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Chemical Oxidation as an Efficient Alternative for Activated Sludge in Small Communities in Egypt

Engy El Saka[1] and Ahmed M. Hassanain[2*]

[1]Department of Civil Engineering, Faculty of Engineering, Modern University for Information and Technology, Cairo, Egypt.
[2]Department of Civil Engineering, Faculty of Engineering at Shoubra, Benha University, Cairo, Egypt.

Authors' contributions

This work was carried out in collaboration between both authors. Author AMH designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author EES managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: This research was done in an attempt to evaluate the performance of wastewater treatment plants which apply the chemical oxidation treatment and reasons for its success and failure in some of the small communities in Egypt, compared to conventional activated sludge technologies, without increasing the cost and related burden on the state.
Study Design: The results of different wastewater treatment processes were collected, analyzed, and compared to evaluate the efficiency and cost of chemical oxidation wastewater treatment compared to extended aeration and oxidation ditch technology.
Methodology: Data collected from the records of wastewater quality tests of the Holding Company for Water and Wastewater for the following Egyptian Governorates Kafr El-Sheikh, EL-Gharbia, EL-Sharqia , El-Monofyia ,Damietta, Red Sea, Suez, South Sinai, and El-Fayoum, Governorates.
The measured parameters were BOD, COD, TSS and pH for both the influent and effluent in chemical oxidation, oxidation ditches, and extended aeration treatment plants.
Results: The interrelation between removal efficiency and BOD, removal efficiency and COD, removal efficiency and TSSin each studied type of wastewater treatment, graphically represented,

**Corresponding author: Email: eng_ahmed_hassanain@yahoo.com;*

analyzed, and discussed in order to recommend the optimum treatment technology with minimum initial and operation cost.

Conclusion: The study concluded that the chemical oxidation treatment technology gives an excellent efficiency for the studied wastewater discharges and under the study conditions. The performance of oxidation ditch technology was superior to that of the extended aeration technology was lower than expected, while the oxidation ditches plant showed the lowest performance.

Keywords: Chemical oxidation of wastewater; activated sludge; wastewater treatment in small communities; cost optimization of wastewater treatment.

1. INTRODUCTION

The wastewater treatment processes of raw wastewater, before it can be disposed- of soundly or used for public consumption, must be based on removal level of contaminants to comply with various guidelines. Municipal wastewater is mainly comprised of water (99.9%) together with relatively small concentrations of suspended and dissolved organic and inorganic solids [1-2]. The extent of treatment depends upon the characteristics of the raw sewage and the desired quality of treated wastewater. The objectives of wastewater treatment include: reduction of biological oxygen demand (BOD), reduction of suspended solids (SS), destruction of pathogens and removal of nutrients, toxic compounds, non-biodegradable compounds and dissolved solids, [3]. Relatively simple domestic wastewater treatment technologies can be provided to maintain low cost sanitation and environmentally sound disposal while beneficially reuse the treated wastewater [4]. These technologies use natural aquatic and terrestrial systems. Oxidation, by definition, is a process by which electrons are transferred from one substance to another. Chemical oxidation appears to be one of the solutions to enable complying with the local legislations and standards in a determined receptor medium. It can also be considered as an economically suitable preliminary stage to a secondary treatment of biological oxidation for the destruction of non-biodegradable compounds. [5-6]. A reference parameter in case of using chemical oxidation as treatment process is the COD Only waters with relatively small COD contents (≤0.5 g.L-1) can be suitably treated by means of these processes [7-8]. In general, it can be said that chemical oxidation shows good prospects for use in the elimination of non-biodegradable compounds in the following cases: The first case is using chemical oxidation for the treatment of high concentrations of the compound, Permanganate Fluorine, Hypobromous acid, Hydroxyl radical Atomic oxygen, Ozone, Hydrogen peroxide ,Chlorine dioxide, Chlorine, Bromid iodine, Hypoiodouse acid, to be eliminated, without the interference of other possible compounds [9]. The second case is ,as a pretreatment of currents, to reduce toxicity by avoiding causing problems of inhibition in the biomass when being introduced in a biological treatment, such as activated sludge, [10], as a final treatment for the adjustment of the effluent for the desired discharging conditions [11]. Biological treatment by trickling filters has certain limitations [12], so it was not included in this research.

2. METHODOLOGY

The main biological, chemical, and physical characteristics of fresh and treated wastewater such as, BOD, COD, TSS and pH, were measured, collected and analyzed for 17 different STPs. The selected plants are with small capacities and distributed in nine different Egyptian Governorates. Experiments were held by the Holding Company for Water and Wastewater. Data selected for Kafr El-Sheikh, El-Gharbia, El-Sharqia , El-Monofyia, Damietta, Red Sea, Suez, South Sinai, and El-Fayoum, Governorates. For extended aeration, oxidation ditches, and chemical oxidation treatment the interrelation between BOD removal efficiency & influent BOD, influent COD removal efficiency & COD, and between TSS removal efficiency & influent TSS were studied ,graphically represented, analyzed, and discussed in order to get the optimum treatment technology with minimum cost. A serious discussion for the results was discussed, proper conclusions were drawn, and various recommendations were suggested.

