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Improving the removal efficiency of chemical oxygen demand and total organic carbon from industrial wastewater by magnetic forced vortex and ozone

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ABSTRACT

Some treatments of industrial wastewater suffer from the difficulty of removing or reducing pollution by organic and inorganic materials. This research was conducted to investigate the effect of applying advanced treatment method by using ozone and a magnetic field combined with a forced vortex on the removal efficiency of chemical oxygen demand (COD) and total organic carbon (TOC) from industrial wastewater. Samples of the wastewater of Addora Electric Station, which is located in the southern part of Baghdad, were collected just before being discharged to Tigris River. Experiments on treating the wastewater samples and tests were conducted at the laboratories of Iraqi Ministry of Science and Technology. The experimental treatments were conducted under different flow rates, values of pH, and detention time. The applied flow rates are 0.25, 0.5, 0.75, and 1.0 L/min. Four values of pH of the wastewater were applied, which are 3.0, 5.0, 7.5 and 9.0. The effect of the detention time of 30, 50, 70, and 90 min were investigated. The removal efficiency of COD and TOC when using treatment by ozone and magnetic field combined with forced vortex were compared to that results obtained by using treatment with ozone alone. The results indicated that effect of vortex and magnetic with ozone have a positive effect on COD and TOC removal. The most significant removal efficiency detected COD and TOC were 98% and 97%, respectively, obtained at pH 9.0 and detention time of 90 min as compared to the control samples.

Keywords: Industrial wastewater; Magnetic field; Vortex mixing; Ozone; Chemical oxygen demand; Total organic carbon

1. Introduction

Pollution is one of the hard challenges facing most rivers worldwide, which becomes more serious with the reduction in the flow of rivers due to claimant change and increase water demand. The discharge of industrial wastewater directly to surface water resources without any treatment leads to great negative effects on the aquatic environment. The industrial wastewater contains high concentrations of pollutants such as heavy metals, organic materials, dyes, fats, oils, drugs, detergents and acids [1].

The pollutants of an industrial wastewater depend on industry processes and the used raw materials. Each wastewater of industries such as paper factories, dairy, textile, mining and mineral processing, pharmaceutical, and petrochemical industries require special treatment [2].

Chemical oxygen demand, COD, is an indicator for organic and inorganic materials in industrial wastewater. Total organic carbon, TOC, is used as a measure of the concentration of organic carbon in a wastewater. COD and TOC are positively related and are used to determine the quality of wastewater and the need for treatment. High levels of COD and TOC exist in the industrial wastewater have

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a negative impact on the health of human, wildlife, and generally on the health of the environment [3].

Many studies have been conducted on the treatment of industrial wastewater aiming at reducing the level of the organic contaminants by using ozone under different treatment conditions and techniques.

Chen et al. [4] modeled and investigated the dynamic variations of ozone with pollutants in a commonly used counter-current bubble column. A mixture of ozone and oxygen gas is introduced at the bottom of the column. Pollutants in the wastewater are removed by oxidation with dissolved ozone. The model was validated by comparing the predicted results with the experimental data that showed a well prediction of variations of the ozone, pollutant, and oxygen concentration profiles from the beginning to steady state. Therefore, the developed model can be used for proper prediction of the variables of an ozonation system in a counter-current bubble column. Moreover, under the conditions of the experiments by this study, the results indicated that it needs two to five hydraulic retention times to reach steady state.

Gogate and Pandit [5] overviewed the hybrid methods, a combination of advanced oxidation processes and presented different chemicals degraded. The paper describes in detail some of the important work related to the application of hybrid methods to real effluents. Moreover, some guidelines for further work required to facilitate efficient large-scale operation were proposed. The paper presents a discussion on model effluent treatment scheme based on the various techniques. The conclusions that were made are that the expected interaction between different hybrid methods is mainly due to an identical controlling reaction mechanism.

Zhu et al. [6] conducted an experiential study on the removal of petroleum-based pollutants in water by ozone. The study showed that the petroleum-based pollutants can be effectively removed by ozone. Ozone changes the structure and composition of petroleum. It oxidizes the high molecular organics into low molecular organics, or decomposes some organics directly into CO_2 and H_2O. Non-biodegradable organics are converted into biodegradable organics. The study concluded that ozonation can be used separately or combined with biodegradation, membrane separation technique and etc. to process petroleum-contained water.

