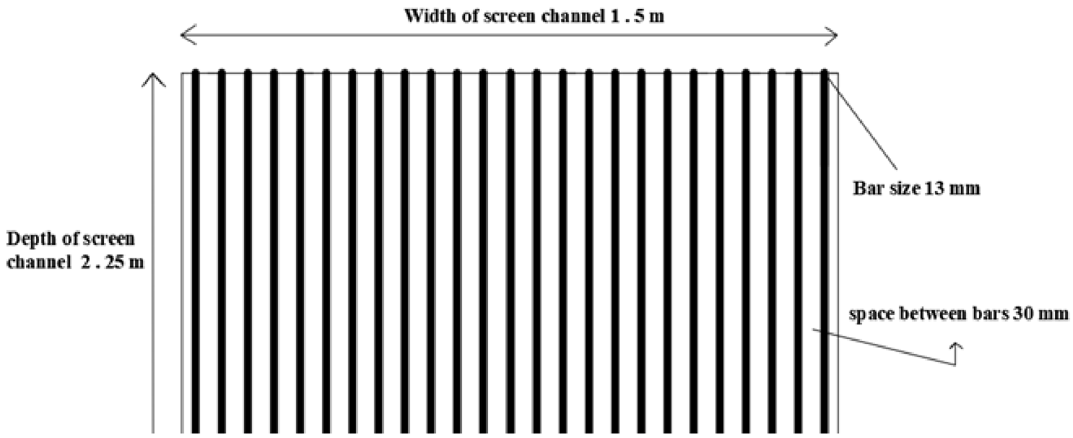

Fig. 6 Screening front view section

where C = empirical discharge coefficient = 0.7;
V = velocity of flow though the openings (m/s);
v = approach velocity in upstream channel (m/s);
g = acceleration due to gravity (m/s^2) (Tchobanoglous *et al*. 2003).
From continuity equation

$$Va \times Aa = Vb \times Ab \tag{2}$$

$$Vb = \frac{Va \times Aa}{Ab} \tag{3}$$

Assume the channel has a width of W and a depth of D;
Area of channel = WD

$$\text{Net area of screen} = WD \times 30/(30 + 13) = 0.697\,WD \tag{4}$$

$$Vb = \frac{1 \times WD}{0.697\,WD} = 1.43 \text{ m/s} \tag{5}$$

When the velocity becomes 1.43 m/s, the head loss become

$$hl = \frac{1\,(1.43^2 - 0.6^2)}{0.7 \times 2 \times 9.81} = 0.122 \text{ m} \tag{6}$$

$$= 0.122 \text{ m} \times 1000 \text{ mm/m} = 122 \text{ mm} \tag{7}$$

3.2.2 Grit chamber

Grit chamber should provide to all WW treatment plants. The main objective is to prevent clogging in pipes, heavy deposits in channels (Metcalf and Eddy Inc 2014, Qasim 2017). The details for designing grit chamber are given below (Tchobanoglous *et al*. 2003).

Detention time: 60 sec;
Horizontal velocity: 0.3 m/sec;
Settling velocity for a 65-mesh material: 1.15 m/min;

Head loss: 30~40% of the maximum water depth in the channel;
Grit removal: Manual;
For calculating a volume of grit chamber;
From the measuring discharge in the site Q = 30 m^3/h.
So, Q = 30/3600 = 0.00834 m^3/s.
Let peak flow = 4;
Volume = discharge × time;

Detention time ranges between 2 to 5 minutes and is based on the peak flow rate (Tchobanoglous *et al*. 2003).

V = 0.0083 × 5 min × 4 × 60 sec/min = 9.96 ≈ 10 m^3
Selecting a rectangular shape for grit chamber:
Typically, the ratio between depth-width = 1.5-1 (Tchobanoglous *et al*. 2003).
The width is 1.5m; then the depth will be: 1.5 × 1.5 = 2.25 m
Generally, in design, the actual length is 1.2-1.5 times the theoretical length.

The ideal length of the grit chamber is: 10 m/1.5 × 2.25 = 2.96 m ≈ 3m, the actual length = 1.5 × theoretical length.

The actual length = 3 × 1.5 = 4.5 m.

