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ABSTRACT

The textile industry is one of the most complicated manufacturing industries because it is a fragmented and heterogeneous sector dominated by small and medium enterprises (SMEs). Energy is one of the main cost factors in the textile industry. Especially in times of high energy price volatility, improving energy efficiency should be a primary concern for textile plants. There are various energy-efficiency opportunities that exist in every textile plant, many of which are cost-effective. However, even cost-effective options often are not implemented in textile plants mostly because of limited information on how to implement energy-efficiency measures, especially given the fact that a majority of textile plants are categorized as SMEs and hence they have limited resources to acquire this information. Know-how on energy-efficiency technologies and practices should, therefore, be prepared and disseminated to textile plants.

This guidebook provides information on energy-efficiency technologies and measures applicable to the textile industry. The guidebook includes case studies from textile plants around the world and includes energy savings and cost information when available. First, the guidebook gives a brief overview of the textile industry around the world, with an explanation of major textile processes. An analysis of the type and the share of energy used in different textile processes is also included in the guidebook. Subsequently, energy-efficiency improvement opportunities available within some of the major textile sub-sectors are given with a brief explanation of each measure. The conclusion includes a short section dedicated to highlighting a few emerging technologies in the textile industry as well as the potential for the use of renewable energy in the textile industry.

Energy-Efficiency Improvement Opportunities for the Textile Industry

Contents

1. Introduction

As manufacturers face an increasingly competitive global business environment, they seek opportunities to reduce production costs without negatively affecting product yield or quality. For public and private companies alike, rising energy prices are driving up costs and decreasing value added at the plant. Successful, cost-effective investment into energy-efficiency technologies and practices meets the challenge of maintaining the output of a high quality product despite reduced production costs. This is especially important in the current age, as energy-efficient technologies often include "additional" benefits, such as increasing the productivity of the company or reducing the water and/or materials consumption.

Energy efficiency is an important component of a company's environmental strategy. End-of-pipe solutions can be expensive and inefficient while energy efficiency can often be an inexpensive opportunity to reduce emissions of criteria and other pollutants. In short, energy-efficiency investment is a sound business strategy in today's manufacturing environment (Worrell and Galitsky, 2004). In many countries, government policies and programs aim to assist industry to improve competitiveness through increased energy efficiency and reduced environmental impact. However, usually there are only limited information sources available on how to improve energy-efficiency, especially for small and medium enterprises (SMEs)[1]. Energy-efficiency technologies and practices know-how should, therefore, be prepared and disseminated to industrial plants.

This guidebook provides information on energy-efficiency technologies and production measures applicable to the textile industry. The guidebook also includes case studies from textile plants around the world and includes energy saving and cost information when available. For some measures the guide provides a range of savings and payback periods found under varying conditions. At all times, the reader must bear in mind that the values presented in this guidebook are offered as guidelines. Actual cost and energy savings for the measures will vary, depending on plant configuration and size, plant location, plant operating characteristics, production and product characteristics, the local supply of raw materials and energy, and several other factors. For example, for some of the energy-efficiency measures, the significant portion of the cost is the labor cost. Thus, the cost of these measures in the developed and developing countries may vary significantly.

Wherever available, the energy savings and costs are given per tonne of product or as the percentage of energy use by the equipment. However, due to a lack of information, energy savings and costs are given per year or per equipment/year for many measures and technologies. In these cases, especial care should be taken while interpreting the data. The term "average" is used to show that the savings and costs are the average value for the implementation of that measure on similar equipment. The other important issue that needs to be highlighted is that the cost values given in this guidebook are all presented as nominal costs. Therefore, the time value of the money should be considered while using the cost data from this report.

Although an extensive survey was conducted to identify different measures, this guide is not exhaustive, as new ways to improve energy efficiency are developed continuously. To enable

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[1] The definition of SME varies according to the country.

easy access to information, this guidebook adopts a classification of energy-efficiency measures based on textile sub-sectors and processes. However, sometimes the systems are interconnected and the energy=efficiency measures applicable to that system should not be regarded as independent from one another. In order to achieve optimal energy-efficiency, a systems energy-efficiency approach is essential. It also should be noted that the focus of this guidebook is the textile industry; the garment (clothing) industry is not addressed in this guidebook.

Since around 190 energy-efficiency measures and technologies for four major sub-sectors of the textile industry as well as for all the major cross-cutting technologies are explained in this guidebook, it can be overwhelming for some readers who are looking for specific information related to their plants. Below is a list of sections that should be reviewed by plants in each textile sub-sector.

- Spinning plants: sections 3.2, 4.2.1, 5, 6.1, 6.5.
- Weaving plants: sections 3.3, 4.2.3, 5, 6.2, 6.5.
- Wet-processing plants: sections 3.4, 4.2.2, 4.2.3, 5, 6.3, 6.5, 7, 8.
- Man-made fiber production plants: sections 3.1, 5, 6.4, 6.5, 8.

2. Overview of the textile industry

The textile industry has played an important role in the development of human civilization over several millennia. Coal, iron/steel and cotton were the principal materials upon which the industrial revolution was based. Technological developments from the second part of the eighteenth century onwards led to an exponential growth of cotton output, first starting in the U.K., and later spreading to other European countries. The production of synthetic fibers that started at the beginning of the twentieth century also grew exponentially (Schönberger and Schäfer, 2003) Figure 1 shows the relationship between world population and total textile demand. Assuming that world population will grow to 10 billion in 2050, and further to 11.6 billion in 2150 when it is expected to plateau, total textile consumption is forecast to double, even using the relatively conservative 1990's figure of per capita annual average textile consumption (8 kg/person) (UNIDO, 1992).

The textile industry is traditionally regarded as a labor-intensive industry developed on the basis of an abundant labor supply. The number of persons employed in the textile and clothing industry was around 2.45 million in the European Union (EU) in 2006 (European Commission, 2009a), around 500,000 in the U.S. in 2008 (USDL, 2010), and about 8 million in China in 2005 (Qiu, 2005).

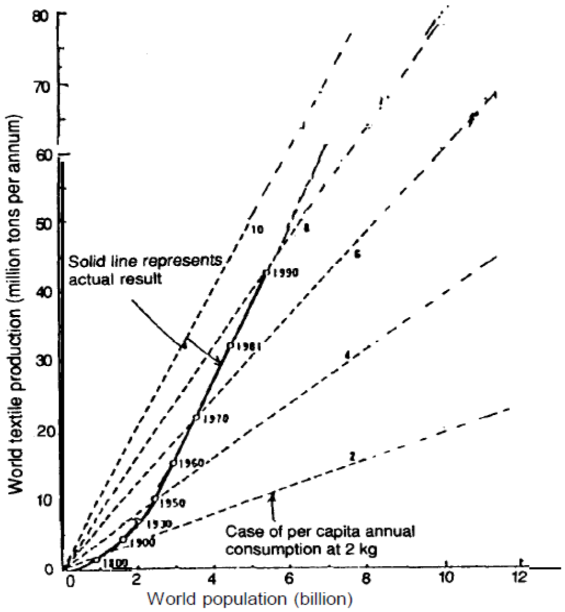

Figure 1. Relationship Between World Population and World Textile Consumption and Production (UNIDO, 1992)

China is the world's top textile exporter with 40% of world textile and clothing exports (European Commission, 2009b). The textile and clothing industry is the largest manufacturing industry in China with about 24,000 enterprises. The value of its total output was 1,064 billion Yuan in 2002 (US $129.8 billion[2]). China is the largest clothing producer in the world and has the largest production capacity for textile products consisting of cotton, manmade fibers and silk (Qiu, 2005). In 2008, the total export value of China's textile industry was US $65.406 billion, an increase of 16.6% compared to 2007. With the rising living standard of the Chinese people, local demand for high quality textiles and apparel goods continues to increase (CRI, 2010). China is also the largest importer of textile machinery and Germany is the largest exporter of textile machinery (Textile Exchange, 2009). Figure 2 and Figure 3 show the leading exporters and importers of textiles in 2003 with the amount of exports and imports in billion U.S. dollars. It should be noted that the graphs are just for textiles and do not include clothing. As can be seen in the figures, EU, China, and US are the top three textile importers and exporters.

The EU textile and clothing sector represents 29% of the world textile and clothing exports, not including trade between EU Member countries, which places the EU second after China (European Commission, 2009b). In 2000, the European textile and clothing industry represented 3.4% of the EU manufacturing industry's turnover, 3.8% of the added value and 6.9% of the industrial employment (European Commission, 2003).

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[2] Assuming the average exchange rate of 8.2 Yuan/US$ in 2002.

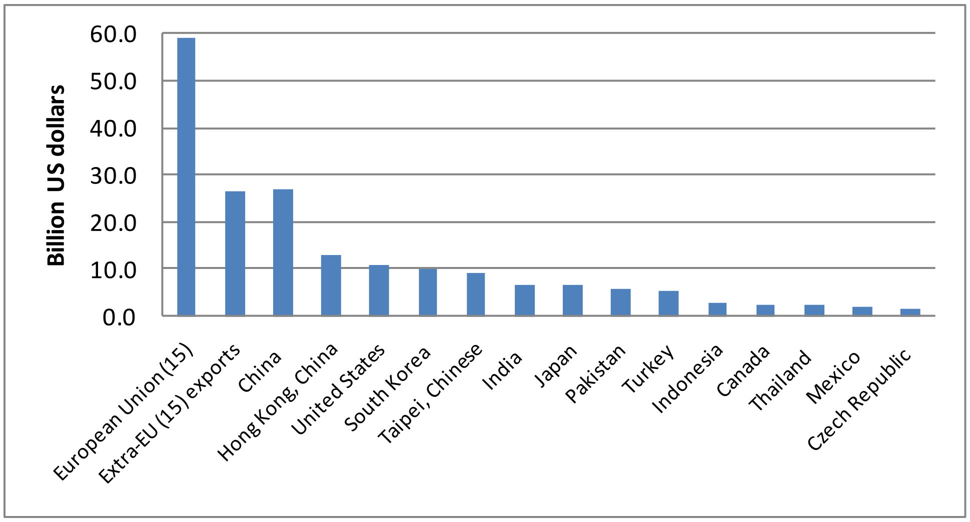

Figure 2. Leading Exporters of Textiles in 2003 (WTO, 2004)

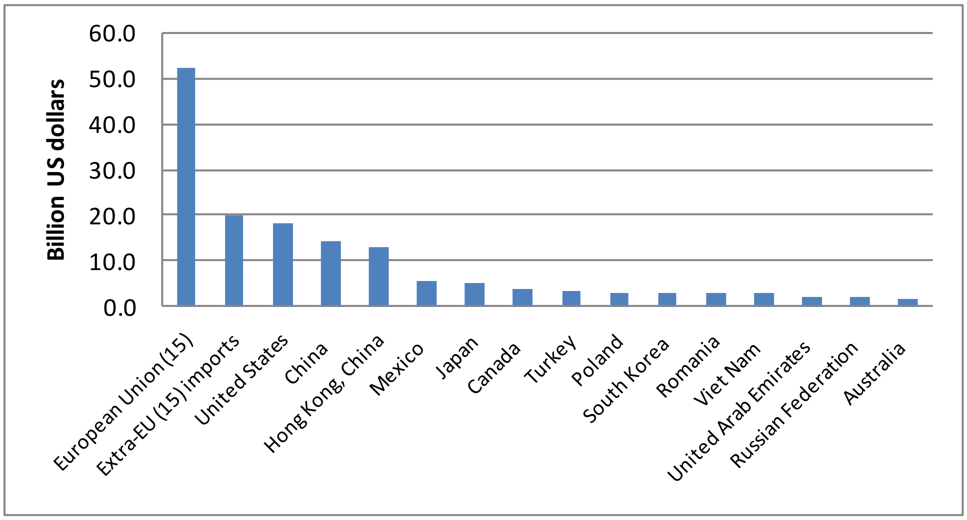

Figure 3. Leading Importers of Textiles in 2003 (WTO, 2004)

3. Textile processes

The textile industry has one of the most complicated industrial chains in the manufacturing industry. It is a fragmented and heterogeneous sector dominated by SMEs, with a demand mainly driven by three dominant end-uses: clothing, home furnishing and industrial use. Characterizing the textile manufacturing is complex because of the wide variety of substrates, processes, machinery and components used, and finishing steps undertaken. Different types of fibers or yarns, methods of fabric production, and finishing processes (preparation, printing, dyeing, chemical/mechanical finishing, and coating), all interrelate in producing a finished fabric. When one of these components is changed, the properties of the end product are affected. There are several properties that can be used to define a fabric. Some examples of fabric properties include weight, appearance, texture, strength, luster, flexibility, and affinity to dyestuff.

Figure 4 is a generalized flow diagram depicting the various textile processes that are involved in converting raw materials in to a finished product. All of these processes do not occur at a single facility, although there are some integrated plants that have several steps of the process all in one plant. There are also several niche areas and specialized products that have developed in the textile industry which may entail the use of special processing steps that are not shown in Figure 4 (US EPA, 1998).

Due to the variety of the processes involved in the textile industry, there are too many processes to be explained within the space constraints of this guidebook. Thus, the brief descriptions only for the major textile processes for which the energy-efficiency measures are given here are presented in Appendix 1. Flowcharts of the processes are also given to help the reader better understand manufacturing sequences and process steps. The major textile processes that are discussed in the guidebook are:

- Spun Yarn Spinning
- Weaving
- Wet-processing (preparation, dyeing, printing, and finishing)
- Man-made fiber production

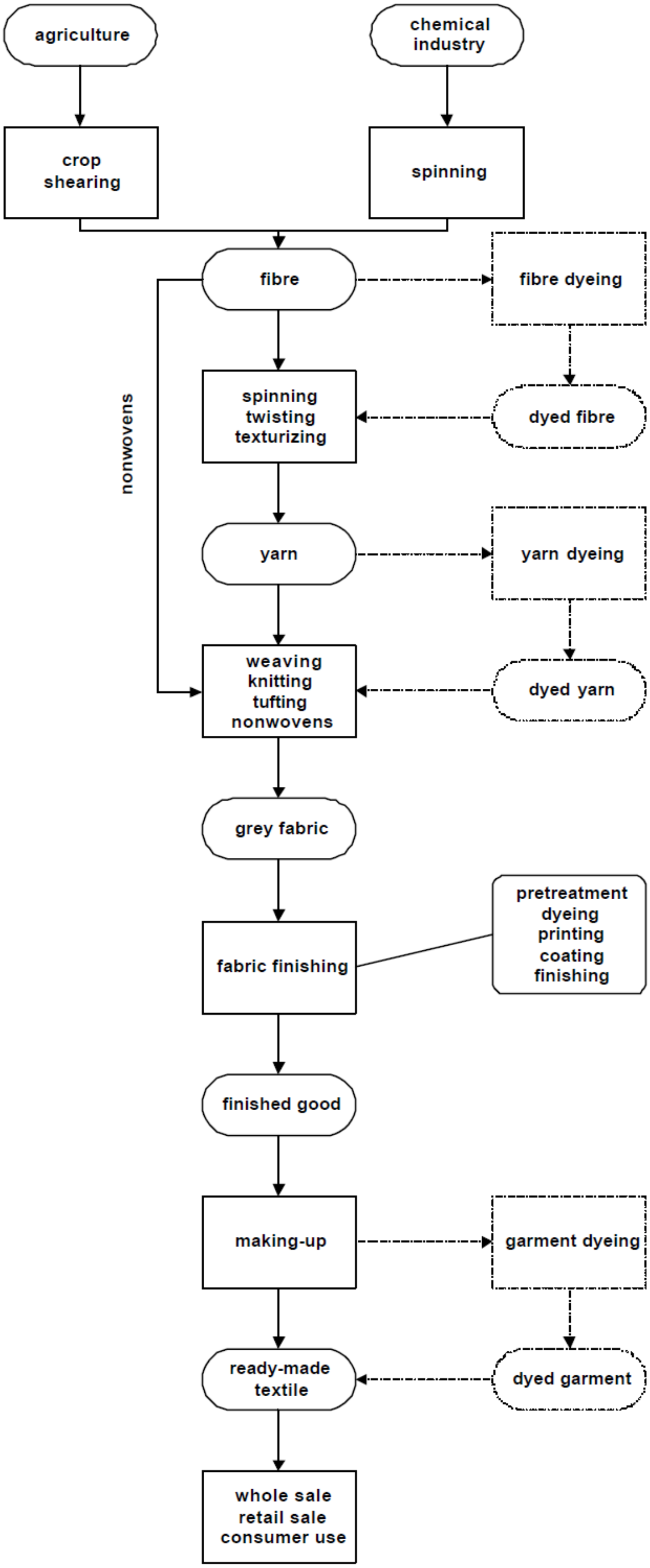

Figure 4. The Textile Chain (Schönberger and Schäfer, 2003)

4. Energy use in the textile industry

The textile industry, in general, is not considered an energy-intensive industry. However, the textile industry comprises a large number of plants which all together consume a significant amount of energy. The share of total manufacturing energy consumed by the textile industry in a particular country depends upon the structure of the manufacturing sector in that country. For instance, the textile industry accounts for about 4% of the final energy use in manufacturing in China (LBNL, 2007), while this share is less than 2% in the US (U.S. DOE, 2010).

The share of the total product cost expended on energy in the textile industry also varies by country. Table 1 shows general shares of cost factors for 20 Tex[3] combed cotton yarn in several countries. Energy cost is often the third or fourth highest share of total product cost.

Table 1. Share of Manufacturing Cost Factors for 20 Tex Combed Cotton Yarn in Several Countries in 2003 (Koç and Kaplan, 2007)

Cost factors	Brazil	China	India	Italy	Korea	Turkey	USA
Raw material	50%	61%	51%	40%	53%	49%	44%
Waste	7%	11%	7%	6%	8%	8%	6%
Labor	2%	2%	2%	24%	8%	4%	19%
Energy	5%	8%	12%	10%	6%	9%	6%
Auxiliary material	4%	4%	5%	3%	4%	4%	4%
Capital	32%	14%	23%	17%	21%	26%	21%
Total	100%	100%	100%	100%	100%	100%	100%

The textile industry uses large quantities of both electricity and fuels. The share of electricity and fuels within the total final energy use of any one country's textile sector depends on the structure of the textile industry in that country. For instance, in spun yarn spinning, electricity is the dominant energy source, whereas in wet-processing the major energy source is fuels. Manufacturing census data from 2002 in the U.S. shows that 61% of the final energy used in the U.S. textile industry was fuel energy and 39% was electricity. The U.S. textile industry is also ranked the 5th largest steam consumer amongst 16 major industrial sectors studied in the U.S. The same study showed that around 36% of the energy input to the textile industry is lost onsite (e.g. in boilers, motor system, distribution, etc.) (US DOE, 2004).

4.1. Breakdown of energy use by end-use

In a textile plant, energy is used in different end-uses for different purposes. Figure 5 shows the Breakdown of final energy use by end use in the U.S. textile industry (US, DOE, 2004). Although the percentages shown in the graph can vary from one country to another, this figure gives an indication of final energy end-use in the textile industry. However, it should be noted that it is more likely that the textile industry in the U.S. does not include as many labor-intensive processes (e.g. spinning and weaving) as it does in some developing countries like China and India where the cost of labor is lower. As is shown in the figure below, in the U.S. textile industry steam and motor-driven systems (pumps, fans, compressed air, material handling,

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[3] The Tex is one of the several systems to measure the yarn count (fineness). The Tex count represents the weight in grams per 1 kilometer (1000 meters) of yarn. For example, a yarn numbered 20 Tex weighs 20 grams per kilometer. The Tex number increases with the size of the yarn.

material processing, etc.) have the highest share of the end-use energy use and each accounts for 28% of total final energy use in the U.S. textile industry.

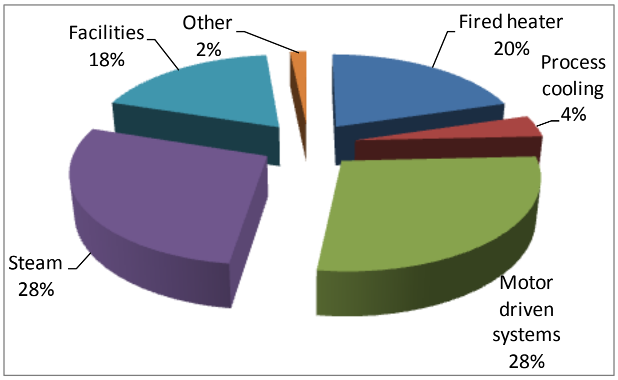

Figure 5. Final Energy End-Use in the U.S. Textile Industry (U.S. DOE, 2004)

As indicated, there are significant losses of energy within textile plants. Figure 6 below shows the onsite energy loss profile for the U.S. textile industry (US DOE, 2004). Around 36% of the energy input to the U.S. textile industry is lost onsite. Motor driven systems have the highest share of onsite energy waste (13%) followed by distribution[4] and boiler losses (8% and 7% respectively). The share of losses could vary for the textile industry in other countries depending on the structure of the industry in those countries. However, the figure below gives an illustration of where the losses happen and the relative importance of each loss in the U.S. textile industry.

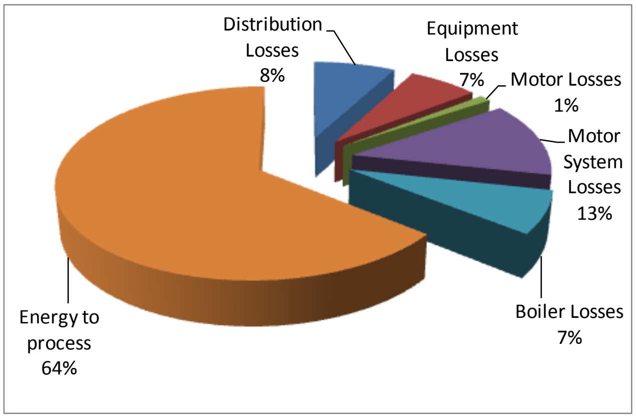

Figure 6. Onsite Energy Loss Profile for the U.S. Textile Industry (US DOE, 2004).

As shown above, motor driven systems are one of the major end-use energy wasters in the textile industry. Figure 7 below shows the Breakdown of the energy used by motor systems in different processes in the U.S. textile industry. As can be seen, material processing has the highest share of the energy used by motor driven systems (31%) followed by pumps, compressed air, and fan systems (19%, 15%, and 14% respectively). Again, these percentages in other countries will highly depend on the structure of the textile industry in those countries. For instance, if the weaving industry in a country has a significantly higher share of air-jet weaving machines

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[4] Energy distribution losses are for both inside and outside of the plant boundary.

(which consume high amounts of compressed air) than in the U.S., the share of total motor driven system energy consumed by compressed air energy systems would probably be higher than indicated in Figure 7.

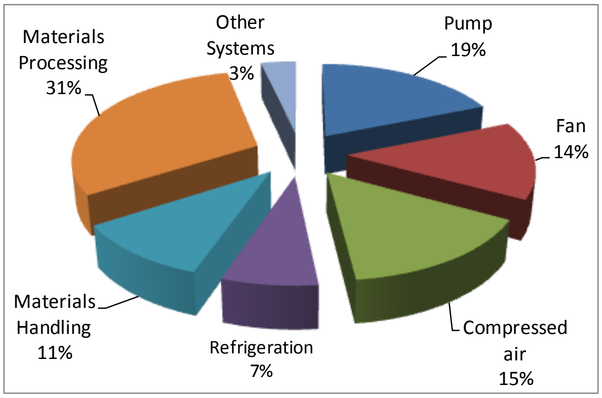

Figure 7. Breakdown of Motor Systems Energy Use in the U.S. Textile Industry (US DOE, 2004)

4.2. Breakdown of energy use by textile processes

4.2.1. Energy use in the spinning process

Electricity is the major type of energy used in spinning plants, especially in cotton spinning systems. If the spinning plant just produces raw yarn in a cotton spinning system, and does not dye or fix the produced yarn, the fuel may just be used to provide steam for the humidification system in the cold seasons for preheating the fibers before spinning them together. Therefore, the fuel used by a cotton spinning plant highly depends on the geographical location and climate in the area where the plant is located. Figure 8 shows the Breakdown of final energy use in a sample spinning plant that has both ring and open-end spinning machines.

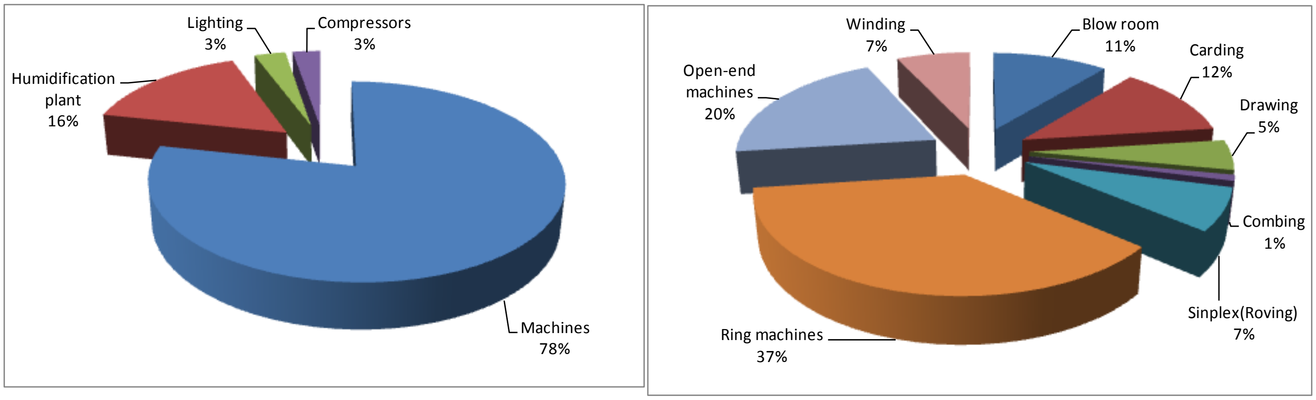

Figure 8. Breakdown of the Final Energy use in a Spinning Plant that has Both Ring and Open-End Spinning Machines (US DOE, 2004)

Note: The graph on the right shows the breakdown of the energy use by the category "machines" that is shown in the graph on the left.

Koç and Kaplan (2007) calculated the energy consumption for spinning different types and counts of yarn and the results are shown in Table 2. For all types of fibers, finer yarn spinning consumes more energy. That said, yarns used for weaving involves more twisting than yarns used for knitting. Also, production speed is low for weaving yarn compared to that of knitting yarn. As a result, with the same yarn count, more energy is consumed for weaving yarn. Also, for the same yarn count, the energy consumption for combed yarn is higher because of the additional production step (combing).

Table 2. Typical Specific Energy Consumption (kWh/kg) for Yarns with Different Yarn Counts and Final Use (Weaving vs. Knitting) (Koç and Kaplan, 2007)

Yarn Count (Tex)	Combed Yarn		Carded yarn	
	Knitting	Weaving	Knitting	Weaving
37	138	163	134	162
33	158	188	154	186
30	179	212	173	209
25	219	260	211	255
20	306	364	296	357
17	389	462	374	453
15	442	525	423	512
12	552	681	552	672

<u>Calculation of energy consumption of ring machines:</u>

Since the highest energy consumption occurs in spinning machines during yarn manufacturing, many studies have been carried out on the energy consumption of spinning machines. One of these studies shows that specific energy consumption in a ring spinning machine can be calculated with the equation given below.

$$SEC = 106.7 \times F^{-1.482} \times Dr^{3.343} \times n^{0.917} \times \alpha_{text}^{0.993}$$

Where; SEC is the specific energy consumption (kWh/kg) in a ring spinning machine; F is the linear density of yarn (tex); Dr is the diameter of the ring (m); n is the speed of the spindle (1000 r.p.m.); and α_{text} is the twist factor of the yarn. The production parameters assumed for 20 tex combed yarn are $n = 17500$ r.p.m.; $\alpha_{text} = 3828$; and $Dr = 0.04$ m. If these parameters are used in the equation above, the specific energy consumption of ring machines is found as 1.36 kWh/kg. However, there might be a slight difference between the calculated and actual values that is attributable to the difference in parameters such as speed, waste ratio, mechanical efficiency and energy loss of ring spinning machines (Koç and Kaplan, 2007).

4.2.2. Energy use in wet-processing

Wet-processing is the major energy consumer in the textile industry because it uses a high amount of thermal energy in the forms of both steam and heat). The energy used in wet-processing depends on various factors such as the form of the product being processed (fiber, yarn, fabric, cloth), the machine type, the specific process type, the state of the final product, etc. Table 3 shows the typical energy requirements for textile wet-process processes by the product form, machine type, and process.

Table 4 gives a breakdown of thermal energy use in a dyeing plant (with all dyeing processes included). Although the values in this table are the average values for dyeing plants in Japan, it gives a good idea about where the thermal energy is used, allowing the discovery of opportunities for energy-efficiency improvement. It can be seen that a significant share of thermal energy in a dyeing plant is lost through wastewater loss, heat released from equipment, exhaust gas loss, idling, evaporation from liquid surfaces, un-recovered condensate, loss during condensate recovery, and during product drying (e.g. by over-drying). These losses can be reduced by different energy-efficiency measures explained in the next section of this guidebook.

Table 3. Typical Energy Requirements for Textile Wet- Processes, by Product Form, Machine Type and Process (Carbon Trust, 1997)

Product form/machine type	Process	Energy requirement (GJ/tonne output)
Desize unit	Desizing	1.0 - 3.5
Kier	Scouring/bleaching	6.0 - 7.5
J-box	Scouring	6.5 - 10.0
Open width range	Scouring/bleaching	3.0 - 7.0
Low energy steam purge	Scouring/bleaching	1.5 - 5.0
Jig/winch	Scouring	5.0 - 7.0
Jig/winch	Bleaching	3.0 - 6.5
Jig	Dyeing	1.5 - 7.0
Winch	Dyeing	6.0 - 17.0
Jet	Dyeing	3.5 - 16.0
Beam	Dyeing	7.5 - 12.5
Pad/batch	Dyeing	1.5 - 4.5
Continuous/thermosol	Dyeing	7.0 - 20.0
Rotary Screen	Printing	2.5 - 8.5
Steam cylinders	Drying	2.5 - 4.5
Stenter	Drying	2.5 - 7.5
Stenter	Heat setting	4.0 - 9.0
Package/yarn	Preparation/dyeing (cotton)	5.0 - 18.0
Package/yarn	Preparation/dyeing (polyester)	9.0 - 12.5
Continuous hank	Scouring	3.0 - 5.0
Hank	Dyeing	10.0 - 16.0
Hank	Drying	4.5 - 6.5

Table 4. Breakdown of Thermal Energy Use in a Dyeing Plant (Average in Japan) (ECCJ, 2007a)

Item	Share of total thermal energy use
Product heating	16.6 %
Product drying	17.2 %
Waste water loss	24.9 %
Heat released from equipment	12.3 %
Exhaust gas loss	9.3 %
Idling	3.7 %
Evaporation from liquid surfaces	4.7 %
Un-recovered condensate	4.1 %
Loss during condensate recovery	0.6 %
Others	6.6 %
Total	100%

4.2.3. Breakdown of energy use in composite textile plants (spinning-weaving-wet processing)

A composite textile plant is a plant that has spinning, weaving/knitting, and wet-processing (preparation, dyeing/printing, finishing) all on the same site. Figure 9 shows the Breakdown of the typical electricity and thermal energy use in a composite textile plant (Sathaye, et al., 2005). As can be seen, spinning consumes the greatest share of electricity (41%) followed by weaving (weaving preparation and weaving) (18%). Wet-processing preparation (desizing, bleaching, etc) and finishing together consume the greatest share of thermal energy (35%). A significant amount of thermal energy is also lost during steam generation and distribution (35%). These percentages will vary by plant.

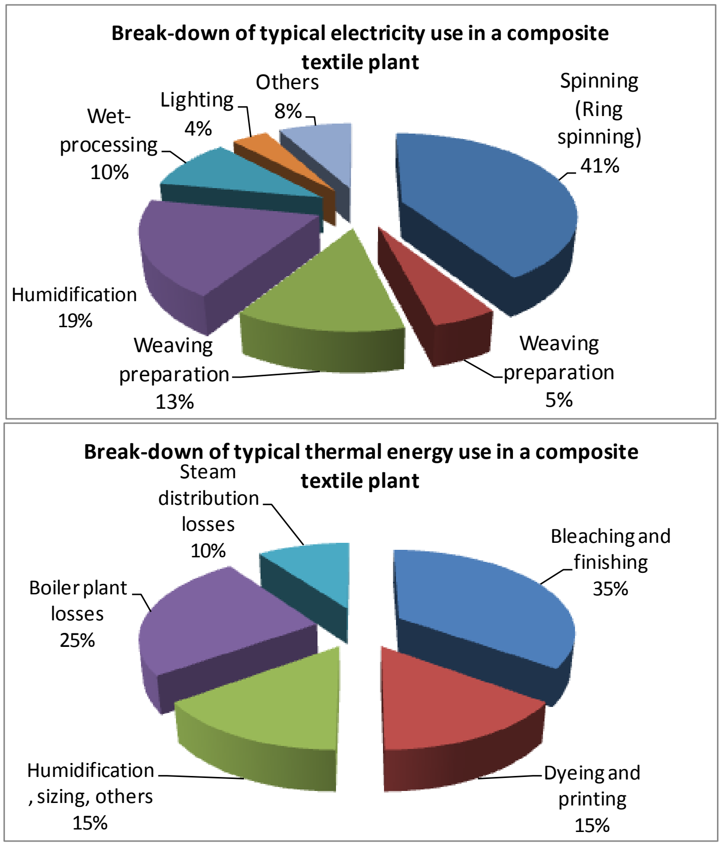

Figure 9. Breakdown of Typical Electricity and Thermal Energy Used in a Composite Textile Plant (Sathaye et al., 2005)

5. Energy-efficiency improvement opportunities in the textile industry

This analysis of energy-efficiency improvement opportunities in the textile industry includes both opportunities for retrofit/process optimization as well as the complete replacement of the current machinery with state-of-the-art new technology. However, special attention is paid to retrofit measures since state-of-the-art new technologies have high upfront capital costs, and therefore the energy savings which result from the replacement of current equipment with new equipment alone in many cases may not justify the cost. However, if all the benefits received from the installation of the new technologies, such as water savings, material saving, less waste, less waste water, less redoing, higher product quality, etc. are taken into account, the new technologies are more justifiable economically.

Furthermore, we have tried to present measures for which we could find quantitative values for energy savings and cost. However, in some cases we could not find such quantitative values, yet since some measures are already well-known for their energy-saving value, we decided to include them in the guidebook despite lacking quantitative metrics of their potential. We believe that the qualitative information given for such technologies/measures can help the textile plant engineers to identify available opportunities for energy-efficiency improvements. However, it should be noted that the energy saving and cost data provided in this guidebook are either typical saving/cost or plant/case-specific data. The savings from and cost of the measures can vary depending on various factors such as plant and process-specific factors, the type of fiber, yarn, or fabric, the quality of raw materials, the specifications of the final product as well as raw materials (e.g. fineness of fiber or yarn, width or specific weight of fabric g/m^2, etc), the plant's geographical location, etc. For instance, for some of the energy-efficiency measures, a significant portion of the cost is the labor cost. Thus, the cost of these measures in the developed and developing may vary significantly.

Around 190 energy-efficiency measures and technologies are listed in this guidebook. .

5.1. Energy Management Programs

5.1.1. Strategic energy management programs [5]

Changing how energy is managed by implementing an organization-wide energy management program is one of the most successful and cost-effective ways to bring about energy-efficiency improvements. Ideally, such a program would include facility, operation, environmental, health, safety and personnel management. A sound energy management program is required to create a foundation for positive change and to provide guidance for managing energy throughout an organization. Continuous improvements to energy-efficiency, therefore, only occur when a strong organizational commitment exists. Energy management programs help to ensure that energy-efficiency improvements do not just happen on a one-time basis, but rather are continuously identified and implemented in a process of continuous improvement.

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[5] This section is excerpted from Worrell et al. (2010)

In companies without a clear program in place, opportunities for improvement may be known, but may not be promoted or implemented because of organizational barriers, even when energy is a significant cost. These barriers may include a lack of communication among plants, a poor understanding of how to create support for an energy-efficiency project, limited finances, poor accountability for measures, or organizational inertia adverse to changes from the status quo. The major elements in a strategic energy management program are shown in Figure 10. It could be noted that the concept shown in this figure for energy management system builds from the ISO quality management system's philosophy of Plan-Do-Check-Act.

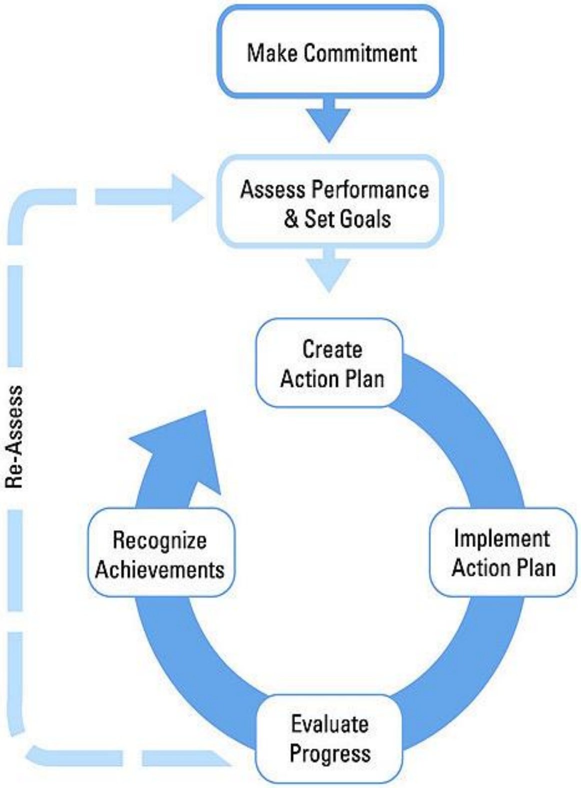

Figure 10. Main Elements of a Strategic Energy Management Program (EnergyStar, 2004)

A successful energy management program begins with a strong organizational commitment to the continuous improvement of energy-efficiency. This involves assigning oversight and management duties to an energy director, establishing an energy policy, and creating a cross-functional energy team. Steps and procedures are then put in place to assess performance through regular reviews of energy data, technical assessments, and benchmarking. From this assessment, an organization is able to develop a baseline of energy use and set goals for improvement. Such performance goals help to shape the development and implementation of an action plan.

An important aspect for ensuring the success of the action plan is involving personnel throughout the organization. Personnel at all levels should be aware of energy use and goals for efficiency. Staff should be trained in general approaches to energy efficiency in day-to-day practices. Evaluating performance involves the regular review of both energy use data and the activities carried out as part of the action plan. Information gathered during the formal review process helps in setting new performance goals and action plans and in revealing best practices. Establishing a strong communications program and seeking recognition for accomplishments are critical steps to build support and momentum for future activities (EnergyStar, 2004; Worrell et al., 2010)

5.1.2. Create an action plan [6]

In practice there are barriers that prevent the successful implementation of energy-efficiency measures recommended in the energy audit report. Therefore, it is necessary to establish a clear procedure, which ensures the successful realization of improvements. The action plan should be described in a simple way with clear aims, savings targets and definitions of roles and responsibilities for its execution (Austrian Energy Agency 2007).

A detailed action plan helps to ensure a systematic process to implement energy-efficiency measures. Unlike the energy policy, the action plan is regularly updated, most often on an annual basis, to reflect recent achievements, changes in performance, and shifting priorities. While the scope and scale of the action plan is often dependent on the organization, the steps below outline a basic starting point for creating a plan:

1. Define technical steps and targets.
2. Determine roles and resources.

Before finalizing the action plan, it is better to consult and brainstorm with division managers and key engineers in the plant to get their input on the action plan (US EPA, 2007).