Shankar et al. [7] conducted field experiments on the removal of COD, TOC, and color from pulp and paper industry by using electro coagulation in a batch reactor. The effects of various parameters on the removal of COD, TOC, and color process variables. These parameters are pH, treatment time, current density, and inter-electrode distance. The optimum condition of theses parameters were found to be as pH: 7, treatment time: 75 min, current density: 115 A/m, and inter-electrode distance: 1.5 cm with a combined desirability index value of 0.816. Under these conditions, the removals of COD, TOC, and color 77%, 78.8%, and 99.6%, respectively.

Katal et al. [8] conducted an experimental study by using a bench-scale anaerobic bioreactor to investigate the effect of organic loading rate and hydraulic retention time on treatment of organic matters in the textile wastewater. The experimental results showed that the maximum removal values of COD and color were 94.8% and 84.4%, respectively. Biogas and methane were produced. The maximum rate of methane gas production was achieved 36 L/d. The purity of biogas in terms of methane content was 79%.

Ladwani and Ramteke [9] carried out a laboratory experiment on COD removal from effluent of industrial wastewater. They applied advanced oxidation process of UV/O_3 for removal COD from wastewater. Variable values of parameters that affect the oxidation process were applied such as pH, ozone dose, and exposure time of UV. The results showed that the best removal of COD was at pH = 7, the ozone dose of 4 mg/h, and 60 min of UV.

Jin et al. [10] designed a recycling-flow three-dimensional electro-reactor system for the purpose of conducting experiments on degrading synthetic Rhodamine B wastewater as dye. The results indicated that recycling led to higher current efficiency and lower energy consumption by 40%. The proportion of BOD and COD became lower than 0.3.

Albakrey et al. [11] investigated experimentally the degradation of organic and inorganic matter in two types of wastewaters by using conventional ozonation and ozone/UV AOPs. The two types of wastewater are industrial and synthetic having the same COD. The results indicated that varying solution pH and employing UV clearly showed that oxidation during ozonation process was dominated by OH reactions. With 2 g/h maximum ozone dose, conventional ozonation led to 56% COD removal efficiency in synthetic wastewater and 52% in the industrial wastewater. Applying UV improves the efficiency of oxidation to 70% and 62% in the synthetic and the industrial wastewater, respectively.

Dyan et al. [12] conducted experiments with the aim of lowering the levels of COD to meet the effluent quality standard. The variables included in the experiments are pH and the concentration ratio of COD:N. the study concluded that the optimum pH value for biogas is 7, the maximum COD removal is 72.39% at optimum pH value of 6, and the optimum operation mode COD:N for biogas production and COD removal was 500:7.

The use of conventional methods proved to remove a large percentage of these pollutants from industrial wastewater, but in many cases, they do not meet the environmental control requirements. One of those methods is advanced oxidation using ozone, which is a very effective and fast oxidant. Using a magnetic field connected to a forced vortex that was proved to change the physical characteristic reaction of chemical compounds of the water can be helpful in increasing the efficiency of oxidizing and reducing organic material in industrial wastewater [13].

The aim of this study is to experimentally investigate the effect of the forced vortex connected to a magnetization system on the removal of COD and TOC from industrial wastewater traded by ozone.

2. Materials and methods

Ozone generator and magnetic system with vortex were used to remove COD and TOC from industrial wastewater collected from the wastewater of Addora Electric Station, located south of Baghdad. The treatment was carried out in two stages; the first treatment is conducted by using ozone only as a control, and the second stage by using a magnetization system and a forced vortex device in addition to treatment by ozone device together.

Fig. 1 shows a schematic diagram of a wastewater treatment system installed in the laboratory that consists of: a wastewater reservoir, pump, and magnetic-vortex unit. The water flows through pipe with internal diameter of 1.25 cm. Three valves were used to control the water flow rate, the first, is installed at the outlet of feed pipe. The second valve was installed to control the water passing through the vortex and magnetic unit to the reactor column for treatment, and the third valve was used to control the water leaving to the reactor column for treatment.

Magnetic-vortex system consists of two parts, the magnetization device, shown by Fig. 2, having a magnetic intensity of 3000Gauss. This magnetic was produced by the Water Research Center of the Directorate of Environment and Water of the Ministry of Science and Technology.

