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Chemical industry wastewater treatment

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Abstract Treatment of chemical industrial wastewater from building and construction chemicals factory and plastic shoes manufacturing factory was investigated. The two factories discharge their wastewater into the public sewerage network. The results showed the wastewater discharged from the building and construction chemicals factory was highly contaminated with organic compounds. The average values of chemical oxygen demand (COD) and biochemical oxygen demand (BOD) were 2912 and 150 mgO_2/l. Phenol concentration up to 0.3 mg/l was detected. Chemical treatment using lime aided with ferric chloride proved to be effective and produced an effluent characteristics in compliance with Egyptian permissible limits. With respect to the other factory, industrial wastewater was mixed with domestic wastewater in order to lower the organic load. The COD, BOD values after mixing reached 5239 and 2615 mgO_2/l. The average concentration of phenol was 0.5 mg/l. Biological treatment using activated sludge or rotating biological contactor (RBC) proved to be an effective treatment system in terms of producing an effluent characteristic within the permissible limits set by the law. Therefore, the characteristics of chemical industrial wastewater determine which treatment system to utilize. Based on laboratory results engineering design of each treatment system was developed and cost estimate prepared.

Keywords Biological · Chemical · Chemical industry · Treatment · Wastewater

1 Introduction

The chemical industry is of importance in terms of its impact on the environment. The wastewaters from this industry are generally highly concentrated with organic

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and inorganic pollutants and may contain toxic pollutants. Chemical industrial wastewaters usually contain organic and inorganic matter in varying concentrations. Many materials in the chemical industry are toxic, mutagenic, carcinogenic or simply almost non-biodegradable. Surfactants, emulsifiers and petroleum hydrocarbons that are being used in chemical industry reduce performance efficiency of many treatment unit operations (EPA, Wastewater Treatment Technologies, 1998) The best strategy for toxic industrial wastewater is in general to segregate at the source (Peringer, 1997) and sometimes by applying onsite treatment within the production lines with recycling of treated effluent (Hu et al., 1999).

In the chemical industry, the high variability, stringent effluent permits, and extreme operating conditions define the practice of wastewater treatment (Bury et al., 2002). Hu et al. (1999) proposed the concept to select the appropriate treatment process for chemical industrial wastewater based on molecular size and biodegradability of the pollutants. Chemical industrial wastewater can be treated by some biological oxidation methods such as trickling filters, rotating biological contactor (RBC), activated sludge, or lagoons (Nemerow and Dasgupta, 1991; Jobbagy et al., 2000). Pollutants with molecular sizes larger than 10,000–20,000, can be treated by coagulation followed by sedimentation or flotation (Hu et al., 1999).

Waste minimization in the production process in the chemical industry is the first and most important step to avoid waste formation during production (Carini, 1999; Alverez et al., 2004). Because of the fluctuation in the strength and flow rate, Bury et al. (2002) applied dynamic simulation to chemical-industry wastewater treatment to manage and control the treatment plant.

The main objective of the present study was to evaluate the use of alternative methods for the treatment of chemical industry wastewater.

2 Materials and methods

For this study two factories represent the chemical industry discharging their wastewater into the sewerage system were selected (Table 1). Composite samples from the different departments and the final effluents were collected. Physicochemical analyses were carried out according to the (APHA, 1998). Laboratory experiments have been carried out to recommend the appropriate treatment. Chemical coagulation precipitation and biological treatment via aerobic systems were investigated.

Table 1 Basic information about the selected factories

Item	Building and construction chemicals	Plastic shoes manufacturing
Product	Special building chemicals	Plastic shoes
No. of employee	100	150
Working shifts	1	2
Working hours	8	16
Water consumption m^3/d	20–25	7
Water discharge m^3/d	11–15	6
Point of discharge	Public sewerage system	Public sewerage system

Table 2 Specification of the continuous chemical treatment unit

Item	Unit	Flash mixing	Flocculation Tank	Sedimentation
Dimension	cm	10 × 7× 5	15 × 10 × 30	40 × 15 × 25
Volume	cm^3	350	4500	15000
Flow rate	liter/hour	5	5	5
Detention time	minute	4.2	54	180

2.1 Chemical treatment

Chemical treatment was applied using lime aided with ferric chloride and lime aided with aluminum sulfate. The optimum pH and coagulant dose values, which gave the best removal, were determined using a jar test procedure. A continuous chemical treatment unit (Abou-Elela et al., 1995) was operated at the optimum pH and coagulant dose. A schematic diagram and specification of the treatment unit are given in Table 2 and Fig. 1.