Define technical steps and targets

The audit results can give an indication of the technical performance of the plant and its gap from efficient performance. Based on this, opportunities for energy-efficiency improvements can be identified and prioritized. Three key steps are:

- **Create performance targets** for each facility, department, and operation of the organization to track progress towards achieving goals.
- **Set timelines** for actions, including regular meetings among key personnel to evaluate progress, completion dates, milestones and expected outcomes.
- **Establish a monitoring system** to track and monitor the progress of actions taken. This system should track and measure energy use and project/program activities.

Determine roles and resources:

Identify internal roles

The action plan should determine who is involved in the energy-efficiency program and what their responsibilities are. Depending on the organization and action plan, this might include departments such as:

- Facility and operations management,
- Financial management—capital investments, budget planning,
- Human resources—staffing, training, and performance standards,
- Maintenance,
- Supply management—procurement procedures, energy purchasing and equipment and materials,

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[6] This section is excerpted from US EPA (2007), unless different source is given.

- Building and plant design,
- Engineering,
- Communications marketing, and
- Environmental, health, and safety

Identify external roles

The action plan should determine the degree to which consultants, service providers, vendors, and other product providers will be used. Some organizations may choose to outsource entire aspects of their action plan while others may only want to contract with specific vendors for limited projects. If contractors will be used, the action plan should determine what standards will be used to evaluate bids and incorporated these metrics into agreements with contractors.

Determine resources

For each project or program in the action plan, management must estimate the cost for each item in terms of both human resources and capital/expense. Then, management should develop the business case for justifying and gaining funding approval for action plan projects and resources needed (US EPA, 2007).

5.1.3. Implement the action plan

To successfully implement the action plan, it is vital to gain support from personnel within the plant involved in the efficiency improvement programs. To implement your action plan, the following steps should be considered:

1. Create a communication plan: develop targeted information for key audiences about your energy-efficiency action plan,
2. Raise awareness: build support for all levels of your organization for energy-efficiency initiatives and goals,
3. Build capacity: through training, access to information, and transfer of successful practices and procedures you can expand the capacity of your staff,
4. Motivate: create incentives that encourage staff to improve energy performance to achieve goals,
5. Track and monitor: use a tracking system developed as part of the action plan to track and monitor progress regularly.

Evaluate progress

Plants can evaluate the progress of their activities using energy data and the formal review of activities taken as part of the action plan and compare them to the established goals. This formal review can be used to revise the action plan and see the lessons learned. The regular evaluation of energy performance and the effectiveness of energy-efficiency initiatives also allows energy managers to:

- Measure the effectiveness of projects and programs implemented,
- Make informed decisions about future energy projects,
- Reward individuals and teams for accomplishments,
- Document additional savings opportunities as well as non-quantifiable benefits that can be leveraged for future initiatives (US EPA, 2007).

5.2. Energy-efficiency technologies and measures in the spun yarn spinning process

Table 5. shows the list of measures/technologies included in this guidebook for the spun yarn spinning process.

Table 5. List of Energy-efficiency Measures and Technologies for the Spinning Process *

No.	Energy-efficiency Technologies and Measures	Fuel saving	Electricity saving	Capital Cost (US$)	Payback Period (Year)**
5.1	**Spinning**				
5.1.1	**Preparatory process**				
1	Installation of electronic Roving end-break stop-motion detector instead of pneumatic system		3.2 MWh/year/machine	180/roving machine	< 1
2	High-speed carding machine			100,000/carding machine	<2
5.1.2	**Ring Frame**				
3	Use of energy-efficient spindle oil		3% - 7% of ring frame energy use		
4	Optimum oil level in the spindle bolsters				
5	Replacement of lighter spindle in place of conventional spindle in Ring frame		23 MWh/year/ring frame	13,500 /ring frame	8
6	Synthetic sandwich tapes for Ring frames		4.4 - 8 MWh/ring frame/year	540 -683/ring frame	1 - 2
7	Optimization of Ring diameter with respect to yarn count in ring frames		10% of ring frame energy use	1600 /ring frame	2
8	False ceiling in Ring spinning section		8 kWh/ year/spindle	0.7/spindle	1.2
9	Installation of energy-efficient motor in Ring frame		6.3 -18.83 MWh/year/motor	1950 - 2200 /motor	2 - 4
10	Installation of energy-efficient excel fans in place of conventional aluminum fans in the suction of Ring Frame		5.8 - 40 MWh/year/fan	195 - 310 /fan	< 1
11	The use of light weight bobbins in Ring frame		10.8 MWh/year/ring frame	660 /ring frame	< 1
12	High-speed Ring spinning frame		10% - 20% of ring frame energy use		
13	Installation of a soft starter on motor drive of Ring frame		1 – 5.2 MWh/year/ring frame		2
5.1.3	**Windings, Doubling, and finishing process**				
14	Installation of Variable Frequency Drive on Autoconer machine		331.2 MWh/year/plant	19500/plant	< 1
15	Intermittent mode of movement of empty bobbin conveyor in the Autoconer/cone winding machines		49.4 MWh/year/plant	1100/plant	< 1
16	Modified outer pot in Tow-For-One (TFO) machines		4% of TFO energy use		
17	Optimization of balloon setting in Two-For-One (TFO) machines				
18	Replacing the Electrical heating system with steam heating system for the yarn polishing machine	increased 31.7 tonnes steam/year/machine	19.5 MWh/year/machine	980/ humidification plant	< 1
5.1.4	**Air conditioning and Humidification system**				
19	Replacement of nozzles with energy-efficient mist nozzles in yarn conditioning room		31MWh/year/humidification plant	1700/ humidification plant	< 1
20	Installation of Variable Frequency Drive (VFD) for washer pump motor in Humidification plant		20 MWh/year/humidification plant	1100/ humidification plant	< 1
21	Replacement of the existing Aluminium alloy fan impellers with high efficiency F.R.P (Fiberglass Reinforced Plastic) impellers in humidification fans and cooling tower fans		55.5 MWh/year/fan	650/ fan	< 1
22	Installation of VFD on Humidification system fan motors for the flow control		18 -105 MWh/year/fan	1900 -8660/ fan	1 - 2
23	Installation of VFD on Humidification system pumps		35 MWh/year/ humidification plant	7100/ humidification plant	2.7

No.	Energy-efficiency Technologies and Measures	Fuel saving	Electricity saving	Capital Cost (US$)	Payback Period (Year)**
24	Energy-efficient control system for humidification system		50 MWh/year/ humidification plant	7300 to 12,200/ humidification plant	2 - 3.5
5.1.5	**General measures for Spinning plants**				
25	Energy conservation measures in Overhead Travelling Cleaner (OHTC)		5.3 - 5.8 MWh/year/ OHTC	180 -980/ OHTC	0.5 - 2.5
26	Energy-efficient blower fans for Overhead Travelling Cleaner (OHTC)		2 MWh/year/fan	100/fan	< 1
27	Improving the Power Factor of the plant (Reduction of reactive power)		24.1 MWh/year/plant	3300/plant	1.8
28	Replacement of Ordinary ‘V – Belts’ by Cogged ‘V – Belts’		1.5 MWh/year/belt	12.2/belt	< 1

* The energy savings, costs, and payback periods given in the table are for the specific conditions cited. There are also some ancillary (non-energy) benefits from the implementation of some measures. Read the explanation of each measure in the report text to get a complete understanding of the savings and costs.
**Wherever the payback period was not provided, but the energy and cost were given, the payback period is calculated assuming the price of electricity of US$75/MWh (US$0.075/kWh).

5.2.1. Preparatory process

1. Installation of electronic roving end break stop-motion detectors instead of pneumatic systems

In a simplex (roving) machine, the roving end-break system can be converted from a pneumatic suction tube detector to a photoelectric stop-motion system end-break detector in order to save energy. This measure is implemented in many textile plants around the world. The average energy saving reported from implementation in two Indian spinning plants is 3.2 MWh/year/machine with an average investment cost of about US$180 per roving machine. (EMT, 2008a)

2. High-speed carding machine

This machine is used in the secondary processing of raw cotton. The machine separates the lumps of small fibers that result from the disentangling of tufts in the “opening-and-picking” stage of primary processing, and simultaneously removes impurities, lint balls, and short fibers, improving the arrangement of good quality fibers in the longitudinal direction, and producing fiber bundles (slivers) in strands.

This new carding machine is large and each machine consumes considerable amounts of electricity. On the other hand, since productivity is high, 1/3 the number of new machines and half the total power can produce the same production capacity as ordinary carding machines. For instance, twelve conventional machines requiring 27kW/machine can be replaced by four of the new machines requiring 41 kW/machine, and thus results in power-savings of 160kW. There are many examples of installation of new carding machines in major plants throughout Japan and this technology is certainly applicable in any developing country. The capital cost of the new carding machine is about US$100,000. The payback period for the investment is about 1.3 years (NEDO, 2008).

5.2.2. Ring frames [7]

3. Use of energy-efficient spindle oil

The incorporation of a dispersant additive system to the mineral-based spindle oil may result in energy savings of up to 3% when compared to conventional oils. The amount of actual savings will depend upon the condition of the machinery and their operation condition. Energy saving also can be achieved by using light weight spindles. However, synthetic-based spindle oils (energy-efficient grades) along with certain metal compatibility additives may result in higher energy savings, in the range of 5 – 7% depending upon viscosity. The energy-efficiency potential of particular oil can be assessed in two ways:

(1) The reduction in electricity consumption, and
(2) The reduction in bolster temperature rise over ambient: energy saving oils result in lesser temperature increases.

While selecting any energy saving spindle oil, one should carefully evaluate important characteristics related to the service life of the oil, i.e., temperature rise, thermal stability, metal compatibility, sludge forming tendency and anti-wear/antifriction properties (Jha, 2002).

4. Optimum oil level in the spindle bolsters

Jha (2002) explains that "the electricity consumption in the Ring frame increases with an increase in the oil level in the bolsters because of resistance caused by the oil. Also, an excessively high oil level in the bolster may disturb the proper running of the spindle. Normally, 75% of the bolster capacity is filled with oil. The usual method of determining the depth of oil level in the bolster is by lifting the spindle and observing the oiliness of the spindle blade. This assessment method may not be accurate if one is trying to find out the normal and minimum level of oil required. The correct or exact amount of oil for each type of spindle insert could be assured by using a dipstick. The dipstick has two distinct markings, i.e. the bottom marking for minimum and the top marking for maximum oil levels.

The normal tendency in many plants is to fill up the bolster to a near full level at the time of filling and then topping up as needed – this leads not only to wastage of lubricant but also to higher energy consumption. The oil level should, therefore, be checked with a dipstick after every topping and the level should be maintained within the limits prescribed by the machinery manufacturers. In this regard, various oil dosing equipment are available today for filling and topping spindle bolsters with the predetermined quantity of oil. The novel feature of these equipment is the volume control mechanism, which facilitates dosing out required quantities of spindle oil (5 cc to 20 cc) to suit the capacity of different bolsters used in Ring frames. As there is no excess filling of spindle oil into the bolster, it prevents wastage of oil as well as energy" (Jha, 2002).

5. Replacement of lighter spindles in place of conventional spindles in ring frames

As mentioned above, ring frames are the largest energy consumer in the ring spinning process. Within a ring frame, spindles rotation is the largest energy consumer. Thus, the weight of the

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[7] See Appendix 2 for the example of technical parameters of the ring frame (e.g. installed power, compressed air use, etc.)

spindles is directly related to the energy use of the machine. There are so-called high efficiency spindles on the market which are lighter than the conventional spindles and hence use less energy. A spinning plant in India replaced the conventional spindles with lighter weight ones in their ring frames and on average saved 23 MWh/year/ring frame. The investment cost of this measure was around US$13,500 per ring frame (EMT, 2008b).

6. Synthetic sandwich tapes for ring frames

Synthetic sandwich spindle tapes are made of polyamide, cotton yarn and a special synthetic rubber mix. Sandwich tapes run stable, have good dimensional stability, don't break, result in less weak-twist yarn, do not cause fiber sticking, and are made of soft and flexible tape bodies. Because of these special characteristics, these tapes offer 5 – 10% energy saving. Based on an assessment conducted for an Indian spinning plant, replacing cotton tapes with synthetic sandwich spindle tapes can result in average savings of 8 MWh/ring frame/year (92.5 kWh/ton/year). The capital cost of replacement is US$540 for each ring frame (with a payback period of about 10 months) (Palanichamy and Sundar Babu, 2005).

In another spinning plant in India, the installation of energy-efficient tapes in ring frames in average resulted in energy savings of 4.4 MWh/year/ring frame for a capital cost of US$683 per ring frame. The cause of the difference between energy saving of these two case-studies could be the difference between the size of the ring frames in each plant (number of spindles in each ring frame) (EMT, 2008c).

7. Optimization of ring diameter with respect to yarn count in ring frames

Ring diameter significantly influences the energy use of the ring frame. Larger ring diameters facilitate higher bobbin content with a heavier package, resulting in excess energy consumption. A reduction of about 10% in bobbin content lowers ring frame energy intensity by about 10%. For finer yarn counts, 38 millimeter (mm)/ 36mm diameter and for medium yarn counts, 40mm ring diameters are recommended. The cost of implementation is about US$1600 for a long length ring frame of 1008 spindles and the payback period is about 2 years. Before ring diameter modification is undertaken the technical feasibility of the modification should be assesses, which may include the following items as given in Chandran and Muthukumaraswamy(2002):

- "The yarn count range for a specific period is unpredictable. The solution to this issue is that, based on the count ranges, the ring frames should be segregated by suitable ring diameter in the way that each group of ring frames produce specific yarn count.
- The life span of existing rings is also unpredictable due to high-speed operation.
- Overall efficiency is reduced in the post spinning phase (e.g. cone winding) due to lower bobbin content. However, the reduction in efficiency in the post spinning phase can be compensated by running the machines at a higher speed."

8. False ceiling over the ring frames areas

The spinning process needs to be done under a maintained temperature and humidity. This is done in a humidification area within plants. The energy used by the humidification facility is directly related to the volume of the facility where the spinning process is carried out. The use of a false ceiling can help to reduce this volume, thereby reducing energy consumption. In a spinning plant in India, the volume of a spinning hall with 15000 spindles reduced energy use through the installation of a false ceiling under the hall's roof. This measure resulted in

125MWh/year electricity savings (8 kWh/spindle/ year). The capital cost for this renovation was about US$11000 (US$0.7/spindle) (EMT, 2008d).

9. Installation of energy-efficient motors in ring frames

As mentioned above, ring frames are the most energy intensive equipment in the spinning process. Hence, it is important to make sure that the electric motors installed in the ring frames have the highest possible efficiency. Even a slight efficiency improvement in ring frame motors could result in significant electricity savings that could pay back the initial investment in a short period. In a spinning plant in India, motors were replaced with energy-efficient ones in four ring frames. The efficiency of the efficient motors was 94.6%, an improvement over the efficiency of the original motors (92.5%). This resulted in significant energy savings as well as an improvement in the power factor. The average annual energy saving was 6.3 MWh per motor replaced and the investment cost was around US$1950 per motor (EMT, 2008b).

Another Indian plant replaced old and inefficient ring frame motors with energy-efficient ones, resulting in higher average energy savings equal to 18.83 MWh/year/motor with higher investment cost of about US$2200 per motor. The difference between the two case-studies could be due to differences in the number of operation hours per year for each plant and the efficiency of the motors. For instance, we have information about the base case efficiency for the first case-study mentioned above, but we do not have the same information for the second case-study. It could be expected that the difference between the energy use of the base case and high efficiency motors in the second case-study is larger, so the energy savings there was higher (EMT, 2008E).

10. Installation of energy-efficient excel fans in place of conventional aluminum fans in the suction system of ring frames

Ring frames have suction fans, which are used to collect fibers when a yarn break occurs. Energy-efficient excel fans could be installed in place of conventional aluminum fans in the suction system of ring frames. The average electricity savings from the implementation of this measure is reported to be between 5.8 and 40 MWh/year/fan with a capital cost of about US$195 – 310 per fan (EMT, 2008B; EMT, 2007a)

11. The use of light weight bobbins in ring frames

In ring frames, yarn is collected on bobbins. Bobbins are rotated by spindles upon which they sit. The rotating of spindles is the highest energy consumption activity in ring machines. The heavier the bobbins are, the more energy is required for the rotation of bobbins and hence spindles. Nowadays, the use of lighter bobbins in place of conventional ones is getting more attention. In a spinning plant in India, the replacement of 30 – 35 gram bobbins (cops) with 28 gram bobbins resulted in average electricity savings of 10.8 MWh/year/ring frame (assuming 12 doff[8] a day). The capital cost for this retrofit measure was US$660 per ring frame (EMT, 2008C).

12. High-speed ring spinning machine

This machine has an increased operating speed by 10 – 20% with similar power consumption as compared to conventional equipment. As a result, the power requirement is 36.0 – 40.5kW in comparison with that of 45kW for conventional ring spinning machines for the same production

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[8] Each time that the bobbins on the ring frame are full and are replaced with the new empty bobbins is called one doff.

capacity. Furthermore, this equipment adopts an energy saving spindle that uses a small diameter warp, which contributes a power savings of approximately 6% (NEDO, 2008).

13. Installation of a soft-starter on ring frame motor drives

The starting current drawn by an induction motor is directly proportional to the applied voltage. A soft-starter is designed to make it possible to choose the lowest voltage possible (the "pedestal voltage") at which the motor can be started – the lowest voltage being dependent on the load on the motor. The voltage is ramped up from this pedestal level to full voltage within a preset time. Pedestal voltage and ramp-up time can be set at the site. It is also possible to provide controlled-torque soft-starts with current limit options. The soft-starter is also suited to situations where a smooth start is desirable to avoid shocks to the drive system or where a gradual start is required to avoid damage to the product/process/drive system and accessories.

In spinning plants, a soft-starter can reduce the costs incurred by yarn breaks on a ring frame when its motor starts after each doff, as smooth starts and gradual acceleration of motors eliminate shocks during starting. Average electricity savings reported from the implementation of this measure on ring frames is about 1 – 5.2 MWh/year per ring frame (Vijay Energy, 2009). The payback period of this measure is about 2 years (CADDET, 1993). In addition to the electricity savings, the other advantages of this measure are a reduction in the maximum power demand and an improvement in the power factor.

5.2.3. Windings, doubling, and yarn finishing process

14. Installation of variable frequency drives on Autoconer machines

Autoconer is the name of the machine which usually is used subsequent to ring frames in the yarn spinning process. The small bobbins of yarn are rewound onto larger cones by this machine. The installation of variable frequency drives (VFD) on an Autoconer's main motor can help maintain a constant vacuum and save energy. The adoption of this measure in an Indian spinning plant resulted in electricity savings of 331.2 MWh/year (however, the number of Autoconers in which this measure was applied is not given). The investment cost associated with this measure was about US$19,500 (EMT, 2008F).

15. Intermittent modes of the movement of empty bobbin conveyors in Autoconer/cone winding machines

The continuous movement of empty bobbin conveyor belts can be converted into an intermittent mode of movement. This measure results in not only substantial energy saving but also results in maintenance cost savings and waste reduction. In a spinning plant in India, they converted the continuous conveyor system to an intermittent mode whereby the belts are running for 6 minutes only and stopping for 54 minutes in an hour. This resulted in electricity savings of 49.4 MWh/year (the number of Autoconers to which this measure was applied is not reported). The investment cost associated with this measure was about US$1100 (EMT, 2008F).

16. Using a modified outer pot for two-for-one (TFO) machines

The process of twisting and doubling is an indispensable means of improving certain yarn properties and satisfying textile requirements that cannot be fulfilled by single yarns. The method of twisting two or more single yarns is called doubling, folding or ply twisting. Such yarns are designated as doubled yarn, folded yarn or plied yarn and the machines which conduct this work are called doublers, ply-twisters or two-for-one (TFO) twisters. Traditionally, ring doublers were used for ply twisting spun yarns and uptwisters were used for twisting filament yarns. Nowadays, TFO twisters are gaining world-wide acceptance in both the spun yarn and filament yarn sectors mainly because of their inherent advantages like the production of long lengths of knot-free yarns, which facilitates better performance in the subsequent processes and results in higher productivity (Shanmuganandam, 1997).

In two-for-one twisting machines, the balloon tension of yarn accounts for about 50% of total energy consumption. The balloon diameter can be reduced with a reduction in yarn tension by providing a modified outer pot. This measure saves about 4% of total energy consumption in TFOs. Research shows that there is no deterioration in yarn quality (Chandran and Muthukumaraswamy, 2002).

17. Optimization of balloon settings in TFO machines

It has been observed above that that TFOs consume less electricity at lower balloon settings. Balloon size can be optimized by taking account of various studies with respect to different yarn counts. An Indian textile plant saved about 250MWh/year by optimizing the balloon setting of its TFO machines without any investment required (the number of TFO machine in which this measure was applied is not reported) (EMT, 2007a).

18. Replacing electrical heating systems with steam heating systems for yarn polishing machines

After applying a liquid polishing material on yarns, the yarn becomes wet and needs drying. In some plants yarn polishing machines use electrical heaters. These electrical heaters can be replaced by steam heaters which can reduce overall energy use. A textile plant in India implemented this measure for two polishing machines. Steam consumption increased by about 31.7 tonnes steam/year for each machine, while electricity use declined in average by about 19.5 MWh/year/machine. The investment cost for this retrofit measure is reported to be about US$980 for each machine (with a payback period of about half a year) (EMT, 2008g).

5.2.4. Air conditioning and humidification system

19. Replacement of nozzles with energy-efficient mist nozzles in yarn conditioning rooms

In some textile plants the yarn cones are put in a yarn conditioning room in which yarn is kept under a maintained temperature and humidity. In such rooms, usually water is sprayed in to the air to provide the required moisture for the yarn to improve its strength, the softness and quality of the yarn and to increase its weigh. The type of nozzles used for spraying the water can effectively influence the electricity use of the yarn conditioning system. In a case-study in India, the jet nozzles were replaced with energy-efficient mist nozzles in a yarn conditioning room, resulting in 31MWh/year electricity savings. The cost of this replacement was about US$1700 (EMT, 2008e).

20. Installation of variable frequency drives (VFD) for washer pump motors in humidification plants

In humidification plants, an inverter can be installed on washer pump motors with auto speed regulation, which can be adjusted to meet the required humidity levels**.** Usually the pumps runs at 100% speed and humidity is controlled by by-passes, resulting in wasted energy**.** With VFDs, pump motor speed can be adjusted according to the requirements of the humidification plant. This could result in electricity saving a high as 20 MWh/year with an investment cost of about US$1100 (EMT, 2007a). The standard relative humidity (RH) in the different process steps of spinning and weaving plants are presented in table 6. These numbers are averages from Japanese textile plants.

Table 6. Standard Relative Humidity (RH) in Different Process Steps (Averages in Japanese Plants) (ECCJ, 2007a)

Process step	Cotton (%)	Worsted (%)	Synthetic Fibers (%)
Blending and Scutching	45 - 60	-	-
Carding	45 – 55	65 – 70	55 – 65
Combing	55 – 65	60 – 70	55 – 65
Drawing	50 - 60	50 – 60	55 – 65
Pre-spinning (Roving)	50 - 60	50 – 60	55 – 65
Spinning	50 – 65 [a]	50 – 55	60 – 65
Winding	60 - 70	50 – 60	60 - 70
Twisting	60 - 70	50 – 60	
Wrapping	60 - 70	50 – 60	
Weaving	70 - 85	50 – 60	

[a] Temperature: 24 – 29 degree Celsius

21. Replacement of existing aluminum alloy fan impellers with high efficiency FRP (fiberglass reinforced plastic) impellers in humidification fans and cooling tower fans of spinning mills

Axial fans are widely used for providing required airflow in sections of textile industry plants. These sections include cooling towers and air-conditioning, ventilation, and humidification systems. Optimal aerodynamic design of FRP (fiberglass reinforced plastic) fan impellers provides higher efficiencies for any specific application. A reduction in the overall weight of fans also extends the life of mechanical drive systems. Fans with FRP impellers require lower drive motor ratings and light duty bearing systems. Fans with FRP impellers consume less electricity compared to fans with aluminum alloy impellers under the same working conditions. In a case-study, a spinning plant replaced the impellers of 17 fans in the humidification system and cooling towers with FRP impellers. This retrofit measure resulted in average savings of 55.5 MWh/year/fan. The average investment cost of the replacement of impellers for each fan was about US$650 (EMT, 2004a).

22. Installation of VFD on humidification system fan motors for flow control [9]

Temperature and humidity levels must be closely monitored and maintained for textile processes (especially spinning and weaving) so that yarns will run smoothly through the processing machines; a well functioning ventilation system is imperative to the plant's successful operation. Ventilation systems use supply fans (SFs) and return fans (RFs) to circulate high humidity air to

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[9] This section is excerpted from US DOE (2005), unless different source is given.

maintain proper ambient conditions, cool process machinery, and control suspended particulate and airborne fibers. Initially, the mixture of return air and fresh air is cleaned, cooled, and humidified by four air washers. This air is then supplied to the facility by the SFs and distributed to the plant through ceiling mounted ducts and diffusers, producing required temperatures and relative humidity levels. The RFs then pull air through the processing machines into a network of underground tunnels that filter out suspended particles and fibers, usually through rotary drum filters on the inlet of each RF.

While the psychometric qualities and volumes of air supplied and returned from each area remain relatively constant in the system, seasonal variations occasionally cause minor changes in ventilation rates. In addition, different products result in changing heat loads in the plant due to a varying number of running motors and/or loads on the motor. Factors that influence the pressure, volume, or resistance of the system directly impact the fan energy requirements. Therefore, air density, changes to damper positions, system pressure and air filter pressure drops, supply and return air system interaction, and parallel fan operation all affect how much energy the fans require and must be monitored to ensure the efficient functioning of the system. Variable inlet guide vanes (VIVs) and outlet dampers usually initially control the system's air flow, and these are highly inefficient. Setting these devices is imprecise, resetting the openings can be done manually or automatically, and the VIVs and dampers can experience corrosion problems due to the high humidity in the air.

VFDs can be installed on flow controls; these devices control fan speed instead of changing the dampers' position. Thus, damper control is no longer necessary, so in the use of VFDs fan control dampers are opened 100 percent, thereby save electricity use by the fans. The average electricity saving reported for this retrofit in a plant in the U.S. is 105 MWh/year/fan with the cost of US$8660 (US DOE, 2005), whereas an Indian textile plant has reported the average energy saving of 18 MWh/year/fan with the cost of US$1900. The saving and cost of the measure depend on various factors such as the size of the fan, the operating conditions, the climate, the type of VFD used, etc. (EMT, 2004a).

23. Installation of VFD on humidification system pumps

Pumps of humidification systems in spinning plants are usually running at full strength and throttling valves are used for controlling relative humidity. In place of throttling valves, variable frequency drives can be installed for controlling relative humidity, and thereby the speed of the pumps can be reduced. This retrofit measure resulted in electricity savings equal to 35 MWh/year in a worsted spinning plant in India. The investment cost was about US$7100. (The number of VFDs installed is not reported.) (EMT, 2004a)

24. Energy-efficient control systems for humidification systems

On average, the humidification plants in textile plants consume about 15% to 25% of the total energy of the plant. Energy-efficient control systems have been developed for humidification plants in textile plants. The control system consists of variable speed drives for supply air fans, exhaust air fans and pumps in addition to control actuators for fresh air, recirculation and exhaust dampers. Energy savings in the range of 25% to 60% is possible by incorporating such control systems in the plants depending on the outside climate. These measures can be easily retrofitted in the existing humidification plants (both in automatic and manually-operated humidification plants) and the entire system can be controlled through a central computer. The investment cost for one such control system provided by SITRA will vary from US$7300 to US$12,200 per humidification plant, depending on the size of the humidification system and other factors. The estimated energy saving by implementing this control system is about 50 MWh/year (Prakasam, 2006; ITJ, 2008).

5.2.5. General energy-efficiency measures in spinning plants

25. Energy conservation measures in overhead traveling cleaner (OHTC)[10]

Textile plants, especially spinning and weaving plants, usually need to effectively manage the waste (fluff) generated during fiber processing, which affects the quality of the outgoing yarn/fabric. It is imperative for textile plants to have control over waste removal out of the processing area to ensure best yarn and fabric quality. Fluff removal and machine cleaning can be accomplished with the support of overhead traveling cleaners (OHTC), which use an ancillary drive associated with spinning and weaving sections of textile plants. A common waste collection system (WCS) is an independent sub-system designated to collect waste from groups of OHTC(s).

In modern mills, one overhead traveling cleaner serves every 1008/1200-spindle ring spinning frame. It moves on rails at a speed of about 16 meters per minute. It takes about 140 seconds to move from one end of the ring frame to the other end. OHTC is continuously blowing/sucking off air and waste in and around different component parts of the machine during its traverse motion. In general, one overhead travelling cleaner consumes about 17,000 kWh per year. Some technology providers have developed different innovative methods of energy savings in overhead cleaners. Some these methods are described below (Expresstextile, 2005).

a. Timer-based control system for overhead traveling cleaners (OHTC)

An energy-efficient control system using timer circuits can be introduced in addition to a main contactor provided in the control box to start and stop the OHTC whenever it touches the ends of the ring frame over which it moves in a linear path. An off timer can be incorporated, with a feature of extending the delay of operation for 0 to 30 minutes in a stepped manner. The case-study showed that the operating time can be reduced by about 33%; hence energy consumption can be reduced by 33% when compared with base conditions. This method can be adopted for plants processing fine counts in which dust liberation is less. This system is not suited for plants processing coarser counts, as fly liberation will be greater. The average electricity savings reported from a case-study were 5.8 MWh/year per OHTC. The investment cost was about US$180 per OHTC unit (Expresstextile, 2005).

b. Optical control system for overhead traveling cleaners (OHTC)

An optical sensor to sense the position of the OHTCs on the ring frames can also be used. This system will start running the blower fan of the WCS only during the required operation time. In a case-study, it is reported that the energy consumption was reduced by 41% when compared with base conditions. This can be translated to average electricity savings equal to 5.3 MWh/year per

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[10] This section is excerpted from Expresstextile (2005).

OHTC. The investment required for this retrofit measure was US$980 per unit (Expresstextile, 2005).

26. Energy-efficient blower fans for overhead traveling cleaners (OHTC)

Existing blower fans of OHTCs can be replaced by energy-efficient fans with smaller diameters and less weight. An energy savings of about 20% is achievable with a quick payback period of less than 6 months. A case-study implementing this measure reported average electricity savings of 2 MWh/year for each fan. The investment cost of the retrofit was about US$100 per fan (Expresstextile, 2005).

27. Improving the power factor of the plant (reduction of reactive power)

There are many electric motors in a spinning plant that can cause reactive power. Therefore, reducing reactive power by improving the power factor of the plant is an important measure in reducing energy use and costs. For example, an Indian spinning plant replaced low value capacitors and added new capacitors where required. In this process system losses were reduced. The reported electricity saving is 24.1 MWh/year. The investment cost is reported to be around US$3300 (EMT, 2008c).

28. Replacement of ordinary ‘V – belts’ with cogged ‘V – belts’ at various machines

In textile plants, many motors are connected to the rotating device with pulleys and belts. In many cases, a V-belt is used to transfer the motion. Ordinary V-belts can be replaced with cogged v-belts to reduce friction losses, thereby saving energy. The implementation of such modification on 20 V-belt drives in a spinning plant in India resulted in electricity savings equal to 30 MWh/year. The capital cost of this modification was US$244 (EMT, 2008c).

5.3. Energy-efficiency technologies and measures in the weaving process

Table 7. shows the list of measures/technologies included in this guidebook for the weaving process.

Table 7. List of Energy-efficiency Measures and Technologies for the Weaving Process

No.	Energy-efficiency Technologies and Measures	Fuel saving	Electricity saving	Capital Cost
5.2	**Weaving**			
29	Evaluation and enhancement of the energy efficiency of compressed air system in the Air-jet weaving plant		US$440,000 /year (for 500 air jet looms)	
30	General measures to save energy in weaving plants			

29. Evaluation and enhancement of the energy efficiency of compressed air systems in air-jet weaving plants

Air-jet weaving machines use compressed air for weft yarn insertion. The conversion efficiency to produce compressed air is fairly low (less than 15% efficiency without heat recovery). Most textile companies rely on compressed air in their production, and improving the use of compressed air will have significant economic benefit for plants.

For example, in a case-study conducted by Georgia Technical Institute, it was found that by reducing air leakage from 12% to 6% and lowering system air pressure by 16 psi, a saving of about US$440,000 annually is expected for a compressed air system operating 500 looms (weaving machines). They found that loom performance was not significantly affected by air pressure until the pressure drops below a certain level, beyond which a drastic increase in filling stops was observed. In their study, unacceptable weaving performance only occurred when the pressure in the flowmeter was lower than 64 psi, and this represents the minimum pressure required for the experimental loom, a level considerably lower than the manufacturer's suggested pressure of 80 psi (Wang, 2001).

30. General measures to save energy in weaving plants

Weaving machines (looms) account for about 50-60% of total energy consumption in a weaving plant. Humidification, compressor and lighting accounts for the rest of the energy used, depending on the types of the looms and wet insertion techniques (Sivaramakrishnan et al., 2009). Since a loom is just one machine, there are not many physical retrofits that can be done on existing looms to improve their efficiency. Of course the looms differ in their energy intensity (energy use per unit of product). However, for a given type of the loom, most of the opportunities for energy-efficiency improvements are related to the way the loom is used (productivity), the auxiliary utility (humidification, compressed air system, lighting, etc), and the maintenance of the looms.

All the measures mentioned in the previous sections which improve the efficiency of humidification and compressed air systems used in spinning processes are also to a great extent applicable to weaving plants. In addition to these, the below measures for efficiency improvements of the weaving process are also available opportunities:

- Loom utilization should be more than 90%. A 10% drop in utilization of loom machines will increase specific energy consumption by 3-4% (Sivaramakrishnan et al., 2009).
- The electric motor of the loom can be replaced by an energy-efficient motor.
- The type of weaving machine can significantly influence the energy use per unit of product. Therefore, when buying new looms, the energy efficiency of the loom should be kept in mind. However, it should be noted that some looms can only produce fabrics with certain specifications and not all looms can produce all types of fabrics. Hence, we cannot give a general suggestion for the type of the loom that should be used; rather, analysis should be done for each specific condition.
- The quality of warp and weft yarn directly influences the productivity and hence efficiency of the weaving process. Therefore, using yarns with higher quality that may have a higher cost will result in less yarn breakage and stoppage in the weaving process and can eventually be more cost-effective than using cheap, low quality yarns in weaving.

5.4. Energy-efficiency technologies and measures in wet-processing

Table 4 in Section 4.2.2 of this guidebook showed a snapshot of the average values for thermal energy use in dyeing plants in Japan. That table gives a good idea of the proportion of thermal energy use and losses for each purpose in a dyeing plant, clearly indicating where the greatest energy-efficiency potential lies. Additionally, the table gives useful information about where losses are most significant and therefore which losses should be addressed first. We have again presented the table below (Table 8) along with the general ways of reducing the losses mentioned in the table.

Table 8. Thermal Energy Use in Dyeing Plants (Average of Japan) (ECCJ, 2007a)

Item	Share of total thermal energy use	Way to reduce losses [a]
Product heating	16.6%	
Product drying	17.2%	Avoid over-drying
Losses through waste liquor	24.9%	Recovery of waste heat
Heat released from equipment	12.3%	Improved insulation
Exhaust losses	9.3%	Reduction of exhaust gas
Equipment idling losses	3.7%	Stop energy during idling
Evaporation from liquid surface	4.7%	Install a cover
Un-recovered condensate	4.1%	Condensate recovery
Loss during condensate recovery	0.6%	
Others	6.6%	
Total	100%	

[a]: Here in this table we have just given a general example of methods of reducing thermal energy losses. More detail of these methods is given below for different process steps.

Table 9 shows the list of measures/technologies included in this guidebook for the wet-processing.

Table 9. List of Energy-efficiency Measures and Technologies for the Wet-Processing[11] *

No.	Energy-efficiency Technologies and Measures	Fuel saving	Electricity saving	Capital Cost	Payback Period (Year)***
5.3	**Wet-Processing**				
5.3.1	**Preparatory Process**				
31	Combine Preparatory Treatments in wet processing	up to 80% of Preparatory Treatments energy use			
32	Cold-Pad-Batch pretreatment	up to 38% of pretreatment fuel use	up to 50% of pretreatment electricity use		
33	Bleach bath recovery system **	US$38,500 - US$118,400 saving	80000 -246,000	2.1	
34	Use of Counter-flow Current for washing	41% - 62% of washing energy use			
35	Installing Covers on Nips and Tanks in continuous washing machine				
36	Installing automatic valves in continuous washing machine				< 0.5
37	Installing heat recovery equipment in continuous washing machine	5 GJ/tonne fabric			
38	Reduce live steam pressure in continuous washing machine				
39	Introducing Point-of-Use water heating in continuous washing machine	up to 50% of washing energy use			
40	Interlocking the running of exhaust hood fans with water tray movement in the yarn mercerizing machine		12.3 MWh/year/machine		< 0.5
41	Energy saving in cooling blower motor by interlocking it with fabric gas singeing machine's main motor		2.43 MWh/year/machine		< 0.5
42	Energy saving in shearing machine's blower motor by interlocking it with the main motor		2.43 MWh/year/machine		< 0.5
43	Enzymatic removal of residual hydrogen peroxide after bleach	2,780 GJ/year/plant			
44	Enzymatic scouring				
45	Use of integrated dirt removal/grease recovery loops in wool scouring plant	2 MJ/kg of greasy wool		615,000 - 1,230,000/system	2 - 4
5.3.2	**Dyeing and Printing Process**				
46	Installation of Variable Frequency Drive on pump motor of Top dyeing machines		26.9 MWh/year/machine	3100 /machine	1.5
47	Heat Insulation of high temperature/ high pressure dyeing machines	210 - 280 GJ/year/plant		9000 - 13,000 /plant	3.8 - 4.9
48	Automated preparation and dispensing of chemicals in dyeing plants			Chemical Dispensing System: 150,000 - 890,000 ; Dye Dissolving and Distribution: 100,000 - 400,000; Bulk Powder Dissolution and Distribution:76,000 - 600,000	1.3 - 6.2 ; 4 - 5.7 ; 3.8 - 7.5
49	Automated dyestuff preparation in fabric printing plants			23,100 - 2,308,000/system	
50	Automatic dye machine controllers **			57,000 - 150,000/system	1 - 5
51	Cooling water recovery in batch dyeing machines (Jet, Beam, Package, Hank, Jig and Winches)	1.6 - 2.1 GJ/tonne fabric		143,000 - 212,000/system	1.3 - 3.6
52	Cold-Pad-Batch dyeing system	16.3 GJ/tonne of dyed fabric		1215000/ system	1.4 - 3.7

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[11] Typical Energy Requirements for Textile Wet- Processes, by Product Form, Machine Type and Process are given in Table 3.

