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Sustainable Production Methods in Textile Industry

Miray Emreol Gönlüğü

Abstract

The textile industry is part of the industries that continuously harm the environment because of the high water consumption and the presence of various pollutants in the wastewater. Wastewater treatment is lacking or includes only physical treatment in underdeveloped and developing countries due to installation and operating costs of a treatment plant. As a result, a broad spectrum of hazardous and toxic substances, such as (azo) dyes, heavy metals, acids, soda, and aromatic hydrocarbons, pollute precious sources of clean water, in which untreated water is discharged. The main solution to this problem is to reduce the treatment cost. For this purpose, the process should be optimized to reduce the amount of water and chemicals. In this chapter, first studies on the reference document (BAT) referred by the European Council are reviewed. Minimizing production costs, obtaining high-quality products, and reducing the amount and the pollutant content of wastewater are complex problems that cannot be solved by the conventional optimization methods. Therefore, nonconventional optimization methods applied on the textile processes are also reviewed from the latest studies in the literature.

Keywords: sustainability, BAT, optimization, metaheuristics, genetic algorithm

1. Introduction

Textile industry is the foremost sector in terms of the discharged volume and the composition of the wastewater [1]. Most of the textile production processes, such as scouring, washing, dyeing, bleaching, sizing, and finishing, consume large volumes of fresh water and discharge large volumes of effluent which are generally with intense color, high concentration of organic compounds, and large variations in composition [2, 3]. Especially wet process, which has five main stages including pretreatment, dyeing, finishing, drying, and quality control, is the major part of the textile industry due to the long processing time and technical complexity [4]. Specific water consumption range is given as 10–645 L/kg product for the textile industry and 21–645 L/kg for the mills with finishing and dyeing processes in (ref BAT-EC). In another source, it is reported that the consumed amount of water could reach to 932 L/kg product depending on the fiber and applied technology [5–7].

In recent years, depleted resources, global warming, and climate change resulting in challenging regulations enforce manufacturing enterprises to give efforts to reduce the waste of the processes, which motivate firms for the sustainable (cleaner) production. Besides environmental considerations, the effective planning of the production is also obligatory to reduce the production costs to be able to compete with other manufacturers. Moreover, an empirical study built on the

theoretical model derived from the Cobbe-Douglas production function revealed that customers prefer the environmentally friendly goods produced by using cleaner production principles in Japan [8].

Cleaner production is defined in the report of the United Nations Environment Program (UNEP) [9] as “the continuous application of an integrated preventive environmental strategy to processes, products, and services, to increase overall efficiency, and reduce risks to humans and the environment.” Unlike the end-of-pipe (EOP) treatment, which takes the design of the production fixed and attempts to solve the problem after the occurrence of pollution, cleaner production approach aims to solve the problem before it happens by considering pollution and wastes mostly as a result of the inadequacy, inefficiency, and ineffectiveness of the design, utilization of resources, and production processes stages. Necessary developments in these stages are suggested to provide sustainability to the processes [10].

The European Commission referred the best available techniques (BAT) reference document for the textile industry in 2003 [11]. The purpose of the document is to achieve a high level of protection for the environment as a whole. The document includes general information on the industrial sector concerned and on the industrial processes used within the sector, data and information about emission and consumption levels, emission reduction and other techniques that are considered to be most relevant for determining BAT and BAT-based permit conditions, and the techniques and the emission and consumption levels that are considered to be compatible with BAT.

Optimization ensures the most efficient use of existing processes. In the production facilities, the problem of reducing the use of water and energy used to produce high-quality products for a limited time is a complex problem to solve with conventional optimization methods. The consumption of energy and by means of noncostly changes and production planning, the use of waste treatment, and the reduction of water usage in the process, the environment will be covered. Multi-objective optimization methods target this type of complex problems.

Metaheuristic optimization methods are problem-independent techniques unlike the heuristic methods. However, it is necessary to introduce the intrinsic parameters of the problem to adapt the technique. Application of metaheuristic optimization methods to textile processes is a novel subject, and there are different perspectives on it. In some of the studies, the lot size and scheduling [12] are tried to optimize, while some of them try to model the end-of-pipe treatments [13–19]. However, only a few studies are meant to reduce the amount of wastewater and improve the process for clean production [4, 20–23].

