

ASSESSING THE POTENTIAL BENEFITS FROM THE APPLICATION OF
BEST AVAILABLE TECHNIQUES IN THE TEXTILE INDUSTRY

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ABSTRACT

ASSESSING THE POTENTIAL BENEFITS FROM THE APPLICATION OF BEST AVAILABLE TECHNIQUES IN THE TEXTILE INDUSTRY

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The Integrated Pollution Prevention and Control (IPPC) Directive, which was recasted as the Industrial Emission Directive (IED) in 2010, is the main EU's legal instrument regulating pollutant emissions from industrial establishments. As a candidate country to join the EU, Turkey is expected to harmonize domestic legislation with the IED and implement it. In 2018, the Ministry of Environment and Urbanization (MoEU) published a draft regulation entitled "Integrated Pollution Prevention and Control (IPPC)" for the transposition and implementation of the IED in Turkey. According to this regulation, in setting the permit conditions for the IPPC installations best available techniques (BATs) should be taken as the reference, and BATs to comply with will be published as sectoral communiqués. One of the draft sectoral communiqués prepared so far is for the textile sector. In this study, an assessment of the benefits from implementing BATs presented in this draft communiqué was carried out. First, a medium-sized textile mill was selected as the study plant and the BATs to be implemented in this plant for the IPPC compliance were identified. Then, a bottom-up assessment was carried out to evaluate the monetary benefit that will arise from the adaptation of each BAT. In this assessment,

information gathered from literature and the study plant was used and the benefits of implementing each BAT were calculated as monetary equivalent. The total monetary benefit of fitting BATs to be received from a BAT compliance investment of €689,500 was calculated as €7,157,465/yr with a pay-back period of a maximum of 2 years. Finally, the potential saving to be obtained for Turkey with the implementation of the BATs given in the draft communiqué by the IPPC textile factories was calculated as €1,057,500,665. The BATs were then grouped according to the extent to which the benefits outweighed the costs and a brief adaptation timeline was proposed accordingly.

Keywords: BAT, Best Available Techniques, IPPC Directive, Textile Industry

ÖZ

TEKSTİL ENDÜSTRİSİNDE MEVCUT EN İYİ TEKNİKLERİN UYGULANMASIYLA SAĞLANACAK POTANSİYEL FAYDALARIN DEĞERLENDİRİLMESİ

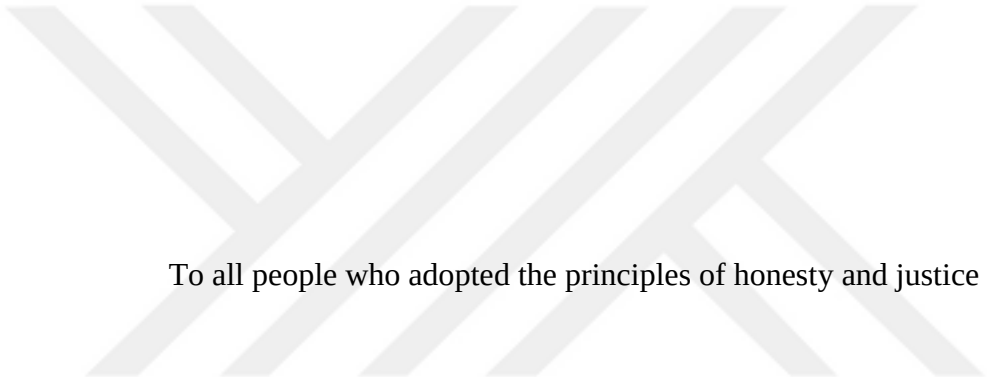
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Entegre Kirlilik Önleme ve Kontrol (EKÖK) Yönetmeliği Avrupa Birliği'nin kirlilik önleme ve emisyon azaltımı konusunda temel aldığı direktiftir ve 2010 yılında Endüstriyel Emisyonlar Direktifi (EED) adını almıştır. Türkiye'den, Avrupa Birliği'ne aday bir ülke olarak, kendi iç mevzuatını EED ile uyumlu hale getirmesi ve uygulaması beklenmektedir. 2018 yılında, Çevre ve Şehircilik Bakanlığı (ÇŞB), EED'nin Türkiye'ye aktarılması ve uygulanması için "Entegre Kirlilik Önleme ve Kontrolü" başlıklı bir taslak yönetmelik yayınlamıştır. Bu yönetmeliğe göre, IPPC yönetmeliğine tabi olan tesislerin izin koşulları belirlenirken Mevcut En İyi Teknikler (MET) referans olarak alınmalıdır ve uyulması gereken MET'ler sektörel tebliğler olarak yayınlanacaktır. Şu ana kadar hazırlanan sektörel tebliğ taslaklarından biri tekstil sektörü içindir. Bu çalışmada, bu taslak tebliğde sunulan MET'lerin uygulanması ile elde edilecek faydaların değerlendirmesi yapılmıştır. İlk olarak, çalışma tesisi olarak orta ölçekli bir tekstil fabrikası seçilmiştir ve IPPC'ye uyum için bu tesiste uygulanacak olan MET'ler belirlenmiştir. Ardından, her bir MET'in uygulanmasıyla elde edilecek maddi kazancı değerlendirmek için aşağıdan

yukarıya bir deęerlendirme yapılmıřtır. Bu deęerlendirmede literatürden ve alıřılan tesisten edinilmiř bilgiler kullanılmıř olup, her bir MET'in uygulanması ile elde edilecek fayda parasal karřılık bakımından hesaplanmıřtır. Toplam yatırım maliyeti 689,500 € olan MET'lerin uygulanması ile elde edilecek olan toplam maddi kazanç yılda 7,157,465 € olarak maksimum 2 yıllık geri ödeme süresi ile hesaplanmıřtır. Son olarak, taslak teblięde verilen MET'lerin Türkiye'deki IPPC kapsamına giren tüm tekstil fabrikaları tarafından uygulanması ile elde edilecek potansiyel tasarruf 1,057,500,665 € olarak hesaplanmıřtır. MET'ler daha sonra faydaların maliyetlerden ağır bastıęı dereceye göre gruplandırılmıř ve buna göre yaklaşık bir uygulama takvimi önerilmiřtir.

Anahtar Kelimeler: MET, Mevcut En İyi Teknikler, IPPC Direktifi, Tekstil Endüstrisi



To all people who adopted the principles of honesty and justice

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LIST OF ABBREVIATIONS

ABBREVIATIONS

AC	Alternating current
BAT-AEL	Emission levels associated with the best available techniques
BAT	Best Available Technique
BESTÜ	Belirli Sektörlerde Temiz Üretim Uygulamaları
BREF	Best Available Techniques Reference Document
CO ₂	Carbon dioxide
COD	Chemical oxygen demand
DN	Diametre nominal
EED	Endüstriyel Emisyonlar Direktifi
EKÖK	Entegre Kirlilik Önleme ve Kontrol Yönetmeliği
ELV	Emission Limit Values
EU	European Union
GJ	Giga joules
HT	High temperature
IED	Industrial Emissions Directive
IPPC	Integrated Pollution Prevention and Control
KJ	Kilo joules
LCPD	Large Combustion Plants Directive
MAM	Marmara Araştırma Merkezi
MBR	Membrane bioreactor
MET	Mevcut En İyi Teknik
MJ	Mega joule
O ₂	Oxygen
PVA	polyvinyl alcohol
RO	Reverse osmosis
TDS	Total dissolved solids
TL	Türk lirası
UNEP	United Nations Environment Program
USD	United States Dollar
VFD	Variable Frequency Drives
VSD	Variable Speed Drives
WID	Waste Incineration Directive

CHAPTER 1

INTRODUCTION

The Integrated Pollution Prevention and Control Directive (IPPC Directive) (96/61/EC) that was released in 1996 aims to achieve a high level of protection of the environment by reducing harmful emissions from industrial installations across the European Union (EU). According to this directive, pollution prevention and control must be managed in an integrated way by taking water, soil and air as an inseparable whole. This directive is accepted as the leading regulatory instrument of the EU in managing emissions from industrial installations [72]. The IPPC Directive aims to prevent and reduce emissions to air, soil and water resulting from industrial and agricultural activities with a high pollution potential and this directive requires having a permit which can be taken only when certain situations are met of these industries. In this way, industries responsible for their actions, and need to prevent and reduce pollution themselves in order to comply with the Emission Limit Values (ELVs) that were determined before based on the best available techniques (BATs) for each sector separately. According to the IPPC, permits and ELVs in the permits must be based on BAT which is defined in the sectoral BAT Reference Documents (BREFs) [60].

In 2010, the IPPC Directive was replaced by the Industrial Emission Directive (IED) (2010/75/EU) and after that, the IED became the main EU instrument regulating pollutant emissions from the industries. The IED replaced not only the IPPC Directive but also recasted six other existing directives [60]. In addition, the IED defined the role of BAT and required that “BAT conclusions” or BATC are the reference points used to set permit conditions for installations covered by the IED. The BAT conclusions are the documents that contain the final evaluations and lay down the conclusions on BAT, their description, information to assess their

applicability, the emission levels associated with the BAT (BAT-AELs), associated monitoring, associated consumption levels and, where appropriate, relevant site remediation measures. Permit conditions are not to exceed the ELVs associated with the BATs as described in those BAT conclusions. The industrial and agricultural sectors covered by the IED are given in Annex I of the Directive.

The textile industry¹ which falls under the IED is one of the most polluting industries because of the produced wastewater amount and its highly polluted composition. Lots of various and complex series of processes requiring the usage of thousands of different chemicals, tons of water and a considerable amount of energy are being carried out in the textile industry [16]. For this reason, it is in the scope of the IPPC-IED, and the European Commission published a BREF document (coded as TXT) for the textile industry to integrate cleaner production applications to the textile sector.

Turkey is a candidate country for full membership to the EU. For this reason, adaptations to legal requirements are important in this period. Since the IED is the main regulatory instrument for the control of industrial pollution and the textile industry is a backbone of the manufacturing industry in Turkey, meeting the requirements of the IED in the textile sector is critical for Turkey.

Turkey has a voice in the textile sector due to its exporter and importer role among the EU countries. Turkey is among the first ten textile supplier countries with a share of 3% in 2018 and it is 8th rank in the world. Germany, Italy, the USA, and England are the top four countries that import Turkish textiles, according to the 2019 records [70]. For this reason, the necessities of the textile industry given in the IED are closely concerned by Turkey especially in the EU membership adaption period. Since there are some legal requirements that Turkey must meet during this period, several projects have been conducting by the Ministry of Environment and

¹ Pre-treatment (operations such as washing, bleaching, mercerisation) or dyeing of textile fibres or textiles where the treatment capacity exceeds 10 ton/day.

Urbanization (MoEU) to decrease environmental damage and economic burden resulting from the processes in the textile industry.

The Turkish National Action Plan For EU Accession Phase-II (June 2015-June 2019) stated that the industrial pollution sub-sector is crucial for transposing the EU acquis in the field of industrial pollution control. As the responsible governmental body, the MoEU is to implement the IED and to harmonize the IPPC Approach of the IED into the national legislation. To this end, the MoEU published a draft regulation entitled “Regulation on Integrated Pollution Prevention and Control (IPPC)²” in 2018. According to this draft legislation; the industrial installations falling under the IED are required to obtain an IPPC permit from the MoEU complying with the sectoral communiqués that will be published by the MoEU. The sectoral communiqués are considered as the equivalent of BATC published by the EC.

The MoEU conducted sectoral projects for the IED compliance in the cement, textile, leather tanning, large combustion plants, automotive and production and processing of metals. One of these projects is the BESTÜ Project that aimed to prepare sectoral communiqués for the textile and leather industries. Within the scope of the BESTÜ Project, after conducting detailed and comprehensive studies and site visits to investigate the level of IED compliance and to collect data relevant to BAT compliance, the draft Integrated Pollution Prevention and Control communiqués for the textile and leather industries were prepared. This textile sector draft communiqué contains several BATs and BAT-AELs that set permit conditions for textile installations to decrease the environmental damage and economic burden resulting from textile processes. In the BESTÜ Project, the initial investment costs required for the compliance of the textile facilities with each BAT were determined, but the return on investment and the corresponding payback periods of these costs were not calculated.

² Taslak Entegre Kirlilik Önleme ve Kontrol Yönetmeliği (EKÖK Yönetmeliği), <https://cygm.csb.gov.tr/taslaklar-i-443>

1.1 Objective and Scope of the Study

The primary goal of this study is to assess the potential economic benefits which will be gained after the application of the selected compulsory BATs in a medium-sized IPPC textile installation, and from this, to calculate the total potential benefit or the total return on investment for all the textile mills covered by the IPPC Directive in Turkey. Another aim is to estimate the payback periods of the investment that will be required to comply with each BAT.

This thesis study is conducted as a part of the above-mentioned project called “Cleaner Production Applications in Certain Industries: Textile and Leather (BESTÜ)”. Within the scope of the Project; a set of compulsory and optional BATs for the textile industry, the current implementation status of these BATs and the investment costs that will be required for the compliance of textile facilities with each of these BATs in Turkey were determined. Based on these findings, a draft communiqué that involves 58 compulsory BATs was prepared. According to the draft Regulation on Integrated Pollution Prevention and Control (EKÖK)”, textile plants applying pretreatment operations such as washing, bleaching, mercerisation, dyeing processes where the installed capacity exceeds 10 tonnes per day fall under to the draft IPPC Regulation and are required to obtain an IPPC permit complying with this communiqué that involves 58 compulsory BATs [41].

According to the BESTÜ Project, the total number of textile plants that fall under the IED in Turkey is 220 [41]. In the present study, a medium-sized textile mill is selected as the study plant to represent these 220 facilities and all the calculations were done for this installation. A set of compulsory BATs in the draft communiqué in terms of their applicability and suitability for the selected mill were chosen and a cost-benefit analysis is done for each technique. Prior to the calculation of benefits, firstly, the benefits or savings achievable when BATs are implemented were identified. The savings or benefits assessed are those that may result from a reduction in water and/or energy usage, a reduction in the amount of wastewater produced, and a decrease in chemical consumption.

In carrying out benefit calculations, the data from the literature, case studies, product catalogs, and from the questionnaires used in BAT compliance assessment in the BESTÜ Project was used (The details about the BESTÜ Project is provided in Section 2.4). The questionnaires used in the BESTÜ Project were in the form of BAT-Control Checklists that aim to collect both BAT compliance level and BAT compliance cost data. Thus, the investment cost data for each BAT determined together with sector employees and via the questionnaires prepared were within the scope of the project. If the applied technique required extra cost for operation and maintenance besides the investment cost, necessary calculations were done and the payback period for each technique was calculated accordingly.

After making a cost-benefit analysis for the application of BATs in a medium-sized textile mill, the answer to the question “How much profit and saving can be gained in total if these BATs are applied in all textile mills within the scope of the IPPC-IED” is given. In addition to this, with the help of total net saving and investment cost, the payback period of each BAT is investigated and a brief adaptation timeline for the BATs is proposed according to the extent to which the benefits outweighed the costs.

In this thesis, Chapter 2 presents background information about the IPPC-IED, the previous studies regarding the application of various BATs in the textile industry and the project entitled “Cleaner Production Applications in Certain Industries: Textile and Leather (BESTÜ) ” are given. Chapter 3 deals with the methodology used for the calculations of potential benefits from the application of BATs in the textile industry and also the payback periods for the investments required for BAT compliance. The results of calculations are given in Chapter 4. In Chapter 5 and Chapter 6 discussion and conclusion are presented, respectively.

CHAPTER 2

BACKGROUND INFORMATION

2.1 Textile Industry and Its Environmental Impacts

The textile industry has different sub-sectors and several heterogeneous processes starting from the fiber until the final product. The general production process starts with yarn production from synthetic or natural fiber. Yarn is the main material for fabric production. Spinning is the process that helps to convert fiber into yarn. After forming yarns, the fabric is produced, mostly through weaving or knitting. During these stages, several chemicals are used to strengthen the yarn. For instance, sizing chemicals are used during fabric production stages to reduce the breakage of the yarn. After forming the fabric, pretreatment processes need to be applied to the material. In fact, pretreatment processes can be applied to fibers, yarn or fabric. Processes are various and the application of these depends on the type of fiber, the material, and intended purpose. Most commonly, washing, desizing, scouring, bleaching and mercerizing are applied to the fabric as pretreatment. Similarly, various chemicals in addition to the auxiliary chemicals are used in these stages. After pretreatment, the material becomes ready for dyeing or printing. Different types of auxiliary chemicals and dyestuffs such as reactive, direct, disperse are applied depending on the fiber type. Acids, bases, salts, detergents, enzymes or surfactants can be given as an example for auxiliary chemicals. The washing step is inevitable after dyeing and printing to remove unused dyes and residuals staying on the material. Finally, the material is exposed to finishing treatments to add special properties to the finished fabric. Various chemicals are used depending on the properties desired such as crease-resistance, water repellence, anti-static, flame retardance [13]. A general flow diagram of the textile chain can be seen in Figure 2.1.

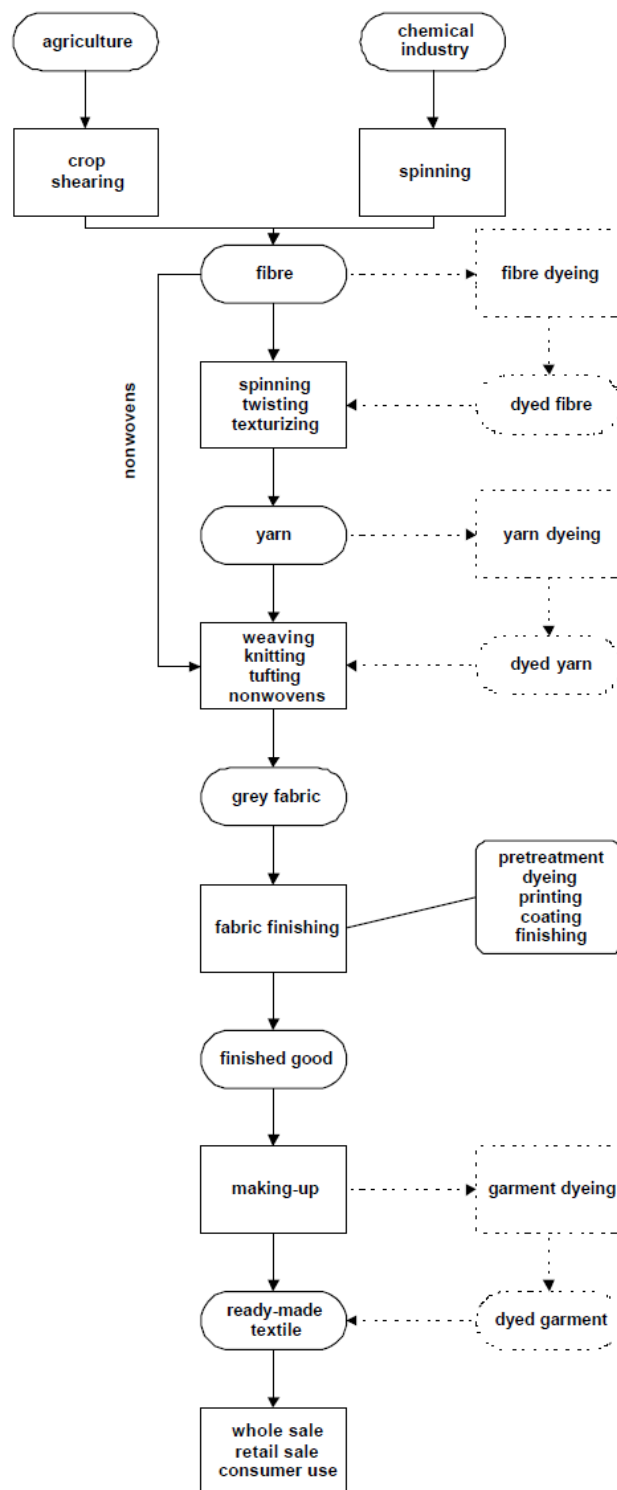


Figure 2.1 General flow diagram of textile chain

[53]

During manufacturing processes, a huge amount of water, energy and different types of chemicals are used. The textile industry is responsible for 8% of total water usage in the total manufacturing industry in Turkey [45]. In the literature, it is stated that water consumption is around 1.6 million liters/ kg fabric in an average-sized textile mill that produces 8000 kg of fabric per day [31]. More generally, specific water consumption is stated as between 3-932 L/kg product. It is highly variable since water consumption depends on the fiber, end product, fabric type, applied techniques, and production processes. For example, while specific water consumption of cotton is between 150-250 kg/product as an average, it is between 150-200 kg/product for the acrylic type of fiber. Similarly, while 284 L of water, as an average value, is needed for 1 kg of wool fabric production, this value is 100 L/kg of yarn production [45]. Since a huge amount of water is used in the textile sector, the generated wastewater amount is also high. Besides the high amount of wastewater production, the pollution load of wastewater is critical due to its composition. Large quantities of chemicals are used in most of the production stages, especially in pretreatment, dyeing, and printing. Various toxic and biologically non-biodegradable chemicals, dyes and impurities cause to increase pollution load of wastewaters [45]. More than 3600 types of textile dyes and 8000 chemicals used in different processes are available in the textile industry[31]. In addition to being water and chemical intensive industry, thermal and electrical energy are used intensively in the production stages, especially in treatment, dyeing and finishing stages. In Turkey, 40-80 MJ per kg product-specific thermal energy and 2.1-5.6 kWh per kg product specific electrical energy are used [45].

As mentioned before, Turkey is one of the leading countries in textile manufacturing due to its high production capacity. It is among the first ten countries in textile export throughout the world with a share of 3% in 2018 [61]. Since the textile industry is a water and energy intensive sector and a huge amount of chemicals and raw materials which cause a high amount of emission are used, to decrease negative environmental damage and economic burden due to high usage of raw materials several projects have been conducting by the MoEU for the EU adaptation period. Since Turkey is

responsible for adapting the legal requirements for this period, the IPPC Directive is the main regulatory instrument that should be taken into consideration during this period.

2.2 Integrated Pollution Prevention and Control Directive

Industrialization plays a vital role in the economic development of countries. Although it is the fact that industrial growth is inevitable and essential for both developed and developing countries for economical reasons, it has some negative consequences, especially on the environment [15]. Generally, since most of the industries use a huge amount of resources namely, water, energy and chemicals in their processes, some necessary national and international measures to decrease the amount of usage of resources have been taken into account more, especially for the last 30 years as the climate change is becoming a critical issue for all over the world.

The United Nations Environment Program (UNEP) launched a new term “Cleaner Production” in 1989 and regarding that, the cleaner production approach has been concerned and tried to be applied more commonly in the manufacturing business, starting from this time for sustainable production initiatives. This term involves, in addition to the economical gains, environmental protection, and efficient resource consumption with some applications such as good housekeeping, process modifications, or implementing environmental-friendly technologies in industries [27].

In line with this development, the IPPC Directive which was published for the first time in 1996 and after being amended several times came into force in 2008 accepted as the EU's main regulatory for waste management and emission control due to activities of specified industries. The IPPC Directive aims to prevent and reduce emissions to air, soil and water resulting from some activity of certain industries and they are given in Annex I of the Directive [63]. Energy industries, production and processing of metals, mineral and chemical industries, waste management and some

other industrial activities which include pulp and paper production industries, textile, tanning and food processing industries, intensive rearing of animals, slaughterhouses etc are the general categories of industrial activities that are listed out in Annex I since these industries have high pollution potential. The prevention and reduction of pollution with some obligations and requirements can be applied in new or existing agricultural or industrial activities. This directive requires having a permit for these specified industries that are above certain production capacities and accordingly, industries are responsible for the prevention and reduction of pollution that they cause [23].

The IPPC Directive has been formed based on five main principles which are an integrated approach, use of BATs, inspection, flexibility and public participation. The IPPC Directive gives importance to determining emission limit values (ELVs) by relying on BATs. The process of determination of BAT's for each industrial activity is to be a result of collaborative work between experts from environmental organizations, industries and members of the EU Member States. Results are published as BAT Reference Documents (BREFs) by European Commission [23].

In 2010, the IPPC Directive was replaced by the IED. After this time, IED became the main EU instrument regulating pollutant emissions from the industries. It brings together seven existing directives (the IPPC, and six sectoral pieces of legislation, including the Large Combustion Plant Directive (LCPD); the Waste Incineration Directive (WID); the Solvent Emissions Directive (SED) and 3 Directives on Titanium Dioxide.) related to industrial emissions into a single clear and coherent directive [52]. The IED is based on several principles, namely an integrated approach, BATs, flexibility, public participation, and inspections [39].

The IED includes both the determination and the implementation of BATs and the investments required for regular storing, combustion, solid waste disposal units in industries. Industries need to have an approach based on the consideration of emissions and pollution together with the production stages rather than focusing on just emission limit values and discharge criteria. In this context, the prevention/

reduction of emissions techniques should be applied in the production phases. Since it requires inevitable changes in the industries, the implementation of the directive will be a challenging and long-term process in Turkey.

The textile industry as being one of the water and energy intensive industries generates considerable pollution. With this characteristic, “textile pre-treatment (operations such as washing, bleaching, mercerisation) or dyeing of textile fibers or textiles where the treatment capacity exceeds 10 tonnes per day” falls under the scope of the IED and is listed as one of the “other activities” included in Annex 1 of the IED.

In order to use natural resources efficiently and minimize polluting emissions into the atmosphere, water, and soil from textile industries, a BATs reference document which is shortly called TXT BREF was prepared for this sector in 2003 [48]. Later in December 2019, the EC European IPPC Bureau revised the TXT document and published it as a draft. The draft revised TXT document established BAT conclusions as different than the previous TXT BREF version published in 2003.

2.3 Literature Survey

Many studies and projects have been conducted for the evaluation of environmental and economical gains with the adoption of cleaner production applications in the textile industry. The textile industry is one of the complicated sectors in terms of its production processes. Since there are different types of fiber and fabric types, the textile industry consists of several sub-processes and its production chain varies accordingly. In addition to this, this industry is not only water and energy-intensive sector but also dyes and auxiliary chemical usage is very high per production. For this reason, following cleaner production applications and integration into the textile plants is essential both environmental and economical reasons. Also, it is expected that shifting from traditional methods to cleaner production applications will be

inevitable in the near future due to the depletion of natural resources all over the world.

Case studies, surveys or experimental studies related to cleaner production application adaption in textile plants can be found in the literature. Since production and finishing processes include several different chains and processes, each study has focused mostly on different processes such as wet processing, dyeing, printing, wastewater treatment or specific textile plants such as denim textile mills. In some of those studies, economic assessment has been conducted in addition to the environmental assessment studies [12].

Öztürk et al. [42] dealt with IPPC and cleaner production applications in the textile industry. In the study, three textile mills in which different processes are taking place were selected and current detailed situations in terms of all inputs and outputs were investigated with site visits. According to current situations, suitability for adaptation to cleaner production applications of these mills and possible environmental and economical benefits with the applications of selected techniques were estimated. Finally, it was pointed out that between 35 and 65% saving in water consumption, 11-34% in energy, 16-43% in chemical consumption, 26-72% reduction in wastewater pollution load, 12-38% reduction in waste gas and 5-20% reduction in solid waste was expected with the application of stated cleaner production applications.

Kocabaş [32] conducted her thesis study about improvements in water and energy consumption after the application of certain BATs in a denim-producing textile mill. In this study, water consumption decreased from 6000 to 4850 ton/day with the applications namely, installation of flow meters, applying semi-counter current rinsing, reuse of reverse osmosis concentrate and compressor cooling water. Moreover, a decrease in specific energy consumption by 9% was achieved with the applications, namely using wastewater waste heat from finishing processes to heat washing water, heat insulation and maintenance applications. The study was conducted by site visits for data collection about water and energy consumption. This

was done by monitoring consumptions at the machine and process level and changes in consumption results with the application of BATs were given accordingly.

Kiran-Ciliz [31] identified environmentally preferable and economically viable cleaner production options. The results of feasibility studies showed that implementing water-water heat exchanger, regeneration process optimization and reduction of acetic acid and detergent usage in dyeing processes were the most suitable ones.

An example study regarding the adoption of the IPPC was conducted by Demirer et al. [15]. In this study, five sustainable applications were implemented in a woven fabric manufacturing mill. Proposed and implemented applications were using drop-fill washing instead of overflow, reusing of stenter and singeing cooling water, replacing existing water softening device with a new one that operates automatically and renovation of some valves and fittings which causes unaccounted water losses in the water transmission system. Environmental and economic performance evaluation of the mill presented and compared with other studies. Changes in specific water, energy and NaCl consumption data in the mill were provided. The results of the study showed that the total water consumption and wastewater generation were decreased by 40.2% and 43.4%, respectively. Moreover, it was seen a reduction in total energy consumption and associated CO₂ emissions by 17.1 and 13.5, respectively. Also, 46% reduction in salt consumption was observed after the implementation of these techniques.

Comprehensive and detailed benefit assessment of one of the BATs which is recovering and reusing mercerization wastewater was studied by Bayar [5]. Bayar carried out the study about the life cycle assessment of evaporative recovery of mercerization wastewater by generating 3 different scenarios. These scenarios were generated by using 3 different fuels (heavy oil, light fuel oil and natural gas) for steam production to be used in the evaporation of 1kg weak lye. In addition to this, the evaporation process was assessed in terms of environmental effects and it was compared with end-of-pipe treatment. At the end of the study, it was found that the

scenario in which natural gas is used for the evaporation process was the most environmentally friendly option.

In 2016, Öztürk et al. [49] focused on water, wastewater and chemical minimization studies conducted in a textile mill employing cotton-polyester weaving-knitting and dyeing-finishing. On-site investigations were done to determine specific consumptions and pollution loads and to analyze water and wastewater. Based on the results, the BATs that can be applied to the mill were investigated and 14 techniques related to good management, water and chemical consumption minimization were suggested to the mill. After implementation of these techniques, a potential decrease in water, chemical, combined wastewater flow rate, and chemical oxygen demand (COD) demand load were presented in the study, in terms of percentage.

A study which was conducted by Yukseler et al. [74] analyzed the BATs for the management of wastewater from a textile mill. The study was conducted in a textile mill that manufactures denim. After a detailed wastewater characterization from different streams and mass balance analysis, possible techniques related to reusing of wastewater and minimization of water consumption and so generated wastewater amount were implemented in the mill. Using flow control valves in dyeing and finishing processes, applying counter-current washing, reusing reverse osmosis concentrate for cleaning purposes and reusing compressor cooling waters in production processes are some of the implemented techniques in the mill. Finally, a wastewater management strategy and accordingly wastewater treatment technologies to reuse wastewater in the mill were identified.

Doğan et al. [19] developed the cost-benefit analysis of the BATs for wastewaters from a denim textile mill. Different treatment alternatives for water recovery from dyeing wastewaters and end of pipe treatment for mixed wastewater treatability were compared with respect to investment cost, operating cost, the amount of COD reduction. The financial and environmental analysis was performed. Finally, the study outcomes showed that since membrane technology was the most promising

and economically applicable option, it was selected as BAT for water recovery and treatability.

