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Development and Economic Evaluation of a Treatment Plant for Tobacco and Cigarettes Wastewater.

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ABSTRACT

Tobacco industry wastewater generated from one of the factories of the Eastern Tobacco Company in Egypt, contains some toxic contaminants which inhibit, due to the shock loadings, the microbial consortium in biological treatment plants. Therefore, chemical coagulation/flocculation, chemical oxidation with hydrogen peroxide, ozone and ultra violet lamp, and finally, electrocoagulation treatment techniques were investigated in the present work. The experimental results allow to precisely considering, for this case, filtration followed by electrocoagulation with 25 mg/l CaO to be the prevailing solution for complete degradation of contaminants. Process design for 70 m^3/day wastewater treatment plant is performed based on previous results. The total fixed capital cost of the developed wastewater treatment plant was 2,911,000 L.E, the annual operating cost was 367,500 L.E, and the estimated cost for treatment of one cubic meter was 25 L.E/m^3 resulting in a 5% rate of revenue investment.

Keywords: Tobacco, wastewater treatment, electrocoagulation, cost estimation.

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INTRODUCTION

Tobacco is an agricultural product which is mainly used for cigarettes production. Today's tobacco products manufacturing includes many chemical additions, to provide a better taste. Since every brand has its own secret flavor, it is almost impossible to know exact composition of these products. Tobacco wastewater quantities are generated during tobacco processing and cigarettes making. Results of many investigations show that the most important sources of the toxic contaminant in tobacco wastewater are nicotine, flavoring chemicals containing glycogen and alcohol, absorbable organic halogens (AOX), and pesticides from tobacco leaves [1]. During the flavoring process, the waste flavorings come out in the form of moisture when spraying process is applied to the blend [2, 3]. This form of waste flavoring, chemicals and pesticides are dissolved in the water and discharged as wastewater.

Shock loadings of these toxic contaminants inhibit the bacterial activity during biological treatment. Input of wastewater containing such toxic substances causes a decrease in bacteria numbers and reduces the treatment efficiency in the plant. Hence the presence of such compounds requires non-biological processes for treatment. Physical and chemical methods were tried to treat these types of wastewater [4-13]. Therefore the main objectives of the present article are to investigate the optimum physical and chemical methods to treat wastewater effluents resulted from Tobacco and Cigarettes industry, design of an integrated developed plant for treatment of this type of wastewater based on the resulted optimum treatment method, and conduct preliminary cost evaluation of the proposed treatment plant.

Situation Analyses of Tobacco and Cigarettes Industry in Egypt

Manufacturing Process Description

Meharam Bek Factory in Alexandria is one of the Eastern Tobacco Company factories in Egypt. Its products include cigarettes and molasses tobacco (Maassel). Cigarette processing includes preparation of tobacco and homogenized tobacco. The tobacco leaves with its roots are compressed into cakes and mechanically shredded. Various additives are combined into the shredded tobacco product mixtures, such as propylene glycol. The final shredded tobacco is then dispersed over a continuous roll of cigarette paper. A machine rolls the shredded tobacco into the paper and cuts it to the desired length. A device then grabs each cigarette and fastens a filter in one end. The completed cigarettes are packed to a package and mechanically sealed in cellophane and hand-placed in cartons. The fine dust of tobacco as a by-product is processed separately into forms where they can then be possibly added back into the cigarette blend without an apparent or marked change in the cigarette's quality. Figure (1) represents the cigarette preparation and the reuse of fine tobacco dust in preparation of homogenized tobacco. Maassel processing is presented in Figure (2). It includes spraying of raw tobacco then drying to 12% moisture content followed by addition of molasses and flavoring blend then packing.