In a recent review [24], different approaches and methods in water conservation for textile wet processing industry were effectively classified into five main groups that have many subgroups: (i) water conservation through textile wastewater treatment and reuse, (ii) water conservation through innovations in textile processing machines, (iii) water conservation through innovations in textile processing methods, (iv) water conservation through innovations in textile chemicals and auxiliaries, and (v) tools for processing water use analysis and conservation. However, only several studies on BAT were mentioned briefly while there is no information on the optimization of production scheduling of wet processes.

In this study, the methods of effective planning of the production of the textile industry have been compiled from the studies. There has not been a review on this scope in the literature so far. This review aims to introduce and compare the different perspectives on sustainable production in textile industry via BAT and nonconventional optimization methods, which suggest affordable solutions to reduce the pollution without increasing operating costs. It is also possible to reduce the energy used in some of the applications.

2. Approaches to sustainable production

Sustainable production is important in order to efficient use of resources, reduction of waste, and related costs. There are several reference documents that are suggesting techniques to analyze and modify the textile processes to decrease the consumption of water and energy resulting in the reduction of the pollution.

As a valuable contribution to the literature on the cleaner processes, 18 emerging technologies using the energy and water effectively in the textile industry were explained with their backgrounds, benefits, and commercialization [25]. The technologies were compared with the ability of water saving, energy saving, material saving, and time saving in addition to the reduction in wastewater. As a result, technologies fulfilled all the abilities were enzymatic treatments, ultrasonic treatments, advanced cotton fiber pre-treatment to increase dye receptivity, plasma technology, and foam technology in the finishing process.

In the literature, BAT and metaheuristic optimization methods are studied to provide sustainability and clean production to the textile processes.

2.1 Applications of the best available techniques (BAT)

Alkaya and Demirer studied environmental performance evaluation and sustainable production applications in a woven fabric manufacturing mill in Turkey [26]. The aim of the study was to decrease water consumption, wastewater generation, energy consumption and resulting greenhouse gas emissions, and sodium salt consumption. Baseline data were collected for 8 months. The amount of water consumed per kilogram of product was found as 138.9 L. Additional 4 months spent on implementation and 12 months for monitoring the sustainable production applications. Environmental benchmarking was done by collecting specific resource consumption and waste generation data, which are known as Environmental Performance Indicators (EPIs). As a result of investigation of the process by using BAT, five applications were applied on the process: use of drop-fill washing instead of overflow, reuse of stender cooling water, reuse of singeing cooling water, renovation of water softening system, and renovation of valves and fittings. As a result, amount of wastewater of the process was reduced by 43.4% and CO₂ emission, which is mainly originated from energy consumption, was decreased by 20.2%. Total water consumption was also reduced by 40.2%. Additionally, total energy consumption was decreased by 17.1%.

Ozturk and coworkers investigated a cotton and polyester knitting-weaving fabric and subsequent finishing-dyeing mill in Turkey in terms of BAT applications [5]. The mill with two main production lines had bleaching and dyeing capacities of 2412 and 6682 tons/year, respectively. Freshwater consumed each day was almost 3100 tons before the modification. After the data for 3 years were analyzed, 14 BAT including good management practices, water minimization, and chemical minimization/substitution were chosen from 92 suitable improvements considering mainly their priority, techno-availability, and potential benefits. Some of them are reuse/recovery of washing/rinsing and softening wastewater, reuse of suitable dye bath, caustic recovery from mercerization process wastewaters using membrane process, chemical substitution, and so on. The mill was consuming 95–102 L water per kg product, 9–10 g dyestuff/kg product, and 347–383 g/kg product. After the implementation of selected BATs, the probable reduction in the consumption of water and chemicals was estimated as 43–51 and 16–39%, respectively. The wastewater flow rate was expected to be reduced by 45–52%. Payback period of the implementation was calculated as 26 months at most.

Kocabas and coworkers [6] carried out BAT on a denim manufacturing mill in Turkey. First, they gathered information about the sources of wastewater and their type, quantity and composition as in the BAT reference document (ref BREF).

The consumption of water and energy was recorded from the beginning till the end of the study. Seven operations were evaluated as installing the flowmeters, semi-countercurrent rinsing, reusing the wastewater after treatment, recovering and reusing the wash water from mercerization, reusing the concentrate stream of reverse osmosis plant in sanitary, minimizing the water consumption during regeneration of ion exchangers used in water softening, and reusing the cooling waters in the production process. After implementation of the BAT actions, total water and energy consumption per kg fabric were reduced by 29.5 and 9%, respectively. As a result, saving from the expenses was roughly estimated as EUR 987,000 annually, while total amount of investment was EUR 45,000. There is no information given about the reduction of the amount of wastewater as a result of improvement.

