

Exploration of Rotating Biological Contactor (RBC) Technology for Treatment of Municipal Wastewater in Erbil City

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Abstract—Recently, biological treatment processes are widely used in wastewater treatment plants (WWTPs) due to their relative low cost and reasonable removal efficiencies. Around the world, there are many WWTPs which based on rotating biological reactor (RBC) treatment processes ranging from small scale size (package unit plant) such as sewage compact treatment units to large size wastewater treatment plants. Generally, RBC used for both industrial and municipal wastewater treatment, but widely used as secondary treatment processes for municipal wastewater treatment, also used as a tertiary (advance) treatment for nitrification and denitrification. RBC is known as low energy consumption technology and low process complexity option for WWTP. This research aimed to study RBC for treatment of Erbil municipal wastewater. The operation expenditure (OPEX) is low because it consumes low energy and is easy to operate. As it is simple system no complex. Consequently, less manpower and skill are required for operation and maintenance. On the other side, RBC has slow process start-up, several mechanical problems and limited process flexibility, and relatively high capital (CAPEX). This research presenting a review of RBCs technology for wastewater treatment process. Also, the proposed RBC unit of WWTP for Erbil has been designed as an aerobic attached growth biological treatment process, which has reasonable removal efficiencies that achieve the consents for reuse especially for irrigation purposes which is more than 85%.

Keywords— Biological treatment, Erbil City, OPEX, RBC, Reuse, Wastewater.

I. INTRODUCTION

A. Attached Growth Process

Generally, in wastewater treatment area there are chemical, physical and biological processes. Each process has own characteristics and basics which are different from each other. Basically, conventional wastewater treatment plants (WWTPs) are consist of a combination of physical, chemical and biological processes. In recent years, due to their relative low cost biological treatment systems are widely used in wastewater

treatment processes (Hibiya et al., 2000). In WWTP there are primary, secondary and tertiary treatment processes. Biological treatment processes are usually applied in secondary treatment which follows primary treatment. Biological processes mainly can be classified as attached growth (biofilm) processes and suspended growth processes (Metcalf and Eddy, 2014).

Attached growth reactors can be anaerobic or aerobic processes. Firstly, rotating biological contactors (RBCs) and trickling filters (TFs) are non-submerged attached growth process while submerged systems includes, biological aerated filters (BAFs), moving bed biofilm reactors (MBBRs) and submerged aerated filters (SAFs) (Loupasakiand and Diamadopoulou, 2013; Husham et al., 2012).

A biofilm is an aggregate of microorganisms (fungi, bacteria, protozoa, etc.) in which cells adhere to each other on a surface. In suspended growth processes such as in conventional activated sludge (CAS), organisms are suspended in the treatment basin and the fluid is called the mixed liquor, but in attached growth systems such as RBC, the microbial biomass (cultured as a biofilm) is attached to an inert and solid medium, known as media (Husham et al., 2012).

Attached growth process has many positives and pros over the activated sludge process which is the most common suspended growth process. RBC is aerobic (non-submerged) biological treatment process, which usually used as secondary treatment for municipal wastewater treatment widely around the world. This paper is focus and present a review of the RBCs technology in wastewater treatment and apply for WWTP in Erbil City for irrigation purposes especially for green zones, parks and landscape areas as a reuse water source.

Erbil City is capital of Kurdistan Region, Iraq. Recently, it has been developed largely. Many different large and small projects were constructed in past two decades. Nowadays, there has a plan to increase green area for Erbil City, so demand of water directly increasing. However, there is a shortage or lack of potable water especially in summer. Therefore, using sewage i.e., municipal wastewater after treatment for irrigation and particularly for parks and landscape area, large gardens, etc. is a good alternative and more sustainable option. Consequently, contribution of RBC technology has advantages and benefits for Erbil wastewater utilities for both small and large wastewater treatment projects. These are due to many

positive points of RBC system in environment and condition for Erbil.