Hasanbeigi and Price [29] carried out a detailed and comprehensive study to show the energy-efficient technologies, improvement opportunities and measures to be taken in the textile industry. In this study, case study examples from all over the world and saving and cost information of these energy-efficient measures were presented. In total, 184 techniques that can be applied to the textile industry were given in this study.

In 2020, Ozturk et al.[46] dealt with energy-efficient techniques to reduce energy consumption and air emissions. The study was conducted in an integrated woolen textile facility. Energy consumption in the processes was investigated with the site visits and specific energy consumption values were calculated. 13 priority energy-efficient techniques both environmentally and economically feasible were determined and suggested for the application. After the implementation of these techniques, it was seen that up to 27% saving in electricity and thermal energy consumption could be obtained. Moreover, air emissions were decreased by 23-45%. Also, the study presented the payback periods for applied techniques.

The textile sector was strongly criticized due to its high demand for water and chemical. Especially in wet processes, a high amount of water is discharged together with residual dyes and chemicals. Wastewater originating from textile plants can be characterized by high COD, high salt content and low biodegradability. Since a large amount of water is used during production processes, a huge amount of wastewater is generated. Since various dyes and chemicals are used in different steps during production processes, the wastewater is extremely variable in terms of composition [61]. Regarding this issue, Ozturk et al. [47] analyzed the various techniques to minimize the chemical cost and to increase environmental performance in terms of chemical consumption. Specific chemical and dyestuff consumptions and chemical loads of wastewaters were investigated with detailed site investigations. Depending on the process analysis and data collection studies, 10 minimization and substitution

techniques were suggested and applied in the mill. Moreover, material safety data sheets of all chemicals used in the mill were examined and 23 chemicals out of 371 were proposed to substitute with eco-friendly ones. Finally, potential savings were calculated and it was concluded that reduction in chemical consumption by 15-32% and reduction in COD load of wastewater by 13-37% can be obtained with the practices.

Öztürk et al.[50] conducted a study about the chemical substitution in a denim-producing factory. Since the various type of chemicals in a large amount are used in the processes, the pollution load of wastewater and its effect on the receiving body should be taken into account. For this reason, in this study, problematic chemicals used in the production processes were determined and possible alternatives were investigated. According to results, 8 chemicals which are in the category of dispersants, sulphur dyes, easy-care finishing agent and complexing agents were found to be problematic and alternatives for them were presented. The results showed that substituting sulphur dyes with low sulphide content ones causes a reduction in sulphide by 70%. Also, using the alternative complexing agent preventing the discharge of 3100 kg COD load to the wastewater monthly and helps to generate more biodegradable wastewater.

2.4 BESTÜ Project

Turkey is not yet a member of the EU, but a candidate country to join the EU. Accession negotiations between the EU and Turkey were started in 2005 and the Environment Chapter was opened in 2009. The MoEU was assigned as the responsible authority for the harmonization of the EU Environmental Acquis in co-operation with other ministries, governmental agencies, local authorities and non-governmental organizations (NGOs). In the scope of the Environment Chapter Negotiations, a harmonization timeline for the IED was given and the full implementation date was set as 2018. In order to harmonize the IED with the national legislation, the MoEU carried out several different projects and implemented a

number of regulations or communiqués. The communicate entitled “IPPC in the textile industry” which was released in 2011 for the purpose of decreasing possible environmental impacts of textile industries is among these pieces of legislation and in fact the first piece of legislation.

In line with the IED adaption studies, The Project entitled “Cleaner Production Applications in Certain Industries (BESTÜ)” has been carried out with the partnership of the MoEU and Middle East Technical University. The main purpose of this project was the selection of the economical and environmentally feasible compulsory and optional techniques that textile mills need to apply and the determination of BAT-AELs. Also, the determination of the technical requirements for the adoption period was one of the aims of the project.

Within the scope of this project, various studies were conducted. Initially, processes taking place in each textile sub-sector were analyzed. Techniques and applications given in the EU BREF documents and literature were researched and evaluated. Detailed and comprehensive questionnaires that include a list of potential BATs that aim to investigate the level of IED compliance in the textile sector were prepared. These questionnaires that are in the form of BAT-check lists also included questions that aim to collect data relevant to BAT compliance in each installation. Each textile installation was asked about the investment needed for the adaptation of each BAT that exists in the BAT checklists. Site visits to textile mills that are representative of the textile industry were organized and textile mills in Uşak, Bursa, Gaziantep, Kahramanmaraş, Denizli and Tekirdağ were visited to see the current application and evaluation of the applicability of techniques in the BAT checklists. These site visits were also important regarding the importance and necessity have given to each BAT by textile installations and estimation of their costs for the sector. In addition to the site visits, questionnaires were made online and sent to textile mills. In total, 40 textile mills were visited and questionnaires were made face-to-face. According to results obtained from the site visits and questionnaires, the draft of the IPPC communiqué which includes 58 compulsory BATs and several optional techniques

was prepared. Also, the current application situation of these techniques in the plants was estimated.

Moreover, the minimum and maximum investment costs for the BATs that were suggested to be involved in the communiqué draft were estimated by the project team together with sector employees to determine the range of total sectoral investment cost and to see how much money must be spent for the mills to comply with the communiqué. The estimated minimum, maximum and average investment costs of the BATs to be applied in the textile sector can be seen in Table 2.1.

This study has been conducted as a continuation of this project on the purpose of estimating the economic and environmental gains with the application of certain BATs in a medium-sized textile mill.

Table 2.1 The estimated costs of the BATs within the scope of the BESTÜ Project [41]

	BAT	Minimum Investment Cost (€)	Average Investment Cost (€)	Maximum Investment Cost (€)
1	Controlling the air-fuel ratio in boilers and application of the optimum one in the boilers	12,000	23,500	35,000
2	Thermal isolation of all machines and steam distribution system equipment	1,000	28,000	55,000
3	Minimization of the amount of blowdown forming in the boilers with better boiler feedwater treatment options such as ion exchanger, reverse osmosis, etc	10,000	30,000	50,000
4	Using inverter in boilers	5,000	12,500	20,000
5	Thermal isolation of all piping system	3,500	5,250	7,000
6	Reuse of all thermal condensate	50,000	50,000	50,000
7	Preheating of boiler feedwater with waste gas heat by installing an economizer	20,000	33,750	47,500
8	Determination of required water quality standards and prevention use of water of higher quality than required	5,000	17,500	30,000
9	Saving water and reducing the amount of wastewater by increasing washing efficiency by using equipment that will provide water efficiency in facility and equipment cleaning (water spray nozzles, spray sprayers, etc.)	1,000	3,000	5,000
10	Separate collection and reuse of cooling water used in all production processes to save water and energy	50,000	50,000	50,000
11	In ion-exchange resin systems, after regeneration, monitoring of hardness level of effluent water (softened water) and washing water with hardness sensors to optimize regeneration frequency and rinsing time	5,000	6,250	7,500
12	Characterization of reverse osmosis (RO) concentrates and reusing it without treatment depending on the characterization	2,500	5,750	9,000
13	Characterization of wastewater coming from the rinsing of ion exchangers after regeneration and reusing it without treatment depending on characterization	10,000	10,000	10,000
14	Selection of the biodegradable and bioeliminable sizing agents	10,000	30,000	50,000
15	Using the last rinsing water in the next dyeing process to decrease wastewater pollution load in discontinuous dyeing processes	50,000	50,000	50,000
16	Applying counter-current washing in continuous washing machines	10,000	30,000	50,000
17	Volume reduction of troughs to reduce residual dye liquor (excluding indigo and sulfur dyeing)	1,000	3,000	5,000
18	Optimization of the speed of stenter according to the moisture content of the fabric	6,000	9,000	12,000
19	Applying squeezing or mechanical dewatering processes before drying	6,000	13,000	20,000
20	Measuring the moisture content of the air coming out of the stenter and according to that adjusting the humidity level	6,000	9,000	12,000
21	Recovery of caustic from mercerization rinsing water by evaporation and reuse it	200,000	300,000	400,000

CHAPTER 3

METHODOLOGY

In this section of the study, the study approach which is used for the assessment of benefits with the application of BATs in the selected textile mill is presented. In addition to this, information about the selected medium-sized mill is given.

3.1 Study Approach

The main aim of the new draft “Integrated Pollution Prevention and Control Communiqué” is to control the emissions, discharges, and wastes resulting from during the production processes and to present procedures regarding the effective use of raw materials and the use of cleaner production applications in the textile plants. Within the scope of this communiqué, 58 BATs with several sub techniques and emission limit values (ELVs) by relying on BATs for the plants with the capacity of pretreatment operations such as washing, bleaching, mercerisation or the capacity of dyeing processes which is above 10 tonnes per day is presented.

Within this framework, potential benefits from the application of these techniques were assessed in this study. A medium-sized textile mill employing cotton-polyester weaving/knitting and dyeing/finishing is selected as the study plant and the potential benefits that will arise from the adaptation of the BAT at this mill were estimated. Since all the BATs given in the draft communiqué are not applicable for the selected mill in terms of the processes applied, the BATs that were adoptable were chosen. In addition to the applicability, the BAT that can be expressed in terms of monetary equivalent in the cost-benefit analysis were selected and potential benefits were calculated for these selected BAT. The techniques that were intended to be implemented into the studied mill can be seen in Table 3.1

Table 3.1 The techniques that were planned to apply to the selected mill

1	Controlling the air-fuel ratio in boilers and application of the optimum one in the boilers (BAT 9)
2	Thermal isolation of all machines and steam distribution system equipment (BAT 9)
3	Minimization of the amount of blowdown forming in the boilers with better boiler feedwater treatment options such as ion exchanger, reverse osmosis, etc (BAT 9)
4	Using inverter in boilers (BAT 9)
5	Thermal isolation of all piping system (BAT 9)
6	Reuse of all thermal condensate (BAT 9)
7	Preheating of boiler feedwater with waste gas heat by installing an economizer (BAT9)
8	Determination of required water quality standards and prevention use of water of higher quality than required (BAT 13)
9	Saving water and reducing the amount of wastewater by increasing washing efficiency by using equipment that will provide water efficiency in facility and equipment cleaning (water spray nozzles, spray sprayers, etc.) (BAT 13)
10	Separate collection and reuse of cooling water used in all production processes to save water and energy (BAT 13)
11	In ion-exchange resin systems, after regeneration, monitoring of hardness level of effluent water (softened water) and washing water with hardness sensors to optimize regeneration frequency and rinsing time (BAT 13)
12	Characterization of reverse osmosis (RO) concentrates and reusing it without treatment depending on the characterization (BAT 13)
13	Characterization of wastewater coming from the rinsing of ion exchangers after regeneration and reusing it without treatment depending on characterization (BAT 13)

Table 3.1 (cont'd)

14	Selection of the biodegradable and bioeliminable sizing agents (BAT 15)
15	Using the last rinsing water in the next dyeing process to decrease wastewater pollution load in discontinuous dyeing processes (BAT 23)
16	Applying counter-current washing in continuous washing machines (BAT 25)
17	Volume reduction of troughs to reduce residual dye liquor (excluding indigo and sulfur dyeing) (BAT 25)
18	Optimization of the speed of stenter according to the moisture content of the fabric (BAT 34)
19	Applying squeezing or mechanical dewatering processes before drying (BAT 34)
20	Measuring the moisture content of the air coming out of the stenter and according to that adjusting the humidity level (BAT 35)
21	Recovery of caustic from mercerization rinsing water by evaporation and reuse it (BAT 39)

After determining the techniques given in Table 3.1, potential benefit sources that can be obtained with the application of each technique are estimated. They can be saving with a decrease in water and/or energy consumption, saving with a reduction in wastewater generation, saving due to a decrease in chemical consumption depending on the technique. For the cost-benefit analysis, besides the benefits part, information about the investment and, if available, operational cost is needed.

The investment cost for each technique is estimated by the project team together with sector employees within the scope of the “BESTÜ project” as mentioned in the background information part. The method used for potential benefit calculations and operational cost studies varied from one technique to another. They are conducted with the help of theoretical information from literature surveys or practical

application information from case studies or brand catalogs. The calculation methods are given in the results part in detail.

Finally, the payback period of each technique is calculated by using the following equation;

$$\text{Payback period (month)} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12$$

3.2 Study Mill

The main aim of the study is the estimation of environmental and economic benefits for a medium-sized textile mill within the scope of IPPC-IED with the application of compulsory BATs. Making benefit analysis for a medium-sized textile mill allows estimating the total benefits for Turkey in the case of the application of compulsory techniques to all textile mills subjected to IPPC-IED.

In the line of this purpose, a medium-sized textile mill employing cotton-polyester weaving/knitting and dyeing/finishing is selected as the study plant. The company was established in 1970 and it is located in Denizli in a 19,833 m² area. The factory currently has 270 employees. Manufacturing takes place with two different production lines which are HT (high temperature) -overflow dyeing and finishing and pad-batch dyeing and finishing. While production takes place with discontinuous and exhaust processes in the HT-over flow production line, in the pad-batch production line semi-continuous and impregnation methods are used. While 64% of total production takes place in HT-over flow production line, 36% of total production takes place in pad-batch line in the mill. The average annual production amount is around 8,650 tons and 5000 tons in HT-over flow and pad-batch lines, respectively. With this production capacity that is equivalent to about 37 tons/day, the study plant does fall under Annex 1 of the IED. As stated before, it is a typical medium-sized textile mill and therefore considered to represent the Turkish Textile Industry.

In the study plant, water used in the textile wet processes is provided from the groundwater resources. Since raw water is hard, water is softened by an ion exchanger to remove Mg^{+2} and Ca^{+2} ions before using in the processes. Water is used mostly in dyeing and finishing processes (81% of total water usage). Also, it is used for steam production (7%), regeneration of ion-exchangers (10%), cleaning (2%), and domestic purposes (0.3%).

In the mill, the required energy is provided mainly from coal and natural gas. Approximately yearly 20,500 tons of coal is used in steam and hot oil boilers for steam production. While 66% of coal is used in steam boilers, the remaining 34% is used in hot oil boilers. Natural gas is used just for the burning (gauze) process. Electricity is used to operate the electric motors and devices, for pumps and compressors and lighting. The average electricity consumption is 8,051,000 kwh yearly in the mill.

Different kinds of dyes and auxiliary chemicals are used in the mill; mainly in pretreatment, dyeing and finishing processes. In addition to these, chemicals are used in ion exchanger system and facility cleaning. In the mill, mostly cotton and polyester knitting and weaving and dyeing, finishing processes take place, and in these processes as an average 3,903 tons of auxiliary chemicals and 76 tons of dyestuff are used in a year. Reactive, indanthrene and disperse dyes are used in HT-over flow and pad-batch processes. Since mostly cotton fiber is processed in higher amounts rather than polyester, reactive dyes are used in the mill. Besides dyestuffs, salt, sodium carbonate, caustic, hydrogen peroxide, acetic acid, sodium silicate, stabilizator are some of the chemicals used in the mill.

The total wastewater amount resulting from wet processes, regeneration, facility cleaning and domestic usage is around 943,000 tons/year. Wastewater is collected and sent to a wastewater treatment plant which serves to similar 5 textile plants nearby.

CHAPTER 4

RESULTS

In this section, the detailed benefit calculations are presented separately for each BAT. In presenting the calculations; for each BAT, three subheadings, namely description of BAT, the benefit to be obtained with the application of BAT, and estimated investment cost and payback period are used. In the first subheading, a technical description of BAT and its potential benefits are given, and the compliance rate of the textile mills in Turkey to this technique is presented. In the next part, calculations for the specified technique are shown and potential saving with the application is given. Lastly, estimated cost data obtained from questionnaires for the specified technique are provided and based on this payback period calculation is presented.

For saving calculations, the unit price of raw water, unit wastewater treatment cost, and fuel cost are used. In Turkey, since the source of raw water used by the textile mills are variable, the determination of the exact raw water unit price is not easy. This value is taken from the project “Determination the Potential of Resource Efficiency in Industry” conducted by the Republic of Turkey Ministry of Science, Industry and Technology and TUBITAK MAM (Marmara Araştırma Merkezi). In the final report of this project, it is stated that “unit price of water used in the manufacturing industry is accepted as 3 TL/m³ for 2015, although this value highly depends on sector and industry”. This value is found from the Turkish Statistical Institute Annual and Industry and Service Statistics and the Turkish Statistical Institute the Manufacturing Industry Water, Wastewater and Waste Statistics. In the same project, wastewater disposal cost is accepted as 2 TL/m³ as average [63]. Since these unit prices belong to 2015, these values should be updated for 2021. In order to find 2021 values, Domestic Producer Price Index data between December 2015 and December 2020 taken from the Turkish Statistical Institute are used. According

to that, the Domestic Producer Price Index has increased by 38% for water supply, sewerage, waste management and recovery activities. The unit prices given for 2015 have been updated for 2021 based on this rate of increase.

The average price of coal is taken from the Turkish Coal Enterprises institution to be used in the fuel-saving calculations [66]. The cost of electricity is taken from the website of the General Directorate of Turkish Electricity Distribution Corporation. Since there are 3 different tariffs (day, peak and night) for tariffing, the average value of these is accepted as the unit price of electricity [58].

Unit prices used in the calculations are given in Table 4.1.

Table 4.1 Unit prices used in the calculations

Item	Unit price	Reference
Average price of water used in the manufacturing industry	4.1 TL/m ³	[63], [64]
Average wastewater disposal cost	2.8 TL/m ³	[63], [64]
Average price of coal	475 TL/ton	[66]
Average price of electricity	68.7 kr/kwh	[58]

4.1 BAT 9: Controlling the air-fuel ratio in boilers and application of the optimum one in the boilers

4.1.1 Description of BAT

This BAT is related directly to boiler efficiency since it optimizes oxygen levels at the stack. Its compliance rate among the textile mills has been found as 29% until 2019 within the scope of the project called “Cleaner Production Applications in Certain Industries: Textile and Leather Industries” in Turkey.

In a combustion process, it is critical to determine the optimum level of the air-fuel ratio which varies according to firing method and fuel type. Because, while usage

of more than the required amount of air in boilers causes rejecting more heat from the stack, and so high fuel consumption, usage of less amount of air than the required level causes incomplete combustion in the system [60]. Since there is no exact information about how much air is required for an average boiler, controlling the excess air is the only essential thing that must be done for determination the optimum oxygen level [49]. Oxygen level in flue gas, the temperature difference between stack gas and inlet air, and unburned combustibles are the parameters that should be controlled to understand the efficiency of the system. Monitoring of O₂ level in stack gas or sometimes in addition to monitoring of O₂, carbon monoxide (CO) measurement is done for controlling the air-fuel ratio. This measurement can be done by installing permanent or portable equipment to analyze flue gas oxygen amount [60]. Excess air control can be made manually or automatically. With the optimization of the air-fuel ratio, continuous complete combustion in the system and working conditions compatible with boiler load can be obtained. Also, unnecessary stopping of the system can be prevented. This application enables an increase in the efficiency of the system and a decrease in fuel consumption and waste heat gas amount [7]. Therefore, the benefits that will arise from the application of this BAT are calculated as the corresponding gains in fuel consumption.

4.1.2 The Benefit to be Obtained with the Application of BAT

In the study plant, 3 coal-fired boilers are used. 20,380 tons of coal is used per year in the mill to produce steam and/or boiling oil to be used in various processes. If the calorific value of coal is taken as 4700 kcal/kg as an average value [67], the total energy amount obtained from the boilers is found as;

$$20,380 \frac{\text{ton}}{\text{year}} * 4700 \frac{\text{kcal}}{\text{kg}} * 0.0042 \frac{\text{MJ}}{\text{kcal}} = 401,024,310 \frac{\text{MJ}}{\text{year}} \cong 401 \text{ million MJ/year}$$

The benefit from the application of this BAT can be calculated by taking into consideration a change in the oxygen level in the stack gas. The application of this

BAT provides a reduction in the excess air amount to an optimum level [69]. Since the air temperature difference between inlet and outlet is critical, combustion air inlet temperature is accepted as 20 °C (68 °F), exhaust gas temperature is taken as 200 °C (392 °F). For the benefit calculation with the application of this BAT, it is assumed that the current oxygen level at stack gas is 8% and the proposed condition is 4% which corresponds to the optimum excess air condition to obtain maximum efficiency when the fuel type is coal [69]. Based on these operating conditions, combustion efficiency tables are used to determine exit gas heat losses. These tables are readily available based on the excess air/oxygen level (%) and net stack temperature (the difference between exit flue gas temperature and combustion air temperature) [57]. Based on the operating conditions of the selected mill, the table prepared for bituminous coal for the net temperature of 150-300 °F is used. According to that, while heat loss of boiler is 13.3% (which means efficiency is 86.7%) when the oxygen level at stack gas is 8%, heat loss is 11.1% (which means efficiency is 88.9%) if the oxygen level is reduced to 4%. The table used for the calculation can be seen in Appendix A.

By taking into consideration efficiency values, a decrease in the amount of fuel used in the process is calculated as shown below.

$$\text{Saving in fuel consumption (\%)} = \left(\frac{\text{Proposed efficiency} - \text{Current efficiency}}{\text{Proposed efficiency}} \right) * 100$$

$$\text{Saving in fuel consumption (\%)} = \left(\frac{88.9 - 86.7}{88.9} \right) * 100 = 2.47\%$$

Since current energy usage in boilers is around 401 million MJ/year, the saving in energy with the application of this BAT is found by using saving in fuel consumption.

$$\text{Fuel saving in boilers} = \frac{\text{Current fuel consumption} * \text{Saving in fuel consumption (\%)}}{100}$$

$$\text{Fuel saving in boilers} = \left(\frac{401,024,310 \frac{\text{MJ}}{\text{year}} * 2.47}{100} \right) = 9,924,111 \frac{\text{MJ}}{\text{year}} = 2,370,373,948 \frac{\text{kcal}}{\text{year}}$$

Since the heating value of coal is taken as 4700 kcal/kg, the decrease in the amount of coal corresponding fuel saving is found as shown below.

$$\text{Decrease in coal amount used in boilers} = \frac{2,370,373,948 \frac{\text{kcal}}{\text{year}}}{4700 \frac{\text{kcal}}{\text{kg}}} = 504,335 \frac{\text{kg}}{\text{year}}$$

$$\text{Decrease in coal amount used in boilers} = 504.335 \frac{\text{ton}}{\text{year}}$$

Based on the decrease in coal amount used in boilers, saving in terms of TL/year and €/year are calculated, as shown below. The cost of coal is taken as 475 TL/ton as the average value [66]. This value equals 52.26 €/kg ton by taking the exchange rate of the average value for March 2021 since €/₺ is 9.09 [65]

$$\text{Saving} = 475 \frac{\text{TL}}{\text{ton}} * 504.335 \frac{\text{ton}}{\text{year}} = 239,559 \frac{\text{TL}}{\text{year}} = 26,354 \frac{\text{Euro}}{\text{year}}$$

$$\text{Fuel Saving} = 239,559 \frac{\text{TL}}{\text{year}} = 26,354 \frac{\text{Euro}}{\text{year}}$$

All data used for the calculations with their references and the results obtained are given in Table 4.2.

Table 4.2 Summary table for the benefit analysis of the BAT “Controlling the air-fuel ratio in boilers and application of the optimum one in the boilers”

Item	Value	Reference
Total amount of coal used in boilers	20,379,364 ton/year	[45]
Average heating value of coal	4,700 kcal/kg	[67]
MJ/kcal ratio	238.9	
Current energy consumption in boilers in the selected textile mill	401,017,420 MJ/year	[45]
Current oxygen level at stack gas	8%	[69]
Proposed oxygen level at stack gas	4%	[69]

Table 4.2 (cont'd)

Combustion air inlet temperature	68 °F	
Exhaust gas air temperature	392 °F	
Temperature difference	324 °F	
Heat loss when the oxygen level at stack gas is %8	13.3%	[57]
Efficiency when the oxygen level at stack gas is %8	86.7%	[57]
Heat loss when the oxygen level at stack gas is %4	11.1%	[57]
Efficiency when the oxygen level at stack gas is %4	88.9%	[57]
Difference in efficiency	2.2%	
Saving in fuel consumption	2.5%	
Energy saving in boilers	9,923,941 MJ/year	
	2,370,333,226 kcal/year	
Decrease in coal amount used in boilers	504,326 kg/year	
	504.3 ton/year	
Average cost of coal (TL/ton)	475	[66]
€/₺ for the average of March 2021	9.1	[65]
Total saving (€/year)	26,353.7 €/ year	
	239,555 ₺/year	

4.1.3 Estimated Investment Cost and Payback Period

As it can be seen in Table 4.3, questions related to this technique in the questionnaire reveals that minimum and maximum investment costs for this BAT are € 12,000 and € 35,000, respectively. Average investment cost is used to calculate the payback period of this technique.

Table 4.3 Investment cost for the technique “Controlling the air-fuel ratio in boilers and application of the optimum one in the boilers”

Cost Item	Value, €
Realistic minimum investment cost	12,000
Realistic maximum investment cost	35,000
Average investment cost	23,500

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{23,500 \text{ €}}{26,354 \text{ €}} * 12 \cong 11 \text{ months}$$

4.2 BAT 9: Thermal isolation of all machines and steam distribution system equipment

4.2.1 Description of BAT

This BAT helps to save energy by decreasing heat losses from the surfaces and steam distribution system. The questionnaire about this BAT reveals that while 50% of textile mills in the scope of the IPPC Directive have already complied with this technique, the remaining 50% of mills need to implement the application into their mills.

Isolation is an easy and reliable method used to decrease heat losses of surfaces, pipes and valves. For this reason, the application of this BAT must be compulsory. Its payback period can be very short depending on the heat losses, isolation cost, energy price. Machines to be isolated can be dyeing or drying machines since the processes taking place in these machines are at high temperatures [7]. The benefits that will arise from the application of this BAT is calculated as the corresponding gains in fuel consumption.

4.2.2 The Benefit to be Obtained with the Application of BAT

This technique provides saving in fuel consumption by thermal isolation of machines and steam distribution system equipment. The questionnaire reveals that while 50% of the textile mills have already applied this technique and the remaining 50% need to implement it.

Benefit analysis with the application of this BAT is done by taking the literature studies as a base. A study was conducted in a textile mill situated in Tekirdağ. In this study, insulation of dyeing machines was done with two different insulation materials which are glass wool and polyethylene. 48 tons of fabric was dyed to investigate unit steam consumption change for different kinds of insulation materials and more importantly to see the steam consumption difference between isolated and non-isolated dyeing machines. The results from this study showed that there is no such a big difference between dyeing machines that are isolated two different isolated materials. An average, 4.35 kg steam/kg fabric is used in the isolated dyeing machine in which cotton-polyester dyeing taking place. On the other hand, 6.13 kg steam/kg fabric is used in the dyeing machine with no isolation. For the cotton dyeing process, while 3.06 kg steam/kg fabric is used as average, 4.01 kg steam is used per kg fabric in the non-isolated dyeing machine [44].

Since both cotton and cotton-polyester dyeing taking place in the studied medium-sized textile mill, the average values of steam consumption were used for calculation. According to that, 28 and 24% less steam was used after isolation, so a decrease in steam consumption by 26% is accepted with the application of this BAT. In the studied mill, both HT- overflow processes and pad batch process takes place. Since only HT-over dyeing machines are proper for isolation, insulation of pad batch dyeing machines has not been considered. In the mill, a total of 7.1 kg steam per kg fabric is used for the HT-over flow process. As an average, half of this value is used in dyeing processes [30]. As a result, 3.5 kg steam/kg fabric is used in non-isolated dyeing machines, this value is decreased to 2.6 by a 26% decrease with proper insulation. 0.9 kg less steam is used per kg fabric, so energy saving is

obtained. In order to determine how much energy is saved in the mill totally, a unit decrease in steam consumption is used. The total net production in HT- overflow process is 6,898,868 kg/year, so the decrease in steam consumption is calculated as shown below.

Decrease in the steam consumption = Unit decrease in steam consumption total net production in HT-over flow process*

$$\text{Decrease in the steam consumption } \left(\frac{\text{kg steam}}{\text{year}} \right) = 0.9 \frac{\text{kg steam}}{\text{kg fabric}} * 6,898,868 \frac{\text{kg fabric}}{\text{year}}$$

$$\text{Decrease in the steam consumption} = 6,451,648 \frac{\text{kg steam}}{\text{year}} = 6452 \frac{\text{ton steam}}{\text{year}}$$

Since as an average 215 kg coal is used to produce 1 ton of steam in the boiler [45], decrease in coal consumption is calculated.

Decrease in the coal consumption ($\frac{\text{kg}}{\text{year}}$)= Amount of coal needed to produce 1 ton of steam Decrease in the steam consumption*

$$\text{Decrease in the coal consumption} = 215 \frac{\text{kg coal}}{\text{ton steam}} * 6,452 \frac{\text{ton steam}}{\text{year}} = 1,387,10 \frac{\text{kg coal}}{\text{year}}$$

$$\text{Decrease in the coal consumption} = 1,387 \frac{\text{ton coal}}{\text{year}}$$

Since the average price of coal is 475 TL/ton the total saving is calculated.

$$\text{Total saving} = 475 \frac{\text{TL}}{\text{ton}} * 1,387 \frac{\text{ton coal}}{\text{year}} = 658,875 \text{ TL/year} = 72,483 \text{ €/year}$$

$\text{Saving with a decrease in fuel consumption} = 658,875 \frac{\text{TL}}{\text{year}} = 72,483 \frac{\text{Euro}}{\text{year}}$
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All the values used in the benefit calculation are given in Table 4.4.

Table 4.4 All data used for the benefit calculation of technique “Thermal isolation of all machines and steam distribution system equipment”

Item	Value	Reference
Specific steam consumption for HT-over flow process in the mill	7.1	[45]
Specific steam consumption for dyeing in HT-over flow process	3.5 kg steam/kg fabric	[30]
Decrease in steam consumption in dyeing machine	28% for the cotton-polyester dyeing process	[44]
	23.7% for the cotton dyeing process	[44]
Average decrease in steam consumption in dyeing machine	26.0%	[44]
Unit decrease in steam consumption for the selected medium-sized textile mill	0.9 kg steam/kg fabric	
Total net production in HT over- flow process	6,898,868 kg/year	
Decrease in the steam consumption in the mill per year	6,451,648 kg steam/year	
	6,452 tons steam/year	
Average amount of coal needed to produce 1 ton of steam	215 kg coal/ ton steam	[45]
Decrease in coal consumption per year	1,387,104 kg coal/year	
	1,387 ton coal/year	
Price of coal	475 TL/ton	
€/£	9.1	[65]
Total saving	658,875 £/year	
	72,483 €/year	

4.2.3 Estimated Investment Cost and Payback Period

Information about the investment cost based on the results of the questionnaire can be seen in Table 4.5. Based on the average investment cost and saving, the payback period is calculated as approximately 5 months.