3. RESULTS AND DISCUSSION

More than 17 small-scale municipal wastewater treatment plants were evaluated in eight Egyptian Governorates, which, namely, were Kafr El-Sheikh, El-Gharbia, El-Sharqia, El-

Monofyia , Damietta, Red Sea, Suez and El-Fayoum. Six plants are using chemical oxidation treatment technology, six plants are using oxidation ditch technology, and five plants are using extended aeration. Performance evaluation for the 17 STPs was introduced in this study and a great variability was noticed in the influent concentrations and in the removal efficiencies, considering all analyzed constituents and all treatment technologies. All the plants are using final settling tanks as separation system.

Table 1. presents the name, governorate, system type, and design flow rates for the understudy plants.

3.1 Chemical Oxidation Plants

Fig. 1. shows the relation between the influent BOD for some of the wastewater treatment plants that rely on chemical oxidation as a secondary treatment and the BOD removal efficiency for the same plants. The plants are distributed in different governorates, which, namely, are Suez, El_Fayoum, Red Sea, El Sharqia, and Damietta. The Figure represents the influent BOD for the understudy wastewater treatment plants that use chemical oxidation on x-axis, and the BOD removal efficiency for the same plants, on y-axis. The BOD removal efficiencies ranged between 96.3% and 97.95%, which comply with, both, Egyptian Standard Specifications (E.S.S.) and the minimum requirements set by (Metcalf and Eddie, 2003) for the secondary treatment of wastewater. However, the influent BOD for these plants ranged between 243.5 and 620 p.p.m. These values indicate that the chemical oxidation by Permanganate Fluorine, Hypobromous acid, Hydroxyl radical, atomic Oxygen, Ozone, Hydrogen Peroxide, Chlorine Dioxide, Chlorine, Bromide Iodine, and Hypoiodouse acid is suitable for a great range of influent BOD. This fact reflects that the chemical treatment of wastewater can substitute the conventional biological treatment, totally, with great success and reasonable cost, especially for small communities and sewage treatment plants (STP) with small capacities, less than 5000 m^3/d. However, the removal efficiencies for the studied plant, reached its peak at influent BOD ranged between 300 and 550 p.p.m. That suggests that the optimum BOD removal efficiency may be obtained at medium values of influent BOD, which can be attributed to the fact that the efficiency of chemical treatment decrease with increasing the influent BOD above 550 p.p.m., at the same dose of chemical oxidation, due to the exhausting of the added chemicals in the treatment reaction and the lack of enough oxidants at the stated doses.

On the other hand, the BOD removal efficiency decrease with decreasing the influent BOD values, which impose less chance to reaction between biodegradable organic content and chemical oxidant.

Equation 1 represents the relation between the influent BOD for the wastewater treatment plants, which rely on chemical oxidation as secondary

Table 1. Classification of the Studied Plants

No.	Plant Name	Governorate	Plant Type (System)	Design flow (m^3/d)
1	AL kayat village	Damietta	chemical oxidation	1250
2	Abo dehom _ Atsa	El-Fayoum	chemical oxidation	500
3	Oriental brach	South Sinai	chemical oxidation	200
4	Suco	Red Sea	chemical oxidation	150
5	Golf porto-Elsokhna	Suez	chemical oxidation	1000
6	Kafr el hamam	El-Sharqia	chemical oxidation	150
7	Sidighazi	Kafr El-Sheikh	oxidation ditch	3000
8	Shabus el malh	Kafr El-Sheikh	oxidation ditch	2000
9	Kafr el garida	Kafr El-Sheikh	oxidation ditch	2100
10	Kabrit	Suez	oxidation ditch	1800
11	El-Borg	Damietta	oxidation ditch	4000
12	Abo Ghanima	Kafr El-Sheikh	oxidation ditch	1250
13	Kom El Hagar	Kafr El-Sheikh	Extend Areation	3000
14	Mahlat Zeiad	El-Gharbia	Extend Areation	2000
15	Nawag	El-Gharbia	Extend Areation	1800
16	Meit Badr Halawa	El-Gharbia	Extend Areation	2000
17	Shenrak	El-Monofyia	Extend Areation	2000

treatment, and the BOD removal efficiency for same plants. The relation is a polynomial equation of 5th order.

$$y = -4E\text{-}11x^5 + 9E\text{-}08x^4 - 7E\text{-}05x^3 + 0.028x^2 - 5.592x + 521.9 \quad (1)$$

Where,

y is the BOD removal efficiency for the secondary treatment of any given wastewater treatment plant that use chemical oxidation by Permanganate Fluorine, Hypobromous acid, Hydroxyl radical, atomic Oxygen, Ozone, Hydrogen peroxide, Chlorine Dioxide, Chlorine, Bromide Iodine, Hypoiodouse acid as an alternative for conventional biological treatment.

x is the influent BOD for the same plant.

The r-squared value for this equation equals 1.0, which reflects perfect matching between the results of BOD tests and the proposed equation. This optimistic fact implies that the proposed equation can be heavily relied on to determine the BOD removal efficiency for any given influent BOD to the chemical oxidation sewage treatment plants.

