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Management of wastewater from ink production and metal plating industries in an Egyptian industrial city

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ABSTRACT

This study focuses on selecting an appropriate treatment technology for wastewater discharged from two metal plating and one ink production factories. All located in an Egyptian industrial city. The study aims to form a useful guideline and reference for application by operating units in similar types of industry. Metal industry in the city was responsible for the highest quantity of wastewater discharge per day (2096 m^3/day). Ink production was characterized by higher organic load than other industries (COD: 30,500 mg/l, TSS: 7490 mg/l, Oil & grease: 409 mg/l, Cu: 22 mg/l). The metal plating factories under investigation produce 30 and 5 m^3/d, besides they are close-by so it was found economically feasible to combine the effluent from the two factories in one treatment unit. Analysis of the mixed samples of the metal plating factories indicated that the wastewater was acidic and contaminated with heavy metals. The concentration of zinc, chromium and nickel was 25.8, 4.0 and 2.5 mg/l, respectively. Chemical treatment of the metal plating wastewater involved the use of an excess dosage of 96 mg/l of ferrous sulphate to reduce chromium hexavalent to chromium trivalent, followed by addition of 330 mg/l of CaO at pH 9 to precipitate chromic hydroxide and the other metals. The produced effluent quality was in compliance with the permissible limits set by the national environmental laws and regulations. Laboratory experiments proved that ink wastewater treatment using Fenton oxidation process is a promising and attractive treatment method that produces an effluent complying with the national environmental laws, however its high cost is a major limitation for its application. The viable alternative investigated in this study is the application of pollution control measures at source due to the economic competitiveness.

Keywords: Fenton; Prevention; Ink; Metal; Wastewater

1. Introduction

Treatment of industrial wastewater receives great interest to preserve the water resources quality for the safe use by human beings. Industrial processes such as metal plating generate wastewater containing heavy metals. Since most of heavy metals are non-degradable into non-toxic end products, their concentration must be reduced to acceptable levels before wastewater discharge into the environment. Otherwise, subject contaminants could pose threats to public health and/or affect the standard quality of potable water. According to World Health Organization (WHO) the metals of immediate concern are chromium, zinc, iron, mercury and lead [1]. A number of conventional treatment technologies have been considered for treatment of

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wastewater contaminated with heavy metals. Previous investigations on the removal of heavy metals from wastewater [2] suggested that systems containing calcium in the form of CaO or $CaCO_3$ are particularly effective in the removal of heavy metals from wastewater. Gupta et al. [3] investigated the removal of zinc and cadmium using a blast furnace waste material. Also, some conventional techniques for metals removal from industrial wastewater such as, adsorption [4–13] and biological processes were investigated [14–17]. Each technique has its advantages and limitations.

Performance and cost-effectiveness of the removal of heavy metals from metal-contaminated wastewater using various low-cost adsorbents derived from agricultural waste, industrial by-product or natural material were studied [18]. The results indicated that low-cost adsorbents can be viable alternatives to activated carbon and adsorption capacities depending on the characteristics of the individual adsorbent, the extent of surface modification and the initial concentration of the adsorbate. Technical applicability and cost-effectiveness are the key factors that play major roles in the selection of the most-suitable adsorbent. The removal of hexavalent chromium using low-cost fertilizer called carbon slurry was studied [19]. The results indicated that the used adsorbent proved to be effective material for the treatment of chromium beating aqueous solutions.

The bio-sorption of heavy metals especially lead from solution by biomass of commonly available, filamentous green algae *spirogyra* sp. was investigated [20]. The adsorption features of the bio-sorbent *spirogyra* sp. were investigated as a function of initial pH, initial heavy metal concentration, bio-sorbent dose, contact time and temperature. The results indicated that the biomass of *spirogyra* sp. is an efficient bio-sorbent for the removal of lead from aqueous solutions.

The hexavalent chromium bio-sorption by raw and acid-treated *oedogonium hatei* from aqueous solutions was studied [21]. The optimum conditions of bio-sorption were found to be, a biomass dose of 0.89/l, contact time of 110 min, pH and temperature, 2 and 318 K, respectively.

