ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Upgrading of an Extended Aeration System to Improve Wastewater Treatment

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Abstract

According to this study, an extended aeration system can be upgraded by adding surface turbine aerators to the tanks and building new primary sedimentation tanks. Moreover, the biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and total suspended solids (TSS) were also observed to be 440, 682, and 212 mg/L after primary settling, respectively. These values represent the removal of about 35% of the organic load and about 68% of the suspended solids, which reduces the organic load and sediments entering the secondary treatment. Furthermore, effluent BOD_5, COD, and TSS values were 30, 47, and 32 mg/L respectively, while those permitted values are 60 mg/L of BOD_5, 80 mg/L of COD, and 50 mg/L of TSS reflecting the success of the upgrading work.

Keywords: Activated sludge; extended aeration; primary sedimentation; upgrade; wastewater treatment.

1. Introduction

Under aerobic conditions, extended aeration is a biological treatment that is an adaptation of the activated sludge process. To maintain aerobic biological processes, oxygen can be delivered via diffused or mechanical aeration. Aeration is required to maintain microbial interaction with dissolved organic matter. The pH must also be controlled to enhance the biological treatment, and essential nutrients must be present to support biological growth and the continued biological degradation of organic materials. The oxidation ditches (ODs) operate in an extended aeration methodology involving long hydraulic and solids retention times which permit more organics to be diminished [1-3]. As one of the applications of the extended aeration system, ODs are extremely well-known wastewater treatment processes around the world as an application of the extended aeration system [3-7]. The Netherlands began to improve ODs in the 1950s when Pasveer [8] prepared the first exhibition report. Carbonaceous biochemical oxygen demand removal, nitrification, and denitrification can all be accomplished in one reactor with ODs [5, 9-10].

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The extended aeration system is equipped with mechanical aerators or air diffusers that provide mixing and aeration [11-14]. To promote mixing and aeration, confirm that horizontal velocity in the reactor is sufficient to create a suitable amount of turbulent flow. Therefore, a significant factor in extended aeration systems is the horizontal velocity, which has a typical range of 0.25 to 0.35 m/s [2, 15-16]. A horizontal velocity of more than 0.25 m/s is normally recommended to: a) supply a sufficient quantity of dissolved oxygen (DO) to sustain aerobic conditions and prevent forming anaerobic zones; b) prevent the settling of organic and solid particles; and c) mix the wastewater with the suspended biomass, nutrients and DO uniformly [10, 15, 17, 18]. However, the horizontal velocity is restricted to a maximum of 0.60 m/s to evade extreme disintegration, inordinate air circulation, excessive recirculation, hydraulic jump, or other undesirable non-uniform flow phenomena [16, 19]. For reliable organic removal and nitrification, the extended aeration system can be operated in totally aerobic conditions with a high horizontal velocity. However, both nitrification and denitrification require alternate periods of oxic and anoxic conditions [5, 16, 20]. Also, the horizontal velocity value is the main factor affecting the aerobic and anoxic zones that must occur inside the extended aeration system [21]. This may result in the loss of anoxic zones upstream of the aerators, or it may reduce the time that the mixed liquor is held in each pass through the anoxic zone when its horizontal velocity is higher [21, 22]. In general, numerous problems appear when operating the extended aeration system under the previous velocity values [10, 23]. Practically wastewater is screened and pumped straightforwardly into the reactors, i.e. sand or grit removal is not provided before to the ditches. Also, due to the lack of a primary sedimentation tank, the existence of combined sewerage systems, and the little attention paid to rainwater flow in some developing countries, inorganic particle solids flow into the extended aeration system by rainfall-induced erosion, aggravating inorganic solid deposition in sludge [10, 24]. Observations from existing oxidation ditches confirmed that the horizontal velocity between 0.3–0.35 m/s inside the reactors, poor mixing, and sedimentation may occur. Therefore, granular particles such as grit and sand may settle in the reactor because their settling velocity limits are very close to the reactor's operational velocity limits [10, 15, 16, 25,26]. Further, a combined sewer or stormwater with high solids content can increase grit settling when receiving large amounts of grit during wet weather conditions. Grit and sand particles settle to the bottom of the reactor, forming a layer of sludge (ditch). As a result of the ditch's small effective volume, accumulated sludge layers can affect performance. There are many potential problems that could arise if the accumulated solid is not cleaned frequently. Moreover, the operational and maintenance costs have been significantly increased due to periodically cleaning of the reactors [27]. Vermande and his colleagues [28] recommended adding surface turbine aerators to develop the aeration process in defective activated sludge systems in general. In this manner, by adding turbine aerators to the recirculation motion, Fouad and El-Morsy [16] upgraded a large-scale wastewater treatment plant (WWTP). Efficiency in removing waste and improving the sludge's characteristics have both significantly improved. This is based on wastewater characteristics, as well as hydraulic characteristics, such as internal flow rate, and oxygen distribution along the reactor [20,23]. The undertaken work was devoted to assessing the performance of an extended aeration system in Meet Abo El-koum WWTP, Egypt before and after upgrade by adding surface turbine aerators. In addition, to evaluate the solution to the problem of accumulation of solids in the reactors after constructing new primary sedimentation tanks.