Fig. 2. shows the relation between the influent COD for the same wastewater treatment plants that rely on chemical oxidation as a secondary treatment and the COD removal efficiency for the same plants. The figure represents the influent COD for the understudy wastewater treatment plants on x-axis, and the COD removal efficiency for the same plant, on y-axis. The removal efficiencies ranged between 96.25% and 97.1%. However, the influent COD for these plants ranged between 405 and 813 p.p.m. These values confirm the previous results, that the chemical oxidation is suitable for a great range of influent COD. However, the removal efficiencies for the studied plant, reached its peak at influent COD at 400 p.p.m. That suggests that the optimum COD removal efficiency can be obtained at medium values of influent COD, which can be attributed to the fact that the efficiency of chemical treatment decrease with increasing the influent COD at 400 p.p.m. or the same dose of chemical oxidation to the exhausting of the added chemicals in the treatment reaction and the lack enough oxidants at the stated doses. In general, the COD removal efficiency decrease with decreasing the influent COD values suggest that the chance for reaction between non-biodegradable organic content and chemical oxidant is minimized by the lack of oxidants at the stated doses.

Equation 2 represents the relation between the influent COD for the wastewater treatment plants that rely on chemical oxidation as secondary treatment and the COD removal efficiency for the same plant. The relation is a polynomial equation of 3rd order

$$y = 1E\text{-}06x^3 - 0.002x^2 + 0.821x - 11.83 \quad (2)$$

Where,

y is the COD removal efficiency for the secondary treatment of any given wastewater treatment plant that use chemical oxidation.

x is the influent COD for the same plants.

The r-squared value for this equation is equal 0.999, which reflect very good matching between the results of COD tests and the proposed equation. This optimistic fact implies that the proposed equation can be heavily relied on to determine the COD removal efficiency for any given influent COD to the chemical oxidation sewage treatment plants.

Fig. 3. shows the relation between the influent TSS for the understudy wastewater treatment plants that rely on chemical oxidation as a secondary treatment and the TSS removal efficiency for the same plants. Volatile suspended solids (VSS) are those solids (mg/l) which can be oxidized to gas at 550 C^o. Most organic compounds are oxidized to CO_2 and HO at that temperature; inorganic compounds remain as ash [13].The figure represents the influent TSS for the understudy wastewater treatment plants that use chemical oxidation on x-axis, and the TSS removal efficiency for the same plant, on y-axis. The removal efficiencies ranged between 96.53 % and 97.2 %, which are, significantly, high. However, the influent TSS for these plants ranged between 300 and 675.5 p.p.m. These values indicate that the chemical oxidation is suitable for a great range of influent TSS. However, the removal efficiencies for the studied plant, reached its peak at influent TSS ranged between 300 and 400 p.p.m.

Equation 3 represents the relation between the influent TSS for the wastewater treatment plants that rely on chemical oxidation as secondary treatment and the TSS removal efficiency for the same plants. The relation is a polynomial equation of 3rd order.

$$y = 1E\text{-}06x^3 + 0.002x^2 + 0.821x - 11.83 \quad (3)$$

Where,

y is the TSS removal efficiency for the secondary treatment of any given wastewater treatment plant that use chemical oxidation by Permanganate Fluorine, Hypobromous acid, Hydroxyl radical, Atomic oxygen, Ozone, Hydrogen peroxide, Chlorine dioxide, Chlorine, Bromid iodine, Hypoiodouse acid as an alternative for conventional biological treatment .

x is the influent TSS for the same plant.

The r-squared value for this equation is equal 0.861, which reflect good matching between the results of TSS tests and the proposed equation. This suggests that the proposed equation can be relied on to determine the TSS removal efficiency for any given influent TSS to the chemical oxidation sewage treatment plants.

Fig. 4. shows the relation between the influent pH for the understudy wastewater treatment plants that rely on chemical oxidation as a secondary treatment compared to the pH of the effluent treated wastewater for the same plants.

The influent pH ranged between 7.2 and 7.7 as indicated. However, the effluent pH for these plants ranged between 7.2 and 7.85. These values indicate that the chemical oxidation didn't affect the pH value for the treated water significantly.

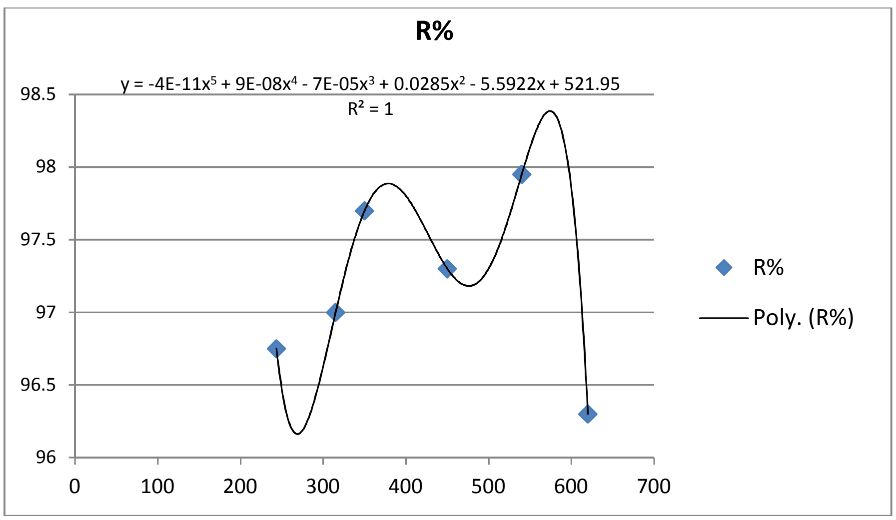

Fig. 1. Relation between Influent BOD and BOD removal efficiency for chemical oxidation