Chemical treatment of industrial wastewater is preferable since industrial wastewaters are frequently complex, high in pollutant load and often containing toxic or resistant materials to the organisms on which biological processes depend. Also, chemical treatment systems are more predictable and controllable by simple techniques [22].

Wastewater produced from chemical industry is usually contaminated with high organic and inorganic pollutants such as acids, alkalis, organic compounds and matters characterized by high chemical oxygen demand (COD), and low suspended solids. Many materials in the chemical industry are toxic, carcinogenic, mutagenic or simply hardly biodegradable. In chemical industry, the high variability, stringent effluent permits, and extreme operating conditions define the practice of wastewater treatment [23].

Ink industry is one of the most important chemical industries. It generates wastewater containing both organic and inorganic matters in addition to various proportions of non-biodegradable constituents. The elimination of chemicals found in ink industry wastewater is presently of great concern, since their complete biodegradation is usually very slow and requires several days or weeks [24].

The trend towards the use of water-based ink as a substitute for organic solvent-based ink systems has altered both the quality and quantity of wastewater produced. In water-based ink, water is being used for cleaning vessels contrary to the organic solvent-based ink systems. This results in increased quantities of chemicals in the wastewater [25].

The most unacceptable characteristics of ink waste streams include their relatively high pH, high levels of COD, pigments of low biodegradability, the high concentrations of metals, suspended solids and the strong color [26]. The typical metals associated with ink wastewater are aluminum, barium, chromium, copper, iron, lead, zinc and titanium [27]. These metals are found either incorporated in the ink pigment (inorganic pigment) or as trace elements within the ink system. The metals are not in soluble state but are attached to the colloidal particles. Pigment molecules are highly structured polymers that are toxic to micro-organisms [28]. In addition, these ink molecules are designed to withstand harsh conditions and are highly resistant to the effects of chemicals such as acids, alkalis and chlorine [29]. These pigments are therefore resistant to treatment with conventional activated sludge treatment processes. Disposal of these waste streams in an untreated form into the sewer system is, therefore, an unsustainable practice. The removal of pigments using adsorption materials was studied.

There are several treatment technologies have been used for the removal of a large number of organic pollutants including some dyes and phenolic pollutants [30–34]. Also, the removal of an azo-dye, acid orange-7 by adsorption over two waste materials, namely, bottom ash, a power plant waste, and de-oiled soya, byproduct obtained during the processing of soybean in soya oil extraction mills was investigated [35]. Both waste materials showed excellent adsorption abilities and can be treated as low-cost adsorbents. They can be used as promising adsorbents for the removal of metanil yellow from wastewaters and adsorption of the dye over these materials is dependent on pH, sieve sizes, concentration of dye, temperature, etc., [36]. Also, sorption studies using ethyl orange, metanil yellow and acid blue-113 have shown that, inorganic adsorbents are not suitable for the sorption of organics, whereas carbonaceous adsorbent (organic nature) are appropriate. Dye adsorption on a carbonaceous adsorbent is both exothermic and physical in nature; the adsorption process is first-order; and; the carbonaceous adsorbent prepared is about 80% as efficient as standard activated charcoal and thus can be suitable for the removal of toxic substances from effluents. Carbonaceous adsorbent being a low cost material need not be regenerated after being loaded with pollutants and can be disposed of by burning.

The most prevalent treatment system for ink wastes is a combination of chemical additive to destabilize the emulsion and encourage coagulation and flocculation, followed by the physical separation of solids from the bulk liquid by sedimentation, filtration or centrifugation. Lime, alum and ferric chloride are used widely as coagulants in water and wastewater treatment whereas polyelectrolytes are used to increase the dewater ability of sludge [37].