3.2.3 Flow equalization

Flow equalization is a unit used to control the operational difficulties caused by flow rate fluctuations, to enhance the performance of the downstream processes, and to decrease the size and cost of downstream treatment techniques. It is basically the damping of flow rate variations to accomplish a constant or near constant flow rate. There are two classes of equalization basins, in-line and off-line equalization tanks (Metcalf and Eddy Inc. 2014).

In equalization basin design, factors need to be considered:

1) Basin geometry
2) Construction materials
3) Mixing & air requirements
4) Operational appurtenances
5) Pump & pump control system.

To determine the volume of equalization basin, information about the flow rate of each hour for 24 hours measured, and according to the table below the volume of the equalization was determined as follows in Table 2.

After measuring the volume of flow in each hour, then average volume for 24 hours determined and it is 26.5 m^3. After that the difference between volume in and volume out for each hour calculate as in column 4 in the table above, at the end accumulative volume founded and the higher value of accumulative volume determined and it was 110.9194 m^3 ≈ 111 m^3

From the volume 111 m^3, if the depth is 3 m, and freeboard 0.3 m, then:
111/3.3 = 33.63 m^2.
The length = 7 m.
The width will be 33.63/7 = 4.8 m.

3.2.4 Biological (secondary) treatment processes

Three biological methods (i.e., CAS, SBR and MBBR) were applied for treatment of Ashty city WW. Detailed design and calculations for the secondary treatment technologies are given below. Additionally, comparison between the techniques were illustrated.

Table 2 Volume of WW for 24 hr in Ashty city and calculations

Time	Vol. in m^3/hr.	Vol. out m^3/hr.	ds m^3 (Vol. in−Vol. out)	∑ds m^3
9,00	29.53	26.5329	2.9971	2.9971
10,00	31.35	26.5329	4.8171	7.8142
11,00	31.91	26.5329	5.3771	13.1913
12,00	33.6	26.5329	7.0671	20.2584
13,00	34.81	26.5329	8.2771	28.5355
14,00	35.1	26.5329	8.5671	37.1197
15,00	36.55	26.5329	10.0171	47.1197
16,00	37.72	26.5329	11.1871	58.3068
17,00	39.45	26.5329	12.9171	71.2239
18,00	39.46	26.5329	12.9271	84.151
19,00	37.72	26.5329	11.1871	95.3381
20,00	36.55	26.5329	10.0171	105.3552
21,00	31.35	26.5329	4.8171	110.1723
22,00	27.28	26.5329	0.7471	110.9194
23,0	24.61	26.5329	−1.9229	108.9965
24,00	22.51	26.5329	−4.0229	104.9736
1,00	16.8	26.5329	−9.7329	95.2407
2,00	10.57	26.5329	−15.9629	79.2778
3,00	9	26.5329	−17.5329	61.7449
4,00	8.97	26.5329	−17.5629	44.182
5,00	9.4	26.5329	−17.1329	27.0491
6,00	10.65	26.5329	−15.8829	11.1662
7,00	17.4	26.5329	−9.1329	2.0333
8,00	24.5	26.5329	−2.0329	0.0004

3.2.4.1 CAS (Conventional Activated Sludge) design

The volume of the tank can be calculated from daily discharge which fluctuates between 30 to 40 m^3/h (measured from the Ashty city site).

Consequently, from taking the bigger discharge which is 40 m^3/h.

40 m^3/h × 24 = 960 m^3/day.

F/M $= Q°S°/VX$.

F/M = food-to-microorganism ratio;

Kg BOD or COD applied per day per kg of total suspended solids in the aeration tank;

$Q°$ = influent WW stream flow rate (m^3/d);

$S°$ = influent WW concentration (BOD or COD in mg/L);

V = aeration-tank volume (m^3);

X = total suspended solids concentration in aeration tank (mg/L).

If volatile SS are used

F/M $= Q°S°/VX_v$;

F/M = food-to-microorganism ratio on volatile solids basis, kg BOD or COD per day per kg of volatile suspended solids in aeration tank.

X_v = volatile suspended solids concentration in aeration tank (mg/L)

For a traditional design and for domestic sewage, F/M ratio suggested is 0.25~0.5 kg BOD/kg MLSS × *d* (Tchobanoglous *et al*. 2003).

$S°$ =200 mg/l, X_v = 1,600 mg/l, then F/M_v = 0.5 kg BOD/kg MLSS × d, $\mathrm{F/M} = Q°S°/VX$.