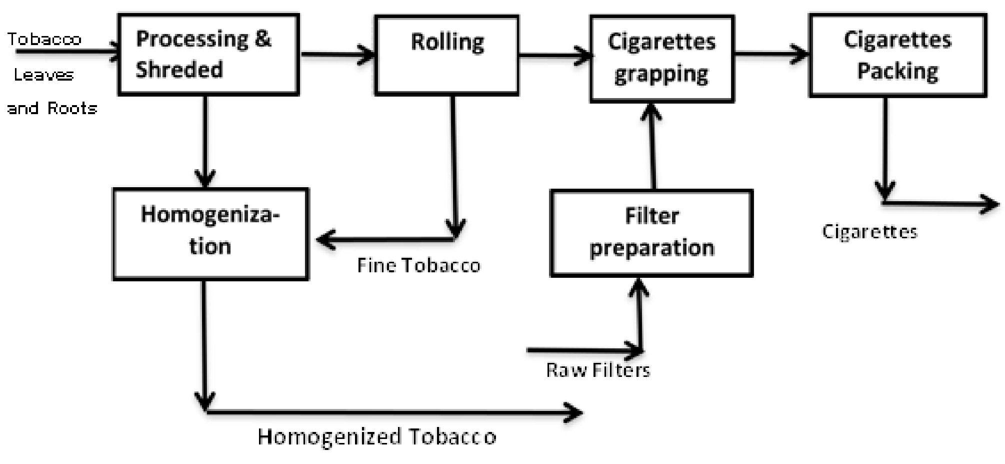

Figure 1: Cigarettes and Homogenized Tobacco Manufacturing processes

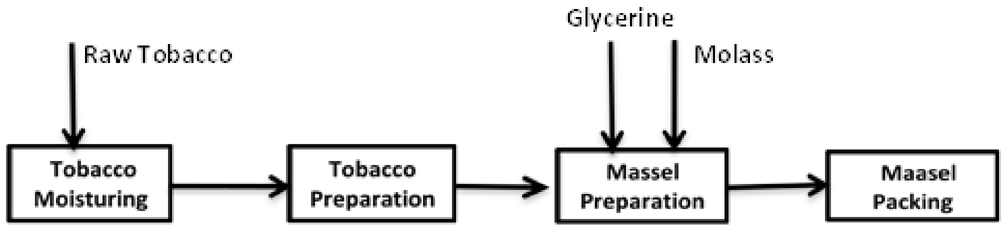

Figure 2: Maassel Manufacturing Processing

Quantity and Quality of Wastewater

The average wastewater discharge flow rate in Meharem Bek factory is 70 m^3/day. Grap samples were collected from final wastewater discharging effluent, which is loaded mainly by the pollutants resulted from the preparation, the homogenization and Maassel processes, to be analyzed. The analyzed parameters were color, pH, chemical oxygen demand (COD), biological oxygen demand (BOD), total solids (TS), dissolved solids (DS), total suspended solids (TSS) and oil and grease. The analyses were carried out according to standard methods [14].

EXPERIMENTAL

Three techniques were investigated for the treatment of wastewater effluents of Tobacco and Cigarettes industry: 1) Filtration and Coagulation, 2) Chemical Oxidation by using hydrogen peroxide (H_2O_2), Ozone (O_3), and Ultra Violet (UV) rays and 3) Electrocoagulation.

Filtration and Coagulation Experiments

The samples were first filtrated then subjected to coagulation/flocculation process by using Jar Test apparatus. Alum, ferric chloride and calcium oxide were used as inorganic flocculants with doses of 1, 2, 3, 4 and 5 mg/l. In addition, three commercial polymers: anionic, cationic, and nonionic were used as organic flocculants with doses of 0.5, 1, 1.5, 2, 2.5 and 3 mg/l. The samples were stirred vigorously to obtain a homogeneous medium, and then a volume of 800 ml portion was poured in each of the 6 jar-test containers, and stirred at 120 rpm during the addition of coagulant doses. After dosing, the stirring-speed was reduced to 100 rpm for 10 minutes, and then reduced again to 20 rpm for twenty minutes; the solution was left to settle for 30 minutes. The supernatant was withdrawn from a point located about 2 cm below the top of the liquid level of the beaker to determine the COD and the TSS by using the standard methods of analyses.

Chemical Oxidation Experiments

Advanced chemical oxidation treatment methods were used. Three sets of oxidation experiments were investigated by using:1) Hydrogen peroxide at 10%, 20%, 30% concentrations, 2) Ozone with doses ranged from 10 to 600 mg/l for one hour, followed by investigating the optimum dose of ozone at variable time (0 – 65 minutes), 3) UV technique with variable time (1-4 hours).