To date, the city has no centralized WWTP. However, there are many proposals and studies about central WWTP for Erbil City which done by many different companies, NGOs, UN, Governments, etc. However, there are many different compact units depend on SBR and some of them are MBBR and CAS in different projects.

The disposal of wastewater into environment without treatment is source of significant pollution problems threatening the communities and environment. Therefore, it needs treatment prior to disposal to the natural environment. Treated WW reduces environmental and health problems. Also, wastewater can be a source of water supply for irrigation, carwash, landscape, industrial reuse, etc. in Erbil City.

The main objective of this study is to treat municipal wastewater using RBC technology then, finding optimum and best design and operational parameters for RBC treatment process for reusing taking all aspects and considerations. In the end, recently Erbil has been largely developed and many small and large scale projects constructed; this method would thus benefit wastewater utilities in Erbil for both large and small scale applications.

B. RBC Process

RBC is defining a series of closely spaced disks on a shaft which submerged in wastewater and rotates slowly through it. The basic principle is microorganisms attached to the disk surfaces as a biofilm. The rotation of the disks alternately encourages contacts of the biomass with the organic matter in the wastewater and allows the oxygen from the atmosphere to adsorb into the biofilm to maintain aerobic degradation. RBC consists of a number of components such as illustrated in Figure 1.

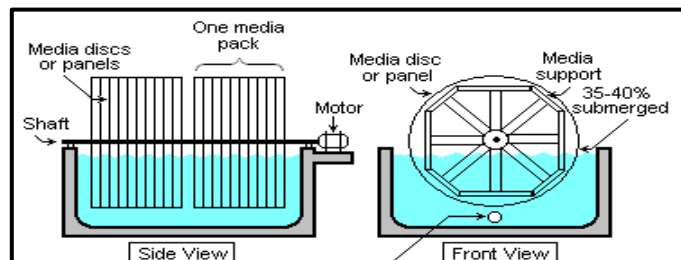


Fig. 1. Typical RBC Schematic diagram, (Parker, 2013)

Details of RBC are given below:

- Shaft: transfers the rotational movement from the motor to the media and attached to the frames to support the load of the media packs.
- Frame: used to join the shaft and the media pack.
- Media: the substrate/support for the biofilm.
- Motor and gear: the drive system providing rotational movement.
- Bearings: supporting the weight of the RBC, usually spherical split roller bearings.
- Enclosure: usually a plastic cover provided over each

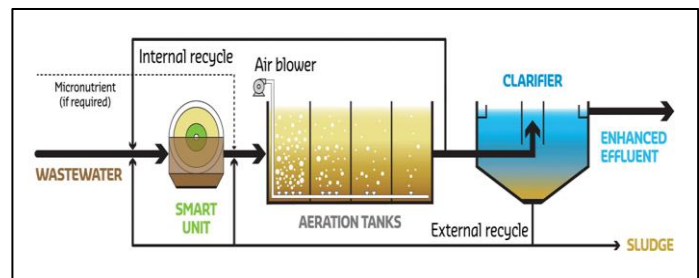
shaft.

- Tankage: optimized at 0.0049 m³/m² of disc area.

According to the depth of immersion there are only two types of RBC systems which are conventional and submerged RBCs. The main difference between them is that in the submerged one the depth of immersion is higher which around 70% to 90%. But, in a conventional RBC about 40% to 50% of the RBC media pack is submerged in wastewater (Metcalf and Eddy, 2014).

C. HYBACS (Hybrid Activated Sludge)

First of all, HYBACS is a biological unit which composed of two biological processes, Figure 2. Recently, in Europe countries particularly among many famous companies in wastewater treatment area it has got an acceptance. As it is a new technology relatively in the wastewater treatment. Subsequently, there is a limited amount of both works as a real project on the ground (i.e large scale and published paper on it). An example of HYBACS in Middle East which have nearly same condition for IRAQ is a full-scale HYBACS installation at Tubli WWTP of the Kingdom of Bahrain which treats up to 300,000 m³/d of municipal wastewater (Bluewater Bio, 2011). However, there is several HYBACS installation around the world which has widely gaining acceptance. The positive points for this system are firstly, reduction in energy consumption about 50% and secondly, decrease about 50% of land use (i.e saving in footprint area furthermore); it is less odour compare to activated sludge technology all these are according to the suppliers (Bluewater Bio, 2011). Moreover, it provides good effluent which suitable for reusing for instance, about 10 mg/L TSS, 50 mg/L COD, 10 mg/L BOD₅ and 3 mg/L NH₄-N



without advance (tertiary) treatment.

