A NEW APPROACH TO ACCOMPLISH WASTEWATER REGULATION IN TEXTILE SECTOR: AN EGYPTIAN CASE STUDY

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The textile industry is characterized by huge water consumption and produced wastewater. The end-of-pipe treatment technology moves an undesirable waste material from one medium to another, thus tending to create chains of waste products.

The alternative solution of water pollution control at the source significantly reduces the pollution load. In the present study, the cleaner production (CP) opportunities for a cluster of five textile factories versus end-of-pipe treatment have been investigated. The CP opportunities proposed are the following: replacement of acetic acid by formic acid, elimination of the bisulfite treatment step after full bleaching of cones or fabric, replacing chemical scouring by bio-scouring, avoiding the use of carrier in polyester dyeing and replacing mono-functional reactive dyes by bi-functional dyestuffs. The use of Upflow Anaerobic Sludge Blanket (UASB) reactor, followed by either activated sludge treatment or chemical coagulation treatment, can produce treated effluent satisfying the Egyptian standards regulating wastewater discharge into receiving water bodies.

Keywords: textile, cleaner production, wastewater, anaerobic, aerobic, treatment

INTRODUCTION

The textile industry is one of the oldest industries in the world. The oldest known textiles, which date back to about 5000 BC, are scraps of linen cloth found in Egyptian caves. Today, the textile sector in Egypt consists of well over 3.000 companies, ranging from modern and highly automated plants, to small traditional units for hand-made products. The textile industry has a major impact on Egypt's economy. It accounts for more than 34% of the total export.

Textile wet processes consume dyes, auxiliaries, chemicals, detergents and finishing agents used for the conversion of raw materials into a finished product. The specific water use varies from 60 to 400 L/kg of fabric, depending on the type of fabric wet application.[1,2] Generally, textile effluents are highly colored, contain non-biodegradable compounds and are characterized by high Biological and Chemical Oxygen Demand. The presence of metals and other dye compounds inhibits microbial activity and, in some cases, may cause failure of biological treatment systems.[3]

Traditionally, textile wastewater management practices have been concerned with treating the effluents once they are generated, in expensive end-of-pipe treatment systems.[4-6] These treatment systems often move an undesirable waste material from one medium to another, thus tending to create chains of waste products, which lead to extra expenses and liability propagated through many layers of treatment. Several studies indicated that physical chemical treatment alone is inadequate for treating textile industry wastewater.[7,8] It is recommended that the primary treatment should incorporate biological treatment to achieve an effluent complying with the environmental regulations.[9,10]

The pollution control at source in the textile industry has proven to be an economical and effective solution. It relies on the application of pollution prevention measures, a proactive approach that produces an acceptable effluent according to the national environmental regulations.[11-13] Cleaner production (CP) can generate short- and long-term environmental and social improvements, well beyond those possible with regulatory compliance programs. It can also improve the competitiveness of industry by increasing revenues and decreasing non-product output.[14-16] The concept of cleaner production (CP) has been practiced for many years in many countries.[17,18] CP activities include measures, such as pollution prevention, source reduction, waste minimization.[19,20]

Therefore, the main objective of the present study has been to emphasize the benefits accrued by the industry upon implementation of cleaner production.

EXPERIMENTAL

Industrial auditing

An inventory of relevant inputs and outputs was compiled. The potential impacts of inputs and outputs were assessed in relation to the goals of the study. In this way, negative environmental impacts were accounted for at every stage of the production processes.

Wastewater characterization

A continuous monitoring program was carried out to identify the magnitude of variation in the quality and quantity of wastewater discharge. The wastewater samples were subjected to physical chemical analysis according to APHA Standard Methods for Water and Wastewater Examination.[21]

Application of pollution prevention options

The cleaner production possibilities applied in this study included: replacement of acetic acid by formic acid, elimination of the bisulfate treatment step after full bleaching of cones or fabric, replacing chemical scouring by bio-scouring, avoiding the use of carrier in polyester dyeing and replacing mono-functional reactive dyes by bi-functional dyestuffs in reactive dyeing. Closing tight dyestuff containers at the chemical store has been also considered.

