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Original Article

Evaluation of an Existing RBC Plant in Egypt

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Abstract - *Rotating biological contactors technology is one of the applied wastewater treatment technologies in Egyptian rural areas. RBC plants' performance in Egypt falls below the expected standards from their design criteria. This study investigates the causes of deterioration and the problems facing RBC technology in Egypt. This was achieved through reviewing and evaluating the existing situation for El-Manayel WWTP, including design review and evaluation of existing structure status for plant units, as well as evaluation of the applied operation and maintenance procedure. The study's findings revealed that the treatment units could achieve their designed effluent results for a short period only; after this period, the biological treatment deteriorates because of the random operation and the lack of preventive maintenance. The major detected problems were the repetitive mechanical equipment failures, and using non-durable materials for the replaced parts during performing the corrective maintenance. It has been proven that the design of the plant's treatment units is suitable for the incoming influent, adequate for the local climate, and capable of achieving the required effluent quality, complying with the Egyptian law no.48 of 1982 concerning the protection of the Nile and the water channels against pollution.*

Keywords - *Wastewater, Rotating Biological Contactors, RBC, Biological wastewater treatment, O&M.*

1. Introduction

Wastewater treatment has a significant role in conserving water resources and achieving environmental sustainability. Wastewater treatment plants also conserve the natural bodies from pollution and safeguard the aquatic ecosystems.

The need for effective wastewater treatment facilities in Egypt is increasing due to rapid population growth and urbanization. In Egypt, there are more than 600 wastewater treatment plants using various wastewater treatment technologies. One of these technologies is the Rotating Biological Contactors (RBC), which is spread throughout the country.

The total number of RBC treatment plants in Egypt is 40, with design capacities ranging from (1000 m^3/d to 12000 m^3/d), and the estimated total design capacity for RBC plants all over Egypt is 243,000 m^3/d of treated wastewater.

Although RBC technology is considered a suitable and highly performance technology worldwide, RBC plants in Egypt suffer from many problems that affect their performance and cause environmental consequences. The equipment of these plants is often exposed to repetitive failures affecting the treatment processes. While implementing maintenance for major failures requires setting the tanks out of service, thus discharging untreated wastewater directly to the water stream, which deteriorates water quality and causes severe environmental and health problems.

The discharge of inadequately treated wastewater from Rotating biological contractor plants in Egypt because of O&M problems, causing water bodies pollution, increasing the risk of waterborne diseases and threatening aquatic life.

The performance of existing RBC plants in Egypt with the small area required for such plants raises the need to conduct more studies on the evaluation and improvement that could be applied to this system.

This paper identifies the causes of deterioration and the problems facing the RBC technology in Egypt by evaluating a selected existing RBC plant in Egypt; this plant would be representative of the various RBC treatment plants in Egypt as they all share the same design with various capacities.

2. Literature Review

The Rotating Biological Contactor (RBC) is one of the moving-medium attached growth biofilm systems, offering an alternative method to the Activated Sludge Process (ASP) treatment. The media consists of several large discs with biofilm attached to their surfaces, which are mounted on the same shaft partially submerged in wastewater. These discs rotate through contoured tanks, allowing wastewater to flow continuously. RBC systems typically offer a specific surface area ranging from 150 to 250 m^2/m^3 of liquid. [1]

The rotating biological contactor, or RBC, was first installed commercially in Germany in 1960 and later introduced in the US for treating municipal and industrial wastewater. [3]

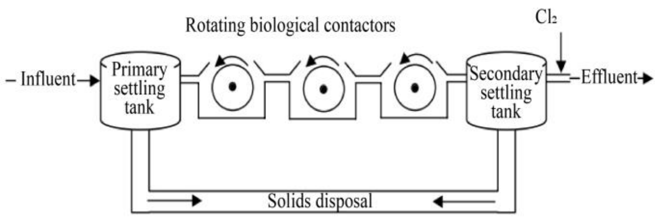

Fig. 1 Flow diagram of an RBC process[2]

The performance and energy consumption of the rotating biological contactor were assessed in a study conducted in Indonesia. The energy requirement analysis revealed that RBCs consume less energy than other biological treatment methods, such as MBR and SBR. The operational benefits and low energy usage demonstrate the effectiveness of RBCs for municipal wastewater treatment [4].

Milad.R. and Sara.N. [5] examined various strategies for managing water and sludge lines to regulate dissolved oxygen and biomass concentration within activated sludge systems by adjusting aeration intensity and sludge flow rates. Their study concluded that optimizing the aeration system and sludge flow rate enhances effluent quality and increases system reliability, even though it results in higher operational costs.

In a separate study conducted at Cranfield University, researchers evaluated the use of RBC for wastewater treatment, establishing connections across various disciplines while discussing the latest advancements in RBC research. They presented a comparison of the latest process designs and emphasized the microbial characteristics of the RBC biofilm. Additionally, they addressed some topics, such as biological nitrogen removal and the remediation of priority pollutants [6].

A study conducted by Shamas T. et al. evaluated cost-effective and energy-efficient disc materials for Rotating Biological Contactors (RBC). Various parameters, including pH, Dissolved Oxygen (DO), Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD), were monitored for both the influent and effluent of a pilot-scale RBC under different operating conditions. The analysis of the results indicated that submergence plays a more significant role in increasing DO levels than RPM does [7].