Electrocoagulation Experiments

Two sets of electrolysis experiments were investigated: 1) electrolysis without coagulation, 2) electrolysis with different doses of CaO as coagulant (20 - 200 mg/l). Both experiments were carried out at variable time (0 - 120 minutes). After some preliminary studies, St-St 316 L plate electrodes (5.5 cm x 4.5 cm) were chosen as the best anode and cathode. Sodium chloride of 0.1 M concentration was used as supporting electrolyte, optimum pH was 4 and optimum current density was 0.03 A/cm^3. The COD was determined for different CaO coagulant concentrations and at different time.

Experimental Set Up

- Ozone apparatus used for ozonation experiments is Model OZO 6VTTL (OZO MAX LTD, Shefford, Quebec, Canada)
- Photo catalytic apparatus used for UV experiments (Model Heraeus TQ150 with input energy 150 W), consists of a one liter capacity container equipped with a variable high speed stirrer, UV quartz lightening reactor (0.85 l) equipped with a mercury lamp as source of ultra violet rays of 100 - 200 nm. The lamp is immersed in a cooled container to maintain the room temperature constant during exposing the UV light to wastewater.
- Electrochemical laboratory cell of 400 ml volume [Figure (3)] is locally manufactured to be used for electrocoagulation experiments. It consists of 1) D.C Power supply, Type: BK Precision, Voltage: 0-64 volt, Model: 1740, Current density: 0-4 Ampere, 2) Magnetic stirrer: Type, RL aninco LR, the magnetic stirrer is used in order to keep the electrolyte well mixed. The cathode and anode are of St-St 316L plate electrodes (5.5 cm x 4.5 cm) as mentioned above. The power supply was controlled and the current was adjusted at predetermined levels.

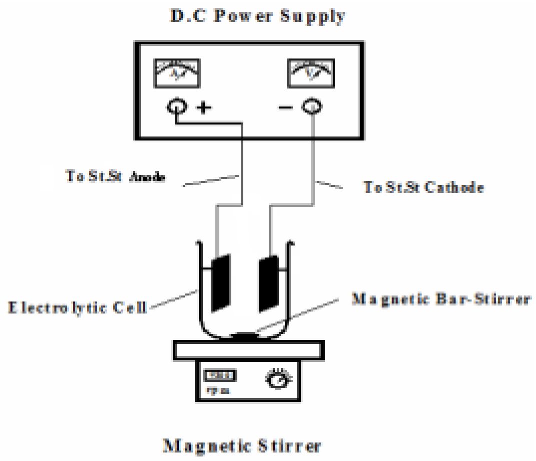

Figure 3: Electro coagulation Treatment Cell

RESULTS AND DISCUSSION

Wastewater characteristics

Table (1) represents the characteristics of five grab wastewater samples collected during year 2014, at a rate of one sample per two months (each sample was the average of three collected samples/month) from the final effluent. The wastewater samples are characterized by remarkable brown color, acidity, high COD, BOD and SS when compared with the allowable permissible limits of Egyptian Law No.93/1962, Decree 44/2000 for discharging industrial wastewater into sewerage system [15].

Table 1: Wastewater Characteristics for Final Effluent (Meharem Bek Factory, Eastern Company, Egypt)

Parameter	Sample N°1	Sample N°2	Sample N°3	Sample N°4	Sample N°5	Max. limit	Law No.93/1962 Decree 44/2000
Color	dark yellow	yellow	yellow	dark yellow	dark yellow	dark yellow	non
Turbidity, NTU	250	403	312	419	Nil	250	non
PH	4.87	4.0	5.0	5.4	Nil	4.87	6-9
Oi l& grease, mg /L	12	10	9	11	4	12	100
TSS, mg/L	2235	611	2112	1905	400	2235	----
D.S, mg/L	1565	580	1513	419	400	1565	---
SS, mg /L	391	420	890	971	Nil	971	800
COD, mg /L	5316	3987	5611	4046	980	5611	1100
BOD, mg /L	724	1818	795	2217	800	2217	600

Filtration and Coagulation Treatment

Filtration experiments proved that the sludge content was 550 mg/l in the average. This means the necessity of using grit to reduce the sludge load before treating the wastewater. Treatment of tobacco effluent by coagulation experiments yields negative results in case of using the two inorganic coagulants: alum and ferric chloride as well as the three commercial polymers: anionic, cationic and nonionic to treat tobacco effluent. While the use of calcium oxide (CaO) exhibits fairly good removal percent as illustrated in Figure (4). As observed, increases in the COD and SS removal percent is accomplished by increases in the coagulant dose, except that the removal rate of SS is much higher than that of COD, e.g., at 25 mg/l CaO dose, about 45% and almost 70% removals of COD and SS are achieved respectively. With respect to the allowable permissible limits of the Egyptian law, the SS in the treated water (320 mg/l) conforms well to those limits (800 mg/l.). However, the COD result indicates the need of additional treatment (3815 mg/l. result compared to 1100 mg/l. permissible limit).