End-of-pipe treatment

Composite samples from the end-of-pipe effluent of the five factories under investigation were collected, mixed according to their discharge ratios and subjected to the following treatment technologies: chemical coagulation/precipitation, anaerobic treatment, and anaerobic treatment followed by either aerobic or chemical treatment.

Design and cost estimate of the treatment system

A design of wastewater collection and treatment alternatives has been developed. The capital and operation cost have been estimated.

RESULTS AND DISCUSSION

Process description

All five factories investigated have similar processes: full and half bleaching of cotton cones and fabrics, scouring and reactive dying of cotton cones and fabrics; direct dyeing of cotton fabrics and light and dark shade dyeing of polyester (Fig. 1).

Cleaner production opportunities

Replacement of acetic acid by formic acid

Acetic acid is used in most of the dye-houses for neutralization and pH adjustment during softening. In this study, the replacement of acetic acid by formic acid has been attempted. Formic acid is not only cheaper and stronger, but also of lower BOD and COD, as compared to acetic acid. One kg of acetic acid (96%) is equivalent to 1.07 kg COD and 0.64 kg BOD. The corresponding values for formic acid (80%) are 0.21 and 0.096, respectively. It is worth mentioning that the price of one kg of acetic acid was USD 1.2, while that of formic acid was USD 0.8 at the time of the study.

Elimination of the bi-sulfite treatment step after full bleaching of cones or fabric In some factories, a bi-sulfite treatment step is performed after scouring/full bleaching, hoping that it protects the optically brightened fabric from the negative effect of H_2O_2 traces remaining after bleaching.

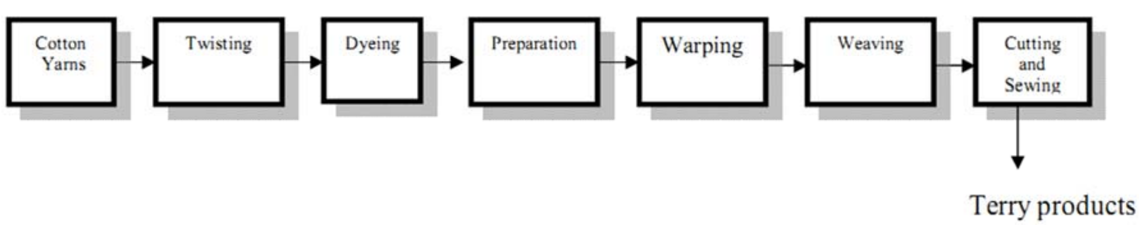

Figure 1: Process flowchart for converting cotton yarns to Terry products

This assumption is not accurate, since the optical brightener is added to H_2O_2 itself during full bleaching. Therefore, the elimination of this step has been recommended. This reduced the COD of the final effluent by 37 mg/L.

Replacing chemical scouring by bio-scouring

Chemical scouring is currently used in most of the dye-houses in full and half bleaching, as well as before dark shade dyeing. The process is conducted at the boiling point using caustic soda. Bio-scouring can be carried out using enzymes at 60 ºC for shorter time. This can result in a reduction in energy consumption, improvement of wastewater quality (reduction in TDS) and shortening of process time (by 55 min). A slight increase in COD ranging from 2.4 to 5.0 mg/L has been recorded.

Avoiding the use of carrier in polyester dyeing

In some factories, light shade disperse dyeing of polyester fabric is carried out at 100 ºC, which mandates the use of carrier to ensure effective dyeing. Carriers are environmentally hazardous, because most of them are chlorinated aromatic compounds. High temperature dyeing (130 ºC) has been recommended to avoid the use of carriers. This step achieved a COD reduction by 51 mg/L.

Replacing mono-functional reactive dyes by bi-functional dyestuffs

Mono-functional reactive dyes are used in most factories. Under optimum conditions, the amount of dye fixed onto the fabric is of 60% and the rest (40%) finds its way into the wastewater. Bi-functional reactive dyestuffs are characterized by higher fixation ratio (81%), compared to mono-functional dyes. Shifting from mono- to bi-functional reactive dyestuffs is expected to produce a reduction in the COD value of the wastewater ranging from 28 to 90 mg/L, based on the consumption of each factory. The high cost of bi-functional dyestuffs can be compensated by the small amount used due to the higher fixation ratio and the reduction in the cost of wastewater treatment.