At a university in Malaysia, a study examined the impact of organic and nitrogen loading rates in a rotating biological contactor for wastewater treatment. The findings revealed that higher loading rates led to improved removal rates but decreased removal efficiency for both organics and nitrogen. Additionally, an energy consumption analysis indicated that RBCs use significantly less energy compared to other biological processes [8].

A study made in Agnita, Romania, using 40% $FeCl_3$ solution in the RBC WWTP proved the success of improving the plant removal efficiency for both nitrogen and phosphorus, which produces cleaner effluent [9].

Some studies about RBC systems were conducted in Egypt. The National Research Centre in collaboration with Wageningen University, carried out a study about the Physico-chemical factors affecting the E.coli removal in a Rotating Biological Contactor (RBC) treating UASB effluent.

The results showed that the primary mechanism for removing E. coli in the biofilm is the adsorption process, followed by sedimentation. A rapid adsorption of E. coli to the biofilm was observed during the initial days following the addition of the cationic polymer, but this process slowed down afterwards.[10]

Recent research was made about Using Geotextiles, Sugarcane Straw and Steel Cylinders in Rotating Biological Contactor Wastewater Treatment at Zenin WWTP in Giza, Egypt. It was concluded that rotation speed is a key factor affecting the removal rates for COD, BOD, and TSS; also, using contactor shapes and two phases rather than one phase greatly increased treatment efficiency. [11]

The performance of existing RBC plants in Egypt with the small area required for such plants raises the need to conduct more studies on the evaluation and improvement that could be applied to this system.

Rotating biological contactors can be implemented in Integral Systems containing a single unit or in Modular Systems with separate operations. Another emerging type of RBC is the Modified Rotating Biological Contactors System MRBC, which combines activated sludge and fixed film processes into a single system.

The modified rotating biological contactor system is the only existing type of RBC system in Egypt, and this study evaluates its structure and performance.

Most of the 40 MRBC plants implemented in Egypt face challenges and suffer from deterioration in their performance; this study has been conducted in order to investigate the causes of the low performance of the MRBC plants in the country.

The MRBC consists of a number of cylindrical contactors, which are arranged circularly around a horizontal shaft. Contactors are partially immersed in the wastewater and driven by a rotational movement by a mechanical drive system consisting of a gear motor and chain drive. The percentage of submergence in MRBC is about 80%, as shown in Figure 2.

Fig. 2 Modified rotating biological contactor

3. Material and Methodology

The study location is El-Manayel WWTP, located in Qalyubia governorate in Egypt, in an agricultural area North of El Khanka district.

A study working program was designed to investigate and evaluate the problems that affect the plant performance; it included the review and evaluation of the existing situation for plant units due to design, structure status, and operation procedures. These were achieved through the following steps:

- Reviewing the sizing due to hydraulic and organic loads.
- Identifying existing design problems.
- Evaluating the structure status for the components of the units.
- Determining the reason causing the unit's damages.
- Evaluating the applied operation procedures.
- Comparing operation procedures with the operation manual of the supplier to determine its problems.

The study focused mainly on three parameters: BOD, COD and TSS. The measurements for these parameters are done according to the American standard methods for examining water and wastewater [11] in the El-Manayel WWTP laboratory and the Qalyubia Company's central laboratory for water and wastewater.

3.1. Plant Description

El-Manayel WWTP is a modified rotating biological contactor plant, depending on a hybrid activated sludge system. The plant was established in 2020. It is a secondary treatment plant designed for municipal wastewater capacity of 10000 m3/day. The plant consists of two lines; one of them is not functioning due to problems.

The components of the El-Manayel treatment plant include the inlet chamber, screens, grit removal chamber, biological tanks, sedimentation tanks and chlorine and disinfection system. Besides the sludge units, thickeners, pumps, and drying beds are illustrated in Figure 3.

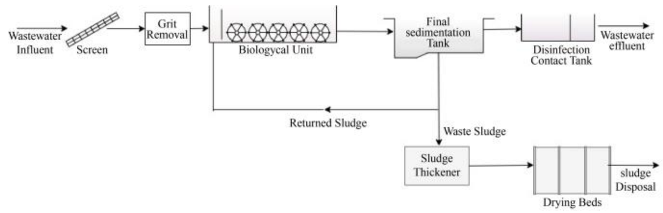

Fig. 3 Flow Diagram for El-Manayel WWTP

3.2. Biological Units RBCs

The plant contains four biological tanks; each tank contains 5 wheels, and each wheel consists of a shaft surrounded by cylinders loaded with discs, as shown in Figure 4. A mechanism that rotates the wheels consists of a motor and a drive chain connecting two gears, controlled by a gearbox powered by an electric motor. The level of aeration can be controlled by utilizing a variable-speed drive. Increasing or decreasing the rotor's speed according to the actual oxygen demand.

