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Investigation of Energy Consumption in Yarn Production with Special Reference to Open-End Rotor Spinning

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Abstract
The aim of this study is to evaluate the energy consumption, in general, for open-end rotor type yarn manufacturing systems and to examine the energy consumption in a chosen spinning mill by considering available data including installed power as well as monthly and yearly energy usage. A simple theoretical approach for predicting specific energy consumption in a particular yarn type produced in the spinning mill selected has been developed. The results obtained by applying this model to a specific yarn have been compared with relevant values available in literature.

Key words: *energy consumption, yarn manufacturing, open-end rotor spinning, textile.*

Introduction

Yarn manufacturing

The formation of spun yarn is realised when basic manufacturing processes, such as opening, cleaning, blending, carding, drafting and spinning are performed. In some systems combing and roving processes are added to these steps. The properties and structure of a yarn change not only according to the production steps but also to the spinning system used for manufacturing. The system utilised for yarn formation depends on such factors as the fibres to be used, properties of the yarn to be produced and economic implications. The ring spinning system can be considered as conventional (traditional), whereas the open-end, wrap, air-jet and self-twist spinning systems are unconventional (nontraditional). In all these systems twisting and winding the yarn on the package is undertaken by applying different mechanisms. Although studies and developments of new spinning systems are still going on, the ring and open-end rotor spinning systems are the most widespread for yarn manufacturing [1 - 7].

The open-end rotor system is the only real alternative to ring spinning for producing coarser yarn counts with the successful processing of fibre at significantly higher speeds. The basic principle involves the separation of the sliver fed into individual fibres, which are gathered on the collection groove of the rotating rotor, inserting twist into the fibres. The yarn produced is then taken up onto a cross wound package, eliminating the need for a separate winding process, as in ring spinning. Compared with ring spinning, open-end spinning has the following advantages:

- Elimination of some processes, such as roving and winding,
- Lower yarn fault content,
- Cheap raw material is available and there is less waste,
- Larger delivery package size,
- Reduced labour requirements and open to automation,
- Higher speed of twist insertion and delivery speed up to 200 m/min,
- Lower power consumption per kg of yarn produced for short staple yarns thicker than approx. 20 to 30 tex [4, 7 - 9].

Manufacturing cost of a yarn

Producing high quality yarns with reasonable costs is a key factor in competing with other manufacturers in today's competitive conditions. Gaining more profit depends on minimising the manufacturing cost of yarns since free market conditions determine the price of products irrespective of the administration of spinning mills. In particular, cheaper yarns produced by Far East countries, such as China and Indonesia, draw the attention of consumers. This negatively affects other countries' yarn manufacturers, and factors such as cost calculation and cost minimisation become primarily important [10].

The cost of a yarn consists of several cost factors, such as the raw material cost, energy or power cost, labour cost, capital cost etc. The cost of a yarn excluding raw material is termed the manufacturing cost. The share of cost factors in the manufacturing cost changes according to the yarn properties, machine operational properties and economic situation of the spinning mill [3, 10, 11].

Table 1 illustrates the general shares of cost factors for 20 tex carded open-end rotor cotton yarn for selected countries.

Raw material (fibre) forms more than half of the total cost of yarn, and other cost factors such as labour, energy, the capital cost of machines, the auxiliary material cost and waste make up the remaining part. After raw material costs, capital and energy costs have the highest proportions in the total cost. The power or energy cost has a 7% share of the total specific yarn cost in Turkey. This share increases to 26.4% if the raw material cost is excluded. Since the unit price of energy and labour changes independently from spinning mill conditions, reducing these costs depends on minimising energy usage and labour requirements.

Various studies have been done to determine the energy cost and consumption of spinning systems [2, 3]. The International Textile Manufacturer Federation [12, 13] has made a comparison of the manufacturing costs of textile processes, including spinning, texturing, weaving and knitting in their yearly technical report. This report contains costs calculated for specific ring and open-end rotor spun yarn for the countries selected.

The cost factors which affect the total cost of ring and open-end rotor yarn were investigated by Kuşçuoğlu [14]. The labour and energy cost of a chosen spinning mill was examined, and the costs of different types of yarns with changing machine parameters were evaluated by Koç and Kuşçuoğlu [15, 16]. Örtlek et al [17] compared the calculated cost of 20tex ring, open-end and Vortex (MVS) yarns. It was found that the energy cost of 1 kg of ring yarn is the highest of the three, Vortex being the most advantageous of them. Kaplan [10] studied cost factors which make up the total product cost for the textile industry including spinning, weaving, finishing and the product cost of selected ring yarn by using empirical formulas with specific operating conditions, and the machine parameters selected can be estimated. Koç and Kaplan [11] evaluated the energy consumption of a chosen spinning mill and tried to calculate the unit energy consumption of selected ring yarn using a simple theoretical model that they developed. Furthermore, the data calculated are compared with those in literature.