In-plant control measures

In factories, dyeing containers are not tightly closed during use, especially those opened for daily use. This can cause hydrolysis of reactive dyestuffs or agglomeration of disperse and direct dyestuffs upon exposure to humid air, especially during hot weather. Hydrolyzed dyestuffs do not combine with cotton substrate and leach out in wastewater, whereas agglomerated dyestuffs don't dissolve in the dyeing solution and hence, can be either precipitated on fabric (resulting in an uneven dyeing) or disposed of in wastewater. A simple measure, such as prevention, would produce a reduction in the COD value of the final effluent by 4 mg/L and a saving in the amount of used dyestuff. From the available results, it can be concluded that considerable cost reduction per year is assured due to the implementation of the proposed CP opportunities.

Wastewater treatment

Wastewater characteristics

The wastewaters from the end-of-pipe of each of the five factories are presented in Table 1. The results show that the wastewater is not complying with the standards set by the National regulations for discharging industrial wastewater into the agricultural drains. The end-of-pipe wastewater analysis indicated the deviation of several pollution indicators from the limits set by law. The non-compliance was obvious in the COD, BOD, TSS, Oil and grease, and sulphides values.

The wastewater discharged from the end-of-pipe of the five factories were mixed according to their actual discharge ratio and subjected to the following treatment techniques:

-Chemical treatment using $FeSO_4.7H_2O$ and $FeCl_3$, aided with lime;

-Anaerobic biological treatment;

-Anaerobic biological treatment followed by aerobic biological treatment;

-Anaerobic biological treatment followed by chemical treatment.

Chemical treatment

The mixed wastewater was chemically treated using different coagulants at their optimum doses and pH values. The coagulants used were ferric chloride aided by lime and ferrous sulphate aided by lime. The results show that the characteristics of the chemically treated wastewater do not satisfy the standard set by the Egyptian law regulating discharge of industrial wastewater into agricultural drains. The average COD and TSS were of 400 mg O_2/L and 50 mg/L.

Anaerobic biological treatment

In an attempt to reduce energy costs associated with aerobic treatment, the treatment of the mixed wastewater via anaerobic digestion has been investigated. The experiment was performed using a Perspex laboratory scale reactor with an effective volume of 2.5 liters. The reactor was inoculated with 11.5 g VSS/L sludge from a nearby anaerobic sludge treatment plant. The hydraulic detention time was 24 hours. The results showed that the anaerobic treatment could be only considered as a pretreatment step and an appropriate post-treatment step is required. COD and BOD ranged from 184 to 366 mg O_2/L and from 52 to 150 mg O_2/L, with average values of 244 and 95 mg O_2/L. Total suspended solids ranged from 19 to 114 mg/L. Average concentrations of the nitrates, sulphides and phosphorus were of 0.74, 4.9 and 2.4 mg/L, respectively.

Two treatment schemes were investigated. The first consisted in the use of a UASB reactor followed by activated sludge, and the second scheme consisted in the use of a UASB followed by chemical treatment.

The UASB reactor was operated at a hydraulic detention time of 8 h and 12 g VSS/ L. The results obtained indicated significant improvement in the UASB effluent quality (Table 2). The average residual values of BOD, COD, Oil and grease, TSS were of 94.5, 190, 17.4 and 56 mg/L.

Anaerobic biological treatment followed by aerobic biological treatment

The biological treatment of the UASB effluent, using activated sludge at HRT of 2 h, indicated that good quality effluent could be obtained using this treatment scheme. The average residual COD, BOD, TSS, and Oil and grease in the treated effluent were of 84, 34.5, 45.6 and 8.5 mg/L, respectively (Table 2). These values are in agreement with the standards set by law.

