Assessment of the best available wastewater management techniques for a textile mill: cost and benefit analysis

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ABSTRACT

In the present study, several water recovery and end-of-pipe wastewater treatment alternatives were evaluated towards the evaluation of Best Available Techniques (BATs) for the management of wastewaters from a denim textile mill in accordance with the European Union's Integrated Pollution Prevention and Control (IPPC) Directive. For this purpose, an assessment that translates the key environmental aspects into a quantitative measure of environmental performance and also financial analysis was performed for each of the alternatives. The alternatives considered for water recovery from dyeing wastewaters were nanofiltration (NF) with coagulation and/or microfiltration (MF) pre-treatment, ozonation or peroxone and Fenton oxidation. On the other hand, for the end-of-pipe treatment of the mill's mixed wastewater, ozonation, Fenton oxidation, membrane bioreactor (MBR) and activated sludge (AS) process followed by membrane filtration technologies were evaluated. The results have indicated that membrane filtration process with the least environmental impacts is the BAT for water recovery. On the other side, MBR technology has appeared as the BAT for the end-of-pipe treatment of the mill's mixed wastewater. A technical and financial comparison of these two BAT alternatives revealed that water recovery via membrane filtration from dyeing wastewaters is selected as the BAT for the water and wastewater management in the mill.

Key words | best available techniques, cost-benefit analysis, cross-media effects, IPPC directive, textile industry

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INTRODUCTION

The European Union (EU) has a set of common rules specified in the Integrated Pollution Prevention and Control (IPPC) Directive (96/61/EC), published in 1996, for permitting of industrial installations in the EU Member States. The aim of this Directive is to develop an integrated approach in order to improve the management and control of industrial facilities so as to achieve a high level of environmental protection taking into account the emissions in air, water and soil as a whole, in particular through application of the Best Available Techniques (BAT). According to the Directive, techniques should be implemented under *economically* and *technically* viable conditions, taking into consideration the *costs* and *advantages* for the relevant industrial sectors. Moreover, there is a requirement that, in the determination of BAT, the technical characteristics of the installation concerned, its geographical location and the local environmental conditions should be taken into account.

Under the framework of the IPPC Directive, a Reference Document called "Economics and Cross-Media Effects" (EC 2006) has been developed by EU in order to reinforce the determination of BAT by setting methodologies. The IPPC Directive indicates that, while determining the best available technique, not only the option that has

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the lowest impact on the environment as a whole is decided as BAT, but also the most economic option should be selected. According to this Reference Document, while determining the BAT for the installation concerned, first step should be the consideration of the environmental effects of the options, namely "Cross-Media Effects". Secondly, costing methodology is mentioned in order to determine the cost for each option considered. After the establishments of cross-media effects and costs of the options, their comparison is needed in order to determine which of the alternatives can be selected to be BAT. According to the abovementioned definition of "available" stated in the Directive, alternatives that are designated to be BAT should be the ones that are technically and economically viable for the implementation in the relevant industrial installations. Therefore, at the end of the cost and benefit analysis, economic viability in the sector needs to be considered taking into account industrial structure, market structure, and resilience of the sector.

This study is the last phase of a project for the first implementation of the IPPC Directive and BREF Document to an industrial facility in Turkey. In the project, all the aspects of the IPPC Directive including application of appropriate preventive measures against pollution, waste management, energy efficiency, prevention of accidents and risks and emissions to water, air and land have been studied with the purpose of selecting the best economically and technically viable alternative for water and wastewater management as the BAT for the facility considered. Thus, the goal of the present study was to realise the selection of the BAT for the facility selected.

In the above mentioned project, a denim producing textile mill had been chosen for the adoption of the IPPC Directive and many water and wastewater management BAT alternatives such as water recovery techniques and wastewater treatability technologies were investigated running laboratory-scale tests and their performances were technically discussed. But, a final selection has not been made. It is the purpose of the present study, firstly, to determine the environmental impacts of each BAT alternative within the framework of cross-media guidelines specified in the Reference Document; secondly, to carry out financial analysis including investment and operational costs of the alternative water and wastewater management techniques identified according to the costing methodology indicated in the Reference Document; and finally, to select the best economically and technically viable alternative for water and wastewater management for the facility.