Let $\mathrm{F/M}$ = 0.25 kg BOD;

Q = 960 m^3/day;

$S° = 200$ mg/l;

V= $Q°S°/$ F/M X;

$V = \frac{960 \times 200}{0.25 \times 1600}$ = 480 m^3.

If the depth is 2.5 m, then area = 480/2.5 = 192 m^2;

BOD loading = $Q°S°/V$;

960 × 100/480 × 1000 = 0.2 kg/m^3 day;

$\tau = V/Q$;

$\tau = 480 \times 24/960$ = 12 h.

3.2.4.2 SBR (Sequencing Batch Reactor) design

Data from the site and from the laboratory are as below:

Q = 960 m^3/day;

BOD = 100 mg/L;

COD = 200 mg/L;

TSS = 400 mg/L ;

NH_4-N = 7 mg/L 7;

Total alkalinity = 212 mg/L;

Design conditions (Tchobanoglous *et al*. 2003, Aziz *et al*. 2013, Metcalf and Eddy Inc 2014):

Use two tanks:

Total liquid depth when full = 3 m.

Select period times:

t_A= 2 h (react and aeration phases);

t_S = 0.5 h (settle phase);

t_D = 0.5 h (decant phase);

t_I = 0 h (idle phase);

t_c = (total cycle time).

Then t_c = 2 + 0.5 + 0.5 = 3 h;

No. of cycle in day = 24/(2 × 3) = 4 cycles;

No. of cycles = 2 tanks × 4 cycle = 8 cycle;

Fill volume / cycle = 960 m^3/d /8 cycles/day = 120 m^3/fill.

Determine fill fraction per cycle (V_F/V_T) allowed and compare to select design value of 0.3.

For determining overall retention time:

Full liquid depth = 3 m;

Decant depth = 3 × 0.3 = 0.9 m

$V_T = V_F/0.3$ = 120/0.3 = 400 m^3

Overall time = 400 × 24 h / 960 = 10 h.

Use 2 tanks each tank 200 m^3.

Length = 10 m;

Depth = 3 m;
Width = 200/30 = 6.65 m;
Area = 10 × 6.65 = 66.5 m^2 × 2 tank = 133 m^2.

3.2.4.3 MBBR (Moving Bed Biofilm Reactors) design

The particular surface area of MBBR carriers (m^2/m^3) is normally in the range from 350 m^2 to 1200 m^2/m^3. The void ratio classically ranges between 60% to 90%. Design parameters for determining MBBR tank dimensions is the Surface Area Loading Rate (SALR) in g/m^2/day. Accordingly, for BOD removal the SALR would be g BOD/day entering the MBBR basin per m^2 of carrier surface area. For a nitrification process, the SALR would be g NH_3-N/day coming to the MBBR tank per m^2 of carrier surface area. Lastly, for denitrification process, the SALR would be g NO_3-N /day entering the MBBR reactor per m^2 of carrier surface area (Bengtson 2010).

MBBR design procedure is as follows:

1 - BOD loading rate $= Q \times S_{\circ} \times 8.34 \times 453.59$
where Q = the WW flow rate into the MBBR tank (MGD);
$S_{\circ}$ is the BOD concentration in that inlet (mg/L);
8.43 is the conversion factor from mg/L to Ib/mg;
Conversion factor from Ib to g is 453.59;
BOD loading rate unit is g/day.

2 - Essential carrier surface area = BOD loading rate/SALR
where BOD loading rate (g/day);
SALR (g/m^2/day) is explained before.

3 - Required carrier volume = required carrier surface area/carrier specific surface area
where Necessary carrier surface area (m^2);
Carrier specific surface area (m^2/m^3);
The required volume of the carrier will be in m^3.

4 - Required reactor volume = Essential carrier volume/carrier fill %

5 - Liquid volume in the basin = Necessary reactor volume – $[\text{Essential carrier volume}(1 - \text{carrier \% void space})]$.

6 - HT = volume of liquid in the tank/Q/24 × 60;
HT = Hydraulic retention time (h).

For the current MBBR design, data from the site and from the laboratory are as below:
Q = 960 m^3/day;
BOD = 100 mg/L;
COD = 200 mg/L;
TSS = 200 mg/L;
NH_4-N = 7 mg/L.