The details of a vortex device are shown in Fig. 3. It is a perfect symmetry in its function, uses principle of spin. The principles of spinning water into a vortex for the purpose of structuring water are uses directional nozzle to create a water vortex in perfect symmetry. Water flows into the first chamber, and then it flows through 5 channels, which are shaped as a spline on a cone. All 5 channels meet together on the output and spiral together. The vortex created with silky and smooth with the highest quality. The water passes through the vortex, the velocity was increased and water layers were dispersion, making the flow turbulent. This vortex was purchased from Fractal Water Company, USA.

Wastewater was tested for COD and TOC before and after each treatment. Four different retention times for the ozone column in the reaction column were used. These times are 30, 50, 70, and 90 min. The process of magnetization of wastewater was carried out by passing the wastewater thought the magnetic field. The pH value for wastewater before treatment is 7.5. It was adjusted to pH level of 3.0, 5.0, 7.0 and 9.0 to introduce the pH value as a parameter affecting the treatment. All of the required tests were conducted at the laboratory of Water Research Center of Environment and Water Directorate of the Ministry of Science and Technology. The test analysis of the wastewater of Addora Electric Station are listed in Table 1:

The procedure for conducting the wastewater treatment is as follow:

- Industrial wastewater samples were brought from Addora Electric Station. Samples were kept in a refrigerator at 4°C to reduce any decomposition.
- Analysis of the sample for COD and TOC tests.
- Adjusting the pH value of wastewater under treatment. Four levels of pH value were used; these are 3.0, 5.0, 7.0 and 9.0.
- Supplying the treatment device with the wastewater. Four discharges were used; these are 0.25, 0.50, 0.75, and 1.0 L/min.

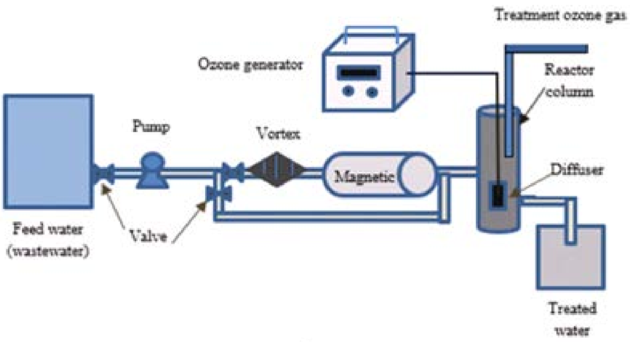

Fig. 1. Schematic diagram showing the treatment system by ozone and magnetic-vortex unit.

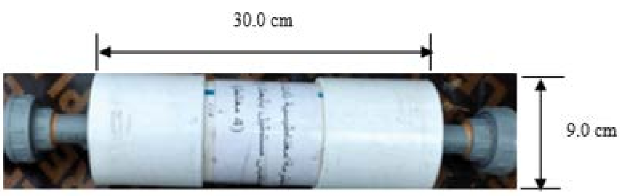

Fig. 2. Magnetization device.

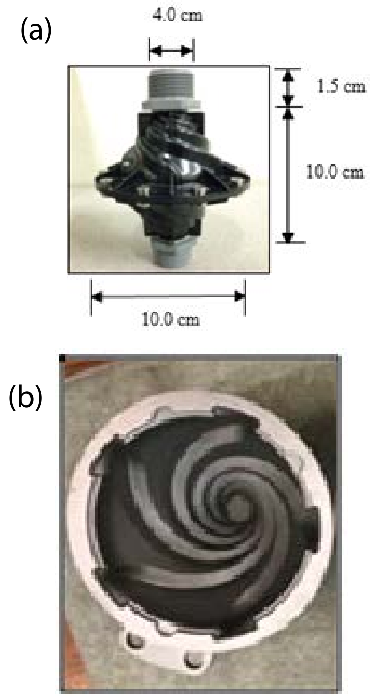

Fig. 3. Vortex device a and b.

Table 1
Tested feed wastewater properties (before treatment)

pH	7.5
EC, μS/cm	948
TDS, ppm	494
NO_3^{-1}, ppm	6.6
Na^{+1}, ppm	94.0
Cl^{-1}, ppm	5.64
Chemical oxygen demand, ppm	185.4
TOC, ppm	61.8

- Application of ozone in the column reactor. Four detention time of ozone application, these are 30, 50, 70, and 90 min.
- The system was operated by using ozone treatment only, and then the ozone was operated with magnetic-vortex treatment.
- All experiments were carried out at lab temperature of about 20°C.