2.2 Biological treatment

Biological treatment via activated sludge and RBC was carried out.

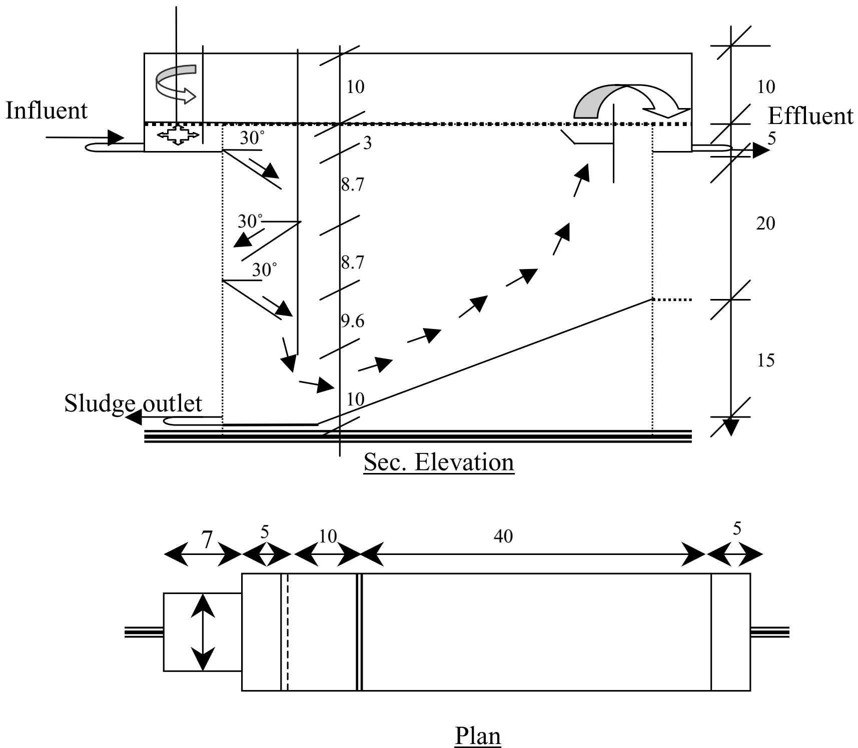

Fig. 1 Schematic diagram of continuous chemical treatment unit

2.2.1 Activated sludge treatment unit

Batch laboratory experiments were carried out using activated sludge process. Two liters Plexiglas laboratory columns were used. The wastewater was inoculated with activated sludge from plant treating domestic sewage. Daily the aeration was stopped to let the sludge settle then the supernatant was drained and the column was refilled again with the wastewater till considerable amount of adapted sludge was produced. To study the effect of aeration period on the activated sludge, several experiments were conducted. A fixed amount of sludge (3–4 g/l) was transferred to a different column to which the pretreated wastewater was added. A detention time ranging from one hour to twenty-four hours was examined. Dissolved oxygen concentration was adjusted to maintain a minimum concentration of 2 mgO_2/l. Characterization of the treated wastewater was carried out after 60 min settlement; sludge analysis was also carried out.

2.2.2 Rotating biological contactor (RBC) unit

The aerobic unit was based on bio-film reactor followed by sedimentation tank, Fig. 2 (Watanabe et al., 1995; Badr, 1988). Table 3 represents the geometric data of the experimental RBC system.

3 Results and discussion

3.1 Case study 1: Building and construction chemicals factory

The factory produces special building chemicals; concrete add mixture, painting and coating materials and bitumen emulsion. The factory produces 11–15 m^3/d of wastewater. Analysis of the end-of-pipe showed that the wastewater was highly contaminated with non-biodegradable and toxic organic matter. This is obvious from the average values of BOD (150 mgO_2/l) and COD (2912 mgO_2/l), (Table 4). The BOD/COD ratio was 6% in average. The analysis detected the presence of phenol with a concentration reaches 0.3 mg/l. The oil & grease ranged between 149 and 600 mg/l with an average value of 371 mg/l. Average value of total suspended solids concentration was 200 mg/l.