Fig. 4 Biological units

Table. 1 El-Manayel WWTP Raw Influent Wastewater Characteristics

	TSS mg/l	COD mg/l	BOD_5 mg/l	PH	Temp °c	Flow Rates m^3/day
Average	265.3	387.1	242.5	7.7	24	7102
Maximum	362	523	295	7.9	26	7354
Minimum	162	310	196	7.4	22	6687

3.3. Final Sedimentation Tank

There are four rectangular sedimentation tanks in the plant. Inside each tank, a motorized sludge scraping mechanism scrapes the settled sludge towards the sludge hoppers. Each hopper has a pump to lift the sludge from the sedimentation tank to the inlet of the biological tank or the sludge thickener.

4. Design Review

The study focused on the review and evaluation of the operation of the plant; it consists of three stages: design review, structure evaluation for the units, and operational procedure evaluation.

The influent wastewater flow was measured, and samples were collected through a month (April 2024); the concentrations for Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS) and daily flow are illustrated in table 1.

Design calculations for the biological treatment units and final sedimentation tanks were carried out based on the design values of the wastewater characteristics and design flow rate and the actual average values of the measured raw wastewater influent characteristics and flow.

4.1. Biological Units RBCs Calculations

There are 4 MRBC tanks; each has the following specifications: Top water level in tank 20.10 m, Tank bottom level 15.00 m, Tank height: 6 m, max., water level: 5.1 m, length: 40.3 m, width: 7.2 m, Volume: 1479.8 m³. Design review calculations for the biological treatment MRBC unit are shown in Table 2.

4.2. Final Sedimentation Tanks (FST) Calculations

There are 4 Final Sedimentation Tanks (FST); each has the following specifications: Top water level in tank m 19.95, tank bottom level 15.00 m, tank height: 6 m, Max., water level: 4.95 m, length: 34.2 m, width: 7.2 m, Volume: 1218.9 m³, weir length per tank: 7.2 × 4 (each tank outlet is through two (v-notch) channels across the tank as shown in figure 5. Design review calculations for sedimentation tanks are shown in Table 3.

Table 2. Design review calculations for biological treatment MRBC unit

	Design Values	**Actual Average Values**
Flow Rate	$Q_{av.d}$: 10,000 m^3 /d	$Q_{av.d}$: 7102 m^3/d
Hourly peak flow rate (PF: 2)	Q_{peak}: 833. 3 m^3 /h	Q_{peak}: 591.8 m^3/h
BOD_5-concentration	450 mg BOD_5/l	242.5 mg BOD_5/l
Daily BOD_5-load	4500 kg BOD_5/d	1722.24 kg BOD_5/d
TSS Concentration	500 g/m³	265.3 g/m³
Daily TSS- load	5000 kg/d	1884.2 kg/d
Volume of each tank	1,479.8 m³	1,479.8 m³
Total Volume of 4 Tanks	5,920 m³	5,920 m³
Hydraulic Retention Time (HRT) at peak	HRT = 5,920 m³ / 833.3 m³/h = 7.1 h	HRT = 5,920 m³ / (591.8 m³/h) = 10 h
Organic Loading Rate = (BOD_5 load) / (Total volume of biological tanks)	= 4500000 g/day / 5,920 m³ = 0.76 kg BOD_5/m³ /day	= 1,722,200 g/day/ 5,920 m³ = 0.29 kg BOD_5/m³/day

Table 3. Design review calculations for final sedimentation tanks

	Design Values	**Actual Average Values**
Flow Rate	$Q_{av.d}$: 10,000 m^3 /d	$Q_{av.d}$: 7102 m^3 /d
Hourly peak flow rate (PF: 2)	Q_{peak}: 833. 3 m^3 /h	Q_{peak}: 591.8 m^3/h
BOD_5-concentration	450 mg BOD_5/l	242.5 mg BOD_5/l
Daily BOD_5-load	4500 kg BOD_5/d	1722.24 kg BOD_5/d
TSS Concentration	500 g/m³	265.3 g/m³
Daily TSS- load	5000 kg/d	1884.2 kg/d
Volume of 1 FST	1,218.9 m³	
Total Volume of 4 FST	4,875.5 m³	
Hydraulic Retention Time (HRT) at peak	= 4,875.5 m³ / 833.33 m³/h = 5.85 h	= 4,875.5 m³ / 591.8 m³/h = 8.24 hours
Overflow rate = (Average flow rate) / (Total surface area of final sedimentation tanks)	=10,000 m³/day / 984.96 m² = 10.15 m³/m²/day	7102 m³/day / 984.96 m² = 7.21 m³/m²/day
Total Weir Length	= (4 × 7.2 m) × 4 = 115.2 m	= (4 × 7.2 m) × 4 = 115.2 m
Weir Loading Rate = (Average flow rate) / (Total weir length)	= 10,000 m³/day / (115.2 m) = 86.8 m³/m/day	7102 m³/day / (115.2 m) = 61.65 m³/m/day
Solids Loading Rate (SLR) on the FST = (Concentration of TSS × Peak flow rate) / Total area of FST	= Total area of four FST is 984.96 m²	
	SLR = 0.42 kg TSS/m²/h	SLR = 0.16 kg TSS/m²/h

Fig. 5 Sedimentation tanks outlet channels

5. Discussions of Design Review Calculations

From the design review calculations for the biological treatment MRBC units, it has been found that the actual average values of the measured raw wastewater influent characteristics and flow gave a safer and more relaxed operation than the designed influent flow and characteristics assumptions.