Energy is necessary for each step of spinning processes to drive machines, air conditioning and for illumination, but the highest energy consumption occurs during the spinning process in spinning machines. Tarakçıoğlu [18] showed that the electrical energy consumption of 1 kg of yarn changes between 2.7 kWh/kg and 4 kWh/kg, whereas the thermal energy changes between 1.1 MJ/kg and 4.7 MJ/kg, which is necessary for processes such as fixation besides electrical energy needs. Additionally, it was pointed out that unit energy consumption can change between 1.8 - 2.9 kWh/kg according to the yarn count. A general assessment of energy consumption and conservation in fibre-producing and textile industries has been done by Kim et al [19] in which the power requirement of specific ring and open-end spinning machines with selected machine parameters was determined.

Energy consumption at the spinning stage in open-end rotor spinning is high compared with ring spinning, but the absence of certain spinning preparatory (combing and roving) and post spinning operations (winding) causes lower energy consumption for the total spinning processes than ring spinning for coarse yarns. Energy is consumed mostly during fibre separation, twist insertion and winding in an open-end rotor machine. Approximately 60% or more of the total energy is consumed by rotors in open-end spinning compared with 85-90% consumed by spindle rotation in ring spinning [7, 20, 21]. Since the highest power is required by spinning machines, many studies have been carried out to determine the power demand of spinning machines. Krause and Soliman [22] attempted to find a general formula for calculating power/energy consumption per 1 kg of yarn in ring and open-end rotor machines. It was found that in the coarse yarn range (tex > 60) the open-end rotor machine needed less energy per kg of yarn than the ring frame for warp yarns, whereas for finer yarns (tex < 30), the oe-rotor machine demanded more energy per kg yarn than the ring frame.

Table 1. *Cost factors for specific open-end rotor yarn in $/kg and share in % given in bracket (2006) [12].*

Cost Factors	Brazil	China	India	Italy	Korea	Turkey	USA
Waste	0.09 (5)	0.12 (5)	0.07 (5)	0.09 (4)	0.09 (5)	0.09 (5)	0.08 (4)
Labour	0.02 (1)	0.01 (1)	0.01 (1)	0.18 (9)	0.06 (3)	0.05 (2)	0.11 (7)
Energy	0.08 (4)	0.13 (6)	0.16 (10)	0.18 (9)	0.10 (6)	0.14 (7)	0.08 (4)
Auxiliary Material	0.08 (4)	0.08 (3)	0.08 (5)	0.08 (4)	0.08 (4)	0.08 (4)	0.08 (5)
Capital	0.30 (16)	0.18 (8)	0.18 (12)	0.20 (10)	0.19 (10)	0.17 (9)	0.27 (16)
Production cost (Excluding raw material)	0.57 (31)	0.52 (23)	0.50 (33)	0.73 (37)	0.52 (28)	0.53 (28)	0.62 (36)
Raw material	1.28 (69)	1.76 (77)	1.02 (67)	1.24 (63)	1.29 (72)	1.36 (72)	1.13 (64)
Total yarn cost (Index - Italy: 100)	1.85 (95)	2.28 (116)	1.52 (77)	1.97 (100)	1.81 (92)	1.89 (96)	1.75 (90)

Syen [21] tried to optimise energy consumption during open-end spinning without adversely affecting yarn quality or the rate of production. The method of optimisation consisted in testing yarn spun at various levels of rotor and combing roller speed to determine the effect of machine parameters on yarn properties. It was found that lower combing roller and rotor speeds result in lower energy consumption.

The factors affecting power consumption in open-end rotor spinning machines was examined by Paradkar and Desai [23]. Power consumption during the production of yarns with different counts, twist levels, rotor diameters and rotor speeds was measured with the help of a power meter connected to the rotor spinning machine. A mathematical model linking the unit power consumption per kg of yarn with the count, twist level, rotor speed and diameter was developed, and it was shown that yarn count has a predominant role in unit energy consumption.