Table 3 Geometric data of the experimental RBC

• No. of stages	4
• Arrangement of discs	4×8
• Disc diameter (cm)	14
• Total discs surface area (m^2)	0.95
• Basin's volume in liters	5.19
• % submersion	50%
• Specific surface area (m^2/m^3)	183
• Rotation speed, (rpm)	4
• Hydraulic load (m^3/m^2/d)	0.107

Table 4 Characteristics of wastewater from the end-of-pipe (Building and construction chemicals factory)

Parameters	Units	Min.	Max.	Average	Egyptian decree 44 for 2000
pH		6.1	9.5	7.5	6–9.5
Chemical Oxygen demand	mg O_2/l	1870	3924	2912	1100
Biological Oxygen Demand	mg O_2/l	210	570	150	600
Total suspended solids	mg/l	157	519	200	800
Phosphorous	mg P/l	0.8	30	9	25
Organic Nitrogen	mg N_2/l	9	25	19	100
Phenols	mg/l	0.06	0.3	0.1	0.05
Oil & Grease	mg/l	149	600	371	100

*Average of 7 samples.

3.1.1 Biological treatment

Biological treatment of the end-of-pipe wastewater using activated sludge was carried out. Analysis of the wastewater indicated deficiency in the nitrogen and phosphorous concentration. Nitrogen and phosphorous salts were added to adjust their concentration to meet requirements of the biomass in the biological treatment unit. Characteristics of the treated effluent did not comply with the permissible limits. This result attributed to the low biodegradability as indicated by the BOD/COD ratio, which provide 6% only.

3.1.2 Chemical treatment

Chemical treatment using lime aided with ferric chloride and lime aided with aluminum sulfate was carried out on a bench scale, first to get the best coagulant and the optimum dose and pH then, a continuous system was used.

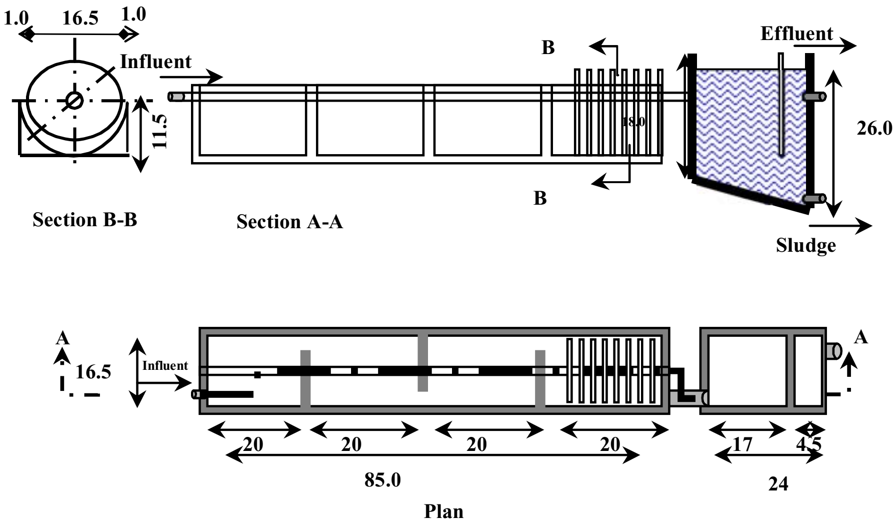

Fig. 2 Schematic diagram of the RBC unit

Table 5 Average results of the chemical treatment using different coagulant (Building and construction chemical factory)

Item	Raw	Lime with ferric chloride	% R	Lime with aluminum sulfate	% R	Egyptian decree 44 for 2000
pH	7.2	8.0		6.5		6–9.5
Chemical oxygen demand (mg O_2/l)	3900	113	94	417	98	1100
Total suspended solids (mg/l)	440	80	81	75	83	800
Oil & grease (mg/l)	625	52	91	82	87	100
Sludge analysis						
Sludge volume (ml/l)		100		150		
Sludge weight (g/l)		3.8		2		
Sludge volume Index		26.3		75		

∗Average of 5 samples.