Fig. 2. HYBACS system of hybrid activated sludge

II. DESIGN PARAMETERS FOR RBC (RBC UNIT DESIGN)

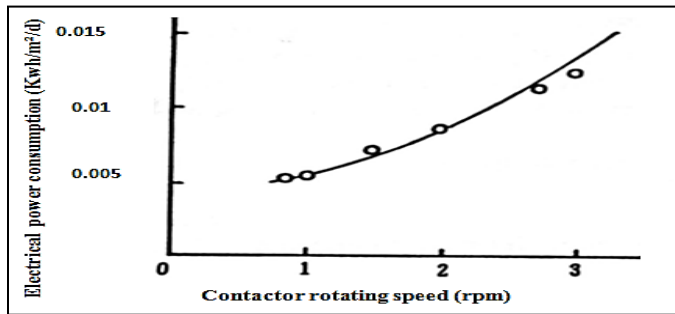
A. Speed of Rotation

In general, increasing of dissolved oxygen (DO) is done by increasing of speed of rotation which is consequently increasing of consumption of electrical power and also make shearing off of the attached biofilm from the media that is less economically

for the process (Ramsay et al., 2006). As a result, always minimum rotation of speed should be selected which can nonetheless provide acceptable treatment, Figure 3.

Fig. 3. Electric power consumption of RBC, (Watanabe et al., 1993)

B. RBC Media



First of all, there are different types of materials that used for media in RBCs units such as different kinds of plastics like, PVC (polyvinyl chloride), PE (polyethylene), GRP (glass reinforced plastic), polycarbonate sheets, etc, Figure 4. But surface energy and surface roughness are the main considerations for selection of media which affect growth and



adhesion of the biofilm (Rodriguez, 2012). All these materials that mentioned can be configured in several shapes such as corrugated sheet, flat disc, meshes and random packed. The main point is to increase the surface area per unit volume. Based on the surface area of the discs can be classified into three types, which are high, medium and low density (Metcalf and Eddy, 2014). According to Cortez et al. (2008), specific surface area varies from 115 to 200 m²/m³. For instance, for a shaft around 7.6 m length the surface area of a disc varies about 9300 m² to 16700 m². Moreover, according to Ware et al. (1990), increasing the complexity of medium led to increase its cost.

Fig. 4. Types of media used for RBC system

C. RBC Staging

Regarding RBC staging, there are different kinds of stage arrangement, Figure 5. For small-WWTP the flow direction is parallel to the RBC shafts, but for large WWTP they are perpendicular to the direction of flow. According to Metcalf and Eddy (2014), generally removal for both biological oxygen demand (BOD) and ammonium (NH₄-N) are required more than 4 stages and BOD is required 2 to 4 stages. As a result, staging of the RBCs are recommended to maximize removal of both BOD and NH₄-N (Cortez et al., 2008). For example, a three stages RBCs produce higher rate of BOD removal than

two stages for the same quantity of wastewater and same surface area (Patwardhan, 2003).

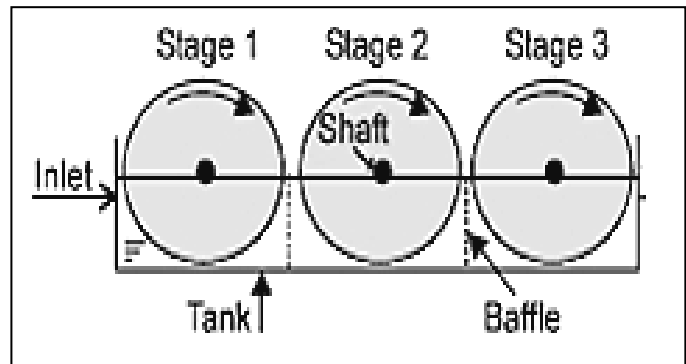


Fig. 5. RBC unit staging arrangements

D. Hydraulic Retention Time (HRT)

Firstly, short HRT reduce removal rates (i.e not efficient in the other side long HRT is not economic which increase the cost). In Table I typical values of HRTs are shown. As a result the shortest possible HRT with the most removal efficiencies are recommended always.

