

ENHANCING EFFLUENT QUALITY OF WASTEWATER TREATMENT PLANTS USING ADVANCED OXIDATION PROCESS

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ABSTRACT

The critical situation about water resources in Egypt forces the state to increase its uses from non-conventional water resources (reuse of wastewater and desalination). Wastewater reuse represent a potential source for a round 8 Billion Cubic Meters (BCM) /year. The micropollutant and the sophisticated specification hinder the usage of wastewater. Advanced oxidation process represents a new potential way for improving the effluent of Waste Water Treatment Plants (WWTPs). In this work the discharge of three WWTPs (Arab-Abosaaed station located in Helwan-Cairo, El-Berka station located in El-Salam city-Cairo and Balaqs station located in Shubra El-Kheima-Cairo) were investigated and treated. The investigation illustrated that El Berka WWTP is the most vulnerable WWTP this why its effluent was used to conduct further treatment on it. The three WWTPs are appropriate for use according to Egyptian law 48/1982 and the uses quality for treated wastewater are fitted with Class D and Class C Code 501/2015 specification. Effluent from the three-treatment plant is unsuitable for uses according to Class A and B. Hydrogen peroxide, Fenton, and photo-Fenton were used as advanced oxidants to improve the effluent quality. All the oxidants used has been successfully implemented to achieve 100% WWQI for different reuse purposes. However, the cost benefit of using hydrogen

peroxide is more favorable as it cheaper. Further comparison between the scaleup option, hydrogen peroxide is more applicable to be scaled up and moreover, it could be nationalized as a strategic industry.

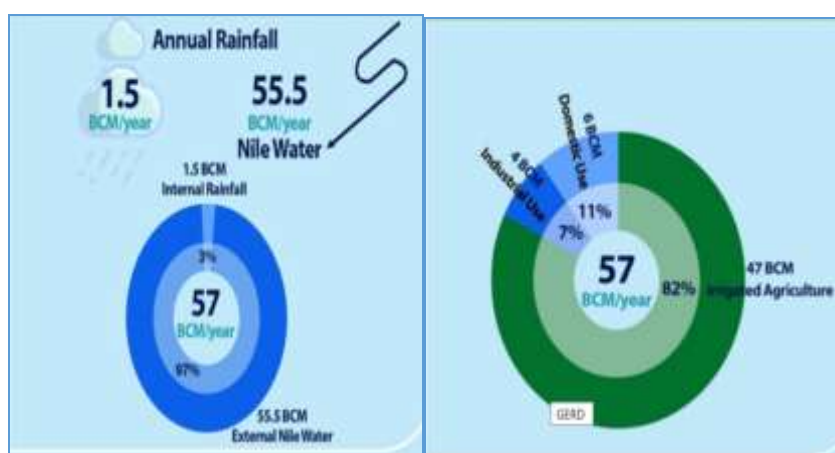
Keywords: Wastewater; WWQI; Reuse; Oxidation; Fenton.

INTRODUCTION

Water represents almost three-quarters of Earth planet surface. Most of this water is saltwater (Abd Ellah, 2020). Less than 3 percent of this water is freshwater, and most of it exists in the form of ice and snow in polar glaciers (Gleick, 1993). However, Bengtsson, (2010) and Koutsoyiannis, (2011) reported that the distribution of global water and the quantity of earth's freshwater available is depending on the global water cycle (Schuol, et al. 2008). (Sircoulon, 1991) summarized this fact, stating that there is an increasing awareness of the significant relationship between climate, water (lakes and rivers), and environment.

As many catchment areas are often focal points in terms of environmental and conservation issues, they have been shown to be good proxy indicators of local, regional, and global climatic change (Benveniste and Berry, 2004). The Intergovernmental Panel on Climate Change's (IPCC, 2007) predictions indicated that over the next decades, the increased water stress will be affecting between 75 and 250 million people due to the climate change. The same report states that the developing countries, including African countries, are the most at risk of being severely affected by climate change.

Egypt reached the highest population in Africa of over 100 million in 2020. It has experienced rapid population growth, which leads to additional demand of water due to its limited water resources. It is predicted that Egypt's total population will be about 110 million by the year 2025 (Ferrari et al., 2014). Due to the high population and geographic location of Egypt, there is an increasing demand for water and decreasing per capita water share. Since 1990s, Egypt already has one of the lowest per capita water shares in the world. The per capita share already under the poverty line, in 2015, annual per capita consumption of renewed fresh water was 650 m³, which is significantly below the 1,000 m³/year water scarcity threshold. Indeed, the Nile River provides the country with some 93% of its water requirements. The total amount of deep groundwater has been estimated at about 40,000 BCM (MWRI, 2014) (Fig 1).



Figure(1): Water resources and demand in Egypt (AbuZeid, 2020).

The critical situation about water resources in Egypt forces the state to increase its uses from non-conventional water resources (reuse of wastewater and desalination). These resources represent 22.2% of the total available water resources. The production of desalination is calculated to be 0.5 BCM per year, according to the same strategy the amount of produced desalinated water will reach 1 BCM by year 2030. The fact that the available water resources in Egypt are very limited, the gap between the available water resources and the demand between reaches 15 billion cubic meters forced the state to develop the National Water Strategy.

Due to limited water resources, Egypt government has adapted a new strategy aligned with Sustainable Development Goals (SDGs) to expand its production from alternative water resources, i.e. desalination due to the fact of the high demand and very limited water resources also, according to this strategy, Egypt intend to cover 100% of population with wastewater treatment current cover is estimated to 56%, reuse of the treated wastewater is included in this strategy to reuse 100% of this treated wastewater (Cheremisinoff, 2019).