2. Methodology

2.1. Study area description

The case study in this paper is the recently upgraded WWTP to accommodate 10,000 m^3/d of municipal wastewater, where the plant is currently being piloted in preparation for entering service in 2021. The WWTP was established in the 1970s of the last century, and extensions were added to it during the 1990s to accommodate 4,600 m^3/d of sewage at that time. The WWTP was designed to treat wastewater with an extended aeration system, which contains four compact units. Each unit is a ring-shaped reactor of extended aeration that surrounds a final clarifier as a compact unit that merges aeration and final sedimentation in a single unit for activated sludge processing. The plant was implemented in Meet Abo El-koum Village, El-Menoufya Governorate, Egypt. As represented in Figure (1). The raw wastewater characteristics were statistically analyzed as represented in Table (1). The parameters and the equipment utilized in the laboratory tests are represented in Table (2). All tests were conducted in the Laboratory of Meet Abo El-koum WWTP according to Standard Methods [29].

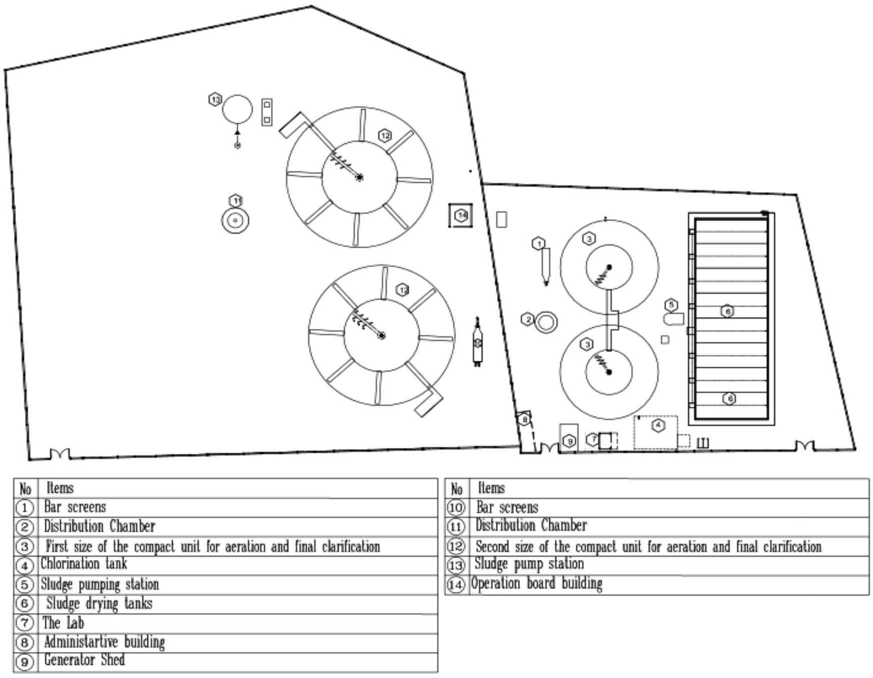
Table 1: The raw wastewater characteristics of Meet Abo El-koum WWTP

Parameter	Raw sewage
pH	9.0 ± 0.35
Temperature (ºC)	24.5 ± 4.9
BOD_5 (mg/L)	670 ± 55
COD (mg/L)	1020 ± 89
TSS (mg/L)	657 ± 82
TDS (mg/L)	3850 ± 202
DO (mg/L)	1.9 ± 0.14
Oil and grease (mg/L)	55.7 ± 7.2