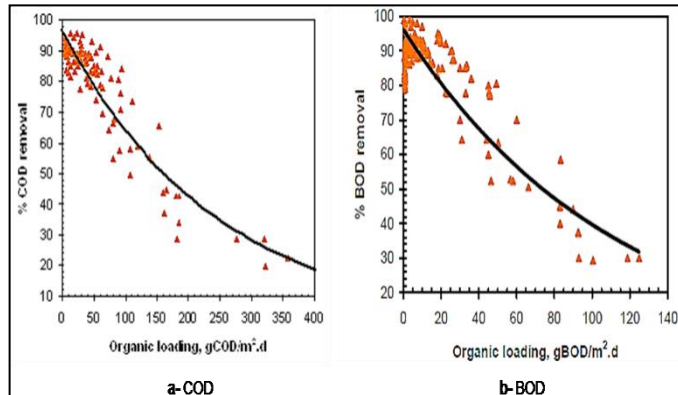
TABLE I
TYPICAL DESIGN PARAMETERS FOR RBCS, (METCALF AND EDDY, 2014)

Parameter	BOD + NH ₄ Combined	BOD	NH ₄ Separate nitrification
Hydraulic loading (m ³ /m ² .day)	0.030 - 0.08	0.08 - 0.16	0.04 - 0.10
Organic (BOD) loading(g/m ² .day)	5.0 - 16.0	8.0 - 20.0	1.0 - 2.0
Maximum 1 st stage organic loading (BOD) (g/m ² .day)	24.0 - 30.0	24.0 - 30.0	
NH ₄ loading(g/m ² .day)	0.75 - 1.5		
Hydraulic retention time (h)	1.5 - 4.0	0.7 - 1.5	1.2 - 3.0
Effluent NH ₄ (mg/L)			1-2
Effluent BOD(mg/L)	7-15	15-30	7-15

E. Hydraulic and organic loadings

Both hydraulic and organic loading are so important for RBCs design. The impact of organic loading on the removal efficiencies is presented in Figures 6 and 7. Firstly, the organic loading of the RBCs are required to be more accurate in design for both the over all stages and first stage. Secondly, when the RBCs systems are overloaded resulting very low dissolved oxygen concentrations in the RBC units which then leads to poor removal rates and odour emission. In general, poor performances have been observed when the systems are

overloaded. In Metcalf and Eddy (2014) there is a benchmark design data as shown in Table 1 for WWTP that based on RBCs in secondary treatment as a biological treatment at various design loading rates with removals for both BOD and ammonia. It can be seen that COD and BOD removal efficiencies decrease with the increase of organic loading rate, Figure 6. Additionally, COD removal decrease with the increase of



hydraulic loading, Figure 7.

Fig. 6. BOD and COD removal efficiencies vs. organic loading, (Al-Ahmady, 2005)

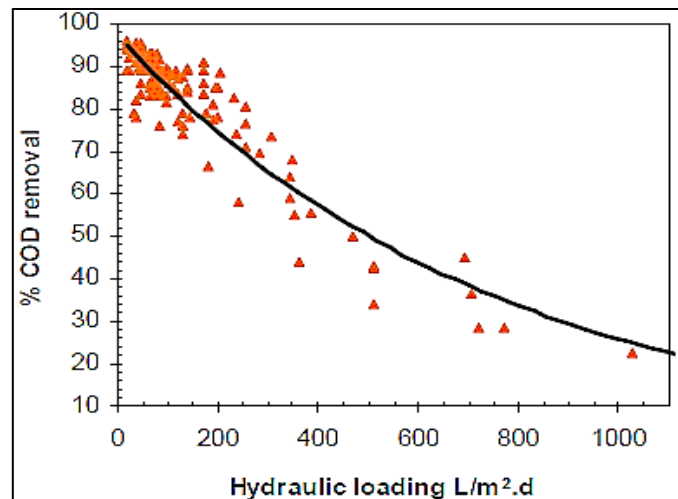


Fig. 7. COD removal efficiencies vs. hydraulic loading, (Al-Ahmady, 2005)