Recently, Fenton oxidation reaction is used for the degradation of organic materials. The efficiency of these systems is based on the production of strong oxidant species, such as hydroxyl radicals, which are able to oxidize almost all organic pollutants. The Fenton reaction has been known since 1894 and is currently one of the most powerful oxidizing reactions available. The reaction involves hydrogen peroxide and a ferrous iron catalyst. The peroxide is broken down into a hydroxide ion and a hydroxyl free radical. The hydroxyl free radical is the primary oxidizing species and can be used to oxidize and break organic molecules. It is well known that organic compounds can be easily oxidized [38]. One primary advantage of the Fenton reaction is that it does not produce further organic compounds or inorganic solids such as permanganate and dichromate since there is no carbon in the peroxide. This makes the Fenton's reaction more appealing than a biological process, if the goal is the removal of organic compounds [39,40].

The main objective of this study is to propose an appropriate treatment technology for wastewater discharged from metal plating and ink production industries located in an Egyptian industrial city, in order to form a general guideline and reference for implementation by production units in subject industries.

2. Material and methods

An ink production factory representing chemical industry and two metal plating factories representing metal industries were selected for this study. The plants are located in Sadat new industrial city which is located between Cairo and Alexandria next to the Delta. The plants discharge their wastewater into the sewerage system of the city. Industrial auditing of subject factories was carried out including; plant activities, industrial processes and environmental status. The audits aimed to identify the main sources of pollution, hence selecting the most appropriate in-plant control measures such as; good housekeeping, pollution prevention, raw materials recovery, wastewater recycling and reuse.

2.1. Wastewater sampling and analysis

Five composite samples from the end-of-pipe of each factory were collected for physico-chemical analysis. The analyses were carried out according to the APHA, 2005 [41] guidelines and covered pH, COD, total suspended solids (TSS), Total kjeldahl nitrogen (TKN) and oil & grease. All heavy metals analyses were performed using an Atomic Absorption Spectrometer (Varian SpectrAA 220) with graphite furnace accessory and equipped with deuterium as background corrector.

2.2. Chemical Treatment

Bench scale chemical coagulation process was carried out using Jar test procedure. This was intended to obtain the pH value and coagulant dosage required for the best removal of the pollutants. Ferrous sulphate aided with lime was chosen as an efficient coagulant for this type of wastewater. An excess dose of ferrous sulphate was added to the wastewater to reduce chromium hexavalent to chromium trivalent followed by addition of lime to reach pH 9. Flash mixing at a speed of 200 rpm for duration of 2 min followed by slow mixing at a speed of 40 rpm for duration of 15 min was applied. The resulting flocs were allowed to settle for one hour. Each experiment was repeated five times for assuring accuracy of results.

2.3. Fenton treatment process

The use of wet hydrogen peroxide catalytic oxidation using Fenton reagent has been investigated. Fenton process was carried out at room temperature. The required amount of H_2O_2 was fed under continuous stirring for a period of four hours. This step was followed by the addition of lime to raise the pH to 9. Lime was added under continuous stirring at a speed of 200 rpm, for duration of 2 min, followed by slow mixing at a speed of 40 rpm, for duration of 20 min, and finally settling for duration of 120 min.

Optimum operating conditions for Fenton process (pH, COD/ H_2O_2, Fe/H_2O_2 & contact time) were determined as follows: the optimal COD/ H_2O_2 was worked out in the sequence: 1:1, 1:0.5 and 1:0.75, while the other three variables were fixed at values taken from previous Fenton studies [28]. The optimal Fe/H_2O_2 was worked out at 1:10, 1:25 and 1:50 using the predetermined optimal COD/ H_2O whereas the two remaining variables were fixed as before (taken from previous Fenton studies). The above steps were repeated in the same order to obtain the optimal pH and contact time.

3. Results and discussion

3.1. Environmental status of the investigated factories

The site survey and state records show a total of 135 factories, operating in Sadat city in five industrial zones. These factories cover metal, textile, paper, plastics, chemical, food, electrical, building & construction and miscellaneous industries. Table 1 shows the number of factories and the quantity of wastewater discharged per day in each industry. Metal and chemical industries were selected for this study as the metal industry produced the maximum quantity of wastewater compared to other industries, whereas the chemical industry was characterized by the highest organic load.