No.	Energy-efficiency Technologies and Measures	Fuel saving	Electricity saving	Capital Cost	Payback Period (Year)***
53	Discontinuous dyeing with airflow dyeing machine	up to 60% of machine's fuel use		190500 - 362,000/machine	
54	Installation of VFD on circulation pumps and color tank stirrers		138 MWh/year/plant	2300/plant	< 1
55	Dyebath Reuse	US$4500 saving/ dye machine		24,000 - 34,000/dye machine	
56	Equipment optimization in winch beck dyeing machine		30% of machine's electricity use		
57	Equipment optimization in jet dyeing machines	1.8 - 2.4 kg steam /kg fabric	increased 0.07 - 0.12 kWh/kg fabric	221,000 /machine	1.4 - 3.1
58	Single-rope flow dyeing machines	2.5 kg steam /kg fabric	0.16 - 0.20 kWh/kg fabric		< 1
59	Microwave dyeing equipment	96% reduction compared to beam dyeing	90% reduction compared to beam dyeing	450000/ machine	
60	Reducing the process temperature in wet batch pressure-dyeing machines				
61	Use of steam coil instead of direct steam heating in batch dyeing machines (Winch and Jigger)	4580 GJ/year/plant		165500/plant	
62	Reducing the process time in wet batch pressure-dyeing machines				
63	Installation of covers or hoods in atmospheric wet batch machines				
64	Careful control of temperature in atmospheric wet batch machines	27 - 91 kg steam/hour			
65	Jiggers with a variable liquor ratio	26% reduction compared to conventional jigger			
66	Heat recovery of hot waste water in Autoclave	554 MJ/batch product			
67	Insulation of un-insulated surface of Autoclave	15 MJ/batch product			
68	Reducing the need for re-processing in dyeing	10% -12%			
69	Recover heat from hot rinse water	1.4 - 7.5 GJ/tonne fabric rinsed		44,000 - 95,000	< 0.5
70	Reuse of washing and rinsing water				
71	Reduce rinse water temperature	10%		0	
5.3.3	**Drying**				
	Energy-efficiency improvement in Cylinder dryer				
72	Introduce Mechanical Pre-drying				
73	Selection of Hybrid Systems	25% - 40%			
74	Recover Condensate and Flash Steam				
75	End Panel Insulation				
76	Select Processes for their Low Water Add-on Characteristics				
77	Avoid Intermediate Drying				
78	Avoid Overdrying				
79	Reduce Idling Times and Use Multiple Fabric Drying				
80	Operate Cylinders at Higher Steam Pressures				
81	Maintenance of the dryer				
82	The use of radio frequency dryer for drying acrylic yarn	US$45,000 saving/plant		200000/plant	
83	The use of Low Pressure Microwave drying machine for bobbin drying instead of dry-steam heater		107 kWh/tonne yarn	500000/plant	< 3
84	High-frequency reduced-pressure dryer for bobbin drying after dyeing process		200 kWh/tonne product	500000/machine	

No.	Energy-efficiency Technologies and Measures	Fuel saving	Electricity saving	Capital Cost	Payback Period (Year)***
5.3.4	**Finishing Process**				
	Energy-efficiency improvement in Stenters				
85	Conversion of Thermic Fluid heating system to Direct Gas Firing system in Stenters and dryers	11000 GJ/year/plant	120 MWh/year/plant	50000/plant	1
86	Introduce Mechanical De-watering or Contact Drying Before Stenter	13% - 50% of stenter energy use			
87	Avoid Overdrying				
88	Close Exhaust Streams during Idling				
89	Drying at Higher Temperatures				
90	Close and Seal Side Panels				
91	Proper Insulation	20% of stenter energy use			
92	Optimize Exhaust Humidity	20 - 80% of stenter energy use			
93	Install Heat Recovery Equipment	30% of stenter energy use		77,000 - 460,000/system	1.5-6.6
94	Efficient burner technology in Direct Gas Fired systems				
95	The Use of Sensors and Control Systems in Stenter	22% of stenter fuel use	11% of stenter electricity use	moisture humidity controllers: 20,000 – 220,000 ; dwell time controls: 80,000 – 400,000	moisture humidity controllers: 1.5 - 5 ; dwell time controls: 4 - 6.7
5.3.5	**General energy-efficiency measures for wet-processing**				
96	Automatic steam control valves in Desizing, Dyeing, and Finishing	3250 GJ/year/plant		5100/plant	
97	The recovery of condensate in wet processing plants	1.3 - 2 GJ/tonne fabric		1000 - 16,000	1 - 6
98	Heat recovery from the air compressors for use in drying woven nylon nets	7560 GJ/year/plant		8500/year/plant	
99	Utilization of heat exchanger for heat recovery from wet-processes wastewater	1.1 – 1.4 GJ/tonne finished fabric		328820 / system	

* The energy savings, costs, and payback periods given in the table are for the specific conditions. There are also some ancillary (non-energy) benefits from the implementation of some measures. Please read the explanation of each measure to get the complete understanding of the savings and costs.

** Savings of this measure is the net annual operating savings (average per plant) which includes energy and non-energy savings.

***Wherever the payback period was not given while the energy and cost are given, the payback period is calculated assuming the price of electricity of US$75/MWh (US$0.075/kWh).

5.4.1. Preparatory process

31. Combine preparatory treatments in wet processing

Combining preparatory treatments such as the combined de-sizing, scouring and bleaching of a cotton fabric could lead to a process step reduction from the original eight-stage process to just two stages; this method would employ a steam purge and cold-pad-batch technique. The elimination of three intermediate washings, one hot kier and a cold acid process could reduce energy requirements by as much as 80% (Carbon Trust, 1997).

32. Cold-pad-batch pretreatment

The cold-pad-batch method can be used for pretreatment in dyeing and finishing plants. In this method, alkali/hydrogen peroxide is embedded into the fabric using a padder, and the fabric is then stored to allow complete reaction between the fabric and chemicals prior to rinse. As much as 50% of the water and electricity, and 38% of the steam used in pretreatment can be reduced with this method. However, cold-pad-batch technology is limited to woven cotton fabrics (Greer et al., 2010).

33. Bleach bath recovery system[12]

Since large amounts of water is used in wet-processing operations, recycling and reuse of rinse water can greatly reduce hydraulic loadings in wastewater treatment systems, while at the same time creating savings through reduced water use, energy consumption and wastewater disposal. There are two ways to reuse spent rinse and wash water. This water can be reused in another rinse operation which accepts low-grade rinse water, or it can be reused as process water in wet-processing operations with or without the addition of chemicals. Examples include:

- the reuse of wash water from bleaching in caustic washing and scouring make-up and rinse water;
- the reuse of rinse water from scouring for desizing or washing printing equipment;
- the reuse of wash water from mercerizing to prepare scouring, bleaching, and wetting-out baths.

In these cases, preparation chemicals, especially optical brighteners and tints, must be selected in such a way that reuse does not create quality problems such as spotting. Storage tanks may be necessary to store process liquor for reuse in the makeup of the next bath.

The bleach bath recovery system can be utilized in both the knit and woven segments, and can result in a reuse of 50% of the total water used in a typical 100% cotton full bleach process, including pre-scour, bleach and neutralization. Savings also arise from reduced energy consumption and wastewater disposal charges. The average temperature of the recovered water is estimated to be 40°C. The value of the energy saved has been estimated at US$51,000 per year for a medium size plant[13].

For example, the warm rinse water in a kier can be used for the next scour liquor, resulting in energy savings of more than 10% (Carbon Trust, 1997). A dyeing and finishing company in the

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[12] This section is excerpted from Marbek Resource Consultants (2001), unless different source is given.

[13] Assuming the average temperature for fresh water of 13°C.

U.K. reduced its water consumption by 50% by using the spent rinse water from the bleaching process in the scouring wash, and saved about US$16,900/year in effluent disposal and water costs (Marbek Resource Consultants, 2001). Table 10 shows the capital cost and annual operating cost of bleach bath recovery systems for different plant sizes.

Table 10. The Capital Cost and Annual Operating Cost of Bleach Bath Recovery Systems (Marbek Resource Consultants, 2001)

Cost item	Plant Size		
	Small	Medium	Large
Capital cost (average per plant)	$80,000	$123,000	$246,000
Net annual operating savings (average per plant)	$38,500	$59,200	$118,400
Simple payback period (medium-size plant)	2.1 years		

Note: Costs and savings are associated with the amount of production for each plant size and not just for one machine.

34. Use of counter-flow currents for washing

In this system, as the fabric runs through the washing compartments from entry to exit, clean water is passed through the plant from the back to the front. This means that the cleanest fabric comes into contact with the cleanest washing liquor. By applying this counter-flow principle, it is possible to save both water and energy. This process was developed to reduce water consumption for washing and is composed of washing equipment, a washing and dehydration mechanism, filter equipment, sensors and pumps. Washing water is supplied from a direction in the reverse of fabric flow, and the sensor detects water impurity to adjust automatically the feed rate of the water (ECCJ, 2007a).

For example, during dyeing with the cold-pad-batch dyeing method, a padder with nip-controlled rollers is used to apply dyestuffs to the fabric in a defined manner. After a dwelling time (which varies depending on the dyestuff) the excess dyestuff needs to be washed out. Here, a distinction is made between the following processes:

- Rinsing out dyestuff from the fabric surface
- Soaping (the dyes are moved from the core of the fibers to the surface)
- Neutralization
- Washing out of the salts produced during neutralization

This process normally requires 20 liters of water and 1.6 kg of steam per kg of fabric. However, the counter-flow principle can be applied sequentially to each individual processes, resulting in water and energy savings. The water used to wash out the salts in the back compartment is directed around the soaping compartments and is then used again when the surface dyestuffs are rinsed out. As the level of soil is low in the back part of the washing process, this liquor can be used effectively to wash in the front part. In addition, less heating of the water is required for the soaping process, which saves energy in the form of steam. The consumption of resources in this counter-flow current process amounts to 9 liters of water and 0.95 kg of steam per kg of fabric. In addition, less energy is required in the downstream section for the drying process, as the temperature is already 40 ℃ higher than in conventional processes. For this specific example, water savings of 55% and steam savings of 41% have been achieved (Textiledigest, 2009).

ECCJ (2007a), however, has reported an even higher 50% steam saving and up to around 90% water saving by using counter-flow current technology. The saving depends on the process for which the counter-flow current washing is used. Carbon Trust (1997) has reported that a nine-tank continuous washer which had a counter-flow system retrofit installed in its seven heated tanks; this measure achieved 62% savings in both energy and water usage without any loss in washing performance. Figure 11 shows a schematic of counter-flow current washing process.

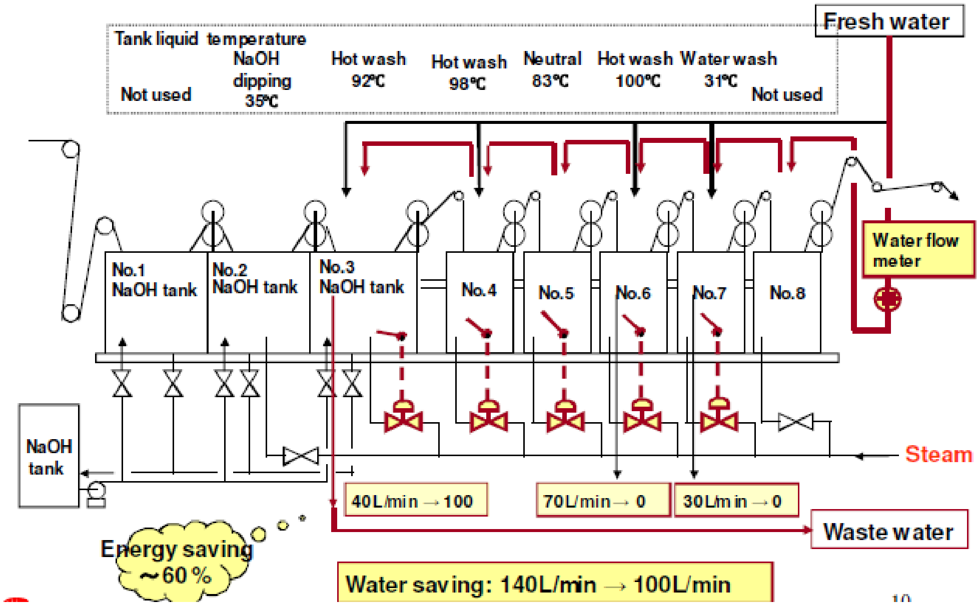

Figure 11. Schematic of counter-flow current washing process (ECCJ, 2007b)

Energy saving in continuous washing machines[14]

Continuous washing machines are generally used after preparatory processes such as scouring, bleaching and mercerizing, or after dyeing. A continuous washing machine (a “washing range”) is made up of a number of tanks, compartments or becks connected by tension compensators and nip rollers. The fabric is threaded, open width, around a series of rollers in each tank. The rollers help to increase liquor agitation and the transfer of impurities, to improve washing efficiency (Carbon Trust, 1997). Figure 12 shows the schematic of a continuous washing range. Table 11 shows the typical energy and water requirements for washing after a number of different processes. Table 12 shows the typical energy breakdown for a washing machine.

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[14] This section on energy efficiency measures in continuous washing machines is excerpted from Carbon Trust, 1997, unless different source is given.

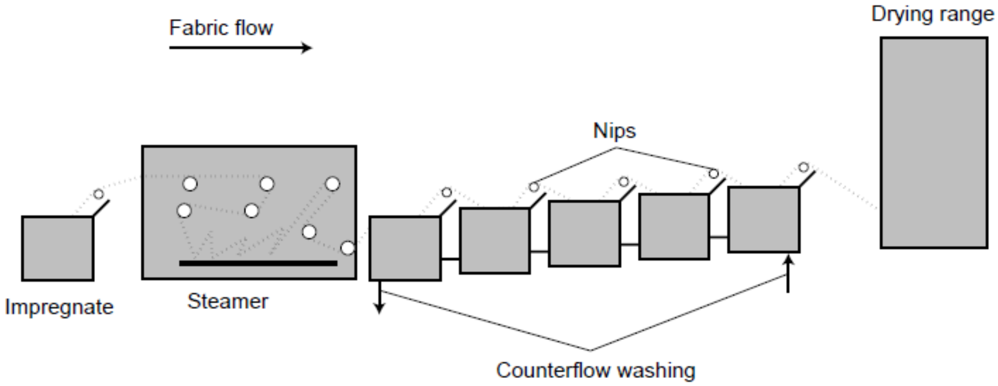

Figure 12. Schematic of a Continuous Washing Machine (Carbon Trust, 1997)

Table 11. The Typical Energy and Water Requirements for Washing After a Number of Different Processes (Carbon Trust, 1997)

Process after which the washing is done	Washing machine type	Typical specific energy consumption (GJ/ton)	Typical specific water consumption (m^3/ton)
Bleaching	5 hot standing tanks	7.5	10.4
Bleaching	4 tanks, fully counter flow, with heat exchanger	2.8	4.3
Scouring/bleaching	5 tanks, fully counter flow, with heat exchanger	3.0	5.5
Dyeing	4 tanks counter flow and 1 cold standing tank	6.6	8.2
Printing	4 hot counter flow and 3 cold individual flow	10.5	35.0
Printing	4 hot counter flow with heat exchanger and 3 cold individual flow	5.5	35.0

Table 12. Typical Energy Breakdown for a Continuous Washing Machine (Carbon Trust, 1997)

Component	Share of energy use from total energy use
Water heating	50%
Nip losses	36%
Radiation and convection losses	3%
Evaporation losses	11%
Total	100%

35. Installing covers on nips and tanks in continuous washing machines

Table 12 above shows that the losses at nips are considerable and even in some cases they can exceed 40% of total energy demand of washing machines. Hence, it is important to cover them as well as the hot tanks. Any fitted covers should be easily removable to allow quick access. This simple retrofit measure can result in significant energy savings (Carbon Trust, 1997).

36. Installing automatic valves in continuous washing machines

Automatic stop valves which link the main drive systems of machines to water flows can save considerable amounts of energy and water by shutting off water flow as soon as a stoppage occurs. A series of shorter stoppages typically accounts for up to 20% of machine working time. Often both the water flow and the heating are left on throughout these short interruptions, which in total will result in significant energy and water wastage. The payback period for installing automatic stop valves on continuous washing machines could be as low as one month (Carbon Trust, 1997).

37. Installing heat recovery equipment in continuous washing machines

Installing heat recovery equipment on a continuous washer is usually a simple but very effective measure since water inflow and effluent outflow are matched and this eliminates the need for holding tanks. The effluent from these machines can become contaminated with fibrous material, so it is important to install a heat exchanger capable of handling such loads. One option is a self-cleaning, rotating element exchanger which has an efficiency of about 70%. Another measure is to install a simple plate heat exchanger with a pre-filter, which may have a higher initial cost, but which also has an efficiency that could be higher than 90%.

Table 11 above illustrates the energy saving potential of a heat exchanger on a continuous washer. For example, for washing after printing without heat recovery, energy intensity is 10.5 GJ/tonne fabric processed; with a heat exchanger the energy intensity drops to 5.5 GJ/tonne fabric (Carbon Trust, 1997).

38. Reduce live steam pressure in continuous washing machines

A reduction in live steam pressure can prevent steam breakthroughs, thus improving heat transfer efficiency in direct steam heating applications. Similarly, reducing steam pressure in closed coils will have take advantage of the fact that lower pressure steam has higher latent heat content (Carbon Trust, 1997).

39. Introducing point-of-use water heating in continuous washing machines

Point-of-use gas-fired water heaters can be used to enable processes to be run independently of plant central boiler systems. This means that boiler and distribution losses associated with centralized systems (which can be as much as 50% of the fuel input) can be eliminated. Point-of-use heating also offers greater flexibility since it allows operation outside of main boiler operating hours. This measure, however, requires significant changes to the washing machine and may have a high capital cost (Carbon Trust, 1997).

40. Interlocking the running of exhaust hood fans with water tray movement in yarn mercerizing machines

In many plants, the exhaust hood fans fitted on the fume extractor hoods of yarn mercerizing machines remain on during the working time of the machine. However, the running of exhaust hood fans can be electrically interlocked with the forward movement of the water tray, as the fans have to remove the fumes generated during the washing phase only. The implementation of this measure will result in electricity savings in fan use. One case-study showed electricity savings of 12.3 MWh/year/machine. The investment cost for this measure is minimal (EMT, 2006a).

41. Energy saving in cooling blower motors by interlocking motors with the fabric gas singeing machine's main motor

It often happens in textile plants that for many machines, while a machine is stopped the auxiliary units are still running continuously, resulting in energy waste. One such case is the operation of fabric singeing machines. In many plants, the cooling blower is running continuously even after the singeing machine is stopped. The solution to this is to interlock the cooling blower motor with the singeing machine’s main motor, thereby saving energy. The implementation of this measure in a plant in India resulted in 2.43 MWh/year/machine electricity savings. The investment cost of this measure is zero or very small (EMT, 2005a).

42. Energy saving in shearing machine blower motors by interlocking motors with the main motor

Similar to the measure mentioned above for the fabric gas singeing machine, the interlocking of blower motors with the machine’s main motor can also be implemented in fabric shearing machines. Based on a case-study of the implementation of this measure in a textile plant in India, energy savings of 2.43 MWh/year/machine can be achieved. The investment cost of this measure is zero or very small (EMT, 2005a).

43. Enzymatic removal of residual hydrogen peroxide after bleaching

Raw cotton fabric requires bleaching, usually achieved with hydrogen peroxide. To achieve reproducible bleaching results, residual hydrogen peroxide content of 10-15% of the initial quantity should be still available at the end of bleaching. The residual hydrogen content must be completely removed to prevent any change of shade of dyestuffs, which are sensitive to oxidation. Reducing agents and several rinsing steps are necessary in common peroxide removal techniques. High energy and water consumption and the use of sulfurous reducing agents are main disadvantages of the conventional technique.

Special enzymes (peroxides) catalyze the reduction of hydrogen peroxide to oxygen and water. No side reactions with the substrate or with dyestuffs occur. Peroxides are completely biodegradable. Rinsing steps after peroxide bleaching can be reduced with enzymatic peroxide removal (normally only one rinsing step with hot water is necessary). Peroxides have no negative influence on downstream dyeing processes. A typical process include these steps: peroxide bleaching - liquor change - one rinsing bath (hot water) - liquor change - enzymatic peroxide removal - dyeing without previous liquor change.

Enzymatic peroxide removal is possible in a discontinuous, semi-continuous, and continuous production method. The method is applicable both in new and existing installations. Savings in water and energy consumption can be in the range of 6-8% of production costs (E-textile toolbox, 2005a). Barclay and Buckley (2000) reports that approximately US$15 to 30/tonne fabric can be saved, depending on the local cost of water and energy. The Skjern Tricotage-Farveri textile plant in Denmark implemented this measure and achieved 2,780 GJ/year in energy savings and 13500 kl/year in water savings.

44. Enzymatic scouring[15]

Desizing, scouring with strong alkali and bleaching are typical pre-treatment steps in cotton finishing plants. Scouring and bleaching steps are often combined. With the use of enzymes the alkaline scouring process can be replaced. Due to the better bleaching ability of enzyme, scoured textiles bleaching can be carried out with reduced amounts of bleaching chemicals and auxiliaries. With enzymatic scouring, sodium hydroxide used in common scouring is not necessary. In term of quality, the enzymatic scouring will achieve good reproducibility, reduced fiber damages, good dimensional stability of fabrics, increased color yield, and a soft fabric texture.

The rinsing water consumption for scouring can be reduced to 20% of traditional techniques. If the enzymatic scouring is combined with bleaching with reduced concentrations of peroxide alkali, the rinsing water consumption can be reduced to 50% of traditional techniques; hence saving energy. This method can be applied to cellulosic fibers and their blends (woven and knitted goods) in continuous and discontinuous processes. Existing machines (jets, overflows, winches, pad batches, pad steamers and pad rollers) can be used for this purpose. This method is applied world-wide, especially in German finishing plants. The method offers savings in water, time, chemical auxiliaries and energy, depending on on-site conditions (E-textile toolbox, 2005b).

45. Use of integrated dirt removal/grease recovery loops in wool scouring plants

Wool scouring is an energy-intensive process. In addition to generally applicable good housekeeping techniques, the biggest energy savings in the wool scouring process come from reducing effluent flowdown to drains or to onsite effluent treatment plants by the installation of a dirt/grease recovery loop. Techniques include fitting a heat exchanger to recover heat from the dirt/grease loop flowdown. The implementation of dirt removal/grease recovery loops allows:

- a reduction in water consumption ranging from 25% to more than 50% (the consumption of water of a conventional plant operating in counter-current is between 5 and 10 l/kg of greasy wool);
- energy savings from a dirt/grease recovery loop can be estimated at about 2 MJ/kg of greasy wool if a scour with loop and a heat exchanger is used;
- the production of wool grease which is a valuable by-product;
- a reduction in detergent consumption proportional to the water savings achieved; and
- a reduction of the load (oxygen-demanding substances and suspended solids) sent to the effluent treatment plant, which means a reduction in the consumption of energy and chemicals for the treatment of the waste water.

It is estimated that the installation of dirt removal/grease recovery loops at a plant processing 15,000 to 25,000 tonnes/year of greasy wool would cost between US$615,000 to US$1,230,000, depending on the specifications, the quality and the capacity of the particular system chosen. The payback time of the installation, ignoring the benefits of reduced effluent disposal costs, would be between 2 and 4 years. It should be noted that the cost information refers to the U.K. situation at the time of the study reported (European Commission, 2003).

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[15] This section is excerpted from E-textile toolbox (2005b).

5.4.2. Dyeing and printing process

46. Installation of variable frequency drives on pump motors of Top dyeing machines

Top dyeing is a method for dyeing combed wool before spinning. In this process, the wool "top" is placed in large vats and dye liquor is circulated through the tops at high temperatures. Variable frequency drives (VFDs)_ can be installed on the pump motor of the top dyeing machine in order to save energy by setting the speed of the pump motor based on the dyeing process requirements. A textile plant in India installed VFDs on the pump motors of 25 top dyeing machines. The average electricity saving resulting from this retrofit was about 26.9 MWh/year/machine. The investment cost is reported to be about US$3100 for each machine (EMT, 2008H).

47. Heat insulation of high temperature/high pressure (HT/HP) dyeing machines

Insulation of pipes, valves, tanks and machines is a general principle of good housekeeping practice that should be applied in all steam consuming processes in textile plants. It is reported that insulation can save up to 9 % of the total energy required in high temperature/high pressure wet-processing machines (Carbon Trust, 1997).

The insulation material may be exposed to water, chemicals and physical shock. Any insulation should, therefore, be covered or coated with a hard-wearing, chemical/water resistant outer layer. The fuel saving potential of such insulation in a plant is reported to be as high as 210 – 280 GJ/year with an investment cost of US$9000 – US$13,000 per plant (including both the cost of insulation materials and installation). The payback period is about 3.8 – 4.9 years (European Commission, 2003).

In another case-study in India, HT/HP package dyeing machines were used for dyeing the cotton/ polyester yarns. After putting yarn packages in the dyeing machine, the dyeing vessel was filled with soft water. Dyes and other chemicals were added and the liquor was heated to 130 °C. The dyeing vessels were not insulated at the beginning in this plant and there were huge heat losses from these machines. The steam required per kilogram of dyed yarn was 7.2 Kg. All the dyeing machines then were then insulated and as a result the steam required per kilogram of product was reduced to 7.05 kg steam (EMT, 2008G)

Saad El-Din (2004) also reports that reinforcement of the heat insulation of machines and steam systems in fabric wet-processing plants can result in fuel savings of about 4 GJ/tonne fabric and electricity savings of 6.3 kWh/tonne fabric processed. The investment cost associated with the savings is about US$5.2/tonne of fabric processed.

48. Automated preparation and dispensing of chemicals in dyeing plants[16]

Automated color kitchens and automated chemical dosing and dispensing systems are now commonly used in many companies in the textile industry, mostly in developed countries. Microprocessor-controlled dosing systems meter chemicals automatically according to a variety of profiles, such as constant rates or variable rates. In modern dosing and dispensing systems, the water used for washing the preparation vessel and supply pipes is taken into account when the quantity of liquor to be prepared is calculated. This approach reduces waste water, but still

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[16] This section is excerpted from European Commission (2003), unless different source is given.

involves the premixing of chemicals. Other automated dosing systems are available where the chemicals are not premixed before being introduced into the applicator or dyeing machine. In this second case, individual streams are used for each of the products. As a result, there is no need to clean the containers, pumps and pipes before the next step, saving even more chemicals, water, energy and time. This is an important feature in continuous processing lines.

Figure 13 shows an example of an automated systems for dispensing chemicals for the preparation of pretreatment and finishing liquors (without the premixing of chemicals). Similar devices can be used in semi-continuous (cold-pad-batch) and continuous dyeing.

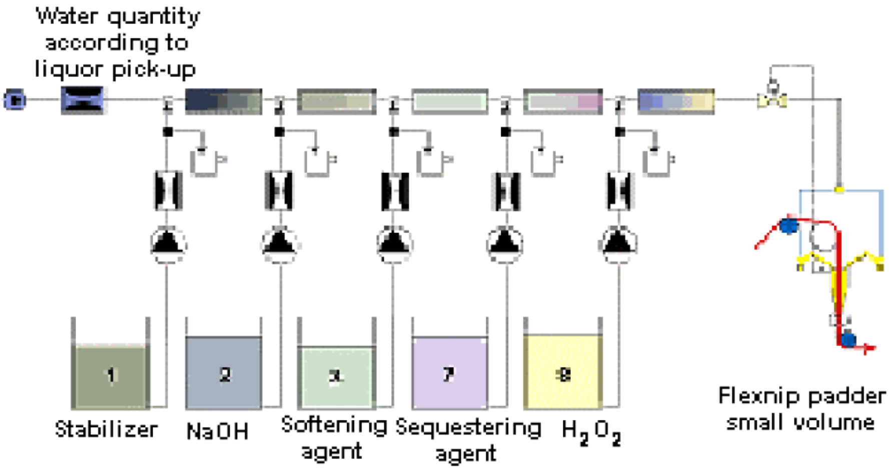

Figure 13. Example of Automated Systems for Dispensing Chemicals (European Commission, 2003)

Automation allows for improved right-first-time performance, which means minimizing corrective measures such as reworks, redyes, stripping and shade adjustment. This results in significant energy, water, chemical, and time savings. Secondly, automated systems with just-in-time preparation of liquors and separate dispensing of the different chemicals (i.e. no premixing) allow a significant reduction of waste water pollution and wasted chemicals. Another important issue to consider is a safer and healthier working environment. Eliminating human contact means no workers handling and breathing toxic and hazardous substances. Data from a textile dyehouse (size 5500 tons/year) show the following improvements after the installation of an automated dosing and dispensing system for chemicals:

- Reworks: 17% reduction
- Chemicals costs: 11.2% reduction
- Labor cost (in the dyehouse): 10% reduction
- The dye machine efficiency: 5% increase

Typical automated dosing and dispensing techniques described in this section are applicable to both new and existing installations. The size and the age of the plant do not seem to represent a limitation in the applicability of automated dosing and dispensing systems in general. Investment costs for the automated dosing of *liquid* chemicals, depending on the number of machines to be served, liquors to be prepared and chemicals to be used range from US$354,000 to US$477,000. For *powder dyes*, the investment is between US$385,000 and US$1,077,000, whereas for *powder* *auxiliaries* the investment ranges from a minimum of US$170,000 up to a maximum of US$477,000. The reported figures do not include costs for pipes and conjunctions (European Commission, 2003).

CIPEC (2007), however, gives the following ranges for the cost and payback periods of automated preparation and dispensing of chemicals in dyeing houses (Table 13). Cost savings can be derived from a reduction of consumption of chemicals, energy and water; an increase of reproducibility; and a decrease in staff costs. Cost savings of up to 30% have been reported.

Table 13. Cost and Payback Periods of Automated Preparation and Dispensing of Chemicals in Dyeing Houses (CIPEC, 2007)

	Capital Cost	**Pay back (yr)**
Automatic Chemical Dispensing System in Batch Dyeing Machines (Jet, Beam, Package, Hank, Jig and Winches)	$150,000—$890,000	1.3 - 6.2
Automatic Dye Dissolving and Distribution System in Batch Dyeing Machines	$100,000–$400,000	4 - 5.7
Automatic Bulk Powder Dissolution and Distribution Systems in Batch Dyeing Machines	$76,000–$600,000	3.8 - 7.5

Plants with automated dosing and dispensing systems represent more than 60% of the existing dye and printing houses in Europe. Automated systems for liquid chemicals are the most common (70% of the plants), whereas automated dosing and dispensing for powder dyes and auxiliaries are present in 20% of the European installations. The share of plants with automated dosing and dispensing systems is lower in some developing countries with large textile industries (European Commission, 2003).

49. Automated dyestuff preparation in fabric printing plants

Dyestuff preparation in the continuous screen-printing process consists of mixing paint and pigment paste. In the process, excess paste tends to be generated which needs to be discharged. The excess paste can be reduced through the application of an automated dosing technique. Automation helps to better determine the effect of a number of key factors on dyestuff consumption (e.g. the dyestuff fixation of the material and the material strength). Another option to prevent excess paste preparation is the introduction of a continuous and automated mixing system for the print and/or pigment paste. In these systems, paste consumption is measured real-time and the results determine the production of new print paste. The mixing is therefore fully adjusted to the specific needs of the dyestuff and printing process.

Improved mixing of the pigment paste increases the efficiency of the printing process. The amount of excess paste is reduced to a minimum. This means a reduction in raw materials, water and energy consumption per unit product. An automatic dyestuff mixing kitchen for printing can result in savings of US$154,000 per year on wastewater charges, and pigment, energy and water consumption. The investment cost varies between US$23,100 and US$2,308,000, depending on the size and type of the system (E-textile toolbox, 2005c).

50. Automatic dye machine controllers

Automatic dye machine controllers offer an effective means for enhanced control over dyeing processes. They are based on microprocessors and allow for feedback control of process parameters such as pH, color, and temperature. They analyze process parameters continuously and respond more quickly and accurately than manually controlled systems. Dye machine controllers can be retrofitted for many of the dye machines used in plants (Marbek Resource Consultants, 2001).

Automatic dye machine controllers control the dye cycle, including the amount of water utilized in the process, and hence the amount of water and pollutants discharged as effluent. Automatic host controllers include dye program management and reporting systems, on line scheduling, recipe management, and costs analysis (energy, dyes, and chemicals, etc.). Dye machine controllers have the potential to reduce the volume of industry effluents by up to 4.3%. Table 14 shows the costs and benefits from the implementation of dye machine controllers in plants of different sizes.

Table 14. Dye Machines Controllers Costs and Benefits (Marbek Resource Consultants, 2001)

Cost item	Small Plant (8,000 kg/week)	Medium Plant (60,000 kg/week)	Large Plant (117,000 kg/week)
Capital cost (average per plant)	$280,000	$450,000	$800,000
Net annual operating savings (average per plant)	$79,770	$128,200	$227,900
Simple payback period (year)	3.5		

Note: Costs and savings are associated with the amount of production for each plant size and not just for one machine.

The benefits of dye machine controllers have been demonstrated in various case studies around the world. For example, a U.S. textile company, Amital, automated dyebath flow and temperature control in a new acrylic yarn production facility. This resulted in clean exhausted dyebath and, therefore, eliminated the need for post-rinsing. Hence, water, energy and chemical use were reduced. Another example is instrument upgrading from manual to computer control for a dyeing process implemented at Bloomsburg plants in the U.S. Since washing time after dyeing was controlled more precisely with automated instrumentation, water use fell by 28% and energy consumption was reduced by 16% (Marbek Resource Consultants, 2001).

In another dyeing plant in India, initially the operation was manual; therefore, process parameters were set manually causing higher steam consumption. By installing automatic control systems and software the process parameters were set automatically resulting in process optimization as well as reductions in steam use. The total energy saving benefit was about US$100,000/year. The investment cost of the implementation of the measure in this plant is reported to be about US$222,000 resulting in a payback period of 2.2 years (EMT, 2006b). In another report, CIPEC (2007) has provided the capital cost and payback periods for process automation and quality control systems in dyeing plants; these are presented in Table 15.

Table 15. Capital Cost and Payback Period for Process Automation and Quality Control in Dyeing Plants (CIPEC, 2007)

Technology	Capital Cost	Pay back (years)
Dyehouse Host Computer Control System	$57,000 - $150,000	3.8 – 5.0
Automatic Microprocessor Dyeing Machine Controllers	$79,000	0.9
Automatic Dye Laboratory Colour Mixing	$100,000	2.5

51. Cooling water recovery in batch dyeing machines (jet, beam, package, hank, jigger, and winches)

Cooling water and condensate water are non-process water uses. Many cooling water systems are operated on a once-through basis. In general, cooling water and condensate water can be pumped to hot water storage tanks for reuse in functions where heated water is required, such as for dye makeup water, bleaching, rinsing, and cleaning. Recovery of cooling water can save about half of the total energy requirements for dyeing under pressure at high temperatures. The recovery of cooling water also reduces water and effluent costs. Table 16 (an example of the breakdown of annual energy use for a jet-dyeing machine) shows that, the cooling water contains approximately 43% of the total energy input. Much of this energy can be recovered by directing the cooling water stream into a hot water storage system for re-use at 50 °C – 60 °C. However, care must be taken to restrict the initial dye liquor temperature to avoid dyestuff strike-rate problems and fabric creasing (Carbon Trust, 1997)

Table 16. An Example of a Breakdown of Annual Energy Use for a Jet-Dyeing Machine (Carbon Trust, 1997)

Component	Energy use (GJ/year)	Share from total energy use	Water discharge temperature (°C)
Scour effluent	278	18%	40
Dye effluent	448	29%	60
Cooling water	653	43%	61
Radiation/convection losses	145	10%	
Total	1524	100%	

The principal cost items of this measure are pumps, piping modifications, and hot water storage tanks. A U.K.-based textile company saved about 11,000 m^3 of water by recycling and reusing cooling and condenser water. Savings on effluent disposal alone amounted to US$6000/year, not including additional savings in water pumping, treatment and energy use. Another Scottish cloth finisher saved approximately US$10,000/year by recycling cooling water from its solvent-scouring plant for use in wet processing. Apart from reducing water and effluent costs, the company also achieved energy savings as a result of reduced demand for water preheating and pumping (Marbek Resource Consultants, 2001).

Based on case-studies in several textile plants in China, NRDC (Natural Resources Defense Council) reported fuel saving of 1.6 – 2.1 GJ/tonne fabric and water savings of 1.44 – 7.4 tonne water/tonne fabric by recovering cooling waters (Greer et al., 2010).

CIPEC (2007) has given the investment cost for the installation of cooling water recovery systems in batch dyeing machines as US$90,000, with a payback period of 3.6 years. In a separate report, Marbek Resource Consultants (2001) has provided the capital cost and the savings from the recycling and reuse of cooling water and condensate water in wet-processing plants with different sizes (see Table 17). It should be noted that the initial investment cost for the system highly depends on the size of the plant and the number of machines to which the recovery system will be connected. The higher numbers for investment and savings are for the plant-wide implementation of this measure, whereas the lower numbers are for system/machine-wide implementation.

Table 17. Capital Cost and Savings from the Recycling and Reuse of Cooling Water and Condensate Water (Marbek Resource Consultants, 2001) [a]

Item	Medium Plant (60,000 kg/week)	Large Plant (117,000 kg/week)
Capital cost (average per plant)	\$143,000	\$212,000
Net annual operating savings (average per plant)	\$82,900	\$161,500
Simple payback period (years)	1.7	1.3

[a] It should be noted that the costs and savings given in this table are aggregate values for both cooling water and condensate. The reuse of condensate is discussed separately later in other section.

Note: Costs and savings are associated with the amount of production for each plant size and not just for one machine.

52. Cold-pad-batch dyeing systems[17]

Cold-pad-batch dyeing is a flexible, versatile dyeing method. At the start, prepared fabric is impregnated with liquor containing premixed fiber-reactive dyestuff and alkali. Excess liquid is squeezed out on a device known as a mangle. The fabric is then batched onto rolls or into boxes and covered with plastic film to prevent absorption of CO_2 from the air and evaporation of water. The fabric is then stored for 2 – 12 hours. The goods can be washed with becks, beams, or other available machines. Typical production is between 70 and 140 meters a minute, depending on the construction and weight of the fabric involved. Either woven or knit fabrics can be dyed in this way, and shades can be changed frequently because the reactive dyes remain water soluble. Cleaning operations are minimal due to the flexibility of pad-batch equipment and the use of water soluble dyes.

Energy consumption can be reduced from about 20.9 MJ/kg of dyed fabric for winch dyeing to under 4.6 MJ/kg of dyed fabric for cold-pad-batch dyeing with beam washing (a reduction of over 350%). Chemicals also greatly reduced due to the implementation of cold-pad-batch dyeing are salts, lubricants, levelling agents, antimigrants, fixatives, and defoamers. Other benefits associated with pad-batch dyeing include savings on water and labor. Water consumption for pad-batch dyeing with beam wash-off is only 10% of the amount used to dye fabrics using winch machines (a 90% reduction). In addition, labor costs can be reduced by up to 80% as compared to atmospheric winch dyeing methods (Marbek Resource Consultants, 2001).

Although it is a cost-effective way for facilities to apply reactive dyes to cotton and rayon, this method may not achieve the desired final fabric properties for all cottons. Cold-pad-batch dyeing is also not appropriate for dyeing synthetic fabrics. The average capital cost and savings in operation costs of the cold-pad-batch dyeing system is presented in Table 18.

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[17] This section is excerpted from Marbek Resource Consultants (2001).

Table 18. Capital Cost and Saving in Operation Costs of the Cold-Pad-batch Dyeing System (Marbek Resource Consultants, 2001)

Item	**Small Plant (15,000 kg/week)**	**Medium Plant (40,000 kg/week)**
Capital cost (average per plant) [a]	$1,215,000	$1,215,000
Net annual operating savings (average per plant)	$329,000	$878,000
Simple payback (years)	3.7	1.4

[a] Capital costs do not vary with the plant size

Note: Costs and savings are associated with the amount of production for each plant size and not just for one machine.

