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 COD and 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.
Key words: chemical industry, wastewater, treatment, chemical, biological

Introduction

The chemical industry is of importance in terms of its impact on the environment. The wastewaters from this industry are generally strong and may contain toxic pollutants.

Chemical industrial wastes usually contain organic and inorganic matter in varying degrees of concentration. It contains acids, bases, toxic materials, and matter high in biological oxygen demand, color, and low in suspended solids. Many materials in the chemical industry are toxic, mutagenic, carcinogenic or simply hardly biodegradable. Surfactants, emulsifiers and petroleum hydrocarbons that are being used in chemical industry reduce performance efficiency of many treatment unit operations (EPA, 1998). The best strategy to clean highly contaminated and toxic industrial wastewater is in general to treat them at the source (Peringer, 1997) and sometimes by applying onsite treatment within the production lines with recycling of treated effluent (Hu et al., 1999). Since these wastes differ from domestic sewage in general characteristics, pretreatment is required to produce an equivalent effluent (Meric et al., 1999).

In 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 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 a molecular size 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 chemical industry is the first and most important step to avoid waste formation during the production (Carini, 1999; Alvarez 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.

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

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-Ella *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 Figure 1.

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

Biological Treatment

Biological treatment via activated sludge and rotating biological contactor was carried out.

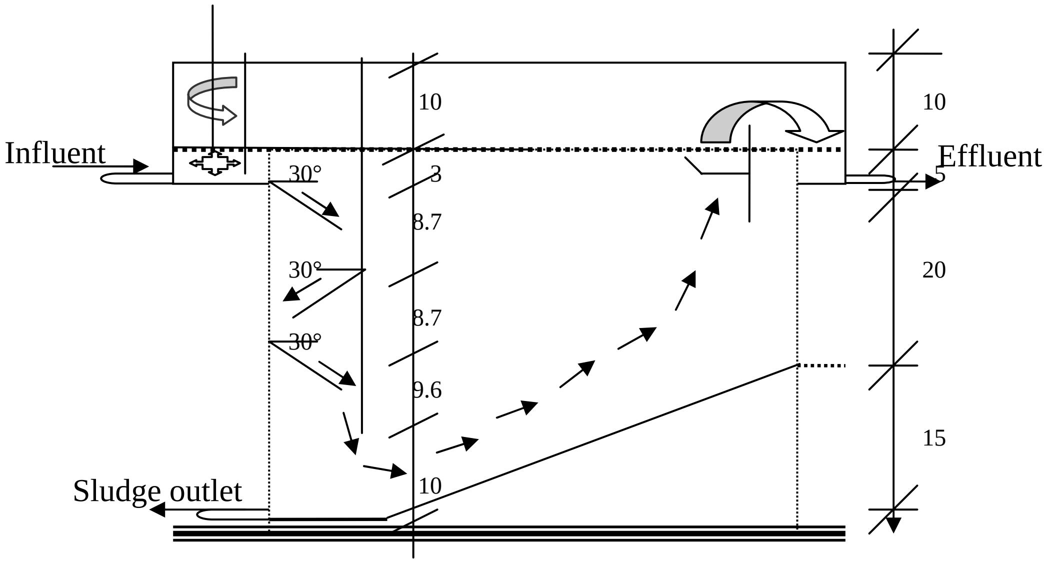
Activated Sludge Treatment Unit

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 minutes settlement, sludge analysis was also carried out.

Rotating Biological contactor (RBC) Unit

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



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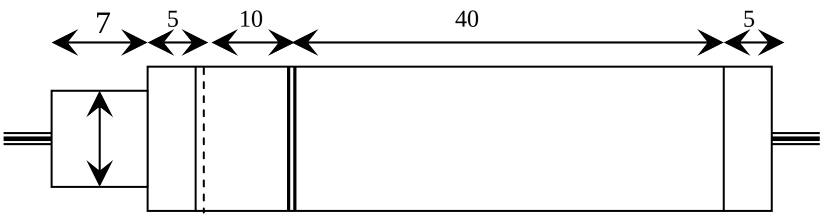