In both cases (the design values and the actual average values), the organic loading rate was 0.76 kg BOD_5/m^3/day and 0.29 kg BOD_5/m^3/day, within the typical range for RBC systems.

The hydraulic retention time at peak for the biological treatment MRBC units according to design values flow was 7.1 hours, while it was 10 hours according to the actual flow, where both were within the typical range for RBC systems.

The design review calculations for final sedimentation tanks showed that in both cases (the design values and the actual average values), the overflow rate was 10.15 m^3/m^2/day and 7.21 m^3/m^2/day, which is lower than the typical value of 30 m^3/m^2/day, indicating that the final sedimentation tanks are oversized.

The hydraulic retention time at peak for final sedimentation tanks according to design values flow was 5.85, while it was 8.24 hours according to the actual flow, where both were within the typical range for RBC systems.

Based on the accomplished design review of the wastewater treatment plant, it has been concluded that the overall system is well-designed and equipped to meet the design and current actual operational requirements.

6. Structure Evaluation for Units

Although El-Manayel WWTP has been working for less than four years, its performance falls below the designed efficiency due to the deterioration in mechanical parts, and the repeated damages raised the maintenance cost and running costs. The structure status of the plant's units was evaluated to determine the reason causing the unit's damages.

El-Manayel WWTP has been designed to treat 10000 m^3/d of wastewater. After the preliminary treatment, the plant is split into two parallel biological treatment lines, as demonstrated in Figure 6.

6.1. Current Status of Headwork

The influent wastewater is directed to the plant location through a pressurized pipe (500 mm). Besides, an overflow discharge line (600mm) and another line (100 mm) discharge the collected water from the supernatant pumps.

The Preliminary of the sewage starts by screening. There are two mechanical screens and one manual screen, all connected in parallel. The type of the mechanical screen is HUBER (Complete Plant ROTAMAT® Ro9). Both Mechanical screens are working properly, and their motors are in good condition.

There are two grit and sand removal units using the vortex technology without any moving parts. The outer chambers of the grit removal units are made of concert, while the internal components are made of steel coated by epoxy.

Both units are operating properly without any apparent defect or rust. These units remove about 90% of particles equal to or greater than 75 microns at the design flow rate. After the screening and grit removal, the wastewater is directed to one of the two biological treatment lines.

6.2. Current Status of Biological Units

The biological treatment contains 4 biological tanks of the modified rotating biological contactor type; each tank contains 5 wheels (Rotary Aerators) that act as the central equipment for treatment and oxygen supply.

The wheels are designed to submerge 75 to 80 % of the wastewater. Each wheel consists of a slowly rotating central shaft and steel cage structure that supports specially designed polypropylene media bundles.

The axis of the RBC shaft is placed perpendicular to the direction of flow, and it rotates in the direction that causes the top of the media to move opposite to the direction of flow to minimize the short circuits, as demonstrated in Figure 7.

The Biological Tank number 1 was out of service, as shown in Figure 8, for more than six months due to repetitive failures in operating the rotating mechanism and the drive chain.

Both biological tanks number 2 and 3 are working, although biological tank number 3 has 3 working wheels and two wheels out of service, and all the driving chains for the five wheels are rusty.