1 - The BOD loading rate = 960 m^3/day × 100 g/m^3 = 96000 g BOD/day.

2 - From Table 3, an appropriate design SALR figure for BOD removal with a BOD removal of 90% to 95% would be 7.5 g/m^2/day.

3 - Essential carrier surface area = 96000/7.5 = 9200 m^2.

Where the particular surface area of MBBR carriers (m^2/m^3) is ordinarily varies from 350 m^2/m^3 to 1200 m^2/m^3. The void proportion regularly ranged between 60% to 90%.

In the present design, 500 m^2/m^3 was selected (Bengtson 2010).

Necessary carrier volume = 9200/500 = 18.4 m^3.

For 40% carrier fill, tank volume = 18.4/0.4 = 46 m^3.

Table 3 Typical design SALR values for BOD removal (Bengtson 2010)

Typical design values for MBBR reactors at 15°C		
Purpose	Treatment target % removal	Design SALR g/m^2-d
BOD removal		
High rate	75-80 (BOD_7)	25 (BOD_7)
Normal rate	85-90 (BOD_7)	15 (BOD_7)
Low rate	90-95 (BOD_7)	7.5 (BOD_7)

Table 4 Outline of CAS, SBR and MBBR biological treatment methods

Parameters	CAS design	SBR design	MBBR design
Volume of tank	480 m^3	400 m^3	38.64 m^3 + 18.4 m^3 carrier
Retention time	12 hr	10 hr	58 min
BOD removal	97.8% (Tandukar *et al*. 2007)	89-98 % (Fontenot *et al*. 2007)	86-90% (Thakur and Khedikar 2015)
COD removal	96.1% (Tandukar *et al*. 2007)	98% (Fontenot *et al*. 2007)	94-96% (Thakur and Khedikar 2015)
TSS removal	98.5% (Tandukar *et al*. 2007)	90% (Aziz *et al*. 2011)	60-65% (Thakur and Khedikar 2015)
Ammonia removal	66.9% (Tandukar *et al*. 2007)	89% (Aziz *et al*. 2011)	99.72% (Kermani *et al.* 2008)
Phosphor removal	-	84% (Dutta and Sarkar 2015)	78.4% (Kermani *et al.* 2008)
Air required	2 g/m^3 (Balku 2007)	0.47 m^3/kg_{TN} (Lackner and Horn 2013)	4.5 l/min (Kawan *et al.* 2016)
Secondary clarifier	Need for a clarifier (Kawan *et al*. 2016)	No need for a clarifier (Kawan *et al*. 2016)	No need for a clarifier (Kawan *et al.* 2016)
Sludge produced	Large quantity	Low quantity	Low quantity
Advantage and disadvantage	Generally low sludge settling capacity, foaming and sludge bulking issues, high surplus biomass production (Kawan *et al*. 2016)	Using one tank and the operation is more complex than CAS (Aziz *et al*. 2013, Mojiri *et al*. 2014)	Easy to operate and simple design, low maintenance and no problem of obstructing (Kawan *et al*. 2016)

4 - The volume of liquid in the reactor can be determined as:
Tank volume – $[\text{Essential carrier volume}(1 - \text{carrier \% void space})]$;
46 -$[18.4(1 - \text{carrier } 60\%)]$= 38.64 m^3;
5- HT = volume of liquid in the reactor/(Q/24 × 60) = 38.64/(60/24 × 60) = 57.96 $\approx$ 58 min.

3.2.5 Evaluation of the treatment methods

Information of biological treatment processes (i.e., CAS, SBR and MBBR) are outlined in Table 4. From the calculations and Table 4, it is clear that SBR and MBBR method have better efficiency than CAS. But, SBR is more complex operation and discontinuous discharge (Kawan *et al*. 2016) with more effectiveness than MBBR method. MBBR method is easy to operation and simple design, low maintenance, no issue of clogging, littler space request, lower HRT, increased resiliency, higher biomass holding period, raised of active biomass clusters, enhancement of recalcitrant substance degradation as well as reduced rate in microbial proliferation (Kawan *et al*. 2016). Consequently and particularly in this research, MBBR method was superior than CAS and SBR technologies.