3.2. Case study I: metal plating factories

Two factories representing metal plating were selected for this study. The first factory produces electric distribution panel boards and circuit breakers. The second factory produces artificial limbs and prosthetic devices. The production process of the first factory consists of three process lines; zinc plating, copper plating and electrostatic spray. Circuit breakers undergo either zinc or copper plating followed by rinsing. The panel boards undergo shear, cutting and forming processes followed by welding and finally electrostatic paint spray. The next step is assembling the components with the panel, and then packing.

The production process in the second factory includes cutting of the steel pipes to the specified length then folding, abrasive cleaning, electric welding, polishing then transferring to the plating unit for chromium, copper, nickel plating. Assembly takes place after that, fitting all appurtenances such as; seat, back, upholstery, wheels and breaks then packing the final product.

It was observed that wastewater is produced from rinsing process that follows plating process. The wastewater produced by the first and second factory was 30 and 5 m^3/day, respectively. Therefore, it was found economically feasible, and due to the proximity of the said factors, to combine their produced wastewater in one treatment unit.

Table 1
Number of different factories and quantities of wastewater discharged from each industry in Sadat City.

Industry	Number of factories	Wastewater production (m^3/day)
Metal	27	2096
Textile	11	1490
Paper	4	32
Plastic	14	36
Chemical	16	144
Food	28	925
Electrical	8	101
Building and construction	9	1538
Miscellaneous	18	142

3.2.1. Characterization of wastewater

Analysis of the wastewater from the first and second factory and the mixed sample is presented in Table 2. The results indicated that the first factory wastewater was acidic (pH 2.5–3) and highly contaminated with zinc (30 mg/l). The second factory wastewater carries significant quantities of chromium and nickel, 6 and 5.5 mg/l, respectively. A mixed sample proportional to the quantity of discharge from each factory was prepared in the laboratory for further analysis. Analysis of the mixed sample indicated that the wastewater was acidic and contaminated with heavy metals. The concentration of zinc, chromium and nickel was, 25.8, 4.0 and 2.5 mg/l, respectively.

3.2.2. Treatment using chemical coagulation

Chemical coagulation of the mixed wastewater using ferrous sulphate aided with lime was carried out. To determine the optimum coagulant dose and pH value, series of experiments using the Jar-test procedure were carried out.

Hexavalent chromium was completely reduced to trivalent chromium as shown in Fig. 1 using an excess dosage of 1.5 times the theoretical stoichiometric amount of ferrous sulphate (96 mg/l). This was followed by addition of 330 mg/l of CaO reaching pH 9 to precipitate chromium as chromic hydroxide and the other metals with removal efficiency reached

Table 2
Characteristics of raw and treated wastewater (metal plating factories).

Parameters	Unit	First factory	Second factory	Mixture from both factories	*Treated effluent	**Permissible limits
pH	–	2.5–3.0	6.5–7.0	3.0–3.5	9.0	6–9.5
COD	mgO_2/l	489 (110)	78.7 (15)	420 (100)	220 (52)	1100
TSS	mg/l	118 (36)	52 (15)	109 (25)	4.7 (1)	800
Oil & Grease	mg/l	49.7 (12)	32 (9)	47 (12)	2.0 (0.5)	100
TKN	mgN/l	63.8 (10)	12 (4)	57 (13)	6.4 (1.9)	100
Total Cyanide	mg/l	N.D	N.D	N.D.	N.D	0.2
Copper	mg/l	0.1 (0.01)	0.5 (0.1)	0.2 (0.02)	<0.05	1.5
Chromium	mg/l	0.1 (0.01)	6.0 (1.5)	4.0 (1)	<0.05	0.5
Lead	mg/l	0.1 (0.01)	<0.05	<0.05	<0.05	1.0
Nickel	mg/l	<0.05	5.5 (1.3)	2.5 (0.9)	<0.05	1.0
Zinc	mg/l	30 (9)	0.15 (0.02)	25.8 (5)	< 0.05	2.0

*Average of five samples.
**Permissible limits set by the Egyptian law for Wastewater Discharge into Public Sewerage System. Standard deviations shown between brackets.