The usual method of municipal or industrial waste effluents treatment processes contained with large amount of sludge having various organic and inorganic compounds occurred, pose danger for safety aspects and quality related to environmental concerns (Harrison *et al.*, 2006). Further, the usual sludge handling processes, thickening, drying, digestion, and lime

stabilization contribute to the on-site odors, became a severe environmental burden. (Theodore, 2009).

Studies have shown that the use of advanced oxidation processes (AOP's) yields tremendous results in removing pollutants and eliminating pathogens in wastewater treatment processes. The use of hydrogen peroxide with ultraviolet rays, where the process of combining ozone with hydrogen peroxide works to generate these oxidative radicals (OH-) The process is called Peroxonation (Zaviska *et al.* 2009). This study aims at investigating the possible improvement of the wastewater treatment plants effluent quality using advanced oxidation process to be more valuable for reuse.

METHODOLOGY

Based on the objectives of the study, the methodology encompassed 3 phases as follows:

- **Phase 1:** Allocation of the most vulnerable sanitation system through monitoring of WWTPs 2020, and Wastewater Quality Index (WWQI) will be used as a tool to accomplish the quality comparison.
- **Phase 2:** Determination of the effectiveness of using different oxidants (Hydrogen peroxide – Fenton – photo Fenton).
- **Phase 3:** Comprehensive comparison of the different techniques and recommendations.

- **Phase I: Allocation of the most vulnerable sanitation system:** A survey was done to assess the quality of effluent from 3 wastewater treatment plants (Arab-Abosaaed – Balaqs – El-Berka). Information about these three treatments is provided in table (1).

Table(1): Typical information about the monitored Wastewater Treatment Plants (WWTPs)

Wastewater treatment plant	Arab-Abosaaed	Balaqs	El-Berka
Place	Helwan, Cairo	Shubra El- Kheima, Cairo	El-Salam City, Cairo
Number of served residence (Million)	2.4	1.7	2.01
Amount of treated wastewater (m3/day)	600,000	400,000	450,000
Location of discharge point	El-Saff Drain	Shibin El Kanater Drain	Al-Gabal Al-Asfar Drain
Type of treatment train	Secondary Conventional Biological treatment		

Samples were taken from these treatment plants for the inlet and outlet as well. Analysis for BOD, COD, TSS, TOC, and Total coliform was done according to Standard Method for Water and Wastewater 2017(Rice E.W.*et al.* 2017) The samples were analyzed at the reference laboratory for the wastewater (Accredited ISO 17025). All the chemicals used in analytical grades. The sampling period covers the year 2020. WWQI was used as a statical tool to allocate the most vulnerable site. WWQI was calculated based on the CCME-2001 Method (Bilgin, 2018).

This method depends on the calculation of three factors:

- Scope: (related to the number of incompliance parameters to all the number of analyzed parameters)
- Frequency (related to the repetition of non-compliance with time)
- Amplitude (related to how far the results of noncompliance from the standard) as the following:

(a) The measure for scope is (F1): This represents the extent of water quality guideline non-compliance over the time period of interest.

$$F_1 = \frac{\text{Number of Failed Variables}}{\text{Total Number of Variables}} * 100 \text{ ----- (1)}$$

(b) The measure for frequency is (F2): This represents the percentage of individual tests that do not meet objectives (“failed tests”).

$$F_2 = \frac{\text{Number of Failed Tests}}{\text{Total Number of Tests}} * 100 \text{ ----- (2)}$$

(c) The measure for amplitude is F3: This represents the amount by which failed test values do not meet their objectives. This is calculated in three steps:

$$F_3 = \frac{nse}{0.01 nse + 0.01} \text{ ----- (3)}$$

The WWQI is then calculated as:

$$WQI = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732} \right) \text{ ----- (4)}$$

Once the CCME WQI value has been determined, then The WQI values are converted into rankings by using the categorization scheme presented in Table (2) to express the water quality.

Table (2): WWQI ranks and color code representation.

Meaning	Percent	Grade	Color code
Water quality is protected with the virtual absence of threat or impairment; conditions very close to natural or pristine levels	94 - 100 %	Excellent	
Water quality is protected with an only a minor degree of threat or important; conditions rarely depart from natural or desirable levels	79 - 94 %	Good	
Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels	64 - 79 %	Marginal	
Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels	44 -64 %	Fair	
Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels	0 - 44 %	poor	

WWQI: WasteWater Quality Index

After selection of the most vulnerable WWTP. Different AOPs used to improve the effluent of the selected vulnerable WWTP. The treatment removal percent will be calculated, and a comparison will be done to investigate the applicability of each. The optimum condition for each oxidant will be also specified.

The following statistical equation has been used for the calculation of removals percent

$$\text{Removal percent} = \frac{\text{conc. befor treatment} - \text{Conc. after treatment}}{\text{Conc. befor treatment}} * 100$$

The limits used for the comparison and to identify the efficiency of the treatment are the national standard. Egyptian code for reuse of treated

wastewater in agriculture (Code 501/2015) and according to the specification of Egyptian law 48/1982.

Phase II: Determination of the effectiveness of different oxidants:

Different oxidants were used to enhance the quality of the effluent via oxidation and/or coagulation the following oxidant were used:

- Hydrogen peroxide Treatment: Jar test was used as apparatus to conduct the treatment process. Samples were collected from the effluent of El-Berka WWTP. Baseline parameters were measured to determine the removal percentage after treatment. Hydrogen peroxide purchased from Aldrich (50%) was used to inject the effluent by different doses (5, 10, 15, 20, 25 and 30 mg/l). Different contact time and stirring rate were also tested to determine the optimum condition.
- Fenton treatment: the effluent of El Berka was injected by hydrogen peroxide (15 mg/l), and the stirring was adjusted at 20 RPM for 30 min with no pH correction. ferrous sulfate was added by different doses 5, 10, 15, and 20 mg/l. then the water was tested for the different quality parameters to determine the removal efficiency.
- Photo-Fenton: UV lamp was purchased from local provider with wavelength 189 nm and power of 6 watt, the sample was collected from the effluent of El Berka WWTP and treated according to the optimum conditions results from the conducted experiment.