Table 4.5 Investment cost for the technique “Thermal isolation of all machines and steam distribution system equipment”

Cost Item	Value, €
Realistic minimum investment cost	1,000
Realistic maximum investment cost	55,000
Average investment cost	28,000

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{28,000 \text{ €}}{72,483 \text{ €}} * 12 \cong 5 \text{ months}$$

4.3 BAT 9: Minimization of the amount of blowdown forming in the boilers with better boiler feedwater treatment options such as ion exchanger, reverse osmosis, etc

4.3.1 Description of BAT

This BAT allows decreasing in water usage and preventing energy losses through blowdown by decreasing the blowdown amount with the additional treatment of feedwater. The questionnaire shows that the compliance rate to this BAT is 58%. The remaining 42% of the textile mills need to implement it.

In boiler systems, while water is converted into steam any impurities in feedwater such as dissolved and suspended solids remain as they are in the boiler water and their concentrations increase with time. Since this accumulation can be harmful to the system, the concentration of impurities which is measured as total dissolved solids (TDS) should be kept at a certain level in the boiler water by removing a part of the water from the bottom of the boiler with a process known as bottom blowdown [9]. Application of optimum rate of blowdown is critical for boiler systems because while the insufficient blowdown cause to increase of deposit, more

than adequate blowdown results in unnecessary usage of energy, water, and chemicals. Blowdown can be done both manually or automatically. The required blowdown rate is determined based on TDS in the feedwater and the maximum allowable TDS in the boiler water. Also, it is important to know the percentage of makeup water used in the boiler for steam production [9]. Reducing the blowdown rate helps to decrease energy losses with water and the amount of makeup water [28]. Therefore, the benefits that will arise from the application of this BAT are calculated as the corresponding gains in water and fuel consumption. Also since the amount of water used in the system decreases, the amount of wastewater generating also decreases.

4.3.2 The benefit to be obtained with the application of BAT

Since well water contains a high concentration of ions causing hardness in the water, it needs pretreatment before using as process water. There are two steam boilers in the mill and 35,000 tons/year (3996 kg/hour) steam is produced in each boiler. In the mill, cationic ion exchangers are already used to decrease the hardness level of water to prevent corrosion and scale formation problems. For this reason, process water used in the selected mill is analyzed regularly and it is seen that the TDS of process water is around 330 mg/L. Since the application of this BAT requires additional treatment of boiler water for minimization of boiler blowdown, the application of reverse osmosis (RO) as a further treatment to lower the TDS of the product water is considered. Typically, RO systems can remove up to 95% or more of the contaminants from water [3]. For benefit calculations, to be on the safe side, it is assumed 85% removal which corresponds to approximately 50 mg/L (ppm) TDS in water. If the maximum permissible TDS value in a boiler is 3000 ppm [9], the blowdown rate is calculated for the first situation (when the TDS of process water is 340 ppm and RO system is not available) and for the final situation (when the TDS of process water is 50 ppm with RO system).

Blowdown rate is calculated with the formula given below

$$\frac{\text{TDS concentration in coming water} * \text{steam production rate in boiler}}{(\text{maximum allowed TDS concentration in boiler} - \text{TDS concentration in coming water})}$$

when the TDS concentration of water is 340 ppm

$$\text{blowdown rate} = \frac{340 \text{ ppm} * 3996 \text{ kg/hour}}{(3000 \text{ ppm} - 340 \text{ ppm})} = 511 \text{ kg/hour}$$

when the TDS concentration of water is 50 ppm

$$\text{blowdown rate} = \frac{50 \text{ ppm} * 3996 \text{ kg/hour}}{(3000 \text{ ppm} - 50 \text{ ppm})} = 68 \text{ kg/hour}$$

Since the blowdown rate is decreased, the amount of makeup water that is sent to the boiler as feed water to substitute blowdown will also reduce. Also, since the blowdown has a higher temperature, when the blowdown rate decreases, the energy wasted with water also will decrease. For this reason, savings in both water and energy can be obtained with the application of this technique.

Since the decrease in blowdown causes less makeup water usage, saving in water is calculated by taking into consideration blowdown decrease.

Makeup water saving for one boiler = Blowdown reduction

Makeup water saving for one boiler = 511 kg/hour - 68 kg/hour = 443 kg/hour

Makeup water saving for one boiler = 10,632 kg/day = 3,881 ton/year

*Makeup water saving for two boilers = 2 * 3,881 ton/year = 7,762 ton/year*

Since the unit price of water is 4.1 TL/m³ water saving is found as 15,910 TL/year which equals 1,750 €/year. In total, for 2 boilers, savings due to the reduction in water consumption is found as shown below:

$$\text{Makeup water saving for two boilers} = 2 * 1750 \text{ €/year} = 3500 \text{ €/year}$$

Using less water in the boilers means less wastewater is given to the wastewater treatment plant. If 90% of the water used in the system is generated as wastewater and wastewater disposal cost is 2.8 TL/ m³, saving due to a decrease in wastewater is calculated as shown below.

$$\text{Decrease in wastewater amount} = 7762 \text{ ton/year} * 0.9 = 6986 \text{ ton/year}$$

$$\text{Saving with reduction in wastewater generation} = 2.8 \frac{\text{TL}}{\text{m}^3} * 6986 \frac{\text{ton}}{\text{year}} = 19,560 \frac{\text{TL}}{\text{year}}$$

$$\text{Saving with the reduction in wastewater generation} = 2,152 \frac{\text{€}}{\text{year}}$$

The saving in energy with the application of this technique is calculated by taking into consideration blowdown reduction and blowdown heat content. A saturated steam table is used to find blowdown heat content and absolute pressure is taken as 1 bar, same as with the atmospheric pressure. Boiler efficiency is assumed as 75%. All data used in calculations are given in Table 4.6.

The savings in fuel consumption for two boilers is calculated with the formula given below.

$$\text{Fuel saving} = \frac{\text{Blowdown reduction} * \text{Blowdown heat content} * \text{Fuel cost}}{\text{Fuel heating value} * \text{Boiler efficiency}}$$

$$\text{Fuel saving in one boiler} = \frac{10632 \frac{\text{kg}}{\text{day}} * 99.2 \frac{\text{kcal}}{\text{kg}} * 475 \frac{\text{TL}}{\text{ton}} * 1 \frac{\text{ton}}{1000 \text{kg}}}{4700 \frac{\text{kcal}}{\text{kg}} * 0.75} = 142 \text{ TL/day}$$

$$\text{Fuel saving in one boiler} = 51,872 \text{ TL/year} = 5,707 \text{ €/year}$$

$$\text{Fuel saving in two boilers} = 5,707 \text{ €/year} * 2 = 11,413 \text{ €/year}$$

<i>Saving due to decrease in water consumption</i>	$= 31,819 \frac{TL}{year} = 3,500 \frac{Euro}{year}$
<i>Saving due to decrease in wastewater disposal</i>	$= 19,560 \frac{TL}{year} = 2,152 \frac{Euro}{year}$
<i>Saving due to decrease in fuel consumption</i>	$= 103,743 \frac{TL}{year} = 11,413 \frac{Euro}{year}$
<i>Total saving</i>	$= 17,065 Euro/year$

Table 4.6 All data used for the benefit calculation of technique “Minimization of the amount of blowdown forming in the boilers with better boiler feedwater treatment options such as ion exchanger, reverse osmosis, etc”

Item	Value	Reference
Total steam production (for 2 boilers) in the selected textile mill	70,000 ton/year	[45]
Steam production in one boiler	35,000 ton/year	
	3996 kg/hour	
Boiler efficiency	75%	
TDS in raw water (first case)	340 ppm	[45]
TDS after reverse osmosis process (final case)	50 ppm	
Maximum allowable TDS concentration in a boiler	3000 ppm	[9]
Blowdown rate in the first case	510.7 kg/hour	
Blowdown rate in the final case	67.7 kg/hour	
Makeup water saving due to reduction in blowdown amount	443 kg/hour	
Unit price of water	4.1 TL/m ³	[63]
Saving due to reduction in water consumption	31,819 TL/year	
	3,500 €/year	
Wastewater disposal cost	2.8 TL/m ³	[63]
Saving due to reduction in wastewater generation	19,560 TL/year	
	2,152 €/year	
Blowdown heat content	99.2 kcal/kg	[20]
Fuel cost	475 TL/ton	[66]
Heating value of coal	4,700 kcal/kg	[67]
Saving due to decrease in fuel consumption	103,743 TL/year	
	11,413 €/year	
Total saving	17,065 €/year	

4.3.3 Estimated Investment Cost and Payback Period

Maximum, minimum, and average investment costs based on the results of the questionnaire can be seen in Table 4.7. According to saving and investment cost, the payback period calculation is shown below.

Table 4.7 Investment cost for the technique “Minimization of the amount of blowdown forming in the boilers with better boiler feedwater treatment options such as ion exchanger, reverse osmosis, etc”

Cost Item	Value, €
Realistic minimum investment cost	10,000
Realistic maximum investment cost	50,000
Average investment cost	30,000

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{30,000 \text{ €}}{17,065 \text{ €}} * 12 \cong 22 \text{ months}$$

4.4 BAT 9: Using inverter in boilers

4.4.1 Description of BAT

This technique requires using an inverter in connection with the fan or pump motor in the boilers and it enables electricity saving with speed adjustment of pump and fan. The compliance rate to this technique of the textile mills in Turkey which are falling under the IPPC Directive is 46%. 54% of the mills need to integrate this technique into their facilities.

The usage of an inverter in a motor enables to adjustment of rotation speed (rpm) and acceleration of an alternating current (AC) motor by controlling the frequency of power supplied to the motor. The motor operates at full speed in the case of there is no inverter [42]. Inverters, mostly called Variable Speed Drives (VSD) or

Variable Frequency Drives (VFD), are important for the energy management since it enables accurate control of motor speed and prevents operation fast than needed. Drives are integrated with pumps or fan motors to control the speed according to demand. Electrical energy saving is obtained by slowing down an AC motor of fan or pump in industrial or commercial boilers [55]. The benefit that will arise from the application of this BAT is calculated as the corresponding gains in electricity consumption.

4.4.2 The benefit to be obtained with the application of BAT

The potential benefit from the application of this technique is calculated with the help of a study that was conducted in a boiler house. It is assumed that a similar application can be done for the fan motor in a boiler in a textile mill. In the study, combustion air was supplied from a fan which is 30 kW at 1450 rpm and a variable speed drive was used for the fan motor in the boiler to control fan motor speed for prevention of redundant usage. According to the label on the fan motor, the motor power was 30 kW and its speed was 1465 rpm [43]. If this fan motor works without an inverter, it works at 100% operating speed in all the working time (100% operating speed in 100% operating time). Motor efficiency was given as 0.93, so the power drawn was given as 32.25 kW. When an inverter (variable speed driver) was used in the system, since power drawn by the motor depends on the operating speed and operating time, the total drawn power changes. In this way, since the fan motor does not work at 100% speed all the time, electricity consumption decreases. According to the study, thanks to the inverter, the fan motor works at 4 different speeds which are 100, 80, 60 and 40% with 10, 30, 40 and 20% operating time, respectively. Power draw values corresponding to operating speed were given in the study and it was stated that these values were determined with the help of motor power curves and data obtained from the facility [43]. Operating speed and time with and without VFD can be seen in Table 4.8.

Table 4.8 Operating speed and operating time with and without VFD of the fan motor

Without variable frequency drive		
Operating speed	Operating time	Power draw (kW)
100%	100%	32.25 kW
With variable frequency drive		
Operating speed	Operating time	Power draw (kW)
100%	10%	32.25 kW
80%	30%	25.8 kW
60%	40%	19.35 kW
40%	20%	12.9 kW

According to these values, electricity consumption is calculated for both situations.

*Power consumption without inverter = power draw * operating time*

$$\text{Power consumption without inverter} = 32.25 \text{ kW} * 8760 \frac{\text{hours}}{\text{year}} = 282,510 \text{ kwh/year}$$

$$\text{Power consumption with inverter} = 32.25 \text{ kW} * 0.1 + 25.8 \text{ kW} * 0.3 + 19.35 \text{ kW} * 0.4 + 12.9 \text{ kW} * 0.2$$

$$\text{Power consumption with inverter} = 21.285 \text{ kW} * 8760 \frac{\text{hours}}{\text{year}} = 186,456.6 \frac{\text{kwh}}{\text{year}}$$

$$\text{Annual power consumption difference} = 282,510 \frac{\text{kwh}}{\text{year}} - 186,456.6 \frac{\text{kwh}}{\text{year}} = 96053.4$$

$$\frac{\text{kwh}}{\text{year}}$$

*Electricity Saving = Annual power consumption difference * Price of electricity*

$$\text{Electricity Saving} = 96053.4 \frac{\text{kwh}}{\text{year}} * 68.7 \frac{\text{TL}}{\text{kwh}} = 65,998 \text{ TL/year} = 7260.5 \text{ €/year}$$

The benefit calculation summary table of the technique can be seen in Table 4.9.

$\text{Electricity Saving} = 65,998 \frac{\text{TL}}{\text{year}} = 7260.5 \frac{\text{Euro}}{\text{year}}$

Table 4.9 Summary table for the benefit calculation of BAT “Using inverter in boilers”

Item	Value	Reference
Power output of fan motor	30 kW	[43]
Motor efficiency	93%	[43]
Annual operating hours	8760 hours/year	
Power consumption without inverter	282510 kWh/year	
Power consumption with inverter	186456.6 kWh/year	
The difference in power consumption	96053.4 kWh/year	
Cost of electricity	68.7 kr/kwh	[58]
Electricity saving	65998 TL/year	
	7260.5 €/year	

4.4.3 Estimated Investment Cost and Payback Period

Maximum, minimum and average investment cost based on results of the questionnaire can be seen in Table 4.10. According to saving and investment cost, the payback period is calculated and found as approximately 21 months.

Table 4.10 Investment cost for the technique “Using inverter in boilers”

Cost Item	Value, €
Realistic minimum investment cost	5,000
Realistic maximum investment cost	20,000
Average investment cost	12,500

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{12,500 \text{ €}}{7260.5 \text{ €}} * 12 \cong 21 \text{ months}$$

4.5 BAT 9: Thermal isolation of all piping system

4.5.1 Description of BAT

This BAT aims to prevent heat loss through the steam distribution lines. The questionnaire shows that while the compliance rate to this BAT is 54%, 46% of total mills need to apply this technique. Thermal insulation plays a critical role in having an energy-efficient system for both cold and hot systems since heat loss through steam distribution is inevitable [73]. Since thermal insulation enables a reduction of heat transfer, a significant amount of energy requirement of a system can be reduced. The selection of insulation material and thickness of the insulation layer is critical decisions that should be done carefully since different systems require different applications [68]. If pipes are not isolated properly, they cause heat dissipation which depends on the steam temperature inside a pipe, ambient air temperature and the surface area. Isolation helps to decrease steam production since it decreases heat loss from the surfaces of steam lines. In other words, the consumed fuel to reach the required steam temperature decreases [10]. Therefore, the benefit that will arise from the application of this BAT is calculated as the corresponding gains in fuel consumption.

Theoretically, heat loss from a pipe with insulation can be calculated by using formulas that include thermal conductivity, temperature differences and insulation thickness. Readily available tables can also be used to determine the quantity of heat loss with insulation of different thicknesses. In these calculations or evaluations, it is assumed customarily that the temperature of the pipe surface is at the same temperature as steam inside the pipe.

The application of this BAT and the estimation of associated benefits require the identification of isolation material, its diameter and also its economic thickness [4]. In the proceeding section, the benefits are calculated based on assuming mineral

wool isolation material used on four pipes which have diameters of DN50, DN32, DN25, DN25.

4.5.2 The benefit to be obtained with the application of BAT

To see the benefit gained with the application of this BAT it is assumed that four piping line sections in different lengths and diameters will need to be isolated in a medium-sized textile mill. With the light of a study related to this issue, pipe lengths and diameters are assumed and appropriate insulation material and thickness are determined for benefit calculations [71]. DN50, DN32, DN25, DN25 are the diameters of selected four pipes for insulation calculations and the lengths of uninsulated pipe sections are 118m, 60m, 28m, and 18m, respectively. While steam pressure is 6 bar, the steam temperature is 165 °C.

Depending on the steam and ambient temperature and diameter of pipes, ideal insulation thickness is determined. As an insulation material, rock wool also known as mineral wool is chosen [71]. For the calculations, isolation material guides are used since these guides include readily available tables which show minimum insulation thickness for process pipework and equipment to control heat losses. These tables are prepared by taking into consideration different pipe diameters and surface temperatures. The tables prepared for rockwool insulation material are used as a base. Air temperature is assumed as 20 °C. By looking at pipe diameter hot surface temperature, corresponding minimum insulation thickness (mm) and heat loss (W/m) are found out [52]. To be on the safe side, the selection of larger insulation thickness than the minimum required one is more reliable. This table is given in Appendix B.

After determining insulation thickness, the heat loss of bare surface and heat loss of surface after insulation are compared and the difference is used to calculate energy saving. For these, industrial insulation guides which provide readily available tables showing heat losses based on insulation thickness are used.

According to the determined insulation thickness and diameter of the pipe, heat losses(W/m) are found out for both insulated pipes and uninsulated pipes [14]. These tables can be seen in Appendix C. For calculation of total heat losses, these values are multiplied by the length of the uninsulated pipe. The summary table can be seen in Table 4.11.

Table 4.11 Summary table for the technique “Thermal isolation of all piping system”

Item	pipe#1	pipe#2	pipe#3	pipe#4	Reference
Steam pressure	6 bar	6 bar	6 bar	6 bar	[71]
Steam temperature	165 °C	165 °C	165 °C	165 °C	
Diameter	DN 50	DN32	DN25	DN25	
Diameter	60.3 mm	42.4 mm	33.7 mm	33.7 mm	
Length of uninsulated pipe section	118 m	60 m	28 m	18 m	
Determined insulation thickness	50 mm	38 mm	38 mm	38 mm	[52]
Heat loss after insulation	38 W/m	31 W/m	31 W/m	31 W/m	[14]
Total heat loss after insulation	4484 W	1860 W	868 W	558 W	
Heat loss of bare surface	509 W/m	372 W/m	303 W/m	303 W/m	[14]
Total heat loss of bare surface	60062 W	22320 W	8484 W	5454 W	
Energy saving	55578 J/s	20460 J/s	7616 J/s	4896 J/s	

As it can be seen from Table 4.11, energy saving results are given in J/s. The total energy saving in the textile mill is calculated by adding saving in each pipe and the following result is obtained:

$$\text{Total energy saving in the mill(J/s)} = 55578 + 20460 + 7616 + 4896 = 88550 \text{ J/s}$$

The textile mill works 24 hour/day. It is assumed that the efficiency of the boiler is 75%. The average heating value of coal is taken as 4700 kcal/kg which equals 19,677,960 joule/kg. Based on these quantities, the decrease in the amount of coal with obtained total energy saving is calculated.

The amount of coal corresponding to this total energy saving(kg/year) is calculated by using the given equation:

$$\text{Reduction in coal consumption} = \frac{\text{total anergy saving} * \text{working hours of the mill}}{\text{boiler efficiency} * \text{heating value of coal}}$$

$$\text{Reduction in coal consumption} = \frac{88550 \text{ J/sec} * 31536000 \text{ sec/year}}{0.75 * 19677960 \text{ J/kg}} = 189,214 \text{ kg/year}$$

which equals 189.2 ton of coal /year

Since the average cost of coal is 475 TL/ton [66] total saving is found as

$$\text{Saving} = 475 \frac{\text{TL}}{\text{ton}} * 189.2 \frac{\text{ton}}{\text{year}} = 89,877 \frac{\text{TL}}{\text{year}} = 9,887 \frac{\text{Euro}}{\text{year}}$$

$$\text{Fuel Saving} = 89,877 \frac{\text{TL}}{\text{year}} = 9,887 \frac{\text{Euro}}{\text{year}}$$

4.5.3 Estimated Investment Cost and Payback Period

Questionnaires related to this BAT reveals that the average investment cost of application of this BAT is € 5250. Information about the investment cost based on the results of the questionnaire can be seen in Table 4.12. According to saving and investment cost, the payback period is calculated and found as approximately 7 months.

Table 4.12 The investment cost for the technique “Thermal isolation of all piping system”

Cost Item	Value, €
Realistic minimum investment cost	3,500
Realistic maximum investment cost	7,000
Average investment cost	5,250

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{5250 \text{ €}}{9887 \text{ €}} * 12 \cong 7 \text{ months}$$

4.6 BAT 9 : Reuse of all thermal condensate

4.6.1 Description of BAT

This BAT enables separating condensate from the steam in a boiler and makes it possible to send it to the boiler to be used as feedwater again. According to the questionnaire, while 50% of facilities already implemented this technique, the remaining 50% of facilities need to implement it.

The textile industry uses a high amount of steam which is generated in boilers during production processes. When this generated steam encounters a surface that has a lower temperature than the steam saturation temperature, the condensed steam starts to turn into the liquid form of steam which is called condensate [37]. The generated condensate is quite pure and at a high temperature. The condensate can be used in the boiler again. When the condensate is used as feedwater, makeup water consumption decreases. In addition to this, since condensate is very pure -if it is not contaminated by processes- the amount of contaminant in water that will be sent to the boiler will be less. Moreover, since the temperature of condensate is higher, it is beneficial to use it again for energy saving. Wasting condensate means that more energy is needed to increase the temperature of makeup water[9]. For this reason, the condensate should be separated from the steam and collected to reuse. After collection, it must be pumped to the place where it is used again. Generally, the usage of condensate in a boiler as feedwater and converting it into steam again is recommended since it is highly valuable due to its high-temperature content and clean quantity. Since this technique requires the installation of new pipes for capturing and diverting steam, drain lines and steam traps are the critical system components to reuse the condensate [25]. Reusing condensate in a boiler as feedwater helps to decrease water and energy usage. Also, since less wastewater is sent to the treatment plant, the cost of wastewater treatment is less.

4.6.2 The benefit to be obtained with the application of BAT

Benefit analysis of this BAT has bases of “each kilogram condensate not returned to the boiler must be compensated makeup water”. In the selected mill, average steam production is determined as 69,531 tons/year which equals around 7,937 kg/hour. This value also equals the evaporation rate of the mill. Condensate return is assumed as 70%, so the condensate amount returning to the boiler is calculated as 5556 kg/hour.

$$\text{Condensate amount returning to the boiler } \left(\frac{\text{kg}}{\text{hour}}\right) = 7937 \frac{\text{kg}}{\text{hour}} * \frac{70}{100} = 5556 \frac{\text{kg}}{\text{hour}}$$

$$\text{Condensate amount returning to the boiler } \left(\frac{\text{ton}}{\text{year}}\right) = 5556 \frac{\text{kg}}{\text{hour}} * 8760 \frac{\text{hour}}{\text{year}} * \frac{1 \text{ ton}}{1000 \text{ kg}}$$

$$\text{Condensate amount returning to the boiler } \left(\frac{\text{ton}}{\text{year}}\right) = 48,672 \frac{\text{ton}}{\text{year}}$$

This amount of water is saved and reused again in boilers as feedwater, so saving due to the decrease in water consumption is calculated based on that. Also, since the wastewater amount given to the discharge line decreases, saving due to this reduction is also calculated. It is assumed that 90% of the water used in the processes is generated as wastewater.

Saving due to reduction in water usage = Raw water unit price Decrease in water consumption*

$$\text{Water saving} = 4.1 \frac{\text{TL}}{\text{ton}} * 48,672 \frac{\text{ton}}{\text{year}} = 199,554 \frac{\text{TL}}{\text{year}} = 21,953 \frac{\text{Euro}}{\text{year}}$$

Wastewater saving = Effluent cost Decrease in wastewater generation*

$$\text{Saving due to wastewater reduction} = 2.8 \frac{\text{TL}}{\text{ton}} * 48,672 \frac{\text{ton}}{\text{year}} * 0.9$$

$$\text{Saving due to wastewater reduction} = 122,653 \frac{\text{TL}}{\text{year}} = 13,493 \frac{\text{Euro}}{\text{year}}$$

Raw water and condensate temperatures are assumed as 15 and 88 °C, respectively, and boiler efficiency is assumed as 75%. For the calculation, specific heat formula

is used and the question “how much heat would be needed what if any condensate is not returned to the boiler as feedwater” is asked to calculate the saving.

$$Q = m * c * \Delta T$$

Where ;

Q: heat transfer (kJ/year)

m: mass of the substance (kg)

c: specific heat (KJ/(kg °C))

ΔT : temperature difference (°C)

$$Q = 5556 \frac{\text{kg}}{\text{hour}} * 8760 \frac{\text{hours}}{\text{year}} * 4.18 \frac{\text{kJ}}{\text{kg}^\circ\text{C}} * (88-15)^\circ\text{C} = 14,851,684,845 \frac{\text{kJ}}{\text{year}}$$

This value corresponds to the energy requirement for heating makeup water. Since boiler efficiency is assumed as 75% of the energy supplied to heat the make-up water is found as shown below.

$$\frac{14,851,684,845 \text{ kJ/year}}{0.75} = 19,802,246,460 \frac{\text{kJ}}{\text{year}} = 4,732,736,904 \frac{\text{kcal}}{\text{year}}$$

To find the coal amount corresponding to this energy, the average heating value of coal which is 4700 kcal/kg is used.

$$\text{Decrease in the coal amount} = \frac{4,732,736,904 \frac{\text{kcal}}{\text{year}}}{\frac{4700 \text{ kcal}}{\text{kg}}} = 1,006,965 \text{ kg/year} = 1007 \text{ ton/year}$$

$$\text{Saving in fuel consumption} = 1007 \frac{\text{ton}}{\text{year}} * 475 \frac{\text{TL}}{\text{ton}} = 478,309 \frac{\text{TL}}{\text{year}} = 52,619 \frac{\text{Euro}}{\text{year}}$$

The summary table for the benefit calculation of the technique can be seen in Table 4.13.

<i>Saving due to decrease in water consumption</i>	$= 21,953 \frac{\text{Euro}}{\text{year}}$
<i>Saving due to decrease in fuel consumption</i>	$= 52,619 \frac{\text{Euro}}{\text{year}}$
<i>Saving due to decrease in wastewater generation</i>	$= 13,493 \frac{\text{Euro}}{\text{year}}$
<i>Total saving</i>	$= 88,066 \frac{\text{Euro}}{\text{year}}$

Table 4.13 Summary table for the benefit calculation of the technique “Reuse of all thermal condensate”

Item	Value	Reference
Average steam production in the mill	69531 ton/year	[45]
	7937 kg/hour	
Evaporation rate	7937 kg/hour	
Percentage of condensate returning to the boiler	70%	
Amount of condensate returning to the boiler	5556 kg/hour	
	48,672 ton/year	
Unit price of water	4.8 TL/m ³	[63]
Water saving	199,554 TL/year	
	21,953 €/year	
Wastewater to water ratio	90 %	
Reduction in wastewater amount	43,805 m ³ /year	
Wastewater disposal cost	2.8 TL/m ³	[63]
Saving due to reduction in wastewater	122,653 TL/year	
	13,493 €/year	
Operation hours of mill	8760 hours/year	
Raw makeup water temperature	15 °C	
	88 °F	
Condensate temperature	88 °C	
	190 °F	
Boiler efficiency	75%	
m	5556 kg/hour	
Cp	4.18 KJ/(kg*°C)	[21]
ΔT	73 °C	
Q	14,887,215,191 kJ/year	
For a plant in operation 8760 h/year, the energy required to heat make-up water	14,887,215,191 kJ/year	

Table 4.13 (cont'd)

When the average boiler efficiency is 75%, the energy supplied to heat the make-up water is:	19,849,620,255 kJ/year	
	4,744,059,241 kcal/year	
Average heating value of coal	4700 kcal/kg	[67]
Amount of coal corresponding to energy requirement	1,009,374.31 kg/year	
	1009.4 ton/year	
Average cost of coal (TL/ton)	475	[66]
€/t	9.1	[65]
Fuel saving	479,452.8 TL/year	
	52,745 €/year	

4.6.3 Estimated Investment Cost and Payback Period

As can be seen from Table 4.14, the average investment cost of this BAT is determined as €50,000 based on the questionnaire results. Based on the calculated saving and average investment cost, the payback period is calculated, and it is found as around 7 months.

Table 4.14 Investment cost of BAT “Reuse of all thermal condensate”

Cost Item	Value, €
Realistic minimum investment cost	50,000
Realistic maximum investment cost	50,000
Average investment cost	50,000

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{50,000 \text{ €}}{88,066 \text{ €}} * 12 \cong 7 \text{ months}$$

4.7 BAT 9 : Preheating of boiler feedwater with waste gas heat by installing an economizer

4.7.1 Description of BAT

This technique allows energy saving with the help of economizers. The questionnaire related to this technique reveals that 50% of the mills need to apply this technique. Half of the textile mills have already complied with this technique. Economizers are used in order to extract heat from the waste gas and use it to heat water. Heat recovery is accomplished with these types of equipment and they help to prevent wasting of heat inside the waste gas by decreasing flue gas temperature [69]. Economizers can be used to preheat combustion air or feedwater. As a rule of thumb, Each 10°C increase in feedwater by economizer, 1% fuel cost can be saved. Energy saving potential depends on the boiler and fuel type used in the system [9]. The boiler stack economizer system for preheating feed water can be seen in Figure 4.1.

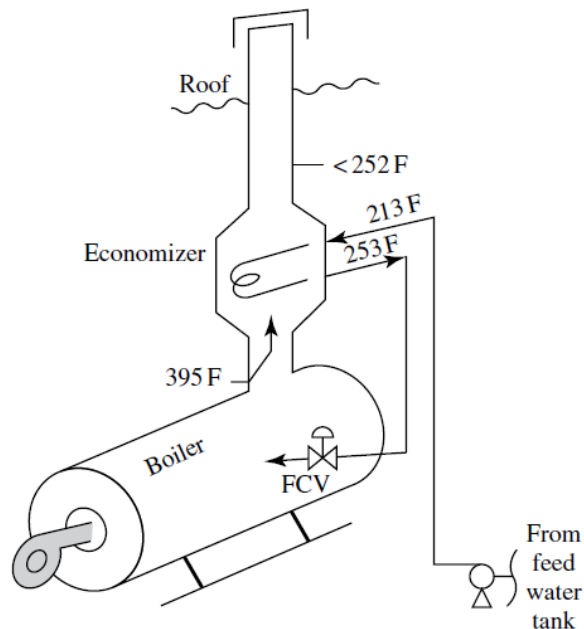


Figure 4.1 Boiler stack economizer system for preheating feed water

[37]

4.7.2 The benefit to be obtained with the application of BAT

In the medium-sized textile mill, the benefit analysis is done by taking into consideration the temperature difference between stack gas and inlet air temperature before and after installing an economizer. In the mill 401,024,309.6 MJ energy is used each year in the boilers. The combustion air temperature is assumed as 20°C (68°F). Stack gas temperature before and after installing an economizer is taken as 200 and 155°C, respectively [35]. Based on these values, the temperature difference between inlet air and stack gas before and after installing an economizer is calculated and these results are used to investigate heat losses. Readily available tables are used to determine heat losses. These tables are prepared depending on the oxygen level in stack gas and temperature differences between inlet air and stack gas (See appendix C). Heat losses, in percentage, are found with the help of these tables and based on that, the efficiency of the boiler in the current and proposed condition is found. All data used in the benefit analysis can be seen in Table 4.15.