53. Discontinuous dyeing with airflow dyeing machines[18]

Discontinuous processing of textile products, in general, requires more water and energy compared to continuous processes. For a long time, efforts were undertaken to optimize discontinuous processes with respect to productivity, efficiency and also to minimize energy and water consumption. This has led to the development of jet dyeing machines in which liquor ratios have been reduced step by step. The latest developments (airflow dyeing machines) have a liquor ratio of 1:3 (for woven and polyester fabrics) and 1:4.5 liquor ratio (for woven cotton fabrics), instead of 1:10–1:12 in conventional jet dyeing machines. Additionally, airflow dyeing machines offer a combination of high productivity and reduced water, chemicals and energy consumption. To achieve such low liquor ratios, within the jet dyeing machine the fabric is moved by moisturized air or a mixture of steam and air only (no liquids), aided by a winch. The prepared solutions of the dyestuffs, auxiliaries and basic chemicals are injected into the gas stream.

The application of this technology requires investments in new dyeing machines as existing machines cannot be retrofitted. These machines can be used for both knit and woven fabric, however this process is not applicable to fabrics consisting of wool or wool blends with a percentage of more than 50% wool because of felting problems. Due to lower liquor ratios, new airflow-dyeing machines are expected to save up to 60% of both water and heating energy, 40% in chemicals, 35% in salts, and even 10% in dyestuffs. The investment cost of airflow dyeing machines, compared to conventional dyeing jets, is around one-third higher. The capital cost of airflow dyeing machines are given below, based on the number of storage chambers and total capacity.

- For one storage chamber, 150kg, a new jet dyeing machine costs US$190,500
- For two storage chambers, 450kg, the machine costs US$240,000
- For three storage chambers, 625kg, the machine costs US$309,500
- For four storage chambers, 900kg, the machine costs US$362,000 (E-textile toolbox, 2005d).

54. Installation of VFD on circulation pumps and color tank stirrers

Circulation pumps are used to circulate chemicals in machine chambers in the dye house. In many plants, especially those with old equipment, the flow of chemicals is often controlled by closing ball valves. VFDs can be installed instead of ball valves for flow control, thereby saving energy. Stirrers are installed on color tanks and are used for mixing the colors. VFDs could also be installed on the stirrers to control their speed, as it is not necessary to run the stirrers at full

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[18] This section is excerpted from E-textile toolbox (2005d).

speed. The implementation of these two retrofit measures in a plant in India resulted in 138 MWh/year electricity saving. The investment cost associated with this saving was about US$2300. (The number of equipment on which the VFDs are installed is not reported.) (EMT, 2005b)

55. Dyebath reuse[19]

Dyebath reuse is the process by which exhausted hot dyebaths are analyzed for residual colorant concentrations, replenished, and reused to dye additional batches of material. Dyebath reuse reduces effluent volume and pollutant concentrations in the effluent. Dyebath reuse carries the higher risk of shade variation because impurities can build up in the dyebath and decrease the reliability of the process. If properly controlled, dyebaths can be reused for 15 or more cycles (ranging from five to 25 cycles). For maximum dyebath reuse benefits, dye classes that undergo minimal changes during the dyeing process (such as acid dyes for nylon and wool, basic dyes for acrylic and some copolymers, direct dyes for cotton, and disperse dyes for synthetic polymers) must be used (see Table 19). Vat, sulfur, and fiber reactive dyes are very difficult to reuse. One complication is that each of the individual color components added to the dye bath to achieve the desired outcome color may have different affinities for binding to the fabric; thus, replenishing the bath correctly may require that different proportions of individual colors to be added compared to the initial recipe. This adds to the complexity of getting the color right for reuse.

Table 19. Appropriate Systems for Dyebath Reuse (U.S. EPA/SEMARNAP, 1996)

Final Product	Fiber	Dye Class	Machine
Knit fabric	• Polyester • Cotton • Polyester/cotton	• Disperse • Reactive or direct • Disperse/reactive or direct	• Jet • Beck • Beck
Yarn package	• Polyester • Polyester/cotton • Acrylic	• Disperse • Disperse/reactive or direct • Basic	• Package • Package • Package
Socks	• Nylon/spandex	• Acid	• Paddle
Pantyhose	• Nylon/spandex	• Disperse/acid • Disperse	• Beck • Paddle/drum
Carpet	• Nylon • Polyester	• Disperse/acid • Disperse	• Beck • Beck
Woven fabric	• Aramid/nomex • Cotton • Cotton	• Basic • Direct • Vat/Sulfur	• Jet • Reel • Jig
Skein	• Acrylic	• Basic	• Skein

Dyebath reuse offers a return on the investment in the form of dye, chemical, and energy savings and the reduction of waste water and waste water treatment. Typical costs for dyebath reuse include capital costs of about US$24,000 to US$34,000 per dye machine for lab equipment and machine modifications, and additional annual operating costs of $1,000 to $2,000 per dye machine. Typical annual savings (in the form of dyes, chemicals, water, sewer, and energy reductions) is about US$21,000 per dye machine. This savings estimate is disaggregated in Table 20 (U.S. EPA/SEMARNAP, 1996).

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[19] This section is mostly excerpted from U.S. EPA/SEMARNAP (1996)

Table 20. Typical Savings of Dyebath Reuse (U.S. EPA/SEMARNAP, 1996)

Saving item	Saving per machine (US$)
Dye and chemical	15000
Water	750
Sewer	750
Energy	4500
Total	21000

Note: Total and disaggregated savings may vary on the plant and country basis.

56. Equipment optimization in winch beck dyeing machines[20]

A number of technological improvements have been introduced in winch beck dyeing machines, which are:

- Heating: the liquor in the early winches was usually heated by direct steam injection through a perforated pipe. This system provided both rapid heating and vigorous agitation in the beck, but entailed dilution which had to be taken into account. Indirect heating/cooling is now more commonly used to overcome dilution and water spillage.
- Liquor ratio: recently developed winch becks operate at liquor ratios that are significantly lower than conventional machines. Moreover, an outstanding feature is that small batches can be dyed with approximately the same liquor ratio as for maximum loads.
- Rinsing: modern winches are designed to remove the carpet without draining the bath and without cooling or diluting the bath with rinsing water. This system is called the "hot-drawing-out system", in it the carpet is automatically taken out of the beck and passed over a vacuum extractor which removes the non-bound water. The recovered liquor is diverted back to the dye bath.
- Modern winches are fitted with hoods to help maintain temperature and minimize losses.
- Modern winches are also equipped with automated dosing and process control systems for full control of the temperature profile and the chemicals injected during the dyeing process (Figure 14).

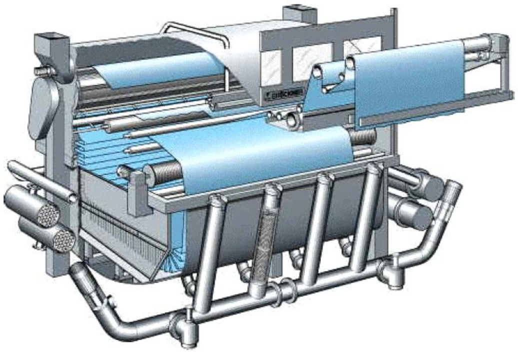

Figure 14. Modern Carpet Winch (European Commission, 2003)

The features described above bring about substantial savings in terms of water, chemicals and energy consumption. Reductions of 40 to 50% in fresh water for the total dyeing process (up to 94% of these savings occurring in rinsing water reductions) and a 30% reduction in electricity consumption are claimed by the machines' manufacturers. The advanced concept applied in this type of winch beck is that the rinsing step is no longer carried out in batches, but rather in a

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[20] This section is mostly excerpted from European Commission (2003).

continuous mode in a separate section of the equipment without contact between the substrate and the bath. Due to this method, there is no mixing between the rinsing water stream and the hot exhausted bath water, which makes it possible to re-use both streams and to recover the thermal energy (European Commission, 2003).

57. Equipment optimization in jet dyeing machines[21]

In the latest development of jet dyeing machines, the fabric is moved by means of moisturized air, or a mixture of steam and air, in the total absence of liquid (Figure 15). The dyestuffs, chemicals and auxiliaries are injected into the gas stream. Liquor ratios of 1:2 may be reached for woven polyester fabric, while 1:4.5 is the lowest limit achievable for woven cotton fabric with such air-jet machines. This machine can be used both for knit and woven fabrics and for nearly all types of fibers.

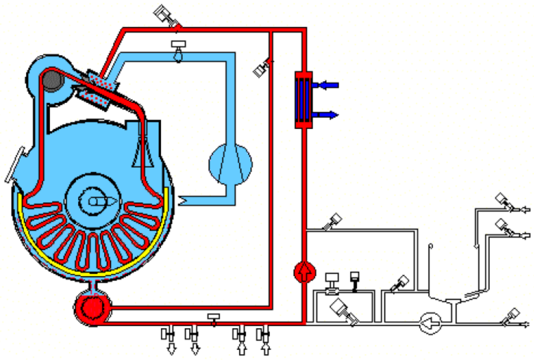

Figure 15. Illustration of an Airflow Dyeing Machine with Indication of Air Circulation and Injection of the Bath (European Commission, 2003)

By contrast with conventional machines, during the whole rinsing process, the bottom valve is open and the rinsing water, initially sprayed onto the fabric when it enters the jet, is immediately drained without additional contact with the fabric. Thus, rinsing is no longer a batch operation, but instead offers all the potential advantages of continuous processing (time saving, possibility of discharging the bath after high-temperature dyeing at 130 ℃ for optimum heat recovery, maximum cut-off between hot bath liquors and rinsing water, etc.).

The consumption of those chemicals (e.g. salts) for which dosage is based on the amount of dyebath can be reduced by about 40%. Less water is consumed (up to 50% water savings are achieved compared to conventional machines operating at L.R.s of 1:8 – 1:12). Marbek Resource Consultants (2001) reports even higher savings by low L.R jet equipment: water savings of 70% and chemical use reductions of 60% in comparison with conventional equipment (liquor ratio = 1:8). Low liquor ratio dyeing minimizes energy use. In general, the heating of dyebaths constitutes the major portion of the energy consumed in dyeing; therefore, low liquor ratio dyeing equipment results in major reductions in steam use. Another benefit associated with low liquor ratio dyeing is reduced cycle times due to quick machine draining and filling and rapid heating and cooling (Marbek Resource Consultants, 2001). Table 21 shows specific input data ranges for cotton dyeing with reactive dyestuffs in a conventional jet operating at L.R.s of 1:8 –

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[21] This section is mostly excerpted from European Commission (2003) and Marbek Resource Consultants (2001)

1:12 and in the airflow machine described above. The data are derived from measurements taken at different production sites in Europe.

Table 21. Comparison of Specific Input Data for Cotton Dyeing with Reactive Dyestuffs in a Conventional Jet (L.R. 1:8 – 1:12) and in the Airflow Jet Machine (European Commission, 2003)

Input	Unit	Conventional jet operating at L.R. 1:8 – 1:12	Airflow jet operating at L.R. 1:2 – 1:3 (polyester) / 1:4.5 (cotton)
Water [a]	l/kg	Polyester: 100 Cotton: 150	Polyester: 20 Cotton: 80
Auxiliaries	g/kg	12 – 72	4 – 24
Salt	g/kg	80 – 960	20 – 320
Dyestuffs	g/kg	5 – 80	5 – 80
Steam	kg/kg	3.6 – 4.8	1.8 – 2.4
Electricity	kWh/kg	0.24 – 0.35	0.36 – 0.42

[a]: Including rinsing

It should be noted that this measure is not a retrofit measure and represents an investment in new machinery with lower liquor ratios (Carbon Trust, 1997). The investment cost for this type of machine is around one third higher than conventional jets, but due to high savings the payback period is relatively short. High productivity and repeatability still remain the main driving forces, followed by savings in water, chemicals and energy consumption (European Commission, 2003). Table 22 shows the capital cost and annual operating cost saving for low L.R. jet dyeing machines in different size plants.

Table 22. Capital Cost and Savings of Low Liquor Ratio Jet Dyeing (Marbek Resource Consultants, 2001)

Cost item	Plant Size		
	Small (10,000 kg/week)	Medium (60,000 kg/week)	Large (120,000 kg/week)
Capital cost (average per plant)	$928,000	$3,370,000	$4,900,000
Net annual operating savings (average per plant)	$298,000	$1,790,000	$3,580,000
Simple payback period	3.1 years	1.9 years	1.4 years

Note: Costs and savings are associated with the amount of production for each plant size and not just for one machine.

At its Lumberton, North Carolina facility, Alamac Knit upgraded their jet dyeing machinery to low liquor ratio machines with shorter cycles. This modification reduced dye chemicals by 60 – 70%. Shrigley Dyers Ltd., a U.K.-based commission dyer and finisher of knitted fabrics, achieved both economic and environmental benefits by installing a state-of-the-art enclosed jet dyeing machine. Operation data showed that the water consumption of the new machine (64 m^3 per tonne of fabric) was less than half that of conventional machines (142 m^3 per tonne of fabric) used by the company. The average steam demand for the new machine was 980 kg/batch compared with 1,480 kg/batch for the conventional machines. The new machine takes about 20% less time to process a single batch than the conventional machine and the throughput is therefore higher. The new machine was installed at a cost of US$221,000 in 1996 and the investment was paid back in 1.6 years (Marbek Resource Consultants, 2001).

58. Single-rope flow dyeing machines[22]

The configuration of this jet machine is shown in Figure 16. The way in which it handles the fabric and the dyeing cycle is very different from conventional rope dyeing machines. First, there is only one fabric rope which passes through all flow groups and compartments, returning to the first compartment after the lap is complete. The single rope approach ensures both optimum uniformity of the system and repeatability of the results (European Commission, 2003).

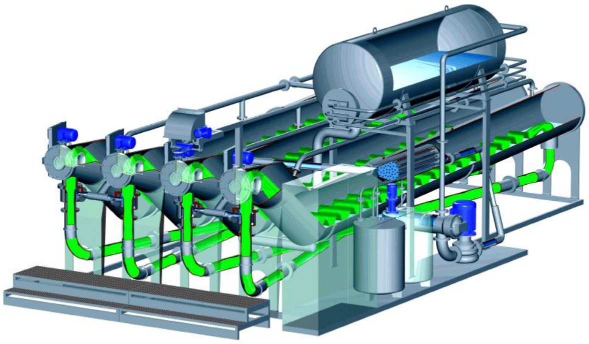

Figure 16. Representation of the Single-Rope Dyeing Machine (European Commission, 2003)

Very short cycles and other features of this machine result in significant water and energy savings (up to 35%) compared to conventional multi-rope machines. High repeatability and reliability of the final results bring about additional environmental benefits. A reduction of reworks from 5% to 2% has been observed in companies where this technique has been applied. Table 23 shows the results of the same dyeing process in a conventional machine (L.R. 1:10 – 1:12), a "new generation machine" (typified by an L.R. of 1:8 and fitted with the latest timesaving devices) and the single-rope machine described above (L.R. 1:6). The data are derived from measurements taken at different production sites in Europe (European Commission, 2003).

Table 23. Comparison of the Performance of Cotton Dyeing with Reactive Dyestuffs in a Conventional Jet Machine, a New Generation Jet Machine, and the Single-Rope Machine Described Above (European Commission, 2003)

Input	Unit	Conventional jet machine	New generation jet machine	Single-rope jet machine
Water [a]	l/kg	100-130	50-90	30-70
Auxiliaries	g/kg	15-75	8-40	5-25
Dyestuffs	g/kg	10-80	10-80	10-80
Steam	Kg/kg	4-5	2-3	1.5-2.5
Electricity	kWh/kg	0.34-0.42	0.26-0.32	0.18-0.22
Time [b]	min	510-570	330-390	210-220

[a]: Including rinsing
[b]: Including loading/unloading

The single-rope machine is used successfully for processing both knit and woven fabrics of nearly all types of fibers. Unless the horizontal model of this machine is used, limitations are observed when dyeing wool and silk and blends of these two fibers. The investment cost for this

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[22] This section is mostly excerpted from European Commission (2003).

type of machine is 20 – 30% higher compared to new conventional type machines, but thanks to savings and higher productivity the payback period can be less than a year (European Commission, 2003).

59. Microwave dyeing equipment

Microwave dyeing equipment employs microwaves for rapid, efficient and energy-saving dispersion and penetration of dyes and chemicals into fabric. This equipment differs from conventional dyeing equipment. Since microwave irradiation generates heat through dielectric losses, the heat is absorbed by objects having large losses, and thus fabric containing moisture is heated without heating of the surrounding air and equipment itself. Furthermore, in contrast to the case of moisture (dyeing solution) penetrating the fabric, the fabric itself becomes a steam generator through internal heating, and penetration and dispersion of dyes and chemicals occurs rapidly and uniformly, ensuring suitability for continuous dyeing in mass production. Energy-savings in comparison to similar conventional beam dyeing equipment are shown in the Table 24. The schematic of the microwave dyeing machine is shown in Figure 17. The capital cost including the construction cost is about US$450,000 (ECCJ, 2007a).

Table 24. Energy-Savings of Microwave Dyeing Machines Compared to Beam Dyeing Machines for Batch Dyeing (ECCJ, 2007a)

Energy consumption	Beam dyeing machine	Microwave dyeing machine	Reduction
Typical Electricity consumption (kW)	50	5	90%
Typical Steam consumption (kg steam/h)	3600	150	96%

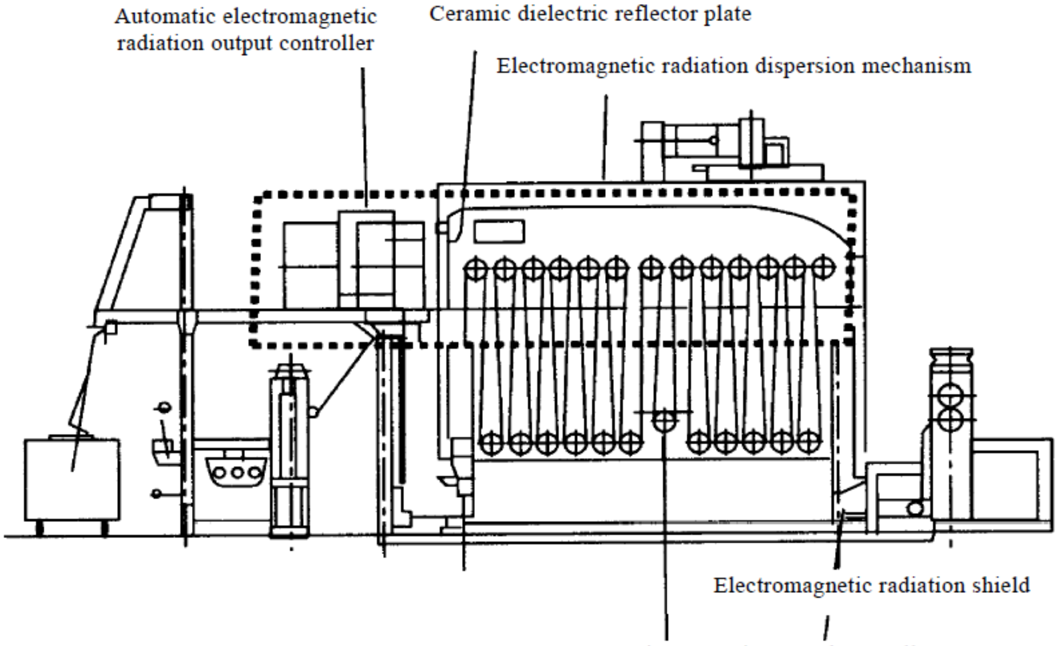

Figure 17. A Schematic of a Microwave Dyeing Machine (ECCJ, 2007a)

60. Reducing the process temperature in wet batch pressure-dyeing machines

A reduction in the process temperature may also be achieved in wet batch pressure-dyeing machines by introducing alternative processes. For example, under suitable circumstances, direct dyeing machines operated at 100 – 120 ℃ may be replaced with reactive dyeing at 40 – 60 ℃, thus minimizing water heating and radiation/convection losses. The application of this measure, however, should be assessed in plant as well as on a product basis (Carbon Trust, 1997).

61. Use of steam coils instead of direct steam heating in batch dyeing machines (winch and jigger)

In older batch dyeing machines like winches and jiggers, dyebaths are traditionally heated by sparging with raw steam. This is a very inefficient use of steam for heating the dyebath. A steam coil submerged in the dyebath now allows for the recycling of the condensate, resulting in significant fuel savings. A plant in Canada replaced their steam sparging system with a steam coil for dyebath heating and achieved fuel savings of 4580 GJ/year. The cost of the replacement is reported to be about US$165,500 (CADDET, 1993)

62. Reducing the process time in wet batch pressure-dyeing machines

Processing times can sometimes be reduced simply by making modifications to the temperature profiles of certain dyeing cycles. This can result in energy savings and improved productivity. Preparatory processes can also be sped up just by the use of different chemical formulations. One example, which involved modifying a kier scour/bleach formulation, is reported to have reduced processing times from ten hours to just over two hours. This measure, however, is not applicable to all processes and its potential application should be studied on plant/process and product bases (Carbon Trust, 1997).

63. Installation of covers or hoods in atmospheric wet batch machines

Using covers or hoods in atmospheric wet batch machines may seem obvious, but many jiggers and winches are operated at high temperatures without hoods or with open hoods. Using covers or hoods can reduce evaporative losses by approximately half. Evaporation is particularly important in processes with temperatures above 60 ℃ (Carbon Trust, 1997).

64. Careful control of temperature in atmospheric wet batch machines[23]

Overheating is a common problem in atmospheric wet batch machines. It is most often caused by poor controls, especially in older machines. The maximum achievable temperature in an atmospheric vessel is 95 – 100 ℃. Once the dye liquor is boiling, further heat input will not raise the temperature, but will increase evaporation. Although a faster boil does lead to greater agitation of the fabric, this can be achieved more efficiently by installing a circulator. At temperatures above 80 ℃, live steam breakthrough may occur; as much as 15% of steam can be lost in this way (Carbon Trust, 1997). Table 25 illustrates the energy savings that can be achieved by reducing temperatures and by consistently closing the hoods on jiggers.

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[23] This section is mostly excerpted from Carbon Trust (1997).

Table 25. Steam Used by a Jigger with Varying Temperature and Conditions (Carbon Trust, 1997)

Operating Temperature (°C)	Typical Steam Use (kg/hour)		Steam Saving (kg/hour)
	Open Hood	Closed Hood	
80	50	23	27
90	61	28	33
95	73	34	39
100 (simmer)	91	55	36
100 (vigorous boiling)	218	127	91

The energy savings, even for small reductions in operating temperatures, are significant. For instance, a jigger set at 95°C uses only about between 27% and 33% of that needed for a 100°C (vigorous boiling) with closed hood and open hood, respectively. Closing the hoods results in even more energy savings compared with open hoods. Just changing from a vigorous boil to a simmer (keeping operating temperatures at 100°C) and closing hoods reduces energy use by 75% (Carbon Trust, 1997).

65. Jiggers with a variable liquor ratio

In textile processing, the delivery of relatively small batches of textile products is becoming increasingly important. In some production facilities, more than 50% of the overall production volume consists of such small batches. Conventional jiggers have a number of disadvantages for these jobs. They do not have a variable liquor ratio, which is why the quantities of water, pigments and chemicals cannot be adjusted properly to the varying quantities of fabric being processed. Additionally, starting up a new batch requires prolonged cooling of the equipment, the washing of the fabric requires a lot of time, and extra fabric has to be added at the end of a batch to prevent the fabric from slipping off the presses.

In order to cope with these disadvantages, a new generation of jiggers with a variable liquor ratio has been developed. These jiggers make use of a heat exchanger, allowing the heat to be removed and applied elsewhere in the plant. In each passage, the length of the cloth is measured, so extra fabric at the end of the batch can be avoided. Because of additional features such as a vacuum system and sprinklers, the number of passages in washing cycles can be reduced significantly (in a specific case, from twenty to five cycles). In one particular case, energy savings of 26%, water savings of 19%, and a 5% reduction in the use of chemicals were achieved (E-textile toolbox, 2005e).

66. Heat recovery of hot waste water in autoclaves

Autoclave (high temperature/high pressure) dyeing machines generate relatively high temperature waste water at 75°C, which in many plants is wasted away directly through drain disposal. On the other hand, fresh water at 13 to 25°C is heated to 130°C in the steam heater. A heat exchanger and surrounding equipment like water tanks and pumps for recovering heat from hot waste water as a heat source can be installed. A plate-type heat exchanger is usually recommended.

Steam condensate can be recovered in hot water tanks (Figure 18). Waste water coming from autoclave dyeing machines as well as other machines like continuous washers can be treated in the same heat recovery system. A case-study of the implementation of this measure in a textile plant in Iran showed a fuel savings of 554 MJ/batch[24] in autoclave machines (ECCJ, 2007b).

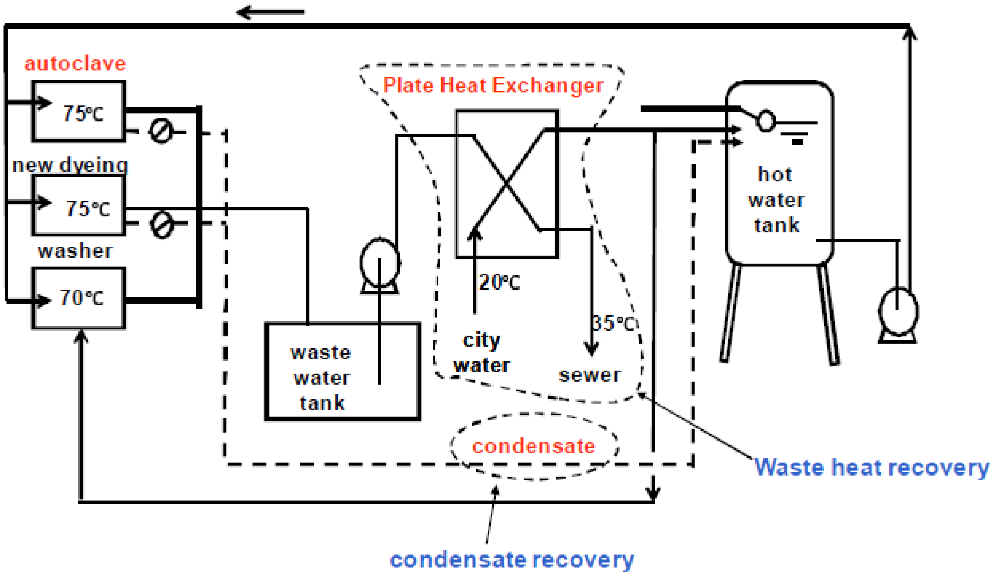

Figure 18. Schematic of the Heat Recovery System of Autoclaves (ECCJ, 2007b)

67. Insulation of un-insulated surface of autoclaves

If the surface of the autoclave is not insulated, the surface temperature is as high as 100 ℃ to 110 ℃. This does not only waste energy but also makes for very unpleasant working conditions. Hence, all the hot surfaces should be insulated, including those of the main vessel, air vent tank, heat exchanger and water circulation piping. Water-resistant, easy-paste type insulation material is usually recommended. By using insulation calculation software, energy savings of 15 MJ/batch have been reported (ECCJ, 2007b).

68. Reducing the need for re-processing in dyeing

One of the main causes of re-processing is the difficulty and time-consuming nature of fabric sampling procedures, especially on older machines. It is therefore vital that dyehouses aim to achieve correct shades quickly and consistently. This may be done simply by improving manual control through better staff training. For large installations there are complete dyehouse management and control systems which are capable of real time machinery supervision, dye cycle editing, and production scheduling.

Dyehouse control systems are gradually shifting away from the more rigid read-only memory programs, to flexible software programming which enables schedules and processes to be tailored on-site. Product quality and productivity can be improved while the use of dyes, chemicals, water and energy are optimized. Improved controls will typically lead to just 5% of the product requiring shading, which results in energy savings of around 10 – 12% (Carbon Trust, 1997).

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[24] Each time that the material is processed in the Autoclave is called one "Batch".

69. Recovering heat from hot rinse water

In textile wet-processing, large amounts of hot (up to 80 °Celsius) water is used to rinse fabric or yarn. Plants may discharge a mass of rinse water up to thirty times the weight of the yarn/fabric that is rinsed. The heat from the rinse water can be captured and used for pre-heating the incoming water for the next hot rinse. This option provides the important ancillary benefit of reducing the temperature of the wastewater prior to treatment as well. However, many textile plants around the world are not recovering heat from their hot rinse water.

Plate heat exchangers can be used to transfer the heat from the rinse wastewater to the incoming cold freshwater. Simple heat exchangers are sufficient for continuous processes. In discontinuous processes, the heat exchanger would have to be fitted with buffer tanks and process control devices. Based on case-studies in several textile plants in China, NRDC (Natural Resources Defense Council) reported fuel savings of 1.4 – 7.5 GJ/tonne fabric rinsed by the implementation of this measure. The investment cost is reported to be between US$44,000 and US$95,000 depending on mill size and layout. The payback period was less than six months in all cases studied by NRDC (Greer et al., 2010).

70. Reuse of washing and rinsing water[25]

Generally, the rinse water resulting after bleaching or discontinuous dyeing can be reused several times. The rinse water of bleaching processes can often be reused for rinsing after a caustic treatment. In some cases, the water can be reused for a third time to rinse degraded sizing agents. After discontinuous dyeing, the final-step rinse water is hardly contaminated and can possibly be reused for the first rinsing step of the next dyeing process. If the fabric at the start of the process is put into the bath and is taken out after washing, then the rinse water can remain in the bath and there is no need to store it separately.

The wash water can also be used in pre-treatment before the dyeing process. In practice, the reuse of rinse water from dyeing processes is complicated due to pigments remaining in the water (especially in the case of dark colors). Consequently, a prerequisite for recycling is the application of light colors (low pigment concentrations) of pigments with a high fixation rate. Before implementing this measure in a specific company, an assessment has to be made of whether the wash and/or rinse water is sufficiently clean to be reused.

Energy savings per washing machine by the implementation of this measure are significant and annual water savings of 3000 m^3 – 8000 m^3 can be achieved. Recycling of the last rinse water requires only a small capital investment for collection, pumps and a filter or sieve to capture contaminants. Further reutilization that requires purifying the water requires a larger investment (E-textile toolbox, 2005f).

71. Reduce rinse water temperatures

Rinse water for rinsing after dyeing is heated to a temperature of about 60 ℃ to produce a good quality product. Operational practices in different plants have demonstrated that a reduced temperature of about 50 ℃ can be used without degrading product quality. This will result in significant fuel saving. A plant in Georgia, U.S., has reported a 10% reduction in fuel use by

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[25] This section is mostly excerpted from E-textile toolbox (2005f).

implementing this measure. There is no investment cost for the implementation of this measure. Hence, it will result in substantial cost savings without upfront investment (US DOE ITP, 2007).

5.4.3. Drying

Energy-efficiency improvements in cylinder dryer[26]

Contact drying is mainly used for intermediate drying, rather than final drying (since there is no way of controlling fabric width), and for pre-drying prior to stentering. Fabric is passed around a series of cylinders, which are heated by steam supplied at pressures varying from 35 psi to 65 psi. Cylinders can be used to dry a wide range of fabrics. However, since the surface of the fabric is compressed, the process is not suitable for fabrics with a raised surface effect (Carbon Trust, 1997). A typical energy breakdown for a set of 12 cylinders, heated by steam at 60 psi, and being used to dry a cotton fabric from 55% to 5% moisture content, is shown in Table 26.

Table 26. Energy Breakdown for a Set of Steam Cylinders Dryers (Carbon Trust, 1997)

Component	Energy use (GJ/tonne of product)	Share of energy use from total energy use
Evaporation	1.35	52%
Radiation and convection losses	0.87	34%
Fabric	0.16	6%
Moisture	0.14	5%
Friction	0.07	3%
Total	2.59	100%

In this example the amount of water removed amounts to 50% moisture content by weight of fabric, and evaporative losses account for more than 50% of the energy required. Fabric is often dried from over 100% moisture content to completely dry, increasing evaporative losses to around 75% of the total (Carbon Trust, 1997). Some of the energy-efficiency measures that can be implemented on cylinder dryers are explained below.

72. Introduce mechanical pre-drying

Mechanical pre-drying methods such as mangling, centrifugal drying, suction slot or air knife de-watering are used to reduce drying costs by removing some of the water from the fabric prior to contact drying in cylinder dryer. A slot is three times more energy intensive than a typical mangle, but consistently provides lower water retention rates over a range of fabric types. The effectiveness of mangling depends on a number of factors such as: the diameter and hardness of the bowl; the pressure applied; the temperature of the water in the fabric; and the fabric speed. Centrifugal de-watering may also be used for some fabrics, although its tendency to cause creasing means that the process is mainly used to de-water yarn or staple. In terms of cost and performance, centrifuges fall between mangles and suction slots.

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[26] This section on energy efficiency in cylinder dryer is mostly excerpted from Carbon Trust (1997).

Suction slots can be located in the front of a dryer. The slots draw air through the fabric which runs at speed over a slot. The extracted air/water is then filtered and passed through a water separator (Figure 19). Although they are very effective, slots require a high electrical power input (up to about 50 kW) (Carbon Trust, 1997). Typical proportionate limit retentions for a variety of fibers, using mangles and suction slots, are shown in Table 27.

Table 27 indicates that, in general, lower retention rates are achieved by suction slots. This is particularly true when suction slots are used to de-water *hydrophobic* fibers (e.g. diacetate, nylon 6.6, and polyester). In practice, the figures given for mangling are seldom achieved, and performance can be quite poor. For example, it is quite common to see retentions of only 80 – 100% for cotton. This makes the suction slot seem attractive even for the *hydrophilic* fibers (e.g. cotton and viscose), but its relative energy consumption must be taken into consideration (Carbon Trust, 1997).

Table 27. Typical Retention Limits for a Number of Fibers (Carbon Trust, 1997)

Fiber	Mangle Retention (%)	Suction Slot Retention (%)
Cotton	45-70	40-55
Viscose	60-100	60-80
Diacetate	40-50	27-40
Nylon 6.6	20-40	14-30
Polyester	20-30	10-16
Wool	58-60	35-55

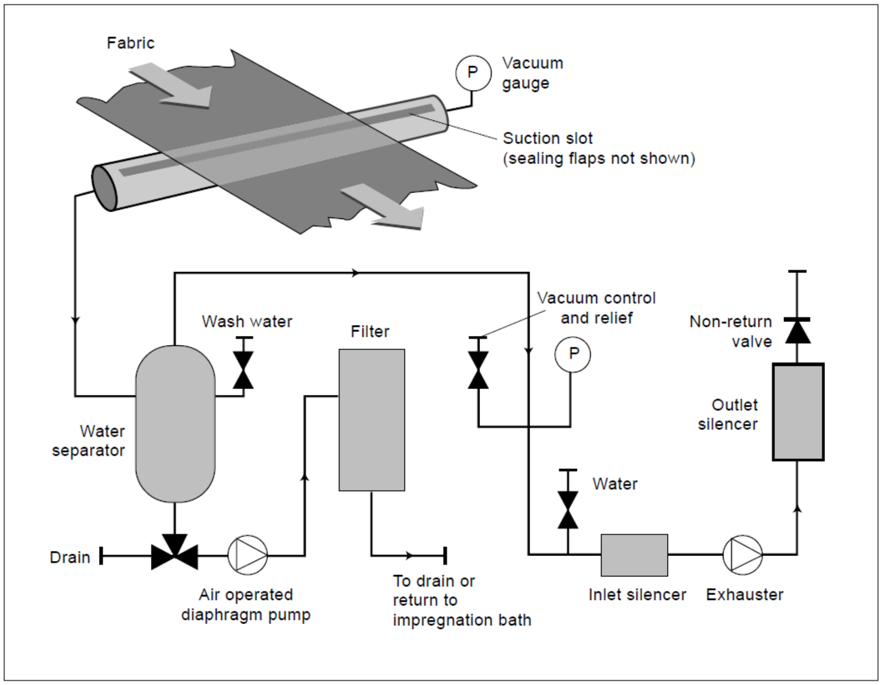

Figure 19. Schematic of the Installation of a Suction Slot System in the Front of a Dryer (Carbon Trust, 1997)

73. Selection of hybrid systems in cylinder dryer

The performance of steam cylinders can be enhanced by the use of directed air, either at ambient or elevated temperatures. Directed air equipment helps to disperse evaporated moisture. One example is the ATIRA Rapidry system, an Indian development, which uses air jets and claims increased drying rates of around 25 – 30%. The other example is the Shirley Hood which is used for sizing and coating operations. It is reported that Shirley Hoods could increase drying rates by as much as 40% (Carbon Trust, 1997).

74. Recover condensate and flash steam in cylinder dryer

Since a large amount of steam is used in cylinder dryer, there is also a significant amount of condensate that should be recovered and returned to the boiler house. In addition, flash steam which is produced when condensate is reduced to atmospheric pressure can be recovered as low-pressure steam, and used to heat water or other low-pressure steam processes (Carbon Trust, 1997).

75. End panel insulation in cylinder dryer

The insulation of end sections can reduce heat waste, thereby saving fuel. This measure, however, is more practical for cylinders with a diameter of one meter or more. For small diameter cylinders, this may not be practicable since the steam pipe, condensate pipe and safety valve get in the way (Carbon Trust, 1997).

76. Select processes for their low water add-on characteristics

This measure is looking one step back before drying to see whether the pre-drying processes could be modified or replaced to minimize the amount of water introduced to the fabric. The use of finishes processes using foam, lick rollers or spray application methods are the options that could be considered (Carbon Trust, 1997).

77. Avoid intermediate drying in cylinder dryer

There are systems which allow finishes to be applied ‘wet on wet’ to avoid intermediate drying between processes. Typically a fabric is dried two to three times (sometimes even more) during its passage through a finishing process. In addition to being energy intensive, drying is a bottleneck in the finishing process. Hence, elimination of just one step in drying would result in both energy efficiency and productivity increases (Carbon Trust, 1997).

78. Avoid overdrying in cylinder dryer

Overdrying of fabric is a very common problem in the textile industry. Fibers have an equilibrium moisture regain, or natural moisture level, below which it is useless to dry them. For some fibers the moisture regain value can be quite high. It is therefore important to control the speed of the drying cylinders so that the equilibrium moisture level is not exceeded. Hand-held moisture meters can be used with a roller sensor to monitor the moisture content of fabrics leaving the drying cylinders. Typical regains at 20 ℃ and 65% relative humidity (RH) of ambient air are shown in Table 28. Figure 20 shows the schematic of the fabric moisture control mechanism in a cylinder dryers.

Table 28. Typical Moisture Regain Values for a Number of Fibers (Carbon Trust, 1997)

Fiber	Moisture Regain Value (%)
Cotton	7.0
Wool	16-18
Viscose	12.5
Diacetate	6.9
Triacetate	4.5
Nylon 6.6	4.3
Nylon 6	4.4
Polyester	0.4
Acrylic	1.5
Polypropylene	0.0

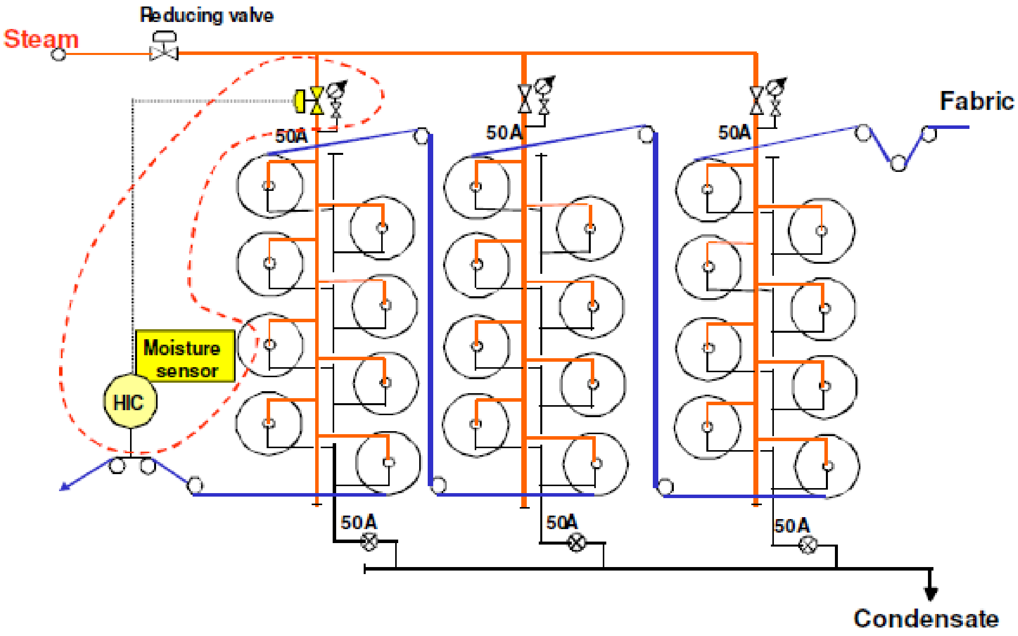

Figure 20. Fabric Moisture Control in a Cylinder Dryer (ECCJ, 2007b)

79. Reduce idling times and using multiple fabric drying in cylinder dryer

Careful scheduling of fabric batches arriving at the cylinders can reduce idling time, thereby saving energy. Similarly, efficiency can be improved by making cylinders extra wide to allow two batches of narrow fabric to run side by side. To maximize energy savings, it is better to have batches with the same length of fabric, so that they start and finish together. This will help to avoid the idling of one side of the cylinders (Carbon Trust, 1997).