Phase III: Comprehensive comparison of the different techniques and recommendations: Based on the results achieved and the economic value of each oxidant together with its technical feasibility, the comparison will allow the best selection. Different factors have been studied to determine the best oxidants.

RESULTS AND DISCUSSION

1. Monitoring of WWTPs: The following table represents the results of survey all over the year 2020. Samples were taken from inlet and outlet of the three WWTPs.

Table(3): Results of input and output of Arab-Abosaaed

Month	Location	TSS mg/l	BOD5 mg/l	COD mg/l	TOC mg/l	TC CFU/100ml
Jan.	Input	188	168	411	154	88*107
	Output	18	21	62	24	6500
Feb.	Input	211	205	417	159	63*107
	Output	23	22	65	24	5400
Mar.	Input	303	277	512	197	65*107
	Output	26	24	67	25	6500
Apr.	Input	197	188	490	178	65*107
	Output	22	21	58	22	6700
May.	Input	213	197	505	192	71*107
	Output	26	23	59	22	7100
Jun.	Input	276	245	566	213	61*107
	Output	33	27	74	28	5400
Jul.	Input	178	158	404	152	45*107
	Output	16	18	53	20	5200
Aug.	Input	199	179	449	173	64*107
	Output	21	18	61	26	5600
Sep.	Input	218	205	437	169	68*107
	Output	28	25	66	26	5500
Oct.	Input	202	189	398	151	65*107
	Output	23	25	64	27	4800
Nov.	Input	214	198	423	161	88*107
	Output	24	27	68	29	6500
Dec.	Input	212	199	443	171	71*107
	Output	23	25	71	28	7600

TSS: Total Suspended Solids, BOD₅: Biochemical Oxygen Demand, COD: Chemical Oxygen Demand, TOC: Total Organic Carbon, TC: Total Coliform

Table(4): Results of input and output of El-Berka

Month	Location	TSS mg/l	BOD5 mg/l	COD mg/l	TOC mg/l	TC CFU/100ml
Jan.	Input	330	288	611	231	65*107
	Output	41	34	77	31	14200
Feb.	Input	343	317	698	259	78*107
	Output	39	34	73	27	9400
Mar.	Input	377	354	688	256	67*107
	Output	43	35	77	29	12300
Apr	Input	345	307	634	240	75*107
	Output	45	36	78	29	8900
May.	Input	355	311	602	233	56*107
	Output	37	32	73	27	8700
Jun.	Input	431	379	711	277	78*107
	Output	38	23	69	29	8890
Jul.	Input	388	367	645	244	63*107
	Output	43	35	88	31	12000
Aug.	Input	331	301	677	244	45*107
	Output	44	37	78	29	7760
Sep.	Input	310	277	644	240	67*107
	Output	36	30	71	34	6700
Oct.	Input	430	389	755	288	64*107
	Output	46	41	75	31	10900
Nov.	Input	338	322	678	266	83*108
	Output	45	41	78	29	7600
Dec.	Input	333	289	711	277	75*107
	Output	43	37	75	28	7700

TSS: Total Suspended Solids, BOD₅: Biochemical Oxygen Demand, COD: Chemical Oxygen Demand, TOC: Total Organic Carbon, TC: Total Coliform

Table(5): Results of input and output of Balaqs

Month	Location	TSS mg/l	BOD5 mg/l	COD mg/l	TOC mg/l	TC CFU/100ml
Jan.	Input	220	189	455	171	43*107
	Output	22	19	61	23	1060
Feb.	Input	276	256	489	188	45*107
	Output	27	23	68	24	9450
Mar.	Input	178	164	379	144	69*107
	Output	17	14	53	19	7080
Apr.	Input	266	231	512	192	48*107
	Output	31	27	69	27	9400
May.	Input	366	311	617	233	45*107
	Output	35	32	77	29	8750
Jun.	Input	230	211	544	204	61*107
	Output	31	23	69	26	6700
Jul.	Input	188	172	388	147	41*107
	Output	22	19	61	23	5800
Aug.	Input	200	181	407	153	45*107
	Output	19	17	56	22	9400
Sep.	Input	310	277	644	240	35*107
	Output	31	26	78	30	8000
Oct.	Input	233	211	508	191	64*107
	Output	26	22	66	25	10900
Nov.	Input	190	177	432	162	33*107
	Output	24	22	63	24	7600
Dec.	Input	180	190	410	154	55*107
	Output	19	21	56	24	7700

TSS: Total Suspended Solids, BOD₅: Biochemical Oxygen Demand, COD: Chemical Oxygen Demand, TOC: Total Organic Carbon, TC: Total Coliform

To clarify the effectiveness of different WTPs the removal percent of the different WWTP have been determined. The percent removal of TSS is ranging from 85% to 92% with the lowest removal for El-Berka and highest removal was accomplished for Arab Abosaaed. The removal percent of

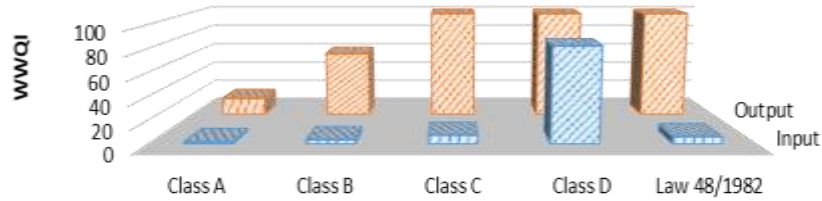
BOD ranging from 86% to 94% for Arab Abosaaed and El Berka, respectively. The removal percent for COD ranging from 83% to 90% for Arab Abosaaed and El Berka, respectively. Finally, for the removal of TOC range from 81% to 90% % for Arab Abosaaed and El Berka, respectively. Biological treatment processes, in combination with primary sedimentation, typically remove 85 % of the BOD and TSS originally present in the raw wastewater and some of the heavy metals. Activated sludge generally produces an effluent of slightly higher quality, in terms of these constituents, than biofilters or RBCs (Asano and Tchobanoglous, 1987).