Table 1
Physicochemical characteristics of wastewater discharged from the five factories

Parameters*	Unit	1	2	3	4	5	Mixed sample	Permissible limits
Temperature	°C	34.1	33	50.7	26.4	43.6	-	35
pH-value	-	7.9	8.3	8.9	7.9	8.4	8.8	6-9
COD	mg O_2/L	277	510	479	673	446	507	100
BOD	mg O_2/L	120	174	170	301	237	229	60
TSS	mg/L	70.5	87.5	46	243	35	79.8	60
Oil, grease	mg/L	14	40.7	53	110	28.6	41.1	10
TKN	mg N/L	27	15	18.4	82.2	15	20.2	-
Nitrate	mg N/L	0.5	0.48	0.37	0.4	0.42	0.46	40
Sulphides	mg S/L	6.7	1.8	5	6	2.7	4.4	1
Phosphorus	mg P/L	1.5	3.5	2.7	2.9	1.9	4.9	10

*Average of 15 samples

Table 2
Performance of wastewater treatment schemes

Parameters*	Unit	Raw wastewater	UASB 8 h	UASB + As 2 h	UASB + CaO = 100 FeSO4 = 250 mg/L	Permissible limits
pH value	-	8.8	7.9	8	8	6-9
COD	mgO_2/L	507	190	84	68.8	100
BOD	mgO_2/L	229	94.5	34.5	29.3	60
TSS	mg/L	59.8	56	45.6	43	60
Oil, grease	mg/L	41.1	17.4	8.5	8.7	10
Nitrate	mgN/L	0.46	-	0.6	0.54	40
Sulphides	mgS/L	4.4	1.9	0.9	0.8	1
Phosphorus	mgP/L	4.9	2.7	1.3	1.5	10
Faecal coliforms	MPN/100 mL	$2.7x10^4$	$4.5x10^2$	$2x10^3$	-	5000

*Average of 15 samples

Anaerobic biological treatment followed by chemical treatment

Chemical treatment of the UASB effluent, using ferrous sulphate (250-350 mg/L) and CaO (80-100 mg/L), was carried out. The results obtained are shown in Table 2, the average residual COD, BOD and TSS were of 68.8, 29.3

and 43 mg/L, respectively. These values are in compliance with the standards set by the law.

Design of the treatment system
Wastewater collection

A proposed wastewater collection system is designed to handle the total flow rate from the five factories. It comprises main collector, equalization tank and a pump station to receive a flow rate range from 14.7 m^3/h to 31.9 m^3/h with an average of 22.4 m^3/h. A 200 mm diameter gravity pipeline for collecting the wastewater from each factory is proposed. The pipeline will discharge its flow to an equalization tank of 76 m^3 capacity at the site of the treatment plant. The raw wastewater pump station consists of three submersible pumps of 6.3 L/s capacity each, one working and 2 units in standby. The pump station function is to withdraw wastewater from the equalization tank and pump it to the treatment plant.

The first treatment scheme: UASB followed by activated sludge

The UASB design parameters are as follows: 180 m^3 volume, 7.5 m diameter, 4 m height, 0.3-0.6 m/h upward velocity and 8 h detention time. A combined aeration sedimentation activated sludge of circular shape was designed (Fig. 2).

The second treatment scheme: UASB followed by chemical coagulation/sedimentation

The treatment system consists of a UASB unit similar to that described in the first design. The effluent of the UASB is fed to a mixing tank of 0.37 m^3 volume and detention time of 30-60 seconds, whereas coagulant ($FeSO_4$) and coagulant aid (CaO) are added before the effluent is fed to the flocculation sedimentation tank. The tank is double-wall cylindrical shaped, with inner and outer cylinders. Flocculation takes place in the inner tank assisted by mechanical agitator. The design parameters of the inner tank are the following: 2.4 m diameter, 2.5 m depth, 0.5 h detention time and a volume of 11.2 m^3. Sedimentation occurs in the outer tank of 5.5 m diameter, 3 m depth, 2.5 h detention time and 67.2 m^3 volume (Fig. 3).