In the current condition (before installing an economizer), the temperature difference between inlet air and stack gas before installing an economizer is

$$392\text{ }^{\circ}\text{F} - 68\text{ }^{\circ}\text{F} = 324\text{ }^{\circ}\text{F}.$$

If the oxygen level at the stack gas is assumed as 4%, the heat loss corresponding to these values is found as 11.1% which equals 88.9% efficiency [57].

In the proposed condition (after installing an economizer), the temperature difference between inlet air and stack gas before installing an economizer is

$$311\text{ }^{\circ}\text{F} - 68\text{ }^{\circ}\text{F} = 243\text{ }^{\circ}\text{F}.$$

If the oxygen level at the stack gas is assumed as 4%, the heat loss corresponding to these values is found as 9.2% which equals 90.8% efficiency [57].

Efficiency difference before and after installing an economizer 90.8-88.9=1.9%

$$\text{Fuel-saving as percentage} = \frac{\text{Efficiency after economizer} - \text{Efficiency before economizer}}{\text{Efficiency after economizer}} * 100$$

$$\text{Fuel-saving as percentage} = \frac{90.8 \% - 88.9 \%}{90.8 \%} * 100 = 2.1\%$$

$$\text{Fuel-saving} = \frac{\text{Current energy consumption} * \text{Fuel saving as percentage}}{100}$$

$$\text{Fuel-saving} = \frac{401,024,309.6 \text{ MJ/year} * 2.1}{100} = 8,391,477.8 \text{ MJ/year}$$

$$\text{Fuel-saving} = 2,004,304,483 \text{ kcal/year}$$

The average heating value of coal is 4700 kcal/kg and so the amount of coal corresponding to the energy requirement is found as shown below.

$$\text{Amount of coal corresponding to energy requirement} = \frac{2,004,304,483 \text{ kcal/year}}{4700 \text{ kcal/kg}}$$

$$\text{Amount of coal corresponding to energy requirement} = 426447.8 \frac{\text{kg}}{\text{year}} = 426.4 \frac{\text{ton}}{\text{year}}$$

Since the average cost of coal 475 TL/ton, fuel saving is calculated as shown below.

$$\text{Saving due to decrease in fuel consumption} = 426.4 \frac{\text{ton}}{\text{year}} * 475 \frac{\text{TL}}{\text{ton}} = 202,563 \frac{\text{TL}}{\text{year}}$$

$$\text{Saving due to decrease in fuel consumption} = 22,260 \frac{\text{Euro}}{\text{year}}$$

$\text{Saving due to decrease in fuel consumption} = 202,563 \frac{\text{TL}}{\text{year}} = 22,260 \frac{\text{Euro}}{\text{year}}$
--

Table 4.15 All data used for benefit calculation of the BAT “Preheating of boiler feedwater with waste gas heat by installing an economizer”

Item	Value	Reference
Total energy consumption in the boilers	401,024,309.6 MJ/year	[45]
	200,512,154.8 MJ/year	
Combustion air temperature	20 °C	
	68 °F	
Stack gas temperature before installing an economizer	200 °C	[35]
	392 °F	
Stack gas temperature after installing an economizer	155 °C	[35]
	311 °F	
The temperature difference between inlet air and stack gas before installing an economizer	324 °F	
The temperature difference between inlet air and stack gas after installing an economizer	243 °F	
Heat loss percentage when the temperature difference is 324°F and 4% oxygen level	11.1%	[57]
Efficiency when the temperature difference is 324°F and 4% oxygen level	88.9 %	
Heat loss percentage when the temperature difference is 243°F and 4% oxygen level	9.2 %	[57]
Efficiency when the temperature difference is 243°F and 4% oxygen level	90.8 %	
Efficiency difference before and after installing an economizer	1.9 %	
Fuel-saving as percentage	2.1%	
Fuel-saving for coal-fired boiler	8,391,477.8 MJ/year	
	2,004,304,483kcal/year	
The average heating value of coal	4700 kcal/kg	[67]
Amount of coal corresponding to energy requirement	426447.8 kg/year	
	426.4 ton/year	
The average cost of coal (TL/ton)	475	[66]
€/t	9.1	[65]
Fuel-saving	202,562.7 TL/year	
	22,260 €/year	

4.7.3 Estimated Investment Cost and Payback Period

As can be seen from Table 4.16, the average investment cost of this BAT is determined as €33,750 based on the questionnaire results. Based on the average investment cost and saving, the payback period is calculated, and it is found as approximately 1.5 years.

Table 4.16 Investment cost of the BAT “Preheating of boiler feedwater with waste gas heat by installing an economizer”

Cost Item	Value, €
Realistic minimum investment cost	20,000
Realistic maximum investment cost	47,500
Average investment cost	33,750

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{33,750 \text{ €}}{22,260 \text{ €}} * 12 \cong 18 \text{ months}$$

4.8 BAT 13 : Determination of required water quality standards and prevention use of water of higher quality than required

4.8.1 Description of BAT

This BAT allows the prevention of unnecessary high-quality water usage in the production steps. According to questionnaire results, 54% of the mills need to comply with this technique and 46% of the mills have already implemented it.

In different production steps in the manufacturing industry, different quality of water can be used depending on the demand and purpose. Since each step of production does not require high-quality water, water quality standards for each production step should be determined to prevent unnecessary treatment of water. This is valid also for the textile industry. Most of the textile mills use water drawn

from the wells as raw water. Since the hardness level of well water is high, raw water is treated with a cationic ion exchanger, reverse osmosis or sand filter before using as process water in the mill. In some textile mills, water in drinking water quality is used although it is not necessary and being costly. For this reason, required water quality in each process step should be investigated and unnecessary high-quality water usage should be prevented. This enables the reduction of water supply and treatment costs [7].

4.8.2 The benefit to be obtained with the application of BAT

In the selected mill, 98% of raw water is softened by using ion exchangers and after softening it is used in the processes. Raw water consumption is 1,033,590 ton/year and 1,014,978 ton/year of water is softened for process water usage. Since there is no exact data and required water quality highly depends on the process and its requirements, the benefit calculation is done with a rough estimation for this technique. It is assumed that in total 10% of total water is not needed to be softened by ion exchanger with the determination of water quality for each process. According to questionnaire results obtained from textile mills, the unit cost of water treatment in an ion exchanger is 0.3 €/m³. The summary table for the benefit calculation can be seen in Table 4.17.

Average process water amount used in the mill = 1,012,918 ton/year

If 10% of water is not softened with the application of the technique

$$1,012,918 \frac{\text{ton}}{\text{year}} * 0.1 = 101,292 \text{ ton water is not softened per year}$$

Since the unit treatment cost of an ion exchanger is 0.3 €/ton, total saving is calculated by multiplying the water amount that is not softened with the unit treatment cost of an ion exchanger.

$$\text{Saving due to less water treatment in ion exchangers} = 0.3 \frac{\text{€}}{\text{ton}} * 101,292 \frac{\text{ton}}{\text{year}}$$

$$\text{Saving due to less water treatment in ion exchangers} = 30,388 \frac{\text{€}}{\text{year}}$$

$$\text{Saving due to decrease in water treated by ion exchanger} = 202,563 \frac{\text{TL}}{\text{year}} = 30,388 \frac{\text{€}}{\text{year}}$$

Table 4.17 Summary table for the benefit calculation of BAT “Determination of required water quality standards and prevention use of water of higher quality than required”

Item	Value	Reference
Average amount of raw water used in the mill	1,033,590 ton/year	[45]
Percentage of raw water softened in ion exchangers	98%	[45]
Average amount of process water used in the mill	1012918.2 ton/year	[45]
Water amount not to be softened with the application of BAT	10% of total water	
	101,292 ton/year	
Unit treatment cost of ion exchanger	0.3 €/m ³	[8]
Saving due to less water treatment in ion exchangers	276,227 TL/year	
	30,388 €/year	

4.8.3 Estimated Investment Cost and Payback Period

As can be seen from Table 4.18, the average investment cost of this BAT is determined as €17,500 based on the questionnaire results. Based on the average investment cost and saving, the payback period is calculated, and it is found as approximately 7 months.

Table 4.18 Investment cost of the BAT “Determination of required water quality standards and prevention use of water of higher quality than required”

Cost Item	Value, €
Realistic minimum investment cost	5,000
Realistic maximum investment cost	30,000
Average investment cost	17,500

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{17,500 \text{ €}}{30,388 \text{ €}} * 12 \cong 7 \text{ months}$$

4.9 BAT 13 : Saving water and reducing the amount of wastewater by increasing washing efficiency by using equipment that will provide water efficiency in facility and equipment cleaning (water spray nozzles, spray sprayers, etc.)

4.9.1 Description of BAT

This technique aims to decrease water usage and implicitly decreasing wastewater generation amount by using high efficient cleaning equipment for cleaning purposes. Questions related to this technique show that while more than half (58%) of textile mills comply with this BAT, 42% of the mills need to implement it in their mills.

Cleaning and sanitation of facility require a high amount of water, so it is critical to use high-efficiency cleaning equipment such as nozzles and sprays for workplace and equipment cleaning since they improve the efficiency in cleaning. These devices help to do work with less amount of water by increasing the surface area of droplets and increasing the number of liquid droplets [62]. For this reason, putting nozzles in which pressure is optimized and active sensors to the points where there

is higher water consumption is essential for water efficiency [22]. Increasing water efficiency during cleaning helps to decrease water consumption and at the same time wastewater amount to be discharged wastewater treatment line.

4.9.2 The benefit to be obtained with the application of BAT

Several resources, case studies and product catalogs are searched for benefit analysis. A summary table of different applications and corresponding water-saving percentages are given in Table 4.19.

Table 4.19 Examples of high efficient system applications and corresponding saving in water in different plants

Application	Water saving	Reference
A chemical processing plant has changed the cleaning system to clean totes in the plant. A new system was designed around a motorized tank washer and thanks to it cleaning cycle was reduced from 30 minutes to 10 minutes per tote with better cleaning performance.	Each tote was cleaned with 1045 liters of water before modification, now 488 liters of water are used. A total of 37% water savings per year was observed.	[56]
Using spray guns instead of open hoses for plant cleaning	Water consumption can be reduced by 50% per year	[56]
Using an optimized motor-driven tank washer equipped with flash nozzles for hot wort receivers in the beer brewing process.	51% water saving in cleaning per year was observed in the plant.	[56]
Using hoses equipped with spray guns instead of 15 open-end sanitation hoses in turkey processing plant	3.5% water saving in cleaning per year was obtained.	[56]
For spray rinsing, using water-efficient nozzles in the textile industry	Up to 10%, water saving can be obtained.	[1]

As it can be seen from the applications, it is obvious that water consumption in equipment and plant cleaning can be reduced with efficient equipment such as spraying devices, aerosol sprayers in the mills. Based on the different applications,

water saving can vary, so in benefit calculation for this BAT, an average percentage value for water saving is assumed. It is accepted that 20% less water is used per year in the middle-sized textile mill. Based on this assumption, since the water amount for cleaning purposes is known, water amount corresponding to 20% water conservation is calculated and saving is determined. The summary table of benefit calculation can be seen in Table 4.20.

Water amount used for cleaning=18,612 ton/year

Unit raw water price is taken as 4.1 TL/m³. Water saving corresponding to a 20% reduction in water usage with the application of BAT is calculated as shown below.

*Water amount corresponding to 20% reduction =18,612 $\frac{\text{ton}}{\text{year}}$ *0.2=3,722 $\frac{\text{ton}}{\text{year}}$*

*Saving due to water amount reduction = 4.1 $\frac{\text{TL}}{\text{ton}}$ *3,722 $\frac{\text{ton}}{\text{year}}$ =15261.84 $\frac{\text{TL}}{\text{year}}$ = 1679 $\frac{\text{Euro}}{\text{year}}$*

If it is assumed that 90% of the water used in the processes generates as wastewaters and wastewater treatment cost is taken as 2.8 TL/m³, the saving due to reduction in wastewater generation is calculated as shown below.

*Reduction in wastewater amount = 3,722 $\frac{\text{ton}}{\text{year}}$ * 0.9 = 3350 $\frac{\text{ton}}{\text{year}}$*

*Saving due to wastewater amount reduction =2.8 $\frac{\text{TL}}{\text{ton}}$ *3350 $\frac{\text{ton}}{\text{year}}$ =9380 $\frac{\text{TL}}{\text{year}}$*

Saving due to wastewater amount reduction =1032 $\frac{\text{Euro}}{\text{year}}$

Saving due to water reduction=15,262 $\frac{\text{TL}}{\text{year}}$ = 1679 $\frac{\text{Euro}}{\text{year}}$

Saving due to wastewater amount reduction =9380 $\frac{\text{TL}}{\text{year}}$ =1032 $\frac{\text{Euro}}{\text{year}}$

Total saving =24642 $\frac{\text{TL}}{\text{year}}$ =2711 $\frac{\text{Euro}}{\text{year}}$

Table 4.20 Summary table for the benefit calculation of the BAT “Saving water and reducing the amount of wastewater by increasing washing efficiency by using equipment that will provide water efficiency in facility and equipment cleaning”

Item	Value	Reference
Amount of water used for cleaning in the mill before applying BAT	18,612 ton/year	[45]
Decrease in water amount after applying BAT	20%	
Decrease in water usage for cleaning purposes after applying BAT	3,722 ton/year	
Price of raw water	4.1 TL/m ³	[63],[64]
Saving due to reduction in water usage	15,262 TL/year	
	1679 €/year	
Water/wastewater ratio	90%	
Decreased wastewater amount	3350 ton/year	
Wastewater treatment cost	2.8 TL/m ³	[63],[64]
Saving due to reduction in wastewater amount	9380 TL/year	
	1032 €/year	

4.9.3 Estimated Investment Cost and Payback Period

As can be seen from Table 4.21, the average investment cost of this BAT is determined as €3000 based on the questionnaire results. Based on the average investment cost and saving, the payback period is calculated, and it is found as approximately 1.2 years.

Table 4.21 Investment cost for the technique “Saving water and reducing the amount of wastewater by increasing washing efficiency by using equipment that will provide water efficiency in facility and equipment cleaning”

Cost Item	Value, €
Realistic minimum investment cost	1000
Realistic maximum investment cost	5000
Average investment cost	3000

$$\text{Payback period} = \frac{\text{Amount to be invsted}}{\text{Estimated annual net cash flow}} * 12 = \frac{3000 \text{ €}}{2711 \text{ €}} * 12 \cong 14 \text{ months}$$

4.10 BAT 13 : Separate collection and reuse of cooling water used in all production processes to save water and energy

4.10.1 Description of BAT

This technique provides water and energy saving by collecting and reusing cooling water in the system. The questionnaire related to this BAT reveals that the compliance rate to this technique is 38% of textile mills. 62% of textile mills need to implement this technique.

Cooling water is used in processes in which thermal energy is used intensively and cooling is necessary. Cooling water allows heat removal from components or different types of equipment in the plant by energy transfer [26]. It is in a good condition in terms of quality and high temperature. For this reason, cooling water that is not in contact with fabric or chemicals/auxiliaries can be recycled and reused again in different processes such as desizing, scouring, washing, rinsing or dyeing as process water or can be sent to the boiler. Also, since cooling water is heated up after a certain time and its temperature increases, heat recovery can be done with the help of heat exchangers [24]. As a result, water and energy can be obtained with the application of this BAT. Condenser cooling water, cooling roll water, yarn dryers, pressure dyeing machines or air compressors can be given as examples for uncontaminated cooling water sources and they can be reused in dyeing, bleaching, rinsing or cleaning purposes in a textile facility after collecting [11]. This technique requires preventing cooling water to mix with other effluent wastewater and discharging wastewater collection channel. Cooling water should be stored in a different tank so this BAT requires the installation of a water recirculation system or recycling system including pipe, valve, storage tank, and control system [32].

4.10.2 The benefit to be obtained with the application of BAT

This technique helps to use less water and so the amount of wastewater that is sent to the wastewater discharge line decreases. In addition to this, since cooling water is at a high temperature around 50-60°C, reusing it in different processes where heated water is needed, allows energy saving [28].

Reusing cooling water in the plant can provide 2-10% water saving and up to 10% energy saving [7]. Also, it is seen that 1.6 – 2.1 GJ/tonne fabric and 1.44 – 7.4 tonne water/tonne fabric can be saved based on the case studies applied in many China textile plants [28].

Cooling water from different points such as condensers, heat exchangers, dryers, dyeing machines, or air compressors can be collected and can be reused in different processes, namely in dyeing, bleaching, cleaning or for boilers as feedwater [54]. Various studies and projects have been searched for benefit analysis. They can be seen in Table 4.22.

Table 4.22 Reusing cooling water applications and savings in different textile mills

Textile Mill	Application	Saving	Reference
Medium-sized mill: Charming Fabrics Co., Ltd., Jiangmen City, Guangdong Province	Reuse dyeing process cooling water for dyeing and rinsing processes	20% water saving	[40]
Medium-sized mill: Datang Printing & Dyeing Clothing Fabric Co., Ltd., Foshan City, Guangdong Province	Reuse cooling water from singeing machine	1.5% water saving	[40]
Interlining fabrics mill: Kufner Textilwerke in Weißkirchen/ Stmk.	Reuse of cooling water as process water	10% water saving	[36]

Table 4.22 (cont'd)

Medium-sized mill: Prosperity Textile (HK) Limited, Shaoguan City, Guangdong Province	Reuse cooling water for hot rinsing	4-5% water saving, 3-4 % energy saving	[40]
Medium-sized mill: Mill M16	Reuse cooling water from air compressor and dryer for dyeing	0.3% water saving, 3% energy saving, 0.5% electricity saving	[40]
Medium-sized mill: Shaoxing Huashen Textile Dyeing & Finishing Co., Lt d., Shaoxing City, Zhejiang Province	Reuse cooling water from singeing machine to printing rinse	4% water saving	[40]

As can be seen from the different applications, collection and reuse of cooling water in the plant provides up to 20% water saving depending on the amount of cooling water reused. This BAT forces to reuse all cooling water used in the system. For this reason, it is accepted that a middle-sized textile mill can save 8% of water and 5% energy by reusing cooling water.

In the studied medium-sized textile mill, 842,432 ton/year process water is used in HT-over flow and pad-batch processes. Since it is assumed that 8% of water is saved by reusing cooling water, saving due to a decrease in water usage is calculated by taking unit raw water price as 4.1 TL/m³ and it is shown below.

$$\text{Reduction in water usage amount} = 842,432 \frac{\text{ton}}{\text{year}} * 0.08 = 67,395 \frac{\text{ton}}{\text{year}}$$

$$\text{Saving due to water amount reduction} = 4.1 \frac{\text{TL}}{\text{ton}} * 67,395 \frac{\text{ton}}{\text{year}} = 276,318 \frac{\text{TL}}{\text{year}} = 30,398 \frac{\text{Euro}}{\text{year}}$$

If it is assumed that 90% of the water used in the processes generates as wastewaters and wastewater treatment cost is 2.8 TL/m³, due to less usage of water, the wastewater amount also decreases.

$$\text{Reduction in wastewater amount} = 67,395 \frac{\text{ton}}{\text{year}} * 0.9 = 60655.5 \frac{\text{ton}}{\text{year}}$$

$$\text{Saving due to wastewater amount reduction} = 2.8 \frac{\text{TL}}{\text{ton}} * 60655.5 \frac{\text{ton}}{\text{year}} = 169,835 \frac{\text{TL}}{\text{year}}$$

$$\text{Saving due to wastewater amount reduction} = 18,684 \frac{\text{Euro}}{\text{year}}$$

Since cooling water is at a high temperature around 50°C- 60°C, reusing it in different processes where heated water is needed, energy saving can be obtained and it is assumed that 5% energy saving is obtained with the application of the technique by taking references the case studies about it, as mentioned in the previous part.

In the selected mill, on average 526,372,825 MJ thermal energy is used per year. If a 5% reduction in thermal energy usage takes place,

$$\text{Saving in energy} = 526,372,825 \frac{\text{Mj}}{\text{year}} * 0.05 = 26,318,641 \frac{\text{Mj}}{\text{year}} \text{ is obtained}$$

Since 1MJ=238.85 kcal

$$26,318,641 \frac{\text{Mj}}{\text{year}} = 6,286,207,463 \frac{\text{kcal}}{\text{year}} \text{ energy saving is obtained.}$$

It is assumed that all the thermal energy is obtained from coal in boilers in the selected mill, so the corresponding amount of coal to this energy saving is calculated.

If the calorific value of coal is taken as 4700 kcal/kg as an average value, the coal amount corresponding to this energy is calculated as shown below.

$$\text{Amount of coal corresponding energy} = \frac{6,286,207,463 \frac{\text{kcal}}{\text{year}}}{4700 \frac{\text{kcal}}{\text{kg}}} = 1,337,491 \frac{\text{kg}}{\text{year}} = 1337.5 \frac{\text{ton}}{\text{year}}$$

The cost of coal is taken as 475 TL/ton as average value and saving due to a decrease in energy consumption is calculated as shown below.

$$\text{Saving with decrease in energy consumption} = 1337.5 \frac{\text{ton}}{\text{year}} * 475 \frac{\text{TL}}{\text{ton}} = 635,308 \frac{\text{TL}}{\text{year}}$$

$$\text{Saving with decrease in energy consumption} = 69,891 \frac{\text{Euro}}{\text{year}}$$

The summary table for the calculations can be seen in Table 4.23.

<i>Saving due to water reduction</i>	$= 276,318 \frac{TL}{year} = 30,398 \frac{Euro}{year}$
<i>Saving due to wastewater amount reduction</i>	$= 169835.4 \frac{TL}{year} = 18,684 \frac{Euro}{year}$
<i>Saving due to decrease in energy consumption</i>	$= 635,308 \frac{TL}{year} = 69,891 \frac{Euro}{year}$
<i>Total saving</i>	$= 118,973 \frac{Euro}{year}$

Table 4.23 Summary table for the benefit calculation of the BAT “Separate collection and reuse of cooling water used in all production processes to save water and energy”

Item	Value	Reference
Process water amount used in the mill	842,432 ton/year	[45]
Percentage of water saved by reusing cooling water	8%	
Reduction in water usage amount	67,395 ton/year	
Unit raw water price	4.1 TL/m ³	[63]
Saving due to water amount reduction	276,318 TL/year	
	30,398 €/year	
Water/wastewater ratio	90%	
Reduction in wastewater amount	60,655.5 ton/year	
Wastewater treatment cost	2.8 TL/m ³	[63]
Saving due to wastewater amount reduction	169835.4 TL/year	
	18684 €/year	
Thermal energy needed in the mill	526,372,825 MJ /year	
Percentage of energy saved when cooling water is reused	5%	
Energy saving by reusing cooling water	26,318,641 MJ/year	
	6,286,207,463 kcal/year	
Calorific value of coal	4700 kcal/kg	[67]
Amount of coal corresponding energy saving	1337491 kg/year	
	1337.5 ton/year	
Price of coal	475 TL/ton	[66]
Saving due to decrease in energy consumption	635,308 TL/year	
	69,891 €/year	

4.10.3 Estimated Investment Cost and Payback Period

The investment cost of this technique results from pumps, modification in the piping system and constructing hot water storage tank [26]. As shown in Table 4.24, the questionnaire reveals that the average investment cost for this technique is €50,000

Table 4.24 Investment cost of the BAT “Separate collection and reuse of cooling water used in all production processes to save water and energy”

Cost Item	Value, €
Realistic minimum investment cost	50,000
Realistic maximum investment cost	50,000
Average investment cost	50,000

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{50,000 \text{ €}}{118,973 \text{ €}} * 12 \cong 5 \text{ months}$$

4.11 BAT 13 : In ion-exchange resin systems, after regeneration, monitoring of hardness level of effluent water (softened water) and washing water by hardness sensors to optimize regeneration frequency and rinsing time

4.11.1 Description of BAT

This technique aims reduction in the amount of water usage and salt usage in the ion exchange resin systems by optimizing regeneration frequency and rinsing time. In Turkey, 79% of the textile mills among 220 textile mills have already applied this technique in their plants. 21% of the mills need to implement it.

If process water is supplied from groundwater resources it contains a high concentration of Ca^{+2} and Mg^{+2} and so it must be softened with the help of an ion exchanger to be used in the processes. Generally, cationic ion exchangers are used for water softening and after a certain time, while ions are removed from the water, the resin becomes saturated with these ions and needs to be regenerated to be used again. This regeneration process is done with brine water [7]. Most of the time, although regeneration time is determined by the manufacturer, it must be done based on a metered system. In other words, since the hardness of water depends on the location and water source, optimization of regeneration should be done by monitoring of hardness level of softened water and washing water by sensors. Based on the results, regeneration frequency and rinsing time can be determined to prevent the usage of water and salt more than required.

4.11.2 The benefit to be obtained with the application of BAT

According to the questionnaire belongs to the selected mill, 2 ion exchange columns are used to soften the water. After softening, regeneration is applied per 6 hours after 380 m³ water is softened. In total, 6 times regeneration for 2 columns is applied in a day. Also, it was stated that regeneration time is set as 45 minutes and after regeneration rinsing is applied for 15 minutes [8]. For the benefit calculations, case studies are researched and a study which was conducted by Kıran Cılız [33] for optimization of regeneration frequency and rinsing time was taken as a base. According to this study, it was noticed that after 43 minutes starting from the backwashing hardness level of water reached almost 0 although the backwashing process was ended after 62 minutes from the starting time. This means that backwashing lasting 19 minutes was done unnecessarily, and this causes redundant usage of salt and water. It is seen that up to 30% water and salt saving can be obtained with the application of the BAT [33]. This study was taken as a base and it was assumed that between 20-25% reduction takes place in regeneration and rinsing time. Thus, reduction of regeneration time from 45 min to 37 min and

reduction of rinsing time from 15 min to 10 min was assumed and backwashing and rinsing duration can take place 13 min less in total and calculations are done based on these values. All values can be seen in Table 4.25.

Column sizes are determined as 1.5 m depth and 1.5 m diameter. The volume of each resin is calculated by using the cylindrical shape volume formula.

$$\text{Volume of each resin bed} = \frac{\pi * R^2 * H}{4} = \frac{\pi * 1.5^2 * 1.5}{4} = 2.65 \text{ m}^3$$

The flow rate of rinsing water and flow rate of salty water is assumed as 0.27 m³/min-m³ and 0.07 m³/min-m³, respectively.

Since regeneration duration will be less with the application of the technique, less water and salt will be used in the regeneration process. Savings due to the reduction in water and salt are calculated by using the time difference after and before application.

*Reduction in water amount in regeneration = volume of resin bed * flowrate of salty water * regeneration times per day * reduction in regeneration duration*

$$\text{Reduction in water amount in regeneration} = 2.65 \text{ m}^3 * 0.07 \frac{\text{m}^3}{\text{m}^3 - \text{min}} * 6 * 8 \text{ min}$$

$$\text{Reduction in water amount in regeneration} = 8.9 \text{ m}^3/\text{day} = 3250 \text{ m}^3/\text{year}$$

Since the price of water is 4.1 TL/ton, saving due to reduction in water amount in regeneration is calculated as shown below.

$$\text{Saving due to reduction in water amount in regeneration} = 3250 \frac{\text{m}^3}{\text{year}} * 4.1 \frac{\text{TL}}{\text{m}^3}$$

$$\text{Saving due to reduction in water amount in regeneration} = 13,325 \frac{\text{TL}}{\text{year}} = 1466 \frac{\text{Euro}}{\text{year}}$$

Salt is used as a solution in the regeneration process, and it is assumed as it is 10% concentration.

$$\text{Reduction in the salt amount in regeneration} = 8.9 \frac{\text{m}^3}{\text{day}} * 0.1 = 0.89 \frac{\text{kg}}{\text{day}} = 325 \frac{\text{kg}}{\text{year}}$$

The price of salt is taken from a firm selling industrial salts to several industries. Salt is sold in a packet which is 25 kg and its price 25 TL. It means the unit price of salt is 0.8 TL/kg.

$$\text{Saving due to salt amount reduction} = \text{Reduction in salt amount} * \text{Unit price}$$

$$\text{Saving due to salt amount reduction} = 325 \frac{\text{kg}}{\text{year}} * 0.8 \frac{\text{TL}}{\text{kg}} = 260 \frac{\text{TL}}{\text{year}} = 28.6 \frac{\text{Euro}}{\text{year}}$$

Since rinsing time is also decreased with the optimization, water saving is directly proportional to the reduction in rinsing duration.

$$\text{Reduction in water amount used in rinsing} = \text{volume of resin bed} * \text{flowrate of rinsing water} * \text{regeneration times per day} * \text{reduction in rinsing duration}$$

$$\text{Reduction in water amount used in rinsing} = 2.65 \text{ m}^3 * 0.27 \frac{\text{m}^3}{\text{m}^3\text{-min}} * 6 * 5 \text{ min}$$

$$\text{Reduction in water amount used in rinsing} = 21.5 \text{ m}^3/\text{day} = 7835 \text{ m}^3/\text{year}$$

$$\text{Saving with water amount reduction for rinsing} = 7835 \frac{\text{m}^3}{\text{year}} * 4.1 \frac{\text{TL}}{\text{m}^3} = 32,122 \frac{\text{TL}}{\text{year}}$$

$$\text{Saving with water amount reduction for rinsing} = 3534 \frac{\text{Euro}}{\text{year}}$$

Total saving due to reduction in water usage is the total amount of saving due to water amount reduction for regeneration and rinsing.

$$\text{Total saving due to reduction in water usage} = 45,447 \frac{\text{TL}}{\text{year}} = 4999.7 \frac{\text{Euro}}{\text{year}}$$

$$\text{Saving due to water reduction} = 45,447 \frac{\text{TL}}{\text{year}} = 5000 \frac{\text{€}}{\text{year}}$$

$$\text{Saving due to salt consumption reduction} = 260 \frac{\text{TL}}{\text{year}} = 28.6 \frac{\text{€}}{\text{year}}$$

$$\text{Total saving} = 5028.6 \frac{\text{€}}{\text{year}}$$

Table 4.25 Summary table for the benefit calculation of the BAT “In ion-exchange resin systems, after regeneration, monitoring of hardness level of effluent water (softened water) and washing water with hardness sensors to optimize regeneration frequency and rinsing time”

Item	Value	Reference
Softened water amount in the mill	1.014.978 ton/year	[45]
Regeneration frequency	per 6 hours	[8]
	3 times per column	[8]
Number of ion exchanger columns	2	
Total regeneration times per day	6	[8]
Rinsing duration after applying BAT	10 min	
Reduction in regeneration time	8 min	
Reduction in rinsing time	5 min	
Height of a column	1.5 m	[2]
Diameter of a column	1.5 m	[2]
Volume of resin bed	2.65 m ³	
Flowrate of rinsing water	0.27 m ³ /min-m ³	[2]
Flowrate of salt water	0.07 m ³ /min-m ³	[2]
Reduction in water amount in regeneration	8.9 m ³ /day	
	3250 m ³ /year	
Regeneration duration before applying BAT	45 min	[8]
Rinsing duration before applying BAT	15 min	[8]
Regeneration duration after applying BAT	37 min	
Price of raw water	4.1 TL/m ³	[63]
Saving due to water amount reduction for regeneration	13,325 TL/year	
	1466 €/year	
Concentration of salt	10%	[2]
Reduction in salt amount in regeneration	0.89 kg/day	
	325 kg/year	
Price of salt	20 TL/ (25 kg salt)	
	0.8 TL/kg salt	
Saving due to salt amount reduction	260 TL/year	
	28.6 €/year	
Reduction in water amount used in rinsing	21.5 m ³ /day	
	7835 m ³ /year	
Saving due to water amount reduction for rinsing	32,122 TL/year	
	3534 €/year	
Total saving due to water amount reduction	45,447 TL/year	
	4999.7 €/year	

4.11.3 The benefit to be obtained with the application of BAT

As can be seen from Table 4.26, the average investment cost of this BAT is determined as €6250 based on the questionnaire results. Based on the average investment cost and saving, the payback period is calculated, and it is found as approximately 1.3 years.