3. Results and analysis

Fig. 4 shows the efficiency removal of COD when using the treatment with ozone only as the control experiment. Different rang of flow rates water used 0.25, 0.5, 0.75, and 1.0 L/min with four applied of pH function 3.0, 5.0, 7.0 and 9.0. The ozone detention time of 70 min was used (as an average of the selected detention times). The efficiency of COD removal is increased at flow rates 0.5 and 0.75 L/min and with increased value of pH. The highest removal value was 45% when using pH 7.0 and pH 9.0, and the lowest removal value was 18% obtained when using pH 3.0 at discharge of 0.25 L/min.

The reason for the increase in the removal efficiency of COD at a pH equal to 9 is referred to the ability to decompose ozone in the alkalinity media due to the presence of OH^-, which exceed up the dissociation of O_3 to OH^-, H_2O means that the half-life of ozone decreases in the alkalinity media, and the reason of increase at high discharge rates is due to organic substances that interact with ozone or inorganic substances dissolved in water that act as catalysts for the reaction. That is, the half-life of ozone, or the rate of decomposition of ozone, increases with the increase of impurities or pollutants in polluted water.

Fig. 5 shows the efficiency of COD removal rate when using magnetic-vortex unit with ozone treatment wastewater. Four detention time of ozone in column reactor were used, 30, 50, 70, and 90 min with four applied of pH 3.0, 5.0, 7.0 and 9.0. The COD removal rate was increased when increasing pH value and detention time of ozone. The highest removal value was 98% obtained when using pH 9.0 at a detention time of 90 min. But the lowest removal value was 62% obtained when using pH 3.0 at a detention time of 30 min. The increased efficiency compared to the control is due to the use of magnetic-vortex unit, which works to atomize the polluted water layers and increase the exposure area of organic and inorganic materials to ozone and

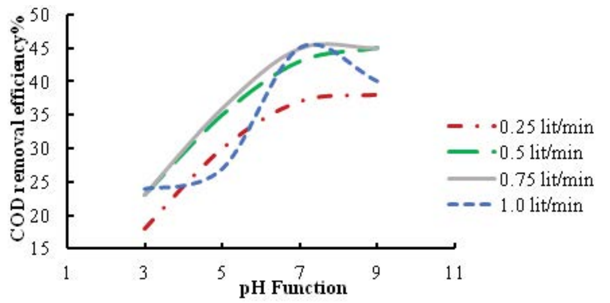

Fig. 4. Chemical oxygen demand removal with ozone only (control).

increase or enhance the interaction of ozone and the formation of other compounds, especially when the pH is high between 8–9, as the alkaline level has OH^- is already high.

Fig. 6 shows the TOC removal rate of wastewater treatment when using four values of detention time of ozone 30, 50, 70, and 90 min with the four applied of pH 3.0, 5.0, 7.0 and 9.0 for treatment of ozone device with the magnetic and vortex. The TOC removal rate was increased when increasing pH value and detention time of ozone. The maximum removal value was 97% obtained when using pH 9.0 at detention time of 90 min, the minimum value was 61% obtained when using pH 3.0 at detention time of 30 min.

The treatment of COD removal when using the discharge 0.5 L/min as shown in Fig. 7. The maximum value of removal COD was 55% at pH 7.0 with ozone detention time of 90 min. The minimum value of COD removal was 12% at pH 3.0 at ozone detention time 30 min. That is due to the effect of pH level which caused high concentration

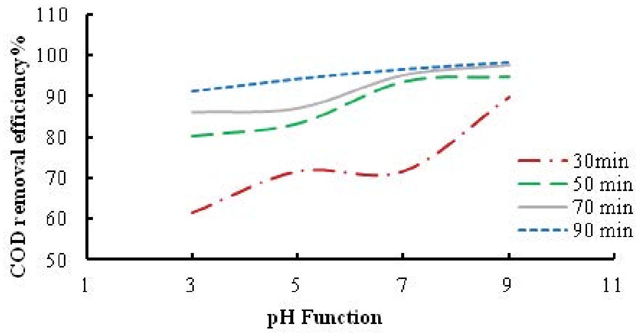

Fig. 5. Efficiency of chemical oxygen demand removal.