Yukseler and coworkers [27] tried to implement cleaner production to denim manufacturing textile mill in Turkey. The BAT methodology was followed to reduce the amount of consumed water and wastewater generation through the characterization of the wastewater and selection of the wastewater streams to reuse in the process. Selected BAT actions were reusing of wastewaters in the dyeing process after the treatment, recovering of caustic from alkaline finishing wastewaters, reusing of biologically treated composite mill effluent after membrane process, minimizing the wash water consumption in the water softening plant, reusing the concentrate stream from reverse osmosis plant, and reducing water consumption by countercurrent washing in dyeing and finishing processes. As a result, the reduction in the total specific water consumption was evaluated as 30%.

Ozturk and coworkers studied on the improvement of a wool and acrylic fiber production mill in Turkey to a cleaner production by using BAT measures [28]. Suggested BAT actions were reuse of wastewaters from wool yarn softening, LP-VP printing machines and acrylic yarn washing, machinery modifications, reuse of steam condensate, and good management practices. Additionally, replacement of 12 toxic chemicals with biodegradable ones and installing an automatic dosage system were suggested in order to reduce the chemical load in the wastewaters. Energy saving precautions were determined as the implementation of energy recovery systems for high-temperature wastewater flows and flue gas streams, process monitoring control, and various machinery optimizations. After the mass balance calculations, it was estimated that all of the implementations could reduce total water consumption by 35–65%, total energy consumption by 70%, chemical load by 31%, and waste generation by 5–10%. The payback period of the installations was estimated as 4 years.

Kalliala and Talvenmaa investigated the major six textile manufacturers in Finland considering environmental effect of wet processing and suggested appropriate actions of BAT [29]. The study was found especially important since all the industrial manufacturers discharge their wastewater to municipal sewage treatment plants under a strict control in Finland. Energy, water, and chemical consumption data of the processes were collected from the process statistics of the companies. Energy consumption was evaluated between 55 and 152 MJ/kg product, while water consumption was between 144 and 380 L/kg product, and the CO₂ emission was found between 3484 and 8937 g/kg product. A detailed chemical consumption table was also prepared for the study. As a result, suggested BAT actions were planned as the application of automatic dosing of chemicals and dyes, effective use of equipment capacity, recycling and monitoring of process water and energy used, recovery and purification of process liquor, monitoring of wastewater with toxicity analyses, and monitoring of flue gas emissions.

A LIFE funded project BATTLE (05 ENV/IT/000846) was proposed to evaluate the applicability of BAT such as those described in the textile reference documents (BREFs) for the implementation of the European Directive IPPC 96/91/CE to small-medium enterprises (SMEs) in terms of technical and economical feasibility of water recycling for European textile sector [30]. In the project, a prototype

application was included for cleaner production in a textile dyeing and printing company. After the environmental impact and process data were evaluated, the process was modified to recover and reuse the process water. As a result, the amount of total recovered water was determined as 7691 m³/month with an appropriate quality. The reduced values in the water consumption, energy consumption, wastewater, and greenhouse gas generation given in the literature are tabulated in **Table 1**.

2.2 Metaheuristics

Using nonconventional optimization methods in the textile industry by considering both the delivery date and environmental issues is a quiet new area in the literature. Although the major part of these studies is accumulated on the scheduling of the dyeing process, novel optimization and decision-making algorithms (AI—Artificial Intelligence) have a huge potential in a large area of textile production such as cotton grading, yarn CPS (count strength product) prediction, yarn grading, fabric colorfastness grading, fabric comfort, and fabric inspection [31].

The studies on the nonconventional optimization methods can be classified into two groups: studies on the development of hybrid metaheuristic algorithms and the studies on the application of the genetic algorithm in real processes.

2.2.1 Developed hybrid algorithms

Huynh and Chien [4] worked on the parallel batch processing machine scheduling with sequence-dependent setup, arbitrary job size, different due date, and incompatible job family. They proposed a multi-subpopulation genetic algorithm with heuristics embedded (MSGGA-H) to improve batching and scheduling simultaneously. The validity of the algorithm was tested by an empirical study with data supplied from a textile dyeing manufacturing in Taiwan. The results have shown the practical viability of the proposed MSGGA-H. The reduction of used water and wastewater were not reported in this study.