Table 4.26 Investment cost of the BAT “In ion-exchange resin systems, after regeneration, monitoring of hardness level of effluent water (softened water) and washing water with hardness sensors to optimize regeneration frequency and rinsing time”

Cost Item	Value, €
Realistic minimum investment cost	5000
Realistic maximum investment cost	7500
Average investment cost	6250

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{6250 \text{ €}}{5028 \text{ €}} * 12 \cong 15 \text{ months} \cong 1.3 \text{ years}$$

4.12 BAT 13 : Characterization of reverse osmosis (RO) concentrates and reusing it without treatment depending on the characterization

4.12.1 Description of BAT

Water amount used in the processes can be decreased by reusing reverse osmosis concentrates in the system and so wastewater amount to be sent to the discharge line can also decrease. The questionnaire shows that while 79% of mills have already applied this technique in their plants, the remaining 21% of mills need to integrate it into their systems.

In the selected textile mill, reverse osmosis systems are used after ion exchangers to treat water further to obtain demineralized water. This demineralized water is

used in the boilers for steam production. If the reverse osmosis system works properly, 20-25% of water forms as a concentrate (reject) and this wastewater can be used in facility or equipment cleaning, rather than sending it to the wastewater collection system [7].

4.12.2 The benefit to be obtained with the application of BAT

In the textile mill, if the raw water is used for steam production, it is sent to the reverse osmosis system after ion exchangers. 71,049 tons of water is used in steam boilers for steam production per year and this amount also equals to water amount treated in reverse osmosis system. The recovery rate is assumed as 75% for the benefit analysis and so, concentrate concentration is calculated as shown below.

$$\text{Amount of concentrate} = 71,049 \frac{\text{ton}}{\text{year}} * 0.25 = 17,762 \frac{\text{ton}}{\text{year}}$$

In the mill, on average 18,612 tons of water is used yearly to clean the plant. As it is seen from the amount of concentrate, the whole concentrate from reverse osmosis can be used for plant cleaning. In that situation, since concentrate is reused for cleaning, saving due to reduction in raw water consumption is obtained. Since raw water price is 4.1 TL/ton, saving corresponding to the water reduction is calculated as shown below.

$$\text{Saving due to reduction in water consumption} = 4.1 \frac{\text{TL}}{\text{ton}} * 17,762 \frac{\text{ton}}{\text{year}} = 72,824 \frac{\text{TL}}{\text{year}}$$

$$\text{Saving due to reduction in water consumption} = 8,011 \frac{\text{Euro}}{\text{year}}$$

Since water consumption decreases, the wastewater amount that is sent to the wastewater collection system also decreases. It is assumed that 90% of the water used in the processes is generated as wastewater. Saving due to wastewater amount reduction is calculated as shown below.

$$\text{Wastewater disposal cost} = 2.8 \text{ TL}/\text{m}^3$$

$$\text{Decreased amount of wastewater} = 17,762 \frac{\text{ton}}{\text{year}} * 0.9 = 15,985.8 \frac{\text{ton}}{\text{year}}$$

$$\text{Saving due to less amount of wastewater generation} = 2.8 \frac{\text{TL}}{\text{m}^3} * 15985.8 \frac{\text{ton}}{\text{year}}$$

$$\text{Saving due to less amount of wastewater generation} = 44.760 \frac{\text{TL}}{\text{year}} = 4,924 \frac{\text{€}}{\text{year}}$$

The summary table for the benefit calculation can be seen in Table 4.27.

<i>Saving due to reduction in water consumption</i>	$= 72,824 \frac{\text{TL}}{\text{year}} = 8,011 \frac{\text{Euro}}{\text{year}}$
<i>Saving due to wastewater amount reduction</i>	$= 44.760 \frac{\text{TL}}{\text{year}} = 4,924 \frac{\text{Euro}}{\text{year}}$
<i>Total saving</i>	$= 12,936 \frac{\text{Euro}}{\text{year}}$

Table 4.27 Summary table for the benefit calculation of the BAT “Characterization of reverse osmosis (RO) concentrates and reusing it without treatment depending on the characterization”

Item	Value	Reference
Water amount used in steam boilers for steam production	71,049 ton/year	[45]
Water amount treated in reverse osmosis system	71,049 ton/year	[45]
	195 ton/day	
Recovery rates	75%-85%	
Concentrate concentration if recovery rate is assumed as 75%	17,762 ton/yıl	
	49 ton/day	
Required water amount for plant cleaning	18,612 ton/year	[45]
	51 ton/day	
Raw water price	4.1 TL/m ³	[63]
Saving due to water reduction	72,824 TL/year	
	8011 €/year	
Wastewater treatment cost	2.8 TL/m ³	[63]
Water/wastewater ratio	0.9	
Reduction in wastewater generation	15985.8 ton/year	
Wastewater treatment cost saving	44,760 TL/year	
	4,924 €/year	

4.12.3 Estimated Investment Cost and Payback Period

As can be seen from Table 4.28, the average investment cost of this BAT is determined as €5750 based on the questionnaire results. Based on the average investment cost and saving, the payback period is calculated, and it is found as approximately 1.3 years.

Table 4.28 The investment cost for the technique “Characterization of reverse osmosis (RO) concentrates and reusing it without treatment depending on the characterization”

Cost Item	Value, €
Realistic minimum investment cost	2500
Realistic maximum investment cost	9000
Average investment cost	5750

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{5750 \text{ €}}{12936 \text{ €}} * 12 \cong 6 \text{ months}$$

4.13 BAT 13 : Characterization of wastewater coming from the rinsing of ion exchangers after regeneration and reusing it without treatment depending on the characterization

4.13.1 Description of BAT

This technique provides reusing wastewater resulting from the regeneration process in other processes in which high water quality is not needed. In Turkey, while 88% of textile mills do not comply with this technique, only 12% of mills have already applied it.

Ion exchange resin beds are backwashed from time to time to remove accumulated particles on the resin bed. Backwashing is done with salty water and wastewater resulting from backwashing of ion exchangers has the quality of process water except for high conductivity content due to salt. Wastewater resulting from backwashing can be reused in the plant by collecting it in a reserve tank. It requires pumps, a piping system, and a tank. For example, it can be used without treatment for facility cleaning. Also, it can be reused for the processes that require high salt content [8]. For instance, a high amount of salt is used in the preparation of cotton fabric dyeing baths in reactive dyeing and so, backwashing wastewater can be used in reactive dyeing baths [45].

4.13.2 The benefit to be obtained with the application of BAT

In the mill, a high amount of salt is required for the reactive dyeing of cotton fabric. For this reason, it is assumed that wastewater resulting from backwashing is used in the dyeing baths.

In the mill, 1364 tons of salt and 123,600 m³ water are used each year for reactive dyeing baths in HT-over flow processes.

Since there is no information about the resins, the volume of each resin bed is calculated by assuming the diameter and height taken from the literature. The salt amount used in the regeneration process is found by using resin bed volume and salt dosage range found in the literature [2]. The typical height and diameter of a resin bed are given as between 1-2 m and between 0.6-2.4 m, respectively. 1.5 m is assumed for height and diameter. According to that, the volume of each resin bed and salt dosages are calculated as shown below.

$$\text{The volume of each resin bed} = \frac{\pi * R^2 * H}{4} = \frac{\pi * 1.5^2 * 1.5}{4} = 2.65 \text{ m}^3$$

$$\text{Salt dosage} = 2.65 \text{ m}^3 * \frac{250 \text{ kg}}{\text{m}^3 \text{ resin bed}} * \frac{6 \text{ times regeneration}}{\text{day}} = 3975 \frac{\text{kg salt}}{\text{day}} = 1451 \frac{\text{ton salt}}{\text{year}}$$

1451 ton salt is used yearly for backwashing. Since salt is given in the form of 10% solution, 14,509 m³ salt solution is used each year. It is assumed that regeneration wastewater contains 1% salt, it can be changed based on the need, at the outlet of the ion exchanger and this equals 145 tons of salt /year.

$$\text{Salt solution at inlet and outlet of regeneration} = 14,509 \frac{\text{m}^3 \text{ salt solution}}{\text{year}}$$

$$\text{Salt amount at the inlet of ion exchanger (10\% salt solution)} = 1451 \frac{\text{ton salt}}{\text{year}}$$

$$\text{Salt amount at the outlet of ion exchanger (1\% salt solution)} = 145 \frac{\text{ton salt}}{\text{year}}$$

As it can be seen from the calculations, wastewater originating from the regeneration process contains salt and it is assumed this wastewater is used in the reactive dyeing baths in HT-over flow processes. This provides saving due to a reduction in water, wastewater, and salt amount.

$$\text{Reduction in water usage amount} = 14,509 \frac{\text{ton}}{\text{year}}$$

$$\text{Unit raw water price is } 4.1 \text{ TL/m}^3$$

$$\text{Saving with water amount reduction} = 4.1 \frac{\text{TL}}{\text{ton}} * 14,509 \frac{\text{ton}}{\text{year}} = 59,487 \frac{\text{TL}}{\text{year}} = 6544 \frac{\text{Euro}}{\text{year}}$$

If it is assumed that 90% of the water used in the processes generates as wastewaters and wastewater treatment cost is 2.8 TL/m³, due to a decrease in water consumption, the wastewater amount also decreases.

$$\text{Reduction in wastewater amount} = 14,509 \frac{\text{ton}}{\text{year}} * 0.9 = 13,058 \frac{\text{ton}}{\text{year}}$$

$$\text{Saving with wastewater amount reduction} = 2.8 \frac{\text{TL}}{\text{ton}} * 13,058 \frac{\text{ton}}{\text{year}} = 36,562 \frac{\text{TL}}{\text{year}} = 4022 \frac{\text{Euro}}{\text{year}}$$

The price of regeneration salt is taken from a firm selling industrial salts to several industries. Salt is sold in a packet which is 25 kg and its price 25 TL. It means the unit price of salt 0.7 TL/kg.

*Saving due to salt amount reduction = Reduction in salt amount * Unit cost*

$$\text{Saving due to salt amount reduction} = 145.1 \frac{\text{ton}}{\text{year}} * \frac{1000\text{kg}}{\text{ton}} = 0.7 \frac{\text{TL}}{\text{kg}}$$

$$\text{Saving due to salt amount reduction} = 101,570 \frac{\text{TL}}{\text{year}} = 11,174 \frac{\text{Euro}}{\text{year}}$$

The summary table and values used for all calculations can be seen in Table 4.29.

<i>Saving due to reduction in water consumption</i>	<i>=59,487 $\frac{\text{TL}}{\text{year}}$ = 6,544 $\frac{\text{Euro}}{\text{year}}$</i>
<i>Saving due to wastewater amount reduction</i>	<i>=36,562 $\frac{\text{TL}}{\text{year}}$ = 4,022 $\frac{\text{Euro}}{\text{year}}$</i>
<i>Saving due to decrease in salt consumption</i>	<i>=101,570 $\frac{\text{TL}}{\text{year}}$ = 11,174 $\frac{\text{Euro}}{\text{year}}$</i>
<i>Total saving</i>	<i>=21,740 $\frac{\text{Euro}}{\text{year}}$</i>

Table 4.29 Summary table for the benefit calculation of the BAT of “Characterization of wastewater coming from the rinsing of ion exchangers after regeneration and reusing it without treatment depending on characterization”

Item	Value	Reference
The required salt amount for reactive dyeing bath	1364 ton/year	[45]
Water amount used in HT-overflow dyeing	123,600 ton/year	[45]
Wastewater amount originating from regeneration	98,815 ton/year	[45]
Salt amount given for the regeneration (10% solution)	1450.9 ton/year	
Salt solution at inlet and outlet of regeneration	14509 m ³ /year	
Salt amount after regeneration (1% solution)	145.1 ton/year	
Price of raw water	4.1 TL/m ³	[63]
Saving due to reduction of water usage	59,487 TL/year	
	6544 €/year	
Price of salt	17.5 TL/ (25 kg salt)	
	0.7 TL/kg salt	

Table 4.29 (cont'd)

Saving due to salt amount reduction	101,570 TL/year	
	11,174 €/year	
Wastewater treatment cost	2.8 TL/m ³	[63]
Water/wastewater ratio	0.9	
Reduction in wastewater generation amount	13058 ton/year	
Wastewater treatment cost saving	36,562 TL/year	
	4022 €/year	

4.13.3 Estimated Investment Cost and Payback Period

As can be seen from Table 4.30, the average investment cost of this BAT is determined as €10,000 based on the questionnaire results. Based on the average investment cost and saving, the payback period is calculated, and it is found as approximately 6 months.

Table 4.30 Investment cost of the BAT “Characterization of reverse osmosis (RO) concentrates and reusing it without treatment depending on the characterization”

Cost Item	Value, €
Realistic minimum investment cost	10,000
Realistic maximum investment cost	10,000
Average investment cost	10,000

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{10,000 \text{ €}}{21,740 \text{ €}} * 12 \cong 6 \text{ months}$$

4.14 BAT 15 : Selection of the biodegradable and bioeliminable sizing agents

4.14.1 Description of BAT

This technique requires using environmentally optimized sizing agents for the reduction of organic load in the final effluent. It allows COD reduction in wastewater. The questionnaire related to this BAT reveals that only 13% of textile mills have already implemented it, 87% of mills need to integrate this technique into their plants.

Sizing agents are applied to warp yarns to prevent breakage of threads during weaving and these sizing agents need to be removed totally from the fabric in the next processes. This step is known as desizing and it requires using a huge amount of water. Also, the addition of several auxiliaries is needed for the desizing process. Since wastewater originating from the desizing step includes high COD content (it accounts for 30-70 % of total COD load), the selection of environmentally optimized sizing agents is critical for the reduction of emission to water. In the BATs (BAT) Reference Document for the Textiles Industry, alternative recipes including modified polyacrylates, polyvinyl alcohol (PVA), wax as sizing agents are recommended for COD reduction [26].

4.14.2 The benefit to be obtained with the application of BAT

Benefit analysis is done by assuming sizing agents are responsible for 40% of COD load in wastewater given to the discharge line. The selection of biodegradable and bioeliminable sizing agents provide 35% COD reduction, as an average value. In the selected mill, it is accepted that 942,514 tons of wastewater are generated each year, as an average value based on the analysis results. Also, wastewater analysis showed that the COD concentration of wastewater is 1126 mg/L. After the application of the technique total COD reduction is calculated and saving due to decrease in the COD amount of wastewater is calculated by taking into

consideration unit cost of COD reduction in wastewater treatment plants. Unit cost is taken from a study which is about the evaluation of various water recovery and end-of-pipe wastewater treatment alternatives of wastewaters from a denim textile mill in accordance with the IPPC Directive. Since this study found the membrane bioreactor (MBR) technology as the BAT for end-of-pipe treatment for the mixed wastewater of denim textile mill, the unit cost of COD reduction by MBR technology is taken as cost-effectiveness value. Cost effectiveness analysis is a type of cost-benefit analysis. According to the study, cost effectiveness is given as 0.42 United States Dollar (USD) per kg COD removed. It means that 0.42 USD should be spent to remove each kilogram of COD from the wastewater by using MBR technology. The benefit is calculated by using the unit cost of COD reduction with MBR technology and the assumption about COD reduction [19]. Calculations for the benefit analysis are given in below and the summary table for this technique can be seen in Table 4.31.

$$\text{Total COD reduction after applying BAT} = \frac{40 \times 35}{100} = 14\%$$

$$\text{Wastewater amount generated in the mill} = 942,514 \text{ m}^3/\text{year}$$

$$\text{COD concentration in wastewater} = 1126 \text{ mg/L}$$

$$\text{COD load before BAT} = 942,514 \frac{\text{m}^3}{\text{year}} * 1126 \frac{\text{mg}}{\text{L}} * 1000 \frac{\text{L}}{\text{m}^3} * \frac{\text{kg}}{10^6 \text{mg}} = 1,061,271 \frac{\text{kg}}{\text{year}}$$

$$\text{Reduction in COD load with BAT} = 148,578 \frac{\text{kg}}{\text{year}} * \frac{14}{100} = 148,578 \frac{\text{kg}}{\text{year}}$$

$$\text{COD load after BAT implementation} = 1,061,271 \frac{\text{kg}}{\text{year}} - 148,578 = 912,693 \frac{\text{kg}}{\text{year}}$$

$$\text{Unit cost of COD reduction} = 0.42 \frac{\text{USD}}{\text{kg COD reduced}}$$

$$\text{Saving with COD reduction} = 148,578 \frac{\text{kg}}{\text{year}} * 0.42 \frac{\text{USD}}{\text{kg COD reduced}} = 62,403 \frac{\text{USD}}{\text{year}}$$

$$\text{Saving with COD reduction} = 476,133 \frac{\text{TL}}{\text{year}} = 52,380 \frac{\text{Euro}}{\text{year}}$$

$$\text{Saving due to COD reduction in wastewater} = 476,133 \frac{\text{TL}}{\text{year}} = 52,380 \frac{\text{Euro}}{\text{year}}$$

Table 4.31 Summary table of the BAT “Selection the biodegradable and bioeliminable sizing agents”

Item	Value	Reference
COD reduction assumption with BAT	35%	[21]
The total amount of wastewater generated in the mill	942,514 ton/year	[38]
COD reduction with BAT	14%	[6,21]
COD concentration in wastewater	1126 mg/L	[45]
Total COD load of wastewater	1,061,271 kg/year	
Reduction in COD load with BAT	148,578 kg/year	
The unit cost of COD reduction	0.42 USD/kg COD reduced	[14]
Saving with COD reduction	62,403 \$/year	
Saving with COD reduction	52,380 €/year	
	476,133 TL/year	
	272,700 TL/year	
Operational cost	30,000 €/year	
Total net saving	22,380 €/year	

4.14.3 Estimated Operational Cost and Payback Period

The application of this technique does not include any investment cost since it requires just chemical change. As can be seen from Table 4.32, the questionnaire about this technique shows that the average operational cost of the application, cost due to using biodegradable and bioeliminable sizing agents in a medium-sized textile mill, is determined as € 30,000. Since there is no investment cost for the application, the payback period could not be calculated for this technique, the calculation of total net saving per year is presented.

Table 4.32 Operational cost of the BAT “Selection the biodegradable and bioeliminable sizing agents”

Cost Item	Value, €
Realistic minimum investment cost	10,000
Realistic maximum investment cost	50,000
Average investment cost	30,000

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{30,000 \text{ €}}{52,380 \text{ €}} * 12 \cong 7 \text{ months}$$

4.15 BAT 23 : In discontinuous dyeing processes, the last rinsing water must be used in the next dyeing process to decrease wastewater pollution load

4.15.1 Description of BAT

This technique provides water saving and so, a reduction in wastewater amount generated from the dyeing. The questionnaire related to this BAT reveals that while 50% of total mills have already implemented it, the remaining half of the mills need to implement this technique.

Rinsing is done to remove impurities remaining on the fiber after dying of the fabric. The number of required rinsing stages depends on the color tone of dyeing. Wastewater originating from rinsing stages can be reused directly or used after treatment. Although the first rinsing baths have higher COD and color content, the last rinsing water has relatively low COD and color, so it can be reused in the next dyeing step without treatment. This provides a reduction in water consumption and so, a decrease in the amount of wastewater generation [7].

4.15.2 The benefit to be obtained with the application of BAT

In the selected textile mill, around 420,000 m³ water is used in HT-over flow processes each year. The questionnaire belongs to the selected mill shows that the amount of water used for the rinsing is about 4 times more than the amount of water used in the dyeing. For this reason, the total amount of water is divided based on this ratio.

Water amount used in rinsing in the mill for HT-overflow process = 335,798 m³/year

Water amount used in dyeing in the mill for HT-overflow process=83,950 m³/year

It is assumed that 3 baths, as an average value, are used in the mill in the HT-over flow process and if the last rinsing water is reused in the next dyeing bath, water is saved. The amount of water that is reused is calculated by dividing the total amount of water by the number of baths. Since in total 335,798 m³ water for 3 baths is used for the rinsing, the amount of water used in the last rinsing step is found as 111,933 m³ in each year. Saving due to water and wastewater reduction is calculated based on this value. The summary table can be seen in Table 4.33.

Water saving = Raw water unit price Decrease in water consumption*

$$\text{Saving due to reduction in water usage} = 4.1 \frac{\text{TL}}{\text{ton}} * 111,933 \frac{\text{ton}}{\text{year}} = 458,924 \frac{\text{TL}}{\text{year}}$$

$$\text{Saving due to reduction in water usage} = 50,487 \frac{\text{Euro}}{\text{year}}$$

Wastewater saving=Effluent cost Decrease in wastewater generation*

$$\text{Saving due to wastewater reduction} = 2.8 \frac{\text{TL}}{\text{ton}} * 111,933 \frac{\text{ton}}{\text{year}} * 0.9 = 282,071 \frac{\text{TL}}{\text{year}}$$

$$\text{Saving due to wastewater reduction} = 31,031 \frac{\text{Euro}}{\text{year}}$$

$$\text{Saving due to water reduction} = 458,924 \frac{\text{TL}}{\text{year}} = 50,487 \frac{\text{Euro}}{\text{year}}$$

$$\text{Saving due to wastewater amount reduction} = 282,071 \frac{\text{TL}}{\text{year}} = 31,031 \frac{\text{Euro}}{\text{year}}$$

$$\text{Total saving} = 81,518 \frac{\text{Euro}}{\text{year}}$$

Table 4.33 Summary table for the benefit analysis of the BAT “In discontinuous dyeing processes, the last rinsing water must be used in the next dyeing process to decrease wastewater pollution load”

Item	Value	Reference
Wastewater amount resulting from HT-over flow process (dyeing+finishing)	419,748 ton/year	[45]
Wastewater amount due to dyeing	83,950 ton/year	[8]
Wastewater amount due to rinsing	335,798 ton/year	[8]
Number of baths for rinsing	3	
Amount of water used for the last rinsing	111,933 ton/year	
Raw water price	4.1 TL/m ³	[63]
Saving due to water amount reduction	458,924 TL/year	
	50,487 €/year	
Wastewater treatment cost	2.8 TL/m ³	[63]
Water/wastewater ratio	0.9	
Reduction in wastewater generation amount	100,740 ton/year	
Wastewater treatment cost saving	282,071 TL/year	
	31,031 €/year	

4.15.3 Estimated Investment Cost and Payback Period

As can be seen from Table 4.34, the average investment cost of this BAT is determined as €50,000 based on the questionnaire results. Based on the average investment cost and saving, the payback period is calculated, and it is found as approximately 8 months.

Table 4.34 Investment cost of the BAT “In discontinuous dyeing processes, the last rinsing water must be used in the next dyeing process to decrease wastewater pollution load”

Cost Item	Value, €
Realistic minimum investment cost	50,000
Realistic maximum investment cost	50,000
Average investment cost	50,000

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{50,000 \text{ €}}{81,518 \text{ €}} * 12 \cong 8 \text{ months}$$

4.16 BAT 25: Applying counter-current washing in continuous washing machines

4.16.1 Description of BAT

This technique provides water saving by reusing water with a counter-current washing system. The questionnaire related to this technique reveals that only 25% of textile mills have implemented it, but 75% of the mills need to apply it. Padbatch dyeing is a continuous process applied in the textile mills and process sketch can be seen from Figure 4.2.

Counter-current washing means that the least contaminated washing water from the final wash is reused in the second-to-last wash and the movement of water continues until the water reaches the first wash stage where it is discharged. Thus, the cleanest water comes into contact with the cleanest fabric [26]. This technique can be applied for washing after continuous de-sizing, scouring, bleaching, dyeing or printing [34].

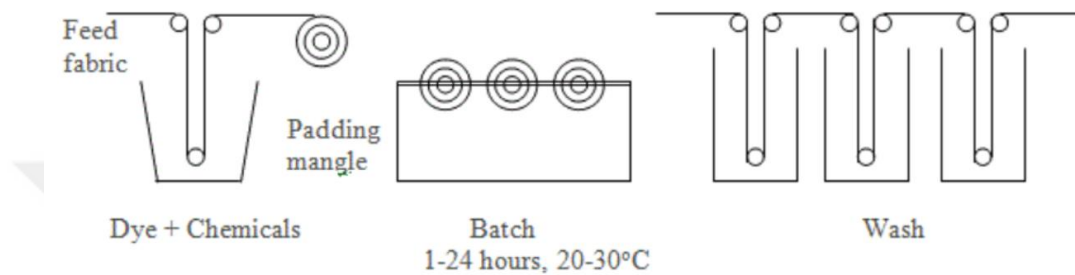


Figure 4.2 Sketch of pad batch process

[59]

4.16.2 The benefit to be obtained with the application of BAT

In the study mill, continuous processes take place with pad batch dyeing and washing machines. For the benefit analysis, it is assumed that there are 5 cabins in the washing machine and water used in the last wash stage is reused in the first two washing stages. This means that while clean water is given for every 5 cabins before applying this technique, clean water will be given to 3 cabins after this technique is applied since water from the last wash stage will be sent to the first two cabins where the fabrics enter to the washing system. In the selected mill, around 135,000 m³ water is used in the pad-batch process for dyeing and finishing processes. The questionnaire belongs to the selected mill shows that the amount of water used for the rinsing is about 4 times more than the amount of water used in the dyeing. For this reason, the total amount of water is divided based on this ratio and it is found

that 107,901 tons of water are used for rinsing yearly. After the application of the technique, 40% water reduction can be obtained since the water used in the last stage is reused in the first wash stages. This means that clean water is given to 3 cabins out of 5.

Water amount used for rinsing= 107,901 ton/year

Percentage of water reduction = 40%

*Reduction in water usage=107,901*0.4=43,160 ton/year*

Unit raw water price = 4.1 TL/m³

Saving with water reduction = $4.1 \frac{TL}{ton} * 43,160 \frac{ton}{year} = 176,957 \frac{TL}{year} = 19,467 \frac{Euro}{year}$

If it is assumed that 90% of the water used in the processes generates as wastewater and wastewater treatment cost is taken as 2.8 TL/m³. The wastewater amount also decreases due to a decrease in water consumption. The summary table prepared for this technique can be seen in Table 4.35.

Decreased wastewater amount $43,160 \frac{ton}{year} * 0.9 = 38,844 \frac{ton}{year}$

Saving with wastewater reduction = $2.8 \frac{TL}{ton} * 38,844 \frac{ton}{year} = 108,764 \frac{TL}{year} = 11,965 \frac{Euro}{year}$

Saving due to water reduction = $176,957 \frac{TL}{year} = 19,467 \frac{Euro}{year}$

Saving due to wastewater amount reduction = $108,764 \frac{TL}{year} = 11,965 \frac{Euro}{year}$

Total saving = $31,432 \frac{Euro}{year}$

Table 4.35 Summary table for the benefit analysis of the BAT “Applying counter-current washing in continuous washing machines”

Item	Value	Reference
Total water amount used in padbatch process for dyeing and finishing	134,876 ton/year	[45]
Water amount used in dyeing	26,975 ton/year	[8]
Water amount used in rinsing	107,901 ton/year	[8]
Number of cabins in washing	5	
Percentage of water reduction if the water used in the last wash stage is reused in the first two washing stages.	40%	
Reduction in water amount	43,160 ton/year	
Total water amount used for rinsing after applying BAT	64,740 ton/year	
Unit raw water price	4.1 TL/m ³	[63],[64]
Saving due to water amount reduction	176,957 TL/year	
	19,467 €/year	
Water/wastewater ratio	90%	
Reduction in wastewater amount	38,844 ton/year	
Wastewater treatment cost	2.8 TL/m ³	[63],[64]
Saving due to wastewater amount reduction	108,764 TL/year	
	11,965 €/year	

4.16.3 Estimated Investment Cost and Payback Period

As can be seen from Table 4.36, the average investment cost of this BAT is determined as €30,000 based on the questionnaire results. Based on the average investment cost and saving, the payback period is calculated, and it is found as approximately 1 year.

Table 4.36 Investment cost of the BAT “Applying counter-current washing in continuous washing machines”

Cost Item	Value, €
Realistic minimum investment cost	10,000
Realistic maximum investment cost	50,000
Average investment cost	30,000

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{30,000 \text{ €}}{31,432 \text{ €}} * 12 \cong 12 \text{ months}$$

4.17 BAT 25 : Volume reduction of troughs to reduce residual dye liquor (excluding indigo and sulfur dyeing)

4.17.1 Description of BAT

This technique provides residual dye liquor saving with a reduction in the volume of troughs. The questionnaire about this technique showed that while 39% of the mills have already implemented it, 61% of the textile mills need to integrate this technique into their mills. In continuous or semi-continuous dyeing processes, impregnation or other application systems are used for the application of dye liquor on the fabric. In continuous dyeing processes, less amount of water is used when compared to discontinuous systems which means dye concentration is higher in the continuous processes. Since residual padding liquor must be removed from the system (padders, pumps and pipes) at the end of each lot when dyeing is done with a new color, it causes discarding of highly concentrated effluent frequently if optimized systems are not used. For example, using small pad batch troughs, pipes and pumps help to decrease the amount of residual padding liquor effluent [26]. The capacity of conventional troughs varies between 30-100 L. If the capacity is decreased with new applications such as using flex-shaft, or U-shaft systems the total amount of unused dye liquor reduces. An average U-shaft trough has a 12 L

capacity [26]. Thus, volume reduction of troughs provides a decrease in the residual dye liquor amount, and in addition to this, the wastewater amount to be sent to the wastewater treatment plant decreases.