In the present study, the general energy consumption of spinning mills is explained, and the energy consumption of a chosen spinning mill has been analysed using data for installed power as well as monthly and yearly energy usage. Additionally, a simple approach for calculating the specific energy consumption of certain yarn has been developed. Calculation of the specific energy consumption of particular open-end rotor yarn produced in the spinning mill chosen has been conducted using the formulas recommended, and the results obtained have been compared with relevant values given in literature.

Energy consumption in yarn manufacturing

General energy usage in open-end rotor spinning

Generally, energy is needed for operating machines, air conditioning and illuminating the place where yarns are manufactured in spinning mills. Additionally, compressors, which provide compressed air to the spinning line, use energy. Electrical energy and thermal energy are of the type that can be used in a specific spinning mill. Machines, air conditioning, lamps used for illumination and compressors consume electrical energy, while thermal energy is consumed by air conditioning and processes such as the fixation of yarns. Thermal energy is generally obtained from coal, diesel oil, fuel oil, natural gas and steam [10, 11, 24].

The specific energy consumption and energy cost of both 20 tex combed ring-spun yarn and 20 tex open-end yarn for selected countries are illustrated in ***Table 2***.

Specific energy is the unit energy needed during the production of a unit mass of yarn in kWh/kg. The amount of energy needed for ring yarn changes between 2 - 4.167 kWh/kg, while the energy needed for open-end yarn is between 1.6 and 1.778 kWh/kg. Electrical energy prices are different in the countries selected, although the consumption is nearly the same.

Table 3 shows the specific energy consumption for 20 tex cotton carded open-end rotor yarn and energy prices for selected countries for the years 1997-2006 according to reports of the International Textile Manufacturers Federation. The specific energy consumption and energy price of each country changes depending on the economic conditions in the given years. The specific energy consumption of most of the countries showed an increasing trend until 1999, and after 1999 it decreases depending on the year under consideration. In Turkey, the specific energy consumption of 20 tex carded open-end rotor yarn changed between 1.667-2.919 kWh/kg in the given years (***Table 3*** and ***Figure 1***).

The energy prices, specific energy consumption and energy cost of relevant yarn for Turkey from 1997 to 2006 have been extracted from the table and used to form a bar graph, as shown in ***Figure 1***. The specific energy cost can easily be calculated by multiplying the energy price by the specific energy consumption. For 1997, the energy price for Turkey is 0.07 \$/kWh, and the energy cost of 1 kg of 20 tex open-end rotor yarn is 0.202 \$/kg, which is obtained as

$$0.07 \text{ \$/kWh} \times 2.886 \text{ kWh/kg} = 0.202 \text{ \$/kg}.$$

A similar method is applied for each year i.e. in 2006 the specific energy cost of the yarn concerned is 0.14 \$/kg.

Table 2. *Energy consumption for specific ring and open-end yarn (2006) [12].*

Countries	Electrical energy prices, \$/kWh	Ring Yarn (Combed)		Open-End Yarn	
		Energy consumption, kWh/kg	Energy cost, \$/kg	Energy consumption, kWh/kg	Energy cost, \$/kg
China	0.080	3.375	0.27	1.625	0.13
India	0.095	3.368	0.32	1.684	0.16
Turkey	0.140	2.000	0.28	1.667	0.14
Brazil	0.050	3.400	0.17	1.600	0.08
S. Korea	0.100	2.000	0.20	1.667	0.10
USA	0.045	3.334	0.15	1.778	0.08
Italy	0.084	4.167	0.35	1.714	0.18

Table 3. *Energy consumption for specific open-end yarn in the given years (1997 - 2006) [10, 12].*

Countries	1997		1999		2001		2003		2006	
	Energy prices, \$/kWh	Energy cons., kWh/kg	Energy prices, \$/kWh	Energy cons., kWh/kg	Energy prices, \$/kWh	Energy cons., kWh/kg	Energy prices, \$/kWh	Energy cons., kWh/kg	Energy prices, \$/kWh	Energy cons., kWh/kg
Indonesia	0.0565	2.903	0.0298	2.919	0.0264	3.030	-	-	-	-
China	-	-	-	-	-	-	0.066	2.576	0.0800	1.625
India	0.0992	2.893	0.0867	2.918	0.0861	2.787	0.084	2.500	0.0950	1.684
Turkey	0.0700	2.886	0.0555	2.919	0.0761	2.891	0.070	2.571	0.0840	1.667
Brazil	0.0570	2.842	0.0307	2.866	0.0388	2.835	0.031	2.581	0.0500	1.600
S. Korea	0.0533	2.830	0.0404	2.921	0.0422	2.844	0.047	2.553	0.0600	1.667
USA	0.0500	3.000	0.0500	3.000	0.0450	2.889	0.045	2.444	0.045	1.778
Italy	0.0802	2.893	0.0766	2.910	0.0909	2.750	0.105	2.571	0.105	1.714