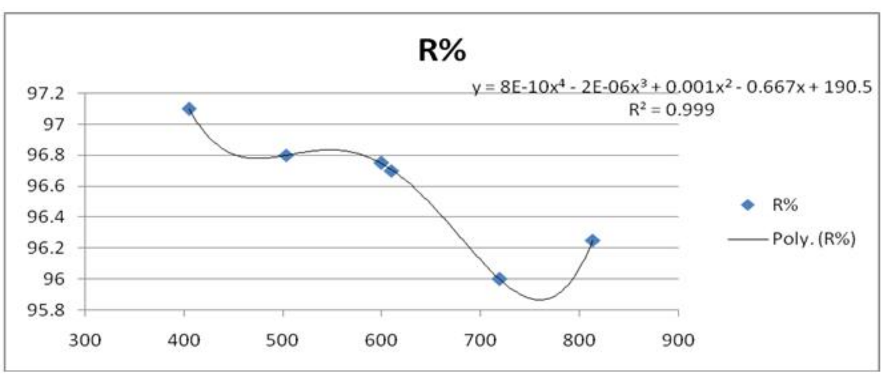

Fig. 2. Relation between influent COD and COD removal efficiency for chemical oxidation

Equation 4 represents the relation between the influent pH value for the wastewater treatment plants that rely on chemical oxidation as secondary treatment and the effluent pH value for the same plant. The relation is a polynomial equation of 4th order.

$$y = -45.08\,x^4 + 1359\,x^3 - 15363\,x^2 + 77140\,x - 14519 \quad (4)$$

Where,

y is the PH influent for the secondary treatment of any given wastewater treatment plant that use chemical oxidation as an alternative for conventional biological treatment.

x is PH effluent for the same plant.

The r-squared value for this equation is equal 0.994, which reflect very good matching between the results of pH tests and the proposed equation. This optimistic fact implies that the proposed equation can be heavily relied on to determine the pH influent and effluent to the chemical oxidation sewage treatment plants.

3.2 Oxidation Ditch Plants

Fig. 5. shows the relation between the influent BOD for some of the wastewater treatment plants that rely on oxidation ditch technology and the BOD removal efficiency for the same plants. The plants are located in Kafr El-Sheikh, El-Monofyia, Damietta, and Suez Governorates. The Figure represents the influent BOD for the understudy wastewater treatment plants that use the oxidation ditch on x-axis, and the BOD removal efficiencies for the same plant, on y-axis. The removal efficiencies are ranging from 86.3% to 94.28%. These results are, significantly, lower than that of chemical oxidation plants. This indicates the suitability of chemical oxidation for small size plants. However, the removal efficiencies for the studied plants, reached its peak at influent BOD ranging from 750 to 950 p.p.m. That suggests that the

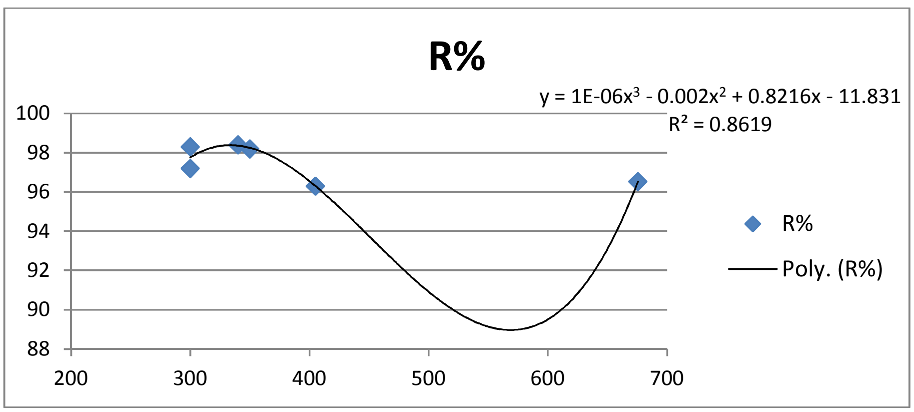

Fig. 3. Relation between influent TSS and TSS removal efficiency for chemical oxidation