4.17.2 The benefit to be obtained with the application of BAT

Benefit analysis is done by assuming changing over U-shaft troughs which have 12 L capacity from the 50 L capacity conventional system and so, 38 L of dye liquor can be saved per batch. Total saving is calculated by taking into consideration the saving due to wastewater reduction and reduction in residual dye liquor. Dye liquor cost is assumed as 0.5 €/L [26]. Calculations are given below, and the summary table can be seen in Table 4.37.

Dye liquor saving per batch = 38 L

$$\text{Total dye liquor saving} = \frac{100 \times 38}{50} = 76\%$$

Wastewater amount originating from dyeing = 13,307 ton/year

Cost of dye liquor = 0.5 €/L

Saving due to reduction in the amount of unused dye liquor equals

$$0.5 \frac{\text{€}}{\text{L}} * 13,307 \frac{\text{m}^3}{\text{year}} * \frac{76}{100} * 1000 \frac{\text{l}}{\text{m}^3} = 5,056,660 \frac{\text{€}}{\text{year}}$$

Cost of wastewater treatment = 2.8 TL/ m³

Saving due to reduction in the wastewater amount equals

$$2.8 \frac{\text{TL}}{\text{m}^3} * 13,307 \frac{\text{m}^3}{\text{year}} * \frac{76}{100} = 28,317 \text{ TL/year} = 3115 \text{ €/year}$$

<i>Saving due to reduction in the amount of unused dye liquor</i> $= 45,965,040 \frac{TL}{year} = 5,056,660 \frac{Euro}{year}$ <i>Saving due to wastewater amount reduction</i> $= 28,317 \frac{TL}{year} = 3115 \frac{Euro}{year}$ <i>Total saving</i> $= 5,059,775 \frac{Euro}{year}$

Table 4.37 Data regarding benefit calculations of the BAT "Volume reduction of troughs to reduce residual dye liquor "

Item	Value	Reference
Wastewater amount resulting from dyeing	13,307 ton/year	[45]
Capacity of conventional system	50 L	[26]
Capacity of U-shaft troughs	12 L	[26]
Dye liquor saving per batch	38 L	
Total dye liquor saving	76%	
Amount of unused dye liquor	10,113 m ³ /year	
Cost of dye liquor	0.5 €/L	[26]
Saving due to reduction in the amount of unused dye liquor	5,056,660 €/year	
Cost of wastewater treatment	2.8 TL/m ³	[63]
Saving due to reduction in the wastewater amount	3115 €/year	

4.17.3 Estimated Investment Cost and Payback Period

As can be seen from Table 4.38, the average investment cost of this BAT is determined as €3,000 based on the questionnaire results. Based on the average investment cost and saving, the payback period is calculated, and it is found as less than 1 month.

Table 4.38 Investment cost of the BAT “Volume reduction of troughs to reduce residual dye liquor ”

Cost Item	Value, €
Realistic minimum investment cost	1,000
Realistic maximum investment cost	5,000
Average investment cost	3,000

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{3000 \text{ €}}{5,059,775 \text{ €}} * 12 \cong \text{less than 1 month}$$

4.18 BAT 34: Optimization of the speed of stenter according to the moisture content of the fabric

4.18.1 Description of BAT

This technique aims to save energy used in the stenters by optimizing stenter speed based on the moisture level of the fabric. In Turkey, the compliance rate of this technique 35%. The remaining 65% of the textile mills need to integrate this BAT into their systems.

Stenters are used for heat-setting, drying and thermofixation in finishing. As an average, each textile material is treated 2.5 times in a stenter and since stenters are the machines that use a huge amount of energy for air heating and evaporation, applying energy-saving techniques in the stenters are critical. Each type of fibers has a different natural moisture level and regain values and so, drying duration should be determined based on that since overdrying until the point below the natural moisture level of fabric is useless and gainless [26]. Therefore, it is beneficial to control the moisture content of the fabric and according to that

optimizing the stenter speed. Hand-held moisture controllers or automatic controllers can be used to monitor the moisture content of the fabric and based on optimum moisture level, drying duration and stenter speed can be optimized [17].

4.18.2 The benefit to be obtained with the application of BAT

Benefit analysis is done based on the relation between the moisture content of fabric and stenter speed. This relationship has been shown with a figure by a company that is active in the production of sensors. Moisture (%) vs speed (m/min) graph has been formed for 100% cotton fabric and it can be seen in Appendix D. It is seen obviously when the moisture level of the fabric increases, stenter speed also increases since the time required for moisture removal decreases. For the calculations, it is assumed that all fabrics are cotton in the mill and before the application of BAT speed stenter is set according to the moisture level of fabric is 3%. After the application of BAT, it is assumed that the moisture level of fabric will be 4%, to be on the safe side, and the speed of the stenter will increase accordingly.

In the selected mill as an average 10,657 ton fabric enters to stenter for drying each year. Fabric width and the basis weight are assumed as 240 cm and 250 gr/m², respectively. According to these, the weight of fabric per length and total length of fabric entering to stenter are calculated as shown below. The summary table for the calculations can be seen in Table 4.39.

Fabric width = 240 cm

*Weight per length = 250 gr/ m²*2.4 m =600 gr/m*

Length per kilogram fabric = $\frac{1000}{600 \frac{gr}{m}} = 1.67 \frac{m}{kg}$

*Total length of fabric entering to stenter = 10,656,792 $\frac{kg}{year}$ *1.67 $\frac{m}{kg}$*

Total length of fabric entering to stenter =17,761,320 $\frac{m}{year}$

In the mill, on average, 20,379,364 kg of coal is used each year. 34% of total coal consumption is used in the hot oil boilers to heat oil to be used in drying processes namely in stenters and turbangs. On average, 3,464,492 kg coal and 1,159,318 MJ electricity are used in stenters and turbangs separately each year.

The calorific value of coal is assumed as 4700 kcal/kg which is 19.7 MJ/kg.

$$\text{Thermal energy consumption in the stenters} = 19.7 \frac{\text{MJ}}{\text{kg}} * 3,464,492 \frac{\text{kg}}{\text{year}}$$

$$\text{Thermal energy consumption in the stenters} = 68,128,540 \text{ MJ/year}$$

$$\text{Electricity consumption used in the stenters} = 1,159,318 \text{ MJ/year}$$

Coal and electricity consumption per length of fabric is calculated by using total fabric length entering to stenter.

$$\text{Coal consumption per length in stenter} = \frac{68,128,540 \text{ MJ/year}}{17,761,320 \text{ m/year}} = 3.84 \text{ MJ/m}$$

$$\text{Electricity consumption per length in stenter} = \frac{1,159,318 \text{ MJ/year}}{17,761,320 \text{ m/year}} = 0.23 \text{ MJ/m}$$

$$\text{Coal and electricity consumption in stenter per length} = 3.84 \frac{\text{MJ}}{\text{m}} + 0.23 \frac{\text{MJ}}{\text{m}}$$

$$\text{Coal and electricity consumption in stenter per length} = 4.07 \frac{\text{MJ}}{\text{m}}$$

Moisture level of fabric before optimization and stenter speed corresponding to this level is 3% and 60 m/min, respectively.

The moisture level of fabric after optimization and stenter speed corresponding to this level is 4% and 70 m/min, respectively.

Based on the thermal and electricity consumption results, total energy consumption is 4.07 MJ per 1-meter fabric with 60 m/min speed, when the speed stenter is 70 m/min energy consumption is calculated as 3.49 MJ/m since there is an inverse proportion. Thus, reduction in energy usage and saving accordingly is calculated as shown below.

$$\text{Reduction in energy consumption} = \frac{4.07 \text{ MJ} - 3.49 \text{ MJ}}{4.07 \text{ MJ}} * 100 = 14.3\%$$

*Electricity saving after applying BAT = electricity consumption per length * reduction in energy consumption * total length of fabric entering to stenter*

$$\text{Electricity saving after applying BAT} = 0.06527 \frac{\text{kwh}}{\text{m}} * \frac{14.3}{100} * 17,761,320 \frac{\text{m}}{\text{year}}$$

$$\text{Electricity saving after applying BAT} = 165,617 \frac{\text{kwh}}{\text{year}}$$

*Coal saving after applying BAT = coal consumption per length * reduction in energy consumption * total length of fabric entering to stenter*

$$\text{Coal saving after applying BAT} = 3.84 \frac{\text{MJ}}{\text{m}} * \frac{14.3}{100} * 17,761,320 \frac{\text{m}}{\text{year}}$$

$$\text{Coal saving after applying BAT} = 9,732,649 \frac{\text{MJ}}{\text{year}} = 2,324,643,109 \frac{\text{kcal}}{\text{year}}$$

Since the calorific value of coal is assumed as 4700 kcal/kg, coal saving in terms of kg/year unit is calculated.

$$\text{Coal saving after applying BAT} = \frac{2,324,643,109 \frac{\text{kcal}}{\text{year}}}{4700 \frac{\text{kcal}}{\text{kg}}} = 494,605 \frac{\text{kg}}{\text{year}} = 495 \frac{\text{ton}}{\text{year}}$$

Since the price of average electricity and coal is 68.71 kr/kwh and 475 TL/ton, respectively saving is calculated as shown below.

*Saving due to reduction in electricity = price of electricity * electricity saving*

$$\text{Saving due to reduction in electricity} = 68.71 \frac{\text{kr}}{\text{kwh}} * 165,617 \frac{\text{kwh}}{\text{year}} = 11,379,531 \frac{\text{kr}}{\text{year}}$$

$$\text{Saving due to reduction in electricity} = 113,795.3 \frac{\text{TL}}{\text{year}} = 12,519 \frac{\text{Euro}}{\text{year}}$$

Saving due to reduction in coal= price of coal coal amount saving*

$$\text{Saving due to reduction in coal} = 475 \frac{\text{TL}}{\text{ton}} * 495 \frac{\text{ton}}{\text{year}} = 234,937 \frac{\text{TL}}{\text{year}}$$

$$\text{Saving due to reduction in coal} = 234,937 \frac{\text{TL}}{\text{year}} = 26,221 \frac{\text{Euro}}{\text{year}}$$

$$\text{Saving due to reduction in electricity consumption} = 113,79 \frac{\text{TL}}{\text{year}} = 12,519 \frac{\text{Euro}}{\text{year}}$$

$$\text{Saving due to reduction in coal consumption} = 234,937 \frac{\text{TL}}{\text{year}} = 26,221 \frac{\text{Euro}}{\text{year}}$$

$$\text{Total saving} = 38,739 \frac{\text{Euro}}{\text{year}}$$

Table 4.39 Summary table for the benefit calculation of the BAT “Optimization of the speed of stenter according to the moisture content of the fabric”

Item	Value	Reference
Fabric amount entering to stenter in mill	10,656,792 kg/year	[45]
	10,657 ton/year	
Fabric width	240 cm	
	2.4 m	
The basis weight of the fabric	250 gr/m ²	
Weight per length	600 gr/m	
Length per kilogram fabric when fabric width is 2.4 m	1.67 m/kg	
The total length of fabric entering to stenter in the mill	17,761,320 m/year	
Coal consumption used for the stenter	3,464,492 kg/year	
Calorific value of coal	4700 kcal/kg	[67]
	19.678 MJ/kg	
Thermal energy used in the stenter	68,128,540 MJ/year	[45]
Electricity consumption in stenters	1,159,318 kwh/year	[45]
	4,173,544.8 MJ/year	
Electricity consumption per length in stenter	0.06527 kwh/meter	
	0.23498 MJ/meter	
Coal consumption per length in stenter	3.84 MJ/meter	
Coal and electricity consumption in stenter per length	4.07 MJ/meter	

Table 4.39 (cont'd)

The moisture level of fabric before optimization	3%	
Stenter speed corresponding to 3% moisture level	60 m/min	[51]
The moisture level of fabric after optimization	4%	
Stenter speed corresponding to 3% moisture level	70 m/min	[51]
If energy consumption is 4.07 MJ/m with 60 m/min speed, energy consumption when the speed stenter is 70 m/min	3.49 MJ/min	
Reduction in energy consumption	14.3 %	
Electricity saving after applying BAT	0.0093 kwh/m	
	165617 kwh/year	
Coal saving after applying BAT	0.55 MJ/m	
	9,732,649 MJ/year	
	2,324,643,109 kcal/year	
Price of coal	475 TL/ton	[66]
Saving due to reduction in coal consumption	234,937 TL/year	
	26,221 €/year	
The average cost of electricity	68.71 kr/kwh	[58]
Saving due to reduction in electricity consumption	11,379,531 kr/year	
	113,795.3TL/year	
	12,519 €/year	

4.18.3 Estimated Investment Cost and Payback Period

As can be seen from Table 4.40, the average investment cost of this BAT is determined as €9,000 based on the questionnaire results. Based on the average investment cost and saving, the payback period is calculated, and it is found as approximately 3 months.

Table 4.40 Investment cost of the BAT “Optimization of the speed of stenter according to the moisture content of the fabric”

Cost Item	Value, €
Realistic minimum investment cost	6,000
Realistic maximum investment cost	12,000
Average investment cost	9,000

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{9000 \text{ €}}{38,739 \text{ €}} * 12 \cong 3 \text{ months}$$

4.19 BAT 34: Applying squeezing or mechanical dewatering processes before drying

4.19.1 Description of BAT

Application of this technique provides energy saving by decreasing the water amount in fabrics with the application of squeezing or mechanical dewatering processes. The questionnaire about this technique reveals that 37% of the textile mills need to integrate this technique into their mills.

Stenters are machines that use a high amount of energy in textile finishing processes for drying and heat setting. Most of the energy is consumed for air heating and evaporation in stenters. Since a huge amount of energy is used for the water removal from the textile material, decreasing the water content of textile material to some extent before entering to stenter is a very beneficial application to decrease energy consumption. This can be done with the help of some equipment such as mechanical dewatering systems, centrifugation, vacuum extraction systems, or squeezing rollers. It is stated that decreasing the moisture content of fabric from 60% to 50% provides up to 15% energy saving [26].

4.19.2 The benefit to be obtained with the application of BAT

Benefit analysis is done by selecting predryer which is applied before the stenter. Calculations are conducted with the help of product catalogs prepared for the predryer machine which is placed in front of the stenter to decrease the moisture content of the fabric. When the moisture content of textile fabrics decreases, time which must be spent on fabrics to reach desired moisture level decreases, so stenter speed would increase. Calculations to see the benefit with the application of BAT are done by taking into consideration the change in stenter speed. The application of this technique also requires steam and electricity consumption to work the predryer. For this reason, it is calculated that how much steam and electricity is required, and it is taken into consideration in the payback period calculations.

As shown in the benefit analysis calculations of the technique “optimization of the speed of stenter according to the moisture content of the fabric (BAT 34)”, the coal and electricity consumption in stenter per length is found as 4.07 MJ/meter. In the calculations, a predryer is chosen to be implemented in the mill and data given in the technical features of the selected predryer is used. According to that, it is expected that the speed of the stenter increases up to 30% by applying the predryer before entering stenters. For this reason, 20% speed increase is assumed for the benefit calculations in this BAT [6]. In that situation, total thermal energy and electricity consumption in stenter per length is found as 3.39 MJ/meter.

$$\text{Reduction in energy consumption} = \frac{4.07 \text{ MJ} - 3.39 \text{ MJ}}{4.07 \text{ MJ}} * 100 = 16.7\%$$

*Electricity saving after applying BAT = electricity consumption per length * reduction in energy consumption * total length of fabric entering to stenter*

$$\text{Electricity saving after applying BAT} = 0.06527 \frac{\text{kwh}}{\text{m}} * \frac{16.7}{100} * 17,761,320 \frac{\text{m}}{\text{year}}$$

$$\text{Electricity saving after applying BAT} = 193,220 \frac{\text{kwh}}{\text{year}}$$

*Coal saving after applying BAT = coal consumption per length * reduction in energy consumption* total length of fabric entering to stenter*

$$\text{Coal saving after applying BAT} = 3.84 \frac{\text{MJ}}{\text{m}} * \frac{16.7}{100} * 17,761,320 \frac{\text{m}}{\text{year}}$$

$$\text{Coal saving after applying BAT} = 11,354,757 \frac{\text{MJ}}{\text{year}} = 2,712,038,207 \frac{\text{kcal}}{\text{year}}$$

Since the calorific value of coal is assumed as 4700 kcal/kg, the reduction in coal usage amount in kg/year is calculated.

$$\text{Coal saving after applying BAT} = \frac{2,712,038,207 \frac{\text{kcal}}{\text{year}}}{4700 \frac{\text{kcal}}{\text{kg}}} = 577,415 \frac{\text{kg}}{\text{year}} = 577.4 \frac{\text{ton}}{\text{year}}$$

Since the price of average electricity and coal is 68.71 kr/kwh and 475 TL/ton, respectively saving is calculated as shown below.

Saving due to reduction in electricity= price of electricity electricity saving*

$$\text{Saving due to reduction in electricity} = 68.71 \frac{\text{kr}}{\text{kwh}} * 193,220 \frac{\text{kwh}}{\text{year}} = 13,276,119.3 \frac{\text{kr}}{\text{year}}$$

$$\text{Saving due to reduction in electricity} = 132,761.2 \frac{\text{TL}}{\text{year}} = 14,605 \frac{\text{Euro}}{\text{year}}$$

Saving due to reduction in coal= price of coal coal amount saving*

$$\text{Saving due to reduction in coal} = 475 \frac{\text{TL}}{\text{ton}} * 577.4 \frac{\text{ton}}{\text{year}} = 274,272.3 \frac{\text{TL}}{\text{year}}$$

$$\text{Saving due to reduction in coal} = 274,272.3 \frac{\text{TL}}{\text{year}} = 30,173 \frac{\text{Euro}}{\text{year}}$$

Since the application of this technique requires steam and electricity, consumption of these resources is calculated to determine how much coal to produce steam and electricity are consumed yearly. Total steam production and total electricity consumption are given in the technical features report belong to the selected predryer. 110 kg/hour steam and 2.8 kWh electricity are needed to work the

predryer. Since operation time is 8760 hours yearly in the selected mill, calculations are done accordingly.

The average amount of coal needed to produce 1 ton of steam is calculated as 215 kg coal [45]. The required steam amount for machine operation is given as 110 kg/hour, this equals 963.6 tons/year. Thus, coal consumption corresponding to this steam amount is found as 207.2 tons coal/year. In other words, 207 tons of coal is required each year to operate a predryer. In addition to steam consumption, the predryer needs electricity. Since its energy requirement is 2.8 kwh, it corresponds to 24,528 kwh for 1 year.

Since the average price of coal is 475 TL/ton cost due to coal consumption in predryer is found as

$$\text{Cost due to coal consumption} = 475 \frac{\text{TL}}{\text{ton}} * 207.2 \frac{\text{ton coal}}{\text{year}} = 98,408 \frac{\text{TL}}{\text{year}} = 10,826 \frac{\text{Euro}}{\text{year}}$$

Since the average price of electricity is 68.71 kr/kwh cost due to electricity consumption in predryer is found as

$$\text{Cost due to electricity consumption} = 24,528 \frac{\text{kwh}}{\text{year}} * 68.71 \frac{\text{kr}}{\text{kwh}} * \frac{\text{TL}}{100 \text{ kr}}$$

$$\text{Cost due to electricity consumption} = 16,853.2 \frac{\text{TL}}{\text{year}} = 1854 \frac{\text{Euro}}{\text{year}}$$

The summary table and data regarding the calculations can be seen in Table 4.41.

<i>Saving due to reduction in electricity consumption</i>	$= 132,761.2 \frac{\text{TL}}{\text{year}} = 14,605 \frac{\text{Euro}}{\text{year}}$
<i>Saving due to reduction in coal consumption</i>	$= 274,272.3 \frac{\text{TL}}{\text{year}} = 30,173 \frac{\text{Euro}}{\text{year}}$
<i>Cost due to coal consumption</i>	$= 98,408 \frac{\text{TL}}{\text{year}} = 10,826 \frac{\text{Euro}}{\text{year}}$
<i>Cost due to electricity consumption</i>	$= 16,853.2 \frac{\text{TL}}{\text{year}} = 1854 \frac{\text{Euro}}{\text{year}}$
<i>Total net saving</i>	$= 32,098 \frac{\text{Euro}}{\text{year}}$

Table 4.41 Data regarding the savings and expenses with the application of the BAT
“Applying squeezing or mechanical dewatering processes before drying”

Item	Value	Reference
Fabric amount entering to stenter in mill	10,656,792 kg/year	[45]
	10,657 ton/year	
Fabric width	240 cm	
	2.4 m	
Basis weight of fabric	250 gr/m ²	
Weight per length	600 gr/m	
Length per kilogram fabric when fabric width is 2.4 m	1.67 m/kg	
The total length of fabric entering to stenter in the mill	17,761,320 m/year	
Data regarding savings		
Coal consumption used for the stenter	3,464,492 kg/year	
Calorific value of coal	4700 kcal/kg	[67]
	19.678 MJ/kg	
Thermal energy used in the stenter	68,128,540 MJ/year	[45]
Electricity consumption in stenters	1,159,318 kwh/year	[45]
	4,173,544.8 MJ/year	
Electricity consumption per length in stenter	0.06527 kwh/meter	
	0.23498 MJ/meter	
Coal consumption per length in stenter	3.84 MJ/meter	
Coal and electricity consumption in stenter per length	4.07 MJ/meter	
Stenter speed before applying BAT	60 m/min	
Increase of speed of stenter	20%	[6]
Stenter speed after applying BAT	72 m/min	
If energy consumption is 4.07 MJ/m with 60 m/min speed, energy consumption when the speed stenter is 72 m/min	3.39 MJ/meter	
Decrease in energy consumption per meter	16.7%	
Electricity saving after applying BAT	0.0109 kwh/m	
	193,220 kwh/year	

Table 4.41 (cont'd)

Coal saving after applying BAT	0.6393 MJ/m	
	11,354,757 MJ/year	
	2,712,038,207kcal/year	
Average heating value of coal	4700 kcal/kg	
Amount of coal corresponding to energy requirement	577,415 kg/year	
	577.4 ton/year	
Price of coal	475 TL/ton	
Saving due to reduction in coal consumption	274,272.3 TL/year	
	30,173 €/year	
Data regarding expenses		
Average amount of coal needed to produce 1 ton of steam	215 kg coal/ ton steam	[45]
Total steam consumption in predryer machine	110 kg/hour	
	963,600 kg/year	
	963.6 ton/year	
Total coal consumption for steam production	207,174 kg coal/year	
	207.2 ton coal/year	
Price of 1 ton of coal	475 TL/ton	[66]
Total cost of coal in predryer	98,408 TL/year	
	10,826 €/year	
Total electricity consumption in predryer machine	2.8 kwh	
	24,528 kwh/year	
Price of electricity	68.71 kr/kwh	[58]
Total cost of electricity in predryer	1685319 kr/year	
	16853.2 TL/year	
	1854 €/year	
Saving due to reduction in electricity consumption	13,276,119.3 kr/year	
	132,761.2 TL/year	
	14,605 €/year	

4.19.3 Estimated Investment Cost and Payback Period

As can be seen from Table 4.42, the average investment cost of this BAT is determined as €13,000 based on the questionnaire results. Based on the average investment cost and saving, the payback period is calculated, and it is found as approximately 5 months.

Table 4.42 Investment cost of the BAT “Applying squeezing or mechanical dewatering processes before drying”

Cost Item	Value, €
Realistic minimum investment cost	6,000
Realistic maximum investment cost	20,000
Average investment cost	13,000

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{13,000 \text{ €}}{32,098 \text{ €}} * 12 \cong 5 \text{ months}$$

4.20 BAT 35: Measuring the moisture content of the air coming out of the stenter and according to that adjusting the humidity level

4.20.1 Description of BAT

This technique aims to prevent using a higher amount of clean air in stenters by controlling the moisture content of air coming out of the stenter. The questionnaire about this technique reveals that 50% of the textile mills have already integrated this technique into their mills.

Stenters are used mostly for drying and heatsetting of fabrics in the finishing processes. Most of the energy is used for evaporation and heating in the stenters. Effluent air coming out of the stenter should be controlled carefully in order to control drying speed and optimize energy usage. If energy usage is not optimized in the stenters, energy consumption in the stenters increases dramatically and it brings the unnecessary extra cost to the mill. Since the moisture content of the effluent air gives information about the energy usage in the system, its control is critical. If effluent water has a very low moisture content which is around 0,05 kg water/kg dry air, it means the discharged air amount is too much, and also energy which is consumed to heat this amount of air is also very high. Moisture content which is between 0,10 and 0,15 kg water/kg dry air implies that energy consumption in the stenters is at optimum level [8].

4.20.2 The benefit to be obtained with the application of BAT

Benefit analysis is done with the help of process analysis results belongs to a firm working on fabric drying and heat setting machines. Process analysis results about the relation between exhaust air and different parameters (heat efficiency, gas consumption, exhaust flow rate) are presented for different types of fabrics (woven or knitter). For this section, graphs showing the relation between exhaust air absolute humidity (g H₂O/kg dry air) and natural gas consumption (m³/kg fabric) created for drying and heatsetting process for the woven fabric is used [18].

Natural gas consumption values are found by using the graph “Exhaust air absolute humidity vs gas consumption”. Since the suggested values for moisture content are between 0.1-0.15 kg water/kg dry air, 70 gr /kg dry air and 120 gr/kg dry air are assumed as the moisture content in the exhaust air for two cases. Natural gas consumption values corresponding to those moisture levels are compared and the difference between them is used. One important point is that coal is used as an energy source in the stenters in the selected mill rather than natural gas. For this reason, the difference between natural gas consumption is expressed in terms of

coal consumption by taking into consideration their calorific values. Graphs and tables used for the calculations can be seen in Appendix E.

In the first case

Exhaust air absolute humidity in the first case: 70 g H₂O/kg dry air

Natural gas consumption if exhaust air humidity is 70 g H₂O/kg dry air = 0.1595 m³/kg fabric

Energy consumption corresponding to natural gas consumption by taking the calorific value of natural gas as 38.3 MJ/m³

$$0.1595 \frac{\text{m}^3}{\text{kg fabric}} * 38.3 \frac{\text{MJ}}{\text{m}^3} = 6.1 \frac{\text{MJ}}{\text{kg fabric}}$$

Coal amount corresponding to energy consumption by taking the calorific value of

$$\text{coal as } 19.678 \text{ MJ/kg coal} = \frac{6.1 \frac{\text{MJ}}{\text{kg fabric}}}{19.679 \frac{\text{MJ}}{\text{kg coal}}} = 0.31 \frac{\text{kg coal}}{\text{kg fabric}}$$

In the second case

Exhaust air absolute humidity in the first case: 120 g H₂O/kg dry air

Natural gas consumption if exhaust air humidity is 120g H₂O/kg dry air = 0.0878 m³/kg fabric

Energy consumption corresponding to natural gas consumption by taking the calorific value of natural gas as 38.3 MJ/m³ = $0.0878 \frac{\text{m}^3}{\text{kg fabric}} * 38.3 \frac{\text{MJ}}{\text{m}^3} = 3.36 \frac{\text{MJ}}{\text{kg fabric}}$

Coal amount corresponding to energy consumption by taking the calorific value of

$$\text{coal as } 19.678 \text{ MJ/kg coal} = \frac{3.36 \frac{\text{MJ}}{\text{kg fabric}}}{19.679 \frac{\text{MJ}}{\text{kg coal}}} = 0.17 \frac{\text{kg coal}}{\text{kg fabric}}$$

The difference in coal consumption between two cases = $0.31 - 0.17 = 0.14 \frac{\text{kg coal}}{\text{kg fabric}}$

Since average production in the mill in each year is 10,656,792 kg fabric, total saving due to a decrease in the coal consumption is calculated as shown below.

$$\text{Decrease in coal consumption} = 0.14 \frac{\text{kg coal}}{\text{kg fabric}} * 10,656,792 \frac{\text{kg fabric}}{\text{year}} * \frac{\text{ton}}{1000 \text{ kg}}$$

$$\text{Decrease in coal consumption} = 1,487.2 \frac{\text{ton coal}}{\text{year}}$$

Since the average cost of coal is 475 TL/ton total saving is found as

$$\text{Saving due to reduction in coal consumption} = 475 \frac{\text{TL}}{\text{ton}} * 1,487.2 \frac{\text{ton coal}}{\text{year}}$$

$$\text{Saving due to reduction in coal consumption} = 706,410 \frac{\text{TL}}{\text{year}} = 77,713 \frac{\text{Euro}}{\text{year}}$$

The summary table prepared for benefit analysis can be seen in Table 4.43.

$$\text{Saving due to reduction in coal consumption} = 706,410 \frac{\text{TL}}{\text{year}} = 77,713 \frac{\text{Euro}}{\text{year}}$$

Table 4.43 Summary table for the benefit calculation of the BAT “Measuring the moisture content of the air coming out of the stenter and according to that adjusting the humidity level”

Item	Value	Reference
Exhaust air absolute humidity in the first case	70 g H ₂ O/kg dry air	
Natural gas consumption when exhaust air humidity is 70 g water/kg dry air	0.1595 m ³ /kg fabric	[18]
Calorific value of natural gas	38.3 MJ/m ³	
Energy consumption corresponding to the amount of consumed natural gas in the first case	6.1 MJ/kg fabric	
Calorific value of coal	4700 kcal/kg	[67]
	19.678 MJ/kg	
Coal amount corresponding to energy consumption in the stenters in the first case	0.31 kg coal/kg fabric	
Exhaust air absolute humidity in the second case	120 g H ₂ O/kg dry air	

Table 4.43 (cont'd)

Natural gas consumption when exhaust air humidity is 120 g water/kg dry air	0.0878 m ³ /kg fabric	
Energy consumption corresponding to the amount of consumed natural gas in the second case	3.36 MJ/kg fabric	
Amount of coal corresponding to energy consumption in the stenters in the second case	0.17 kg coal/kg fabric	
The difference in coal consumption between two cases	0.14 kg coal/kg fabric	
The average amount of fabric production in the mill each year	10,656,792 kg fabric/year	[45]
Decrease in coal consumption	1,487,180 kg coal/year	
	1,487.2 ton coal/year	
Price of coal	475 TL/ton	[66]
Saving due to reduction in coal amount used in the stenters	706,410 TL/year	
	77,713 €/year	

4.20.3 Estimated Investment Cost and Payback Period

As can be seen from Table 4.44, the average investment cost of this BAT is determined as €9,000 based on the questionnaire results. Based on the average investment cost and saving, the payback period is calculated, and it is found as approximately 2 months.

Table 4.44 Investment cost of the BAT “Measuring the moisture content of the air coming out of the stenter and according to that adjusting the humidity level”

Cost Item	Value, €
Realistic minimum investment cost	6,000
Realistic maximum investment cost	12,000
Average investment cost	9,000

$$\text{Payback period} = \frac{\text{Amount to be invsted}}{\text{Estimated annual net cash flow}} * 12 = \frac{9,000 \text{ €}}{77,713 \text{ €}} * 12 \cong 2 \text{ months}$$

4.21 BAT 39 : Recovery of caustic from mercerization rinsing water by evaporation and reuse it

4.21.1 Description of BAT

This technique is about the recovery and reuse of alkaline used in the mercerization process to save strong lye, distilled water, and hot water. The questionnaire about this technique reveals that the compliance rate for this BAT is just 6%. 94% of the textile mills need to integrate this technique into their mills.