BACKGROUND

Textile industry

Textile industry is one of the most complicated industrial sectors among other manufacturing industries where water and energy is consumed in almost every step of the process chain. The most important environmental problem of the sector is the use of large volumes of high quality water and consequently the generation of large volumes of wastewater. The majority of water is utilised in wet processes such as dyeing, sizing and finishing. Thus these processes generate very large volumes of wastewaters which are generally with intense colour, high concentration of organic compounds and large variations in composition (Takahaski & Kumagai 2006). On that account, the results of the BAT study that are presented in this paper are focussed on BAT that are specific measures to reduce the use of high quality water and the discharge of high volume wastewater. Another problem in the sector is the intensive energy use. In general, energy in the textile industry is mostly used in the forms of: electricity, as a common power source for machinery, cooling and temperature control systems, lighting, office equipment, etc.; oil as a fuel for boilers which generate steam; liquefied petroleum gas; coal; and natural gas (UNIDO 1992).

These facts have motivated efforts on the improvement of the energy and water use efficiency in this industry, through the introduction of modern water and energy conservation technologies. In view of this fact, BREF Textile Document suggests many techniques related to process modifications, pollution prevention opportunities, use and optimisation of water and chemicals, control of raw materials, recovery, reuse and recycle options which in turn are experienced to result in significant reductions in terms of chemicals, water and energy without distorting the final product quality and hence improve production efficiency, environmental and economic performance of the textile factory (Kocabas 2008).

The importance of in-plant control technologies in textile industry has been indicated by many researchers. Dulkadiroglu *et al.* (2002) indicated that textile industry can achieve significant reductions in water use, raw material and energy consumption, wastewater production and in some cases even wastewater load with the implementation of in-plant control techniques. In a recent study, Fresner (1998) demonstrated the potential of the cleaner production approach to solve existing environmental problems of textile industry after a pilot study in a textile mill. In this study, water use could be reduced by 30%, the COD of wastewater by 30%, and the gas consumption of the dryers by 15%. These results have proved the potential of the concept of cleaner production. Van Veldhuisen (1991) grouped these in-plant control or cleaner production applications under four major headings: (i) water minimisation; (ii) wastewater recovery and reuse; (iii) chemical substitution and (iv) recovery of valuable substances, and indicated that significant reductions in water and energy use can be achieved by preventing the unnecessary consumption practices in textile mills.

Overview of the mill

The textile mill selected as the pilot plant is one of the largest companies in the world in terms of denim production. It is an integrated establishment having yarn production, dyeing, and finishing processes with an annual capacity of 20,000 tonnes of cotton fibre, and 45 million metres of denim production. With this production capacity, the mill is in the scope of the IPPC Directive. Water is supplied from the wells with a daily consumption rate of 5,000–7,000 tonnes. In the mill, there exists a wastewater treatment plant applying activated sludge process. Wastewaters generated from the sizing, dyeing, and finishing processes and also from all the facilities in the factory are treated and then discharged into the sewerage system of the municipality with the compliance of the discharge standards.

Alternative BAT for wastewaters

Process specific data is mentioned to be vital in order to give priority to the processes in terms of pollution prevention options (EC 2006) and to study the BAT with a view to establishing the emission limit values. Prior to the initiation of the present study, the processes involved in the production chain with types, production amounts, the major waste streams had been investigated; a comprehensive wastewater monitoring programme had been realised; major waste streams requiring treatment had been identified; based on the BREF Textile Document, candidate BAT had been determined; and the lab-scale tests had been performed to evaluate the effectiveness of candidate BAT.

As presented in Table 1, major waste stream from the mill is the indigo dyeing wastewater that is with a very high pollution load. Another major waste stream in the mill is from the finishing process. This waste is highly alkaline due to the presence of NaOH in it (not shown in Table 1). As the management strategy for this wastewater was caustic recovery, it was not included in the present BAT selection study. All waste streams other than indigo dyeing and finishing are thought to reach to the already existing wastewater treatment plant of the mill as these wastewaters are relatively very small in volume and originate from many different processes. Consequently, the basic scenarios considered are water recovery from the indigo dyeing wastewaters and treatment of the mixed wastewater generated from all of the other processes of the mill.