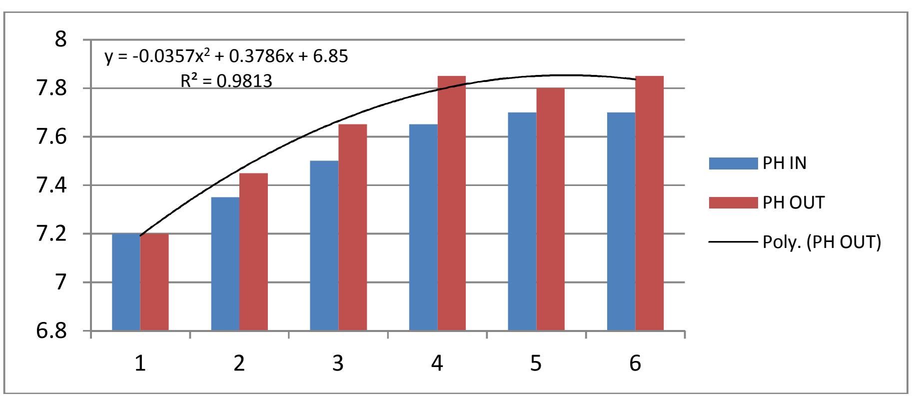

Fig. 4. Influent pH compared to effluent pH for chemical oxidation

optimum BOD removal efficiency can be obtained at very high values of influent BOD. This might be attributed to the fact that the oxidation ditches technology offers, significantly, more long term treatment for organic contact compared to the conventional activate sludge technology. This may results in higher BOD removal range capability. On the other side, the BOD removal efficiency decrease with decreasing the influent BOD values below 650 p.p.m.

Equation 5 represents the relation between the influent BOD for the wastewater treatment plants that rely on oxidation ditch as secondary treatment and the BOD removal efficiency for the same plants. The relation is a polynomial equation of 5th order.

$$y = -5E\ -11x^5 + 1E\text{-}07x^4 + -0.000x^3 + 0.052x^2 - 11.50x - 900.7 \quad (5)$$

Where,

y is the BOD removal efficiency for the secondary treatment of any given wastewater treatment plant that use oxidation ditch for biological treatment.

x is the influent BOD for the same plant.

The r-squared value for this equation is equal 1.0, which reflects impressive matching between the results of BOD tests and the proposed equation. This reflects highly reliable equation is to determine the BOD removal efficiency for any given influent BOD for the oxidation ditch sewage treatment plants.

Fig. 6. shows the relation between the influent COD for the same wastewater treatment plants that rely on oxidation ditch technology as a secondary treatment and the COD removal efficiency for the same plants. The figure represents the influent COD for the understudy wastewater treatment plants that use the oxidation ditch on x-axis, and the COD removal efficiencies for the same plant, on y-axis. The removal efficiencies are ranging, slightly, from 91.11% to 95.11%. However, the influent COD for these plants ranging from 365.5 to 2014 p.p.m. However, the removal efficiencies for the studied plants, reached its peak at influent COD ranging from 700 to 2000 p.p.m. That suggests that the optimum COD removal efficiency can be getting at high levels of influent COD.

Equation 6 represents the relation between the influent COD for the wastewater treatment plants that rely on oxidation ditch as secondary treatment and the COD removal efficiency for the same plants. The relation is a polynomial equation of 3rd order.

$$y = -1E\text{-}07x^3 + 0.000x^2 - 0.267x + 145.4 \quad (6)$$

Where,

y is the COD removal efficiency for the secondary treatment at any given wastewater treatment plant that use oxidation ditch technology for biological treatment.

x is the influent COD for the same plant.

The r-squared value for this equation is equal 0.591, which reflect acceptable matching between the results of COD tests and the proposed equation. This figure indicates that the equation can be moderately relied on to determine the COD removal efficiency for any

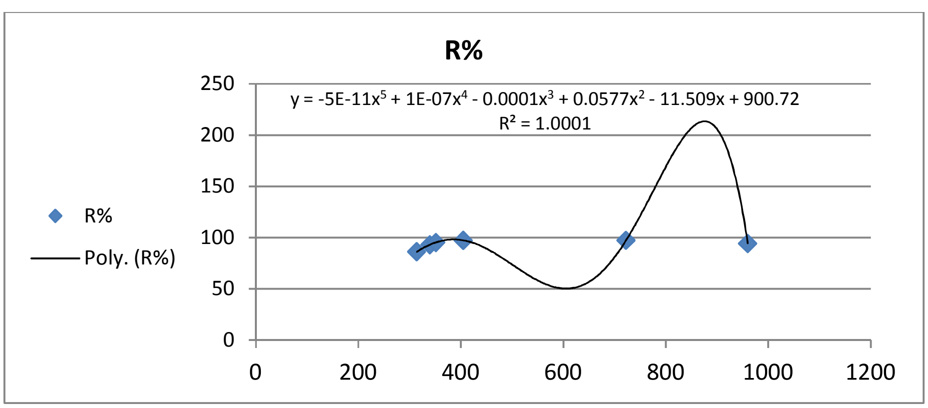

Fig. 5. Relation between Influent BOD and BOD removal efficiency for oxidation ditch technology