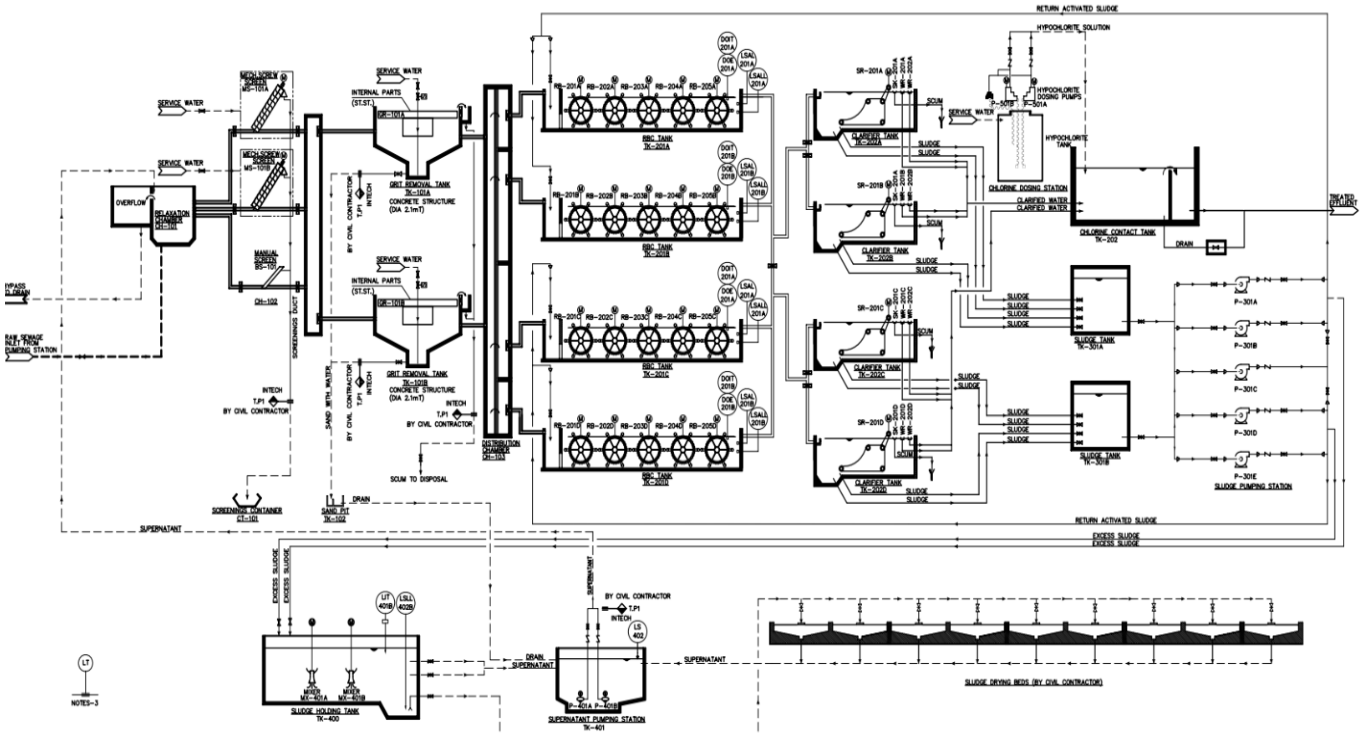

Fig. 6 El-Manayel WWTP process flow diagram

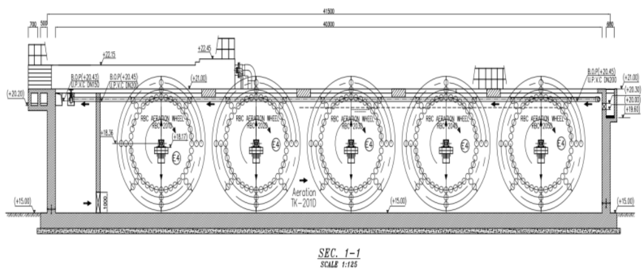

Fig. 7 Cross-section of the Biological Tank

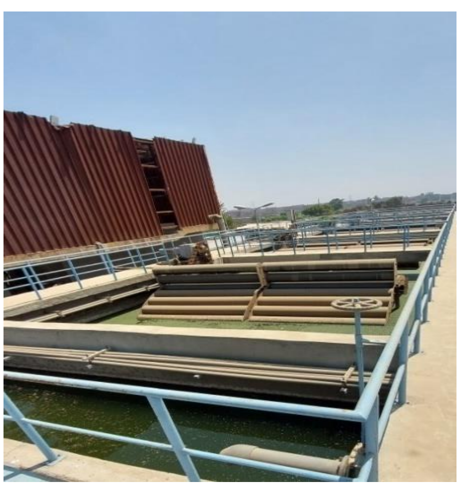

Fig. 8 Biological tank number 1 out of service

In biological tank number 4, the raw wastewater enters the tank, but there is no actual treatment due to the low DO inside the biological tank, as three RBC wheels are out of service and need maintenance.

6.3. Current Status of Final Sedimentation Tanks

There are four final sedimentation tanks; each tank has a scrapper driven by a plastic chain conveyor, as shown in Figure 9. This non-metal chain system provides a reliable operation for the sedimentation tanks.

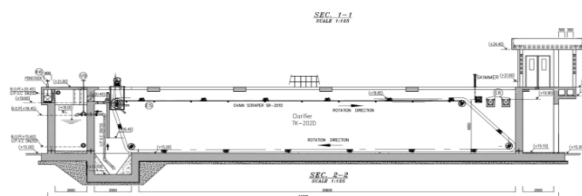

Fig. 9 Cross-section of sedimentation tank

Two sedimentation tanks are operating (numbers 1 and 2). The other two sedimentation tanks are out of service because of the presence of algae and the low quality of the produced water, while the other two are in service and overloaded.

6.4. Current Status of Disinfection Units

The hypochlorite dosing system is not working, and the operators use solid chlorine and mixing tanks instead. The Chlorination contact tank is in poor condition, and the chlorine is injected through two narrow pipes at the entry of the contact tank; these pipes end at a level higher than the water level, as demonstrated in Figure 10.

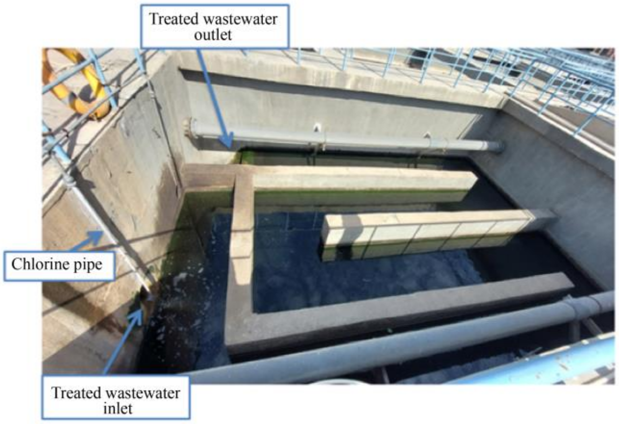

Fig. 10 Disinfection contact tank

7. Discussions of Structure Evaluation for Units

The structure evaluation for the units of the El-Manayel wastewater treatment plant showed that the components of the headwork, screens and grit removal tanks are in good condition and functioning well.