III. REVIEW OF RBC FOR TREATMENT OF WASTEWATERS

As a historical review, RBCs were first innovated and developed in 1920. In Europe, Germany the system was firstly installed in 1960. After that was introduced in USA. Also, it had become commercially available in 1965. RBCs installations were increased to hundreds in the 1970 and the process have been reviewed in many reports for WEF and U.S. EPA (Metcalf and Eddy, 2014). Recently, significant attention has been focused on RBC system (Tawfik et al., 2006; Williams, 2011).

Currently around the world there are many WWTPs which based on RBC technology or processes in different scales starting from small scale like compact units to large scale

WWTPs. For example, small package plant has capacity only for 20 PE as shown in Figure 8 and large size WWTP such as in North Carolina-United States. Asheville WWTP which treat municipal wastewater up to 150,000 m³/day (Figure 8). Moreover, in Canada, also, large scale WWTP such as Niagara - Falls WWTP, which is treating about 68,000 m³ per day of

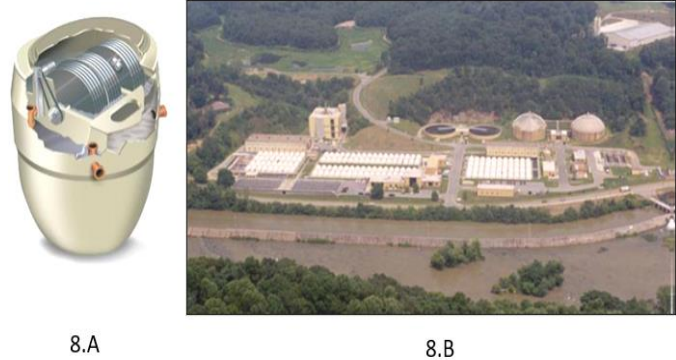


Fig. 8. A-Compact units and Aerial photo – B-Asheville WWTP, (Williams, 2011, Kingspan environmental, 2013).

Fig. 8. A-Compact units and Aerial photo – B-Asheville WWTP, (Williams, 2011) and (Kingspan environmental, 2013)

In Metcalf and Eddy (2014) there is a summarised important table regarding RBCs designing units in wastewater treatment processes. As shown in Table I which explained appropriate designs parameter.

There have many factors affecting the performances of the RBCs process. Some of them have relative greater impacts than the others. According to Al-Ahmady (2005), the important factors which control the performances are hydraulic loading, organic loading, speed of rotation and staging. Shape and geometric formation for media also has great impact. According to Cortez et al. (2008) surface area increases by corrugation which improves oxygen transfer and consequently removal efficiencies. Regarding types of media materials, polytetrafluoro ethylenes, are the best type of media of RBCs.