80. Operating cylinders at higher steam pressures in cylinder dryer

Cylinders can be operated at higher steam pressures and temperatures to reduce radiation and convection losses (Carbon Trust, 1997).

81. Maintenance of cylinder dryer

Vacuum breakers, air vents, rotating joints and steam traps are the common leak sites for steam cylinders. A single dryer could comprise 32 cylinders, so the potential for leakage is considerable.

It is important to have a good maintenance program which should include periodic checking of steam traps (Carbon Trust, 1997).

82. The use of radio frequency dryers for drying acrylic yarn

The steam heated dryer, which is used to dry dyed acrylic yarn skeins, can be replaced by a radio frequency dryer. The RF dryer can reduce yarn drying energy costs as well as maintenance and labor costs. It is also found that radio frequency drying acts on the molecular activity in acrylic yarns, causing them to swell or bulk. This bulking makes a more attractive carpet with a better bloom, improving the quality of products. The case study of the installation of RF dryers in place of steam heated dryers in a carpet producing plant for drying the acrylic yarns used in carpet production has been reported to be around a US$45,000 saving in energy cost with a capital investment of US$200,000 (CADDET, 1993).

83. The use of low pressure microwave drying machines for bobbin drying instead of dry-steam heater

Conventionally, bobbin products are dried by the hot-air drying method using a dry-steam heater. Energy savings could be accomplished by switching from dry-steam heaters to low pressure (LP) microwave drying. The LP microwave drying method features good drying efficiency and the capability to prevent products from over-drying, which happens often in hot-air dryers. The implementation of this measure in Japan resulted in 107 kWh/tonne yarn electricity saving with an investment cost of US$500,000. The payback period of the project in Japan was less than 3 years (ASEAN Center for Energy, 1997).

84. High-frequency reduced-pressure dryers for bobbin drying after the dyeing process

This equipment is a high-frequency reduced-pressure dryer employed in the bobbin drying after the bobbin dyeing process, and achieves 20% electricity saving compared with conventional dry steam-type hot air dryers. A change in the method of temperature control in the drying process from fixed temperature controls to programmed temperature controls, and optimized control of the temperature of the drying vessel in accordance with the material and quantity permits a major reduction in electricity. This equipment increases the number of pressure switches, and employs a two-stage system of setting pressure in which the initial pressure is lowered, eliminating non-uniform drying, and shortening the drying process. Figure 21 shows the hot air drying system prior to improvement; Figure 22 shows the high-frequency reduced-pressure dryer after improvement. These changes resulted in electricity saving of 200 kWh/tonne product. The investment cost is reported to be about US$500,000 (ECCJ, 2007a).

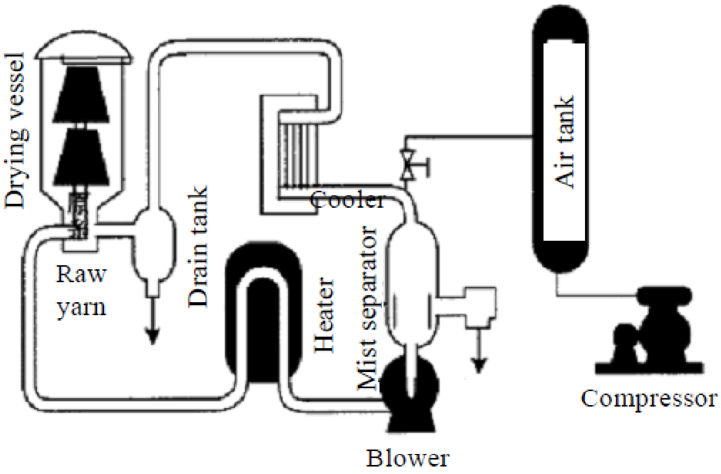

Figure 21. Hot Air Drying System Prior to Improvement (ECCJ, 2007a)

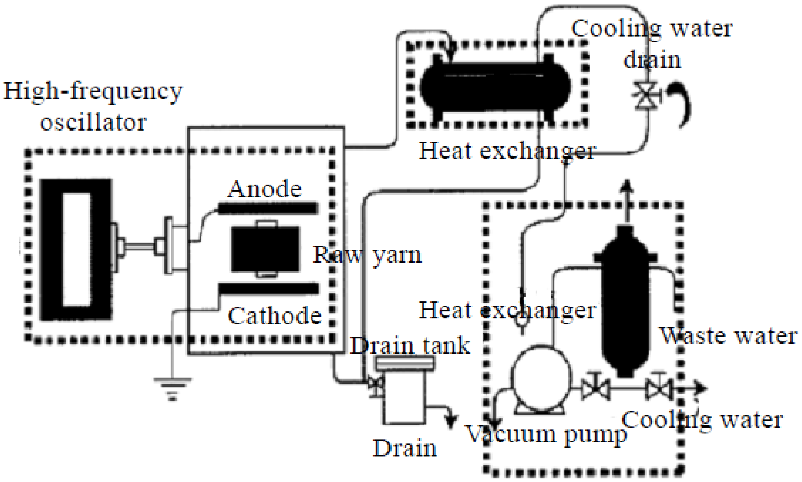

Figure 22. High-Frequency Reduced-Pressure Drying System (ECCJ, 2007a)

5.4.4. Finishing Process

Energy-efficiency improvements in stenters

Stenters have an important role in the dyeing and finishing of fabrics. Stenters are mainly used in textile finishing for heat-setting, drying, thermosol processes and finishing. It can be roughly estimated that, in fabric finishing, the fabric is treated on average 2 – 3 times in a stenter (European Commission, 2003). A stenter essentially consists of a pair of endless traveling chains fitted with clips of fine pins and is carried on tracks. The cloth is firmly held at the selvages by the two chains which diverge as they move forward so that the cloth is brought to the desired width. Similar to heat setting and curing, stenters also affect the finished length, width and properties of the fabrics. Fabric can be processed at speeds from 10 – 100 m/minute and at temperatures of more than 200 °C. Stenters can be heated in a variety of ways, such as direct gas firing and through the use of thermic fluid systems. Gas-fired stenters are highly controllable over a wide range of process temperatures.

Thermic fluid heating for stenters requires a small thermic oil boiler (usually gas-fired) and its associated distribution pipeline. This system is less efficient than direct gas firing and has higher capital and running costs. However, like gas, it can be used over a wide temperature range, but the problem is that this heating can only be done indirectly via a heat exchanger. This system, compared with indirect gas firing, is relatively inefficient, so it is no longer commonly used. Finally, there are a number of steam-heated stenters. Because of their low temperature limits (usually up to a maximum of 160 ℃) these stenters can only be used for drying; they are not suitable for heat setting or thermo fixing of fabrics.

In all stenters the hot air is blown against the fabric and then recirculated. A fraction of this air is exhausted and made up with fresh air. To provide better control, stenters are split-up into a number of compartments, usually between two and eight. Figure 23 shows a stenter with three-meter sections, each fitted with a temperature probe, burner/heat exchanger, fans, exhaust and damper (Figure 23)

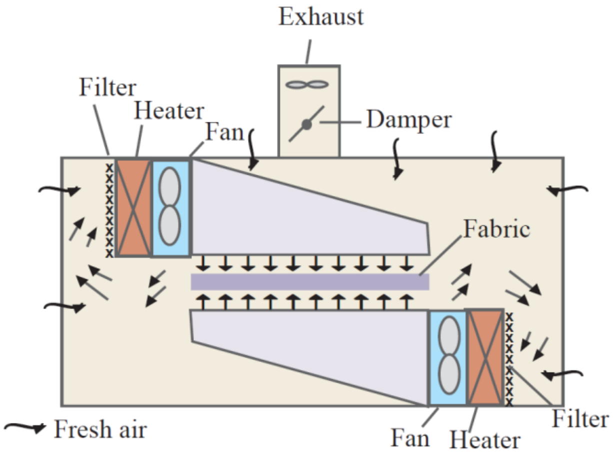

Figure 23. Schematic of the Air Path within a Stenter (CII, 2006)

A typical energy breakdown for a stenter being used for hot-air drying is shown in Table 29. By far the greatest users of energy are the evaporation and air heating components. It is therefore necessary that the fabric moisture content is minimized before the fabric enters the stenter, and that exhaust airflow within the stenter is reduced. Many stenters are still poorly controlled, relying on the manual adjustment of exhausts and operator estimations of fabric dryness (Carbon Trust, 1997).

Table 29. Energy Breakdown for a Typical Stenter (Carbon Trust, 1997)

Component	Energy use (GJ/tonne of product)	Share of energy use from total energy use
Evaporation	2.54	41.0 %
Air heating	2.46	39.7 %
Fabric	0.29	4.6 %
Case	0.39	6.3 %
Chain	0.09	1.5 %
Drives	0.43	6.9 %
Total	6.20	100 %

85. Conversion of thermic fluid heating systems to direct gas firing systems in stenters and dryers

Carbon Trust (1997) explains that "often, thermic fluid heaters are used to provide the heating requirements of stenters and dryers. In this system, a fluid is heated up to 260°C and circulated in the plant through transmission lines. Heat is transferred from the hot fluid to the chambers using radiators. Substantial heat loss happens in the thermic fluid boilers, transmission lines and radiators. To reduce this heat loss, thermic fluid heating systems can be replaced with direct gas firing systems. In the new system, air is directly heated by gas fired burners and the required temperature is obtained by circulating hot air through the chambers.

The direct gas firing system has several advantages over the thermic fluid heating system. First, there is a saving on fuel consumption with the reduced heat losses. The electricity required for pumping the thermic fluid and the risks involved in the circulation of the hot fluid are also eliminated. Besides, the direct gas firing system has the advantage of direct heating at the chamber itself. The temperature in the processes can be attained as per process requirements, without time lag. There is no dependency on the centralized heating system and better production planning can be achieved for the process (E-textile toolbox, 2005g). Heating up times are shorter in stenters with direct gas firing systems, which leads to reduced idling losses. When direct gas firing systems were first introduced there was concern that oxides of nitrogen, formed by the exposure of air to combustion chamber temperatures, would cause fabric yellowing or partial bleaching of dyes. This fear has been shown to be unjustified (Carbon Trust, 1997).

New machines have successfully been designed incorporating direct gas firing systems. In the modified design, the physical size and shape of the drier have not been altered and the existing air passage has been converted into a combustion chamber. A textile plant in India converted their thermic fluid system into a direct gas firing system and achieved 11000 GJ/year savings in fuel use (around 40% of the total fuel use) and 120 MWh/year savings in electricity use (around 90% of the total electricity use). The total investment cost of this retrofit measure was around US$50,000 with a payback period of one year (E-textile toolbox, 2005g).

86. Introduce mechanical de-watering or contact drying before stenter

Stentering is an energy intensive process, so it is important to remove as much water as possible before the fabric enters the oven. This can be achieved using mechanical dewatering equipment such as mangles, centrifuges, suction slots and air knives; or by using contact drying using heated cylinders. Up to 15% energy savings in the stenter (depending on the type of substrate) can be obtained if the moisture content of the fabric is reduced from 60% to 50% before it enters the stenter (European Commission, 2003).

Contact drying is roughly five times more energy intensive than suction slot de-watering, but uses only half to two-thirds the energy of a stenter. Pre-drying fabric to about 25 – 30% moisture content before passing it through the stenter still allows the fabric width to be adjusted to suit customer requirements. Other techniques used to reduce drying costs include infra-red and radio frequency drying. Gas-fired infra-red has been used for the pre-drying of textiles prior to stentering. This can have the effect of increasing drying speed by up to 50%, thereby relieving production bottlenecks which tend to occur at stenters. In addition, energy savings in the range of 50%–70% can be achieved compared to conventional stenter drying (Carbon Trust, 1997).

Radio frequency drying is used extensively for the drying and dye fixing of loose stock, packages, tops and hanks of wool and sewing cotton. The energy requirement of radio frequency drying is approximately 70% of that of a conventional steam-heated dryer. However, its use is limited to loose stock and packages. It cannot be modified, as yet, to accommodate knitted or woven fabric since the traditional pins and clips of the Stenter transport mechanism interfere with the radio frequency drying field, causing discharge.

A case-study of the provision of suction slot before the stenter resulted in annual saving of US$10,400 with an investment cost of US$1550 and operating costs (for suction) of US$1400 (E-textile toolbox, 2005h). BEE (2000) reports that the production rate could be increased by about 50% through the operation of suction slots before the stenter machine. Operation of suction slots increases the electrical load used for drying by approximately 25 kW. The energy use and saving per tonne of fabric produced for different types of fabrics is presented in Table 30. If all the benefit from the installation of suction slots is taken into account, then the payback period will be around 3 months, while the payback period will be around 19 months if only energy savings are taken into consideration.

Table 30. Energy Requirements per Tonne of Fabric Dried in Stenter Machines (BEE, 2000)

Fabric type	Mangle only-Typical energy use (GJ/ton)	Suction slot-Typical energy use(GJ/ton)	Typical % Energy Saving
Polyester and nylon (non-woven)	28.15	14.02	49.6
Nylon (woven)	11.79	5.57	49.1
Polypropylene (woven)	11.19	9.49	12.9

87. Avoid overdrying in stenter

The high-energy cost of running a stenter means that it is vital to avoid overdrying, similar to the concern mentioned in the discussion of cylinder dryers. Automatic infra-red, radioactive or conductivity-based moisture measurement systems can be linked to the stenter speed control to ensure that the appropriate fabric moisture content is achieved (Carbon Trust, 1997).

88. Close exhaust streams during idling in stenter

It is common practice to leave the exhaust systems running during the changing of batches, which may take 10 – 15 minutes or more and in some extreme cases (in some commission dyers) could happen every hour. Since stenters have a large air-heating requirement, it is important, whenever possible, to isolate the exhausts, or at least partially close them during idle periods (Carbon Trust, 1997). Proper scheduling in finishing minimizes machine stops and heating-up/cooling-down steps and is therefore a prerequisite for energy savings (European Commission, 2003).

89. Drying at higher temperatures in stenter

Drying at a higher temperature, if the fabric will tolerate it, means that radiation and convection losses become relatively small compared to evaporation energy, thereby reducing the total energy use per unit of product (Carbon Trust, 1997).

90. Close and seal side panels in stenter

On older machines, side panels may become damaged, distorting the air balance within the oven sections. All faulty panels should be repaired or replaced to provide an effective seal around the oven.

91. Proper insulation

Proper insulation of stenter envelopes reduces heat losses to a considerable extent. Improving stenter insulation is not usually practicable, although on some older machines it may be cost-effective to insulate the roof panels (Carbon Trust, 1997). Savings in energy consumption of 20% can be achieved if the insulation thickness is increased from 120 to 150 mm (provided that the same insulation material is used) (European Commission, 2003).

92. Optimize exhaust humidity in stenter

Table 29 above shows that the main energy requirements for a stenter are for air heating and evaporation. In order to optimize drying rates and energy use, air flows through the oven (and therefore the exhaust rate) must be carefully controlled. A significant number of stenters still rely on manual control of exhausts, although this is actually very difficult and often means that exhausts are left fully open unnecessarily. Energy consumption for air heating can reach up to 60% of the total energy requirement (compared to the 39.7% as shown in Table 29) if airflow is not monitored (European Commission, 2003). For optimum performance, exhaust humidity should be maintained between 0.1 and 0.15 kg water/kg dry air. It is not unusual to find stenters with an exhaust humidity of only 0.05 kg water/kg dry air, indicating that the exhaust volume is too great and excessive energy is being used to heat air.

Equipment is available which will automatically control dampers to maintain exhaust humidity within a specified range, thereby reducing air losses without significantly affecting fabric throughput. However, there are some fabrics and processes (notably pre-setting of some synthetics) which cause considerable fume problems, leading to a ‘blue haze’ emanating from the fabric slots. In these cases the stenter may be required to operate with fully open exhausts (Carbon Trust, 1997).

Another type of equipment is variable speed fans, which will automatically adjust exhaust airflow according to the moisture content of the exhaust air or according to the moisture content or temperature of the fabric after the process. A reduction of fresh air consumption from 10 kg fresh air/kg textile to 5 kg fresh air/kg textile results in 57% energy savings (European Commission, 2003). A case-study in a synthetic textile plant in India intended to control the exhaust air fan as per requirement and reduce losses by using a semi-automatic control system reported fuel savings of 670 GJ/year with an investment cost of only US$600 (E-textile toolbox, 2005i).

ECCJ (2007b) reports 20-80% energy savings by employing exhaust gas control system. The higher energy saving occurs in stenters with low utilization rate with exhaust dampers fully open and exhaust fans at full speed which results in huge heat waste without the exhaust gas control system. In a case-study for the use of automatic humidity control of stenter exhaust gas in a textile factory, it was observed that all exhaust fans of the stenter were operated at full speed. The exhaust gas humidity was controlled at a prescribed humidity by adjusting the flow rate of exhaust gas through the variable speed control of exhaust fans. This resulted in 3840 GJ/year fuel savings. The schematic of the exhaust gas rate control system is shown below.

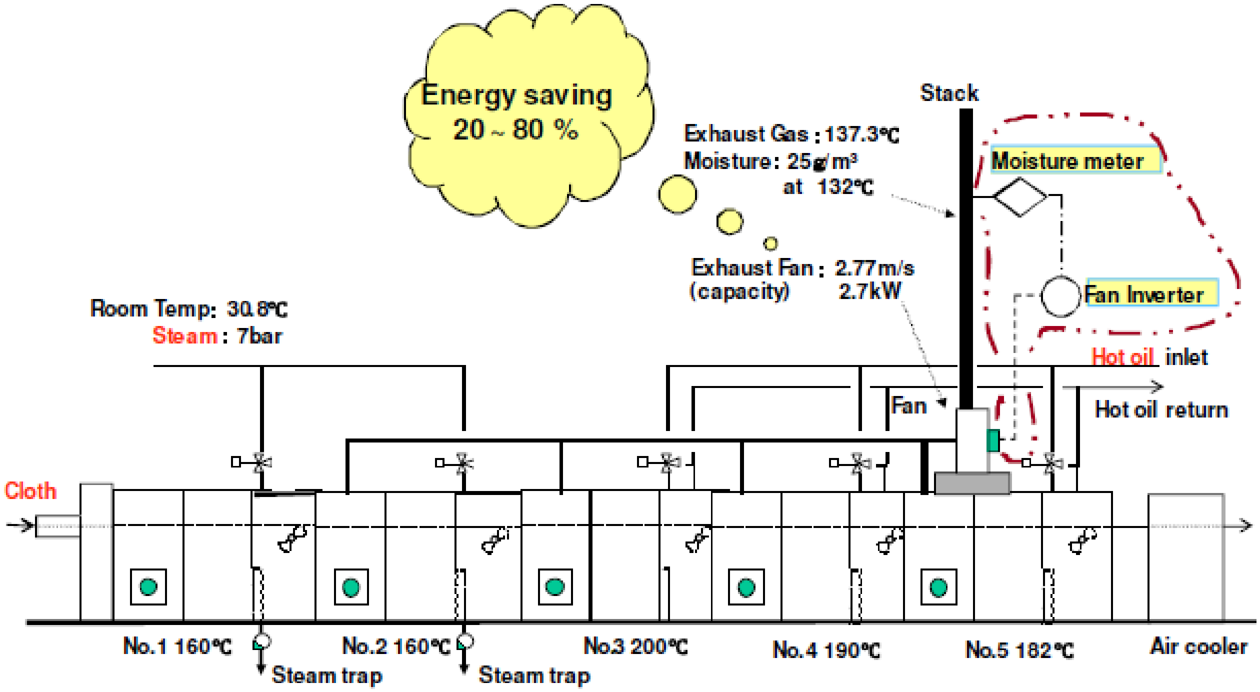

Figure 24. Schematic of the Exhaust Gas Rate Control System in a Stenter (ECCJ, 2007b)

93. Install heat recovery equipment in stenter

There are two types of heat recovery equipment that can be used to recover heat from stenters' exhaust gases. These are:

- Heat-recovery air/air: Uses exhaust air heat to heat up fresh air supplied to the stenter
- Heat-recovery air/water: Uses exhaust air heat to heat up service water for wet finishing (for example washing, dyeing, and bleaching.)

Exhaust heat recovery can be achieved by using air-to-air systems such as plate heat exchangers, glass tube heat exchangers or heat wheels. Efficiencies are generally about 50 – 60%, but there can be problems with air bypass, fouling and corrosion.

Air-to-water systems, such as spray recuperation, avoid fouling and clean the exhaust, but may increase corrosion. Secondary water/water heat exchange equipment is required and a matching heat requirement must be identified. The resultant hot water can be used in dyeing. Approximately 30% savings in energy can be achieved (European Commission, 2003). If large quantities of volatile organics or formaldehyde are generated by the stenter, some form of scrubber, electrostatic precipitator or even an incinerator may be required to comply with limits set by relevant environmental regulations (Carbon Trust, 1997). Due to the cooling of the outgoing airflow, pollutants that are in the air are condensed and can be removed with a filter. In this way organic pollutants are eliminated from the air emissions and the recovered heat can be reused. The investment cost varies from US$77,000 to US$460,000 (E-textile toolbox, 2005j).

Minimizing energy consumption in stenters, especially if heat recovery systems are installed, requires adequate maintenance (cleaning of the heat exchanger and stenter machinery, checking of control/monitoring devices, etc.). European Commission (2003) has given the payback data for heat recovery systems (both air/water and air/air systems) for drying and heat-setting processes, which are illustrated in Table 31.

Table 31. Payback Period of Heat Recovery Systems (Air/Water and Air/Air) for Different Processes (Textiles Drying and Heat Setting) and Required Number of Shifts per Day (European Commission, 2003)

System type	Process	1 shift/day		2 shift/day		3 shift/day	
		Savings (Euro)	Payback Period (yr)	Savings (Euro)	Payback Period (yr)	Savings (Euro)	Payback Period (yr)
Air/water Fresh water T: 15 °C	Drying	32,050	5.7	64,150	2.6	96,150	1.7
	Heat-setting	34,450	5.4	68,900	2.4	103,350	1.5
Air/water Fresh water T: 40 °C	Drying	18,050	12.6	36,100	5.9	54,150	3.3
	Heat-setting	23,350	8.6	46,700	3.7	70,050	2.4
Air/air Fresh water T: 20 °C	Drying	8000	>20	16,000	15.6	24,000	8.5
	Heat-setting	11,000	>20	22,000	9.6	33,000	6.6

Note: These results are based on the following reference data: heat recovery system: counter-flow pipes, drying temperature: 130 °C, heat setting: 190 °C, off-gas volume flow: 15000 m^3/h, off-gas moisture content (drying): 70 g/m^3; off-gas moisture content (heat-setting): 40 g/m^3; Temperature of the fresh water (before heat recovery): 15 °C, efficiency: 70 %, heating value of the gas 9.3 kWh/m^3; cost of the gas: 0.25 Euros/m^3; maintenance cost: 1000 Euros/yr, interest rate: 6 %.

The above information does not consider the installation of other measures such as fabric moisture controls and exhaust humidity controls. If these systems are installed, according to some sources heat recovery may not be cost-effective (European Commission, 2003). Several companies such as BRÜCKNER supply heat recovery equipment for stenters (BRÜCKNER, 2010).

94. Efficient burner technology in direct gas-fired systems in stenter

Optimized firing systems and sufficient maintenance of burners in direct gas-fired stenters can minimize methane emissions, which is important because methane emissions from burners greatly determine actual burner capacity. Stenters should receive general maintenance by specialized companies at regular intervals. There should also be routine checking of the burner air inlet for blockings by lint or oil, cleaning of pipe works to remove precipitates and adjusting of burners by specialists (European Commission, 2003).

95. The use of sensors and control systems in stenters

Sensors and control systems are very important for stenters in order to assure quality control as well as the efficient use of energy. PLEAVA (2009) lists some of the major control systems that are used in stenters as follows:

- *"Exhaust humidity measurement:* Measuring and controlling humidity to load exhaust air most efficiently with humidity. This reduces the volume of hot exhaust air, and thus energy waste, dramatically.
- *Residual moisture measurement:* Residual moisture control provides the highest productivity at the lowest energy cost. Overdrying and overheating of fabric can be avoided by using this control system.
- *Fabric and air temperature measurement:* Several fabric temperature sensors placed inside the stenter along with the fabric provide a good system for the supervision and optimization of heat treatment processes.
- *Process visualization systems:* These systems show the process parameters and how different parts of the machine are performing in real time and gives the operator useful information in order to better monitor the performance of the machine (Figure 25)" (PLEAVA, 2009).

Based on the data monitored by PLEAVA (a control systems provider for stenters) for the performance of its system on a stenter frame in Turkey, a 22% reduction in fuel use, a 11% reduction in electricity use and a 28% increase in production were reported.

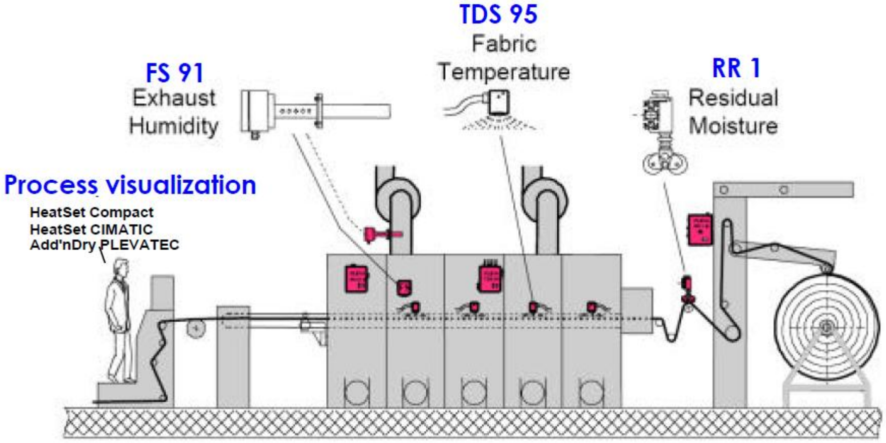

Figure 25. Schematic of the Sensors and Process Control Systems for the Stenter Frame Provided by PLEAVA Company (PLEAVA, 2009)

CIPEC (2007) has reported the capital cost for moisture humidity controllers for dryers and stenters to be in the wide range of US$20,000 – 220,000 with a payback period between of 1.5 and 5 years. Also, CIPEC (2007) has reported the capital cost for the dwell time controls system for dryers and stenters, which is one of the important control systems that can be installed in these machines, in the wide range of US$80,000 – 400,000 with a payback period of between 4 and 6.7 years. Figure 26 below is a quick graphical review of major energy-efficiency opportunities in stenter machines. Some good housekeeping measures for stenters are:

- It is recommended to utilize at least 75 – 80% of the width of the Stenter.
- Periodic cleaning of filters is necessary since clogged filters will impair drying efficiency,
- Ensure leak proof chamber doors and the adequate insulation of the top, bottom, and sides.
- The blower motor should be interlocked with the main drive, i.e. it will stop when the machine stops (E-textile toolbox, 2005k).

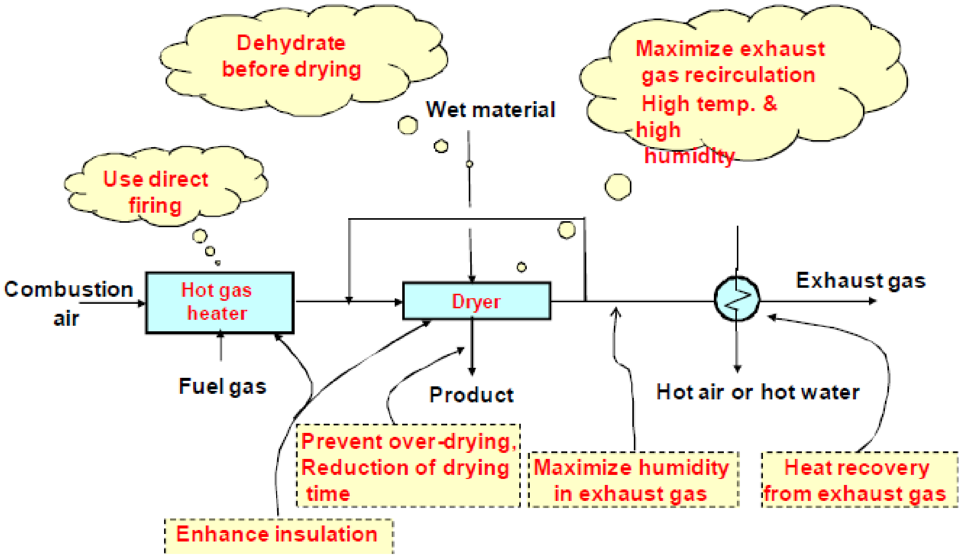

Figure 26. Energy-efficiency Opportunities in Stenter Machines (ECCJ, 2007b)

5.4.5. General energy-efficiency measures for wet-processing

96. Automatic steam control valves in the desizing, dyeing, and finishing of denim fabric

Steam is extensively used in textile wet-processing, such as in the desizing, dyeing and finishing of fabrics. In many plants, especially old ones, steam use is controlled manually in many parts of the process. This usually results in a significant waste of steam. A retrofit program can be introduced in such plants to replace the manual steam control system with an automatic system. An automatic steam control system controls the supply of the steam to each piece of equipment based on the requirements of the process, which are pre-set in the system; thereby avoiding an excess supply of steam into the machines. A denim fabric manufacturing plant in India installed automatic steam control valves in all desizing, dyeing and finishing processes and has reported 3250 GJ/year in fuel savings. The capital cost associated with these savings is reported to be about US$5100 for this case-study. The energy savings and cost can vary on a plant basis depending on the number of equipment on which the automatic steam control valves are installed and the operation of the plant (EMT, 2008I).

97. The recovery of condensate in wet-processing plants

Textile plants rely on a large amount of saturated steam in dyeing and other wet processes. Some of that steam converts into condensed water (condensate) over the course of its use. This condensate has a high temperature and purity. One of the best places to collect large volumes of condensate which forms in the woven fabric dyeing and finishing plants is in the drying cylinders, where fabric is dried by making contact with hot cylinders heated by steam. Knitted fabric plants find large sources of condensate primarily in steam traps. The most efficient use of condensate is to return it to the boiler and convert it back into new steam. However, for companies that buy their steam from an outside supplier or whose boiler is located too far from the process in which steam is used, condensate can serve as a water supply for washing or desizing, thereby recovering both water and heat.

In many textile plants, condensate is directly disposed of as waste water without reuse. In one textile dyeing plant studied by NRDC, the drying cylinders produced condensed water at a speed of 15 kg/h, which translated into 18,975 tonnes of condensed water per year, 2.5 % of the total water consumption in the factory. In addition to the water savings resulting from condensate recovery, the energy savings that accruing from condensate reuse are also substantial. Based on the case-studies in three textile plants in China by NRDC (Natural Resources Defense Council) and another study by Saad El-Din (2004), fuel savings of 1.3 – 2 GJ/tonne fabric and water savings of 2.6 – 6.0 ton/tonne fabric is achievable by implementation of this measure (Greer et al., 2010; Saad El-Din, 2004). This measure requires the installation of pipes to capture and return condensate. Estimates of investment costs have a large range, because they depend on the particular layout of the mill and the proximity of condensate sources to the boiler. Nevertheless, Canadian CIPEC (2007) gives an investment cost of about US$1000 – US$16,000 with a payback period of 2.5 – 6 years for condensate return recovery systems in batch dyeing machines (jet, beam, package, hank, jig and winches). Payback periods for different case-studies in China reported by NRDC were all less than a year (Greer et al., 2010).

98. Heat recovery from the air compressors for use in drying woven nylon nets

Depending on compressor type and loading, up to 85 – 90% of the electricity drawn by an air compressor is eventually wasted as heat. With simple safety modifications, waste heat from air compressors can be used for space heating. The alternative is to use the waste heat in a process where low heat is required. In a U.K.-based textile plant that produces woven nylon nets, a system was designed to use the waste heat from compressors in the net drying systems.

The plant designed and built a simple heat recovery system. The waste heat from the compressor is ducted into a converted shipping container. Inside the container, the waste heat is drawn through a bank of trolleys on which the wet nets are arranged. The hot dry air is drawn through the nets by an electric fan fitted to the base of each trolley, absorbing moisture along the way. The moist air stream is discharged to the atmosphere through vents cut into the side of the container (see Figure 27). The project has delivered annual savings of 7560 GJ.[27] The capital cost of the project was about US$8500 for the design, construction and implementation of the compressor waste heat recovery (Carbon Trust, 2005).

99. Utilization of heat exchangers for heat recovery from wet-process wastewater

Large volumes of heated water are presently being used in textile plants for rinsing in the desizing, scouring, and bleaching steps of continuous preparation ranges as well as in dyeing machines. Much of the hot process water and some of the chemicals that are presently being discharged as waste can be recovered and reused cost-effectively. A large number of different techniques for recovering waste heat exist which can reduce process operation cost and conserve significant amounts of fuel (Pulat et al., 2009).

Kiran-Ciliz (2003) reports energy savings of 1.1 – 1.4 GJ/tonne finished fabric by the utilization of "water to water" heat exchangers for heat recovery from process wastewater in a cotton knit wet-processing plant. For this purpose, a total investment of US$328,820 including the operating cost is reported for all items of installation (Kiran-Ciliz, 2003). Saad El-Din (2004) gives a

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[27] Note: Air compressors must be effectively cooled to prevent overheating, performance loss and damage. Appropriate design advice should be sought before implementing heat recovery projects.

higher energy savings from heat recovery from cooling water and hot/waste water in wet-processing plants. That report gives a fuel savings of 10.5GJ/tonne fabric, an electricity savings of 5.5 kWh/tonne fabric and a water savings of 12.6 m^3/tonne fabric produced. The cost associated with these savings is US$38.4 per annual tonne fabric production capacity.

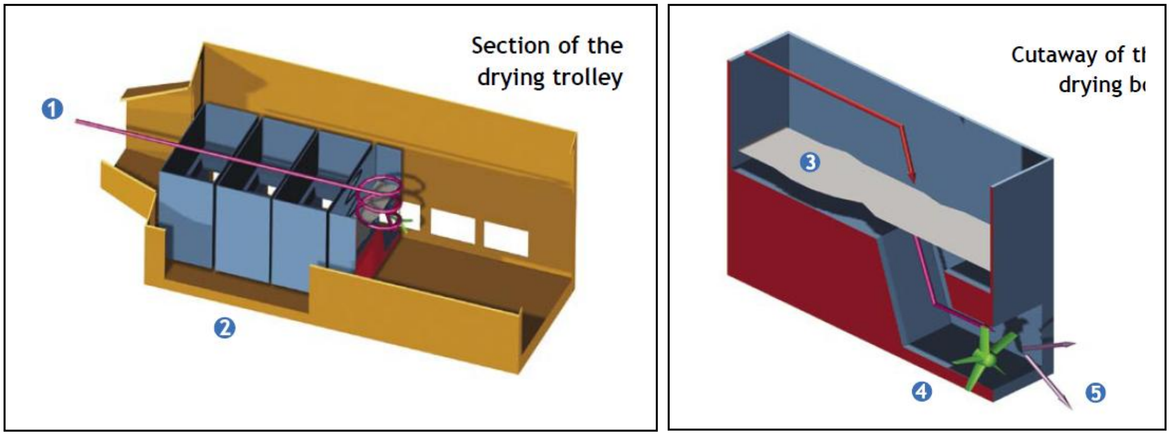

Figure 27. The Schematic of the System Designed for Heat Recovery from Air Compressors (Carbon Trust, 2005)

It should be noted that Saad El-Din (2004) also considers the heat recovery from cooling water, whereas Kiran-Ciliz's (2003) saving values are just for heat recovered from wastewater. CIPEC (2007), however, gives a range of US$58,800 – US$250,000 for the cost of wastewater heat recovery systems in wet-processing plants with a payback period of 0.3 – 4.2 years. A schematic of waste heat recovery from the hot effluent of dyeing machine is shown in Figure 28.

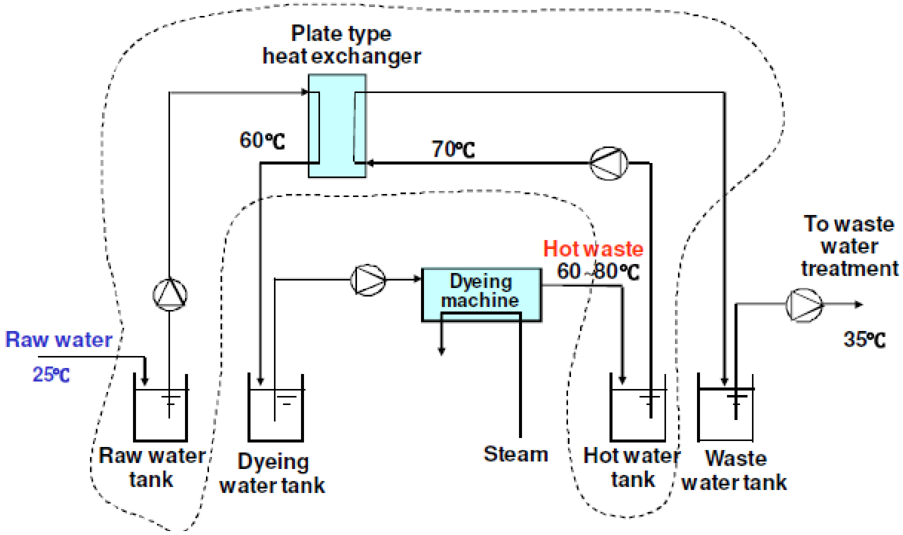

Figure 28. Schematic of Waste Heat Recovery from the Hot Effluent of Dyeing Machines (ECCJ, 2007b)

5.5. Energy-efficiency technologies and measures in man-made fiber production

Table 32 shows the list of measures/technologies included in this guidebook for the man-made fiber production.