2. Assessment of WWTPs: Wastewater quality index is a statistical tool used to summarize the complicated chemical, physical, and microbiological data into one single number. The number ranging from 0-100%. 0% means that water is totally inadequate for the intended uses. 100% means that water is of excellent quality for the intended uses. Different standards were used to assess the quality according to the different uses of the treated waste. Two level of standard were used. Law 48/1982 is specified for the quality for water before discharge to drains fresh water and marine water (MWRI, 2015). Code 501/2015 is specified for the reused water for different purposes (ECP 501 - 2015). The following tables explain further about decrees and specifications.

Table(6): Grade of treatment and types of crops according to code 501/2015

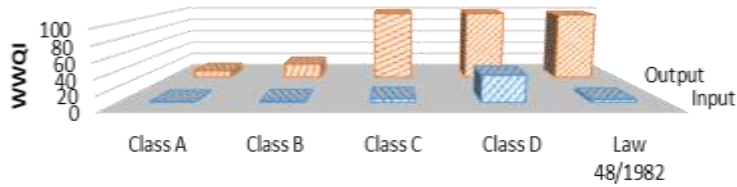
Standard	Scope
Law 48/1982	Quality of discharge waste to drains
Code 501/2015 – Class A	Group 1-1: Green landscapes in educational establishments, public and private parks Group 1-2: Fruits
Code 501/2015 – Class B	Group 2-1: Dry grains crops, cooked & processed vegetables Group 2-2: Fruit Crops Group 2-3: Medicinal Plants
Code 501/2015 – Class C	Group 3-1: Dry grain crops, fruits, medicinal plants contained group (B) Group 3-2: Non-food seeds Group 3-3: All types of seedlings, which are then transplanted in permanent fields Group 3-4: Roses and Cut flowers Group 3-5: Trees suitable for planting in highways and green belts Group 3-6: All types of fiber crops Group 3-7: Grassy forage crops and leguminous crops Group 3-8: Mulberry to produce silkworm silk Group 3-9: All plants and ornamental trees nurseries
Code 501/2015 – Class D	Group 4-1: Solid biomass crops Group 4-2: Crops to produce cellulose Group 4-3: Timber trees

The water is more valuable as its quality is suitable for the different classes from A to D. The following graph represents the Wastewater Quality Index of the three Wastewater Treatment Plants



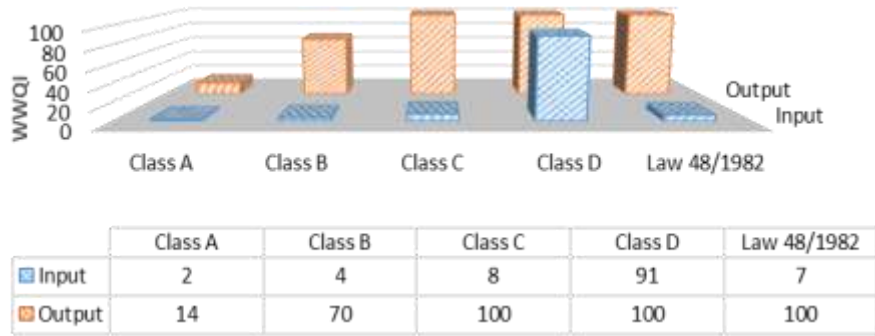
	Class A	Class B	Class C	Class D	Law 48/1982
Input	2	4	8	84	7
Output	16	61	100	100	100

Figure(2): Wastewater Quality Index for the input and output of Balqaq Wastewater Treatment Plant.

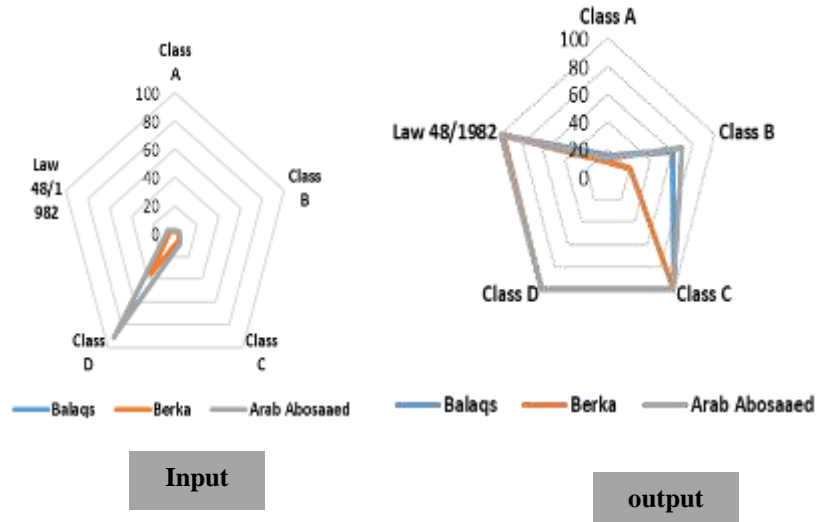


	Class A	Class B	Class C	Class D	Law 48/1982
Input	1	3	5	36	5
Output	11	21	100	100	98

Figure(3): Wastewater Quality Index for the input and output of El-Berka Wastewater Treatment Plant.