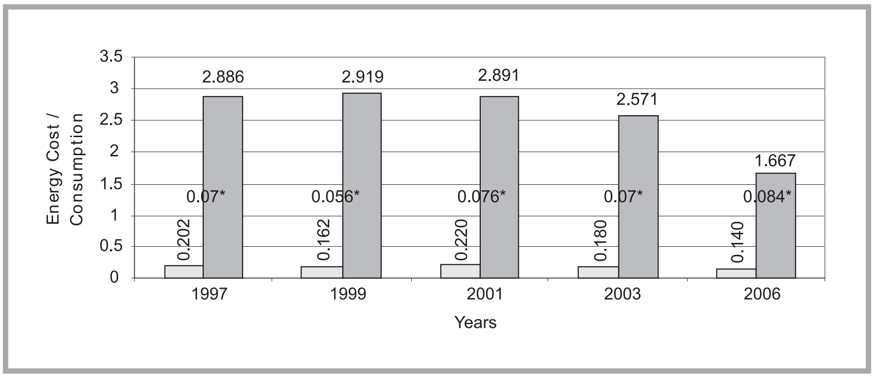

Figure 1. *Energy prices, cost and consumption of relevant open-end rotor yarn in Turkey; * energy prices in \$/kWh, □ energy cost in \$/kg, ■ energy consumption in kWh/kg.*

Energy consumption of chosen spinning mill

In order to obtain the necessary information about the energy consumption of a specific spinning mill, one spinning mill in which every kind of staple fibre (i.e. cotton, linen, polyester, viscose) can be processed in a wide count range using both ring and open-end systems, has been selected. This spinning mill contains not only machines used for manufacturing (blowing room, carding, combing, drawing, roving, spinning and winding) but also 5 air conditioning systems, 2 compressors and 2555 lamps for illumination. Additionally, the spinning mill selected only uses electrical energy.

The unit power needed for corresponding machines on the production line and the power required for the air conditioning system, compressors and lamps can be seen in ***Table 4***. Installed power is that needed by each piece of equipment if there is no energy loss; actual power is calculated considering energy loss or energy efficiency. The total installed and actual power needed for each piece of equipment given in the table is obtained by multiplying the number of machines by the unit power required. The subtotal of each equipment group is also shown, i.e the subtotal of the actual power needed for carding machines is 229.5 kW. In addition, the last column of the table shows the share of the actual power needed for each equipment group in the total actual power consumption, i.e. carding machines comprise 9.44% of the total actual power consumption. The amount of total actual power in the chosen spinning mill is determined as 2432.8 kW, in which machines, air conditioning, compressors and illumination are included, the machines consuming energy comprising 78% of the total energy consumption alone.

The spinning mill chosen operates 3 shifts a day consisting of 8 hours and also works 25 days in a month. Considering the monthly operating time and number of machines, the monthly (May) energy consumption of the chosen spinning mill has been calculated, and all

Table 4. Unit power consumption for chosen spinning mill [11].