Table 32. List of Energy-efficiency Measures and Technologies for the Man-Made Fiber production *

No.	Energy-efficiency Technologies and Measures	Fuel saving	Electricity saving	Capital Cost	Payback period (years)**
5.4	**Man-made fiber Production**				
100	Installation of Variable Frequency Drive (VFD) on hot air fans in after treatment dryer in Viscose Filament production		105 MWh/year/dryer	11,000/ dryer	1.3
101	The use of light weight carbon reinforced spinning pot in place of steel reinforced pot		9.6 MWh/spinning machine/year	680/ machine	< 1
102	Installation of Variable Frequency Drives in fresh air fans of humidification system in man-made fiber spinning plants		32.8 MWh/fan/year	5600/ fan	2.3
103	Installation of Variable Frequency drives on motors of dissolvers		49.5 MWh/agitator/year	9500/ agitator	2.6
104	Adoption of pressure control system with VFD on washing pumps in After Treatment process		40.4 MWh/pump/year	930/ pump	< 1
105	Installation of lead compartment plates between pots of spinning machines		7 MWh/machine/year		< 0.5
106	Energy-efficient High Pressure steam-based Vacuum Ejectors in place of Low Pressure steam-based Vacuum Ejectors for Viscose Deaeration	3800 GJ/year/plant		29000/plant	
107	The use of heat exchanger in dryer in Viscose filament production	1 GJ/hour of dryer operation		66700/system	
108	Optimization of balloon setting in TFO machines		205 MWh/year/plant		
109	Solution spinning high-speed yarn manufacturing equipment (for filament other than urethane polymer)		500 MWh/machine (16 spindles)/year	200000/machine	5.3
110	High-speed multiple thread-line yarn manufacturing equipment for producing nylon and polyester filament		55%	320000/machine	
111	Reduction in height of spinning halls of man-made fiber production by installation of false ceiling		788 MWh/year/plant	190000/plant	3.2
112	Improving motor efficiency in draw false-twist texturing machines		73 MWh/year/machine	80,000/ machine	14.6

* The energy savings, costs, and payback periods given in the table are for the specific conditions. There are also some ancillary (non-energy) benefits from the implementation of some measures. Please read the explanation of each measure to get the complete understanding of the savings and costs.

**Wherever the payback period was not given while the energy and cost are given, the payback period is calculated assuming the price of electricity of US$75/MWh (US$0.075/kWh).

100. Installation of variable frequency drives (VFD) on hot air fans in after treatment dryers in viscose filament production

The raw material for cellulose fiber production (rayon) is wood pulp which is an inexpensive and renewable resource, however the processing of the wood pulp into rayon is a highly energy and water intensive process. The production of rayon involves three stages: 1. dissolution of the wood pulp, 2. extrusion of the yarn, and 3. purification of the yarn by bleaching and washing. The purified rayon is dried using hot air driers (Figure 29).

The drying process of the yarn cakes is the final stage of rayon production and it is carried out using air dryers which circulate hot air to remove moisture from yarn cakes. The drying is carried out in various stages in different zones of the dryer, as shown in Figure 30. Maximum drying occurs in the first two zones, and drying gradually reduces in subsequent zones. In the last zone, the moisture removal rate is very low and is independent of air velocity. Hence the speed of air circulation fans in the last zone, where the drying rate is independent of air velocity, can be reduced.

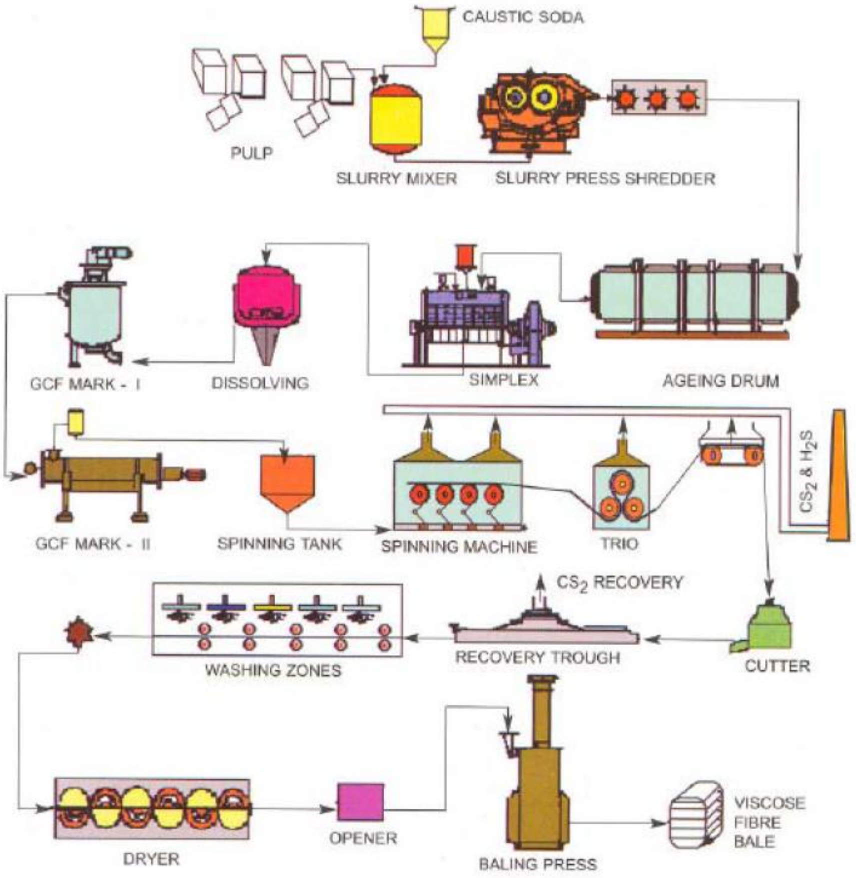

Figure 29. Process Flow Diagram of Viscose Staple Fiber Production (EMT, 2006C)

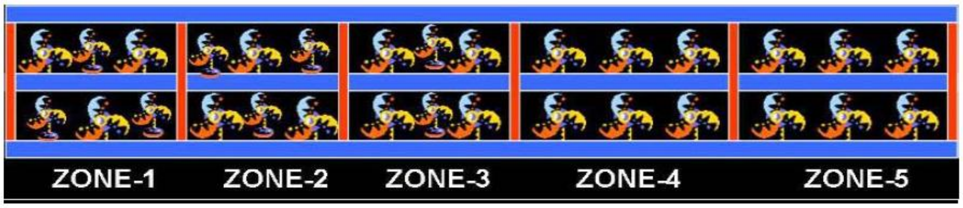

Figure 30. Zones in an After Treatment Dryer (Before Modification) (CII, 2007)

In one of its plants, Century Rayon Company, the largest viscose filament yarn producer in India, modified four of its after treatment dryers in order to optimize the air velocity in the last zones of the dryer. The new system consists of the installation of variable frequency drives (VFD) for a group of motor driven hot air fans and these fans are grouped based on the zones, as shown in Figure 31. In the initial stage (zone 1, 2, 3) where the amount of moisture is high, the VFDs are operated at higher speeds (RPMs) to deliver more hot air flow and thus reduce the moisture content. As the yarn passes through the second stage (zone-4) the speed of the motors is reduced as the moisture removal is reduced from that of the initial stage. In the final stage (zone-5) the amount of moisture is very minimal and thus the speed of the hot air fans is further reduced as, shown in the figure. Fan speed reduction using a variable frequency drive for a group of motors has resulted in significant energy savings (CII, 2007).

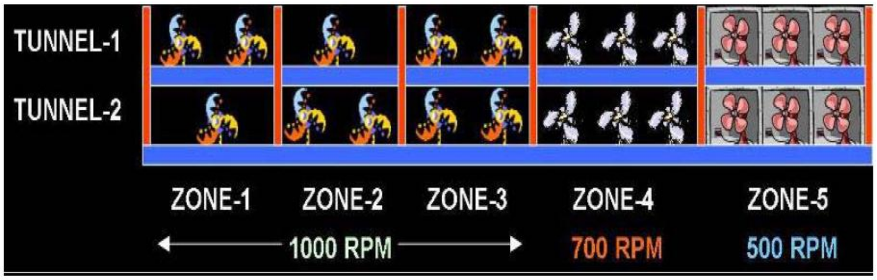

Figure 31. Zones in an After Treatment Dryer (Modified System) (CII, 2007)

Century Rayon Company installed VFDs on all the air circulation fans of the last two zones of all 4 of its Japanese dryers in 2006. The speed of zone 4 was reduced from 1000 to 700 RPMs and the speed of zone 5 was reduced from 1000 to 500 RPMs. This has resulted in 105 MWh/year/dryer in electricity savings with a capital cost of US$11,000 per dryer. The payback period is reported to be around 15 months (EMT, 2006d).

101. The use of light weight carbon reinforced spinning pots in place of steel reinforced pots

Conventionally, steel reinforced spinning pots are used in synthetic fiber production plants. In Century Rayon Company's plant in India, the weight of a steel reinforced spinning pot was 2.8 kg and the energy consumption per spinning machine per day was about 581 kWh. Steel reinforced spinning pots can be replaced with carbon reinforced spinning pots. The weight of the carbon reinforced pots used in Century Rayon Company's plant is 2.2 kg (Figure 32).

After the replacement, the energy consumption per spinning machine per day was reduced to 549 kWh. The reduction in weight of spinning pots thus resulted in a reduction in energy consumption of 9.6 MWh per spinning machine per year. The investment cost of the replacement was around US$680 per machine. Century Rayon Company implemented this retrofit measure on 39 spinning machines and reported a payback period of 9 months for the investment (UNEP Risoe Center, 2007).

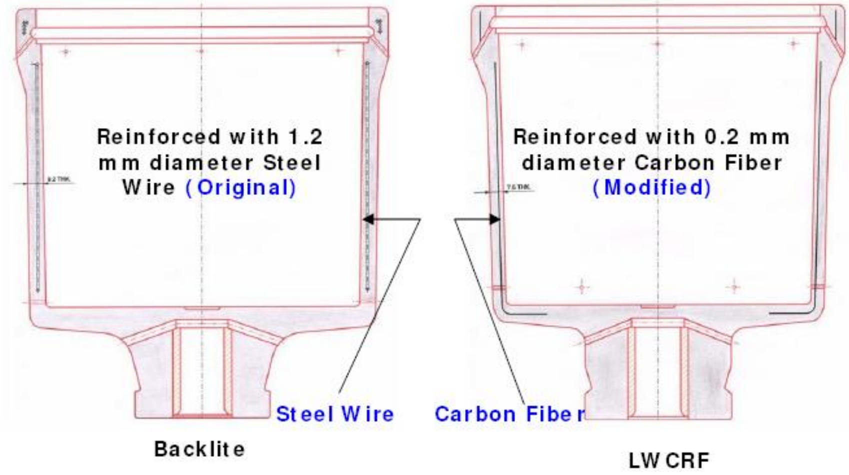

Figure 32. Steel Reinforced and Carbon Reinforced Spinning Pots (UNEP Risoe Center, 2007)

102. Installation of variable frequency drives in fresh air fans of humidification systems in man-made fiber spinning plants

In some parts of the production process of man-made fibers, the temperature and humidity of the ambient air should be controlled and maintained according to certain requirements. Therefore, in man-made fiber production plants, there are several air conditioning and humidification systems. Variable frequency drives can be installed on fresh air fans of the humidification system. The speed of all these fans can be controlled by changing the frequency of the VFD as to meet the requirement for fresh air by measuring the temperature as well as the relative humidity (RH) of the ambient air in the production process. A viscose filament production plant in India installed VFDs on 19 fresh air fans in its humidification systems. This resulted in an average electricity savings of 32.8 MWh/fan/year. The investment cost is reported to be around US$5600 per fan (EMT, 2008J).

103. Installation of variable frequency drives on motors of dissolvers

Dissolvers are used in the production of viscose filaments, for example in the immersion step where the cellulose is dissolved in caustic soda. The dissolvers normally run with a fixed speed, while the speed could be adjusted based on the process requirements. A viscose filament production plant in India installed VFDs on six dissolvers for speed control as per the process requirements. They have reported an average electricity savings of 30.3 MWh/dissolver/year. The investment cost was around US$16,400 per dissolver (EMT, 2008j).

In another plant belonging to Century Rayon Company, every batch in the dissolver takes 180 minutes, during which the agitator was run at a fixed speed of 1000 RPM. They decided to run the agitator at lower speed of 500 RPM for the last 60 minutes (1000 RPM for the first 120 minutes) by installing VFDs. This resulted in electricity savings of 49.5 MWh/agitator/year with an investment cost of about US$9500 per agitator. There was no impact observed on the viscose quality (EMT, 2006d).

104. Adoption of pressure control systems with VFDs on washing pumps in the after treatment process

Variable frequency drives with pressure controls can be installed on washing pumps in the after treatment process of viscose yarn production. In this way, the energy consumption of washing pumps can be optimized by varying the speed of the pumps as per the variation in the denier (thickness) of yarn. A viscose filament production plant in India installed this measure on 19 washing pumps and on average achieved an electricity savings of 40.4 MWh/pump/year with an investment cost of US$930 per pump (EMT, 2007b).

105. Installation of lead compartment plates between pots of spinning machines

In spinning machines, spinning pots are rotating at around 7800 RPM. This produces cross currents of air between adjacent pots. This cross current of air increases the electrical load of machines. Lead compartment plates can be installed between each spinning pot to overcome the cross current of air between the pots (Figure 33). Century Rayon Company in India installed lead compartment plates in 69 spinning machines. They have reported an average electricity savings of 7 MWh/machine/year. The investment cost of the installation is not reported, but it is said that the payback period is immediate (EMT, 2005C).

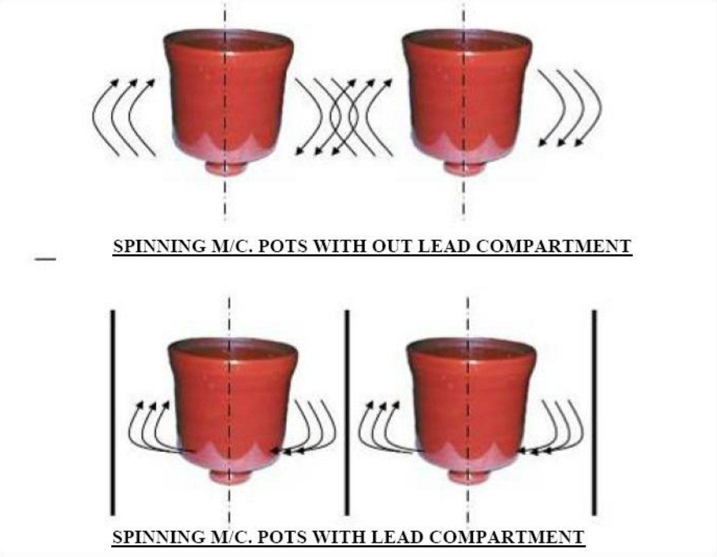

Figure 33. Installation of Lead Compartment Plates Between Pots of Spinning Machines (EMT, 2005C)

106. Energy-efficient high pressure steam-based vacuum ejectors in place of low pressure steam-based vacuum ejectors for viscose deaeration

The function of viscose deaerator is to remove trapped air bubbles from filtered viscose before it is pumped to spinning machine for regeneration. Conventionally, a low pressure, steam-based four stage vacuum ejector is used for this purpose. However, low pressure steam-based four stage ejectors are sometimes not able to create the required vacuum due to less steam pressure. This results in higher steam consumption. To solve this problem, two stage high pressure steam-based ejectors can be installed in place of low pressure steam-based ejectors. The implementation of this measure in a plant in India resulted in fuel savings of about 3800 GJ/year with an investment cost of US$29,000 (EMT, 2004b).

107. The use of heat exchangers in dryers in viscose filament production plants

In dryers in viscose filament production lines, fresh air is usually heated through steam coils and then is circulated to the drying chambers. The moist vapor is then exhausted to the atmosphere at around 90 ℃. A heat exchanger can be installed in order to recover the heat in the exhaust air and use it to preheat the fresh air. This will result in significant fuel savings. The energy savings from the installation of heat exchangers can be as high as 1 GJ/hour of dryer operation. The investment cost for the heat exchanger is reported to be around US$66,700 (BEE, 2003).

108. Optimization of balloon setting in TFO machines

Research has shown that TFO (two-for-one) twister machines consume less electricity at lower yarn balloon settings. However, the balloon size cannot be simply just lowered; rather the balloon setting should be optimized by conducting various studies with respect to different yarn counts and yarn twists. An electricity savings of 205 MWh/year is reported as a result of implementation of this measure, but the number of machines on which the measure was implemented was not specified (gtz, 2007).

109. Solution spinning high-speed yarn manufacturing equipment (for filament other than urethane polymer)[28]

This equipment achieves high-performance and energy savings while employing new technology for the manufacture of yarn from raw materials such as rayon. The equipment is comprised primarily of the raw material mixing equipment and the spinning head. The polymer is extruded by a gear pump through the spinning nozzle while being dissolved, filtered, and degassed in the raw liquid mixing equipment. In the spinning head, the raw liquid exiting the nozzle is passed through the primary, secondary, and tertiary spindle units for molecular alignment, and fully coagulated to form the yarn (Figure 34).

In conventional equipment, 16 filaments can be spun from each machine, whereas with this equipment, an efficient electric motor providing high-speed spinning has been adopted to permit the spinning of 24 filaments per machine. The high-speed and energy-efficient motors employed have increased spinning speed by a factor of approximately 2.7 (300m/min → 800m/min), and also reduced electricity use by about 35%. Electricity savings can be as high as 500 MWh/machine (16 spindles)/year. Furthermore, this equipment has few consumable components, dramatically reducing maintenance costs. The investment cost for the installation of this measure (including construction cost) is about US$200,000. There are many examples of installation of this equipment in large plants throughout Japan (NEDO, 2008).

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[28] This section is excerpted from NEDO (2008).

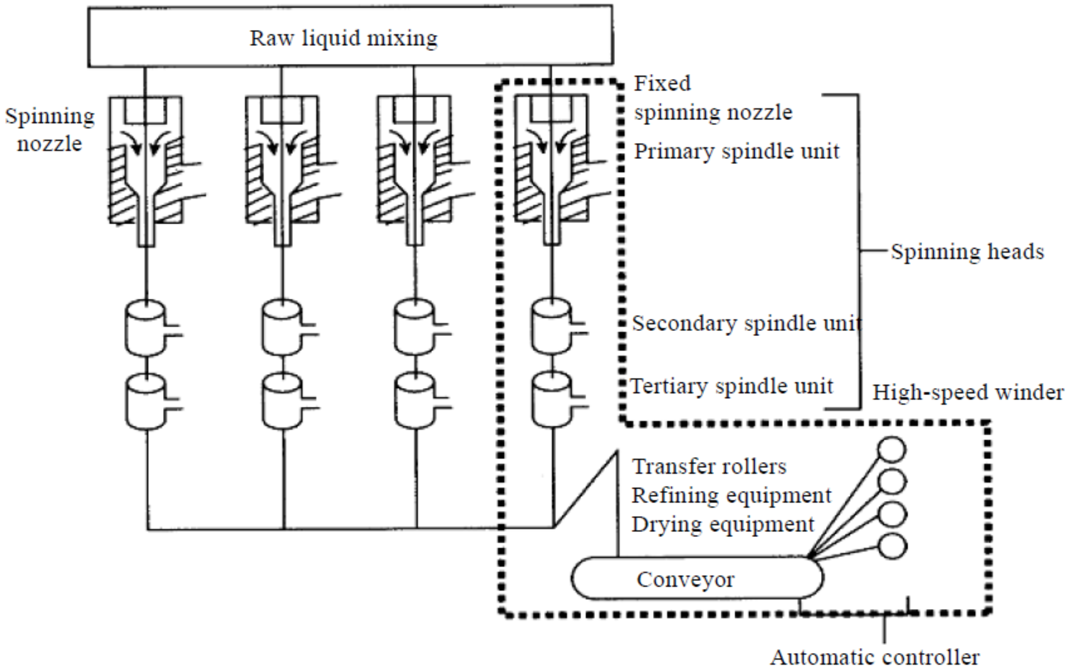

Figure 34. Schematic of Solution Spinning High-Speed Yarn Manufacturing Equipment (NEDO, 2008)

110. High-speed multiple thread-line yarn manufacturing equipment for producing nylon and polyester filament[29]

This equipment is different from the one explained above and it melts and spins nylon and polyester filament to spin fully drawn filament (FDY) or partially oriented filament (POY) at a high speed of 6,000m/min. In addition, drawn winding is performed on the same process to enhance energy efficiency and productivity (Figure 35). Conventional equipment types are batch or indirect continuous, because spun yarn is produced in the spinning and then the final filament (FOY or POY filaments) is produced in drawing machines. The new equipment performs the spinning process and filament making process continuously, resulting in a 55% decrease in electricity consumption. The investment cost for the installation of this equipment is about US$320,000 (NEDO, 2008).

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[29] This section is excerpted from NEDO (2008).

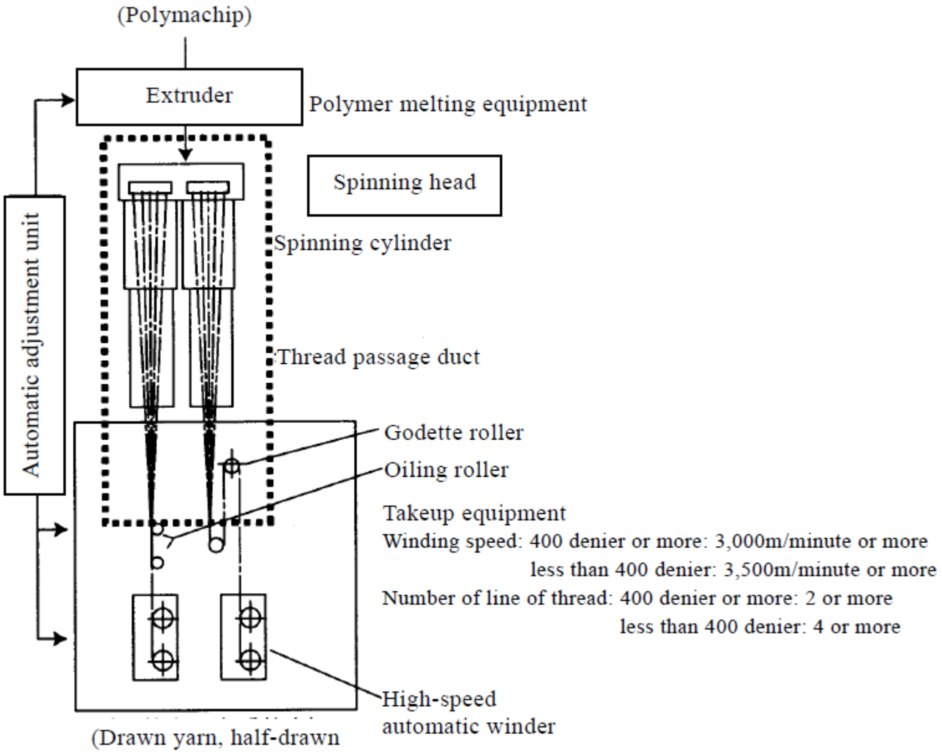

Figure 35. Schematics of the High-Speed Multiple Thread-Line Yarn Manufacturing Equipment (NEDO, 2008)

111. Reduction in the height of spinning halls of man-made fiber production through the installation of false ceilings

Since the spinning halls of almost all man-made fiber production processes needs air conditioning and humidification systems, the volume of the hall has a direct effect on the energy use of the HVAC (humidification, ventilation, and air conditioning) system. In some plants, the height of the spinning halls is unnecessarily high. False ceilings can be installed to reduce the height of the hall; thereby reducing the energy use of the HVAC system. A plant in India installed false ceilings in its spinning halls, reducing the height of the halls by about one meter. This resulted in 788 MWh/year electricity savings in the HVAC system. The investment cost is reported to be around US$190,000. Savings and cost may vary depending on the area of the hall in which the false ceiling is installed (EMT, 2007b).

112. Improving motor efficiency in draw false-twist texturing machines[30]

A draw false-twist texturing machine draws and false-twists undrawn thread in the polyester filament manufacturing process. This equipment is driven by an electric motor, and conventionally employs the primary voltage thyristor control system of induction motors for speed control of the motor. This method has the disadvantages of 1) considerable electricity consumption at low-speeds, and 2) considerable consumption of electricity by the motor cooling fan. Furthermore, since a large amount of heat is generated by the thyristor control system, problems such as seizing of motor bearings are common, resulting in layered yarn and consequent losses, and significant motor repair costs.

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[30] This section is excerpted from NEDO (2008).

The energy efficiency of the draw false-twist texturing machines can be improved by the use of combined transistor-VFD systems for the speed control of the motor (Figure 36). An electricity savings of 73MWh/machine/year can be achieved (24 h/day, 330 day/year operation). The investment cost for this technology is US$80,000 per machine (NEDO, 2008).

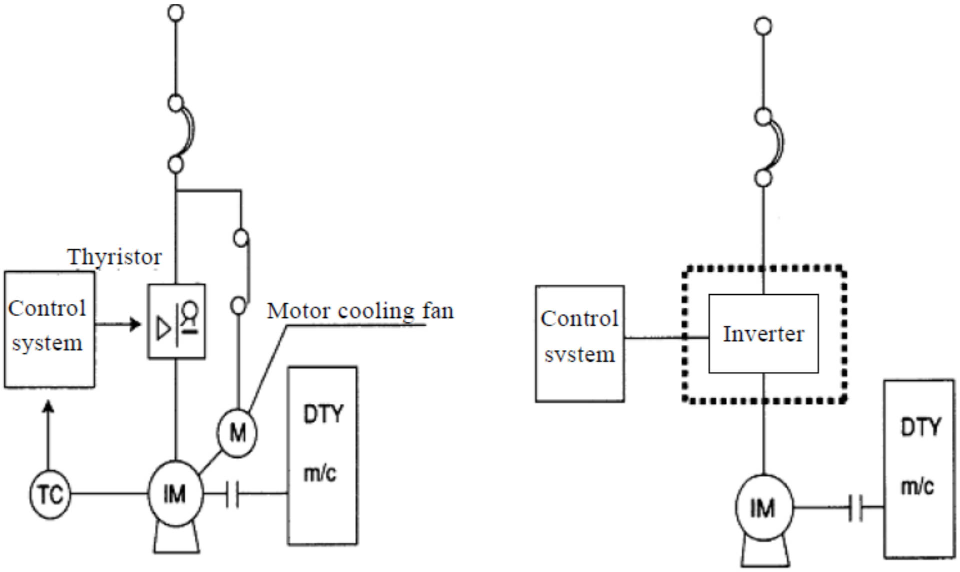

FIG. 1 Thyristor Control System

FIG. 2 Transistor-inverter Frequency Controlled System

Figure 36. The Thyristor System (Fig.1) and the Transistor-Inverter Control System (Fig.2) (NEDO, 2008)

5.6. Cross-cutting energy-efficiency measures

Table 33 shows the list of cross-cutting energy-efficiency measures/technologies included in this guidebook.

Table 33. List of Cross-Cutting Energy-efficiency Measures and Technologies *

No.	Energy-efficiency Technologies and Measures	Fuel saving	Electricity saving	Capital Cost	Payback Period (years)
5.5	**Cross-cutting energy-efficiency measures**				
5.5.1	**Electrical demand control**				
113	Electrical demand control				
5.5.2	**Energy-efficiency improvement opportunities in *electric motors***				
114	Motor management plan				
115	Maintenance		2% - 30% of motor system energy use		
116	Energy-efficient motors				
117	Rewinding of motors				
118	Proper motor sizing				
119	Adjustable speed drives		7% - 60%		< 3
120	Power factor correction				
121	Minimizing voltage unbalances				< 3
5.5.3	**Energy-efficiency improvement opportunities in *compressed air* systems**				
122	Reduction of demand				
123	Maintenance				
124	Monitoring				
125	Reduction of leaks (in pipes and equipment)		up to 20% of compressed air system energy use		
126	Electronic condensate drain traps (ECDTs)				
127	Reduction of the inlet air temperature		each 3 ℃ reduction will save 1% compressor energy use		< 5
128	Maximizing allowable pressure dew point at air intake				
129	Optimizing the compressor to match its load				
130	Proper pipe sizing		up to 3% of compressed air system energy use		
131	Heat recovery		up to 20% of compressed air system energy use		< 1
132	Adjustable speed drives (ASDs)		up to 15% of compressed air system energy use		
5.5.4	**Energy-efficiency improvement opportunities in *pumping* systems**				
133	Maintenance		2% - 7% of pumping electricity use		< 1
134	Monitoring				
135	Controls				
136	Reduction of demand		10% - 20% of pumping electricity use		
137	More efficient pumps		2% - 10% of pumping electricity use		
138	Proper pump sizing		15% - 25% of		< 1

No.	Energy-efficiency Technologies and Measures	Fuel saving	Electricity saving	Capital Cost	Payback Period (years)
			pumping electricity use		
139	Multiple pumps for varying loads		10% - 50% of pumping electricity use		
140	Impeller trimming (or shaving sheaves)		up to 75% of pumping electricity use		
141	Adjustable speed drives (ASDs)		20% - 50% of pumping electricity use		
142	Avoiding throttling valves				
143	Proper pipe sizing				
144	Replacement of belt drives		up to 8% of pumping electricity use		< 0.5
145	Precision castings, surface coatings or polishing				
146	Improvement of sealing				
5.5.5	**Energy-efficiency improvement opportunities in *fan* systems**				
147	Minimizing pressure				
148	Control density				
149	Fan efficiency				
150	Proper fan sizing				
151	Adjustable speed drives (ASDs)		14% - 49% of fan system electricity use		
152	High efficiency belts (cogged belts)		2% of fan system electricity use		1 - 3
5.5.6	**Energy-efficiency improvement opportunities in *lighting* system**				
153	Lighting controls				< 2
154	Replace T-12 tubes by T-8 tubes		114 MWh/year/1196 light bulbs	26800/ 1196 light bulbs	
155	Replace Mercury lights by Metal Halide or High Pressure Sodium lights		50% - 60% / bulb		
156	Replace Metal Halide (HID) with High-Intensity Fluorescent lights		50% / bulb	185/ fixture	
157	Replace Magnetic Ballasts with Electronic Ballasts		936 kWh/ballast/year	8/ ballast	
158	Optimization of plant lighting (Lux optimization) in production and non-production departments				
159	Optimum use of natural sunlight				
5.5.7	**Energy-efficiency improvement opportunities in *steam* systems**				
160	Demand Matching				< 2
161	Boiler allocation control				
162	Flue shut-off dampers				
163	Maintenance	up to 10% of boiler energy use			< 0.5
164	Insulation improvement	6% - 26% of boiler energy use			
165	Reduce Fouling				
166	Optimization of boiler blowdown rate				1 - 3
167	Reduction of flue gas quantities				
168	Reduction of excess air				< 1
169	Flue gas monitoring				< 1
170	Preheating boiler feed water with heat from flue gas (economizer)	5% - 10% of boiler			< 2

No.	Energy-efficiency Technologies and Measures	Fuel saving	Electricity saving	Capital Cost	Payback Period (years)
		energy use			
171	Recovery of heat from boiler blowdown				< 2
172	Recovery of condensate				1
173	Combined Heat and Power (CHP)				
174	Shutting off excess distribution lines				
175	Proper pipe sizing				
176	Insulation related measures				1.1
177	Checking and monitoring steam traps	up to 10% of boiler energy use			< 0.5
178	Thermostatic steam traps				
179	Shutting of steam traps				< 0.5
180	Reduction of distribution pipe leaks				< 0.5
181	Recovery of flash steam				
182	Prescreen coal	1.8 GJ/tonne finished fabric		35000 / system	< 0.5

* The energy savings, costs, and payback periods given in the table are for the specific conditions. There are also some ancillary (non-energy) benefits from the implementation of some measures. Please read the explanation of each measure to get the complete understanding of the savings and costs.

5.6.1. Electrical demand control (113)

Demand control is a follow-up analysis that is normally conducted after the development of a demand/load profile by energy auditors. Demand control is nothing more than a technique for leveling out the load profile, i.e. “shaving” the peaks and “filling” the valleys (Figure 37). The main advantage of demand control and load management is the reduction of electricity costs. In practice the demand limit of a plant is higher than the average electricity requirement since it is rarely possible to operate with constant power consumption. The first step in demand control analysis is to analyze a plant’s electricity utility tariff structure and past history of power demand. The load factor is a useful tool in demand control analysis.

Calculating the load factor (LF):

The load factor is the ratio of the energy consumed during a given period (the period of an electricity bill) to the energy which would have been consumed if maximum demand had been maintained throughout the period.

$$\text{Load factor (\%)} = \frac{\text{Energy used during the period (kWh)}}{\text{Maximum demand (kW)} \times \text{Time under consideration (hr)}} \times 100$$

Maximum demand and total kilowatt-hours are easily obtained from past electricity bills. Normally the load factor is less than 100%. That is, the energy consumed is less than the maximum power demand at any time in the period multiplied by the total period time. In general, if the load factor in a plant is reduced, the total cost of electricity will be higher (Morvay and Gvozdenac 2008). In other words, the load factor is a useful method of determining if a plant is utilizing its energy consuming equipment on a consistent basis (higher LF), or using the equipment for a shorter duration (lower LF), thereby paying a demand penalty. Therefore, the plant's load factor should be analyzed to determine the opportunity for improvement and demand control (Rutgers 2001).

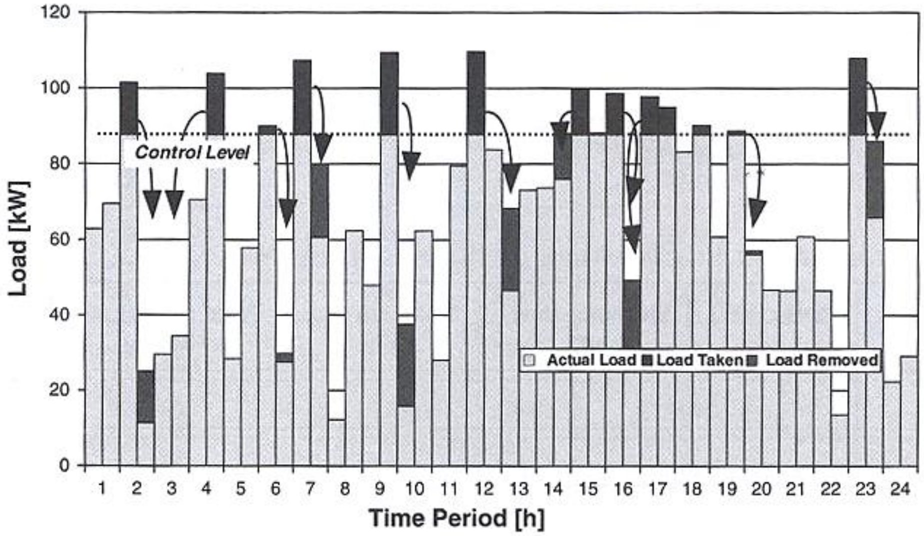

Figure 37. Load Profile with Load Factor Control (LF = 80%) (Morvay and Gvozdenac 2008)

The simplest method for reducing peak loads is to schedule production activities in a way that the big electrical power users do not operate at the peak time at all, or at least some of them do not operate at the same time, if possible. *Machine scheduling* is the practice of turning equipment on or off depending on the time of day, day of week, day type, or other variables and production needs. Improved machine scheduling is achieved through better production planning. Efficient production planning that takes into account the energy aspects of production is one of the most effective ways to avoid machine idling and to reduce peak demand. The *second method* relies on automatic controls which shut down non-essential loads for a predetermined period during peak times by means of some load management devices such as: simple switch on-off devices, single load control devices, demand limiters, or a computerized load management system (Morvay and Gvozdenac 2008).

5.6.2. Energy-efficiency improvement opportunities in *electric motors*[31]

When considering energy-efficiency improvements to a facility's motor systems, a systems approach incorporating pumps, compressors, and fans must be used in order to attain optimal savings and performance. In the following, considerations with respect to energy use and energy saving opportunities for a motor system are presented and in some cases illustrated by case studies. Pumping, fan and compressed air systems are discussed in addition to the electric motors.

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[31] This section is excerpted from Worrell et al. (2010). However, the sources of each section which are given in Worrell et al. (2010) are also provided in the text here. The case-studies are from different sources which are also provided.

114. Motor management plan

A motor management plan is an essential part of a plant's energy management strategy. Having a motor management plan in place can help companies realize long-term motor system energy savings and will ensure that motor failures are handled in a quick and cost effective manner. The Motor Decisions Matter^{SM} Campaign suggests the following key elements for a sound motor management plan (CEE, 2007):

1. Creation of a motor survey and tracking program.
2. Development of guidelines for proactive repair/replace decisions.
3. Preparation for motor failure by creating a spares inventory.
4. Development of a purchasing specification.
5. Development of a repair specification.
6. Development and implementation of a predictive and preventive maintenance program.

115. Maintenance

The purposes of motor maintenance are to prolong motor life and to foresee a motor failure. Motor maintenance measures can therefore be categorized as either preventative or predictive. Preventative measures, include voltage imbalance minimization, load consideration, motor alignment, lubrication and motor ventilation. Some of these measures are further discussed below. Note that some of them aim to prevent increased motor temperature which leads to increased winding resistance, shortened motor life, and increased energy consumption. The purpose of predictive motor maintenance is to observe ongoing motor temperature, vibration, and other operating data to identify when it becomes necessary to overhaul or replace a motor before failure occurs (Barnish *et al.*, 1997).

The savings associated with an ongoing motor maintenance program could range from 2% to 30% of total motor system energy use (Efficiency Partnership, 2004).

116. Energy-efficient motors

Energy-efficient motors reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, energy-efficient motors can also stay cooler, may help reduce facility heating loads, and have higher service factors, longer bearing life, longer insulation life, and less vibration.

The choice of installing a premium efficiency motor strongly depends on motor operating conditions and the life cycle costs associated with the investment. In general, premium efficiency motors are most economically attractive when replacing motors with annual operation exceeding 2,000 hours/year. Sometimes, even replacing an operating motor with a premium efficiency model may have a low payback period. According to data from the Copper Development Association, the upgrade to high-efficiency motors, as compared to motors that achieve the minimum efficiency as specified by the Energy Policy Act of 1992 can have paybacks of less than 15 months for 50 hp motors (CDA, 2001).

117. Rewinding of motors

In some cases, it may be cost-effective to rewind an existing energy-efficient motor, instead of purchasing a new motor. As a rule of thumb, when rewinding costs exceed 60% of the costs of a new motor, purchasing the new motor may be a better choice (CEE, 2007).

When repairing or rewinding a motor, it is important to choose a motor service center that follows best practice motor rewinding standards in order to minimize potential efficiency losses. Such standards have been offered by the Electric Apparatus Service Association (EASA) (EASA, 2006). When best rewinding practices are implemented, efficiency losses are typically less than 1% (EASA, 2003). Software tools such as MotorMaster$^+$ can help identify attractive applications of premium efficiency motors based on the specific conditions at a given plant.

118. Proper motor sizing

It is a persistent myth that oversized motors, especially motors operating below 50% of rated load, are not efficient and should be immediately replaced with appropriately sized energy-efficient units. In actuality, several pieces of information are required to complete an accurate assessment of energy savings. They are the load on the motor, the operating efficiency of the motor at that load point, the full-load speed (in revolutions per minute [rpm]) of the motor to be replaced, and the full-load speed of the downsized replacement motor

The efficiency of both standard and energy-efficient motors typically peaks near 75% of full load and is relatively flat down to the 50% load point. Motors in the larger size ranges can operate with reasonably high efficiency at loads down to 25% of rated load. There are two additional trends: larger motors exhibit both higher full- and partial-load efficiency values, and the efficiency decline below the 50% load point occurs more rapidly for the smaller size motors. Software packages such as MotorMaster$^+$ can aid in proper motor selection.

119. Adjustable speed drives (ASDs)[32]

Adjustable-speed drives better match speed to load requirements for motor operations, and therefore ensure that motor energy use is optimized to a given application. As the energy use of motors is approximately proportional to the cube of the flow rate[33], relatively small reductions in flow, which are proportional to pump speed, already yield significant energy savings.

Adjustable-speed drive systems are offered by many suppliers and are available worldwide. Worrell *et al.* (1997) provides an overview of savings achieved with ASDs in a wide array of applications; typical energy savings were shown to vary between 7% and 60% with estimated simple payback periods for ranging from 0.8 to 2.8 years (Hackett *et al.*, 2005).