In another study on the textile dyeing process [20], parallel machine scheduling problem with environmental requirements and tardiness were solved by generating a multi-objective genetic algorithm with tabu-enhanced local search (MOGA-TIG). Three objective functions were defined to obtain a sustainable schedule: the number

Mill/Process	Reduction in				Ref.
	Wastewater (%)	Total water consumption (%)	Flue gas (%)	Total energy consumption (%)	
Cotton and polyester fabric/ Finishing and dyeing	45–52	49–55	—	—	[5]
Denim/Dyeing and finishing processes	—	29.5	—	9	[6]
Woven fabric/Dyeing, finishing, cooling, and utilities	43.4	40.2	20.2	17.1	[26]
Denim/Waste-water treatment	—	30	—	—	[27]
Wool and acrylic fiber/Dyeing and finishing	—	35–65	25–65	70	[28]

Table 1.
 The reduction values in the water consumption, energy consumption, wastewater, and greenhouse gas generation.

of setups to be minimized to reduce the water consumption and use of detergent caused by the changing of the job, the utilization of the machines to be maximized to prevent the pollution caused by ineffective usage of the batch capacity, and tardiness that may cause penalty on late completion of the jobs to be minimized. When the performance of the algorithm was compared with the latest multi-objective evolutionary algorithms in the literature, it was concluded that the suggested algorithm gives a satisfactory solution in a short time. However, since the algorithm was not applied on a real industrial process, there was no data available for the reduction of the used water and dye in this study.

Zhang and coworkers studied on a similar process with the previous study, and they approached to the problem as bi-objective optimization model [21]. The objectives of the study were to reduce delivery tardiness cost and pollutant emission caused by the cleaning operation of setups before each job. Multi-objective particle swarm optimization algorithm enhanced by problem-specific local search