Through the structure evaluation for biological units, it was found that mechanical breakdowns and malfunctions take place repetitively, causing failure in the treatment system. Most of the identified issues were centered within the rotating mechanism in the biological units, consisting of a motor and a drive chain that rotates the MRBC wheels.

The structure evaluation for the final sedimentation tanks has revealed that there is no presence of mechanical or structural problems. In two sedimentation tanks, there was an accumulation of algae, and their produced treated wastewater quality was low as a result of the low quality of the wastewater entering the tank after the non-efficient operating biological tanks.

8. Evaluation of the Current Performance

The BOD_5 COD and TSS removal were assessed by analyzing the influent raw wastewater and the treated effluent of the plant; these analyses have been carried out by the WWTP laboratory and the central laboratory of Qalyubia Company for water and wastewater.

8.1. TSS

Figure 11 shows the TSS content in the influent raw wastewater and the treated effluent of the plant during April 2024.

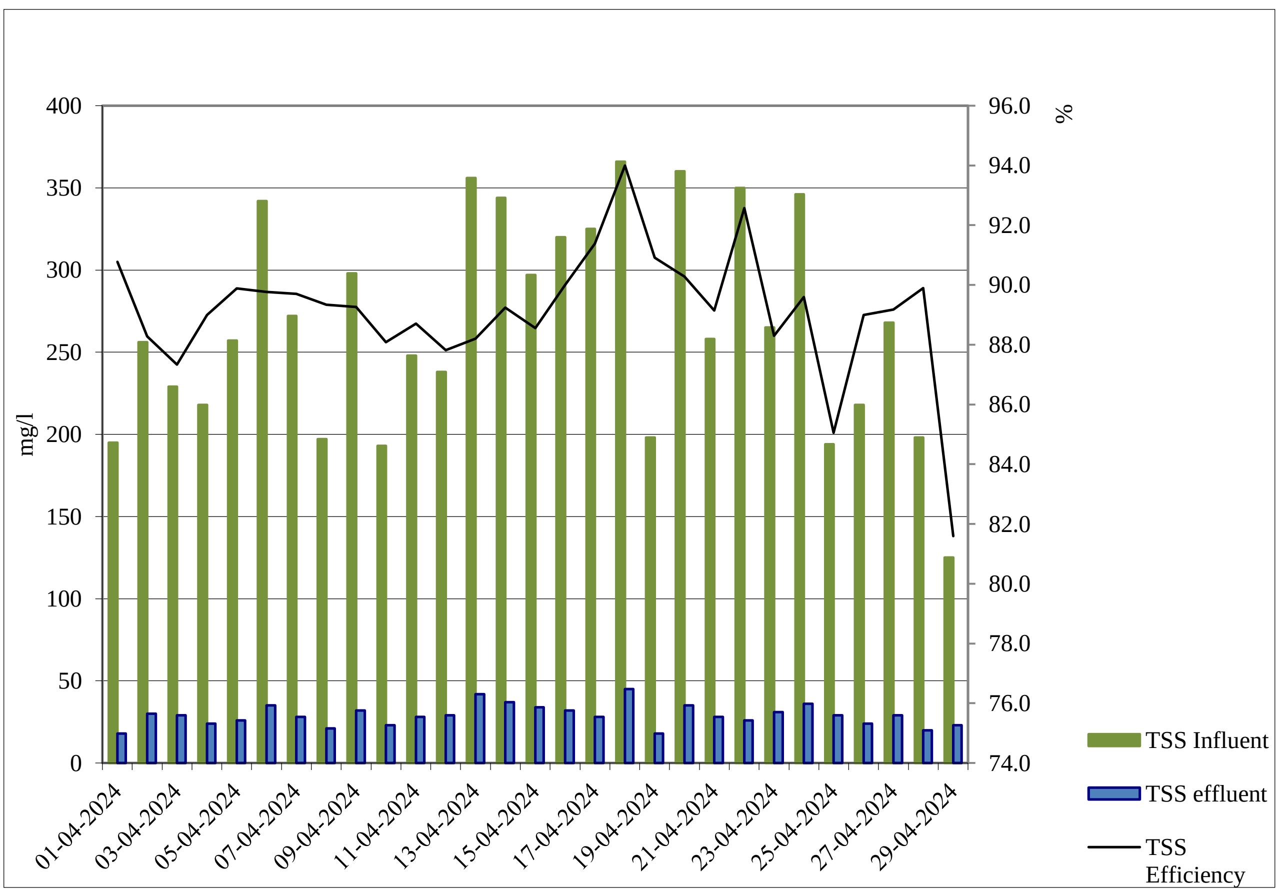

Fig. 11 TSS Concentration in Influent and Final Effluent in April 2024

8.2. COD

Figure 12 shows the COD content in the influent raw wastewater and the treated effluent of the plant during April 2024.