Table 2: Parameters and equipment utilized in the laboratory tests

Parameter	Equipment and product information
pH, Temperature (ºC)	pH / ° C Model CONSORT P400
Total solids (TS) (mg/L)	Drying oven (BINDER®) company- Analytical balance (OHAUS®), Germany
COD (mg/L)	COD reactor (DINKO), and spectrophotometer(biochrom) Model Libra S12
BOD_5 (mg/L)	BOD incubation (Fisher Scientific), USA
Oil and grease (mg/L)	Drying oven (BINDER®) company- Analytical balance (OHAUS®),

(a)



(b)

Figure 1: Meet Abo El-koum WWTP before upgrading in (a) an aerial photo adapted from Google maps in 2010, (b) a general layout

There are two sizes of the compact tanks of aeration and final clarification. Two tanks of each size were implemented. The first established size has an outer diameter of 17.0 m, an inner diameter of 9.6 m, and a water depth of 2.55 m, while the second size has an outer diameter of 29.1 m, an inner diameter of 15.1 m, and a water depth of 2.75 m. The total volume of the ring-ditches of extended aeration is 3460 m^3. The ring ditches were aerated using uniformly distributed air diffusers. The activated sludge was running under retention time of 18 hrs, mean cell residence time of 25 days, mixed liquor suspended solids (MLSS) of 3200 mg/L. Dissolved oxygen (DO) levels were too low because the air diffusers were too weak to produce them. It was very low along the perimeter of the ring ditches and failed to prevent the settling process inside ditches. The treated wastewater characteristics of most pollutants of the plant came down drastically as shown in Table (3) in the period from 2005 to 2010. This was due to the low-grade characteristics of the produced sludge. As a result, the WWTP operator requested an upgrade to meet the required treatment standards.

Table 3: The treated wastewater characteristics of Meet Abo El-koum WWTP before upgrading

Parameter	Effluent (Secondary treated wastewater)	Limits for final effluent*
pH	8.7 ± 0.2	6.5-8.5
Temperature (º C)	22.5± 1.9	25-30
BOD_5 (mg/L)	440± 39	≤60
COD (mg/L)	720 ± 63	≤80
TSS (mg/L)	75 ± 9.2	≤50
TDS (mg/L)	2800 ± 140	≤2000
DO (mg/L)	2.1 ± 0.1	≥4
Oil and grease (mg/L)	17.2 ± 2.7	≤10

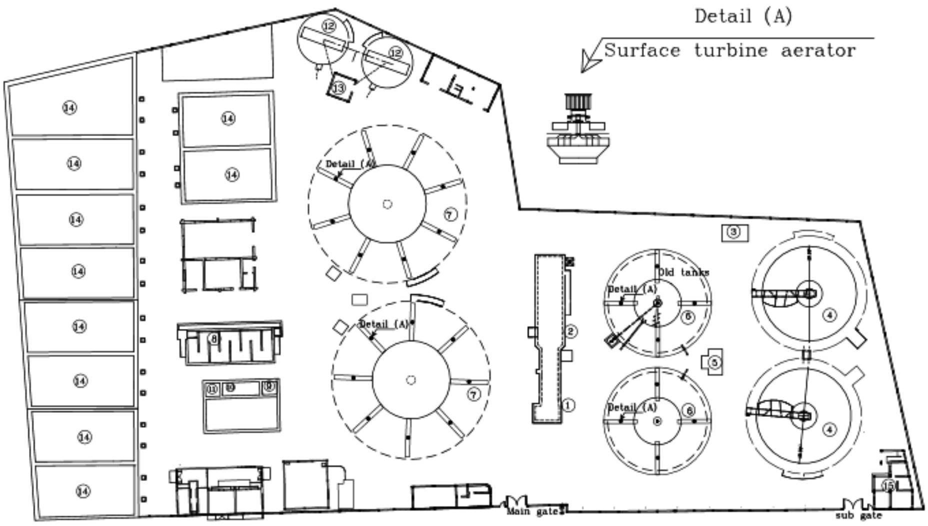
Notes:

*** Adapted from Metcalf and Eddy (2003)**

2.2. Description of the upgrading and raising the design capacity of the WWTP

The basic proposal relied on the conversion of the treatment system from the extended aeration to the conventional activated sludge system, whereby following this system it was possible to raise the design capacity of the plant more than twice. As mentioned before, the upgrading needed to replace the air diffusers with uniformly distributed surface turbine aerators to achieve a suitable DO level. Also, primary settling was required before the existing activated sludge system. To implement this system, it was necessary to make new installations such as primary sedimentation tanks that work to remove about 50 to 65% of the suspended solids and about 30 to 40% of the organic matter. Existing facilities have also been developed and modified to accommodate new behaviour such as the construction of a sludge pumping station and drying beds of larger areas than currently in addition to sludge thickeners and a contact chlorination tank. Figure (2) displays Meet Abo El-koum WWTP after upgrading. Additional surface turbine aerators have been added inside each ring ditch together with the current system of air diffusers. Four surface turbine aerators have been added to each of the smaller size units, and eight surface turbine aerators have been added to each of the two larger size units as shown in Figure (3).

(a)



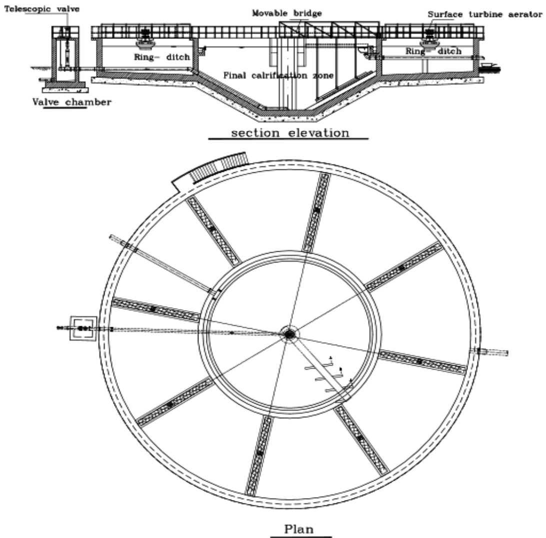
No	Item	No	Item	No	Item
1	Bar screens	6	First size of the compact unit for aeration and final clarification	11	Supernatant pump station
2	Grit Removal	7	Second size of the compact unit for aeration and final clarification	12	Sludge concentration tanks
3	Distribution Chamber	8	Chlorination contact tank	13	Sludge pump station
4	Primary Sedimentation Tank (New)	9	Primary Sedimentation sludge pumping station	14	Sludge drying beds
5	Areation tanks Distribution Chamber	10	excess sludge pumping station	15	Administartion and Lab. building

(b)

Figure 2: Meet Abo El-koum WWTP after upgrading in (a) an aerial photo adapted from Google maps in May2020, (b) a general layout

(a)

(b)



(c)

Figure 3: A compact unit for aeration and final clarification (a) before upgrading, (b) after upgrading by adding surface turbine aerators, (c) in a schematic diagram

3. Results and discussion

3.1. Dissolved oxygen profile along centerline of the ring-ditches

The designers had decided to add four additional surface turbulent aerators inside the first size of the ring-ditch as well as eight additional surface turbulent aerators inside the second size of the ring-ditch as displayed in Figures (1), (2), and (3). The turbulent surface aerators of 10 KWH for each one have been regularly installed on the centerline of each ring-ditch. As a result, the extended aeration system was gradually converted to a conventional activated sludge system using the installed surface turbulent aerators. Figure (4) illustrates the DO profile along the centerline of the ring-ditches. DO values in general enhanced after upgrading in a way that improves the performance of the biological treatment to achieve acceptable values of concentrations of the treated wastewater parameters. In this manner, it is observed that the DO values increase in a limited range around the additional surface turbine aerators that have been installed within the upgrading work. For the first size of the ring-ditch, the DO values ranged from 2.9 to 4.1 mg/L, while they ranged from 2.7 to 3.7 mg/L for the second size of the ring-ditch. On the other hand, the mean DO value along the centerline of the ring-ditches was 2.1 mg/L before upgrading. This means that installing surface turbine aerators increase the DO level by about 60%, and this result is consistent with the results of the research that was prepared by Fouad and El-Morsy [10].