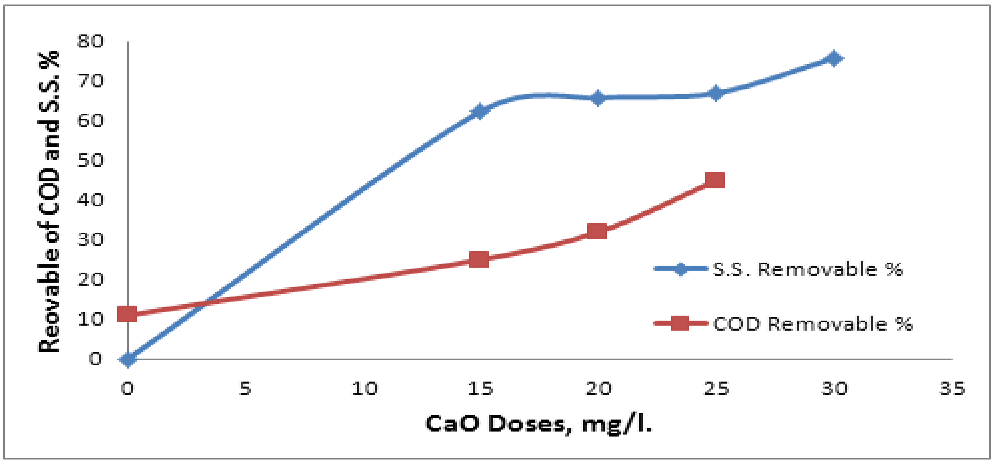

Figure 4: Removal Percent of COD and S.S. Based on coagulation by using different doses of CaO

Oxidation Experiments

As Tobacco wastewater is characterized by containing dissolved organic pollutants, which cannot be easily removed by chemical methods, therefore, advanced oxidation processes (AOPs) were investigated. These methods, in a broad sense, refers to a set of chemical treatment procedures designed to remove organic materials in water and waste water by oxidation through reactions with hydroxyl radicals ($^{\cdot}OH$) [11].

Negative results were obtained when using H_2O_2 as oxidizing agent at different concentrations. Also in case of ozone utilization, it is observed that doses of ozone in the range of 0-55 mg/l at different time (0-120 minutes) gave also negative results, yet, ozone dose of 60 mg/l for 60 minutes results in only 32% removal of COD as shown in Table (2), where 3839 mg/l of the COD is still remained. Ultraviolet (UV) oxidation is a destruction process that oxidizes organic contaminants in water. The results of the UV experiments are presented in Table (3), where 60% of COD is removed only after exposition to UV rays for 4 hours, i.e., 2215 mg/l of the COD is remained. Therefore, for both ozonation and UV techniques, the remained COD in treated water is still much higher than the allowable limits for discharging (1100 mg/l.).

Table 2: Effect of Ozone doses on COD removal at different time (O_3 dose= 60mg/l, sample volume=100 ml, pH=9)

Sample N^o	Time, min.	COD, mg/l.	% COD removal
Original Sample	0	5611	-
1	10	5021	10.50
2	20	4725	15.80
3	30	4430	21.05
4	45	4135	26.31
5	60	3839	31.58
6	65	4430	21.05

Table 3: Effect of UV treatment on COD removal at different time

Sample N°	Time, hr.	COD, mg/l.	% COD removal
Original Sample	0	5611	-
1	1	3101	44.7
2	2	2806	50.0
3	3	2510	55.3
4	4	2215	60.5

Electro coagulation Experiments

In this study, the optimization of electrochemical coagulation oxidation technique for Tobacco wastewater treatment and analysis of the degradation of COD was thoroughly investigated through two parts of experiments, as particular focus was given to electrolysis with and without coagulant at different times. The results are illustrated in Figure (5) and depicted in Table (4).