Plan

Figure (1) Schematic Diagram of Continuous Chemical Treatment unit

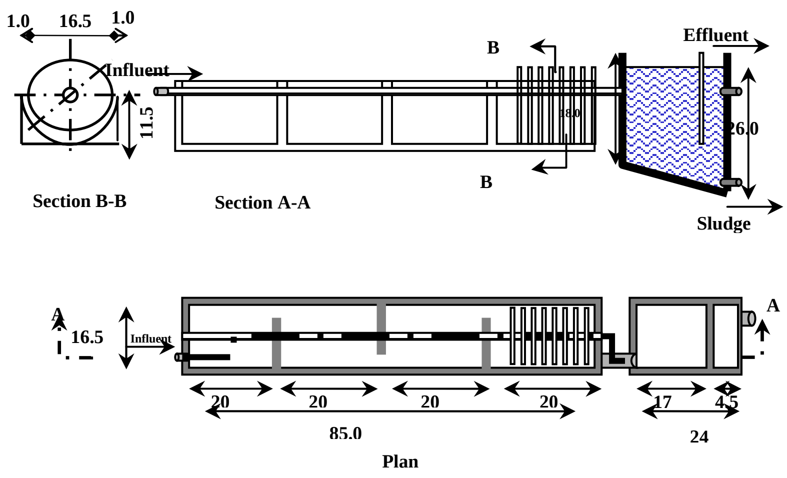

Figure (2) Schematic Diagram of the RBC Unit

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

Results and Discussion

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.

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 suffice for biological treatment. Characteristics of the treated effluent did not comply with the permissible limits.

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.

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

Parameters	Units	Min.	Max.	Average	Permissible Limits
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*

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. 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.

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).

Table (5) Average results of the chemical treatment using different coagulant

(Building and construction chemical factory)

Coagulant / Parameters	units	Raw	Lime + Ferric chloride		Lime + Aluminum sulfate		Permissible Limits
Dose	mg/l		700+600	%R	300+1000	%R	
Ph		7.2	11.5+8.0		9+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*

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

Parameters	Units	Raw	Treated Effluent	Egyptian permissible limits
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***

Design and Economic Study of the Treatment System

Based on the laboratory results a final chemical treatment process design was developed (Figure 3). Cost estimate of the treatment system indicated that the construction cost is LE 211000, while the running cost is LE 70200, (Table 7).