3.1.2.1 Bench scale chemical treatment. Table 5 shows the results of the chemical coagulation–sedimentation of the end-of-pipe using lime aided with ferric chloride and lime aided with aluminum sulfate. The optimum doses for lime aided with ferric chloride were 700 mg of lime and 600 mg of ferric chloride for each liter while the doses in case of lime aided with aluminum sulfate were 300 and 1000 mg per liter for lime and aluminum sulfate respectively. Significant removal of COD, TSS and Oil & Grease were achieved. The removal efficiency of COD, TSS and Oil & Grease were 94%, 81% and 91%, respectively using lime aided with ferric chloride. The settling properties of the sludge in case of lime aided with ferric chloride were better than in case of lime aided with aluminum sulfate.

3.1.2.2 Continuous chemical treatment. Based on the bench scale results the wastewater was chemically treated with Lime aided with ferric chloride using continuous system. The specification of the treatment unit is listed in Table 2. The characteristics of finally treated effluent were compatible with legislation for discharging in public sewer system (Table 6).

3.1.2.3 Design and economic study of the treatment system. Based on the laboratory results a final chemical treatment process design was developed (Fig. 3). Cost estimate of the treatment system indicated that the construction cost in the Egyptian pound is LE 211000 ($ 37017), while the running cost is LE 70200 ($ 12315), (Table 7).

3.2 Case study 2: Plastic shoes manufacturing factory

The second case study involved wastewater discharged from plastic shoes manufacturing factory. The manufacturing process involves raw material (polymers) melting unit, forming the pattern in special moulds transfer the shoes to paint unit where it is sprayed with special dyes and solvents. A field survey indicated that the major source of pollution was the painting department. Wastewater discharged from the painting department was characterized by the high contents of organic compounds (Table 8). The mean values of the chemical oxygen demand and the biological oxygen

Table 6 Characteristics of the chemically treated wastewater (Building and construction chemical factory)

Parameters	Units	Raw	Treated effluent	Egyptian decree 44 for 2000
pH		7.3	7.7	6–9.5
Chemical Oxygen demand	mg O_2/l	3494	229	1100
Biological Oxygen demand	mg O_2/l	642	76	600
Total suspended solids	mg /l	248	51	800
Phosphorous	mg P/l	4	1	25
Organic Nitrogen	mg N_2/l	18	7	100
Phenols	mg/l	0.2	0.02	0.05
Oil & Grease	mg /l	600	86	100
Sludge Analysis				
Sludge volume	ml/l		240	
Sludge weight	mg/l		9.2	
Sludge volume index			26.6	

*Average of 6 samples.

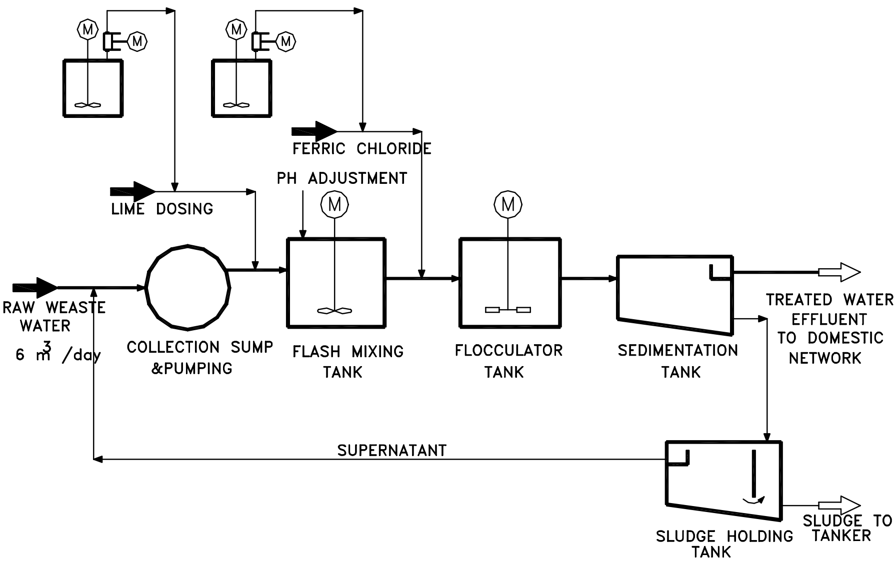

Fig. 3 Schematic diagram of the chemical treatment system (Building and construction chemicals factory)