3.3 Secondary clarifier tank (sedimentation)

In the second stage, the activated sludge is isolated from the processed WW normally by sedimentation basin. The resulting clarifier effluent is then discharged and most of the activated sludge is returned to the first stage, though a sludge return system (Gilhawley 2008).

Depending on the data:

Q of WW = 960 m^3;

Area of CAS tank = 63.36 m^2;

Surface loading rate = Q/Area = 960/63.36 = 15.15 m^3/ (m^2 day);

Normal surface loading rate is ranged from 20 to 30 m^3/ (m^2 day) (JSWA 2013).

Select 20 m^3/ (m^2 day) for the design;

Total volume of secondary clarifier = 15.15 × 20 = 303 m^3.

3.4 Reusing of treated WW and economic issues

The total amount of the green area is about 50000 m^2, and depending on the standards every square meter need 10 liters of water for watering.

50,000 m^2 × 10 liter = 500,000 liter/day = 500 m^3 / day.

The average amount of the WW at minimum flow is 30 m^3/hour.

30 m^3/hour × 24 hour = 720 m^3/ day. It is enough for the watering. Consequently, the reusing amount of treated WW was 720 m^3/day.

The characteristic of raw WW and other sorts of WWs is various and it depends on the source of WW (Aziz *et al*. 2019, Aziz 2020). Different treatment techniques are needed based on the contaminants in the WWs and should be processed to a level to qualify for the different kinds of irrigation, i.e., fruits, vegetables, forest, greenbelt, wheat, etc (Gikas and Tsihrintzi 2014, Aziz *et al*. 2019). Three chief views should be considered for irrigation by treated WW, which attentions about public health for farmers and users, the prevention of atmosphere degradation, and removes the antagonistic that has an effect on the production of crops. Different organizations for using treated WW for irrigation focused on, the quantity of indicator organisms, biodegradable organic matter, suspended solids, turbidity, heavy metals and residual chlorine that has an influence on public health (Paranychianakis *et al*. 2011, Aziz *et al*. 2019, Aziz 2020). In the current work and based on the pH, EC and TDS values, degree on restriction on use for Ashty city WW is none (Aziz *et al*. 2019). Of course, treatment of Ashty city WW using various systems decreases pollutants such as organic matter, suspended solids, nitrogen compounds, etc in the WW (Tandukar *et al*. 2007, Aziz *et al*. 2013, Mojiri *et al*. 2014, Thakur and Khedikar 2015, Kawan *et al*. 2016). As a result, treatment of Ashty city WW enhancing the characteristics of produced WW for irrigation of green areas inside Ashty city.

As an essential aspect of the WWTP and design, a cost-effective inquiry should be conducted to guarantee that the construction and the operation and maintenance are realistic and suitable for the planned level of treatment. A cost-effective choose is one that will limit the total expense of the resources over the life of the treatment units. Resources costs comprise capital (land plus construction), operation, maintenance, and substitutes and social and environmental charges. Advantage from sludge and the outlet sale or reuse will partially offset the costs of the resource (Qasim 2017).

Reusing of the treated WW for irrigation purpose for the green area in Ashty city was very valuable. The advantages of utilizing treated WW incorporate insurance of water resources, avoidance of contamination, recovery of nutrients for agriculture, augmentation of river flow, savings in WW treatment, groundwater restore and sustainability of water resource man and to decrease effects the beauty of the environment. From an economic point of view, re-using treated WW for irrigation is very important and its cheaper than using potable water from drinkable groundwater wells, due to the shortage of water in groundwater in this area.

4. Conclusions

Collected WW samples from Ashty city showed that some quality parameters exceeded the standards for WW disposal and reusing for irrigation. Collected WWs were also noticed as weak to medium WWs with biodegradability ratio of greater than 50%. The WW needs proper treatment processes. Primary treatment processes (such as screening, grit chamber and flow equalization) and biological treatment processes (i.e., CAS, SBR and MBBR) were designed and studied. MBBR was the best biological treatment method. Treated WW can be used for irrigation of the green areas for Ashty city. Reusing of WW for irrigation is economic.

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References

Alagha, O., Allazem, A., Bukhari, A.A., Anil, I. and Mu'azu, N.D. (2020), "Suitability of SBR for wastewater treatment and reuse: Pilot-scale reactor operated in different anoxic conditions", *Int. J. Environ. Res. Public Health*, **17**(5), 1617. https://doi.org/10.3390/ijerph17051617.