TABLE II
APPLICATION OF RBC FOR TREATMENT OF VARIOUS TYPES OF WASTEWATERS

Scale	Type of wastewater	Type of media	Stage/Temp/Submerge	HRT (h)	Hydraulic loading	organic Loading	Performance	Reference
Lab-scale	Domestic wastewater	PVC discs	3 stages, 25° C, 45%submerge	4,6,8,10,12	-	-	65%, 86%, 89%, 85% and 78% for COD removal, respectively HRT fixes on 8 h removal rate of NH ₃ -N is 75%	Fang Li, and Zenglu Qi (2012)
Pilot-scale	Domestic wastewater	Polyurethane	21° C	2.5	-	11gCOD/m ² d 0.23gNH ⁺ 4/m ² d	67±19 mg CODt and 87.0±4.0% removal of ammonia	Loupasaki and Diamadopoul os, (2013)
Full-scale	Food industry wastewater	Plastic packed rings	4 stages	-	0.02 m ³ /m ² d	-	86%, 88%, 71%, 73% and 77% for COD, BOD ₅ , TON, TSS and oil and grease removal, respectively	Cortez et al., (2008)
Pilot-scale	Municipal wastewater	Polystyrene foam discs	2 stages	5	-	COD 22 g/(m ² d)	77 %, 20% and 31% for COD, NH ⁺ 4-N; and TKN removal, respectively	Tawfik et al.,(2006)
Lab-scale	industrial wastewater	Polypropylene square packed rings	1 stages	12	-	BOD ₅ 2.72g/(m ² .d)	92.0%, 78% and 45.2% for BOD ₅ , COD and TKN removal, respectively	Cortez et al., (2008)
pilot-scale	Industrial wastewater	polyethylene discs	6 stages, 8 rpm, 37% submerge	16	0.013 m ³ /m ² .d	sBOD ₅ 5.3–17.8 mg/(m ² d)	"sBOD ₅ 5.3 mg /(m ² d): 75, 76 and 85%for BOD ₅ , COD and sBOD ₅ &; sBOD ₅ 17.8 mg /m ² d: 65, 59 and 74% for BOD ₅ , COD and sBOD ₅ removal, respectively"	Cortez et al., (2008)

IV. PROS AND CONS OF RBC TECHNOLOGY

Nowadays, there are many different technologies that used in the area of wastewater treatment around the world. Each technology has their limitation and positives. Accordingly, selection between alternatives is very important and it depend on many factors which have relations and effect on the process directly and indirectly, so it is true to say that each technology generally has positives and negatives (i.e. advantages and disadvantages). RBC as one of the biological technologies that used in WWTP has pros and cons.

Early RBCs installation were faced with many different mechanical problems, like media breakage structure failure of discs, shaft breaks and bearing failures all these due to insufficient, inadequate and poor design. In the past, shaft failures are one of the common problems, because it always makes total failure of the RBC system which led to loss of treatment process.

Furthermore, RBC has scaleup issues from pilot (small scale) to full (large) scale unit, as well as odour and slow process start-up problems. But recently, many modifications have been made

to solve these problems. Fortunately, several of these problems have solved which simplify operation and maintenance. As a result, current RBC installation is operating successfully and new technologies exist which extend RBC performance such as Hybrid Activated Sludge process, HYBACS.

According to the Table III, RBCs are known as a low energy consumption technology and process compared to CAS which is a suspended growth process. Because activated sludge needs huge amount of air which compressed in a pressure about 500 mbar to the system (Williams, 2012).

TABLE III
APPLICATION OF RBC FOR TREATMENT OF VARIOUS TYPES OF WASTEWATERS

Processes	Treatment Plant Loading	Year of Analysis	Annual Electricity Cost US\$	Electricity Cost US\$
CAS	30 MGD (112,500 m ³ /day)	2011	60,225	0.1/kWh
RBC			29,000	

V. ERBIL MUNICIPAL WASTEWATER QUANTITY AND QUALITY

Generally, wastewater quantity has increased rapidly because of the population growth and development in the city in all area such as in industrial development. the population is estimated to be 1,250,000 and growing at a rate of 3.5% annually (KOICA & K-Water, 2007). However, due to the unstably politically and economically in the other part of Iraq and the neighbour country such as in Syria and Iran the population has increased dramatically. Discharge of wastewater of Turaq area in 2001 and 2020 were 1.7 m³/s and 5.56 m³/s,

respectively (Aziz, 2020).

On the other hand, regarding quality of wastewater, it can be classified in to weak, medium and strong or high strength wastewater (Aziz and Ali, 2018; Aziz, 2020). For example, municipal and domestic WW usually weak or can be medium strength sometimes, on the other side industrial wastewater normally medium or strong, furthermore landfill leachate is high strength wastewater. Thus, according to the quality parameters of wastewater which are characterized by its physical, chemical, and biological compositions, depending on the source of the wastewater.