demand were 15441 and 7776 mg O_2/l, respectively. The average phenol concentration was 0.93 mg/l. Thus the industrial wastewater was mixed with the domestic wastewater at ratio of 1 to 3 (based on the rational amounts of sewage and industrial wastewater discharged in the factory) to achieve an end-of-pipe effluent of lower organic load. Also, addition of domestic wastewater compensates deficiency of nitrogen and phosphorous concentration in the industrial wastewater. Meric et al. (1999) recommended biological treatment for such kind of wastewater regarding dilution requirements and nitrogen and phosphorus supplement. The average values of COD and BOD of the final effluent of the factory after mixing were 5239 and 2615 mgO_2/l,

Table 7 Dimension and cost estimate of the chemical treatment system (Building and construction chemicals factory)

Treatment unit	L (m)	H (m)	W (m)	D (m)	V (m^3)	Cost in L.E
Construction cost						
1. Civil Works (More or less depends on soil conditions)						30,000
2. Treatment units						
• Collection Sump		1.75		1.4	1.875	10,000
1. Flash mixing Tank	0.45	1.25	0.45		0.156	5,500
2. Flocculation Tank	1.7	1.5	0.8		1.718	12,500
3. Sedimentation tanks	2.5	2.5	1.0		5.625	15,000
4. Sludge Tank	1.5	1.5	1.5		2.7	28,000
5. Chemical System						70,000
6. Pipes and valves for all plant						10,000
3. Electrical works						30,000
Total Cost						211,000
Running Cost/year						
• Maintenance works						14,000
• Operation cost						44,000
• Chemical consumption						12,200
Total running cost						70,200

Table 8 Characteristics of the wastewater discharged from plastic shoes manufacturing factory

		Painting department			Final effluent			Egyptian decree 44
Parameters	Unit	Min.	Max.	Avg.	Min.	Max.	Avg.	for 2000
pH		5.6	7.6	6.5	6.8	7.8	7.2	6–9.5
Chemical Oxygen demand	mg O_2/l	10254	20490	15441	2124	6775	5239	1100
Biological Oxygen demand	mg O_2/l	5780	10500	7776	1050	3524	2615	600
Total suspended solids	mg/l	830	1920	1431	192	1054	506	800
Phosphorous	mg P/l	2	18	6	12.8	20	15.5	25
Organic Nitrogen	mg N_2/l	79	598	338	17.2	210	92	100
Phenols	mg/l	0.6	1.2	0.93	0.12	1.3	0.5	0.05
Oil & Grease	mg /l	126	571	377	28	543	218	100

*Average of 7 samples.

respectively (Table 8), which still exceeds the discharging limits into the sewer system.

3.2.1 Chemical treatment

Chemical treatment of the final effluent was carried out using lime in combination with ferric chloride and Lime with aluminum sulfate; however the characteristics of the treated effluent still did not comply with the permissible limits set by the Egyptian Law. These results are in agreement with (Meric et al., 1999) who mentioned that methods such as coagulation, flotation, were not applicable for high concentrated wastewater from polyester manufacturing industry due to the soluble nature of the pollutants.

Table 9 Characteristics of the treated wastewater using activated sludge (Plastic shoes manufacturing factory)*

Parameters	Unit	Raw	Initial	1 (hour)	2 (hour)	3 (hour)	4 (hour)	24 (hour)	Egyptian decree 44 for 2000
COD	mgO_2/l	5239	4820	2358	1467	1048	629	376	1100
Removal	%		8	55	72	80	88	93	
BOD	mgO_2/l	2615	2354	1046	837	628	392	131	600
Removal			10	60	68	76	85	95	
TSS	mg/l	608	535	219	201	182	72	12	800
Removal			12	64	67	70	88	98	
Total Organic Nitrogen	mgN_2/l	181					42	15	100
Total phosphorous	mgP/l	7.2					2.5	1.3	25
Phenols	mg/l	0.4					0.03	N.D	0.05
Oil and Grease	mg/l	231					72	26	100
Sludge analysis									
Sludge volume	ml/l		350				320	270	
Total sludge weight	g/l		4.1				3.5	2.9	
Sludge volume index			85				91	93	

*Average of 3 times.