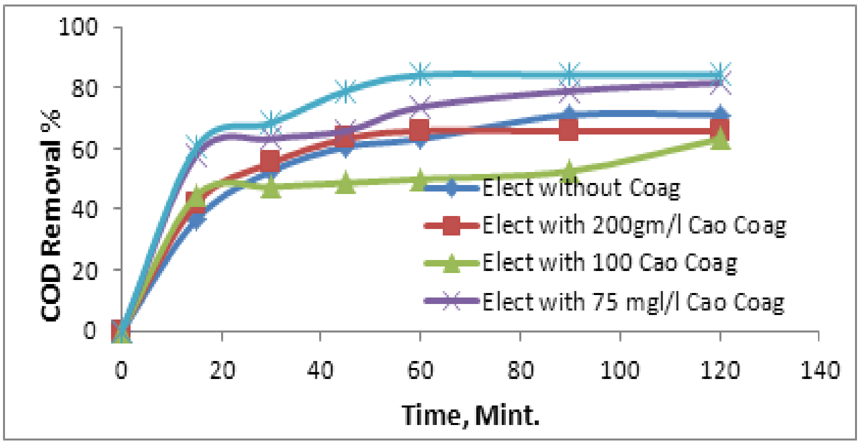

Figure 5: COD Removal % by using electrolysis with and without coagulation

Table 4: Effect of Electrocoagulation on COD Removal at different CaO coagulant doses and different electrolysis time (sample volume=400 ml)

Sample N°	Time, min.	Without CaO		200 mg/l CaO		100 mg/l CaO		75 mg/l CaO		25 mg/l CaO	
		COD, mg/l	% COD removal	COD, mg/l	% COD removal	COD, mg/l	% COD removal	COD, mg/l	% COD removal	COD, mg/l	% COD removal
Initial	0	5611	-	5611	-	5611	-	5611	-	5611	-
1	15	36.8	3544	3249	42.1	3101	44.7	2363	57.9	2244	60.0
2	30	52.6	2658	2510	55.3	2953	47.4	2363	57.9	1964	65.0
3	45	60.5	2215	2067	63.2	2880	48.7	2363	57.9	1291	77.0
4	60	63.2	2067	1920	65.8	2244	60.0	2244	60.0	785	86.0
5	90	71.1	1624	1920	65.8	1181	79.1	1624	71.1	785	86.0
6	120	71.1	1624	1920	65.8	1034	81.6	1624	71.1	785	86.0

The first part concerning the electrolysis experiments without coagulation yields 71.1% as maximum removal percent of COD after 90 minutes which is still not in the allowable limit of discharging the treated water containing 1624 mg/l COD. The second part is referred to the electrolysis with coagulation experiments, where three sets of experiments were conducted according to the way of CaO addition and the results are summarized as follows:

1) Electrolysis with coagulation with different doses of CaO at variable time (0- 120 minutes). The results are summarized as follows:
   - For 200 mg/l CaO dose, the COD removal percent increases as time increases from 15 minutes to 60 minutes, then no remarkable COD removal percent is achieved for longer time (90-120 minutes). The maximum COD removal percent was 65.8% after 60 minutes.

- For 100 mg/l CaO and 75 mg/l doses, removal percentages of COD were 60% for both doses after 60 minutes. But as time increases the removal percent of COD increased to be 81.6% and 71.1% respectively after 120 minutes.
- For 25 mg/l CaO dose, the best COD removal percent was 86% after 60 minutes, revealing 785 mg/l COD in treated water which is in a good compliance with the allowable Egyptian limits (1100 mg/l) for discharging into the sewerage system.

2) Electrolysis followed by coagulation with the optimum above conditions (CaO dose 25 mg/l for 60 minutes) was investigated. The optimum removal percent was 81.6 (the remaining COD was 1034 mg/l).
3) Coagulation followed by electrolysis at the optimum CaO dose 25 mg/l for 60 minutes, proved removal percent of 84% (the remaining COD was 897 mg/l).

Table (5) represents the summary of the three treatment electrocoagulation techniques at optimum conditions (CaO 25 mg/l at 60 minutes).

It can be concluded from the above experimental results that the treatment of tobacco wastewater performed successfully by using the electrolysis with coagulation process using 25 mg/l CaO as coagulant for 60 minutes.