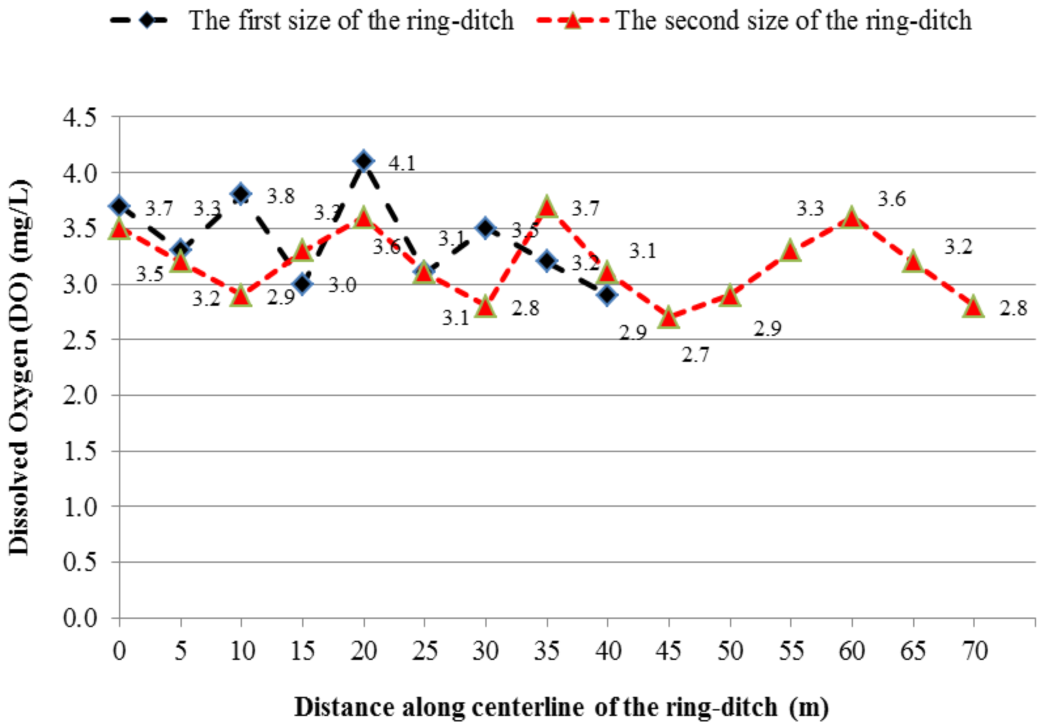


Figure 4: Dissolved oxygen profile along the centerline of the ring-ditches after installing the surface turbulent aerators

3.2. The effect of upgrading work on operational parameters of the WWTP

The results of the operational parameters of Meet Abo El-koum WWTP were collected during the pilot plant operation in a steady-state during the period from June to August 2020 as shown in Table (4). Its compatibility with the design criteria for conventional aeration systems is evident according to Metcalf and Eddy [2]. On the other hand, the operational parameters of the WWTP before upgrading were tabulated also. The activated sludge system was completely modified. However, the operating parameters were compatibles with the design criteria. The MLSS of 2937 mg/L was measured after modification and was very close to that before modification.

Table 4: Average values of the operational parameters of Meet Abo El-koum WWTP before and after upgrading

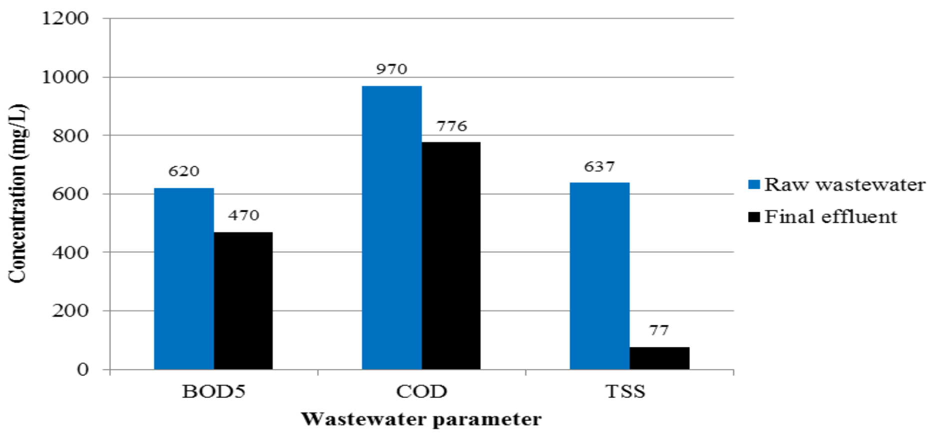
Parameter	Before upgrading (Extended aeration system)	After upgrading (Conventional aeration system)	Design criteria*
Design discharge (Q) (m^3/d)	4600	10000	-
Aeration period (θ) (hr)	18	8	4-8
Mean cell residence time (θ_c) (day)	25	10	3-15
Mixed liquor suspended solids (MLSS) (mg/L)	3200	2937	1000-3000
Food/Mass of microorganisms (F/M) (Kg BOD_5/Kg MLSS)	0.33	0.22	0.2-0.4