For water recovery from indigo dyeing wastewaters, different alternatives were developed. These were membrane filtration and advanced oxidation targeted at water recovery. As pre-treatment to these alternatives, coagulation and microfiltration were applied. In this scenario of water recovery from indigo dyeing wastewaters, it was proposed that the waste streams would be reaching to the existing wastewater treatment plant in the mill and treated there by activated sludge process.

Table 1 | Wastewaters and their characteristics

	Wastewaters considered in the cost-benefit analysis		
Parameters	**Dyeing wastewater**	**Wastewater before activated sludge system**	**Wastewater after activated sludge system**
COD (mg/L)	1,200	1,800	800
Color (Pt-Co)	5,000	3,800	2,100
Flow (m^3/day)	1,140	3,250	3,250

There were eight different treatment options for the treatment of the mixed wastewater coming from all the units of the textile mill. These were biological treatment (activated sludge process) followed by microfiltration and nanofiltration, membrane bioreactor, ozonation, ozonation with hydrogen peroxide, biological treatment followed by ozonation, Fenton oxidation, biological treatment followed by Fenton oxidation, biological treatment followed by Fenton oxidation and microfiltration.

Both water recovery and mixed wastewater treatment options were technically screened according to their COD and colour removal efficiencies, water recovery performances, their sludge generation potentials and their clogging problems if these exist. The aim was to determine the most technically applicable alternative/s. As a result of this screening, membrane filtration which is composed of MF plus NF and ozonation processes appeared to be the most applicable alternative technologies pertinent for water recovery from dyeing effluents. On the other hand, for the treatment of the mixed wastewater, activated sludge process followed by MF and NF, membrane bioreactor, ozonation, ozonation with hydrogen peroxide, biological treatment followed by ozonation alternatives were selected for further assessment. Therefore, among the alternatives, Fenton oxidation was screened out due to excessive sludge generation and the relevant sludge disposal problems.

METHODOLOGY

Study approach

The IPPC Directive (EC 2002) indicates that, while determining the best available technique, not only the option that has the lowest impact on the environment as a whole is decided as BAT, but also the most economic option should be selected.

For the purpose of the present study, the wastewater characteristics presented in Table 1 were used and the costs and benefits of the alternatives were estimated based on these data. Firstly, the alternative wastewater management options presented above were assessed in terms of their environmental effects that need to be prevented, or where this is impossible should be minimised in order to protect the environment as a whole. In order to assess the environmental effects of each alternative scenario considered for water recovery and wastewater treatment, pollutants generated from each alternative were compared with respect to six environmental themes, which are human toxicity, global warming, aquatic toxicity, eutrophication, ozone depletion, photochemical ozone creation potential. Alternatives considered for water recovery studies and wastewater treatability studies in the selected mill have no direct cause on the abovementioned environmental themes. However, due to indirect effects of emissions released from the energy consumptions, cross-media effects were assessed.

After the assessment of the environmental performances of the alternatives, these alternatives were evaluated in terms of economic considerations. The costing methodology given in the Reference Document (EC 2006) was applied to the alternatives under consideration for water recovery and wastewater treatability. Firstly, investment costs and operating costs of each alternative were evaluated using unit cost data derived from many different sources such as reports, journals, websites, and conference proceedings. Revenues were determined and cash flow

Table 2 | Cross-media effects of water recovery and mixed wastewater treatability alternatives

Alternative Options	Human toxicity (kg lead equivalents)	Global warming (kg CO_2 equivalents)	Acidification (kg SO_2 equivalents)	Photochemical ozone creation (kg ethylene equivalents)
MF + NF	0.22	2,737	4.21	14.34
Ozonation	1.27	15,846	24.38	83.00
AS + MF + NF	0.68	8,487	13.06	44.45
MBR	0.27	3,422	5.27	17.92
Ozonation + AS	5.03	62,798	96.61	328.91
Peroxone + AS	6.36	79,362	122.10	415.67
AS + Ozonation	1.59	19,849	30.54	103.96