98% at pH 9.0 (Table 2 and Fig. 2). Similar observations were achieved by Li-Yang [42] who found that ferrous ion reacts with Cr (VI) rapidly at low pH and in order to obtain a complete reaction, an excess dosage of the theoretical ferrous sulphate was used. Also several authors concluded that precipitation of metals by lime treatment is relatively simple, low cost and ease of pH control, as metals form a series of complexes with hydroxides and other ions, so that the theoretical solubility limit becomes a complex function of pH [2,43–45].

Addition of ferrous sulphate produced Fe ions which precipitated as $Fe(OH)_2$ and $Fe(OH)_3$. Under the alkaline condition of the effluent (pH 9), which formed a lot of sedimentation of hydroxide, colloid granule might be caught or swept by these sedimentation of amorphous coagulation, so there was a good effect to remove chromaticity. Such fact is in agreement with Zhi et al. [46].

3.3. Case study 2: ink production factory

The factory produces water based flexographic ink used for printing different types of craft paper. The production process consists of mixing the organic materials coloring powder with water and some additives to help homogeneity according to a set proportion then packing. The main source of wastewater is the washing process of vessels where mixing ingredients takes place, in addition to floor washing. The quantity of wastewater produced is 10 m^3/day. Management and control of wastewater were investigated by applying two different approaches namely; pollution prevention at the source or treatment of the end-of-pipe wastewater using Fenton oxidation process.

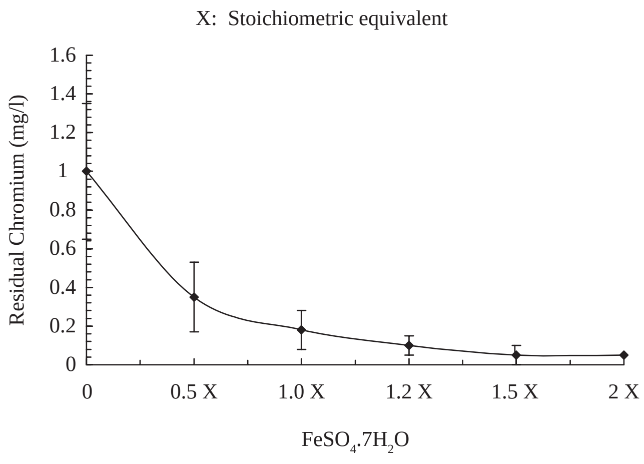

Fig. 1. Effect of ferrous sulfate on chromium reduction (metal plating factories).

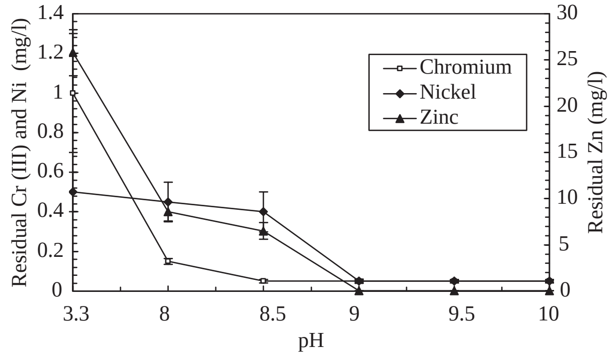

Fig. 2. Effect of pH on metals removal using CaO (metal plating factories).

Table 3
Characteristics of wastewater of ink production factory.

Parameter	Unit	Wastewater	**Permissible limits
pH	–	7.5–8.4	6–9.5
COD	mgO_2/l	30,500 (10,250)	1100
TSS	mg/l	7490 (1520)	800
Oil &grease	mg/l	409 (105)	100
TKN	mgN/l	3280 (1050)	100
CN	mg/l	ND	0.2
Copper	mg/l	22 (7)	1.5
Nickel	mg/l	0.05 (0..01)	1
Chromium	mg/l	0.05 (0.01)	0.5
Lead	mg/l	0.05 (0.01)	1
Zinc	mg/l	0.5 (0.12)	2

* Average of five samples.
** Permissible limits set by the Egyptian law for Wastewater Discharge into Public Sewerage System. Standard deviations shown between brackets.