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[32] Several terms are used in practice to describe a motor system that permits a mechanical load to be driven at variable speeds, including adjustable speed drives (ASDs), variable speed drives (VSDs), adjustable frequency drives (AFDs), and variable frequency drives (VFDs). In this guide different terms are interchangeable.

[33] This equation applies to dynamic systems only. Systems that solely consist of lifting (static head systems) will accrue no benefits from (but will often actually become more inefficient) ASDs because they are independent of flow rate. Similarly, systems with more static head will accrue fewer benefits than systems that are largely dynamic (friction) systems. More careful calculations must be performed to determine actual benefits, if any, for these systems.

120. Power factor correction

Power factor is the ratio of working power to apparent power. It measures how effectively electrical power is being used. A high power factor signals efficient utilization of electrical power, while a low power factor indicates poor utilization of electrical power. Inductive loads like transformers, electric motors, and HID lighting may cause a low power factor. The power factor can be corrected by minimizing idling of electric motors (a motor that is turned off consumes no energy), replacing motors with premium-efficient motors, and installing capacitors in the AC circuit to reduce the magnitude of reactive power in the system (U.S. DOE, 1996).

121. Minimizing voltage unbalances

A voltage unbalance degrades the performance and shortens the life of three-phase motors. A voltage unbalance causes a current unbalance, which will result in torque pulsations, increased vibration and mechanical stress, increased losses, and motor overheating, which can reduce the life of a motor's winding insulation. Voltage unbalances may be caused by faulty operation of power factor correction equipment, an unbalanced transformer bank, or an open circuit. A rule of thumb is that the voltage unbalance at the motor terminals should not exceed 1% although even a 1% unbalance will reduce motor efficiency at part load operation. A 2.5% unbalance will reduce motor efficiency at full load operation.

By regularly monitoring the voltages at the motor terminal and through regular thermographic inspections of motors, voltage unbalances may be identified. It is also recommended to verify that single-phase loads are uniformly distributed and to install ground fault indicators as required. Another indicator for voltage unbalance is a 120 Hz vibration, which should prompt an immediate check of voltage balance (U.S. DOE-OIT, 2005b). The typical payback period for voltage controller installation on lightly loaded motors in the U.S. is 2.6 years (U.S. DOE-IAC, 2006).

Case studies:

Some case studies of the energy-efficiency improvement opportunities in electric motors in the textile industry are given below.

Downsizing of motors in finishing processes

EMT (2008h) has reported that they replaced a 30hp motor with 20hp motor on a rope scouring machine at the finishing department of their plant after the analysis of process requirements. This resulted in 12 MWh/year in electricity savings. The same company conducted another project on downsizing of motors on press machines at the finishing department. This resulted in electricity savings of 33 MWh/year (EMT, 2008h).

Downsizing of motors in spinning processes

In another plant in India, four 4.5kW under-loaded motors were replaced with 2.2kW motors in bobbin winding machines and soft package machines. The average electricity savings achieved was about 5.5 MWh/year/motor with an average investment cost of US$1000 per motor (EMT, 2008g).

Replacement of old inefficient motors by energy-efficient motors in viscose production plants
A viscose production plant in India replaced 39 of its old inefficient motors with energy-efficient motors. This resulted in average energy savings of 7 MWh/year/motor. The investment cost of this retrofit was on average US$1500 per motor replaced (the investment cost of motor replacement varies by motor size) (EMT, 2007b).

Use of Cogged 'v' belts in place of ordinary 'v' belts
A textile plant replaced ordinary 'v' belts with cogged 'v' belts for various machines and achieved an energy savings of 37.5 MWh/year. The investment cost of this measure was low and was about US$260 (EMT, 2005d). The number of replaced belts is not reported.

5.6.3. Energy-efficiency improvement opportunities in *compressed air* systems[34]

Instrumentation consumes large amounts of compressed air at many individual locations in a textile plant, but these uses are susceptible to leakage. Most such leaks are at threaded connection points, rubber hose connections, valves, regulators, seals, and in old pneumatic equipment. Air leaks from knitting operations are very common and can be quite large; these exact a large invisible cost, and the reduced pressure may impair the operation of the dyeing and finishing machines. Integrated mills that contain knitting operations should check the compressed air systems in knitting as well as in the dyeing and finishing areas.

More than 85% of the electrical energy input to an air compressor is lost as waste heat, leaving less than 15% of the electrical energy consumed to be converted to pneumatic compressed air energy (U.S. DOE-ITP EM, 2008). This makes compressed air an expensive energy carrier compared to other energy carriers. Many opportunities exist to reduce energy use of compressed air systems. For optimal savings and performance, it is recommended that a systems approach is used. In the following, energy saving opportunities for compressed air systems are presented.

122. Reduction of demand
Because of the relatively expensive operating costs of compressed air systems, the minimum quantity of compressed air should be used for the shortest possible time, constantly monitored and reweighed against alternatives.

123. Maintenance
Inadequate maintenance can lower compression efficiency, increase air leakage or pressure variability and lead to increased operating temperatures, poor moisture control and excessive contamination. Better maintenance will reduce these problems and save energy.

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[34] This section is excerpted from Worrell et al. (2010). However, the sources of each section given in Worrell et al. (2010) are also provided in the text here. The case studies are from different sources, which are also provided.

124. Monitoring

Maintenance can be supported by monitoring using proper instrumentation, including (CADDET, 1997):

- Pressure gauges on each receiver or main branch line and differential gauges across dryers, filters, etc.
- Temperature gauges across the compressor and its cooling system to detect fouling and blockages.
- Flow meters to measure the quantity of air used.
- Dew point temperature gauges to monitor the effectiveness of air dryers.
- kWh meters and hours run meters on the compressor drive.

125. Reduction of leaks (in pipes and equipment)

Leaks cause an increase in compressor energy and maintenance costs. The most common areas for leaks are couplings, hoses, tubes, fittings, pressure regulators, open condensate traps and shut-off valves, pipe joints, disconnects and thread sealants. Quick connect fittings always leak and should be avoided. In addition to increased energy consumption, leaks can make pneumatic systems/equipment less efficient and adversely affect production, shorten the life of equipment, lead to additional maintenance requirements and increased unscheduled downtime.

A typical plant that has not been well maintained could have a leak rate between 20 to 50% of total compressed air production capacity (Ingersoll Rand 2001). Leak repair and maintenance can sometimes reduce this number to less than 10%. Similar figures are quoted by Cergel *et al.* (2000). Overall, a 20% reduction of annual energy consumption in compressed air systems is projected for fixing leaks (Radgen and Blaustein, 2001).

A simple way to detect large leaks is to apply soapy water to suspect areas. The best way is to use an ultrasonic acoustic detector, which can recognize the high frequency hissing sounds associated with air leaks.

126. Electronic condensate drain traps (ECDTs)

Due to the necessity to remove condensate from the system, continuous bleeding, achieved by forcing a receiver drain valve to open, often becomes the normal operating practice, but is extremely wasteful and costly in terms of air leakage. Electronic condensate drain traps (ECDTs) offer improved reliability and are very efficient as virtually no air is wasted when the condensate is rejected. The payback period depends on the amount of leakage reduced, and is determined by the pressure, operating hours, the physical size of the leak and electricity costs.

127. Reduction of the inlet air temperature

Reducing the inlet air temperature reduces energy used by the compressor. In many plants, it is possible to reduce this inlet air temperature by taking suction from outside the building. Importing fresh air has paybacks of up to 5 years, depending on the location of the compressor air inlet (CADDET, 1997). As a rule of thumb, each 3 °C reduction will save 1% compressor energy use (CADDET, 1997; Parekh, 2000).

128. Maximizing allowable pressure dew point at air intake

Choose the dryer that has the maximum allowable pressure dew point, and best efficiency. A rule of thumb is that desiccant dryers consume 7 to 14% and refrigerated dryers consume 1 to 2% of the total energy of the compressor (Ingersoll-Rand, 2001). Consider using a dryer with a floating dew point. Note that where pneumatic lines are exposed to freezing conditions, refrigerated dryers are not an option.

129. Optimizing the compressor to match its load

Plant personnel have a tendency to purchase larger equipment than needed, driven by safety margins or anticipated additional future capacity. Given the fact that compressors consume more energy during part-load operation, this is something that should be avoided. Some plants have installed modular systems with several smaller compressors to match compressed air needs in a modular way (Cergel *et al.*, 2000). In some cases, the pressure required is so low that the need can be met by a blower instead of a compressor which allows considerable energy savings, since a blower requires only a small fraction of the power needed by a compressor (Cergel *et al.*, 2000).

130. Proper pipe sizing

Pipes must be sized correctly for optimal performance or resized to fit the compressor system. Inadequate pipe sizing can cause pressure losses, increase leaks and increase generating costs. Increasing pipe diameter typically reduces annual compressor energy consumption by 3% (Radgen and Blaustein, 2001).

131. Heat recovery

As mentioned earlier, more than 85% of the electrical energy used by an industrial air compressor is converted into heat (U.S. DOE-ITP EM, 2008). A 150 hp compressor can reject as much heat as a 90 kW electric resistance heater or a 422 MJ/hour natural gas heater when operating (Cergel *et al.*, 2000).

In many cases, a heat recovery unit can recover 50 to 90% of the available thermal energy for space heating, industrial process heating, water heating, makeup air heating, boiler makeup water preheating, industrial drying, industrial cleaning processes, heat pumps, laundries or preheating aspirated air for oil burners (Parekh 2000). With large water-cooled compressors, recovery efficiencies of 50 to 60% are typical (U.S. DOE, 1998). When used for space heating, the recovered heat amount to 20% of the energy used in compressed air systems annually (Radgen and Blaustein, 2001). Paybacks are typically less than one year. In some cases, compressed air is cooled considerably below its dew point in refrigerated dryers to condense and remove the water vapor in the air. The waste heat from these aftercoolers can be regenerated and used for space heating, feedwater heating or process-related heating (Cergel *et al.*, 2000).

132. Adjustable speed drives (ASDs)

When there are strong variations in load and/or ambient temperatures there will be large swings in compressor load and efficiency. In those cases installing an ASD may result in attractive payback periods (Heijkers *et al.* 2000). Implementing adjustable speed drives in rotary compressor systems has saved 15% of the annual compressed air system energy consumption (Radgen and Blaustein, 2001).

Case studies:

Some case studies of energy-efficiency improvement opportunities in compressed air systems in the textile industry are given below.

Compressed air system optimization in an integrated spinning and weaving plant

Thomaston's manufacturing facility in Thomaston, Georgia, is a vertically integrated facility whose 1500 employees produce a full range of textile products. These applications include air jet looms (which use a very large amount of compressed air) and spinning frames. The compressed air system improvement project at the Thomaston plant generated energy savings while improving product quality and increasing system reliability. In the system's current configuration, five centrifugal compressors are base loaded, with a 1000hp compressor for back up. One of the new 350hp compressors is also base loaded and the other one starts and stops as needed. Using a rotary screw compressor as a trim compressor has greatly reduced blow-off from the centrifugal compressors. This has resulted in annual energy savings of 3,431 MWh per year, which represents 4% of annual electricity costs. In addition, by purchasing two 350hp compressors instead of a 900hp centrifugal compressor, the plant achieved a cost avoidance of US$55,000 (US DOE, 2000).

Optimization of compressed air system in a wet-processing plants

Based on the case-studies in several textile plants in China, Greer et al. (2010) reports that 2.3 – 59.1 kWh/tonne fabric electricity savings can be achieved by fixing leaks in the compressed air system and checking and optimizing pressure settings on a regular basis, at least annually. The cost is reportedly minimal and pays itself back immediately. CIPEC (2007) also reports that the heat from the cooling water of the compressor can be used, thereby saving fuel. The capital cost of this measure is about US$6000 with a payback period of around 2.4 years.

Compressed air system optimization in nylon filament production plants

US DOE (2001) reports a plant's compressed air system improvement project that was performed at the system level. The main features of the project were:

- Installation of three pressure/flow controllers and one back-pressure/flow controller along with 60,000 gallons of air storage capacity in two 30,000 gallon tanks,
- Installation of new dryers and mist-eliminating filters on all dryers,
- Installation of a programmable logic control (PLC) compressor automation system,
- Installation of a compressed air management information system (MIS),
- Installation of new piping and retrofits on existing portions of the piping system, and
- Repair of sub-optimally performing compressors and after-coolers.

Due to the improvements in the system's performance, the plant was able to take some of its compressors offline, while maintaining the needed airflow and pressure to satisfy production requirements. This has yielded an annual energy savings of 15,000 MWh. One third of the total energy savings comes from the reduced need for chilled water. The investment cost of this project was about US$1.5 million (US DOE, 2001).

5.6.4. Energy-efficiency improvement opportunities in *pumping* systems [35]

Pump systems consist of pumps, driver, pipe installation and controls (such as ASDs or throttles) and are a part of the overall motor system. Pump applications in the iron and steel industry include pumps for circulating cooling fluids of walls and injection systems.

133. Maintenance

Inadequate maintenance lowers pump system efficiency, causes pumps to wear out more quickly and increases costs. Better maintenance will reduce these problems and save energy. Proper maintenance includes the following (Hydraulic Institute, 1994; U.S. DOE, 1999):

- Replacement of worn impellers, especially in caustic or semi-solid applications.
- Bearing inspection and repair.
- Bearing lubrication replacement, once annually or semiannually.
- Inspection and replacement of packing seals.
- Inspection and replacement of mechanical seals.
- Wear ring and impeller replacement.
- Pump/motor alignment check.
- The largest opportunity is usually to avoid throttling losses.

Typical energy savings for operations and maintenance are estimated to be between 2% and 7% of pumping electricity use for the U.S. industry. The payback usually is less than one year (Xenergy, 1998; U.S. DOE-OIT, 2002).

134. Monitoring

Monitoring in conjunction with operations and maintenance can be used to detect problems and determine solutions to create a more efficient system. Monitoring can determine clearances that need be adjusted, indicate blockage, impeller damage, inadequate suction, operation outside preferences, clogged or gas-filled pumps or pipes, or worn out pumps. Monitoring should include:

- Wear monitoring
- Vibration analyses
- Pressure and flow monitoring
- Current or power monitoring
- Differential head and temperature rise across the pump (also known as thermodynamic monitoring)
- Distribution system inspection for scaling or contaminant build-up

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[35] This section is excerpted from Worrell et al. (2010). However, the sources of each section given in Worrell et al. (2010) are also provided in the text here. The case studies are from different sources, which are also provided.

One of the best indicators to follow for monitoring is specific energy or power consumption as a function of the flow rate (Hovstadius, 2007).

135. Controls

The objective of any control strategy is to shut off unneeded pumps or to reduce the load of individual pumps. Remote controls enable pumping systems to be started and stopped relatively quickly and accurately, and reduce the required labor with respect to traditional control systems.

136. Reduction of demand

Holding tanks can be used to equalize the flow over the production cycle, enhancing energy efficiency and potentially reducing the need to add pump capacity. In addition, bypass loops and other unnecessary flows should be eliminated. Energy savings may be as high as 5-10% for each of these steps (Easton Consultants, 1995). Total head requirements can also be reduced by lowering process static pressure, minimizing elevation rise from suction tank to discharge tank, reducing static elevation change by use of siphons and lowering spray nozzle velocities.

137. More efficient pumps

Pump efficiency may degrade 10% to 25% in its lifetime. Industry experts however point out that this degrading performance is not necessarily due to the age of the pump but can also be caused by changes in the process which may have caused a mismatch between the pump capacity and its operation. Nevertheless, it can sometimes be more efficient to buy a need pump, also because newer models are more efficient.

A number of pumps are available for specific pressure head and flow rate capacity requirements. Choosing the right pump often saves both in operating costs and in capital costs (of purchasing another pump). For a given duty, a pump that runs at the highest speed suitable for the application will generally be the most efficient option with the lowest initial cost (Hydraulic Institute and Europump, 2001). Exceptions include slurry handling pumps, high specific speed pumps or in applications where the pump needs a very low minimum net positive suction head at the pump inlet.

Replacing a pump with a new efficient one reduces energy use by 2% to 10% (Nadel *et al.* 2002). Higher efficiency motors have been shown to increase the efficiency of the pump system 2 to 5% (Tutterow, 1999).

138. Proper pump sizing

A pump may be incorrectly sized for current needs if it operates under throttled conditions, has a high bypass flow rate, or has a flow rate that varies more than 30% from its best efficiency point flow rate (U.S. DOE-OIT, 2005). Where peak loads can be reduced, pump size can also be reduced. A smaller motor will however not always result in energy savings, as these depend on the load of the motor. Only if the larger motor operates at a low efficiency, replacement may result in energy savings. Pump loads may be reduced with alternative pump configurations and improved operations and management practices.

When pumps are dramatically oversized, speed can be reduced with gear or belt drives or a slower speed motor. This practice, however, is not common. Paybacks for implementing these solutions are less than one year (U.S. DOE-OIT, 2002). Oversized and throttled pumps that produce excess pressure are excellent candidates for impeller replacement or “trimming,” to save energy and reduce costs. Correcting for pump oversizing can save 15% to 25% of electricity consumption for pumping (on average for the U.S. industry) (Easton Consultants, 1995).

139. Multiple pumps for varying loads

The use of multiple pumps is often the most cost-effective and most energy-efficient solution for varying loads, particularly in a static head-dominated system. Alternatively, adjustable speed drives could be considered for dynamic systems (see below).

Parallel pumps offer redundancy and increased reliability. The installation of parallel systems for highly variable loads on average would save 10% to 50% of the electricity consumption for pumping for the U.S. industry (Easton Consultants, 1995).

140. Impeller trimming (or shaving sheaves)

Trimming reduces the impeller’s tip speed, which in turn reduces the amount of energy imparted to the pumped fluid; as a result, the pump’s flow rate and pressure both decrease. A smaller or trimmed impeller can thus be used efficiently in applications in which the current impeller is producing excessive heat (U.S. DOE-OIT, 2005). In the food processing, paper and petrochemical industries, trimming impellers or lowering gear ratios is estimated to save as much as 75% of the electricity consumption for specific pump applications (Xenergy, 1998).

141. Adjustable speed drives (ASDs)

ASDs better match speed to load requirements for pumps. As for motors, energy use of pumps is approximately proportional to the cube of the flow rate[36] and relatively small reductions in flow may yield significant energy savings. New installations may result in short payback periods. In addition, the installation of ASDs improves overall productivity, control and product quality, and reduces wear on equipment, thereby reducing future maintenance costs.

Similar to being able to adjust load in motor systems, including modulation features with pumps is estimated to save between 20% and 50% of pump energy consumption, at relatively short payback periods, depending on application, pump size, load and load variation (Xenergy, 1998; Best Practice Programme, 1996). As a general rule of thumb, unless the pump curves are exceptionally flat, a 10% regulation in flow should produce pump savings of 20% and 20% regulation should produce savings of 40% (Best Practice Programme, 1996).

142. Avoiding throttling valves

Variable speed drives or on-off regulated systems always save energy compared to throttling valves (Hovstadius, 2002).The use of these valves should therefore be avoided. Extensive use of throttling valves or bypass loops may be an indication of an oversized pump (Tutterow *et al.*, 2000).

143. Proper pipe sizing

Energy may be saved by reducing losses due to friction through the optimization of pipe diameters. The frictional power required depends on flow, pipe size (diameter), overall pipe

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[36] This equation applies to dynamic systems only.

length, pipe characteristics (surface roughness, material, etc.), and properties of the fluid being pumped. Correct sizing of pipes should be done at the system design stages where costs may not be restrictive (U.S. DOE-OIT, 2005).

144. Replacement of belt drives

Most pumps are directly driven. However, some pumps use standard V-belts which tend to stretch, slip, bend and compress, which lead to a loss of efficiency. Replacing standard V-belts with cog belts can save energy and money, even as a retrofit. It is even better to replace the pump by a direct driven system, resulting in increased savings of up to 8% of pumping systems energy use with payback periods as short as 6 months (Studebaker, 2007).

145. Precision castings, surface coatings or polishing

The use of castings, coatings or polishing reduces surface roughness that in turn, increases energy-efficiency. It may also help maintain efficiency over time. This measure is more effective on smaller pumps.

146. Improvement of sealing

Seal failure accounts for up to 70% of pump failures in many applications (Hydraulic Institute and Europump, 2001). The sealing arrangements on pumps will contribute to the power absorbed. Often the use of gas barrier seals, balanced seals, and no-contacting labyrinth seals can help to optimize pump efficiency.

5.6.5. Energy-efficiency improvement opportunities in *fan* systems[37]

Efficiencies of fan systems vary considerably across impeller types. The average energy saving potential in these systems in the U.S. Manufacturing industry is estimated at 6% (Xenergy, 1998). For optimal savings and performance, it is recommended that a systems approach is used. In the following, energy saving opportunities for fan systems are presented.

147. Minimizing pressure

Pressure offers greater opportunities to reduce energy costs. A system with good airflow characteristics (duct velocities and sizes optimized), matched with the proper control device, pressure monitors, and variable-frequency drives, can help manage system pressure. Most baghouses or other collection devices will have varying pressure drops over the life of the system. Bags are generally more efficient at higher pressure drops, but then use more energy. A good pressure monitoring system that controls system volumetric flow rate can save thousands of dollars every year on the operation of even medium-sized systems. As ASDs become less expensive they are now being found on many installations. Be mindful of duct inefficiencies and fan system effects (elbows at inlets and outlets, etc. These shortcuts increase static pressure and operating costs for the life of the system (Lanham, 2007).

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[37] This section is excerpted from Worrell et al. (2010). However, the sources of each section are given in Worrell et al. (2010) are also provided in the text here. The case-studies are from different sources, which are also provided.

148. Control density
Temperature, moisture, molecular weight, elevation, and the absolute pressure in the duct or vessel affect the density of the transporting gas. A density change may affect the hardware requirements for the system. Evaporative cooling, for example, reduces volume, but the higher-density air requires more power. This may be more than offset by reduced costs for smaller ducts, control devices, and fans (as well as lower the value for volumetric flow rate in the equation) (Lanham, 2007).

149. Fan efficiency
The key to any design is proper fan selection. The design of the fan and its blade type can affect efficiency and power requirements significantly. Laboratory-measured peak fan efficiency may not be the most stable point of operation. If peak efficiency coincides with the peak of the pressure curve then there may be operational problems as volumetric flow rates vary with small changes in system pressure. The designer must consider both curves when selecting the best fan and operating point to optimize reliability and power usage. Fan type may dictate proper selection. Airfoil wheels, while more efficient, may not be a good choice when handling particulate laden air. (Lanham, 2007).

150. Proper fan sizing
Most of the fans are oversized for the particular application, which can result in efficiency losses of 1-5% (Xenergy, 1998). However, it may be more cost-effective to control the speed than to replace the fan system.

151. Adjustable speed drives (ASDs)
Significant energy savings can be achieved by installing adjustable speed drives on fans. Savings may vary between 14 and 49% of fan system energy use when retrofitting fans with ASDs (Xenergy, 1998).

152. High efficiency belts (cogged belts)
Belts make up a variable, but significant portion of the fan system in many plants. Standard V-belts tend to stretch, slip, bend and compress, which lead to a loss of efficiency. Replacing standard V-belts with cogged belts can save energy and money, even as a retrofit. Cogged belts run cooler, last longer, require less maintenance and have an efficiency that is about 2% higher than standard V-belts. Typical payback periods will vary from less than one year to three years (Xenergy, 1998).

5.6.6. Energy-efficiency improvement opportunities in *lighting* system

Lighting accounts for around 3% of the total energy use in a spinning plant (Koç and Kaplan, 2007), or about 4% of the total electricity use in a composite textile plant (plant with spinning, weaving, and wet-processing) (Sathaye et al, 2005). Some energy-efficiency opportunities to reduce energy use cost-effectively are given below.

153. Lighting controls

Lights can be shut off during non-working hours by automatic controls, such as occupancy sensors which turn off lights when a space becomes unoccupied. Manual controls can also be used in addition to automatic controls to save additional energy in smaller areas. The payback period for lighting control systems is generally less than 2 years (Worrell and Galitsky, 2004).

154 Replace T-12 tubes by T-8 tubes

In industry, typically T-12 tubes have been used. T-12 refers to the diameter in 1/8 inch increments (T-12 means 12/8 inch or 3.8 cm diameter tubes). The initial output for these lights is high, but energy consumption is also high. They also have extremely poor efficiency, lamp life, lumen depreciation, and color rendering index. Because of this, maintenance and energy costs are high. Replacing T-12 lamps with T-8 lamps approximately doubles the efficacy of the former, thereby saves electricity (Worrell and Galitsky, 2004).

EMT (2008j) has reported the replacement of 1196 ordinary tube lights with energy-efficient tube lights which resulted in 114 MWh/year electricity saving. The investment cost of this retrofit measure was reported to be about US$26,800. Sathaye et al. (2005) reported a case-study of the replacement of 1172 tube lights and magnetic ballasts (see below) with 880 energy-efficient tube lights and 440 electronic ballasts which resulted in electricity savings of 150 MWh/year. The investment cost is reported to be around US$11,000 which is less than half of the one reported for the previous case-study mentioned above.

155. Replace mercury lights with metal halide or high pressure sodium lights

Where color rendition is critical, metal halide lamps can replace mercury or fluorescent lamps with an energy savings of 50%. Where color rendition is not critical, high pressure sodium lamps offer energy savings of 50 to 60% compared to mercury lamps (Worrell and Galitsky, 2004).

156. Replace metal halide (HID) with high-intensity fluorescent lights

Traditional HID lighting can be replaced with high-intensity fluorescent lighting. These new systems incorporate high-efficiency fluorescent lamps, electronic ballasts and high-efficacy fixtures that maximize output to the work place. Advantages to the new system are: they have lower energy consumption, lower lumen depreciation over the lifetime of the lamp, better dimming options, faster start-up, better color rendition, higher pupil lumens ratings and less glare. High-intensity fluorescent systems yield 50% electricity savings over standard HIDs. Dimming controls that are impractical in the HIDs can also save significant amounts of energy. Retrofitted systems cost about $185 per fixture, including installation costs. In addition to energy savings and better lighting qualities, high-intensity fluorescents can help to reduce maintenance costs (Worrell and Galitsky, 2004).

157. Replace magnetic ballasts with electronic ballasts

A ballast is a mechanism that regulates the amount of electricity required to start a lighting fixture and maintain a steady output of light. Electronic ballasts save 12 – 25% of electricity use compared to magnetic ballast (Worrell and Galitsky, 2004). A textile plant in India has reported energy savings of 936 kWh/ballast/year with the implementation of this measure. The cost of the retrofit was about US$8 per ballast (EMT, 2005d).

158. Optimization of plant lighting (lux[38] optimization) in production and non-production departments

In many plants the lighting system is not specifically designed for the process. There are lux standards for each type of textile process. For instance, the required lux for weaving is usually higher than that of wet-processing. Even within just one production process, the required lux varies by the process step. For example, in a cotton spinning process, the required lux in the blow room should be much lower than that of ring frame section. If the lighting provided is higher than the standard (required lux) for any part of the production, this results in a waste of electricity. Therefore, the plant engineers should optimize the lighting system based on the standard lux specific for each process step.

GIMATEX Company in India optimized the illumination levels in their plant based on the standard lux specified for each process step. This resulted in a reduction of more than 300 light bulbs which resulted in a 108 MWh/year electricity savings without any capital investment required (EMT, 2008b). Electricity savings of 31 – 182 MWh/year is reported from different textile plants as the result of optimization of plant lighting. Energy savings vary based on the plant-specific situation and preexisting lighting system (EMT, 2007a; EMT, 2007b; EMT, 2005e).

159. Optimum use of natural sunlight

Many plants do not use natural sunlight to an optimum level. In addition to optimizing the size of the windows, a transparent sheets can be installed at the roof in order to allow more sunlight to penetrate into the production area. This can reduce the need for lighting during the day. Energy savings of 1 – 11.5 MWh/year is reported as the result of the efficient use of natural light (EMT, 2007a; EMT, 2008i).

5.6.7. Energy-efficiency improvement opportunities in *steam* systems[39]

Steam systems are often found in textile plants and can account for a significant amount of end-use energy consumption. Improving boiler efficiency and capturing excess heat can result in significant energy savings and improved production. Common performance improvement opportunities for the generation and distribution of industrial steam systems are given bellow.

Steam Generation:

160. Demand Matching

A boiler is more efficient in the high-fire setting. Since process heating demands may change over time, situations can occur in which a boiler is operating beneath its optimum efficiency. Also, boilers may have been oversized, for instance because of additions or expansions that never occurred. Installing energy conservation or heat recovery measures may also have reduced the heat demand. As a result, a facility may have multiple boilers, each rated at several times the maximum expected load (U.S. DOE-OIT, 2006). An additional common problem with oversized

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[38] Lux is the SI unit of luminance, equal to one lumen per square meter.

[39] This section is excerpted from Worrell et al. (2010). However, the sources of each section are given in Worrell et al. (2010) are also provided in the text here. The case-studies are from different sources, which are also provided.

boiler is the boiler “short cycling”, which occurs when an oversized boiler quickly satisfies process or space heating demands, and then shuts down until heat is again required.

Fuel savings can be achieved by adding a smaller boiler to a system, sized to meet average loads at a facility. Multiple small boilers offer reliability and flexibility to operators to follow load swings without over-firing and short cycling. In particular, facilities with large seasonal variations in steam demand should use operate small boilers when demand drops, rather than operating their large boilers year-round. Operation measures to operate boilers on the high-fire setting have a average payback time of 0.8 years and the installation smaller boilers to increase the high-fire duty cycle has a average payback time of 1.9 years (U.S. DOE-IAC, 2006).

161. Boiler allocation control

Systems containing multiple boilers offer energy-saving opportunities by using proper boiler allocation strategies. This is especially true if multiple boilers are operated simultaneously at low-fire conditions.

Automatic controllers determine the incremental costs (change in steam cost/change in load) for each boiler in the facility, and then shift loads accordingly. This maximizes efficiency and reduces energy costs. If possible, schedule loads to help optimize boiler system performance.

The efficiency of hot water boilers can improve through use of automatic flow valves. Automatic flow valves shut off boilers that are not being used, preventing the hot water from the fired boiler getting cooled as it passes through the unused boilers in the system. Where valves are left open the average flow temperature is lower than designed for and more fuel is used (CADDET, 2001).

162. Flue shut-off dampers

Where boilers are regularly shut down due to load changes, the heat lost to the chimney can be significant. A solution to stop this loss of hot air is to fit fully closing stack dampers, which only operate when the boiler is not required. Another alternative is to fit similar gas tight dampers to the fan intake (CADDET, 2001).

163. Maintenance

In the absence of a good maintenance system, the burners and condensate return systems can wear or get out of adjustment. These factors can end up costing a steam system up to 20-30% of initial efficiency over 2-3 years (U.S. DOE-OIT, 2001). A simple maintenance program to ensure that all components of the boiler are operating at peak performance can result in substantial savings and furthermore reduce the emission of air pollutants. On average the possible energy savings are estimated at 10% of boiler energy use (U.S. DOE-OIT, 2001). The establishment of a maintenance schedule for boilers has an average payback time of 0.3 years (U.S. DOE-IAC, 2006).

164. Insulation improvement

The shell losses of a well-maintained boiler should be less than 1%. New insulation materials insulate better, and have a lower heat capacity. As a result of this lower heat capacity, the output temperature is more vulnerable to temperature fluctuations in the heating elements. Improved control is therefore required to maintain the output temperature range of the old firebrick system.

Savings of 6-26% can be achieved by combining improved insulation with improved heater circuit controls (Caffal, 1995).

165. Reduce Fouling

Fouling of the fireside of the boiler tubes and scaling waterside of the boiler should be controlled. Tests show that a soot layer of 0.03 inches (0.8 mm) reduces heat transfer by 9.5%, while a 0.18 inch (4.5 mm) layer reduces heat transfer by 69% (CIPEC, 2001). Scale deposits occur when calcium, magnesium, and silica, commonly found in most water supplies, react to form a continuous layer of material on the waterside of the boiler heat exchange tubes. Tests showed that for water-tube boilers 0.04 inches (1 mm) of buildup can increase fuel consumption by 2% (CIPEC, 2001). In fire-tube boilers scaling can lead to a fuel waste up to 5% (U.S. DOE-OIT, 2006). Moreover, scaling may result in tube failures.

Scale removal can be achieved by mechanical means or acid cleaning. The presence of scale can be indicated by the flue gas temperature or be determined by visually inspect of the boiler tubes when the unit is shut down for maintenance. Fouling and scaling are more of a problem with coal-fed boilers than natural gas or oil-fed ones (i.e. boilers that burn solid fuels like coal should be checked more often as they have a higher fouling tendency than liquid fuel boilers do) (U.S. DOE-OIT, 2006).

166. Optimization of boiler blowdown rate

Insufficient blowdown may lead to carryover of boiler water into the steam, or the formation of deposits. Excessive blowdown will waste energy, water, and chemicals. The optimum blowdown rate is determined by various factors including the boiler type, operating pressure, water treatment, and quality of makeup water. Blowdown rates typically range from 4% to 8% depending on boiler feed water flow rate, but can be as high as 10% when makeup water has a high solids content (U.S. DOE-OIT, 2006). Minimizing blowdown rate can therefore substantially reduce energy losses, makeup water and chemical treatment costs (U.S. DOE-IAC, 2006). Optimum blowdown rates can be achieved with an automatic blowdown-control system. In many cases, the savings due to such a system can provide a simple payback of 1 to 3 year (U.S. DOE-OIT, 2006).

167. Reduction of flue gas quantities

Often, excessive flue gas results from leaks in the boiler and the flue, reducing the heat transferred to the steam, and increasing pumping requirements. These leaks are often easily repaired. This measure consists of a periodic repair based on visual inspection or on flue gas monitoring which will be discussed below.

168. Reduction of excess air

The more air is used to burn the fuel, the more heat is wasted in heating air. Air slightly in excess of the ideal stoichometric fuel/air ratio is required for safety, and to reduce NO_x emissions, and is dependent on the type of fuel. Poorly maintained boilers can have up to 140% excess air leading to excessive amounts of waste gas. An efficient natural gas burner however requires 2% to 3% excess oxygen, or 10% to 15% excess air in the flue gas, to burn fuel without forming carbon monoxide. A rule of thumb is that boiler efficiency can be increased by 1% for each 15%

reduction in excess air (U.S. DOE-OIT, 2006). Fuel-air ratios of the burners should be checked regularly. On average the analysis of proper air/fuel mixture had a payback time of 0.6 years.

169. Flue gas monitoring

The oxygen content of the exhaust gas is a combination of excess air (which is deliberately introduced to improve safety or reduce emissions) and air infiltration (air leaking into the boiler). By combining an oxygen monitor with an intake airflow monitor, it is possible to detect (small) leaks. Using a combination of CO and oxygen readings, it is possible to optimize the fuel/air mixture for high flame temperature (and thus the best energy-efficiency) and low emissions. The payback of installing flue gas analyzers to determine proper air/fuel ratios on average is 0.6 years (U.S. DOE-IAC, 2006).

170. Preheating boiler feed water with heat from flue gas (economizer)

Heat from flue gases can be used to preheat boiler feed water in an economizer. By preheating the water supply, the temperature of the water supply at the inlet to the boiler is increased, reducing the amount of heat necessary to generate steam thus saving fuel. While this measure is fairly common in large boilers, there often still is potential for more heat recovery. Generally, boiler efficiency can be increased by 1% for every 22 ℃ reduction in flue gas temperature. By recovering waste heat, an economizer can often reduce fuel requirements by 5% to 10% and pay for itself in less than 2 years (U.S. DOE-OIT, 2006).

171. Recovery of heat from boiler blowdown

When the water is blown from the high-pressure boiler tank, the pressure reduction often produces substantial amounts of steam. Up to 80% of the heat in the discharge is recoverable by using flash vessels and heat exchangers (CADDET, 2001). The recovered heat can subsequently be used for space heating and feed water preheating increasing the efficiency of the system. Any boiler with continuous blow down exceeding 5% of the steam rate is a good candidate for the introduction of blow down waste heat recovery. If there is a non-continuous blow down system, then consider the option of converting it to a continuous blow down system coupled with heat recovery (U.S. DOE-OIT, 2006). Larger energy savings occur with high-pressure boilers. The use of heat from boiler blow down on average has payback period of 1.6 years (U.S. DOE-IAC, 2006).

172. Recovery of condensate

By installing a condensing economizer, companies can improve overall heat recovery and steam system efficiency by up to 10% (U.S. DOE-OIT, 2007). Many boiler applications can benefit from this additional heat recovery. Condensing economizers require site-specific engineering and design, and a thorough understanding of the effect they will have on the existing steam system and water chemistry.

Hot condensate can be returned to the boiler saving energy and reducing the need for treated boiler feed water as condensate, being condensed steam, is extremely pure and has a high heat content. Increasing the amount of returned condensate has an average payback period of 1.1 years (U.S. DOE-IAC, 2006). Condensate has also been used to provide for hot water supply. This measure had an average payback period of 0.8 years (U.S. DOE-IAC, 2006).

173. Combined Heat and Power (CHP)

Combined heat and power (CHP) or cogeneration is the sequential production of two forms of useful energy from a single fuel source. In most CHP applications, chemical energy in fuel is converted to both mechanical and thermal energy. The mechanical energy is generally used to generate electricity, while the thermal energy or heat is used to produce steam, hot water, or hot air.

CHP systems have the ability to extract more useful energy from fuel compared to traditional energy systems such as conventional power plants that only generate electricity and industrial boiler systems that only produce steam or hot water for process applications. CHP provides the opportunity to use internally generated fuels for power production, allowing greater independence of grid operation and even export to the grid. This increases reliability of supply as well as the cost-effectiveness. In addition, transportation losses are minimized when CHP systems are located at or near the end user (Oland, 2004).

The cost benefits of power export to the grid will depend on the regulation in the country where the industry is located, but can provide a major economic incentive. Not all countries allow wheeling of power (i.e. sales of power directly to another customer using the grid for transport) and for the countries that do allow wheeling, regulations may also differ with respect to the tariff structure for power sales to the grid operator.

Steam Distribution System:

174. Shutting off excess distribution lines

Installations and steam demands change over time, which may lead to under-utilization of steam distribution capacity utilization, and extra heat losses. It may be too expensive to optimize the system for changed steam demands. Still, checking for excess distribution lines and shutting off those lines is a cost-effective way to reduce steam distribution losses.

175. Proper pipe sizing

When designing new steam distribution systems it is very important to account for the velocity and pressure drop. This reduces the risk of oversizing a steam pipe, which is not only a cost issue but would also lead to higher heat losses. A pipe that is too small may lead to erosion and increased pressure drop (Van de Ruit, 2000).

176. Insulation related measures

Insulation can typically reduce energy losses by 90% and help ensure proper steam pressure at plant equipment (U.S. DOE-OIT, 2006). The application of insulation can lead to significant energy cost savings with relatively short payback periods. For instance, the average payback period of the insulation on steam and hot water lines is 1.0 years, that of condensate lines 1.1 year and that of the feedwater tank 1.1 years (U.S. DOE-IAC, 2006). The U.S. Department of Energy has developed the software tool 3E-Plus to evaluate the insulation for steam systems.

177. Checking and monitoring steam traps

A simple program of checking steam traps to ensure they operate properly can save significant amounts of energy. If the steam traps are not maintained for 3 to 5 years, 15-30% of the traps can be malfunctioning, thus allowing live steam to escape into the condensate return system. In systems with a regularly scheduled maintenance program, leaking traps should account for less than 5% of the trap population (U.S. DOE-OIT, 2006). The repair and replacement of steam traps has an average payback time of 0.4 years (U.S. DOE-IAC, 2006). Energy savings for a regular system of steam trap checks and follow-up maintenance is estimated to be up to 10% (Jones, 1997; Bloss, 1997).