Table 5: Comparison between the three sets of electrocoagulation experiments

Sample N^o	Time, min	COD, mg/l.	% COD removal
Original Sample	0	5611	-
Electrolysis + coagulation	60	785	86.0
Electrolysis followed by coagulation	60	1034	81.6
Coagulation followed by electrolysis	60	897	84

Process Design of the Integrated Wastewater Treatment Plant

Design of a treatment plant for wastewater is one of the most challenging aspects of environmental engineering when selecting the treatment process flow diagrams capable of meeting the permit requirements.

The above experimental results allow to precisely considering, for this special case, the following integrated wastewater treatment system: Filtration followed by electro-coagulation with 25 mg/l CaO as being the prevailing solution for complete degradation of contaminants of tobacco and cigarettes wastewater**.** Thus a wastewater treatment process is developed depending upon the following major parameters:

a- *Wastewater characteristics*: where maximum pollution load values are considered: the high COD concentration value (5611 mg/l), high BOD (2217 mg/l) and high SS (971 mg/l)

b- *Experimental treatment results:* where Electrolysis with coagulation by using 25 mg/l CaO as coagulant was the most efficient.

Treatment Process Description

Wastewater from preparation, homogenization and Maassel processes is discharged and collected via pipe lines, provided with screens and grit along the water path to remove sludge and coarse particles, into an underground tank, equipped with a submersible pump to lift the wastewater to the homogenizer. Then, water is pumped to a filter centrifuge for sludge separation followed by pH adjustment for the supernatant water by means of 48% NaOH solution at a dose of 0.006 mg/l. The adjusted solution undergoes electro coagulation with the addition of 25 mg/l CaO as coagulant during one hour.

The treated water is discharged to a settling tank where clear water is recycled to be reused as process water, while the obtained sludge, after filtration through a filter press, is packed in filter bags to be land fill. An equipment flow sheet for the developed wastewater treatment plant is illustrated in Figure (6).

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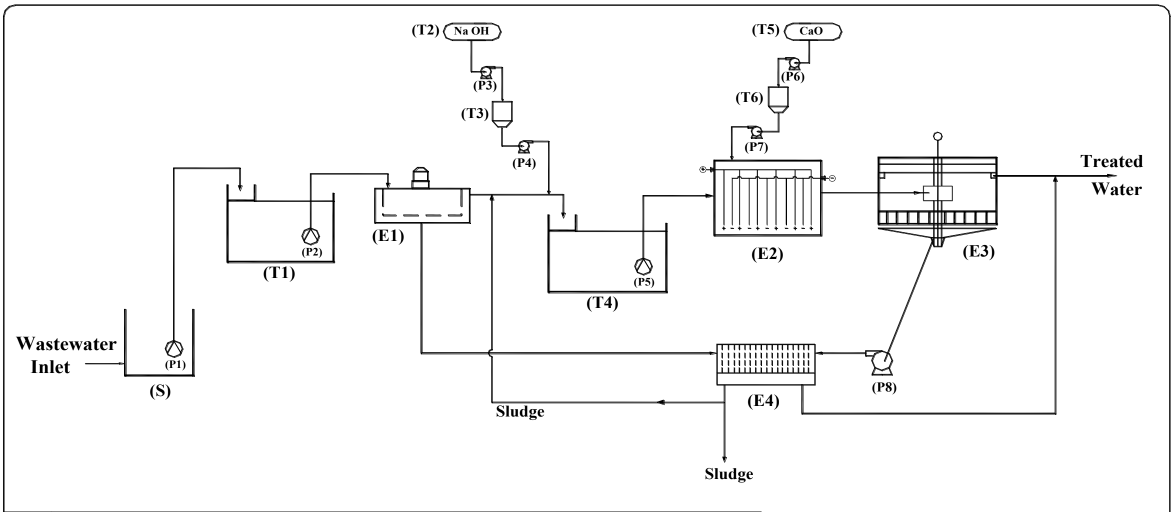

Title	Figure (6): Equipment flow sheet of wastewater treatment plant (Moharem Bek factory)								
Item	Description	Item	Description	Item	Description	Item	Description	Item	Description
S	Inlet sump	E1	Basket centrifuge	P4	NaOH feeding pump	T5	CaO storage tank	E3	Settling tank
P1	Submersible pump	T2	NaOH storage tank	T4	Holding tank	P6	CaO charging pump	P8	Sludge pump
T1	Balancing tank	P3	NaOH charging pump	P5	Submersible pump	T6	CaO feeding tank	E4	Filter press
P2	Submersible pump	T3	Na OH feeding tank	E2	Elyctrolyses unit	P7	CaO feeding pump		

Material balance

According to data obtained from the bench scale experiments, simple material balance calculations [Figure (7)] are performed to estimate the treatment equipment capacities and sizing as well as the quantities of chemicals required. These calculations are performed based on a treatment plant capacity equivalent to 70 m^3/year. This capacity is estimated from the company files as maximum effluent capacity, and by considering a value of 10% in excess as safety factor.