TABLE IV
CHARACTERISTICS OF ERBIL MUNICIPAL WASTEWATER (AZIZ AND ALI,2018)

NO	Parameters	Units	Nov 2015	Jan 2016	March 2016	May 2016	Disposing standards
1	pH	-	6.78	6.96	7.21	8.81	6–9.5*
2	ORP	mV	-33.2	-34.3	-62	-107.4	
3	TD Salts	mg/L	577	322	282	273	
4	Salinity	PSU	0.57	0.32	0.28	0.26	
5	Temp. Atm.	°C	21.86	16.18	17.42	25.05	<35*, 40**
6	Press.	mmHg	724.6	723.1	718.5	720	
7	IS	mg/L	300	500	900	500	
8	TSS TDS	mg/L	200	400	400	400	60*, 35**
9	TVS	mg/L	100	100	500	100	
10	TnVS	mg/L	200	200	300	100	
11		mg/L	100	300	600	400	
12	T. Acidity	mg/L	40	60	30.67	32	
13	T. Alkalinity	mg/L	206	236	204	157.33	
14	T. Hardness BOD5	mg/L	194	264	590	175.33	
15	COD	mg/L	44	56	46	40	<40*
16		mg/L	53	108	80	82	<100*
17	BOD5/COD	-	0.830	0.518	0.575	0.487	
18	Turbidity	FTU	19.77	44.2	29.1	18.28	
19	Chloride	mg/L	30.5	28	30	33.98	750 **
20	Color	Pt. Co	186	379	288	268	Nil *
21	NH3-N	mg/L	3.25	11.4	3.7	3.86	Nil*, 1 **
22	EC	µs/cm	582.61	490	521.5	590	
23	NO2	mg/L	20	26	23	24	1 **
24	NO3	mg/L	22.3	8.4	5.5	5.4	50*, 10**
25	Mn	mg/L	1.3	4.6	1.5	2	0. 2*
26	TOC	Mg/L	19	20	180	20	
27	Phenols	mg/L	0.102	0.055	0.044	0.013	0.01–0.05*, 0.5**
28	Oil & grease	mg/L	1.05	0.04	0.94	0.33	Nil*, 10 **
29	TVC Bacteria	Cfu/mL	110*10 ⁵	112*10 ⁵	127*10 ⁵	176*10 ⁵	
30	SO4	mg/L	0.25	0.0823	0.0823	0.1646	1500**

*: Iraqi Environmental Standard (2011), **: Environmental protection regulations (EPA) (2003).

VI. PROPOSED RBC UNIT DESIGN FOR ERBIL WWTP

According to topography, Erbil City has an elevation increases in the northeast region and situated on a mild sloping plain. This means that topography is enough to support the sewage system which is driven by gravity, so it is called gravity sewer system. The sewer network system reaches 247 km in length according to the study report in 2007 (KOICA & K-Water, 2007), which is an oldest and common type of sewer network system globally. Majority is pipe sewer and minority are box sewer. Sewer network mainly divided in two types which are separate system and combine system. Therefore, in both type all types of wastewater are collected i.e. rain, grey and black wastewater in addition to industrial, commercial wastewater. Also, household connection and other connections was clearly cannot applied because of absent of sewer branches everywhere.

This paper is concentrated on RBC technology and then the design of RBC unit in WWTP as a large scale for Erbil, as shown in Table V.