Figure(4): Wastewater Quality Index for the input and output of Arab-Abosaaed Wastewater Treatment Plant.



Figure(5): Comparison of Wastewater Quality Index for the input and output of Wastewater Treatment Plants.

From figure 5, Raw waste with its characteristic is unsuitable for all uses. However, the class D plants according to Egyptian code for reuse could be a potential user for Balaqs and Arab-Abosaaed input water as its. Wastewater Quality Index (WWQI) for these two plants is around 90% which categorized as excellent water for reuse for plants such as soybean – rapeseed – Jojoba – and Jatropha – Castor that used as biodiesel fuel. However, El Berka shows far less quality input water, Wastewater Quality Index (WWQI) is 36 with poor quality for even class D plants. The lower quality of input water of El Berka Wastewater Treatment Plant could be explained by the presence of many industrial wastes received by the sewer network together with the unorganized time of pumping from pumping stations. For the effluent (output) of the three Wastewater Treatment Plants (WWTPs), mostly the three are appropriate for use according to law 48/1982, Class D and Class C Code 501/2015 specification. However, El Berka showed lower quality. This could be owed to bad input water quality.

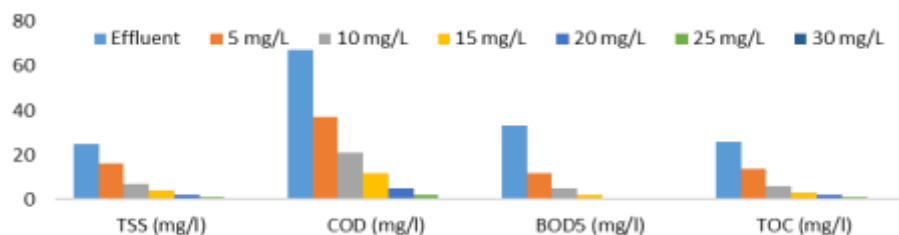
Figure 5, illustrates that effluent from the three-treatment plant is unsuitable for uses according to Class A and B. This hinders the use of water in the production of higher-value agricultural goods. Any improvement of the water quality at these two categories Class A and B plants would be of high economic and social benefit. Furthermore, some of the agricultural land around the drains irrigated using the water from drains, enhancing of water quality in the outlet would for sure have a positive impact on the water quality at the drains and for the public health.

Nicole, *et al.* 2006 illustrated that, the options for sustainable reuse projects are related to the quality of the effluent, and the environmental risk associated with land application for a variety of crops and activities. Patterson (2000) points at the different regulations existing for domestic and industrial effluent at an example of Australia which is valid worldwide. He describes the households as a high potential of pollution since they can discharge “a cocktail of chemicals at varying concentrations, together with biodegradable and non-biodegradable solids” without any concern as to the ramifications of those discharges either on the treatment system or the expected final quality of the discharged water. Whereas discharges from commercial and industrial premises into sewers are under greater scrutiny as government councils implement licensing and monitoring programs. As already mentioned by specifying some advantages, agriculture can be understood as a land treatment system as part of the treatment cycle and is considered as the nutrient recycling part of the loop. The soil as a bioreactor and its capacity to attenuate contaminants are taken into account. Nevertheless, quality requirements of the treated wastewater used for irrigation purposes must be met (Juanico, 1993 cited in Bahari A. 1999). According to the comparison of the three different WWTPs, El Berka was selected as the most vulnerable WWTP, to conduct the treatment experiment on it.

3. Enhancement of El Berka Effluent using different oxidants: In this section experiment was done to determine of the effectiveness of using different oxidants (hydrogen peroxide, Fenton and photo Fenton).

- **Using of hydrogen peroxide to enhance wastewater quality:** 50-liter sample was collected from the effluent of El-Berka WWTP. Different conditions were tested to determine the optimum conditions. Jar test was used as apparatus to conduct the remediation experiment. The effluent water was distributed equally at 1-liter beakers, and the following conditions were studied (oxidant dose, time and Stirring rate)

A. Oxidant dose: Hydrogen peroxide was injected by different doses 5, 10, 15, 20, 25, and 30 mg/l to the effluent of El Berka treatment plant. The rate of stirring was remained fixed at 40 rpm. The samples were taken after 10 min of stirring. The samples were tested for TSS, COD, BOD5, TOC and T. Coliform. The following table summarizes the results of treatment of the El Berka Effluent water via hydrogen peroxide and illustrated graphically at Figure 6.



TSS: Total Suspended Solids, COD: Chemical Oxygen Demand, BOD₅: Biochemical Oxygen Demand, TOC: Total Organic Carbon

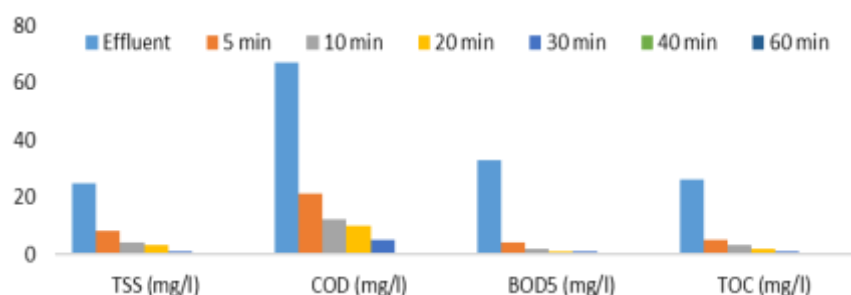
Figure(6): Effect of Hydrogen peroxide dose on the quality of the effluent of El Berka treatment plant

It is clear that hydrogen peroxide by a dose of 15 mg/l is very effective in the removal of different pollutants. The removal percent of TSS, COD, BOD, TOC, and Coliform is 84%, 83%, 94%, 89% and 97%, respectively. The effluent will be suitable for reuse for all the mentioned categories. However, the total coliform is still noncompliance with this concentration. Concentration above 15 mg/l shows significant removal of microbiological aspects.