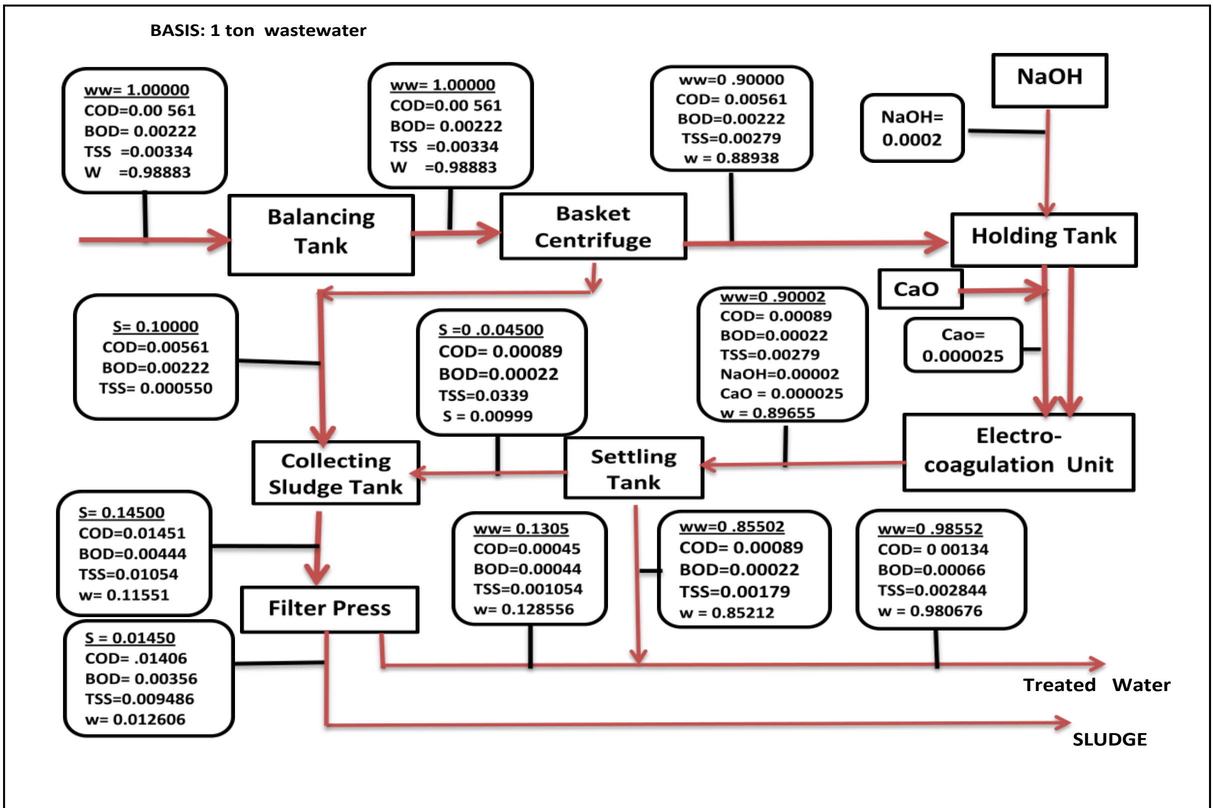

Figure 7: Material Balance of Treatment Units (Meharem Bek Factory)

Economic Evaluation of Integrated Wastewater Treatment Plant

Cost estimation

Cost estimation for the developed wastewater treatment plant is required for preliminary evaluation of the designed scheme. Wastewater treatment costs are basically divided into two categories; total fixed capital cost (TFC), incurred during plant construction, and annual operating and maintenance (O&M) costs, necessary to provide sustained operation for the plant after construction. Data of fixed capital costs and annual operating costs were obtained from various reliable sources.