Notes:

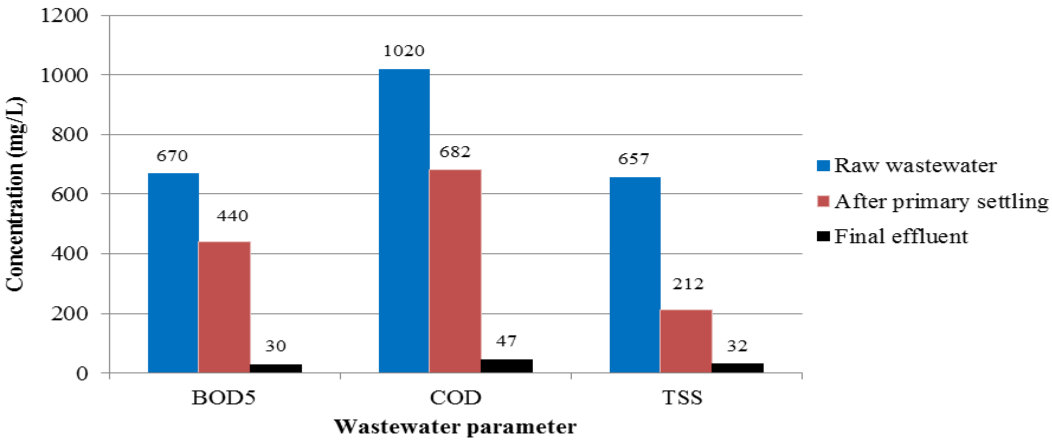
*** Design criteria for the conventional aeration system adapted from Metcalf and Eddy (2003)**

3.3. The effect of upgrading work on the pollutants removal and wastewater characteristics

As mentioned previously, the upgrading of WWTP was done through the implementation of new primary sedimentation tanks before secondary treatment to reduce the organic load to some extent and to get rid of the sediments accumulated in the ring-ditches of the extended aeration system before upgrading, in addition to improving the aeration by adding surface turbine aerators. The results of the raw and treated wastewater treatment were averaged to prepare the charts in Figure (5), which illustrates the convergence of the raw wastewater parameters of BOD_5, COD, and TSS. Figure (5-a) shows that the values of effluent BOD_5, COD, and TSS were 470, 776, and 77 mg/L respectively using an extended aeration system (i.e., the biological treatment system before upgrading of WWTP), while those permitted values according to Metcalf and Eddy (2003) are 60 mg/L of BOD_5, 80 mg/L of COD, and 50 mg/L of TSS reflecting the failure of secondary treatment in the previous status before the upgrading of WWTP. Therefore, the aforementioned design of the WWTP (before upgrading) was developed to upgrade the WWTP so that the extended aeration system is converted to the conventional aeration system for secondary treatment, in addition to the construction of new primary sedimentation tanks as shown in Figures (2) and (3). In this context, Figure (5-b) represents the values of BOD_5, COD, and TSS for raw wastewater, wastewater after primary settling, and effluent wastewater after secondary treatment. It is observed that the values of BOD_5, COD, and TSS were 440, 682, and 212 mg/L respectively after primary settling. These values represent the removal of about 35% of the organic load and about 68% of the suspended solids, which reduces the organic load and sediments entering into the secondary treatment reactor. Furthermore, the BOD_5, COD, and TSS values of the effluent after the secondary treatment were 30, 47, and 32 mg/L respectively, reflecting the success of WWTP upgrading work.