Comparison between the two alternatives, based on a cost-benefit analysis and compliance with national environmental laws has been elaborated.

3.3.1. Characterization of wastewater

Analysis of wastewater indicated that, the waste was highly contaminated with organic and inorganic pollutants. The characteristics of wastewater in terms of COD, TSS, Oil & grease and copper were 30,500, 7490, 409 and 22 mg/l, respectively (Table 3). The waste has different colors according to the production schedule.

3.3.2. Treatment of end-of-pipe wastewater using Fenton process

Fenton oxidation process has proven to be a promising and attractive treatment method for the degradation of a large number of organic pollutants including some dye pollutants [18,47–49]. However, to achieve high treatment performances, the experimental conditions must be optimized. To accomplish that target, the optimum operating conditions such as pH, Fe:H_2O_2, COD:H_2O_2 and contact time which produce the high quality effluent have been investigated [38,50–52].

Determination of the optimum dose of COD:H_2O_2

To obtain the optimum COD:H_2O_2 ratio, investigations were carried out using different COD:H_2O_2 ratios equivalent to 1:0.5, 1:0.75 and 1:1. At 1:0.5 ratios the COD and turbidity were 1360 mg/l and 12.3 NTU. At 1:0.75 COD:H_2O_2 ratio the COD and turbidity were 1110 mg/l and 9.86 NTU. At 1:1 COD:H_2O_2 ratio the COD and turbidity were 840 mg/l and 6.76 NTU. The results indicated significant enhancement of the COD and turbidity removal at COD:H_2O_2 ratio of 1:1. Therefore the ratio 1:1 COD:H_2O_2 has been selected.

Determination of the optimum dose of Fe:H_2O_2 ratio

To obtain the optimum (Fe) dose, investigations were carried out using different Fe:H_2O_2 molar ratios equivalent to 1:10, 1:25 and 1:50. The results presented in Fig. 3(a) and (b) indicated a slight improvement in the quality of the wastewater produced at Fe:H_2O_2 ratio of 1:50. At molar ratios equivalent to 1:10, 1:25 and 1:50 Fe:H_2O_2, the sludge weight (at 105^{o}C) was 5.6, 4.8 and 3.3 gm/l, respectively. Therefore, the ratio of 1:50 for Fe:H_2O_2 has been selected.

Determination of the optimum pH

The experiment was carried out at different pH values (3, 5 and 9) to select the optimum pH value. COD:H_2O_2 and Fe:H_2O_2 ratios were kept constant at 1:1 and 1:50 while the contact time was 4 h. The results showed that the performance at pH value of 3 was the highest compared to the performance at pH values of 9 and 5 as shown in Fig. 4.

Determination of the optimum contact time

Different contact times ranging from 1 to 4 h were investigated. The ratios of COD:H_2O_2 and Fe:H_2O_2 were kept constant at 1:1 and 1:50, respectively at pH 3. Fig. 5 shows that the optimum contact time was 4 h.

Efficiency of Fenton treatment process

The wastewater was treated at the pre-determined optimum operating conditions of: COD:H_2O_2 = 1:1, Fe:H_2O_2 = 1:50, contact time = 4 h, pH = 3 and