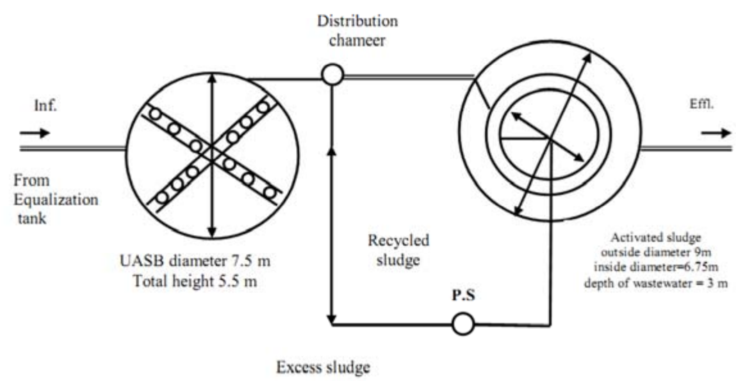

Figure2: The first design of wastewater treatment

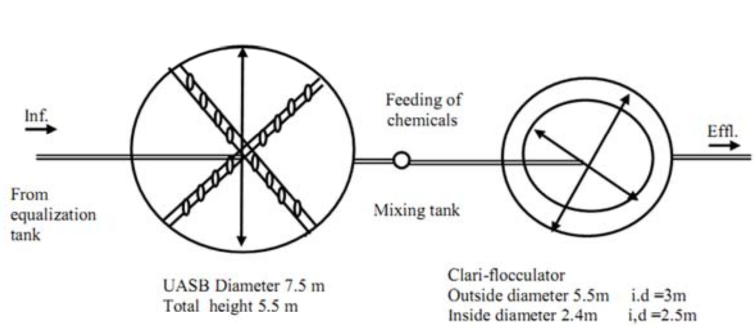

Figure 3: The second design of treatment system

Cost estimate

The capital and operation cost for wastewater collection and treatment systems are estimated and presented in Tables 3 and 4.

The characteristics of the treated mixed wastewater using upflow anaerobic sludge blanket (UASB), followed by an activated sludge or UASB followed by chemical treatment using lime and ferrous sulphate, comply with the National regulatory standards for wastewater discharge into agricultural drains. Based on cost analysis, the treatment scheme consisting of UASB followed by chemical treatment was found to be the most economical.

Table 3
Capital cost of the first design

Works	Cost in USD
Gravity pipeline 200 mm diameter 300 m length, equalization tank and submersible P.S.	96000
UASB	79200
Activated sludge system, completed with connection pipes, aeration system and sludge withdrawal, recirculation equipments, sludge disposal etc.	130000
Total	305200

Table 4
Capital cost of the second design

Works	Cost in USD
Gravity pipeline 200 mm diameter 300 m length, equalization tank and submersible P.S.	96000
UASB	79200
Mixing tank, combined flocculation sedimentation tank, chemical preparation and dosing equipments, inter-connection pipes, mixing and flocculation equipments, scraper, sludge withdrawal, disposal etc.	26400
Total	201600

Construction cost + operation cost for 15 years of the first design = 305200 + 15303 = USD 320503
Construction cost + operation cost for 15 years of the second design = 201600 + 37349= USD 238949
Therefore, the second design is cheaper by about USD 81554.

CONCLUSION

The application of cleaner production opportunities via replacement of acetic acid by formic acid, elimination of the bisulfate treatment step after full bleaching of cones or fabric, replacing chemical scouring by bio-scouring, avoiding the use of carrier in polyester dyeing and replacing mono-functional reactive dyes by bi-functional dyestuffs significantly reduces the pollution load, hence the cost of the wastewater treatment facilities.

The two treatment schemes investigated: upflow anaerobic sludge blanket (UASB), followed by either an activated sludge system or chemical treatment both produced good quality effluent complying with the National regulatory standards for wastewater discharge into water receiving bodies. Based on cost analysis, the treatment scheme consisting of UASB followed by chemical treatment was found to be more economical.

It is recommended that textile plants apply cleaner production measures for reducing pollutant load and support the application of more effective and economical treatment of end-of-pipe wastewater, for compliance with environmental regulatory standards.

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