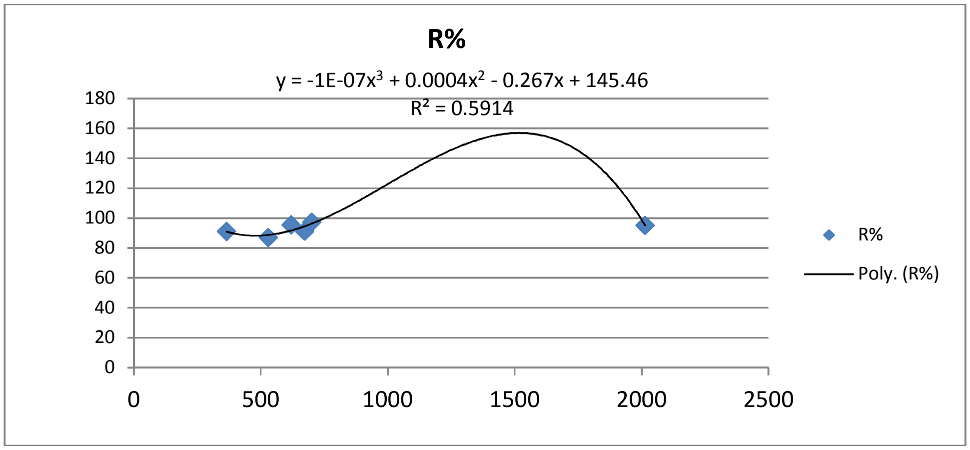

Fig. 6. Relation between Influent COD and COD removal efficiency for oxidation ditch technology

given influent COD to the oxidation ditch sewage treatment plants.

Fig. 7. shows the relation between the influent TSS for some of the wastewater treatment plants that rely on oxidation ditch technology as a secondary treatment and the TSS removal efficiency for the same plants. The plants are located in the four Egyptian Governorates of Kafr El-Sheikh, El-Monofyia, Damietta, and Suez. The figure represents the influent TSS for the understudy wastewater treatment plants that use the oxidation ditch on x-axis, and the TSS removal efficiencies for the same plant, on y-axis. The removal efficiencies are ranging from 88.6% to 94.75%, which are, relatively, high efficiencies. However, the influent TSS for these plants ranged between 181 and 604.5 p.p.m. These values indicate that the oxidation ditch is suitable for a great range of influent TSS. However, the removal efficiencies for the studied plant, reached its peak at influent TSS ranging from 200 to 500 p.p.m. That suggests that the optimum TSS removal efficiency can be obtained at medium values of influent TSS. On the other hand, the TSS removal efficiency decreases with decreasing the influent TSS values.

Equation 7 represents the relation between the influent TSS for the wastewater treatment plants that rely on oxidation ditch as secondary treatment and the TSS removal efficiency for the same plants. The relation is a polynomial equation of 4th order.

$$y = 2E\text{-}08x^4 - 4E\text{-}05x^3 + 0.02x^2 - 4.699x + 475.3 \quad (7)$$

Where,

y is the TSS removal efficiency for the secondary treatment of any given wastewater treatment plant that use oxidation ditch as secondary treatment.

x is the influent TSS for the same plant.

The r-squared value for this equation is equal 0.974, which reflect impressive matching between the results of TSS tests and the proposed equation. This optimistic fact implies that the proposed equation can be heavily relied on to determine the TSS removal efficiency for any given influent TSS to the oxidation ditch sewage treatment plants.

3.3 Extended Aeration Plants

Fig. 8. shows the relation between the influent BOD for some of the wastewater treatment plants that rely on Extend Aeration technology as a secondary treatment and the BOD removal efficiency for the same plants. The Governorates, where the plants are located, are Kafr El- Sheikh and El-Gharbia. The removal efficiencies ranged from 88.3% to 90.23%, which is, slightly, lower than that of the oxidation ditch. However, the influent BOD for these plants ranged between 350 and 420 p.p.m. However, the removal efficiencies for the studied plant, reached its peak at influent BOD at 420 p.p.m. That suggests that the optimum BOD removal efficiency can be obtained at higher values of influent BOD. However, the BOD removal ratios for all the sewage treatment plants (S.T.PS.) complied with the Egyptian standard

Specifications (E.S.S.) and the limits set by (Metalf and Eddie) for wastewater secondary treatment.

Equation 8 represents the relation between the influent BOD for the wastewater treatment plants that rely on extend aeration as secondary treatment and the BOD removal efficiency for the same plants. The relation is a polynomial equation of 3rd order.

$$y = 0.000x^3 - 0.741x^2 + 279.7x - 35019 \qquad (8)$$

Where,

y is the BOD removal efficiency for the secondary treatment of any given wastewater treatment plant that use I oxidation ditch as an alternative for conventional biological treatment.

x is the influent BOD for the same plant.

The r-squared value for this equation is equal 0.981, which reflect impressive matching between the results of BOD tests and the proposed equation. This optimistic fact imply that the proposed equation can be heavily relied on to determine the BOD removal efficiency for any given influent BOD to the extend aeration sewage treatment plants.

Fig. 9. shows the relation between the influent COD for some of the wastewater treatment plants that rely on extend aeration as a secondary treatment and the COD removal efficiency for the same plants. The governorates, where the plants are located, are Kafr El Sheikh and El-Gharbia. The figure represents the relation between the influent COD for the understudy wastewater treatment plants that use the extend aeration on x-axis, and the COD removal efficiencies for the same plant, on y-axis. The removal efficiencies are ranging from 87.84% to 90.95. However, the influent COD for these plants ranged between 598 and 810 p.p.m. These values refers to the fact that the extend aeration is suitable for a medium to range of influent COD.