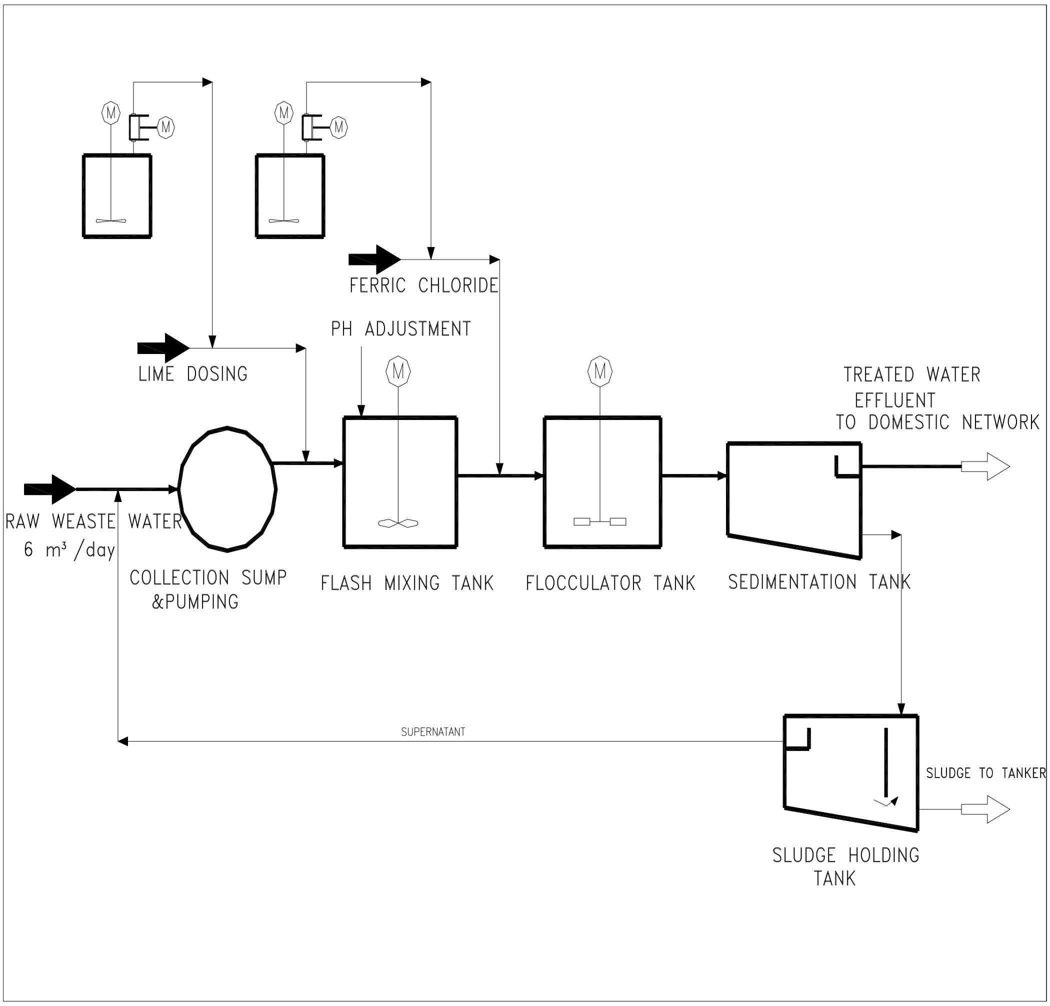

Figure (3) Schematic Diagram of the chemical treatment system

(Building and construction chemicals factory)

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 les depends on soil conditions)						30,000
2. Treatment units						
❑ Collection Sump		1.75		1.4	1.875	10,000
❑ Flash mixing Tank	0.45	1.25	0.45		0.156	5,500
❑ Flocculation Tank	1.7	1.5	0.8		1.718	12,500
❑ Sedimentation tanks	2.5	2.5	1.0		5.625	15,000
❑ Sludge Tank	1.5	1.5	1.5		2.7	28,000
❑ Chemical System						70,000
❑ 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

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 demand were 15441 and 7776 mg O_2/l, respectively. The average phenol concentration was 0.93mg/l. Thus the domestic wastewater was mixed with the industrial wastewater 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 respectively (Table 8) which still exceeds the discharging limits into the sewer system.

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 strong wastewater from polyester manufacturing industry due to the soluble nature of the pollutants.

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

Parameters	unit	Painting dept.			Final Eff.			Egyptian permissible limits
		Min.	Max.	Avg.	Min.	Max.	Avg.	
pH		5.6	7.6	6.5	6.8	7.8	7.2	6-9.5
Chemical Oxygen demand	mg O_2/l	102 54	204 90	154 41	212 4	677 5	523 9	1100
Biological Oxygen demand	mg O_2/l	578 0	105 00	777 6	105 0	352 4	261 5	600
Total suspended solids	mg /l	830	192 0	143 1	192	105 4	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

Biological Treatment

Aerobic biological treatment using activated sludge and RBC were carried out

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 hours (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 (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	Permissible Limits
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 (SVI)		85		91	93

Rotating biological contactor unit

The RBC was fed continuously with the final effluent with an organic load of 7.8kgBOD/m^3.d for 4 months. The results in Table 10 and Figure 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 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, can be effectively treated using biological treatment process

Table (10) Characteristics of the treated wastewater using RBC

(Plastic shoes manufacturing factory).