(a)



(b)

Figure 5: Wastewater characteristics at the inlet of WWTP, then the treatment stages (a) before upgrading, (b) after upgrading by adding primary sedimentation tanks and surface turbine aerators

From the previous results, converting the extended aeration system to a conventional aeration system preceded by primary sedimentation is an effective approach for upgrading Meet Abo El-Koum WWTP and to achieve the quality of treated wastewater in compliance with international standards [2]. In this manner, Figure (6) shows the pollutants removals for the WWTP before and after upgrading, as 95% of BOD_5, 95% of COD, and 95% of TSS were removed after upgrading compared to removing 24%, 20%, and 88% of them respectively before the upgrade, despite that the capacity of the WWTP was also upgraded to accommodate 10,000 m^3/d of sewage compared to its initial capacity of 4,600 m^3/d before the upgrading.

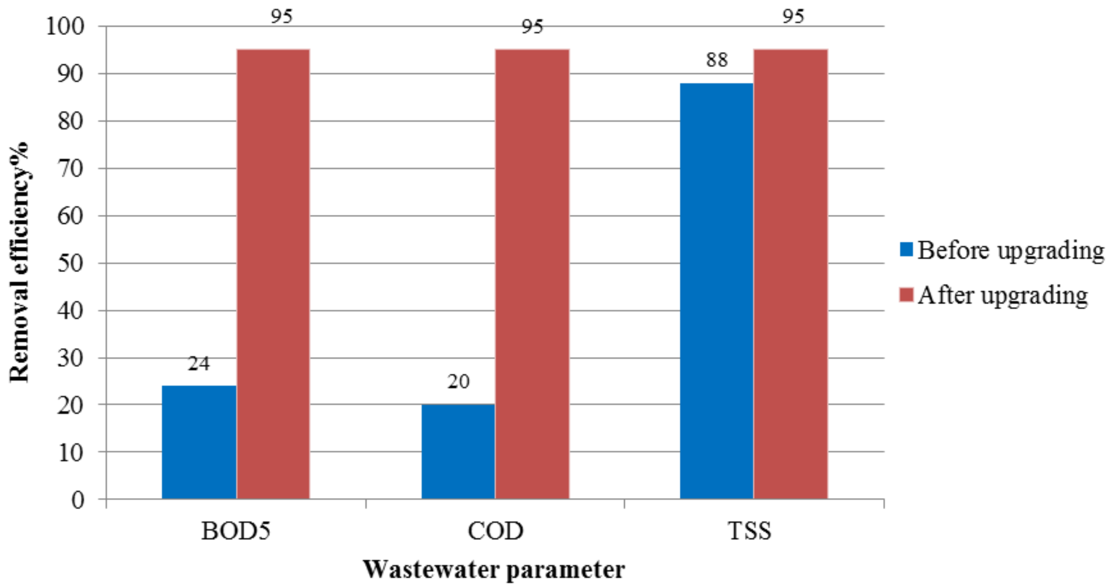


Figure 6: Removals of BOD_5, COD, and TSS before and after upgrading of the WWTP

4. Conclusions

Adding surface turbine-driven aerators to aeration tanks and building new primary sedimentation tanks is a novel approach for upgrading an extended aeration system. As much as 60% more dissolved oxygen is added when surface turbine aerators are installed According to the results obtained after primary settling, the values of BOD_5, COD, and TSS were respectively 444, 682, and 212 mg/L. Approximately 35% of the organic load and about 68% of the suspended solids have been removed, reducing the organic load and sediments entering the secondary treatment process by a considerable amount. Furthermore, BOD_5, COD, and TSS values were 30, 47, and 32 mg/L in the effluent respectively. It is, therefore, possible to upgrade and improve the quality of treated wastewater by replacing the extended aeration system with a conventional aeration system followed by primary sedimentation, despite the WWTP's capacity being increased from 4,600 to 10,000 m^3/d after the upgrade.

Acknowledgement

The authors gratefully acknowledge the staff of Meet Abo El-koum WWTP, and the Water and Wastewater Company in El-Menoufya Governorate, Egypt, for providing the necessary data.

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