Ksibi, 2006 stated that hydrogen peroxide has been used to reduce BOD, COD, offensive odor and foaming in domestic or industrial wastewater for many years. While the cost to clean up these wastewaters through the chemical oxidization is typically more expensive than through the physical or biological means, hydrogen peroxide can be used as an autonomous treatment or as an improvement of existing physical or biologic

treatment processes, according to the situation. Hydrogen peroxide can be used alone or with a catalyst such as iron (Fe^{2+}), UV light, ozone (O_3) catalytic autoxidation and the alkali contribute to the reduction of the BOD/COD in the wastewater. The majority of organic compounds were found to be destroyed by hydrogen peroxide oxidation process, giving 85% reduction of COD and BOD₅/COD. Also, He found that that the number of total coliforms exponentially decreased with increasing dose and fell to low levels at the dose of 2.5 ml/L. A relatively high rate of bacterial inactivation was observed when the concentration of H_2O_2 is equal to 2.5 ml/L. The viable cell count decreased after 120 min to about 3 log orders.

B. Contact time: Hydrogen peroxide was injected by a constant dose of 15 mg/l to the effluent of El Berka treatment plant. The time of treatment was changed from 5 min till 60 min. The rate of stirring was remained fixed at 40 RPM. The supernatant water is then analyzed for the different parameters. The data is mentioned in figure (7).



TSS: Total Suspended Solids, COD: Chemical Oxygen Demand, BOD₅: Biochemical Oxygen Demand, TOC: Total Organic Carbon

Figure(7): Effect of time of treatment on the quality of the effluent of El Berka treatment plant

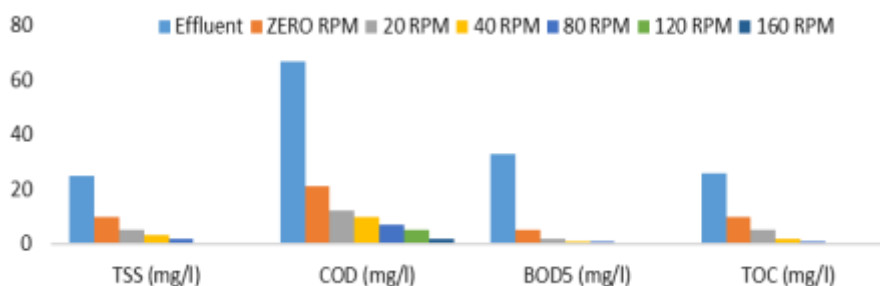
It is clear that the time increase the removal percent of different pollutant increase, the contact time at 30 min. is very effective in the removal of different pollutants. The removal percent of TSS, COD, BOD, TOC, and Coliform is 96%, 93%, 97%, 96% and 100%, respectively. As a rule of thumb 15 mg/l and 30 min mixing time is selected as optimum conditions.

Collivignarelli, et al. (2017) illustrated that, the Fenton process, while showing a moderate efficiency (25% COD removal) in the treatment of high loaded wastewaters, provided excellent results in the treatment of aqueous wastes with high content of surfactants. An average yield removal of 70% for non-ionic surfactants (TAS) and 95% for anionic surfactants (MBAS)

was obtained, under the following optimal conditions: $\text{Fe}_2^+/\text{H}_2\text{O}_2=1/4$, $\text{H}_2\text{O}_2/\text{COD}$ initial ratio = 1, and contact time = 30 min

Karimi, *et al.* (2017) Found that residence time, and H_2O_2 dose are the most important factors affecting the degradation of organic matter. The GAC/Fe catalyst process had a higher efficiency than other absorbents for organic matter oxidation.

c. Rate of stirring: Hydrogen peroxide was injected by a constant dose of 15 mg/l to the effluent of El Berka treatment plant. The time of treatment with adjusted to be with 30 min. The rate of stirring was varied from no stirring to 160 rpm. The supernatant water is then analyzed for the different parameters. The data is mentioned in figure 8.



TSS: Total Suspended Solids, COD: Chemical Oxygen Demand, BOD5: Biochemical Oxygen Demand, TOC: Total Organic Carbon

Figure (8): Effect of rate of stirring on the quality of the effluent of El Berka treatment plant.

It is clear that the stirring increases the removal percent of different pollutant increase, the stirring rate at 40 rpm is very effective in the removal of different pollutants. The removal percent of TSS, COD, BOD, TOC, and Coliform is 88%, 85%, 97%, 92% and 100%, respectively. After reviewing the results, the following is considered the optimum conditions for treatment via hydrogen peroxide so far:

- Dose: 15 mg/l
- Stirring rate: 40 rpm
- Stirring time: 30 min

However, the significant removal of different pollutants accompanied by the usage of hydrogen peroxide, still a margin for improving the removal efficiency and decrease the probability of formulating oxidants byproducts due to formation of free radicals.

- **Using of Fenton (Ferrous sulfate/hydrogen peroxide) to enhance wastewater quality:** Ameta, (2018) stated that Fenton is an effective advanced treatment process. The hydroxyl radical (OH⁻) can be generated from the reaction between aqueous ferrous ions and hydrogen peroxide (H₂O₂), and it can destroy refractory and toxic organic pollutants in wastewater.