Parameters	unit	Raw wastewater	RBC		permissible limits
				% R	
PH		7.2	7.0		6-9.5
Chemical Oxygen demand	mg O_2/l	5239	474	90	1100
Biological Oxygen	mg	2615	277	89	600

demand	O_2/l				
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

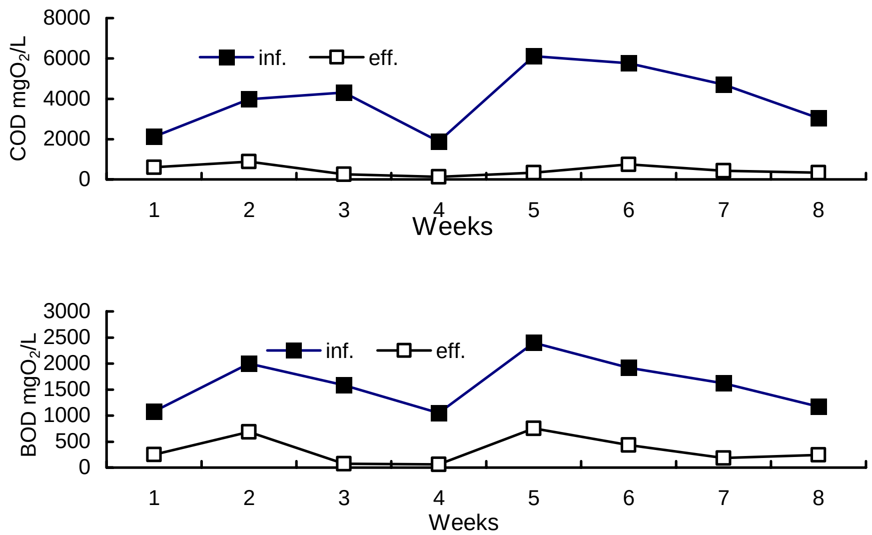

Figure (4) Characteristics of the treated wastewater using RBC
(Plastic shoes manufacturing factory)