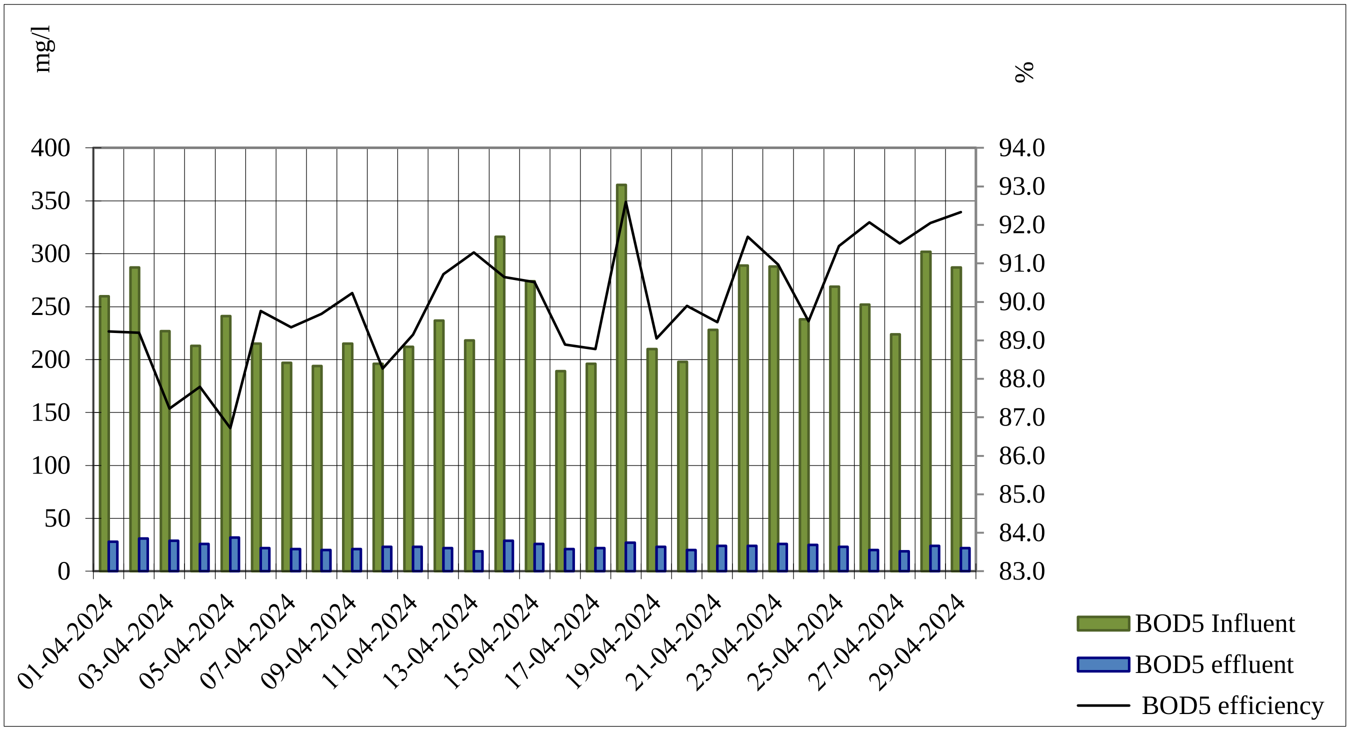

Fig. 12 COD Concentration in Influent and Final Effluent in April 2024

8.3. BOD

Figure 13 shows the BOD_5 content in the influent raw wastewater and the treated effluent of the plant.