Equipment type	Number of machines	Unit Machine installed power, kW	Unit Machine actual power, kW	Total installed power, kW	Total actual power, kW	Share of each in total actual power, %
Blow room (cot-linen line)	1	36.00	22.00	36.00	22.00	8.10
Blow room (automatic)	1	64.00	42.00	64.00	42.00	
Blow room (manuel1)	6	16.30	8.00	97.75	48.00	
Blow room (manuel2)	3	7.15	4.00	21.45	12.00	
Blow room (poly/vis)	4	26.10	10.75	104.50	43.00	
Vertical opener	5	9.40	6.00	47.00	30.00	
Sub total	**-**	**158.95**	**92.75**	**370.70**	**197.00**	
Carding m. (Sacolowell)	5	4.00	3.30	20.00	16.50	9.44
Carding m. (C10)	8	13.25	8.50	106.00	68.00	
Carding m. (Rieter)	10	20.70	14.50	207.00	145.00	
Sub total		**37.95**	**26.30**	**333.00**	**229.50**	
Drawing machines	14	10.00	7.50	140.00	105.00	4.30
Combing machines	4	6.53	5.50	26.12	22.00	0.90
Lap machine	1	13.00	11.00	13.00	11.00	0.45
Roving machines	12	17.30	11.40	207.50	136.80	5.60
Ring spinning machines	33	40.00	34.00	1320.00	700.00	28.80
Ring traveler robots	10	0.497	0.30	4.97	3.00	0.10
Open-end spinning machines 1	5	81.60	60.00	408.00	300.00	15.10
Open-end spinning machines 2	1	100.00	67.50	100.00	67.50	
Winding machine	10	15.50	13.50	155.00	135.00	5.60
Sub total of machines				**3078.29**	**1906.80**	**78.40**
Compressor 1	1	58.00	40.00	58.00	40.00	**2.63**
Compressor2	1	45.00	24.00	45.00	24.00	
Sub total of compressors		**103.00**	**64.00**	**103.00**	**64.00**	
Air conditioning system 1	**1**	110.00	55.00	110.00	55.00	**16.00**
Air conditioning system 2	**1**	147.10	91.00	147.10	91.00	
Air conditioning system 3	**1**	147.10	116.00	147.10	116.00	
Air conditioning system 4	**1**	126.00	73.00	126.00	73.00	
Air conditioning system 5	**1**	81.50	55.00	81.50	55.00	
Sub totalof air conditioning		**611.70**	**390.00**	**611.70**	**390.00**	
Lamps	**2555**	**0.04**	**-**	**102.00**	**72.00**	**2.98**
Total				**3894.99**	**2432.80**	**100**

Table 5. Energy consumption for chosen spinning mill in May [11].

Equipment type	Energy consumption, kWh Hourly	Daily	Monthly
Blow room (cot-linen line)	22	528.0	13200
Blow room (automatic)	42	1008.0	25200
Blow room (manuel1)	48	1152.0	28800
Blow room (manuel2)	12	288.0	7200
Blow room (poly/vis)	43	1032.0	25800
Vertical opener	30	720.0	18000
Sub total	**197**	**4728.0**	**118200**
Carding m. (Sacolowell)	16,5	396.0	9900
Carding m. (C10)	68	1632.0	40800
Carding m. (Rieter)	145	3480.0	87000
Sub total	**229,5**	**5508.0**	**137700**
Drawing machines	105	2520.0	63000
Combing + lap machines	33	792.0	19800
Roving machines	136.8	3283.2	82080
Ring spinning machines + robots	703	16872.0	421800
Open-end spinning machines	367.5	8820.0	220500
Winding machines	135	3240.0	81000
Machine total	**1906.8**	**45763.2**	**1144080**
Air conditioning sytems	390	9360.0	234000
Illumination	72	1728.0	43200
Compressors	64	1536.0	38400
Total	**2432.8**	**58387.2**	**1459680**

the data are shown in ***Table 5***. As the investigation was conducted in May for the spinning mill chosen, detailed data are given for this month. The actual total monthly energy consumption of the spinning mill is 1459680 kWh/month in May, 78.4% of this energy being consumed by machines, see ***Figure 2.a*** (see page 12). 20% of the monthly energy is consumed by open-end rotor spinning machines (***Figure 2.b***).

In order to determine the unit energy consumption of the unit yarn mass, which is known as the specific energy consumption, the monthly energy consumption of the mill investigated has been divided by the monthly production quantity, and the variation obtained is demonstrated in ***Figure 3***. The amount of specific energy consumption changes between 3.23 and 3.76 kWh/kg in the chosen mill for the months selected. These are the average values, which change depending on the yarn properties.

Determination of energy consumption for chosen yarn

A simple approach has been developed to obtain the specific energy consumption of any yarn. Since a production line contains many steps/machines, the approach has been explained here for the first machine, which is described as a bale opener. The approach should be repeated for the rest of the machine/step. According to this approach, a raw material should first be found for each machine, and then the operating time of each machine must be obtained. Using the operating time and actual power of the manufacturing machines, the energy consumption of each machine during manufacturing can easily be calculated [10, 11].