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

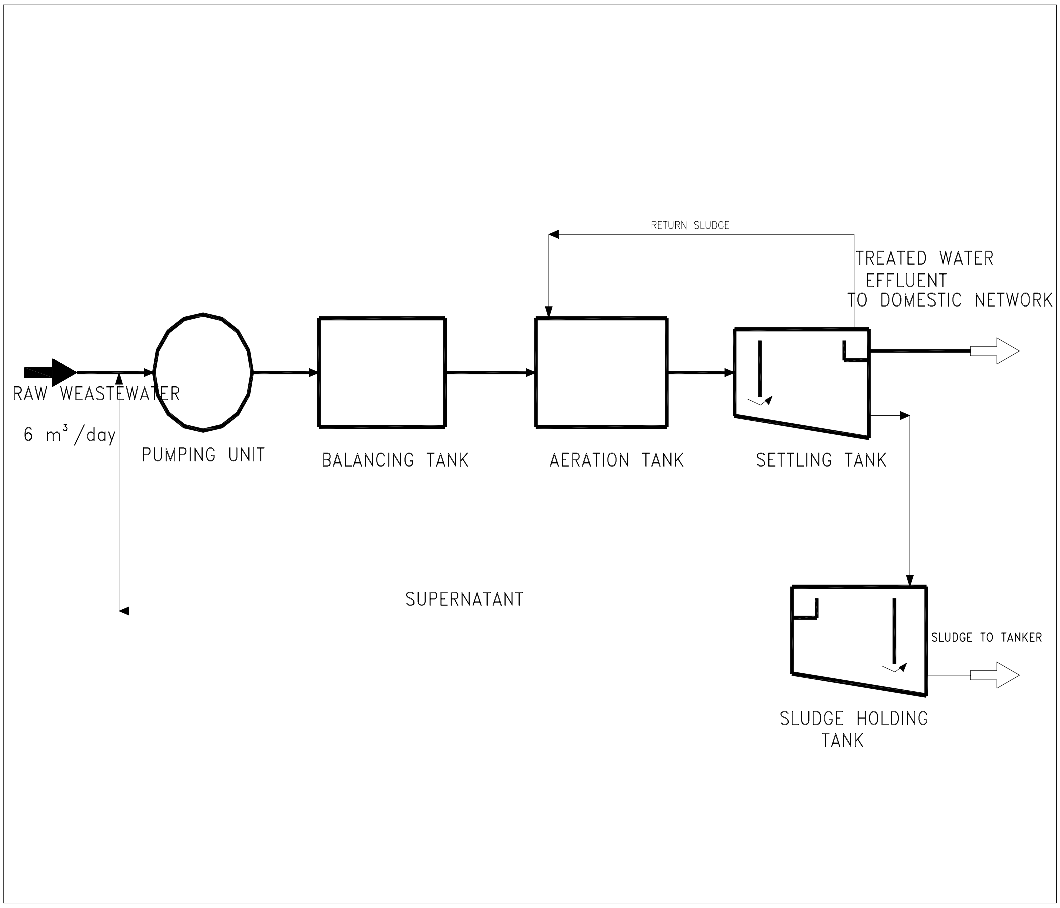

Figure (5) Schematic diagram of the activated sludge treatment system (Plastic shoes manufacturing factory)

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 les 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