3.2.2 Biological treatment

Aerobic biological treatment using activated sludge and RBC was carried out.

3.2.2.1 Activated sludge treatment unit. The reactor was fed with the end-of-pipe wastewater and operated at a detention time ranging from one hour to twenty-four hours using a MLSS of 3 g/l. Analysis of the treated effluent indicated that the highest BOD removal was achieved at a retention time of 24 h (Table 9). Average residual values of COD, BOD, TSS and Oil and Grease were 376 mgO_2/l, 131 mgO_2/l, 12 mg/l and 26 mg/l, respectively. These values are in agreement with the standards set by the Egyptian law for discharging treated wastewater into the sewerage system.

Table 10 Characteristics of the treated wastewater using RBC (Plastic shoes manufacturing factory)*

Parameters	Unit	Raw	Treated	% Removal	Egyptian decree 44 for 2000
PH		7.2	7.0	–	6–9.5
Chemical Oxygen demand	mg O_2/l	5239	474	90	1100
Biological Oxygen demand	mg O_2/l	2615	277	89	600
Total organic nitrogen	mg N_2/l	181	81	56	100
Total phosphorous	mg P/l	7.2	3	57	25
Total suspended solids	mg /l	608	76	88	800
Phenol	mg /l	0.4	0.02	95	0.05
Oil & Grease	mg/l	231	16	93	100

*Average of 7 samples.

3.2.2.2 Rotating biological contactor unit. The RBC was fed continuously with the final effluent with an organic load of 7.8 kgBOD/m^3.d for 4 months. The results in Table 10 and Fig. 4, showed that the average COD and BOD concentration values of the treated effluent were 474 mgO_2/l and 277 mgO_2/l, respectively. The average residual value of the suspended solids was 76 with a removal value 88%. The oil and

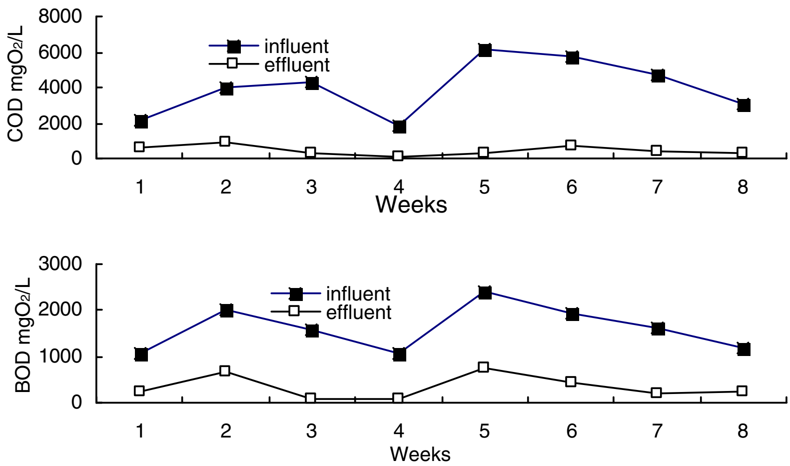

Fig. 4 Characteristics of the treated wastewater using RBC (Plastic shoes manufacturing factory)

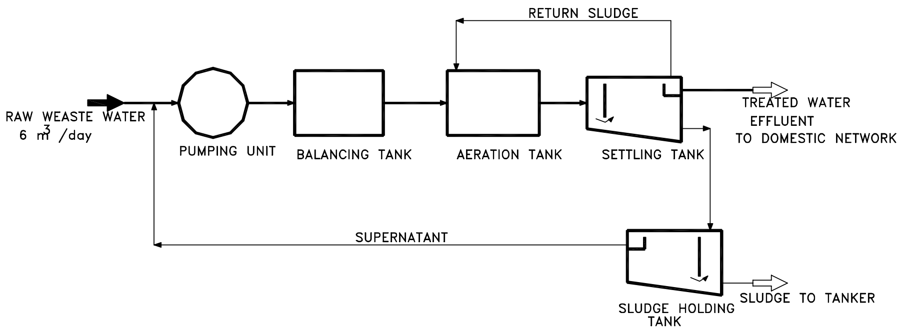

Fig. 5 Schematic diagram of the activated sludge treatment system (Plastic shoes manufacturing factory)