Jar test was used for testing the removal efficiency of Fenton, the optimum condition that was determined for hydrogen peroxide have been

taken into consideration while treating water by Fenton reagent. The data is mentioned in Table 7.

Table (7): Effect of Fenton reagent in wastewater quality

parameter s	Effluent	Fenton 5 mg/l (FeSO 4) +15 mg/l H2O2	Removal %	Fenton 10 mg/l (FeSO 4) +15 mg/l H2O2	Removal %	Fenton 15 mg/l (FeSO 4) +15 mg/l H2O2	Removal %	Fenton 20 mg/l (FeSO 4) +15 mg/l H2O2	Removal %
TSS (mg/l)	25	5	80	1	96	0	100	0	100
COD (mg/l)	67	12	82	5	93	3	96	0	100
BOD5(mg/l)	33	3	91	0	100	0	100	0	100
TOC (mg/l)	26	3	88	1	96	0	100	0	100
TC CFU/100ml	10900	40	100	5	100	2	100	0	100

TSS: Total Suspended Solids, BOD5: Biochemical Oxygen Demand, COD: Chemical Oxygen Demand, TOC: Total Organic Carbon, TC: Total Coliform

Table (7), clarify that Fenton is more efficient than using hydrogen peroxide alone. However, referring to the cost of ferrous sulfate and comparing the reuse codes, it could be more economically efficient to use hydrogen peroxide alone.

In order to improve the wastewater quality, advanced treatment needs the removal of refractory organics from the wastewater (Min Xu *et al.*, 2020). In recent years, Fenton has been used to treat refractory wastewater by combining it with other wastewater treatment technologies. The application of the Fenton oxidation process, as a pretreatment, oxidizes refractory organics and improves the biodegradability, solubility, and

coagulation, which are beneficial to the subsequent treatment. It has many advantages, but drawbacks are significant such as a strong acid environment, the cost of reagents consumption, and the large production of ferric sludge, which limits Fenton's further application.

- **Using of Photo-Fenton (Ferrous sulfate/hydrogen peroxide) to enhance wastewater quality:** Photo-Fenton's process as one of the advanced oxidation processes is a potentially useful oxidation process in treating such wastewater. Lab-scale experiments with UV source, coupled with Fenton's reagent, showed that hydrocarbon oil is degradable through such a process. The reagent (Fe^{2+} and H_2O_2 concentration) and pH are used as the controlling factors to be optimized. Maximal COD reduction (91.7%) was achieved when wastewater samples were treated at pH 3.5 in the presence of hydrogen peroxide and iron in amounts of 403.9 and 48.4 mg/L, respectively, (Tony and Bedri, 2014).

10 mg/l Ferrous sulfate + 15 mg/l hydrogen peroxide were injected to the wastewater. The sample was pumped into the UV lamp chamber to accomplish the photo-Fenton step. The water then tested for the removal efficiency of the different quality parameters. Table (8) represents the results after treatment by Photo-Fenton, the removal efficiency is 100% for all the measured parameters.

Table(8): Effect of Photo-Fenton reagent in wastewater quality

parameters	Effluent	Photo-Fenton 10 mg/l (FeSO ₄) +15 mg/l H ₂ O ₂	Removal%
TSS (mg/l)	25	0	100
COD (mg/l)	67	0	100
BOD5(mg/l)	33	0	100
TOC (mg/l)	26	0	100
TC (CFU/100ml)	10900	0	100

TSS: Total Suspended Solids, BOD5: Biochemical Oxygen Demand, COD: Chemical Oxygen Demand, TOC: Total Organic Carbon, TC: Total Coliform

- **Comprehensive comparison of the different technologies and recommendations:** Based on the results mentioned in section 3.3., the following table concludes the optimum condition for each oxidant used and the corresponding achieved the removal of different parameters together with the corresponding estimated cost of each technology and suitability for different reuse purposes.

Table(9): Comparison between different Oxidants.

Oxidant	Optimum conditions	Achieved removal		Suitability for reuse purposes	Cost estimation
Hydrogen peroxide	<ul style="list-style-type: none"> Dose :15 mg/l Stirring rate: 40 RPM Stirring time: 30 min 	TSS (mg/l)	5	Class A Class B Class C Class D Law 48/1982	0.051 USD/m ³
		COD (mg/l)	12		
		BOD ₅ (mg/l)	2		
		TOC (mg/l)	5		
		TC (CFU/100ml)	15		
Fenton	<ul style="list-style-type: none"> Dose: 10 mg/l (FeSO₄) +15 mg/l H₂O₂ Stirring rate: 40 rpm Stirring time: 30 min 	TSS (mg/l)	1	Class A Class B Class C Class D Law 48/1982 (Nearly fresh water)	0.085 USD/m ³
		COD (mg/l)	5		
		BOD ₅ (mg/l)	0		
		TOC (mg/l)	1		
		TC (CFU/100ml)	5		
Photo-Fenton	<ul style="list-style-type: none"> Dose: 10 mg/l (FeSO₄) +15 mg/l H₂O₂ + UV 189 nm and power of 6 watts, Stirring rate: 40 rpm Stirring time: 30 min 	TSS (mg/l)	0	Class A Class B Class C Class D Law 48/1982 (better than fresh water)	0.1 USD/m ³
		COD (mg/l)	0		
		BOD ₅ (mg/l)	0		
		TOC (mg/l)	0		
		TC (CFU/100ml)	0		
		COD (mg/l)	8		
		BOD ₅ (mg/l)	3		
		TOC (mg/l)	4		
		TC (CFU/100ml)	2		

TSS: Total Suspended Solids, BOD₅: Biochemical Oxygen Demand, COD: Chemical Oxygen Demand, TOC: Total Organic Carbon, TC: Total Coliform

From Table (9), it's clear that all the used oxidants (hydrogen peroxide, Fenton and Photo-Fenton) have accomplished the required removal to allow the water to be reused for each required purpose. However, the cost benefit of using hydrogen peroxide is more favorable as it cheaper. Further comparison between the scaleup option, hydrogen peroxide could be more applicable to be scaled up and moreover, it could be nationalized as a strategic industry.