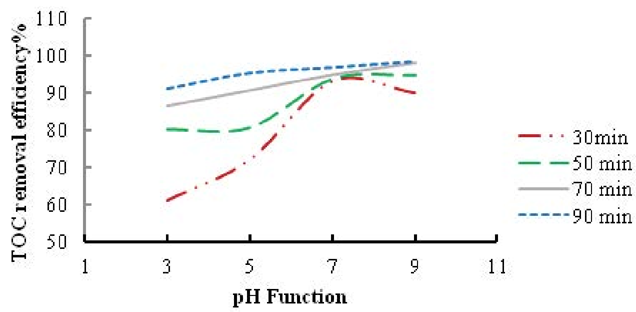

Fig. 6. Efficiency of total organic carbon removal.

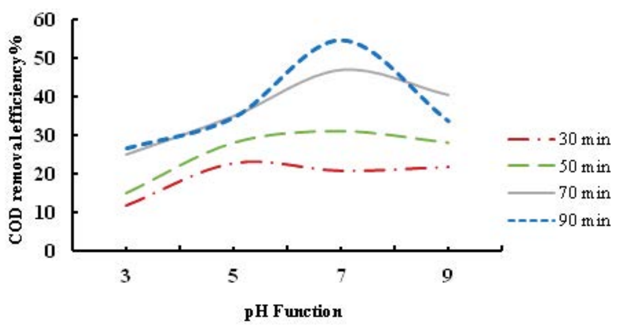

Fig. 7. Chemical oxygen demand removal at flow rate 0.5 L/min.

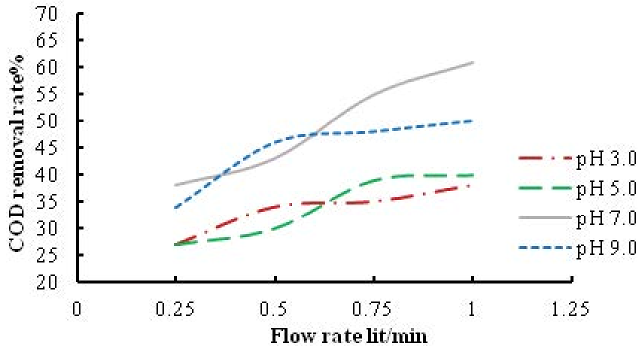

Fig. 8. Effect of ozone and magnetic field on chemical oxygen demand removal efficiency.

of hydroxide ions (OH^-) which reacts with ozone to form hydro peroxide these reactive species to convert them to lags harmful pollutants.

Magnetic field enhanced the reaction as well as the high spread of particles or layers of polluted water. Dispersal by atomization and diffusion of polluted water and its components accelerates the reaction process with ozone and lowers concentrations COD especially in alkaline mediums with a high pH.

Fig. 8 COD removal with ozone and magnetic vortex. The efficiency of removal COD is about (55%–60%), this value comes from the effect of magnetic and dispersion of water when moving through the vortex which increase rate of mixing and perfect reaction of organic reactants. This because vortex can generate high turbulent flow which increase mass transfer rate with good opportunity for water molecules to be exposed to ozone than if it were without vortex, and thus an interaction occurs between water molecules and ozone, forming compounds or reaction products with organic and inorganic compounds, and thus the concentration of the chemical oxygen requirement COD decreases with the effect of pH on the concentration of hydroxyl radical OH^-.

Finally, to research and develop experiments in magnetic field with vortex: it is recommended to continue experimental investigations using spiral dispersants to study their effect on reducing organic pollutants and fats in industrial wastewater. Moreover, the use of mechanical mixers with ozone and the magnetic field in the treatment of drinking water for the purposes of sterilization, removal of pollutants, and improvement of coagulation efficiency. Furthermore, study the using of centrifugal pump as a mechanic mixer with magnetic field for industrial wastewater treatment.

4. Conclusions

In this study, the effects of the ozone and magnetic with vortex system on treatment of the industrial wastewater of Addora Electric Station was investigated to remove COD and TOC rates. Four levels of pH value were used; these are 3.0, 5.0, 7.0 and 9.0. Four discharges were used; these are 0.25, 0.50, 0.75, and 1.0 L/min. Four detention time of ozone application, these are 30, 50, 70, and 90 min. The system was operated by using ozone treatment only, and then the ozone was operated with magnetic-vortex treatment, and the results were compared to of ozone treatment only.

The following conclusions were achieved:

- The effect of magnetic and vortex system is positively affected with the ozone on the removal values of COD and TOC treatment wastewater.
- The highest removal values of COD and TOC were 98% and 97%, respectively obtained when using pH 9.0 at a detention time of 90 min as compared to the control.

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