TABLE V
RBC DESIGN PARAMETERS FOR ERBIL CITY

Parameter	Design value	Unit	Design Range
Disc diameter	3.5	m	3.0 – 4.0
Rotation	1 rpm	rpm	1.0 – 2.0
Submergence	40%	%	40% - 50%
Surface area	9300	m ²	9300 - 16700
Enclosures	GRP cover	L.S	Wide range of Plastic
Shaft length	8.23	m	7.6 m occupied by media from 8.23 (27 ft) length
Tankage	45 m ³ , d _{water} =1.5 m	m ³	0.0049 m ³ /m ² * A _s (m ²)
Power (motor)	3.7/shaft	kW	3.7 – 5.0 per shaft
Effluent BOD ₅	21.5	mg/l	15 - 30
Hydraulic loading	0.084	m ³ /m ² .day	0.08 - 0.16
Influent sBOD ₅	75	mg/l	-
% Removal of efficiency	86	%	"[BOD ₅ inf. – BOD ₅ eff. / BOD ₅ inf.]* 100"
"Over all organic (BOD ₅) loading"	12.5	g/m ² per day	8.0 - 20.0
1 st stage organic (BOD ₅) loading	29.2	g/m ² .day	24.0 – 30.0
Stage(n)	3 (tapered)	No.	2 - 4
Media type	Corrugated HDPE	-	PVC., PP., HDPE., GRP
sBOD ₅ at n stage	"S _n = (-1 + ((1 + 4 x (0.00974) x (A _s /Q) x S _{n-1}) ^ 0.5) / (2 x 0.00974 x (A _s /Q))"		
Flow	210,000	m ³ /d	Large scale

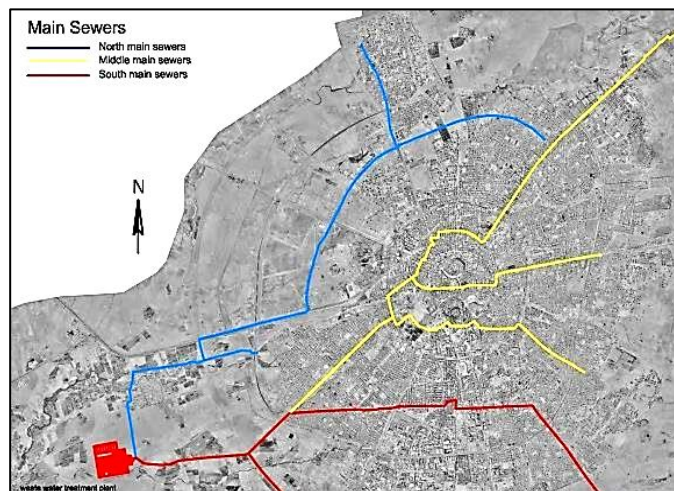


Fig. 9. Erbil WWTP location according to proposed design (KOICA & K-Water, 2007).

VII. REUSING OF TREATED WASTEWATER

First of all, wastewater in Erbil cannot be used for irrigation directly (Aziz et al., 2019). The effluent from treating Erbil municipal wastewater can be reuse for many purposes, which helps surface and subsurface water as a source of water supply system. This paper is concentrated and focused on RBC technology and then the design of RBC unit in WWTP as a large scale for Erbil, as presented before and reusing for irrigation for large gardens, landscape pools & parks in addition of cleaning like carwash, etc.

TABLE VI
WATER REUSE QUALITY FOR IRRIGATION PURPOSES ACCORDING TO FOOD AND AGRICULTURE ORGANIZATION (FAO), 1985

Effluent Parameters	Unit	Value
COD	mg/l	< 90
BOD ₅	mg/l	< 30
TSS	mg/l	< 45
NH ₄ -N	mg/l	< 5

CONCLUSION

Generally, RBC system represents a relatively small footprint (land); using low energy and low process complexity option for wastewater treatment. RBC is known as low energy consumption technology for WWTP. The energy consumption of a WWTP is usually the main contributing factor to OPEX. The value of OPEX is low because it consumes low energy and is easy to operate. Less manpower and skill are required for operation and maintenance as it is simple system no complex. RBCs provide reasonable removal efficiencies which are achieve the consents for reuse for irrigation and other mentioned purposes. On the other side, however RBC has slow process start-up, several mechanical problems and limited process flexibility. Generally, an RBC-based WWTP has relatively high capital (CAPEX). Treated municipal wastewater

using RBC technology can be used for irrigation purpose which saves drinking water sources in Erbil City.

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