The results of each of the oxidants allow the reuse of each of them in different uses of water. This will increase the economic value of the water and its availability. The challenge of the water scarcity in Egypt pushes in the way for searching of alternative sources for water resources. Keeping with the water strategy of Egypt water reuse represents one of the potential solutions for such challenge. The Wastewater Quality Index and cost comparison is illustrated graphically at figure 9.

WWQI: Wastewater Quality Index, Cost: Cost comparison of different oxidation process

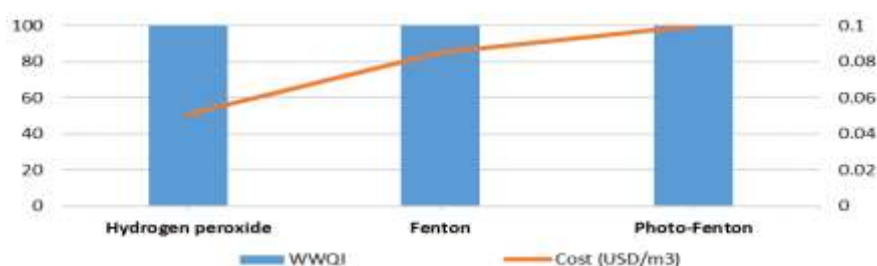


Figure (9): Wastewater Quality Index and cost comparison of different oxidation processes

CONCLUSION

Based on the current water demand and resources in Egypt, the situation represent criticality for decision makers. Strategic direction for searching for alternative is becoming a must. Wastewater reuse represent a potential source for a round 8 Billion Cubic Meters (BCM) /year. The micropollutant and the sophisticated specification hinder the usage of wastewater. Advanced oxidation process represents new potential way for improving the effluent of Wastewater Treatment Plants (WWTPs). Through this study three WWTPs were investigated (Arab-Abosaaed, El Berka and Balaqs. The investigation illustrated that El Berka WWTP is the most vulnerable Wastewater Treatment Plant this why its effluent was used to conduct further treatment on it. Wastewater Quality Index (WWQI) For the effluent (output) of the three WWTPs indicated that mostly the three are appropriate for use according to Egyptian law 48/1982, Class D and Class C code 501/2015 specification. However, El Berka showed lower quality. This could be owed to bad input water quality. Effluent from the three-treatment plant is unsuitable for uses according to Class A and B code 501/2015. This hinders the use of water in the production of higher-value agricultural goods. All the oxidants used has been successfully implemented to achieve 100% WWQI for different reuse purposes. However, the cost benefit of using hydrogen peroxide is more favorable as it cheaper. Further comparison between the scaleup option, hydrogen peroxide is more

applicable to be scaled up and moreover, it could be nationalized as a strategic industry.

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تحسين السيب النهائي بمحطات معالجة مياه الصرف الصحي بإستخدام

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المستخلص

الوضع الحرج للموارد المائية في الدولة المصرية يفرض ضرورة إيجاد حلول ومصادر مياه غير تقليدية مثل إعادة استخدام مياه الصرف الصحي وتحتوية هذه المياه من ملوثات يجعل من الصعب استخدامها إلا بعد معالجتها. عمليات الأكسدة المتقدمة لمعالجة مياه الصرف الصحي يتم فيها التخلص من الملوثات ومن مسببات الأمراض، بهدف استخدامها في كثير من الأغراض. في هذه الدراسة تم عمل مسح بيئي على ٣ محطات معالجة (عرب أبو ساعد الواقعة ببلوان- بلقس الواقعة بشبرا الخيمة - البركة الواقعة بمدينة السلام القاهرة)، وأوضحت النتائج أن السيب النهائي لمحطة معالجة البركة هي أقل كفاءة من حيث جودة المياه، ولذلك تم استخدام المؤكسدات المختلفة على السيب النهائي لمحطة البركة لمعالجة الصرف الصحي لتمثل منطقة الدراسة، وتم استخدام مؤشر جودة المياه WWQI على نتائج المحطات الثلاثة، ولوحظ أنه في الغالب تكون هذه النتائج متوافقة مع المعايير الواردة باللائحة التنفيذية للقانون ٤٨ لسنة ١٩٨٢ في شأن حماية نهر النيل والمياه العذبة من التلوث، أما بالنسبة للكود المصرى لإستخدام مياه الصرف الصحي المعالجة في الزراعة رقم ٥٠١ لسنة ٢٠١٥ فإنها متوافقة فقط مع الفئة الثالثة والرابعة وغير متوافقة مع الفئة الأولى والثانية. تم استخدام فوق أكسيد الهيدروجين، والفينتون، والفوتوفينتون كمواد مؤكسدة لتحسن جودة السيب النهائي وإستخدام هذه المياه في الأغراض المختلفة، وتم تقدير التكلفة لإستخدام هذه المؤكسدات وقد تبين أن إستخدام بيروكسيد الهيدروجين هو الأفضل من حيث التكلفة والتطبيق العملي.

الكلمات المفتاحية: مياه الصرف الصحي - مؤشر جودة مياه الصرف - إعادة الإستخدام - الأكسدة - الفينتون