This fact reflects that extend aeration treatment of wastewater can substitute the conventional biological treatment, totally, with great success and reasonable cost, especially for small communities and sewage treatment plants (S.T.Ps) with small capacities less than 5000 m^3/d. However, the removal efficiencies for the studied plant, reached its peak at influent COD ranging from 598 to 681.5 p.p.m.

Equation (9) represents the relation between the influent COD for the wastewater treatment plants that rely on extend aeration as secondary treatment and the COD removal efficiency for the same plants. The relation is a polynomial equation of 3rd order.

$$y = 2E\text{-}05x^3 - 0.035x^2 + 24.57x - 5488 \qquad (9)$$

Where,

y is the COD removal efficiency for the secondary treatment of any given wastewater treatment plant that use I oxidation ditch as an alternative for conventional biological treatment.

x is the influent COD for the same plant.

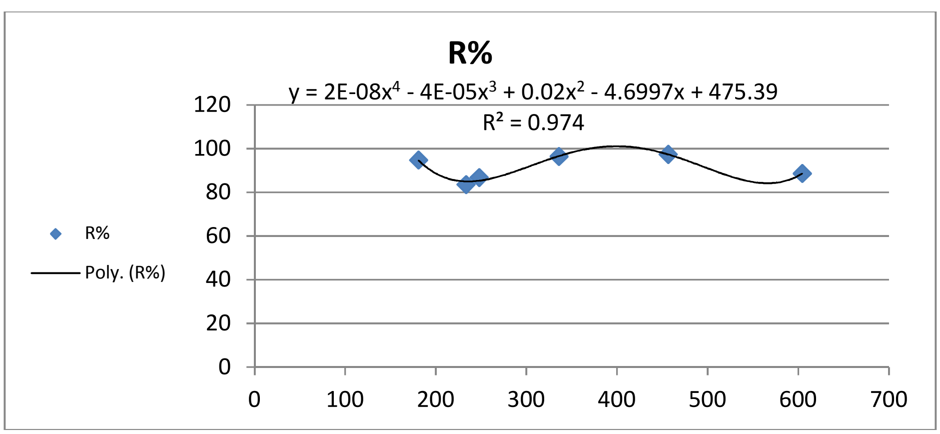

Fig. 7. Relation between influent TSS and TSS removal efficiency for oxidation ditch technology

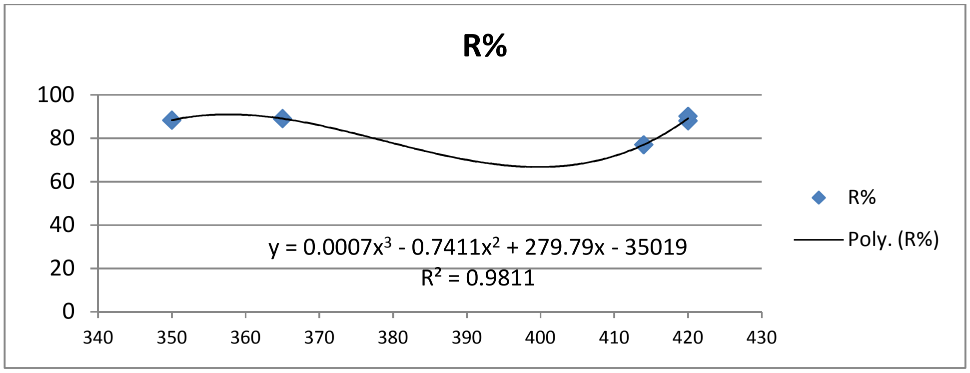

Fig. 8. Relation between influent BOD and BOD removal efficiency for extended aeration technology

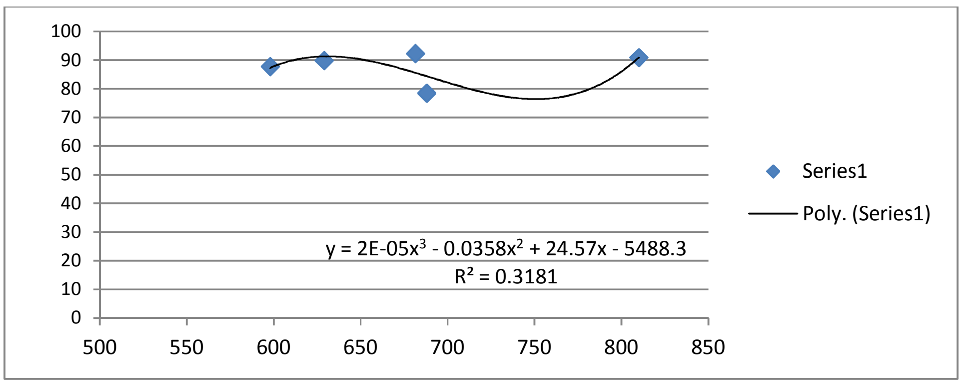

Fig. 9. Relation between influent COD and COD removal efficiency for extended aeration technology