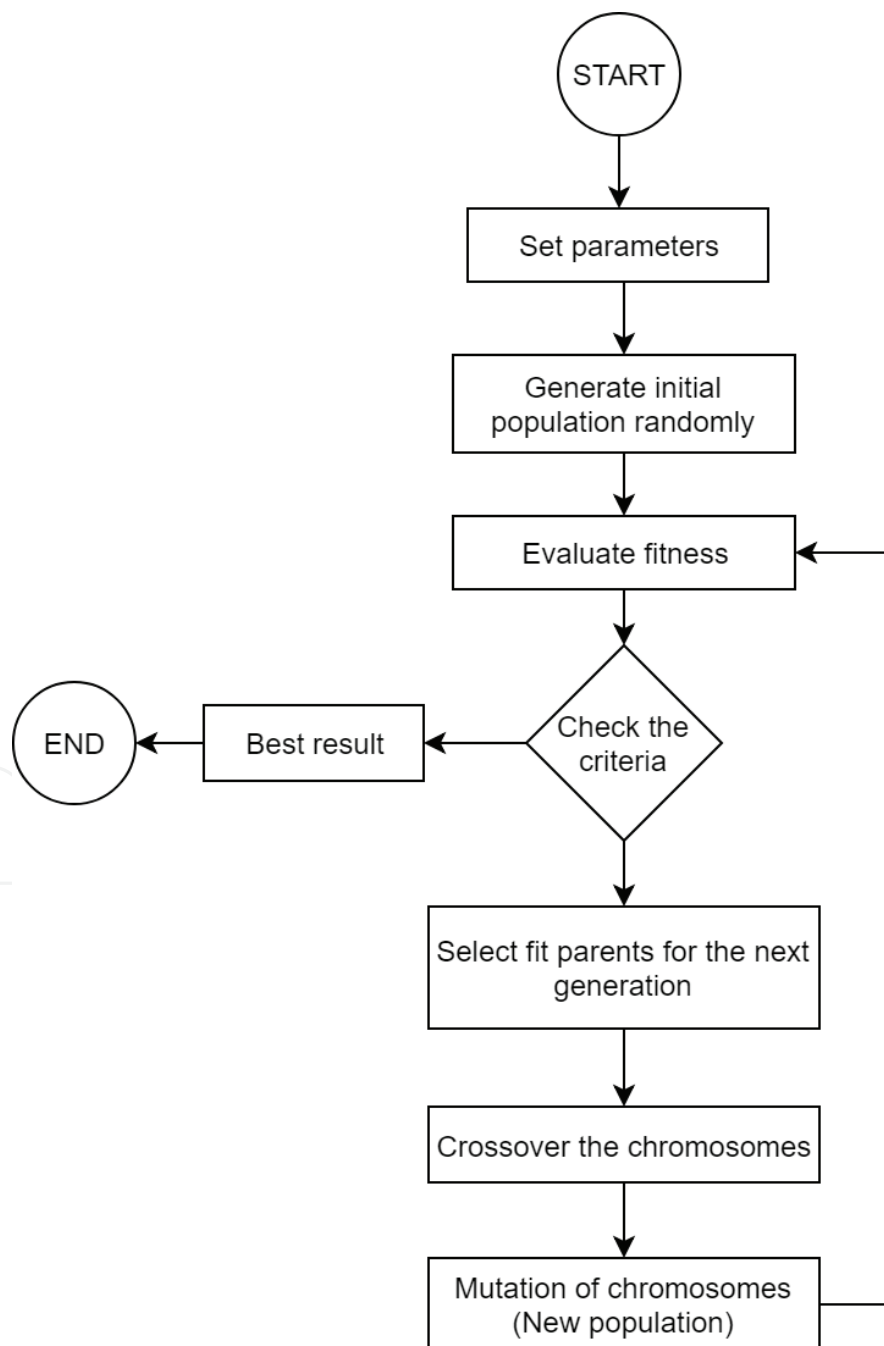


Figure 1.
Flowchart of the genetic algorithm [32].

(MO-PSO-L) technique was utilized to solve the problem. The algorithm was verified on computational experiments by using simplified realistic production data and also compared with the universal multi-objective optimizer NSGA-II and multi-objective imperialist competitive algorithm (MOICA). The performance of the algorithm was measured by using three indicators: the overall nondominated vector generation (ONVG), the C-metric (CM), and the Tan's spacing (TS). It was possible to conclude that MO-PSO-L algorithm found more Pareto solutions and became superior to other algorithms in terms of uniform distribution of the solutions.

2.2.2 Application of the genetic algorithms

Zhou and coworkers [22] used the genetic algorithm to schedule a dyeing process. Scheduling objectives are delivery time of the products, complete filling of the dyeing vessel, putting the same type, color, depth and production process of cloth in the same dyeing vessel, and sorting the depth of color such as from light to dark. Genetic algorithm was started with assigning all orders to different dye vats and producing a number of individuals. Each individual was checked to meet the delivery date. Then, fitness function was computed for the population. After the crossover and mutation steps, next generation was chosen according to the parent and child fitness. The procedure repeated itself until reaching the maximum number of evolutionary. The algorithm was verified on the data supplied from an enterprise in China. It was reported that the optimization of the schedule reduced the freshwater consumption about 18.4–21%, also resulting less wastewater.

The flowchart of a typical genetic algorithm is shown in **Figure 1**.

Jiang and coworkers applied genetic algorithm to the data obtained from a real process in China to optimize production schedule [23]. The aim of the study was to reduce the production time and the volume of freshwater consumed in the dyeing operation. The results showed that the optimized schedule could reduce the production time as 10–15% while reducing the volumes of freshwater and wastewater as 20–30 and 20%, respectively. Additionally, it was found that adding alternative production lines (from 1 to 4) in the process shortens the total production time and lessens the amount of wastewater.

3. Conclusion

Textile industry, which is dominated by small and medium enterprises (SMEs), has a wide variety of products with different colors, fabrics, and fabric types by its nature. Additionally, wet processes consume large amount of water, energy, and chemicals, which are expensive to separate in the treatment processes. In the last decades, the studies with environmental and financial considerations in the textile industry have been increased, and they offered cleaner production approach, such as best available techniques (BAT) referred by the European Council and the nonconventional (metaheuristic) optimization methods, instead of end-of-pipe approach.

From the literature, it was revealed that BAT actions offer a substantial water and energy savings up to 65 and 70%, respectively. However, many of the studies involve potential implementation results, not the real ones. Therefore, more implementation studies should be conducted on actual processes in order to encourage the other enterprises.

Through the age of Industry 4.0, the enterprises, which use intelligent techniques and effective planning, will survive. Consequently, the studies on the optimization of the dyeing process scheduling have become more complex and

multi-objective to be solved with nonconventional optimization methods. In the literature, only a few studies were found because of the novelty of the subject. However, those studies were indicated a remarkable environmental benefit while reducing the costs of the wastewater treatment process. The reduction of water consumption was obtained up to 30% without any installations to the process.

When the literature on BAT and metaheuristic studies are compared, it is seen that the studies used BAT has more industrial sense and feedback; however, just insufficient number of studies that were used metaheuristic optimization quantified the improvement on the studied processes. The information on the application of the novel optimization methods on the actual industrial applications is necessary. Therefore, future studies on this subject will be fruitful for the literature.

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