APHA (2005), *Standard Methods for the Examination of Water and Wastewater*, American Public Health Association, Washington, U.S.A.

Aziz, S.Q. (2020), "Variation of Erbil municipal wastewater characteristics throughout 26 years (1994-2020) with possible treatments and reusing: A review", *Proceedings of the 3rd International Conference on Recent Innovations in Engineering (ICRIE 2020)*, Duhok City, Kurdistan, Iraq, September.

Aziz, S.Q. and Fakhrey, E.S. (2016), "The effect of Kawergosk oil refinery wastewater on surrounding water resources", *ZANCO J. Pure Appl. Sci*., **28**(2), 656-667.

Aziz, S.Q., Aziz, H.A. and Yusoff, M.S. (2011), "Powdered activated carbon augmented double react-settle sequencing batch reactor process for treatment of landfill leachate", *Desalination*, **277**(1-3), 313-320.

https://doi.org/10.1016/j.desal.2011.04.046.

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), 34-43.

Aziz, S.Q., Saleh, S.M. and Omar, I.A. (2019), "Essential treatment processes for industrial wastewaters and reusing for orrigation", *ZANCO J. Pure Appl. Sci.*, **31**(3), 269-275.

Balku, S. (2007), "Comparison between alternating aerobic-anoxic and conventional activated sludge systems", *Water Res.*, **41**(10), 2220-2228. https://doi.org/10.1016/j.watres.2007.01.046.

Bengtson, P.E.H.H. (2010), MBBR Wastewater Treatment Process, SunCam, Florida, U.S.A.

Burghate, S. and Ingole, N. (2013), "Fluidized bed biofilm reactor - a novel WW treatment reactor", *Int. J. Res. Environ. Sci. Technol.*, **3**(4), 145-155.

DHWA (2002), *Draft Guidelines for the Reuse of Gray in Western Australia*, Department of Health, Government of Western Australia, Australia.

Dixon, A.M., Butler, D. and Fewkes, A. (1999), "Guidelines for greywater re-use: Health issues", *Water Environ. J.*, **13**, 322-326. https://doi.org/10.1111/j.1747-6593.1999.tb01056.x.

Dutta, A. and Sarkar, S. (2015), "Sequencing batch reactor for wastewater treatment: Recent advances", *Curr. Pollut. Rep.*, **1**, 177-190. https://doi.org/10.1007/s40726-015-0016-y.

Fontenot, Q., Bonvillain, C., Kilgen, M. and Boopathy, R. (2007), "Effects of temperature, salinity, and carbon: Nitrogen ratio on sequencing batch reactor treating shimp aquaculture wastewater", *Bioresour. Technol.*, **98**, 1700-1703. https://doi.org/10.1016/j.biortech.2006.07.031.

Gikas, G.D. and Tsihrintzis, V.A. (2014), "Municipal wastewater treatment using constructed wetlands", *Water Util. J.*, **8**, 57-65.

Gilhawley, F. (2008), "Factors governing nitrification in an activated sludge system treating a pharmaceutical wastewater", Ph.D. Dissertation, Dublin City University, Dublin, Ireland.

JSWA (2013), "Study on design method of conventional activated sludge process (research of FY 2013)", R&D Annual Report 2013, Japan Sewage Works Agency, Tokyo, Japan.

Kawan, J.A., Hasan, H.A., Suja, F., Jaafar, O.B. and Abd-Rahman, R. (2016), "A review on sewage treatment and polishing using moving bed bioreactor (MBBR)", *J. Eng. Sci. Technol.*, **11**, 1098-1120.

Kermani, M., Bina, B., Movahedian, H., Amin, M. and Nikaein, M. (2008), "Application of moving bed biofilm process for biological organics and nutrients removal from municipal wastewater", *Am. J. Environ. Sci.*, **4**, 675.

Khan, N.A., Ahmed, S., Hussain, A., Changani, F. and Hussain, K. (2019), "Review on SBR (sequencing batch reactor) treatments technology of industrial wastewater", *Water Pollut. Health*, **16**, 154-161.

Lackner, S. and Horn, A.H. (2013), "Comparing the performance and operation stability of an SBR and MBBR for single-stage nitritation-anammox treating wastewater with high organic load", *Environ. Technol.*, **34**, 1319-1328. https://doi.org/10.1080/09593330.2012.746735.