Mercerization is a type of pretreatment which is applied on the cotton fiber with alkaline to increase its tensile strength and absorptive capacities, dimensional stability and lustre of cotton. Mercerization consists of impregation, cooling, stretching, stabilization, neutralization and washing steps [26]. Mercerization is done with caustic and the fabric must be rinsed with hot water after the caustic solution is applied. Since the wastewater which has high alkaline content generates after the mercerization process, recovery and reusing it helps to save lye, water and hot water. Before recovery of caustic with evaporation, initially, coarse particles must be removed with rotary filters or pressurized microfiltration. After this stage, evaporation is done with heat, and NaOH is separated from the water. The remaining concentrated caustic solution is purified with the addition of hydrogen peroxide or settling [38].

4.21.2 The benefit to be obtained with the application of BAT

The benefit analysis is done with the help of a study about the evaporative recovery of mercerization wastewater. In that study, recovery of 1 kg of the weak caustic solution is done with evaporation by using three different types of fuels (heavy fuel

oil, light fuel oil and natural gas) for steam production in order to compare three types of fuel both environmentally and economically. Also, the recovery process is compared with the end-of-pipe treatment of mercerization wastewater. Life cycle assessment and economic analysis studies are conducted in the study, and as a result data regarding revenues from recovery NaOH, distilled water and heat are presented as €/ton, which is the revenues obtained from recovery of mercerization wastewater per ton of weak lye. Also, investment, operation and maintenance cost for recovery process is taken from the producer and they were provided. In the economic analysis part, analysis is done by assuming the revenue obtained due to heat of hot water and distilled water are reused and the cost of these recovered materials are found from the marketing price as if they are bought instead of recovering [5]. Unit values are taken from this study by assuming natural gas is used for evaporation in the selected textile mill. Data used for the benefit calculations can be seen in Table 4.45.

According to study results,

Revenue of strong lye with evaporation = 9.13 €/ ton of weak lye

Revenue of distilled water with evaporation = 1.93 €/ton of weak lye

Revenue of heat from hot water with evaporation = 11.91 €/ton of weak lye

Operation and maintenance cost = 1.01 €/ton of weak lye

If the water amount used in mercerization is taken as 20 L/kg, the total water amount used in mercerization is found as;

$$20 \frac{L}{kg} * 10,047 \frac{kg}{day} = 200,940 \frac{L}{day}$$

Since water amount in weak lye is 6 times higher than the water amount on strong lye, total water consumption is divided accordingly and so,

Water amount in strong lye = 28,706 L/day = 10,585 ton/year

Water amount in weak lye = 172,234 L/day = 62,780 ton/year

Thus, unit prices are multiplied with weak lye amount to find total benefit.

$$\text{Revenue of strong lye with evaporation} = 9.13 \frac{\text{€}}{\text{ton}} * 62,780 \frac{\text{ton}}{\text{year}} = 573,181 \frac{\text{€}}{\text{year}}$$

$$\text{Revenue of distilled water with evaporation} = 1.93 \frac{\text{€}}{\text{ton}} * 62,780 \frac{\text{ton}}{\text{year}} = 121,165 \frac{\text{€}}{\text{year}}$$

$$\text{Revenue of heat from hot water} = 11.91 \frac{\text{€}}{\text{ton}} * 62,780 \frac{\text{ton}}{\text{year}} = 747,710 \frac{\text{€}}{\text{year}}$$

$$\text{Operation and maintenance cost} = 1.01 \frac{\text{€}}{\text{ton}} * 62,780 \frac{\text{ton}}{\text{year}} = 63,408 \frac{\text{€}}{\text{year}}$$

$$\text{Saving due to strong lye} = 573,181 \frac{\text{€}}{\text{year}}$$

$$\text{Saving due to distilled water} = 121,165 \frac{\text{Euro}}{\text{year}}$$

$$\text{Saving due to hot water} = 747,710 \frac{\text{Euro}}{\text{year}}$$

$$\text{Operation and maintenance cost} = 63,408 \frac{\text{Euro}}{\text{year}}$$

$$\text{Total net saving} = 1,378,649 \frac{\text{Euro}}{\text{year}}$$

Table 4.45 Summary table for the benefit calculation of the BAT “Recovery of caustic from mercerization rinsing water by evaporation and reuse it”

Item	Value	Reference
NaOH amount used for mercerization per kg of textile	between 170-350 g NaOH/kg textile	[7]
	between 270-300 g NaOH/L and it is assumed as 280 gr/L	[7]
Weak lye solution (rinsing wastewater)	between 40-50 g NaOH/L and it is assumed as 45 gr/L	[7]
Water amount used in mercerization	6-32 L/kg textile	[45]
Production capacity in pad-batch process	3,666,924 kg/year	[8]
	10,047 kg/day	
If water amount used in mercerization is taken as 20 L/kg textile, total water amount used for mercerization	200,940 L/day	
Water amount in strong lye	28,706 L/day	
	29 ton/day	
	10,585 ton/year	
Water amount in weak lye	172,234 L/day	
	172 ton/day	
	62,780 ton/year	
Revenue of strong lye with evaporation	9.13 €/ ton of weak lye	
	573,181 €/year	
Revenue of distilled water with evaporation	1.93 €/ton of weak lye	
	121,165 €/year	
Revenue of heat from hot water with evaporation	11.91 €/ton of weak lye	
	747,710 €/year	
Operation and maintenance cost	1.01 €/ton of weak lye	
	63,408 €/year	
Net saving	1,378,649 €/year	

4.21.3 Estimated Investment Cost and Payback Period

As can be seen from Table 4.46, the average investment cost of this BAT is determined as €300,000 based on the questionnaire results. Based on the average investment cost and total net saving, the payback period is calculated, and it is found as approximately 3 months.

Table 4.46 Investment cost for the technique “Recovery of caustic from mercerization rinsing water by evaporation and reuse it”

Cost Item	Value, €
Realistic minimum investment cost	200,000
Realistic maximum investment cost	400,000
Average investment cost	300,000

$$\text{Payback period} = \frac{\text{Amount to be invested}}{\text{Estimated annual net cash flow}} * 12 = \frac{300,000 \text{ €}}{1,378,649 \text{ €}} * 12 \cong 3 \text{ months}$$

CHAPTER 5

DISCUSSION

The result of calculations for assessing the savings and payback periods with the application of the BAT in a selected medium-sized textile mill can be seen in Table 5.1. The results of the study indicate that the potential net saving from the application of each BAT varies between 2700 €/year and 5,060,000 €/year while investment costs are in between €3000 and €300,000. Payback period calculations have shown that the payback period of any technique does not exceed 22 months. 14 techniques out of 21 have a payback period which is less than 1 year which means approximately 67% of the applications pay for themselves in less than 1 year.

As understood from Table 5.1, technique 17, which is “volume reduction of troughs to reduce residual dye liquor” has the shortest payback period and at the same time, it is the most profitable application. The potential saving from the application of this technique constitutes around 70% of the total saving with the application of all techniques. Since its net saving is considerably high when compared to its investment cost which is the least one among other techniques, the payback period of this application is quite short which is less than 1 month. High total net saving with this application originates from the high amount of dye liquor saving. Dye liquor price is given as € 0.5 per 1 L [26] and since a high amount of dye liquor can be saved with application, the highest net saving result is obtained. Benefit calculation is done by assuming a decrease in the capacity of troughs from 50 L to 12 L with a new application such as using flex-shaft, or U-shaft systems. Normally, the capacity of conventional troughs varies between 30-100 L [26]. To have an average value, 50 L capacity is taken for the calculations but if the capacity of trough using in the pad batch process is larger than the 50 L in a textile mill, total net saving would be higher and the payback period would be shorter.

Table 5.1. Summary table for the net savings and payback periods of BATs with the application in a medium-sized textile mill

Source and Amount of Saving (€/year)										Average Investment Cost (€)	Payback Period
BAT	Water	Wastewater	Fuel	Electricity	Water treated by ion exchanger	Salt	Pollution load	Chemical (dye liquor, strong lye)	Total Net Saving		
1			26,354						26,355	23,500	11 months
2			72,483						72,485	28,000	5 months
3	3,500	2,152	11,413						17,065	30,000	22 months
4				7260.5					7,260	12,500	21 months
5			9,887						9,890	5,250	7 months
6	21,953	13,493	52,619						88,070	50,000	7 months
7			22,260						22,260	33,750	18 months
8					30,388				30,390	17,500	7 months
9	1,679	1,032							2,700	3,000	14 months
10	30,398	18,684	69,891						118,970	50,000	5 months
11	5000					28.6			5,030	6,250	15 months
12	8,011	4,924							12,940	5,750	6 months
13	6,544	4,022				11,174			21,740	10,000	6 months
14							52,380		22,380		
15	50,487	31,031							81,520	50,000	8 months
16	19,467	11,965							31,430	30,000	12 months
17		3,115						5,056,660	5,059,775	3,000	less than 1 month
18			26,221	12,519					38,740	9,000	3 months
19			30,173	14,605					32,100	13,000	5 months
20			77,713						77,715	9,000	2 months
21	121,165		747,710						1,378,650	300,000	3 months
TOTAL									7,157,465	689,500	

Table 5.2. Summary table for total savings and investment costs with the application of BATs in all textile mills subjected to IPPC for Turkey

Total number of textile mills within the scope of IPPC-IED				220	Compliance rate to stated BAT in Turkey	Noncompliance rate to stated BAT in Turkey	Total investment cost for the textile mills subjected to IPPC-IED in Turkey (€)	Total net saving for the textile mills subjected to IPPC-IED in Turkey (€/year)
BAT	Total net saving for a medium-sized textile mill (€/year)	Average investment cost for the medium-sized textile mill (€)						
1	26,355	23,500	29%		71%	3,670,700	4,116,651	
2	72,485	28,000	50%		50%	3,080,000	7,973,350	
3	17,065	30,000	58%		42%	2,772,000	1,576,806	
4	7,260	12,500	46%		54%	1,485,000	862,488	
5	9,890	5,250	54%		46%	531,300	1,000,868	
6	88,070	50,000	50%		50%	5,500,000	9,687,700	
7	22,260	33,750	50%		50%	3,712,500	2,448,600	
8	30,390	17,500	46%		54%	2,079,000	3,610,332	
9	2,700	3,000	58%		42%	277,200	249,480	
10	118,970	50,000	38%		62%	6,820,000	16,227,508	
11	5,030	6,250	79%		21%	288,750	232,386	
12	12,940	5,750	79%		21%	265,650	298,914	
13	21,740	10,000	12%		88%	1,936,000	4,208,864	
14	22,380		13%		87%		4,283,532	
15	81,520	50,000	50%		50%	5,500,000	8,967,200	
16	31,430	30,000	25%		75%	4,950,000	5,185,950	
17	5,059,775	3,000	39%		61%	402,600	679,021,805	
18	38,740	9,000	35%		65%	1,287,000	5,539,820	
19	32,100	13,000	63%		37%	1,058,200	2,612,940	
20	77,715	9,000	50%		50%	990,000	8,548,650	
21	1,378,650	300,000	6%		94%	62,040,000	285,104,820	
					TOTAL	108,645,900 €	1,057,500,665 €/year	

- 1 Controlling the air-fuel ratio in boilers and application of the optimum one in the boilers
- 2 Thermal isolation of all machines and steam distribution system equipment
- 3 Minimization of the amount of blowdown forming in the boilers with better boiler feedwater treatment options such as ion exchanger, reverse osmosis, etc
- 4 Using inverter in boilers
- 5 Thermal isolation of all piping system
- 6 Reuse of all thermal condensate
- 7 Preheating of boiler feedwater with waste gas heat by installing an economizer
- 8 Determination of required water quality standards and prevention use of water of higher quality than required
- 9 Saving water and reducing the amount of wastewater by increasing washing efficiency by using equipment that will provide water efficiency in facility and equipment cleaning (water spray nozzles, spray sprayers, etc.)
- 10 Separate collection and reuse of cooling water used in all production processes to save water and energy
- 11 In ion-exchange resin systems, after regeneration, monitoring of hardness level of effluent water (softened water) and washing water with hardness sensors to optimize regeneration frequency and rinsing time
- 12 Characterization of reverse osmosis (RO) concentrates and reusing it without treatment depending on the characterization
- 13 Characterization of wastewater coming from the rinsing of ion exchangers after regeneration and reusing it without treatment depending on the characterization
- 14 Selection of the biodegradable and bioeliminable sizing agents
- 15 Using the last rinsing water in the next dyeing process to decrease wastewater pollution load in discontinuous dyeing processes
- 16 Applying counter-current washing in continuous washing machines
- 17 Volume reduction of troughs to reduce residual dye liquor (excluding indigo and sulfur dyeing)
- 18 Optimization of the speed of stenter according to the moisture content of the fabric
- 19 Applying squeezing or mechanical dewatering processes before drying
- 20 Measuring the moisture content of the air coming out of the stenter and according to that adjusting the humidity level
- 21 Recovery of caustic from mercerization rinsing water by evaporation and reuse it

Technique 21 which is “recovery of caustic from mercerization rinsing water by evaporation and reuse it” is the second profitable technique. Although its investment cost is the highest one among all techniques, the payback period is found as only 3 months thanks to its high saving potential.

The least amount of saving which is around €2700 per year is calculated for technique 9 which is “saving water and reducing the amount of wastewater by increasing washing efficiency by using equipment that will provide water efficiency in facility and equipment cleaning”. The reason can be due to the relatively low amount of water (2% of total water consumption in the mill) is consumed for cleaning purposes in the mill since this BAT allows a decrease in water consumption in cleaning and wastewater generation, accordingly.

As a result, the results show that in total approximately €7,158,000 can be saved yearly if the BATs listed in the draft communiqué are implemented in a medium-sized textile mill. It is important to note that this potential saving value is an average value since all calculations are conducted based on a medium-sized textile mill.

After obtaining saving results belongs to a medium-sized textile mill, the question “What would be the total benefit for Turkey if all textile mills subjected to IPPC-IED apply the techniques that were not implemented before in their mills” is tried to be answered. Since compliance and noncompliance rates of each technique were searched within the scope of BESTÜ, total benefit calculations are made to see the general picture for Turkey. The results are presented in Table 5.2. As it can be seen from the table, the noncompliance rates among the textile mills for most of the stated techniques are higher than 50%. In other words, about 70 % of the total techniques have a higher than 50% noncompliance rate which means most of the techniques are not implemented by the textile mills. This situation allows increasing possible total net saving value if all the mills implement all techniques which have not been implemented before.

The average investment cost for the medium-sized textile mill of each technique is multiplied by the number of mills that have not implemented the corresponding

technique to find the total net saving. Calculated saving values are found between 232,400 €/year and 679,021,805 €/year. While technique 11 is the lowest saving value due to its compliance rate is quite high (79%), technique 17 has the highest total net saving value. Similarly, the average investment cost of each technique is multiplied by the number of mills that have not implemented the corresponding technique to find the total investment cost for this technique for Turkey. The total investment cost of techniques is found between 265,650 € (technique 12) and 62,040,000 € (technique 21). Technique 12 “Characterization of reverse osmosis (RO) concentrates and reusing it without treatment depending on the characterization” requires the least investment cost for Turkey when all the textile mills implement it because the noncompliance rate of this technique is quite low (21%). On the contrary, technique 21 “Recovery of caustic from mercerization rinsing water by evaporation and reuse it” requires the most investment cost for Turkey since its compliance rate is quite low (6%) and investment cost for the application is high.

As can be seen from Table 5.2, the noncompliances rates for technique 11 and technique 12 which are “In ion-exchange resin systems, after regeneration, monitoring of hardness level of effluent water (softened water) and washing water with hardness sensors to optimize regeneration frequency and rinsing time” and “Characterization of reverse osmosis (RO) concentrates and reusing it without treatment depending on the characterization” are 21% which is the lowest noncompliance rate among the other techniques. In other words, most of the textile mills have already implemented these techniques into their mills. On the other hand, Technique 21 “Recovery of caustic from mercerization rinsing water by evaporation and reuse it” has the highest non-compliance rate with 94% which means only 6% of the textile mills subjected to the IPPC Directive applied this technique.

According to BESTÜ Project, in Turkey, 220 textile mills are falling under the IPPC-IED. Total investment costs and total net savings are calculated by assuming that all techniques which have not been implemented before in textile mills will be

implemented and so compliance and noncompliance rates are used for the calculations.

The results indicated that if all textile mills falling under the IPPC-IED in Turkey apply the BATs that were not implemented before in their mills around €108,646,000 must be spent. Despite this, after implementing all these techniques, approximately €1,057,500,665 can be saved yearly.

This study focused on the 21 BATs; and their investment costs, total savings, and payback periods of these techniques are presented. As can be seen from Table 5.3, the techniques are divided into 3 groups in case it is necessary to develop a strategy in Turkey regarding the order of application of the BATs by taking into consideration the ratios of investment cost and total net saving. For this, the ratio between total investment cost and total saving obtained after all the textile mills implemented each technique is checked. Within this framework, in this study, the ratios are calculated and according to ratios, techniques are divided into 3 groups and implementation strategies are prepared accordingly. Three groups of techniques can be seen in Table 5.4, Table 5.5 and Table 5.6.

Table 5.3 Three groups of techniques regarding the ratio between total investment cost and total net saving

BAT	Noncompliance rate to stated BAT in Turkey	Total investment cost for the textile mills subjected to IPPC-IED in Turkey (€)	Total net saving for the textile mills subjected to IPPC-IED in Turkey (€/year)	Ratio between total investment cost and total net saving
1	71%	3,670,700	4,116,651	0.892
2	50%	3,080,000	7,973,350	0.386
3	42%	2,772,000	1,576,806	1.758
4	54%	1,485,000	862,488	1.722
5	46%	531,300	1,000,868	0.531
6	50%	5,500,000	9,687,700	0.568
7	50%	3,712,500	2,448,600	1.516
8	54%	2,079,000	3,610,332	0.576
9	42%	277,200	249,480	1.111
10	62%	6,820,000	16,227,508	0.420
11	21%	288,750	232,386	1.243
12	21%	265,650	298,914	0.889
13	88%	1,936,000	4,208,864	0.460
14	87%		4,283,532	0.000
15	50%	5,500,000	8,967,200	0.613
16	75%	4,950,000	5,185,950	0.955
17	61%	402,600	679,021,805	0.001
18	65%	1,287,000	5,539,820	0.232
19	37%	1,058,200	2,612,940	0.405
20	50%	990,000	8,548,650	0.116
21	94%	62,040,000	285,104,820	0.218
TOTAL		108,645,900 €	1,057,500,665 €/year	

Group 1
Group 2
Group 3

The techniques with ratios close to 0 are put into group 1 and shown in yellow color. Group 2 techniques are represented by green color and their ratios are higher than the techniques in group 1 and lower than the techniques in group 3. The pink color is used to represent group 3 and the techniques in this group have the higher total investment cost to total net saving ratio. Since the noncompliance rates for the specified technique are used in the total investment and total saving calculations, the number of mills that have not implemented the stated technique is already taken into account. Techniques in groups 1,2 and 3 can be seen in Table 5.4, Table 5.5, Table 5.6, respectively.

Group 1 consists of the techniques that have lower total investment cost and total net saving ratio. Based on the results, techniques 2,14,17,18,20, and 21 are the techniques that should be implemented immediately.

Table 5.4 BATs in Group 1

BAT	Noncompliance rate to stated BAT in Turkey	Total investment cost for the textile mills subjected to IPPC-IED in Turkey (€)	Total net saving for the textile mills subjected to IPPC-IED in Turkey (€/year)
1	71%	3,670,700	4,116,651
2	50%	3,080,000	7,973,350
3	42%	2,772,000	1,576,806
4	54%	1,485,000	862,488
5	46%	531,300	1,000,868
6	50%	5,500,000	9,687,700
7	50%	3,712,500	2,448,600
8	54%	2,079,000	3,610,332
9	42%	277,200	249,480
10	62%	6,820,000	16,227,508
11	21%	288,750	232,386
12	21%	265,650	298,914
13	88%	1,936,000	4,208,864
14	87%		4,283,532
15	50%	5,500,000	8,967,200
16	75%	4,950,000	5,185,950
17	61%	402,600	679,021,805
18	65%	1,287,000	5,539,820
19	37%	1,058,200	2,612,940
20	50%	990,000	8,548,650
21	94%	62,040,000	285,104,820
TOTAL		67,799,600 €	990,471,977

- 2 Thermal isolation of all machines and steam distribution system equipment
- 14 Selection of the biodegradable and bioeliminable sizing agents
- 17 Volume reduction of troughs to reduce residual dye liquor (excluding indigo and sulfur dyeing)
- 18 Optimization of the speed of stenter according to the moisture content of the fabric
- 20 Measuring the moisture content of the air coming out of the stenter and according to that adjusting the humidity level
- 21 Recovery of caustic from mercerization rinsing water by evaporation and reuse it

Group 2 consists of the BATs that have a higher total investment cost and total net saving ratio than the BATs in group 1. Based on the results, BATs 5,6,10,13,15 and 19 are the techniques that need to be implemented in the second place.

Table 5.5 BATs in Group 2

BAT	Noncompliance rate to stated BAT in Turkey	Total investment cost for the textile mills subjected to IPPC-IED in Turkey (€)	Total net saving for the textile mills subjected to IPPC-IED in Turkey (€/year)
1	71%	3,670,700	4,116,651
2	50%	3,080,000	7,973,350
3	42%	2,772,000	1,576,806
4	54%	1,485,000	862,488
5	46%	531,300	1,000,868
6	50%	5,500,000	9,687,700
7	50%	3,712,500	2,448,600
8	54%	2,079,000	3,610,332
9	42%	277,200	249,480
10	62%	6,820,000	16,227,508
11	21%	288,750	232,386
12	21%	265,650	298,914
13	88%	1,936,000	4,208,864
14	87%		4,283,532
15	50%	5,500,000	8,967,200
16	75%	4,950,000	5,185,950
17	61%	402,600	679,021,805
18	65%	1,287,000	5,539,820
19	37%	1,058,200	2,612,940
20	50%	990,000	8,548,650
21	94%	62,040,000	285,104,820
TOTAL		21,345,500 €	42,705,080

5 Thermal isolation of all piping system

6 Reuse of all thermal condensate

10 Separate collection and reuse of cooling water used in all production processes to save water and energy

13 Characterization of wastewater coming from the rinsing of ion exchangers after regeneration and reusing it without treatment depending on the characterization

15 Using the last rinsing water in the next dyeing process to decrease wastewater pollution load in discontinuous dyeing processes

19 Applying squeezing or mechanical dewatering processes before drying

Group 3 consists of the BATs that have the highest total investment cost and total net saving ratio. Based on the results, BATs 1,3,4,7,9,11,12,16 are the techniques that need to be implemented after the BATs in groups 1 and 2.

Table 5.6 BATs in Group 3

BAT	Noncompliance rate to stated BAT in Turkey	Total investment cost for the textile mills subjected to IPPC-IED in Turkey (€)	Total net saving for the textile mills subjected to IPPC-IED in Turkey (€/year)
1	71%	3,670,700	4,116,651
2	50%	3,080,000	7,973,350
3	42%	2,772,000	1,576,806
4	54%	1,485,000	862,488
5	46%	531,300	1,000,868
6	50%	5,500,000	9,687,700
7	50%	3,712,500	2,448,600
8	54%	2,079,000	3,610,332
9	42%	277,200	249,480
10	62%	6,820,000	16,227,508
11	21%	288,750	232,386
12	21%	265,650	298,914
13	88%	1,936,000	4,208,864
14	87%		4,283,532
15	50%	5,500,000	8,967,200
16	75%	4,950,000	5,185,950
17	61%	402,600	679,021,805
18	65%	1,287,000	5,539,820
19	37%	1,058,200	2,612,940
20	50%	990,000	8,548,650
21	94%	62,040,000	285,104,820
TOTAL		17,421,800 €	14,971,275

- 1 Controlling the air-fuel ratio in boilers and application of the optimum one in the boilers
- 3 Minimization of the amount of blowdown forming in the boilers with better boiler feedwater treatment options such as ion exchanger, reverse osmosis, etc
- 4 Using inverter in boilers
- 7 Preheating of boiler feedwater with waste gas heat by installing an economizer
- 9 Saving water and reducing the amount of wastewater by increasing washing efficiency by using equipment that will provide water efficiency in facility and equipment cleaning (water spray nozzles, spray sprayers, etc.)
- 11 In ion-exchange resin systems, after regeneration, monitoring of hardness level of effluent water (softened water) and washing water with hardness sensors to optimize regeneration frequency and rinsing time
- 12 Characterization of reverse osmosis (RO) concentrates and reusing it without treatment depending on the characterization
- 16 Applying counter-current washing in continuous washing machines



CHAPTER 6

CONCLUSIONS

The EU IED Directive and the associated BAT concept place great emphasis on economic analysis to control emissions from industrial establishments. According to the IED, BATs are defined as the measures which would not lead to disproportionately higher costs compared to the environmental benefits. In this context, it is important to compare the cost of BAT compliance with the economic benefits it will provide. This study assessed the potential benefit from the application of BATs in a selected medium-sized textile mill in Turkey, employing cotton-polyester fabric finishing and dyeing. Initially, what type of benefits (reduction in water and/or energy consumption, decrease in wastewater generation of pollution load and minimization of salt consumption) can be gained with the application of these BATs are determined. These benefits are expressed in terms of monetary equivalent with the help of theoretical information from literature and practical knowledge from case studies. Finally, the total benefit and net saving with the application of BATs for the medium-sized textile mill calculations represented and the results of the study indicated that implementation of the cleaner production techniques results in considerable improvement in water and/or energy consumption, chemical consumption or pollution load in wastewaters.

Since the investment cost of the BATs is determined before, the payback period for each technique is also estimated by using investment cost and total net saving. As can be seen from Table 5.1, the expected payback periods do not exceed the 2 years. Most of the BATs have a payback period of less than 1 year. The longest payback period is found as around 22 months which means implementation of the techniques pays for itself in a short period of time.

In addition to this, the compliance rate of each BAT among the textile mills subjected to the IPPC-IED is determined before within the scope of the BESTÜ project as mentioned in the background information section. With the help of this knowledge, the question “What would be the total benefit for Turkey if all textile mills subjected to IPPC-IED apply the BATs that were not implemented before in their mills?” is asked and it is tried to be answered in this study. In other words, it is searched that the potential saving when the compliance rate for the applications increased among the textile mills. It is important to note that, all BATs given in the draft communiqué, can not be applied to all textile mills in terms of applicability since the textile industry consists of many heterogenous sub-processes. In this regard, selecting a medium-sized textile mill is significant in order to reflect the general situation. Within this framework, total benefit analysis is conducted for all the textile mills and the results are presented in Table 5.2.

The results indicated that approximately €1,057,500,665 can be saved yearly by doing investment of the mentioned BATs about €108,646,000 for the IED compliance in the Turkish Textile Sector. All these findings show that the cost of IPPC-IED compliance is understandable for the Turkish textile mills and the potential revenues from the implementation of BATs will enable textile manufacturers to become more committed to environmentally friendly practices.