178. Thermostatic steam traps

Using modern thermostatic element steam traps can reduce energy use while improving reliability. The main advantages offered by these traps are that they open when the temperature is close to that of the saturated steam (within 2°C), purge non-condensable gases after each opening, and are open on startup to allow a fast steam system warm-up. These traps are also very reliable, and useable for a large range of steam pressures (Alesson, 1995). Energy savings will vary depending on the steam traps installed and the state of maintenance.

179. Shutting of steam traps

Other energy savings can come from shutting of steam traps on superheated steam lines when they are not in use. This has an average payback time 0.2 years (U.S. DOE-IAC, 2006).

180. Reduction of distribution pipe leaks

As with steam traps, the distribution pipes themselves often have leaks that go unnoticed without a program of regular inspection and maintenance. On average leak repair has a payback period of 0.4 years (U.S. DOE-IAC, 2006).

181. Recovery of flash steam

When a steam trap purges condensate from a pressurized steam distribution system to ambient pressure, flash steam is produced. Depending on the pressures involved, the flash steam contains approximately 10% to 40% of the energy content of the original condensate. This energy can be recovered by a heat exchanger and used for space heating or feed water preheating (Johnston, 1995; U.S. DOE-OIT, 2006). The potential for this measure is site dependent, as it is unlikely that a plant will build an entirely new system of pipes to transport this low-grade steam, unless it can be used close to the steam traps. Sites using multi-pressure steam systems can route the flash steam formed from high-pressure condensate to reduced pressure systems.

182. Prescreen coal[40]

In some textile plants in which a coal-fired boiler is used (which is common in China and some other countries) raw coal is fed into the boiler and burned on stoke chains, which allows small-sized coal to pass through the chain and become wasted. To address this loss, companies should adopt spiral coal screen technology to screen the raw coal. This device greatly increases the rate of separation of good and bad quality coal, preventing small coal particles from falling off the stoke chain and increasing the calorific value of the fired coal. The installation of a spiral coal screener could save about 79 kg coal/tonne fabric (1.8 GJ/tonne fabric) in wet-processing plants based on the case-studies in China. It has an estimated cost of $35,000. The screener would pay back its cost in about five months (Greer et al., 2010).

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[40] This opportunity is relevant only to industrial boilers that use coal as a fuel. Although very typical in China, coal-fired boilers are not necessarily typical elsewhere in the world, and so this recommendation will not always apply.

Case studies:
Some case studies of the energy-efficiency improvement opportunities in steam systems in the textile industry are given below.

Install stack gas economizers on boilers
Boiler stack gas temperatures are often very high. A stack gas economizer can be installed on the boiler and the recover heat can be used to preheat the feedwater of the boiler. Gas-fired boilers are inherently better candidates for heat recovery than coal-fired boilers, because gas fuel causes minimal corrosion problems. Corrosion-resistant materials can be used in the heat-recovery systems of boilers using other fuels, however, to minimize the impact of corrosion.

Through the use of steam system assessment tool (*SSAT*) software in one of Shaw Industries' textile plants, it is estimated that installing a stack economizer on their boiler would yield fuel savings of almost 11,600 GJ per year (US DOE ITP, 2008b). Based on several case-studies of wet-processing textile plants in China (Greer et al., 2010), this measure can result in energy savings of about 1.5 GJ/tonne fabric. The cost is reported to be around $22,000. CIPEC (2007) has reported the capital cost of this technology to be between $18,000 and $405,000 with a payback period in the range of 1.4 – 5.1 year.

Installation of variable frequency drives for blowers supplying combustion air to steam boilers
A variable frequency drive can be installed to increase the efficiency of the blower supplying combustion air to the plant's steam boiler. Irregular demand for steam may result in excess oxygen in the combustion chamber. Inlet vane control is usually used, which means that the fan motor continues to operate at near-rated capacity under lower loads. Variable frequency drives can replace vane controls, permitting optimum operation under all loads and eliminating smoke problems. The installation of this measure in a textile plant in Canada resulted in electricity savings of 65 MWh/year (CADDET, 1993).

Replacement of old inefficient boiler feed pumps with energy-efficient pumps
Boiler feed pumps are used to feed the hot water to boilers. In a textile plant in India a boiler feed pump with a power consumption of 12.9 kW was replaced by an energy-efficient pump that consumed only 9.88 kW. Annual electricity savings is reported to be about 27 MWh/year with an investment cost of about US$3000 (gtz, 2007).

Energy savings through leak detection, preventive maintenance, and improved cleaning
Although individual leaks may not seem important in the overall consumption picture, they can be responsible for a surprisingly significant loss of resources over the course of a year. For example, one 2 mm steam leak with saturated steam of 5 kg/cm^2 consumes an estimated 240 GJ per year. Similarly, the electricity loss from one compressed air leak of about 4 mm with 0.6 mPa pressure could be about 52 MWh per year. Experts estimate that textile facilities can reduce resource use by as much as 10 % with an effective leak detection and preventive maintenance program.

Based on observations during plant assessments in China, Greer et al. (2010) estimate that routinely investigating sources of leaks in steam and compressed air systems and implementing an effective preventive maintenance program could result in energy savings in the range of 1.1 – 7.9 GJ/tonne fabric. Greer et al. report that the investment costs of this measure is minimal resulting in a very short payback period (Greer et al., 2010). CIPEC (2007), however, gives the cost range of $10,000 – $35,000 for a preventive maintenance program in a wet-processing plant with a payback period of 2 – 3.5 years. It should be noted that the energy savings and cost of this measure depends on the scope of the activities taken under this measure.

Improving steam system efficiency in a textile plant in the U.S.- a case-study

In 2006, a U.S. Department of Energy (DOE) Save Energy Now energy assessment was performed at one of Shaw Industries' textile plants in Dalton, Georgia, to identify potential energy savings opportunities in their steam system. The assessment the plant began by optimizing the boiler sequencing to base load the more efficient boilers. Next, they installed a waste water heat exchanger on the dye line and on a separate process in the dyehouse. Rather than install a hot water heater at this time, the plant decided to use sparged steam to heat the water back to its required temperature. Finally, they installed a stack economizer on one boiler. This economizer was considered a higher priority than those on the other boilers because this particular boiler ran at a higher rate. Total energy savings from these measures was approximately 98115 GJ/year, with implementation costs of approximately $1.5 million (US DOE ITP, 2008b).

Steam distribution, usage and condensate return systems optimization[41]

Textile plants use steam in a variety of machines and processes. Because of the widespread use of steam at locations across a factory, losses during steam transportation are considerable. For steam transportation over long distances, high-pressure and small-diameter piping is preferable to low-pressure and large-diameter piping. In addition, pressure-reducing valves should be placed as necessary to regulate steam pressure at the point of use, thereby curbing heat loss. According to industry data, the energy loss of one meter of un-insulated steam pipe with 200mm or 51mm diameter (at an inside steam temperature 200 ℃) could account for the equivalent of nearly three tonnes of wasted coal annually. If all the steam pipelines in a typical factory were well insulated, heat loss in this area could be reduced by up to 90 % (Greer et al., 2010).

Most textile plants, especially in developing countries, have poorly insulated pipes, valves and flanges. Maximally improving steam distribution in these plants requires the routine inspection and insulation of all pipes, valves, and flanges in a plant. Breaches in insulation (tears, etc.) should also be repaired and replaced. A popular insulation material is slag wool, which is good quality, high efficiency and low cost, although different locations may require different insulation materials. Greer et al. (2010) estimates fuel savings of 5 – 884 MJ/tonne fabric produced for wet-processing plants based on case-studies in Chinese plant. The associated cost is reported to be around $4,500 for insulating pipes, valves, and flanges. CIPEC (2007) reports that a steam trap surveillance program in wet-processing plants would cost around $3,200 – $10,000 with a 1.5 – 2.5 year payback period.

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[41] This section is excerpted from Greer et al.(2010), unless different source is given.

6. Emerging technologies

Higher energy consumption in textile operations creates a pathway to innovations in various operations and procedures. Some of the emerging technologies, used mostly in textile wet-processing where significant amounts of energy are used, are introduced below.

183. Supercritical dyeing technique

Any gas above its critical temperature retains the free mobility of the gaseous state, but with increasing pressure its density will increase towards that of a liquid. Supercritical fluids are highly compressed gases and combine valuable properties of both liquids and gases. Supercritical fluids have solvent powers similar to a light hydrocarbon for most solutes. Solubility increases with increasing density (i.e., with increasing pressure). However, fluorinated compounds are often more soluble in carbon dioxide than in hydrocarbons, and this increased solubility is important for polymerization. Carbon dioxide is frequently used as a solvent because of some inherent advantages associated with the system such as non-toxicity, non-corrosivity and non-hazardousness. Carbon dioxide is produced commercially and can be transported easily. The critical temperature and pressure for carbon dioxide can be achieved easily compared to other gases (Ramachandran et al., 2008).

The use of supercritical carbon dioxide as a dyeing medium is a new technique. Dyeing is performed in a high pressure vessel called an autoclave. Carbon dioxide exists as a supercritical fluid at temperatures at about 31 ℃ and pressures above 72 bar. The anhydrous process offers a number of ecological and economical advantages such as no preparation of processing water and low energy consumption for heating up the liquor (Prince, 2008).

184. Ultrasonic assisted wet-processing[42]

An ultrasonic assisted process is an alternative to conventional high temperature processing of textile materials. Ultrasound equipment installed in the existing machines offer improved performance in fabric preparation and dyeing without impairing the properties of the processed materials. The influence of ultrasound intensifies mass transfer in the wet-processing of textile materials. The advantages of the use of ultrasonic in textile wet-processing includes energy savings due to reduced processing temperatures and time and the lower consumption of auxiliary chemicals (Prince, 2008). Sound waves are classified into infra-sound (up to 16Hz), audible sound (16 Hz – 16000 Hz) and ultrasound, which includes sound waves higher than audible sound with a frequency above approximately 16 kHz up to 106 kHz. The two beneficial phenomena attributed to ultrasound are the rapid movement of liquids caused by the variation of sonic pressure, which subjects the solvent to compression and rarefaction, and micro-streaming. Heat induced in an ultrasonic process is adequate for the dyeing process and thus eliminates the need for external heating in many cases. The advantages of the use of ultrasonic in textile wet-processing include energy savings by reduced processing temperatures and time, and the lower consumption of auxiliary chemicals.

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[42] This section is excerpted from Ramachandran et al. (2008).

The ultrasonic method has been effectively utilized in various fabric preparation processes including desizing, scouring, bleaching, and mercerization and auxiliary processes like washing and laundering. Attempts have been made to analyze the effect of ultrasonic in dyeing processes on almost all types of fibers using direct, reactive, acid and disperse dyes. Ultrasonic waves accelerate the rate of diffusion of the dye inside the fiber with the enhanced wetting of fibers (Ramachandran et al., 2008).

185. Foam technology[43]

The application of foam processing leads to considerable savings in the energy required for heating, drying, thermo-fixing, and steaming because the water content is greatly reduced (Prince, 2008). In the foam process the liquor is diluted using air instead of the water that is normally used to apply the chemicals over the textile materials. In foam finishing, most of the water is replaced by air which leads to a reduction of energy requirements in the drying processes, resulting in substantial savings in energy cost.

Foam is a colloidal system comprised of a mass of gas bubbles dispersed in a liquid continuum. Foam can be generated by mechanical air blowing, through excess agitation or chemically through the introduction of foaming agents, or a combination of these methods. The relative proportions of air and liquid phases in the foam are designated by the blow ratio. Foam stability, density and diameters are important parameters that need constant attention.

Foam application technique can be used in fabric preparation, dyeing and printing, softening, water and oil proofing, flame retardant finishing, anti-static finishing, mercerization, etc. The foam can be applied either on one or both sides of the fabrics. A foam finishing process can be used to achieve up to an 80% reduction of water consumption and a 60% – 65% reduction in energy use, depending on the type of finishing treatment used. Also noxious gases and related pollution can be minimized. The payback period for the application of foam technology for finishing is between six months and two years (Ramachandran et al., 2008).

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[43] This section is excerpted from Ramachandran et al. (2008), unless different source is given.

7. Use of renewable energy in the textile industry

There are various potentials for the use of renewable energy in the textile industry. Several cases for of such uses are presented below in table 34, but the use of renewable energy in the textile industry is not limited to this few cases.

Table 34. Several cases for the use of renewable energies in the textile industry *

No.	Measures	Fuel saving	Electricity saving	Capital Cost	Payback period (years)**
186	Installation of Turbo Ventilators at the roofs that rotates by wind		23 – 91 MWh/year/plant	6100 - 9100 /plant	1.3 – 3.5
187	Use of direct solar energy for fiber drying	US$4200 per year		2700 /system	0.5
188	Use of solar energy for water heating in the textile industry				

* The energy savings, costs, and payback periods given in the table are for the specific conditions. Please read the explanation of each measure to get the complete understanding of the savings and costs.

**Wherever the payback period was not given while the energy and cost are given, the payback period is calculated assuming the price of electricity of US$75/MWh (US$0.075/kWh).

186. Installation of turbo ventilators that rotate using wind blowing over roofs

Some areas in the textile plant need to have a well-maintained standard temperature and humidity, for which HVAC systems are used. However, this is not the case for the whole plant. There are areas in many textile plants that do not need HVAC systems, such as most of the wet-processing plants and non-production areas. In these areas, usually, fans are used just to ventilate the air. Instead of using fans, turbo ventilators that rotate using natural wind can be installed on roofs. The potential implementation of this measure depends on the geographical location of the plant and also there might be seasonal changes in wind speed and direction. Several textile plants in India have installed turbo ventilators on their roof and have reported electricity savings of 23 – 91 MWh/year. The reported investment cost varies between US$6100 and US$9100. Energy savings and cost depend on the number of ventilators installed and the number of fans replaced (EMT, 2008k; EMT, 2008l).

187. Use of direct solar energy for fiber drying

In some textile plants, wet fibers need to pass through a drying process, such as in the drying of acrylic fibers after the dyeing process. If the plant is located in an area which gets sunshine for several months of the year, then there is the potential to use direct solar energy for fiber drying. A textile plant in India constructed a platform using a chain link fence facing in open area directly under the sun. This resulted in energy cost savings of US$4200 per year with an investment cost of US$2700. It should be noted that the implementation of this measure depends on the geographical location and climatic situation in the area where the plant is located. The type of fibers could also be an influencing factor (EMT, 2008l).

188. Use of solar energy for water heating in the textile industry

There is a high demand for low-temperature hot water in textile wet-processing which partially could be generated using solar energy. A feasibility study to understand the potential for solar energy utilization in a textile plant can be conducted to find out whether or not it is economically feasible to use solar energy to provide low-temperature hot water, given the plant’s geographical location and the climatic situation in the area. Two configurations for the use of solar hot water systems in wet processing plants can be considered. The first configuration is a solar preheat system that can feed the boiler with hot water. This system can be efficiently utilized under different flow rates and output temperatures. The second configuration is to feed dyeing processes that require low-temperature water (up to 85 ℃) directly with hot water produced by a solar system. Economic comparisons between the two configurations can be done to determine the optimal system. A project in a textile plant in Egypt studied the optimal design of the two configurations, taking into account the optimum collector area and flow rates. They found that the second configuration (i.e. feeding the dyeing process directly with low-temperature hot water produced by solar system) was more economical and efficient. (Abdel-Dayem and Mohamad, 2001). There are some other case-studies for the use of solar energy in textile wet-processing, like the one conducted in Pakistan by Muneer et al. (2006).

8. Summary and conclusions

Energy is one of the main cost factors in the textile industry. Especially in times of high energy price volatility, improving energy efficiency should be one of the main concerns of textile plants. There are various energy-efficiency opportunities in textile plants, many of which are cost-effective. However, even cost-effective options often are not implemented in textile plants due mainly to limited information on how to implement energy-efficiency measures, especially given the fact that the majority of textile plants are categorized as SMEs. These plants in particular have limited resources to acquire this information. Know-how regarding energy-efficiency technologies and practices should, therefore, be prepared and disseminated to textile plants.

This guidebook provides information on energy-efficiency technologies and measures applicable to the textile industry. The guidebook includes case studies from textile plants from around the world with energy savings and cost information when available. For some measures the guide provides a range of savings and payback periods found under varying conditions. At all times, the reader must bear in mind that the values presented in this guidebook are offered as guidelines. Actual cost and energy savings for the measures will vary, depending on plant configuration and size, plant location, plant operating characteristics, production and product characteristics, the local supply of raw materials and energy, and several other factors. For instance, for some of the energy-efficiency measures, the significant portion of the cost is the labor cost. Thus, the cost of these measures in the developed and developing may vary significantly. Therefore, for all energy-efficiency measures presented in this guidebook, individual plants should pursue further research on the economics of the measures, as well as on the applicability of different measures to their own unique production practices, in order to assess the feasibility of measure implementation.

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Appendixes

Appendix 1. Textile processes description

A.1. Fiber production[44]

Natural fibers are available from animals and plants. The most important natural fibers are cotton and sheep's wool. The raw materials for man-made fibers can be natural, synthetic polymers, or inorganics. Polyester, polyamide, polyacrylonitrile, polypropylene, regenerated cellulose (viscose), and acetate are the most important man-made fibers in the textile industry. As the energy consumed in the production of man-made fibers is much greater than the energy needed for the preparation of natural fibers, this guidebook only includes energy-efficiency measures applicable to the production of man-made fibers.

Briefly, the production of man-made fibers is as follows. As a first step in man-made fiber processing, filaments from the raw materials are produced by one of the spinning processes:

- melt-spinning
- dry-spinning
- wet-spinning

In melt spinning, which is used for thermoplastic polymers (polyamide, polyester, polypropylene, etc.), the polymer granulates are melted, pressed through spinning nozzles and wound together after cooling. In dry-spinning (for polyacrylonitrile and elastane) and wet-spinning (for viscose and cupro) the polymers are dissolved in an appropriate solvent, which is then removed. In dry-spinning, evaporation of the solvent is done by passing hot air over the filaments as they pass the spinning nozzles. Wet-spinning is carried out by immersing the filaments in a coagulation bath. The removal of the solvents from the fibers in wet spinning occurs through a diffusion-controlled process. After the spinning process, the filaments are drawn to increase the orientation of the macromolecules and thereby the tensile strength of the yarns. Man-made fibers can be used either as filaments or multifilament yarns or, after converting through breaking or cutting, as staple fibers.

If man-made fibers are used as filaments, texturizing processes can be conducted to attain a better heat retentivity, elasticity, and volume in comparison to flat filaments (Schönberger and Schäfer, 2003). In texturizing, mechanical and thermal stress (twisting of the flat yarns at higher temperatures) is applied and the orientation of the macromolecules changes, achieving a crimp effect on the macroscopic level and thereby giving the material a greater volume.

A.2. Spun yarn production [45]

Spun yarn formation is done in spinning plants. Before entering the spinning machine, fiber preparation processing takes place. In succession, this includes opening the fiber bales; mixing the fibers; cleaning, arranging, and paralyzing the fibers; drafting; and twining of the fibers into a yarn. After this initial processing, the yarn is spun. Natural fibers as well as man-made staple

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[44] This section is excerpted from Schönberger and Schäfer (2003)

[45] This section is excerpted from Schönberger and Schäfer (2003)

fibers are produced into yarns with different types of spinning systems. The kind of system used depends on the fiber length, fiber thickness, and the end-use of the product. Ring spinning is the most important and common technology. The open-end technique is the most-commonly used non-conventional spinning technology. Other different spun yarn spinning systems are:

- cotton spinning technologies (all fiber types, especially cotton up to 40 mm length),
- worsted spinning (wool and long staple man-made fibers (especially polyester and polyacrylonitrile)),
- semi worsted spinning (important for coarse wool and long staple man-made fibers, especially polyamide and polyacrylonitrile), and
- woolen spinning (universal technique for wool and fine man-made fibers).

In all the spinning systems mentioned above, the last step is carried out on ring spinning or non-conventional spinning machines (Schönberger and Schäfer, 2003).

A.3. Fabric production

Three most methods to produce fabrics are weaving, knitting, and non-woven technology. Each of these technologies is explained below. There are a few other much less common technologies such as tufting and braiding which are not discussed in this guidebook.

A.3.1. Weaving [46]

Weaving involves interlacing two or more yarn systems crosswise and vertically. Woven textiles are used in all textile sectors (apparel, home textiles, and technical textiles). On the weaving machine (loom) the weft yarn is inserted into the lengthwise-oriented warp yarns (shed). Before the weaving process starts, some preparatory processes have to be carried out. At first, the loom beam has to be prepared. The warp yarns have to be assembled with the help of warping machines. Most of the spun yarns as well as the filament yarns have to be sized before weaving. Sizing is carried out in the weaving plant to protect the warp yarn during the weaving process from damage and breaking. The size forms a protective film on the warp yarn, minimizing protruding fiber ends which might cause loom stops. Sizing is done with help of sizing machines (slashers) (Schönberger and Schäfer, 2003). The weft insertion is carried out using one of the following techniques:

- shuttle
- projectile
- rapier
- water jet
- air jet
- special weft insertion techniques
- circle weave technique

A.3.2. Knitting [47]

In knitting, fabric is formed by interlocking or intermeshing loops of one or more sets of yarns. Knitting is performed using one of two processes: weft or warp knitting. Each of these processes

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[46] This section is excerpted from Schönberger and Schäfer (2003)

[47] This section is excerpted from US EPA (1998)

is done on several different types of machines. In weft knitting, loops are formed by needles knitting the yarn across the width of the fabric. In warp knitting, loops are formed by needles knitting a series of warp yarns fed parallel to the direction of fabric formation. Knitting is used for producing sweaters, hosiery, technical products,[48] and other types of fabric (US EPA, 1998).

Figure A-1 shows a diagram of spun yarn spinning (a cotton spinning system) and weaving/knitting processes.

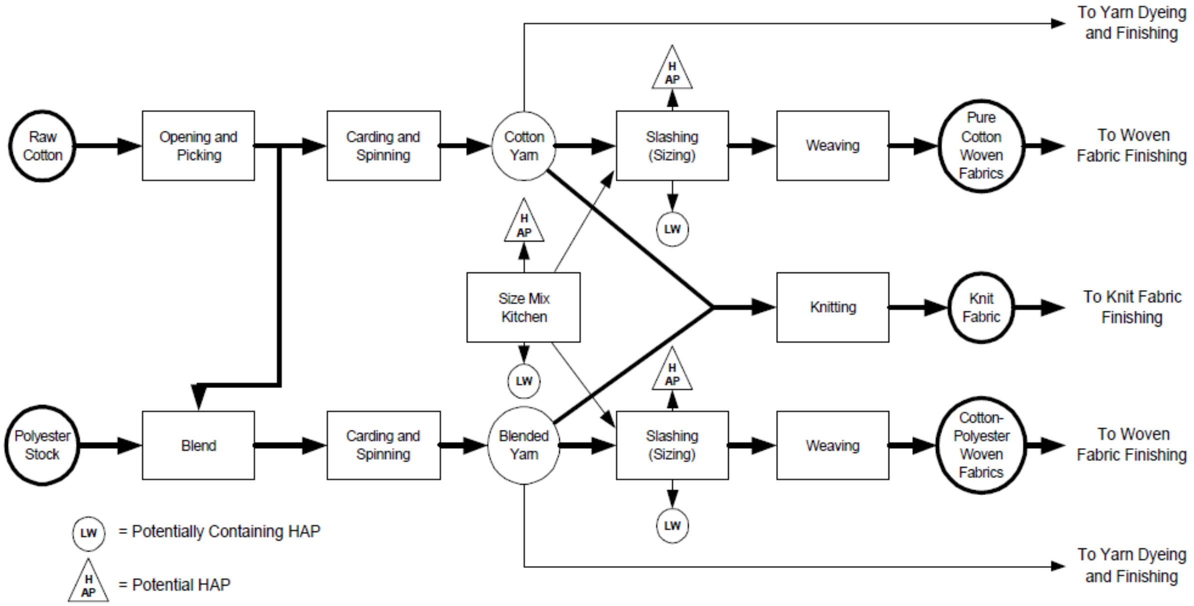

Figure A-1. Diagram of Spun Yarn Spinning and Weaving/Knitting Processes (US EPA, 1998)

Note: HAP: Hazardous Air Pollutants, LW: Liquid Waste potentially containing HAP

A.3.3. Nonwovens [49]

Fabrics made of fibers without intermediate yarn processing are called nonwovens. Nonwovens are essentially sheet or web structures made by bonding and/or interlocking fibers, yarns, or filaments using mechanical, thermal, chemical bond, or solvent means. Nonwovens have several performance advantages such as moldability, and are typically engineered for specific uses, such as geo-textiles, blankets, diapers, electrical insulation, and filters. Nonwovens can be homogenous fiber-web or netlike structures or can be laminates/composites. Typical fibers used in making nonwovens are polyester, polypropylene, rayon, and wood pulp (U.S. EPA, 1998).

A.4. Wet processing [50]

Wet-processing includes several steps that involve adding colors to fiber, yarn, or fabric or imparting patterns to the fabric, along with a variety of finishing steps that provide certain desired characteristics to the end product. These finishing steps are important mainly in cotton and synthetic production. For most wool products and some man-made and cotton products (like

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[48] Technical products are the textiles for special uses such as Geo-textiles.
[49] This section is excerpted from US EPA (1998)
[50] This section is excerpted from US EPA (1998)

gingham), the yarn is dyed prior to weaving and the pattern is woven on the fabric. Figure A-2 shows a schematic of typical woven fabric wet-processing operations.

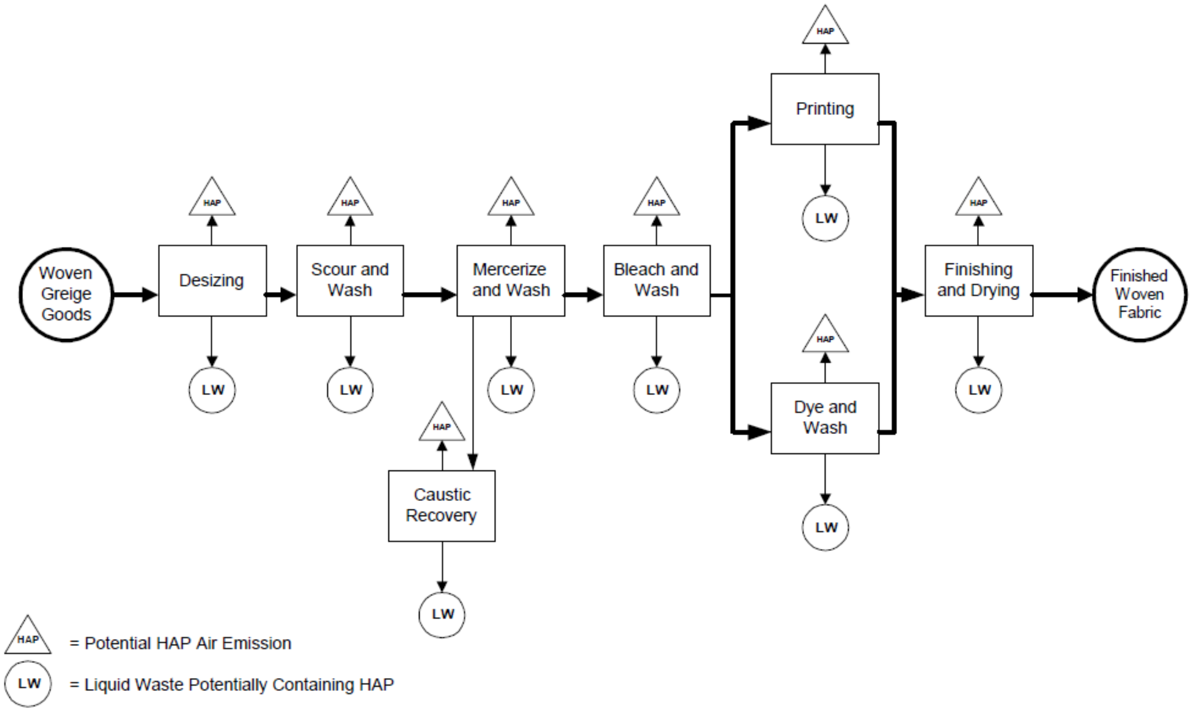


Figure A-2. Schematic of Typical Woven Fabric Wet-Processing Operations (US EPA, 1998)
Note: HAP: Hazardous Air Pollutants, LW: Liquid Waste

A.4.1. Preparation

Preparation includes any of several steps that may be taken to clean or prepare the fabric prior to dyeing/printing. Preparation includes, but is not limited to, heat-setting, desizing (woven only), singeing, scouring, bleaching, and mercerization (cotton only). Different types of equipment and chemicals are used in different preparation steps, and all these steps are not necessarily undertaken for all fabrics. Desizing, scouring, and bleaching operations all involve the removal of impurities and can be done on various types of washers and steamers. Mercerization is an optional process on cotton fabrics. It is done for various purposes such as improving dye affinity/uptake, improving strength, etc. Drying operations are generally done using ovens, cylinder dryers or stenter frames (US EPA, 1998).

A.4.2. Dyeing

Dyeing is the application of color to the whole body of a textile material with some degree of colorfastness. Textiles are dyed using continuous and batch processes and dyeing may take place at any of several stages in the manufacturing process (i.e., prior to fiber extrusion, while the fiber is in staple form, to yarn, to fabrics, and to garments). Various types of dyeing machines are used for both continuous and batch processes. Every dye system has different characteristics in terms of versatility, cost, tension of fabric, use of carriers, weight limitations, etc. Dyeing systems can be aqueous, non-aqueous (inorganic solvents), or use sublimation (thermosol, heat transfer). Hydrophilic fibers such as cotton, rayon, wool, and silk, are typically easier to dye as compared with hydrophobic fibers such as acetate, polyesters, polyamides, and polyacrylonotriles (US EPA, 1998).

A.4.3. Printing

While dyeing is preferred for solid colors or simple patterns, in most other cases, printing techniques are used. Printing processes involve the use of colors, usually in the form of a paste, which are applied to fabrics in patterns. The fabric is treated with steam, heat, or chemicals to fix the color. The types of chemicals used include pigments (majority of printed fabrics) or dyestuffs, and auxiliaries (such as softeners, thickeners, and cross-linking agents). Pigments have some similarities to dyestuffs, but also differ from them in many ways; for example, unlike dyes, pigments are insoluble in water and common solvents. Textile printing can be done on printing ranges using different techniques, the most common ones being rotary screen printing, flat-bed screen printing (mainly used for custom work), engraved roller printing, and heat transfer printing (US EPA, 1998).

A.4.4. Finishing

Finishing refers to any operation (other than preparation and coloring) that improves the appearance and/or usefulness of fabric after it has been woven or knitted. Finishing encompasses any of several mechanical (e.g., texturing, napping, etc.) and chemical processes (e.g., optical finishes, softeners, urea-formaldehyde resins for crease resistance, etc.) performed on fiber, yarn, or fabric to improve its appearance, texture, or performance. The fabric is usually dried prior to finishing using either convective (hot air) or conductive (cylinder dryers) methods. Chemical finishing can be done on a continuous finishing machine (pads and stenter frames). Figure A-3 shows a typical fabric dyeing and finishing process (US EPA, 1998).

Wet-processing can be carried out at all the steps in the textile chain: on loose fibers, slivers, yarns, fabrics, and on the ready-made textile. Figure A-4 shows the share of wet-processing of different textile products in Germany. As can be seen, fabric wet-processing is the most common among other wet-processing. That is why there is also more energy and water used in fabric wet-processing. Thus, more study is conducted on energy efficiency in fabric wet-processing. This guidebook also focuses on energy efficiency in fabric wet-processing.

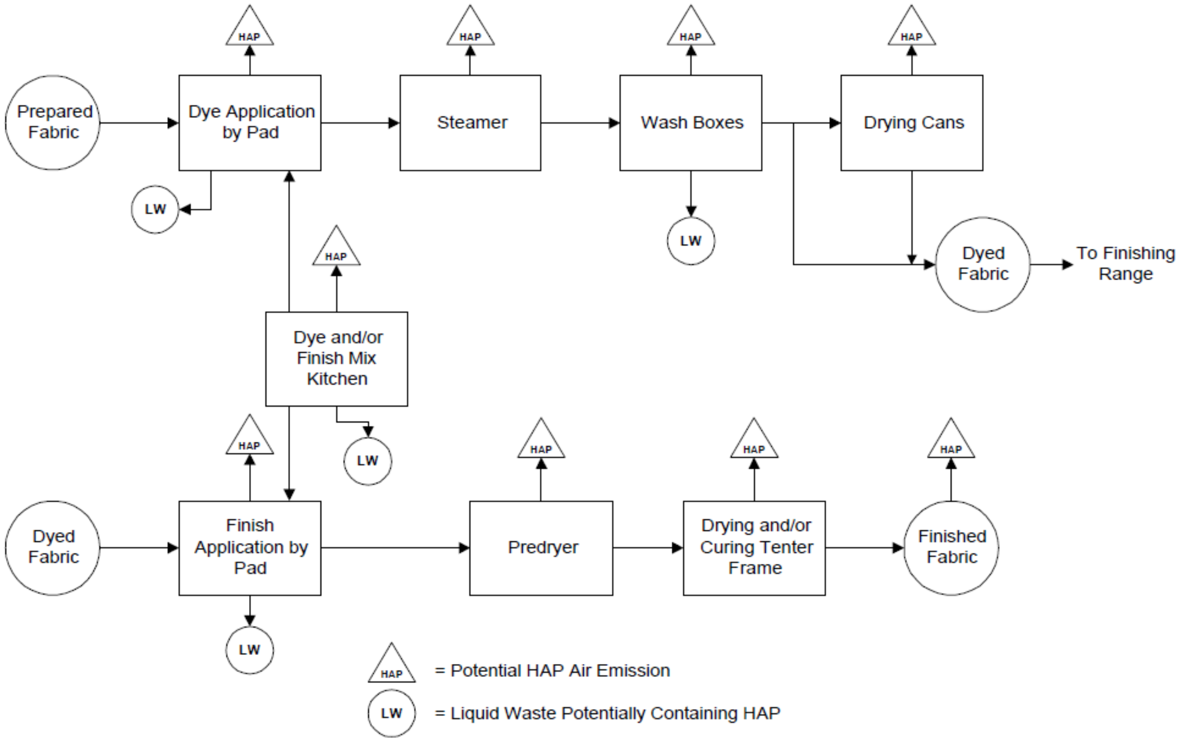


Figure A-3. Typical Fabric Dyeing and Finishing Process (US EPA, 1998)

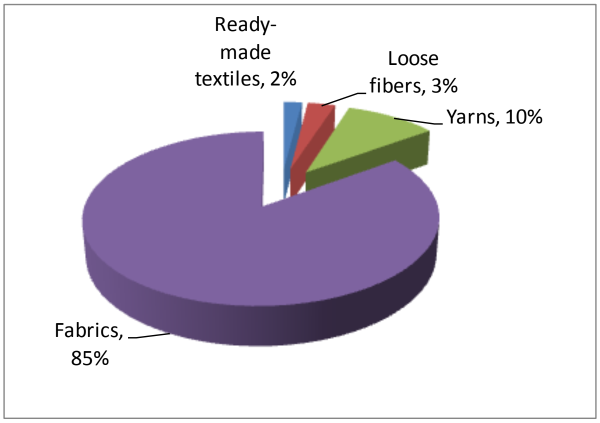
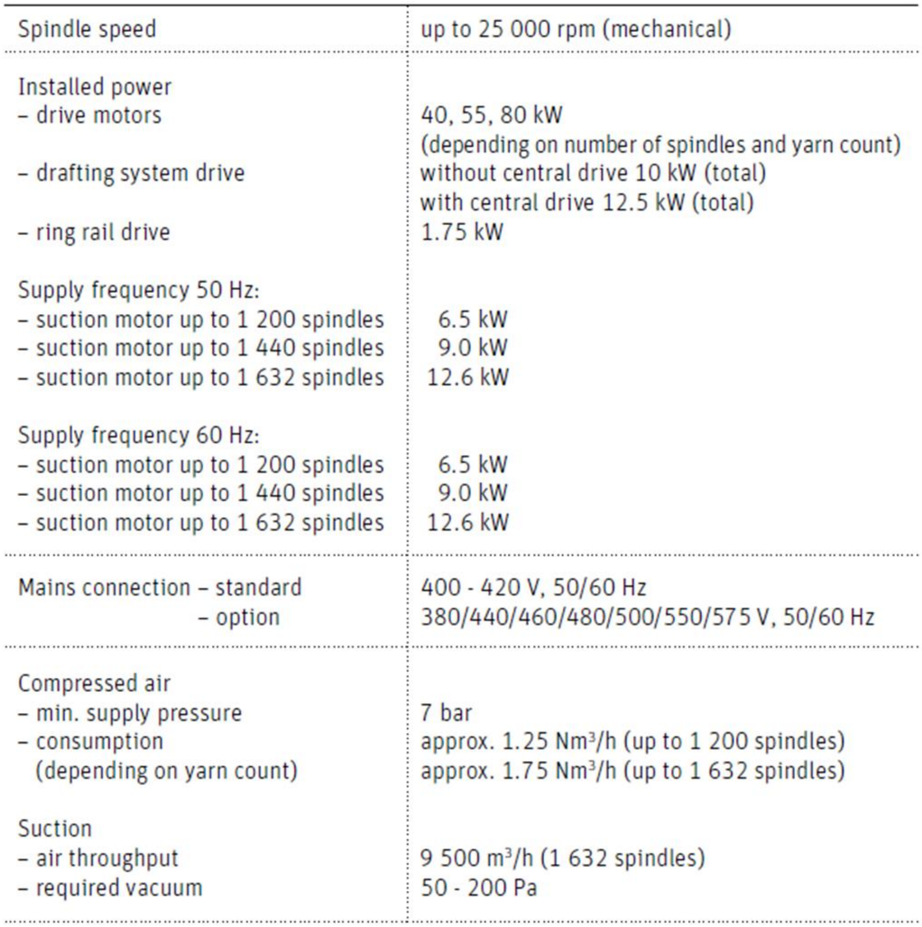


Figure A-4. The Share of Wet-Processing of Different Textile Products in Germany (Schönberger and Schäfer, 2003)

Appendix 2. Example of technical parameters for a ring frame[51]



Spindle speed	up to 25 000 rpm (mechanical)
Installed power	
– drive motors	40, 55, 80 kW (depending on number of spindles and yarn count)
– drafting system drive	without central drive 10 kW (total) with central drive 12.5 kW (total)
– ring rail drive	1.75 kW
Supply frequency 50 Hz:	
– suction motor up to 1 200 spindles	6.5 kW
– suction motor up to 1 440 spindles	9.0 kW
– suction motor up to 1 632 spindles	12.6 kW
Supply frequency 60 Hz:	
– suction motor up to 1 200 spindles	6.5 kW
– suction motor up to 1 440 spindles	9.0 kW
– suction motor up to 1 632 spindles	12.6 kW
Mains connection – standard	400 - 420 V, 50/60 Hz
– option	380/440/460/480/500/550/575 V, 50/60 Hz
Compressed air	
– min. supply pressure	7 bar
– consumption (depending on yarn count)	approx. 1.25 Nm³/h (up to 1 200 spindles) approx. 1.75 Nm³/h (up to 1 632 spindles)
Suction	
– air throughput	9 500 m³/h (1 632 spindles)
– required vacuum	50 - 200 Pa

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[51] Excerpted from: Rieter, 2010. Available at: http://www.rieter.com/cz/textile/short-staple-yarn/ring-spinning/g-35-ring-spinning-machine/?tx_damdownloadcenter_pi1%5Bfile%5D=166336&cHash=a1dcecc3ce