Lindstrom, C. (2000), Graywater: Facts about Graywater-What it is, How to Treat it, When and Where to Use it, Cambridge, Massachusetts, U.S.A. www.graywater.com.

Metcalf and Eddy Inc. (2014), *Wastewater Engineering: Treatment and Reuse*, Fifth Edition, McGraw Hill, California, U.S.A.

Mojiri, A., Aziz, H.A., Zaman, N.Q., Aziz, S.Q. and Zahed, M.A. (2014), "Powdered ZELIAC augmented sequencing batch reactors (SBR) process for co-treatment of landfill leachate and domestic wastewater", *J. Environ. Manag.*, **139**, 1-14. https://doi.org/10.1016/j.jenvman.2014.02.017.

Ntengwe, F. (2006), "Pollutant loads and water quality in streams of heavily populated and industrialised towns", *Phys. Chem. Earth*, **31**(15-16), 832-839. https://doi.org/10.1016/j.pce.2006.08.025.

Paranychianakis, N.V., Salgot, M. and Angelakis, A.N. (2011), *Irrigation with Recycled Water: Guidelines and Regulations*, Blackwell, West Sussex, U.K.

Po, M., Nancarrow, B.E. and Kaercher, J.D. (2003), "Literature review of factors influencing public perceptions of water reuse", Technical Report 54/03, CSIRO Land and Water, Australia.

Qasim, S.R. (2017), *Wastewater Treatment Plants: Planning, Design and Operation*, Routledge, Florida, U.S.A.

Qteishat, O., Myszograj, S. and Suchowska-Kisielewicz, M. (2011), "Changes of wastewater characteristic during transport in sewers", *WSEAS Trans. Environ. Dev.*, **7**(11), 349-358.
Raji, S., Olaleye, K., Adebisi, M. and Nwadike, D. (2017), "Computer aided design of conventional activated sludge treatment plant", *Int. J. Sci. Technol. Res.*, **6**(7), 162-165.
Shahot, K., Idris, A., Omar, R. and Yusoff, H.M. (2014), "Review on biofilm processes for wastewater treatment", *Life Sci. J.*, **11**(11), 1-13.
Showkat, U. and Najar, I.A. (2019), "Study on the efficiency of sequential batch reactor (SBR)-based sewage treatment plant", *Appl. Water Sci.*, **9**(1), 2. https://doi.org/10.1007/s13201-018-0882-8.
Standards, I.E. (2011), "Iraqi Environmental Standards 2011", Contract No. W3QR-50-M074, Rev. No. 03Oct. Morning Star for General Services, LLC Iraq, West Qurna I Project, Exhibit Eight, Iraq.
Tandukar, M., Ohashi, A. and Harada, H. (2007), "Performance comparison of a pilot-scale UASB and DHS system and activated sludge process for the treatment of municipal wastewater", *Water Res.*, **41**(12), 2697-2705. https://doi.org/10.1016/j.watres.2007.02.027.
Tchobanoglous, G., Burten, F.L. and Stensel, H.D. (2003), *Wastewater Engineering Treatment and Reuse*, Fourth Edition, McGraw-Hill, Denver, Colorado, U.S.A.
Thakur, S.A. and Khedikar, I.P. (2015), "Performance evaluation of moving bed bio-film reactor (MBBR) for treatment of domestic wastewater", *Int. J. Sci. Res.*, **6**(4), 973-976.
Wei, Y., Jin, Y. and Zhang, W. (2020), "Treatment of high-concentration wastewater from an oil and gas field via a paired sequencing batch and ceramic membrane reactor", *Int. J. Environ. Res. Public Health*, **17**, 1953. https://doi.org/10.3390/ijerph17061953.
Wilén, B.M., Keiding, K. and Nielsen, P.H. (2000), "Anaerobic deflocculation and aerobic reflocculation of activated sludge", *Water Res.*, **34**(16), 3933-3942. https://doi.org/10.1016/S0043-1354(00)00274-8.
Yang, X., López-Grimau, V., Vilaseca, M. and Crespi, M. (2020), "Treatment of textile wastewater by CAS, MBR and MBBR: A comparative study from technical, economic and environmental perspectives", *Water*, **12**, 1306. https://doi.org/10.3390/w12051306.

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