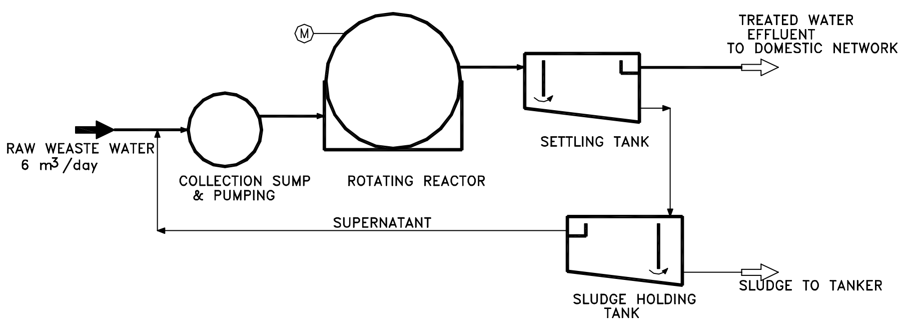

Fig. 6 Schematic diagram of the rotating biological contactor system (Plastic shoes manufacturing factory)

grease percentage removal was 93% with a residual value of 16 mg/l. Characteristics of the treated effluent using the RBC were within the permissible limits. These results are in agreement with (Hu et al., 1999) who reported that pollutants with a high biodegradability, i.e., a high value of BOD/COD ratio, could be effectively treated using biological treatment process.

3.2.2.3 Design and economic study of the treatment system. Based on the laboratory results a final biological treatment process design via activated sludge or RBC was

Table 11 Dimensions and cost estimate of activated sludge system (Plastic shoes manufacturing)

Treatment unit	L (m)	H (m)	W (m)	D (m)	V (m^3)	Cost in L.E
Construction cost						
1. Civil Works (More or less depends on soil conditions)						40,000
2. Treatment units						
• Collection Sump		1.0		1.0	0.2	8,000
• Balance tank	0.9	1.5	0.9		1.0	11,000
• Aeration tank	3.2	2.5	1.25		4.0	150,000
• Sedimentation tanks	0.85	2.0	0.85		1.0	12,000
• Sludge holding tank	1.8	1.5	1.8		3.99	12,000
• Pipes and valves for all plant						10,000
• Measuring and control instruments						30,000
3. Electrical works						40,000
Total Cost						313,000
Running Cost/year						
• Maintenance works						17,500
• Operation cost						96,000
Total running cost/year						113,500

Table 12 Dimensions and cost estimate of rotating biological contactor (Plastic shoes manufacturing factory)

Treatment unit	L (m)	H (m)	W (m)	D (m)	V (m^3)	Cost in L.E
Construction cost						
1. Civil Works (More or less depends on soil conditions)						55,000
2. Treatment units						
• Collection Sump		1.0		1.0	0.2	8,000
• Balance tank	0.9	1.5	0.9		1.0	11,000
• Rotary reactor	8.0			1.4	3.0	130,000
• Sedimentation tanks	0.85	2.0	0.85		1.0	12,000
• Sludge holding tank	1.8	1.5	1.8		3.8	12,000
• Pipes and valves for all plant						10,000
• Measuring and control instruments						30,000
3. Electrical works						40,000
Total Cost						308,000
Running Cost/year						
• Maintenance works						12,500
• Operation cost						48,000
Total running cost/year						60,500

developed (Figs. 5 and 6). Cost estimate for the activated sludge indicated that the construction system is LE 313000 ($ 54912), while the running cost is LE 113500 ($ 19912), (Table 11). The construction cost of the RBC is LE 308000 ($ 54035), while the running cost is LE 60500 ($ 10614), (Table 12). The RBC system is recommended because of the management and operation of the system is easier and technically feasible by the low-skilled personnel.

4 Conclusion

- Characteristics of chemical industrial wastewater determine the adequate treatment system, specifically, solubility, toxicity and biodegradability of the pollutants.
- In the chemical treatment process of wastewater the bench scale is important before going onwards to the continuous system.
- Dilution of chemical industrial wastewaters using domestic sewage in the factory effectively decreases the concentration and toxicity of the pollutants and is cost effective since no chemical salts are required to provide nutrients in the biological treatment system.
- The rotating biological contactor is a simple in operation and management and highly effective system.

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