The amount of raw material R_1 in kg which will be processed in the first machine (bale opener) can be found by using the total waste ratio W_{Tot} in% and mass of the specific yarn M in kg in the following equation

$$R_1 = M \times (1 + W_{Tot}) \qquad (1)$$

The operating time for the first machine, t_1 in hour, can be determined as follows,

$$t_1 = \frac{R_1}{L_1 \times \eta_1 \times n_1} \qquad (2)$$

where L_1 in kg/h is the manufacturing rate of the machine, n_1 is the number of machines and η_1 in % is the mechanical efficiency of the machine. With the given

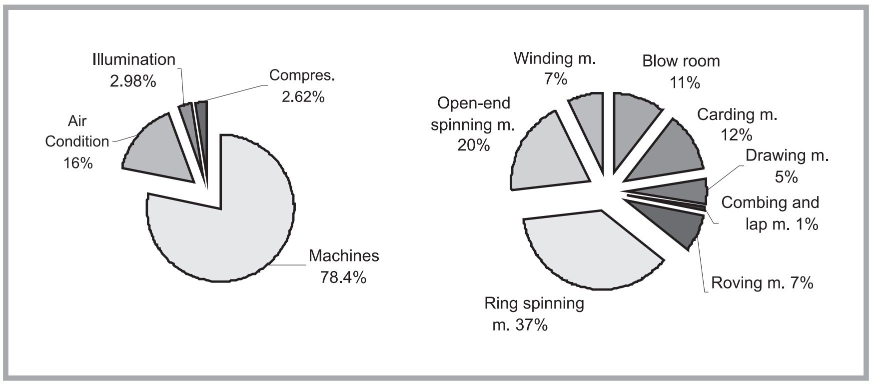

Figure 2. *Percentage distribution of energy consumption in the spinning mill examined [11]; a) % distribution of total monthly energy usage May, b) % distribution of energy used by machines.*

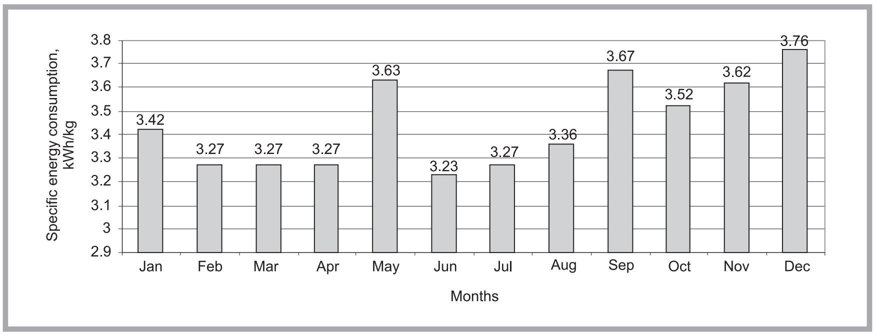

Figure 3. *Monthly specific energy consumption for the spinning mill [11].*

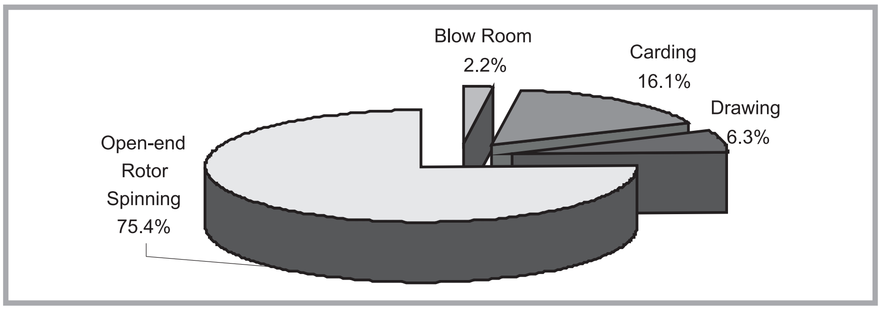

Figure 4. *Share of energy used by machines in %.*

parameters, the electrical energy, E_1 in kWh, used by the first machine can be obtained from

$$E_1 = t_1 \times N_1 \times \eta_{E1} \times n_1 \quad (3)$$

Here, N_1 in kW is the installed power of the first machine, and η_{E1} in % is the energy efficiency concerned. After calculating the energy consumption of each step, the total energy consumed for operating the machines, E_M in kWh, can easily be calculated by the following equation:

$$E_M = \sum_{i=1}^{n} E_i + E_{Ca} + E_D + E_S \quad (4)$$

where E_i is the energy consumption of the blow room (E_1 - energy for bale opener, E_2 - energy for cleaner, E_3 - energy for mixer etc.), E_{Ca} - the energy consumption of carding, E_D - the energy consumption of drawing, E_S - the energy consumption of spinning, i - represents the relevant individual machine, and n is the total number of machines in the blow room.