Fixed Capital Cost

Fixed costs represent the capital necessary for the installed process equipment with all auxiliaries that are needed for complete process operation. This estimation requires determination of the purchased-equipment cost. The other items included in the fixed-capital cost are then estimated as percentages of the purchased equipment costs for the treatment of tobacco and cigarettes wastewater plant. Costs of equipment locally purchased are estimated according to current costs as provided by local market, while imported equipments are estimated according to international firm suppliers included freight and customs charges (1$ = 7.6 L.E based on year 2015). The purchased equipment (holding tanks, surge tanks, centrifuge unit, electrocoagulation unit and filter press) cost is estimated as 2 million LE. Values of the various percentages used in estimating the fixed capital investment (F.C.I.) [16] along with proportional costs of major components of total capital investment (T.C.I.) are demonstrated in Table (6).

Table 6: Estimation of total capital investment for wastewater treatment plant.

Components	**Price, in 1000 L.E**
I) Direct Cost :	
1- Purchased equipment cost (E).	2,000
2- Purchased equipment installation (10% E).	200
3- Instrumentation & control (5% E).	100
4- Piping (10 %E).	200
5-Electrical equipment & materials (2% E).	20
6- Buildings(including services)*	----
7- Services facilities and Yard improvement*	----
8- Land*	----
Total direct cost (D)	**2520**
II)Indirect cost:	
1- Engineering & Supervision (2% D).	50
2-Construction expenses and Contractor's fee (2% D).	50
3- Contingency (10% F.C.I.)	291
Total indirect cost (ID)	**391**
III)Fixed-capital investment (F.C.I.)	**2911**
IV) Working capital (15% T.C.I.)	**514**
V) Total capital investment (T.C.I)	**3425**

*The proposed wastewater treatment unit is a replacement of an old chemical oxidation existing unit.

Annual Operating Cost

Table 7: Annual operating costs

Component	**Annual price in 1000 L.E**
1-Total raw materials cost	0.500
2-Utilities(Electricity)	250
3-Maintenance (5% for installed equipment)	100
4-Operating labor*	----
5- Laboratory charges	12
6-Administrative expenses	5
Total Annual Operating Cost	**367.5**

* No operating labor salaries are included as they are already included in the company cost.

The various cost elements of annual operating costs directly related with the treatment operation are presented in Table (7). The obtained prices of raw materials are 300 L.E/ton for CaO and 3480 LE/ton for 48% sodium hydroxide. The electricity cost is 0.40 L.E/kW.

Annual depreciation rate

It is estimated based on a useful-life period of 10 years of the fixed capital cost. Accordingly, the total depreciation rate cost is 2,911,000/10 = 291,100 L.E/year.

Unit cost of treated wastewater

It is defined as the summation of annual operating costs and depreciation rate per unit volume of treated wastewater. Hence, the unit cost of treated wastewater is calculated via the following: (367,500 + 291,100)/26000 = 25 L.E/ m^3

Profitability Estimation

Generally, profit is defined as the difference between income and expenses and as such, is a function of the quantity of goods produced and the selling price. But in the present case, as there is no product to be sold, the yearly profit is expressed in terms of the annual saving and/or revenue gained by the Company by implementing this project. The considered saving are the cost of recycled water to be used in the factory processes. Cost input parameters are as follows:

Recycled treated water cost is estimated at 25 L.E/m^3. Environmental Charges are determined at 35 L.E/m^3 wastewater (average value taken from the company files). The calculated revenue and the annual return on investment are illustrated in Table (8).

Table 8: Rate of Return on Investment

Components	Saving (L.E)/year
Recycled treated water cost	509250
Environmental Charges	735000
Total saving	225750
Revenue*	141750
Rate of Return on Investment	5%

***The revenue is defined as the difference between the total saving cost and the annual operating cost

CONCLUSION

A comprehensive experimental study is carried out as a tool for selecting appropriate technology for treatment of Tobacco and Cigarettes Company wastewater generated at Meharem Bek Factory. Filtration followed by electrocoagulation technology is proved to be the appropriate treatment and achieved zero discharge by recycling and reusing of the treated water in the company processes. Preliminary cost estimation for 26000 m^3/year wastewater is evaluated resulting in 5% rate of return on investment.

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