Table 3 | Specific energy consumption figures

Alternative techniques	Specific energy consumptions (kWh/m^3)
MF + NF	5.70
Ozonation	13.20–19.80
AS + MF + NF	6.20
MBR	2.50
Ozonation + AS	45.88
Peroxone + AS	52.98
AS + Ozonation	14.50

analysis was performed for 15 years of economic lifetime. Moreover, net present values (NPV), internal rate of returns (IRR), and annual costs of each alternative option were calculated. Discount rate is the rate at which future cash flows are discounted to convert them to present values (Brown 2007). While calculating the NPV for the alternatives, discount rate was assumed to be 10%. In carrying out financial analysis, sensitivity analysis was implemented in order to identify the critical variables for the alternatives (EC 2002). This was done by letting the variables vary according to a given percentage change and observing the subsequent variations in financial indicators. This analysis provides data for the decision that shows how the economic variables would change when key project factors vary from their estimated values (Brown 2007).

Once the environmental effects and the costs had been established, the likely costs and benefits of the alternatives were compared. This comparison was done in terms of cost effectiveness that allows the economic cost of implementing a technique to be balanced against the environmental benefit that it delivers. This assessment led to the BAT that represents value for money in terms of environmental benefit. Finally, 'Industry Structure', the 'Market Structure', and the 'Resilience' of the sector were evaluated for a final decision on BAT for water management.

RESULTS

Environmental impact analysis

Firstly, specific energy consumption of each alternative option was gathered from the literature and, using the flow rates presented in Table 1, the environmental impacts of the energy requirement of each alternative were estimated. In the evaluation of the impacts, multiplication factors that are given in Annex 8 of the Reference Document, for the emissions of SO_2, CO_2, and NO_2 and also for the consumption of oil, gas, and coal per GJ of electricity generation were used and mass rate of emissions from each alternative was calculated (Table 2).

Financial analysis

For the financial analysis, the identification of those costs that relate to investment expenditure and those that relate to operating and maintenance costs was attempted. In evaluating operating costs, the specific energy consumption figures given in Table 3 were used. These figures were either obtained directly from the literature (Tchobanoglous *et al.* 2003) or calculated based on data obtained from the literature (Dogan 2008). Similarly, for the estimation of investment cost, the flowrates presented in Table 1 were considered and multiplied by unit investment costs derived either from the literature or from the market. The estimated costs are presented in Table 4. As can be seen, the highest

Table 4 | Financial figures for water recovery and mixed wastewater treatability alternatives

Alternative techniques	Investment cost (USD)	Operating cost (USD/m^3)	NPV (USD)	IRR (%)
MF + NF	632,949	0.60	1,201,370	42
Ozonation	3,118,746	2.85	−9,385,198	–
AS + MF + NF	1,832,013	1.49	−2,992,510	–
MBR	3,761,574	0.64	2,925,140	24
Ozonation + AS	6,210,184	4.17	−35,389,643	–
Peroxone + AS	6,210,184	5.62	−46,884,731	–
AS + Ozonation	1,711,541	1.89	−15,135,382	–

Table 5 | Cost effectiveness analyses

Alternative techniques	Annual costs (USD)	Annual reduction of COD (kg/year)	Cost effectiveness (USD/kg COD reduced)
MF + NF	277,621	632,472	0.45
Ozonation	1,357,298	399,456	3.77
AS + MF + NF	1,738,425	1,921,725	0.89
MBR	863,747	2,079,258	0.42
Ozonation + AS	5,737,486	1,003,768	5.10
Peroxone + AS	7,439,956	1,003,768	6.76
AS + Ozonation	2,255,637	1,067,625	2.05

investment and operating cost figures were for the advanced oxidation followed by activated sludge process options which aim at the treatment of the mixed wastewater. On the other hand, the lowest cost was for MF + NF water recovery option.

There were six variables assumed as critical in the financial analysis. These were influent COD of the wastewater (maximum, average, minimum), influent colour value of the wastewater (maximum, average, minimum), discount rate (6%, 8%, 10%), unit energy cost (0%, 5%, 10% change), total operating cost (0%, 1%, 2% variations), and exchange rate variation (0%, 1%, 2% variations). In the sensitivity analysis, by changing the critical variables' values, the percentage change in investment costs, operating costs, and net present values was evaluated (not shown). The greatest impact on the investment costs was determined due to the variation in the exchange rate in all of the alternative options whereas operating costs of all of the alternatives were affected mostly by energy cost change. On the other hand, discount rate only affected the net present values of the alternatives. It was observed that wastewater's colour was not a critical variable influencing the cost. Only the treatment efficiency was affected by the colour variation.