The energy consumption of compressors for the first machine, E_{A1}, is found using the following equation:

$$E_{A1} = t_1 \times N_1 \times C_1 \times n_1 \quad (5)$$

where C_1 in m^3/h is the compressed air needed per hour, N_A in kWh/m^3 is the unit power for compressors which can be determined by dividing the installed power of the compressor by the compressed air capacity. The total energy consumption to provide compressed air in general, E_{TA} in kWh, can be found using

$$E_{TA} = \sum_{j=1}^{m} E_{Aj} \quad (6)$$

and here again j represents the relevant machine, and m is the total number of machines that need compressed air in the production line of a specific yarn.

Energy used by air conditioning during concerned yarn production, E_C, is

$$E_C = \frac{E'_C \times M}{G} \quad (7)$$

where E'_C expresses the total energy consumption of an air conditioning system in one month, and G is the monthly yarn production in kg. Similarly, the energy consumption by illumination, E_{il} in kWh, can be established using

$$E_{li} = \frac{E'_l * M}{E'_{li} \times M} \quad (8)$$

Here E'_{il} is the total monthly energy usage of lamps needed for illumination.

Consequently, the total energy consumption for any specific yarn can be calculated by summing the relevant energy consumption equations given above to form

$$E_{Tot} = E_M + E_{TA} + E_C + E_{il} \quad (9)$$

Prediction of energy consumption

In order to give an example, the energy consumption for 20 tex (Ne 30) open-end rotor yarn produced in the spinning mill under investigation is calculated by applying the procedure given above. Here, 3000 kg of 20 tex carded yarn is supposed to be produced in the open-end rotor spinning system at a speed of 107000 rev/min and with a twist factor (α_{tex}) of 3828.

Energy consumption for machines and compressed air

The results obtained by the procedure applied above are demonstrated in ***Table 6*** (see page 12). This table contains production parameters (type and number of machines, actual production rate, actual installed power etc.) and calculated data (operating time, energy use for operating machines and compressed air). For the spinning mill investigated, the unit power needed for compressors to provide unit compressed air (N_A) is determined as 0.12 kWh/m^3. As the machines in the blowing room are interconnected, the compressed air needed has been calculated cumulatively by taking the operat-

Table 6. Energy consumption of chosen yarn.

Machines	Production Parameters				Calculated Data		
	No of mach.	Actual production rate (L), kg/h mac.	Actual unit power (N), kW	Unit comp. air needed (C), m^3/h	Operat. time (t), hour	Energy for machines (E), kWh	Energy for compr. air (E_A), kWh
Uniflock	1	950	6.00		3.338	20.028	
Uniclean	1	950	6.75		3.321	22.420	
Unimix	1	617.5	5.25	14.45	5.06	26.565	9.537
Uniflex	1	570	9.00		5.453	49.100	
Condenser	1	570	4.00		5.400	21.600	
Carding	6	42.53	14.50	9.10	12.03	1046.53	84.062
Drawing I	1	122.136	7.50	0.48	24.98	187.35	0.725
Drawing II	1	113.44	8.25	0.56	26.74	220.605	0.899
Open-end Rotor	5	41.56	67.50	25.00	14.51	4897.125	217.65
Total						6491.323	312.87

Table 7. Comparison of energy consumption.

Machines	Share of energy consupmtion for each machine, %	
	49 tex [25]	20 tex (Present Approach)
Blowing Room	11.2	2.2
Carding	12.8	16.1
Drawing	7.3	6.3
OE-Rotor Spinning	68.7	75.4
Total	100	100

ing time as 5.5 hours. Using the parameters in the table and related equations, the total energy consumed by the machines was found to be 6491.323 kWh, 4897.125 kWh of which was used by open-end rotor spinning machines.

In order to see the percentage of energy used for each machine, ***Figure 4*** (see page 11) was constructed. As can be seen, maximum energy consumption (4897.125 kWh) occurs in open-end rotor spinning machines (75.4%), followed by carding machines with a share of 16.1%.

This figure also provides an opportunity to compare the corresponding data with data available in literature [25], as shown in ***Table 7***. The calculated share of each machine type in the total energy consumption has been compared with the results for 49 tex. As 49 tex yarn is coarser than 20 tex, the share of open-end rotor machines for 20 tex yarn seemed to be higher than that of 49 tex yarn, as expected.

Because of the fact that similar data presenting the shares of machines in the total energy consumption have not been established for 20 tex yarn in literature, the energy consumption for 49 tex yarn was also calculated using the present approach with suitable production parameters for 49 tex yarn (α_{tex} = 3828, 65000 r.p.m.), the results of which have been compared with data in literature [25], as shown in ***Table 8***. The results calculated and data given in literature are nearly the same. The small differences occurring between values is attributed to the exclusion of winding step data in literature and changes faced in production parameters.