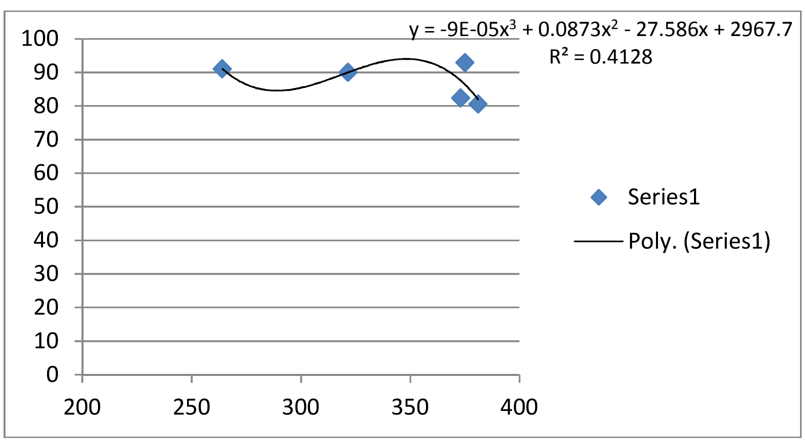

Fig. 10. Relation between influent TSS and TSS removal efficiency for extended aeration technology

Table 2. Economical comparison

	Chemical oxidation	Extended aeration	Oxidation ditch
Electric Consumption (kW/h/m^3)	0.080	0.440	0.412
Required Area (m^2/m^3)	0.167	3.671	6.839
Labor Productivity (m^3/Worker)	50	240	210

The r-squared value for this equation is equal 0.381, which reflect poor matching between the results of COD tests and the imposed equation. But, the proposed equation can, still, be relatively relied on to determine the COD removal efficiency for any given influent COD to the extend aeration sewage treatment plants.

Fig. 10 shows the relation between the influent TSS for some of the wastewater treatment plants that rely on extend areation as a secondary treatment and the TSS removal efficiency for the same plants. The governorates, where the plants are located, are Kafr El-Sheikh, and El-Gharbia. The figure represents the influent TSS for the understudy wastewater treatment plants that use the extend aeration on x-axis, and the TSS removal efficiencies for the same plant, on y- axis. The removal efficiencies are ranging from 80.6% to 91.06%, which indicates high efficiency. However, the influent TSS for these plants ranged between 264 and 381 p.p.m. However, the removal efficiencies for the studied plant, reached its peak at influent TSS ranging from 264 to 375 p.p.m. That suggests that the optimum TSS removal efficiency can be obtained at low values of influent TSS.

Equation (10) represents the relation between the influent TSS for the wastewater treatment plants that rely on extend aeration as secondary treatment and the TSS removal efficiency for the same plants. The relation is a polynomial equation of 3rd order.

$$y = -9E\text{-}0.5x^3 + 0.087x^2 - 27.58x + 2967 \quad (10)$$

Where,

y is the TSS removal efficiency for the secondary treatment of any given wastewater treatment plant that use I oxidation ditch as an alternative for conventional biological treatment.

x is the influent TSS for the same plant.

The r-squared value for this equation is equal 0.412, which reflect moderate matching between the results of TSS tests and the proposed equation. This fact imply that the proposed equation can be, moderately, relied on to determine the TSS removal efficiency for any given influent TSS to the extend aeration sewage treatment plants.

3.4 Economical Evaluation

A small scale economical comparison between the three systems has been introduced. The points of comparison are the average electrical power consumed to treat 1 m^3 of wastewater in kW/hr, the average required land space in m^2 to treat 1 m^3/d of wastewater, and the labor daily productivity of treated wastewater in m^3/worker. The values are shown in above Table 2.

4. CONCLUSIONS

Performance evaluation between eight STPs was introduced in this study and a great variability was noticed in the influent concentrations and in the removal efficiencies, considering all analyzed constituents and all treatment technologies. Based on this stu circumstances, the following conclusion were drawn;

- Chemical oxidation can be used in the treatment of wastewater with great success, as an alternative for biological treatment.
- The higher cost of chemical oxidation compared to conventional biological treatment suggests that chemical oxidation is suitable for discharges below 5000 m^3/d.
- The BOD and COD removal efficiencies of chemical treatment compact STPs were higher than that of the oxidation ditch and extended aeration, especially, for the discharges below 500 m^3/d.
- The overall removal efficiencies of BOD; COD and TSS were 97.95%, 97.31%, and 98.4%, respectively. This technology is applied for the packaged plants.
- The chemical oxidation treatment applied in Red Sea Governorate has proved a great performance for different contaminants. The average removal efficiencies of BOD, COD and TSS were 97.17%; 96.6, and 97.49%, respectively. This technology gives an excellent efficiency for the discharges ranged from 50 m^3/d to 500 m^3/d.
- The performance of oxidation ditch technology was very good. The average removal efficiencies were BOD, COD and TSS were 93.955%, 92.875%, and 91.2%, respectively. The discharges of this technology ranged from 1000 m^3/d to 6000 m^3/d.
- The performance of extended aeration technology was moderate and secured a

BOD, COD and TSS was 86.59%, 87.91%, and 87.40% for removal efficiency, respectively. This performance was lower than expected.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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