Evaluating the alternatives

In accordance with the Reference Document on "Economics and Cross-media Effects", after the estimation of both the environmental effects and economic costs for alternative techniques, each of which is a potential for BAT, the comparison of these alternatives should be done to determine which meet the BAT criteria. Therefore, cost effectiveness of each alternative, apportionment of costs between alternatives, and balance between costs and environmental benefits should be assessed. Cost effectiveness analysis is a type of cost-benefit analysis which is more simplified as environmental benefits are quantified rather than valued. Cost effectiveness of an alternative technique is defined typically as annual cost of the technique per annual reduction of emissions due to its application (EC 2006).

Table 6 | Summary of cross-media effects for the selected alternatives

		Volume treated (m^3/day)	Human toxicity (kg lead eq.)	Global warming (kg CO_2 eq.)	Acidification (kg SO_2 eq.)	Photochemical oxygen creation potential (kg ethylene eq.)
Water recovery from dyeing wastewaters	MF + NF	1,140	0.22	2,737	4.21	14.34
	AS	2,452	0.04	516	0.79	2.70
	Total	3,592	0.26	3,253	5.00	17.04
Treatment of the mixed wastewater by MBR	MBR	3,250	0.27	3,422	5.27	17.92

Table 7 | Summary of financial analysis for the selected alternatives

		Investment cost (USD)	Operating cost (USD/m^3)	NPV (USD)	Internal rate of return (%)	Annual cost (USD)	Cost effectiveness (USD/kg COD removed)
Water recovery from dyeing wastewaters	MF + NF	632,950	0.60	1,201,370	42	277,621	0.59
	AS	–	0.87	–	–	–	–
	Total	632,950	0.78	558,566	26	370,584	0.27
Treatment of the mixed wastewater by MBR	MBR	3,761,574	0.64	2,925,140	24	863,747	0.42

It can be seen from Table 5 that, to reduce each kilogram of COD, more money should be paid in the ozonation process for water recovery alternatives. However, cost of the membrane filtration process is one-eighth of that of the ozonation process. Also, it can be concluded that MBR application could be thought to be the best alternative in terms of cost effectiveness.

Economic viability of the textile sector in Turkey

The textile sector is one of the major industries for the Turkish economy. Moreover, it has also taken an important share in the world trade. At the beginning of the 1980s, the total value of Turkish textile exports equalled 190 million USD. However, in 1999, this value increased sharply to 9.8 billion USD (Akalin 2001). Re-known as one of the major innovation leaders of jeans and sportswear, the selected mill has the vision of "to be a model company internationally in the sportswear sector in terms of business excellence". The company's mission is "as a preferred supplier to manufacturers of sportswear clothing, who give priority to quality and creativity, our basic task is to be able to plan, sustain and create high economic value". With this vision and mission, the company is currently one of the leading companies in the markets in which it offers service. Thus, it is thought that for the mill in consideration the proposed investments are viable and the company can absorb the extra cost, or transfer these costs on to the customer or suppliers.

CONCLUSIONS

As regards the adaptation of the IPPC Directive, it is necessary to set effluent criteria for an industrial facility in the permit that would be given on the basis of BAT application. Thus, it was essential to determine a single set of BATs for the mill. To this end, two BAT alternatives determined for the water recovery from indigo dyeing wastewater and for the treatment of the mixed wastewater were further compared. Tables 6 and 7 present the summary of this comparison (Dogan 2008). As can be depicted, membrane filtration application for water recovery from indigo dyeing wastewater along with activated sludge treatment for the other waste streams was found to be superior to MBR application for the mixed wastewater with respect to both cross-media effects and financial analysis. From this comparison, the selected BATs for the mill were based on membrane technology that appeared to be the most promising alternative in terms of recovery and treatability. In addition, this technology was also economically applicable. Considering the economic viability of the selected BAT, it was thought that the mill can afford the investment need of 632,950 USD as there will be a chance of offsetting the initial high cost of implementing the selected process in the long run by providing water recovery with greater efficiency.

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