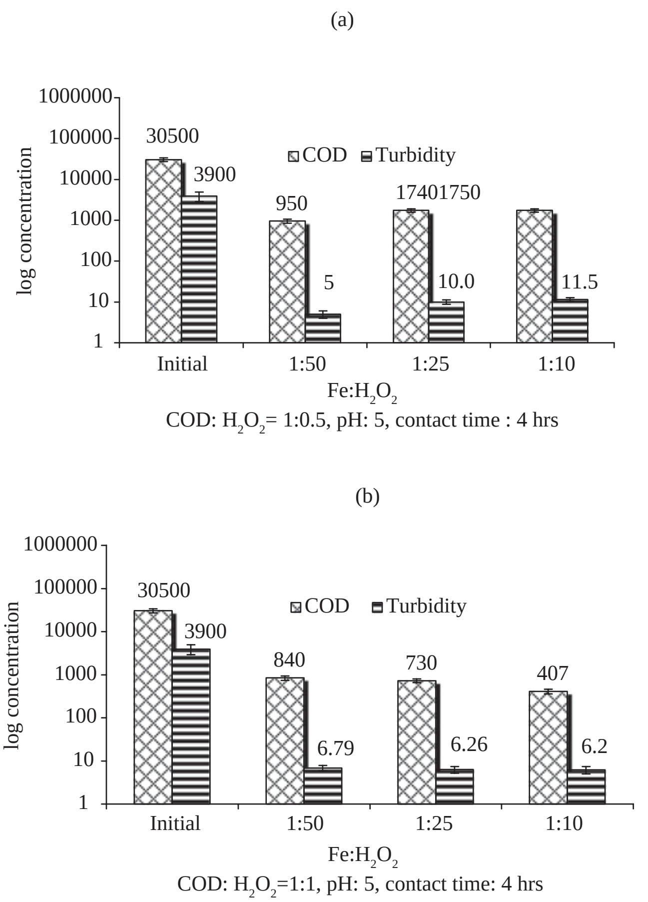

Fig. 3. (a, b). Effect of different Fe:H_2O_2 ratios on the Fenton treatment efficiency.

$CaO = 75$ g/l. The results presented in Fig. 6 show that the quality of treated effluent is quite satisfactory. The concentration of COD, BOD, TN and TSS was reduced from 30,500, 11,483, 3280 and 7490 to 740, 420, 126 and 142 mg/l, respectively. The corresponding removal efficiency was calculated as 97.6%, 96.4%, 96.2% and 98.1%, respectively. The concentration of copper was greatly reduced from 22 to 0.1 mg/l with removal efficiency of 99.55%. Characteristics of the treated effluent were complying with the permissible limits for wastewater discharge into public sewage network. Residual COD, TSS, total nitrogen, oil & grease and copper were 850 mgO_2/l, 85 mg/l, 48 mg/l, 35 mg/l and 0.1 mg/l, respectively.

3.3.3. *Implementation of pollution prevention measures*

Pollution prevention represents a recommended practice for industrial cities as a strategy for curbing environmental degradation in the face of rapid industrial growth. This potential is demonstrated in the chemical sector in the industrial city under study, where

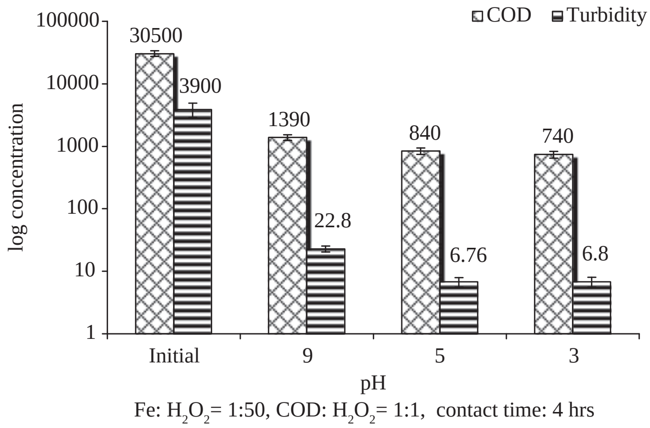

Fig. 4. Effect of different pH values on the Fenton treatment efficiency.

some firms strictly adhere to implementing pollution prevention measures, yielding increased profits and significant cutbacks in pollution.