Total Energy Consumption Including Air Conditioning and Illumination

As explained before, the energy consumption of air conditioning and illumination should be added to the energy consumption of machines and compressors so as to get the total energy consumption during relevant yarn production. Data for the monthly energy consumption of air conditioning, the illuminating system and monthly yarn production should be obtained. As given earlier in ***Table 5***, the monthly energy consumption for air conditioning and illumination has been calculated as 234000 kWh/month and 43200 kWh/month, respectively. Moreover, the amount of monthly yarn production determined from the mill records is 401580 kg/month for the month examined (May). Applying the approach developed, the energy consumption for air conditioning and illumination has been found, the results of which are shown in ***Table 9***.

The specific energy consumption of the yarn considered was determined as 2.95 kWh/kg (given in the last column of the table) by dividing the total energy consumption by the amount of yarn produced. The specific energy consumption for 20 tex carded open-end rotor yarn changes between 1.60 and 3.00 kWh/kg for the countries selected. This value changes between 1.667 - 2.919 kWh for Turkey in the given years (see ***Table 3***). The data obtained from the present study (2.95 kWh/kg) represents a relatively smaller value than that of the selected countries. In addition, this value is within the range of the limit values given for

Table 8. Comparison of the energy share of machines for 49 tex yarn.

Machines	Production parameters			Data calculated for 49 tex		Machines	Calculated energy share for machines, %	Data for 49 tex, % [25]
	No of mach.	Actual production pate (L), kg/h mac.	Actual unit power (N), kW	Operat. time (t), hour	Energy for machines (E), kWh			
Uniflock	1	950.00	6.00	3.380	20.280			
Uniclean	1	950.00	6.75	3.321	22.417			
Unimix	1	617.50	5.25	5.060	26.565	Blowing Room	3.4	11.2
Uniflex	1	570.00	9.00	5.453	49.100			
Condenser	1	570.00	4.00	5.400	21.600			
Carding M.	4	47.84	14.50	10.700	930.400	Carding	22.4	12.8
Drawing M. I	1	132.3	7.50	23.060	172.950	Drawing	8.7	7.3
Drawing M. II	1	132.3	8.25	22.92	188.925			
OE-Rotor Spin.	3	74.84	67.5	13.42	2717.550	OE Rotor Spinning	65.5	68.7
Total					4149.787	Total	100	100

Table 9. *Total energy consumption for chosen yarn.*

Consumption place	Energy consumption, kWh	Share, %	Specific energy consumption, kWh/kg
Machines	6491.323	73.2	
Compressors	312.870	3.5	
Illumination	322.700	3.6	8874.893/3000 = 2.951
Air conditioning	1748.000	19.7	
Total	**8874.893**	**100**	

Turkey. It is thought that the difference between the values comes from changes in the manufacturing parameters of machines, such as the type, waste ratio, speed and energy efficiency.

Summary

As a result of detailed investigations into energy consumption for yarn manufacturing, with special reference to open-end rotor spinning, the following conclusions can be made:

1. It has been shown that manufacturing machines consume 78.4% of the total monthly energy consumption (1459680 kWh/month), while air conditioning comprises 16% of the total energy consumption in the spinning mill selected. Additionally, specific energy consumed for each month in one-year period has been calculated and it has been determined that the calculated values change between 3.23 and 3.76 kWh/kg.
2. Applying the simple model developed, the total energy consumed during the manufacturing of 100% cotton, 20 tex carded open-end rotor spun yarn in the spinning mill chosen has been calculated as 8874.893 kWh, 73.2% of which is consumed by manufacturing machines. The highest energy consumption, with a 75.4% share, is represented by open-end rotor spinning machines alone. The values calculated have been compared with data available in literature, and it has been shown that there is a close agreement between the data calculated and those given in literature. The small differences have been attributed to variations in operation parameters such as the type, mechanical efficiency, energy loss and waste ratio of machines.
3. The specific energy consumption for 20 tex carded open-end rotor yarn has been obtained as 2.95 kWh/kg and compared with values outlined by ITMF (changing between 1.60 and 3.00 kWh/kg for the same yarn type and 1.667 - 2.919 kWh/kg for Turkey). The difference between calculated and reported values is thought to be because of the variation in production parameters.
4. It has been demonstrated that the approach presented in this study can be used to calculate the total and specific energy consumption of a particular yarn type with reasonable confidence.

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