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APPENDICES

A. Tables used for the benefit calculation of the “Controlling the air-fuel ratio in boilers and application of the optimum one in the boilers”

BITUMINOUS COAL 300°F to 450°F

% EXCESS AIR	% OXYGEN	% CO2	NET STACK TEMPERATURE DEG F																
			COMBUSTION AIR TEMPERATURE																
			300	310	320	330	340	350	360	370	380	390	400	410	420	430	440	450	
0.0	0.0	18.5	9.3	9.5	9.7	9.9	10.1	10.3	10.4	10.6	10.8	11.0	11.2	11.4	11.6	11.8	12.0	12.2	
2.3	0.5	18.1	9.4	9.6	9.8	10.0	10.2	10.4	10.6	10.8	11.0	11.2	11.4	11.6	11.8	12.0	12.2	12.4	
4.8	1.0	17.6	9.6	9.8	10.0	10.2	10.4	10.6	10.8	11.0	11.2	11.4	11.6	11.8	12.0	12.2	12.4	12.6	
7.4	1.5	17.2	9.7	9.9	10.1	10.3	10.5	10.7	10.9	11.1	11.3	11.5	11.7	11.9	12.2	12.4	12.6	12.8	
10.1	2.0	16.7	9.9	10.1	10.3	10.5	10.7	10.9	11.1	11.3	11.5	11.7	12.0	12.2	12.4	12.6	12.8	13.0	
13.0	2.5	16.3	10.0	10.2	10.5	10.7	10.9	11.1	11.3	11.5	11.7	12.0	12.2	12.4	12.6	12.8	13.0	13.2	
16.0	3.0	15.9	10.2	10.4	10.6	10.9	11.1	11.3	11.5	11.7	12.0	12.2	12.4	12.6	12.8	13.1	13.3	13.5	
19.2	3.5	15.4	10.4	10.6	10.8	11.0	11.3	11.5	11.7	12.0	12.2	12.4	12.6	12.9	13.1	13.3	13.5	13.8	
22.6	4.0	15.0	10.6	10.8	11.0	11.3	11.5	11.7	12.0	12.2	12.4	12.7	12.9	13.1	13.4	13.6	13.8	14.0	
26.1	4.5	14.5	10.8	11.0	11.2	11.5	11.7	12.0	12.2	12.4	12.7	12.9	13.2	13.4	13.6	13.9	14.1	14.3	
29.9	5.0	14.1	11.0	11.2	11.5	11.7	12.0	12.2	12.4	12.7	12.9	13.2	13.4	13.7	13.9	14.2	14.4	14.7	
34.0	5.5	13.7	11.2	11.4	11.7	12.0	12.2	12.5	12.7	13.0	13.2	13.5	13.7	14.0	14.2	14.5	14.8	15.0	
38.3	6.0	13.2	11.4	11.7	12.0	12.2	12.5	12.7	13.0	13.3	13.5	13.8	14.1	14.3	14.6	14.8	15.1	15.4	
42.9	6.5	12.8	11.7	12.0	12.2	12.5	12.8	13.0	13.3	13.6	13.9	14.1	14.4	14.7	14.9	15.2	15.5	15.8	
47.8	7.0	12.3	12.0	12.2	12.5	12.8	13.1	13.4	13.6	13.9	14.2	14.5	14.8	15.0	15.3	15.6	15.9	16.2	
53.1	7.5	11.9	12.3	12.6	12.8	13.1	13.4	13.7	14.0	14.3	14.6	14.9	15.2	15.5	15.7	16.0	16.3	16.6	
58.8	8.0	11.5	12.6	12.9	13.2	13.5	13.8	14.1	14.4	14.7	15.0	15.3	15.6	15.9	16.2	16.5	16.8	17.1	
65.0	8.5	11.0	12.9	13.2	13.6	13.9	14.2	14.5	14.8	15.1	15.4	15.7	16.1	16.4	16.7	17.0	17.3	17.6	
71.6	9.0	10.6	13.3	13.6	14.0	14.3	14.6	14.9	15.3	15.6	15.9	16.2	16.5	16.9	17.2	17.5	17.8	18.2	
78.8	9.5	10.1	13.7	14.0	14.4	14.7	15.1	15.4	15.7	16.1	16.4	16.8	17.1	17.4	17.8	18.1	18.4	18.8	
86.7	10.0	9.7	14.2	14.5	14.9	15.2	15.6	15.9	16.3	16.6	17.0	17.3	17.7	18.0	18.4	18.7	19.1	19.4	
95.3	10.5	9.3	14.6	15.0	15.4	15.7	16.1	16.5	16.9	17.2	17.6	18.0	18.3	18.7	19.1	19.4	19.8	20.2	
104.7	11.0	8.8	15.2	15.6	15.9	16.3	16.7	17.1	17.5	17.9	18.3	18.7	19.0	19.4	19.8	20.2	20.6	21.0	
115.1	11.5	8.4	15.8	16.2	16.6	17.0	17.4	17.8	18.2	18.6	19.0	19.4	19.8	20.2	20.6	21.0	21.5	21.9	
126.6	12.0	7.9	16.4	16.8	17.3	17.7	18.1	18.6	19.0	19.4	19.8	20.3	20.7	21.1	21.6	22.0	22.4	22.8	
139.5	12.5	7.5	17.2	17.6	18.1	18.5	19.0	19.4	19.9	20.3	20.8	21.2	21.7	22.1	22.6	23.0	23.5	23.9	
154.0	13.0	7.0	18.0	18.5	18.9	19.4	19.9	20.4	20.9	21.3	21.8	22.3	22.8	23.3	23.7	24.2	24.7	25.2	
170.3	13.5	6.6	18.9	19.4	19.9	20.4	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.6	26.1	26.6	
188.9	14.0	6.2	20.0	20.5	21.1	21.6	22.2	22.7	23.3	23.8	24.4	24.9	25.4	26.0	26.5	27.1	27.6	28.2	
210.3	14.5	5.7	21.2	21.8	22.4	23.0	23.6	24.2	24.7	25.3	25.9	26.5	27.1	27.7	28.3	28.9	29.4	30.0	
235.1	15.0	5.3	22.6	23.3	23.9	24.6	25.2	25.8	26.5	27.1	27.7	28.4	29.0	29.6	30.3	30.9	31.6	32.2	
264.4	15.5	4.8	24.3	25.0	25.7	26.4	27.1	27.8	28.5	29.2	29.9	30.6	31.3	32.0	32.7	33.4	34.0	34.7	
299.2	16.0	4.4	26.4	27.1	27.9	28.7	29.4	30.2	31.0	31.7	32.5	33.2	34.0	34.8	35.5	36.3	37.0	37.8	

[57]

Table 21 (BS5422:2009)

Minimum insulation thickness for process pipework and equipment to control heat loss

Diameter of steel pipe on which insulation has been based mm	Hot face temperature (°C)													
	100		200		300		400		500		600		700	
	Ins thk mm	Heat loss W/m	Ins thk mm	Heat loss W/m	Ins thk mm	Heat loss W/m	Ins thk mm	Heat loss W/m	Ins thk mm	Heat loss W/m	Ins thk mm	Heat loss W/m	Ins thk mm	Heat loss W/m
17.2	23	12.8	36	28.7	47	47.1	59	69.1	69	96.1	81	126.9	93	163.6
21.3	24	14.0	38	30.7	50	50.5	62	74.1	72	103.0	86	135.4	97	174.5
26.9	26	15.4	41	33.7	54	55.0	66	80.1	77	110.7	91	145.6	103	186.9
33.7	27	17.3	43	37.1	56	59.9	69	87.2	82	119.8	96	156.8	109	201.2
42.4	29	19.2	46	40.8	60	65.8	73	95.1	86	130.6	101	170.0	115	217.3
48.3	30	20.4	47	43.4	62	69.4	76	99.7	89	137.0	104	178.3	118	227.8
60.3	31	23.2	49	48.4	65	76.7	80	109.9	94	149.3	109	194.3	124	247.2
76.1	33	26.2	52	54.2	69	85.1	85	121.2	99	164.6	116	213.2	131	270.2
88.9	34	28.7	54	58.7	71	92.0	88	130.2	102	176.7	120	227.7	136	288.4
114.3	35	33.9	57	67.3	75	104.6	93	146.8	108	198.2	127	254.2	144	320.7
139.7	36	38.7	59	75.7	78	116.6	96	163.6	113	218.2	132	279.8	150	351.4
168.3	37	44.0	61	84.9	81	129.5	100	180.4	118	240.5	138	305.5	157	383.8
219.1	38	53.4	63	101.2	84	152.7	105	209.6	124	277.8	146	351.0	166	437.2
273.0	39	62.9	65	117.6	87	175.7	110	239.4	129	315.4	158	386.9	172	495.1

NOTE 1 Insulation thicknesses in this table have been calculated according to BS EN ISO 12241:1998 using standardized assumptions: horizontal pipe in still air at 20°C. Surface emissivity corresponding to outer surface specified.

NOTE 2 Maximum heat loss values for intermediate operating temperatures may be deduced by interpolation.

NOTE 3 Heat loss measured in Watts per metre (W/m) relates to the specified thickness and temperature.

NOTE 4 The thermal conductivity of insulation materials increases with mean temperature and for any given material. The use of a different thermal conductivity can be required for each operating temperature.

NOTE 5 These thicknesses may not satisfy other design requirements, in particular those for control of surface temperature (see Table 22, Table 23 and Table 24).

[52]

B. Table used for the benefit calculation of the “ Thermal isolation of all piping system” technique (BAT 9)

INDUSTRIAL DESIGN GUIDE

PIPES: 75°C TO 300°C.
INSULATION: GLASSWOOL & FIBERTEX ROCKWOOL SECTIONAL PIPE INSULATION.
HEAT LOSS TO STILL AIR AT 20°C.

Q' = Heat loss per metre.

t_s = Surface Temperature.

Minimum general purpose thicknesses are highlighted.

Table A7

		Non-Reflective Cladding Surface coefficient: 10 W/m ² K											
Pipe Temperature °C		75		100		150		200		250		300	
Pipe OD	Insulation thickness	Q'	t _s	Q'	t _s	Q'	t _s	Q'	t _s	Q'	t _s	Q'	t _s
mm	mm	W/m	°C	W/m	°C	W/m	°C	W/m	°C	W/m	°C	W/m	°C
21.3	25	9	24	14	26	25	31	38	37	54	44	73	53
	38	7	22	11	24	20	27	31	30	44	34	60	40
	50	7	22	10	23	18	25	28	27	39	30	53	34
	63	6	21	9	22	16	24	25	25	36	28	48	30
26.9	25	10	24	16	27	28	32	44	38	62	46	84	55
	38	8	23	13	24	23	27	35	31	50	35	68	41
	50	7	22	11	23	20	25	31	28	44	31	59	35
	63	7	21	10	22	18	24	28	26	39	28	54	31
33.7	25	12	25	18	27	33	32	50	39	71	47	96	57
	38	10	23	15	24	26	28	40	32	57	36	77	42
	50	8	22	13	23	23	25	35	28	49	32	67	36
	63	7	21	11	22	20	24	31	26	44	29	60	32
42.4	25	14	25	21	27	38	33	58	40	83	48	112	59
	38	11	23	17	24	30	28	46	32	65	37	88	44
	50	9	22	14	23	26	26	39	29	56	32	76	37
	63	8	22	13	22	23	24	35	27	50	29	67	33
48.3	25	15	25	23	28	42	33	64	41	90	49	122	60
	38	12	23	18	25	32	28	50	33	70	38	95	44
	50	10	22	15	23	28	26	42	29	60	33	82	38
	63	9	22	14	22	24	24	37	27	53	30	72	33
60.3	25	18	25	27	28	49	34	75	42	106	51	143	61
	38	14	23	21	25	37	29	57	33	81	39	110	46
	50	12	22	18	24	32	26	49	30	69	34	94	39
	63	10	22	15	23	28	25	43	27	60	30	82	34
76.1	25	21	25	32	28	58	35	89	42	126	52	171	63
	38	16	23	25	25	44	29	67	34	96	40	129	47
	50	14	22	21	24	37	27	56	30	80	34	109	40
	63	12	22	18	23	32	25	49	28	70	31	94	35
88.9	25	24	26	37	28	65	35	100	43	142	53	192	64
	38	18	23	27	25	49	29	75	35	107	41	145	48
	50	15	23	23	24	41	27	63	31	89	35	121	40
	63	13	22	20	23	35	25	54	28	77	31	104	35
101.6	25	27	26	41	29	73	35	111	43	158	53	214	65
	38	20	24	30	25	54	30	83	35	118	41	160	49
	50	17	23	25	24	45	27	69	31	98	35	133	41
	63	14	22	22	23	39	25	59	28	84	32	114	36
114.3	25	29	26	45	29	80	36	123	44	174	54	236	66
	38	22	24	33	26	59	30	91	35	129	42	175	49
	50	18	23	27	24	49	27	75	31	107	36	145	41
	63	15	22	23	23	42	26	64	29	91	32	124	36
139.7	25	35	26	53	29	95	36	145	44	206	55	279	67
	38	26	24	39	26	69	30	106	36	151	42	205	50
	50	21	23	32	24	57	28	87	32	124	36	168	42
	63	18	22	27	23	48	26	74	29	105	33	143	37

continued over page

[14]

C. Heat loss tables used for the benefit calculation of “Preheating of boiler feedwater with waste gas by installing an economizer” technique

BITUMINOUS COAL
150°F to 300°F

EXIT GAS HEAT LOSSES																		
% EXCESS AIR	% OXYGEN	% CO2	NET STACK TEMPERATURE DEG F															
			150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300
0.0	0.0	18.5	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.3	8.5	8.7	8.9	9.1	9.3
2.3	0.5	18.1	6.5	6.7	6.9	7.1	7.3	7.5	7.7	7.9	8.1	8.3	8.5	8.6	8.8	9.0	9.2	9.4
4.8	1.0	17.6	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6	8.8	9.0	9.2	9.4	9.6
7.4	1.5	17.2	6.6	6.8	7.0	7.3	7.5	7.7	7.9	8.1	8.3	8.5	8.7	8.9	9.1	9.3	9.5	9.7
10.1	2.0	16.7	6.7	6.9	7.1	7.3	7.6	7.8	8.0	8.2	8.4	8.6	8.8	9.0	9.2	9.4	9.7	9.9
13.0	2.5	16.3	6.8	7.0	7.2	7.4	7.7	7.9	8.1	8.3	8.5	8.7	8.9	9.2	9.4	9.6	9.8	10.0
16.0	3.0	15.9	6.9	7.1	7.3	7.5	7.8	8.0	8.2	8.4	8.6	8.9	9.1	9.3	9.5	9.7	10.0	10.2
19.2	3.5	15.4	7.0	7.2	7.4	7.6	7.9	8.1	8.3	8.6	8.8	9.0	9.2	9.5	9.7	9.9	10.1	10.4
22.6	4.0	15.0	7.1	7.3	7.5	7.8	8.0	8.2	8.5	8.7	8.9	9.2	9.4	9.6	9.9	10.1	10.3	10.6
26.1	4.5	14.5	7.2	7.4	7.6	7.9	8.1	8.4	8.6	8.8	9.1	9.3	9.6	9.8	10.0	10.3	10.5	10.8
29.9	5.0	14.1	7.3	7.5	7.8	8.0	8.3	8.5	8.7	9.0	9.2	9.5	9.7	10.0	10.2	10.5	10.7	11.0
34.0	5.5	13.7	7.4	7.6	7.9	8.1	8.4	8.7	8.9	9.2	9.4	9.7	9.9	10.2	10.4	10.7	10.9	11.2
38.3	6.0	13.2	7.5	7.8	8.0	8.3	8.5	8.8	9.1	9.3	9.6	9.9	10.1	10.4	10.6	10.9	11.2	11.4
42.9	6.5	12.8	7.6	7.9	8.2	8.4	8.7	9.0	9.3	9.5	9.8	10.1	10.3	10.6	10.9	11.2	11.4	11.7
47.8	7.0	12.3	7.8	8.0	8.3	8.6	8.9	9.2	9.4	9.7	10.0	10.3	10.6	10.8	11.1	11.4	11.7	12.0
53.1	7.5	11.9	7.9	8.2	8.5	8.8	9.1	9.4	9.7	9.9	10.2	10.5	10.8	11.1	11.4	11.7	12.0	12.3
58.8	8.0	11.5	8.1	8.4	8.7	9.0	9.3	9.6	9.9	10.2	10.5	10.8	11.1	11.4	11.7	12.0	12.3	12.6
65.0	8.5	11.0	8.2	8.6	8.9	9.2	9.5	9.8	10.1	10.4	10.7	11.1	11.4	11.7	12.0	12.3	12.6	12.9
71.6	9.0	10.6	8.4	8.8	9.1	9.4	9.7	10.1	10.4	10.7	11.0	11.4	11.7	12.0	12.3	12.7	13.0	13.3
78.8	9.5	10.1	8.6	9.0	9.3	9.7	10.0	10.3	10.7	11.0	11.3	11.7	12.0	12.4	12.7	13.0	13.4	13.7
86.7	10.0	9.7	8.9	9.2	9.6	9.9	10.3	10.6	11.0	11.3	11.7	12.0	12.4	12.7	13.1	13.4	13.8	14.2
95.3	10.5	9.3	9.1	9.5	9.8	10.2	10.6	10.9	11.3	11.7	12.1	12.4	12.8	13.2	13.5	13.9	14.3	14.6
104.7	11.0	8.8	9.4	9.8	10.1	10.5	10.9	11.3	11.7	12.1	12.5	12.9	13.2	13.6	14.0	14.4	14.8	15.2
115.1	11.5	8.4	9.7	10.1	10.5	10.9	11.3	11.7	12.1	12.5	12.9	13.3	13.7	14.1	14.5	14.9	15.4	15.8
126.6	12.0	7.9	10.0	10.4	10.8	11.3	11.7	12.1	12.6	13.0	13.4	13.8	14.3	14.7	15.1	15.6	16.0	16.4
139.5	12.5	7.5	10.4	10.8	11.3	11.7	12.2	12.6	13.1	13.5	14.0	14.4	14.9	15.3	15.8	16.2	16.7	17.2
154.0	13.0	7.0	10.8	11.3	11.7	12.2	12.7	13.2	13.7	14.1	14.6	15.1	15.6	16.1	16.5	17.0	17.5	18.0
170.3	13.5	6.6	11.2	11.7	12.3	12.8	13.3	13.8	14.3	14.8	15.3	15.8	16.4	16.9	17.4	17.9	18.4	18.9
188.9	14.0	6.2	11.8	12.3	12.9	13.4	14.0	14.5	15.1	15.6	16.1	16.7	17.2	17.8	18.3	18.9	19.4	20.0
210.3	14.5	5.7	12.4	13.0	13.6	14.2	14.7	15.3	15.9	16.5	17.1	17.7	18.3	18.9	19.4	20.0	20.6	21.2
235.1	15.0	5.3	13.1	13.7	14.4	15.0	15.7	16.3	16.9	17.6	18.2	18.8	19.5	20.1	20.7	21.4	22.0	22.6
264.4	15.5	4.8	14.0	14.6	15.3	16.0	16.7	17.4	18.1	18.8	19.5	20.2	20.9	21.6	22.3	23.0	23.7	24.3
299.2	16.0	4.4	15.0	15.7	16.5	17.3	18.0	18.8	19.5	20.3	21.1	21.8	22.6	23.3	24.1	24.9	25.6	26.4

[57]

BITUMINOUS COAL 300°F to 450°F

% EXCESS AIR	% OXYGEN	% CO2	NET STACK TEMPERATURE DEG F																
			EXIT FLUE GAS TEMPERATURE - COMBUSTION AIR TEMPERATURE																
			300	310	320	330	340	350	360	370	380	390	400	410	420	430	440	450	
0.0	0.0	18.5	9.3	9.5	9.7	9.9	10.1	10.3	10.4	10.6	10.8	11.0	11.2	11.4	11.6	11.8	12.0	12.2	
2.3	0.5	18.1	9.4	9.6	9.8	10.0	10.2	10.4	10.6	10.8	11.0	11.2	11.4	11.6	11.8	12.0	12.2	12.4	
4.8	1.0	17.6	9.6	9.8	10.0	10.2	10.4	10.6	10.8	11.0	11.2	11.4	11.6	11.8	12.0	12.2	12.4	12.6	
7.4	1.5	17.2	9.7	9.9	10.1	10.3	10.5	10.7	10.9	11.1	11.3	11.6	11.8	12.0	12.2	12.4	12.6	12.8	
10.1	2.0	16.7	9.9	10.1	10.3	10.5	10.7	10.9	11.1	11.3	11.5	11.7	12.0	12.2	12.4	12.6	12.8	13.0	
13.0	2.5	16.3	10.0	10.2	10.5	10.7	10.9	11.1	11.3	11.5	11.7	12.0	12.2	12.4	12.6	12.8	13.0	13.2	
16.0	3.0	15.9	10.2	10.4	10.6	10.9	11.1	11.3	11.5	11.7	12.0	12.2	12.4	12.6	12.8	13.1	13.3	13.5	
19.2	3.5	15.4	10.4	10.6	10.8	11.0	11.3	11.5	11.7	12.0	12.2	12.4	12.6	12.9	13.1	13.3	13.5	13.8	
22.6	4.0	15.0	10.6	10.8	11.0	11.3	11.5	11.7	12.0	12.2	12.4	12.7	12.9	13.1	13.4	13.6	13.8	14.0	
26.1	4.5	14.5	10.8	11.0	11.2	11.5	11.7	12.0	12.2	12.4	12.7	12.9	13.2	13.4	13.6	13.9	14.1	14.3	
29.9	5.0	14.1	11.0	11.2	11.5	11.7	12.0	12.2	12.4	12.7	12.9	13.2	13.4	13.7	13.9	14.2	14.4	14.7	
34.0	5.5	13.7	11.2	11.4	11.7	12.0	12.2	12.5	12.7	13.0	13.2	13.5	13.7	14.0	14.2	14.5	14.8	15.0	
38.3	6.0	13.2	11.4	11.7	12.0	12.2	12.5	12.7	13.0	13.3	13.5	13.8	14.1	14.3	14.6	14.8	15.1	15.4	
42.9	6.5	12.8	11.7	12.0	12.2	12.5	12.8	13.0	13.3	13.6	13.9	14.1	14.4	14.7	14.9	15.2	15.5	15.8	
47.8	7.0	12.3	12.0	12.2	12.5	12.8	13.1	13.4	13.6	13.9	14.2	14.5	14.8	15.0	15.3	15.6	15.9	16.2	
53.1	7.5	11.9	12.3	12.6	12.8	13.1	13.4	13.7	14.0	14.3	14.6	14.9	15.2	15.5	15.7	16.0	16.3	16.6	
58.8	8.0	11.5	12.6	12.9	13.2	13.5	13.8	14.1	14.4	14.7	15.0	15.3	15.6	15.9	16.2	16.5	16.8	17.1	
65.0	8.5	11.0	12.9	13.2	13.6	13.9	14.2	14.5	14.8	15.1	15.4	15.7	16.1	16.4	16.7	17.0	17.3	17.6	
71.6	9.0	10.6	13.3	13.6	14.0	14.3	14.6	14.9	15.3	15.6	15.9	16.2	16.5	16.9	17.2	17.5	17.8	18.2	
78.8	9.5	10.1	13.7	14.0	14.4	14.7	15.1	15.4	15.7	16.1	16.4	16.8	17.1	17.4	17.8	18.1	18.4	18.8	
86.7	10.0	9.7	14.2	14.5	14.9	15.2	15.6	15.9	16.3	16.6	17.0	17.3	17.7	18.0	18.4	18.7	19.1	19.4	
95.3	10.5	9.3	14.6	15.0	15.4	15.7	16.1	16.5	16.9	17.2	17.6	18.0	18.3	18.7	19.1	19.4	19.8	20.2	
104.7	11.0	8.8	15.2	15.6	15.9	16.3	16.7	17.1	17.5	17.9	18.3	18.7	19.0	19.4	19.8	20.2	20.6	21.0	
115.1	11.5	8.4	15.8	16.2	16.6	17.0	17.4	17.8	18.2	18.6	19.0	19.4	19.8	20.2	20.6	21.0	21.5	21.9	
126.6	12.0	7.9	16.4	16.8	17.3	17.7	18.1	18.6	19.0	19.4	19.8	20.3	20.7	21.1	21.6	22.0	22.4	22.8	
139.5	12.5	7.5	17.2	17.6	18.1	18.5	19.0	19.4	19.9	20.3	20.8	21.2	21.7	22.1	22.6	23.0	23.5	23.9	
154.0	13.0	7.0	18.0	18.5	18.9	19.4	19.9	20.4	20.9	21.3	21.8	22.3	22.8	23.3	23.7	24.2	24.7	25.2	
170.3	13.5	6.6	18.9	19.4	19.9	20.4	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.6	26.1	26.6	
188.9	14.0	6.2	20.0	20.5	21.1	21.6	22.2	22.7	23.3	23.8	24.4	24.9	25.4	26.0	26.5	27.1	27.6	28.2	
210.3	14.5	5.7	21.2	21.8	22.4	23.0	23.6	24.2	24.7	25.3	25.9	26.5	27.1	27.7	28.3	28.9	29.4	30.0	
235.1	15.0	5.3	22.6	23.3	23.9	24.6	25.2	25.8	26.5	27.1	27.7	28.4	29.0	29.6	30.3	30.9	31.6	32.2	
264.4	15.5	4.8	24.3	25.0	25.7	26.4	27.1	27.8	28.5	29.2	29.9	30.6	31.3	32.0	32.7	33.4	34.0	34.7	
299.2	16.0	4.4	26.4	27.1	27.9	28.7	29.4	30.2	31.0	31.7	32.5	33.2	34.0	34.8	35.5	36.3	37.0	37.8	

[57]

D. Machine speed versus residual moisture graph used for the benefit calculation of “Optimization of the speed of stenter according to the moisture content of the fabric (BAT 34)”

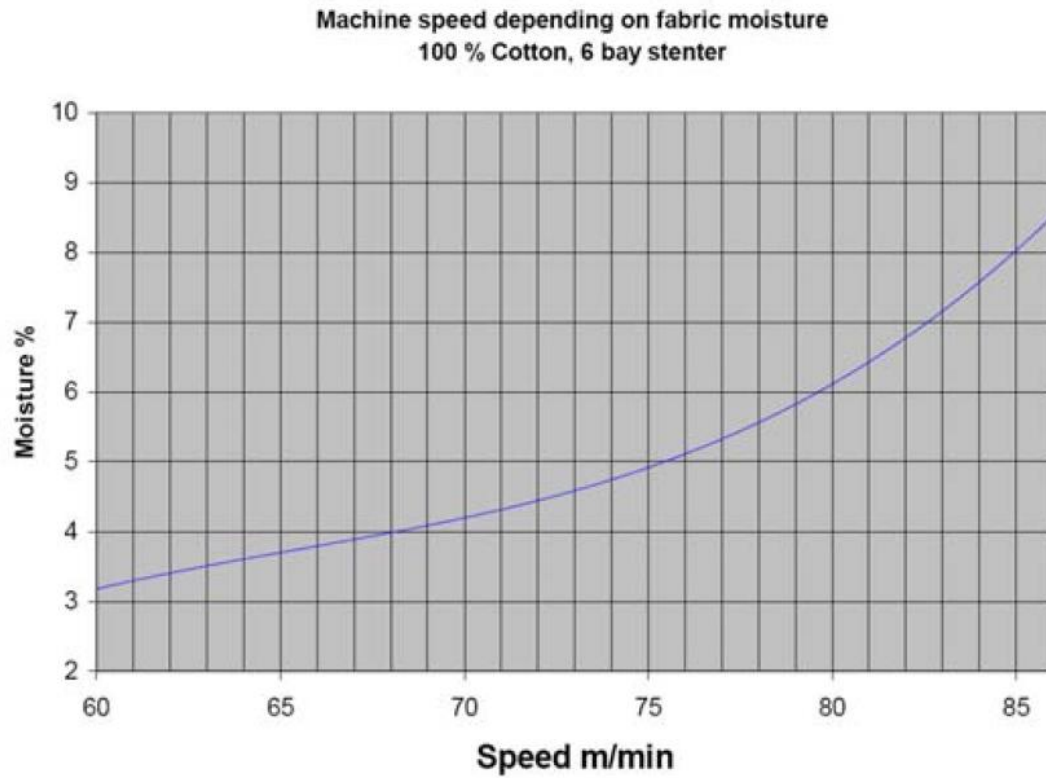
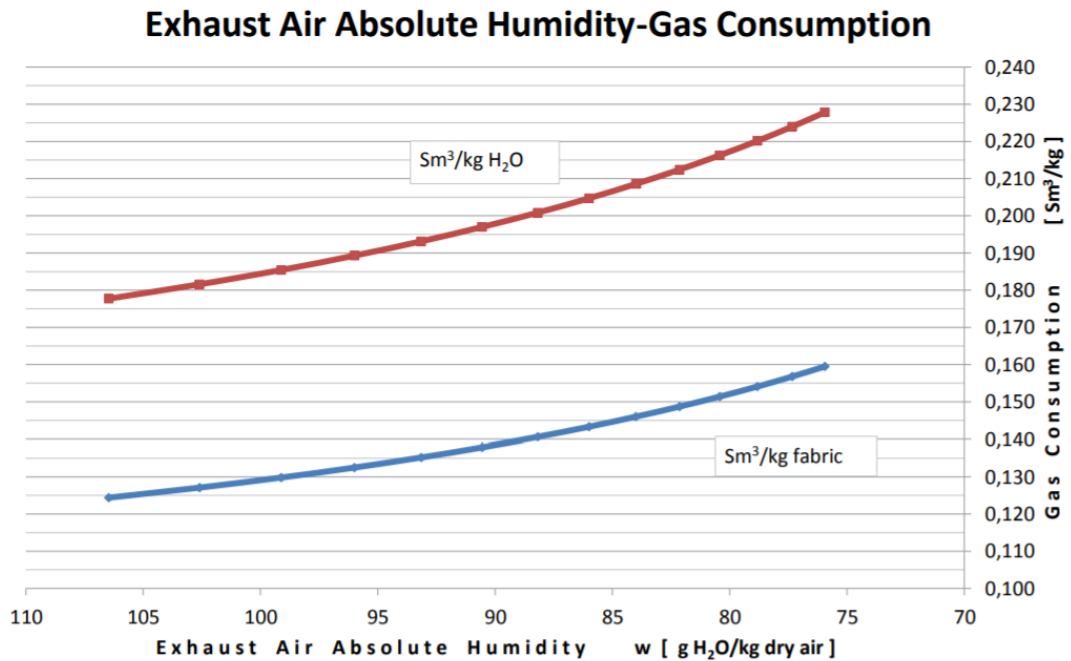
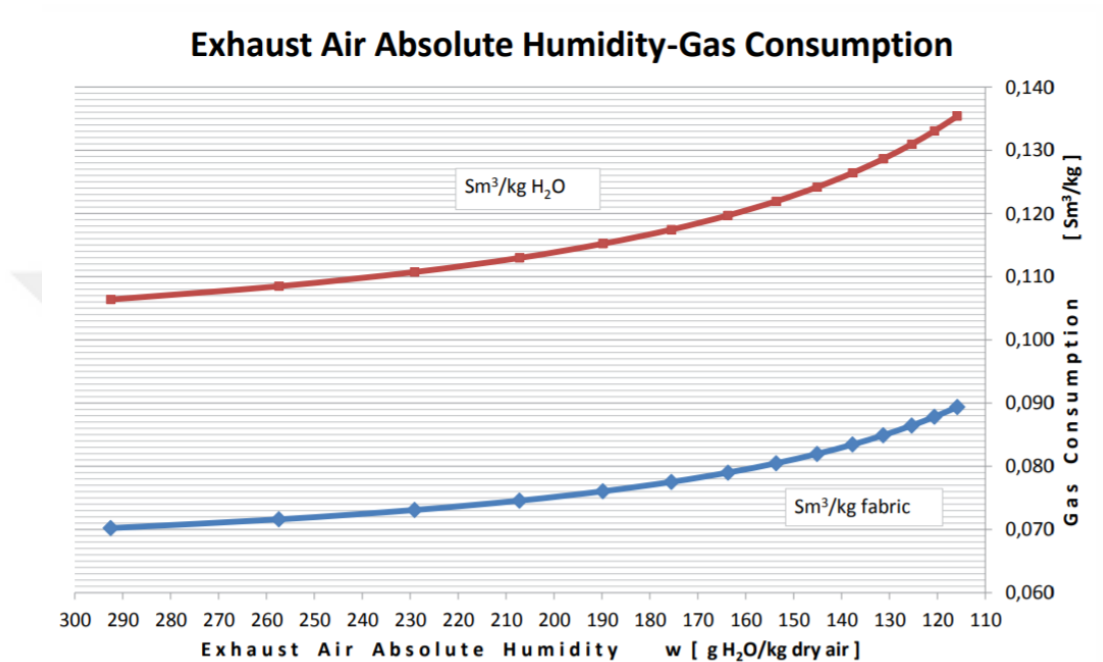


Fig. 6: Graph machine speed versus residual moisture

[51]

E. Graphs and tables used for the gas consumption depending on the exhaust air humidity for the benefit calculation “Measuring the moisture content of the air coming out of the stenter and according to that adjusting the humidity level (BAT 35)” technique



Without Heat Recovery													
55,4	54,3	53,2	52,1	51,1	50,1	49,2	48,3	47,4	46,6	45,8	45,0	44,3	43,5
0,0702	0,0716	0,0731	0,0746	0,0760	0,0775	0,0790	0,0805	0,0820	0,0834	0,0849	0,0864	0,0878	0,0894
0,1064	0,1085	0,1107	0,1130	0,1152	0,1174	0,1197	0,1219	0,1242	0,1264	0,1286	0,1310	0,1331	0,1354
												μ %	Heat Efficiency
												$\text{Sm}^3/\text{kg fabric}$	Gas Consumption Coefficient
												$\text{Sm}^3/\text{kg H}_2\text{O}$	

Without Heat Recovery													
33,1	32,4	31,8	31,1	30,5	29,9	29,3	28,8	28,2	27,7	27,2	26,8	26,3	25,8
0,1244	0,1271	0,1298	0,1325	0,1352	0,1379	0,1406	0,1433	0,1460	0,1487	0,1514	0,1541	0,1568	0,1595
0,1777	0,1816	0,1854	0,1893	0,1931	0,1970	0,2009	0,2047	0,2086	0,2124	0,2163	0,2201	0,2240	0,2278
												μ %	Heat Efficiency
												$\text{Sm}^3/\text{kg fabric}$	Gas Consumption Coefficient
												$\text{Sm}^3/\text{kg H}_2\text{O}$	