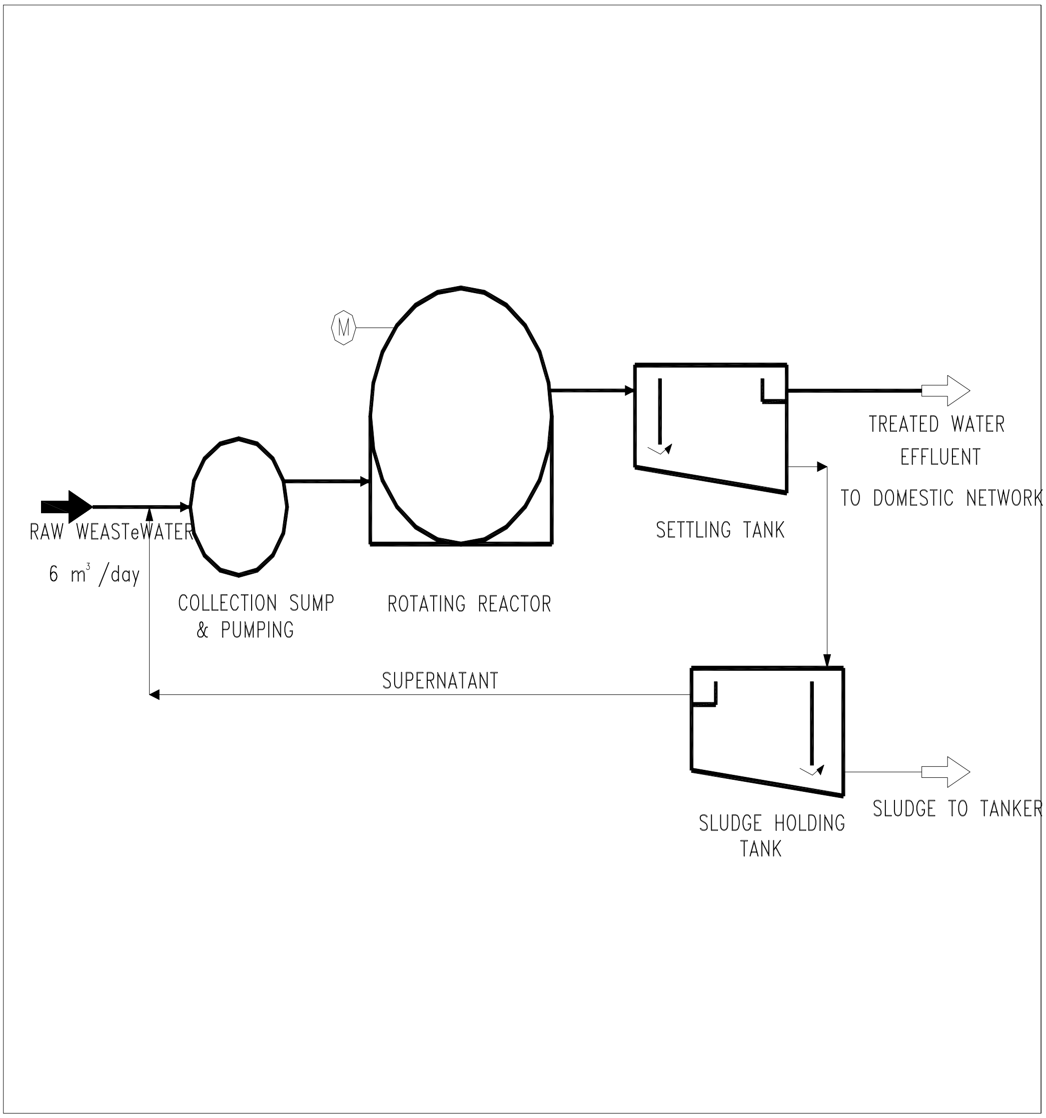

Figure (6) Schematic diagram of the rotating biological contactor system (Plastic shoes manufacturing factory)

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 les 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

Conclusion

Characteristics of chemical industrial wastewater determine the adequate treatment system.. More specifically; concentration, molecular size, solubility, toxicity and biodegradability of the pollutants.

Dilution of chemical industrial pollutants using domestic sewage in the factory effectively decreases the concentration and toxicity of the pollutants and subsequently increases the efficiency of the biological treatment. Also dilution with sewage is cost effective since no chemical salts are required to provide nutrients.

References

Abou-Elela, S.I., El-Kamah, E.M., Aly, H.I. and Abou-Taleb, E. (1995) Management of wastewater from the fertilizer industry. Wat. Sci. Tech. Vol. 32, No. 11, pp. 45-54.

Alvarez, D., Garrido, N. Sans, R. and Carreras, I. (2004) Minimization-optimization of water use in the process of cleaning reactors and containers in a chemical industry. Journal of Cleaner Production, 12, pp. 781-787

American Public health Association, (1998) Slandered Methods for the Examination of Water and Wastewater. 20th ed., Washington. DC.

Badr, N. M. (1988) Factors affecting nitrification of wastewater in the rotating biological contactor, M.Sc. thesis. Cairo University, faculty of science, Cairo, Egypt.

Bury, S.J., Groot, C.K., Huth, C. and Hardt, N. (2002). Dynamic simulation of chemical industry wastewater treatment plants. Water Science & Technology, Vol. 45 No 4-5 pp 355–363

Carini, D. (1999) Treatment of industrial wastewater using chemical-biological sequencing batch biofilm reactor (SBBR) processes.

Ph.D. thesis Swiss Federal Institute of Technology, Zurich, Switzerland.

EPA, (1998). Wastewater Treatment Technologies in: Pollution Prevention (P2) Guidance Manual for the Pesticide Formulating, Packaging and Repackaging Industry including implementing the P2 alternative, EPA, 821-B-98-017 June 1998, Pp. 41-46

Hu, H.-Y., Goto, N. and Fujie, K. (1999). Concepts and methodologies to minimize pollutant discharge for zero-emission production. Wat. Sci. Tech. Vol. 10-11, Pp. 9-16.

Jobbagy, A., Nerbert, N., Altermatt, R.H. and Samhaber, W.M. (2000) Encouraging filament growth in an activated sludge treatment plant of the chemical industry. Wat. Res. Vol. 34, No. 2, pp. 699-703.

Meric, S., Kabdash, I., Tunay, O. and Orhon, D. (1999). Treatability of strong wastewaters from polyester manufacturing industry. Wat. Sci. Tech., Vol. 39, No. 10-11, Pp. 1-7

Nemerow, N.L. and Dasgupta, A. (1991) “Industrial and Hazardous waste Treatment “Van Nostrand Reinhold, New York.

Peringer, P. (1997). "Biologischer Abbau von Xenobiotica." BioWorld (1), pp. 4-7.

Watanabe, Y., Okabe, S., Hirate, K. and Masuda, S. (1995) "Simultaneous Removal of Organic Material and Nitrogen by Micro-Aerobic Biofilms". Wat. Sci. Tech., Vol. 31, No. 1, pp. 195-203.