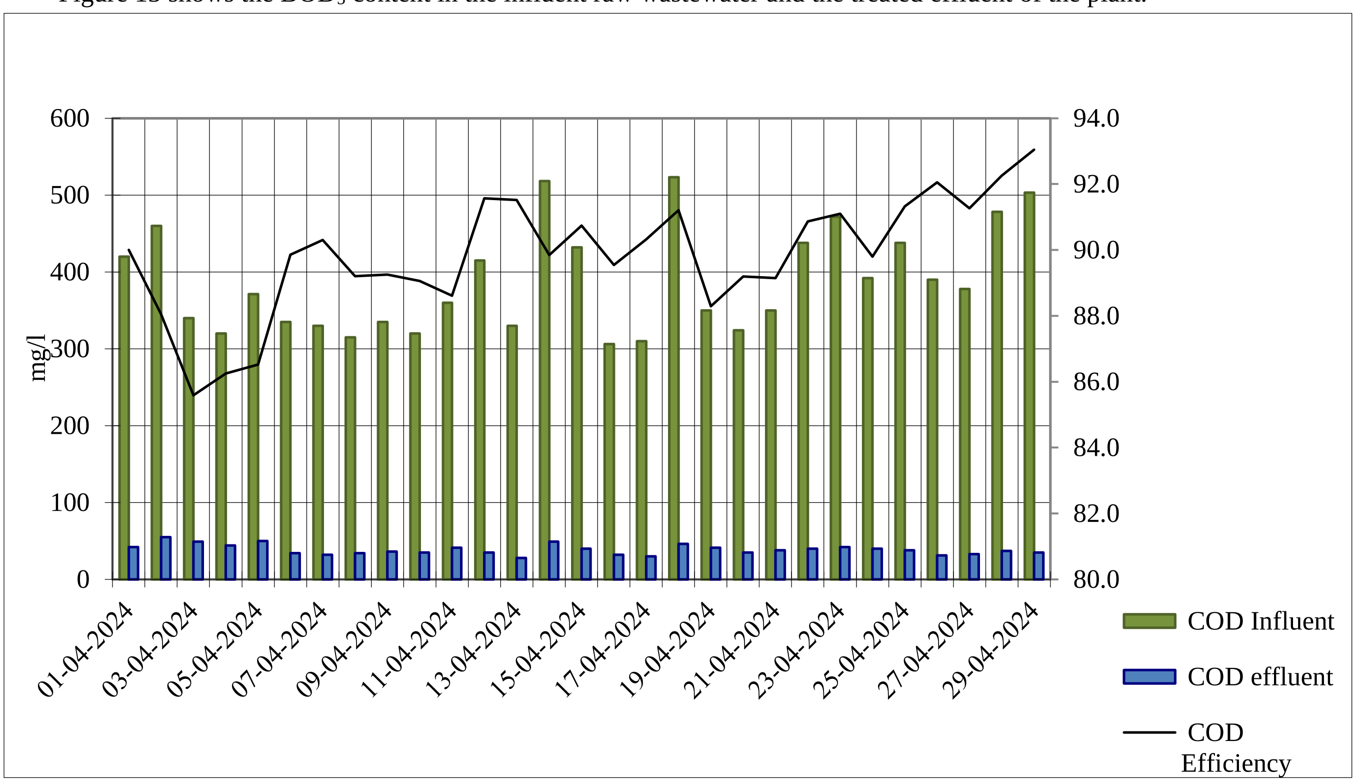

Fig. 13 BOD5 Concentration in Influent and Final Effluent in April 2024

9. Evaluating Current Performance Discussions

From the comprehensive assessment of the quality of the treated effluent, it was found that the treated effluent quality has achieved the requirements for the BOD_5 COD and TSS removal throughout the studied period.

According to the design of the MRBC, the load treatment is divided into two parts: approximately 70% of the load is treated by aeration and activated sludge, while 30% of the load treatment depends on the fixed film process.

The actual properly operating units were only two biological treatment tanks and two sedimentation tanks, and the average influent raw wastewater was 7102 m^3/day, which exceeds the design capacity of these operating units ((5000 m^3/day).

Achieving acceptable treated effluent quality can be justified by the overall operating conditions, as the measured values of the raw wastewater flow and characteristics gave safer and under-loaded operation less than the designed influent flow and characteristics assumptions.

10. Evaluation of the Applied Operation and Maintenance

The applied O&M procedure was evaluated and compared with the unit's manual provided by the supplier to determine the causes of the existing problems, and the following were the main points for the biological tanks and the FSTs:

10.1. Evaluation of the Operation and Maintenance of the Biological Tanks

- Activated sludge is returned from the sedimentation tanks to the inlet zone in the biological tanks according to only the color of wastewater in the biological tank.
- MLSS levels are not measured regularly, which affects the performance of the treatment process.
- The Dissolved Oxygen (DO) level in the RBC tanks is continuously measured by a DO meter on the control panel.
- The operators have been manually operating the rotating contractor system according to a fixed schedule and not linked to measuring the DO levels in the biological tanks.
- The automatic DO control systems are not used as the operators are not trained on how to operate them.
- The existing maintenance procedures are focused only on repairing failures without any preventive maintenance.
- Unsuitable materials were used during the repair of the chains.

10.2. Evaluation of the Operation and Maintenance of Sedimentation Tanks

- The sludge withdrawal rate needed to be adjusted to prevent solids from being carried over into the effluent.
- The returned sludge exceeds the optimal limit, negatively affecting the treatment process.
- The inadequate influent flow distribution on each tank caused problems, as increased flow in some tanks caused poor settling, while the decreased flow in other tanks caused algae accumulation in the tanks.
- The existing maintenance procedures are limited to repairing failures, emptying the tank, and disinfecting it whenever a problem appears, and no preventive maintenance is carried out.

11. Conclusion

Through evaluating the applied operation and maintenance in El-Manayel WWTP, it has been verified that its treatment units achieve their designed effluent results for a short period only; after this period, the biological treatment deteriorates.

The findings of the study about the RBC wastewater treatment plants in Egypt could be summarized in the following:

- It has been proven through the calculations that the design of the MRBC plant's treatment units is suitable for the incoming influent and adequate for the local climate, and capable of achieving the required effluent quality complying with Egyptian law no.48 of 1982 concerning the protection of the Nile and the water channels against pollution.
- The MRBC plants have the advantages of low energy requirements, compact footprint, and reduced operational costs compared to conventional activated sludge plants.
- Lack of preventive maintenance and random operation of the units were the main reasons for the detected problems.
- Through reviewing and evaluating the existing situation for the El-Manayel plant, the major problems that caused the deterioration of the WWTP were the repetitive mechanical equipment failures, especially the breakage of driving mechanisms and gearboxes for the MRBC biological tanks and using non-durable materials for the replaced parts while performing the corrective maintenance.

Recommendations

From the study, the following points are recommended:

1. Implementing suitable maintenance and operation procedures for MRBC plants to achieve successful and safe operation.
2. Applying the O&M procedures on the MRBC plants in Egypt, as they all have a similar design to the design of the studied plant but with different capacities.
3. Preserving and improving the RBC plants in Egypt rather than transforming them into activated sludge.
4. MRBC plants can be implemented by using local manufacturing materials, which would decrease the capital cost and the maintenance cost.

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