Extensive progress has been made in improving a chemical process which enables meeting new standards for decreasing the amount and reducing

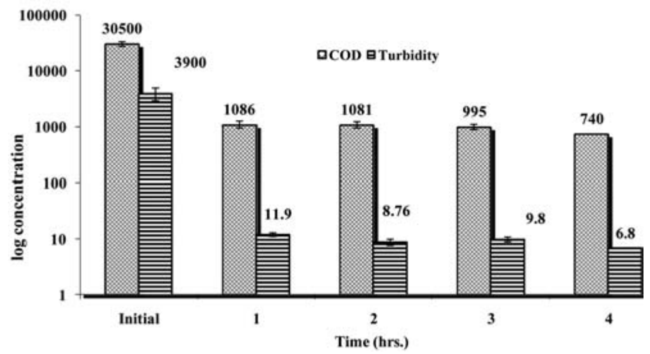

Fig. 5. Effect of different contact time on the Fenton treatment efficiency.

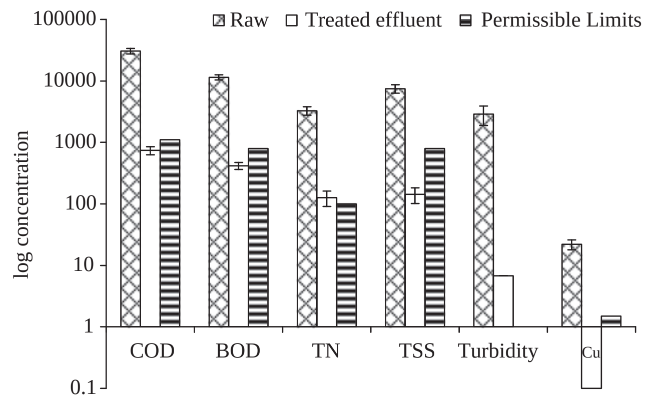

Fig. 6. Efficiency of Fenton process on the treatment of ink wastewater.

Table 4
Cost-benefit analyses of Fenton wastewater treatment unit versus pollution control measures.

Pollution control measures			End of pipe treatment using Fenton process		
	Cost L.E	Benefits L.E		Cost L.E	Benefits L.E
1. Reuse of rinsing water in producing black ink		240,000/year	Wastewater treatment unit		
– construction of two collection unit	8000		– construction of the treatment unit	10,000	-
– operation and maintenance	6000/year				
2. Modification of floor cleaning (Dry cleaning)	8000		– Running cost of the treatment unit	3,00,000/year	
3. Recovery of spent powder	10,000	10,000/ year	– Operation and maintenance	6500/year	-

pollution load of wastewater that may discharge. Increased costs of discharges have cut profit margins and have forced industries to search for new ways to reduce wastewater effluent.

As shown in Table 4 the capital and running cost analysis of the industrial wastewater treatment plant using Fenton oxidation process are quite expensive. Therefore, the study was directed towards pollution prevention at source rather than end-of-pipe treatment. Solution was documented by cost benefit analysis. The corrective action relied on application of three pollution prevention measures. Firstly, reuse of washing water of process vessels. This water was recycled to be used in manufacturing processes of water based flexographic black ink (120 Ton/year) since it contains product and water. Field experiments proved that the quality of the product was not affected by this application. This returns income of LE 1,200,000/year which gives a profit margin of LE 240,000/year. Secondly, good housekeeping via converting the wet washing process of the floor to dry cleaning. This significantly reduced the organic load in the final effluent. Thirdly, recovery of spent powder, through covering the drain channels with suitable cloth to prevent its contamination with poured raw materials, which spread over the floor and in the water channels in the manufacturing plant. This process enables the recovery of poured raw materials for reuse. The application of the above pollution control method lead to prevention of industrial wastewater discharge and only municipal wastewater was discharged. A summary of the cost benefit analysis of the applied solutions is shown in Table 4.

4. Conclusion

In metal plating industries chemical treatment of wastewater that contains high concentration of chromium using excess dose of ferrous sulphate aided with lime has proven to be effective. Chemical treatment of the ink production wastewater using Fenton oxidation produces an effluent in compliance with the national environmental laws; however it is regarded to be costly. The pollution control at source in the ink production industry has proven to be an economic and effective solution. It relies on application of pollution prevention measures, a proactive approach that produces an acceptable effluent to the national environmental regulations. As such and in view of the cost incurred with application of Fenton process in the ink production industry, the only viable system in this case is the application of pollution control measures at source.

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