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Effect of Number of Draw Frame Passages on Rotor-Spun Yarn Quality

Ali Osman HAN[1], Halil İbrahim ÇELİK[2*], Gökhan TANDOĞAN[3]

Keywords
Draw frame,
Rotor spun yarn,
Yarn quality,
Abrage

Abstract **–**This study investigates the effects of the number of passages for draw frame machines on the quality of rotor-spun yarn. In the presented study, the goal is to produce more cost-effective yarn with similar physical properties to those obtained with two drawing passages by reducing the number of drawing passages. Additionally, the study aims to achieve a lower carbon footprint and reduce the environmental impacts of production processes through lower energy consumption. Yarn samples of Ne 20/1 and Ne 10/1 with the same cotton fibre were produced by means of both single-passage and double-passage drawing machines. The unevenness and tensile properties of the produced yarns were measured using Uster Tester and Uster Tensorapid testing devices, while abrage control was evaluated in an abrage cabinet under ultraviolet light. Furthermore, the energy consumption of the eliminated drawing machine was measured using an energy analyzer. The yarn samples produced with the single passage drawing machine demonstrated better IPI (imperfections) values than those produced with the two-passage system, and the tensile strength values remained at comparable levels. Under UV light, no abrage differences were observed between the yarns from the two different production processes. Energy and raw material waste savings were achieved by eliminating one of the drawing machines. Additionally, considering a waste ratio of 0.6% for a single passage drafting machine, it is estimated that approximately 100 tons of cotton waste per year can be prevented in a rotor-spun facility producing 50 tons of yarn daily. The study revealed that the reduction in raw material and energy consumption enables the production process to be carried out with a lower carbon footprint, thereby making a significant contribution to sustainability. Furthermore, this approach results in a notable reduction in yarn production costs.

1. Introduction

Within the scope of the KYOTO protocol and the Paris Climate Agreement established against global warming, carbon footprint calculation that causes global warming has gained great importance, and carbon footprint evaluation has been made in many areas (Başoğul et al, 2021). Energy, ecological and Carbon Footprint (CAI) in the textile sector were evaluated in general terms (Bevilacqua et al., 2011). According to the results obtained from the study on carbon footprint in the textile sector, it was observed that the biggest impact on greenhouse gases comes from electricity and thermal energy (Ozcan and Ozturk, 2019). Türkiye's textile industry commands the biggest percentage of the country's GDP and ranks first among all industrial sectors in terms of both production and exports (Evrim and Seyhun, 2022). Energy makes for 6 - 14 % of the sector's overall costs, whereas it accounts for 7.2% of the industry's total consumption (Hoffman, 2011, Maraşlioğlu, 2018). Within the textile sector, there is a great deal of variation in both goods and process technology. This causes variations in the energy consumption structure and the energy's percentage of overall cost. In spinning-weaving companies, 50% of the energy used is for heat, and 50% is for electricity (Yılmaz, 2010). It is very important to use energy efficiently, especially in Türkiye, which is 70% dependent on foreign sources of energy (Doğan and Yılankırkan, 2015). Energy use is an important parameter that directly affects greenhouse gas emissions. Reducing energy use will play a significant role in reducing both carbon emissions and costs. Since energy is the main input that

[1]Gaziantep University, Textile Engineering Department, Engineering Faculty, Gaziantep, Türkiye. E-mail: han@gantep.edu.tr OrcID: 0009-0009-9143-3269

[2]***Corresponding Author.** Gaziantep University, Textile Engineering Department, Engineering Faculty, Gaziantep, Türkiye.E-mail: hcelik@gantep.edu.tr OrcID: 0000-0002-1145-6471

[3]KIPAS Mensucat R&D Center, Kahramanmaras, Türkiye .E-mail: gtandogan@kipas.com.tr OrcID: 0009-0009-4999-4003

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creates the cost of textile products, studies on reducing energy use or energy recovery have been and are being carried out in every department of textile enterprises (Uçak, 2010).

In textiles, enhancing production efficiency through energy savings and process optimizations by reducing waste rates plays a crucial role in achieving sustainability. Energy is a critical input in all production processes. Improving energy efficiency not only reduces costs but also minimizes environmental impacts. Lower energy consumption contributes to reducing production costs, as well as carbon emissions and greenhouse gas effects, thereby making a positive impact in the fight against climate change. Energy savings in the textile industry are vital for sustainable production and environmental responsibility; through this, both economic and ecological benefits can be achieved, making the future of the textile industry more sustainable. When reviewing the literature, studies generally focus on energy efficiency in textile mills. Efforts have been made to increase efficiency by optimizing production lines. Various parameters of drawing machines, such as gauge settings, draft speeds, coil diameters, and the draft zone of the drawing frame, have been adjusted to examine their effects on the placement of fibers within the yarn diameter and overall yarn quality. Sert et al. (2017) examined various systems to enhance energy efficiency in integrated textile production, including compressed air systems, hotlines and surfaces, lighting systems, ring spinning machines, stenter machines, and steam and hot oil boilers. Şekkeli et al. (2017) implemented a heat recovery system to capture heat from the hot waste air discharged from the chimney of the stenter machine, using the recovered heat to warm the clean cold air, thus achieving a 30% energy saving. Can et al. (1995) concretely demonstrated the economics of heat recovery from waste fluids in textile and similar industries, highlighting the potential energy savings and positive contributions to the economy and environmental benefits in these sectors. In the study conducted by Chaudhari and Raichurkar (2016), the effects of the bottom roller gauge settings of drawing machines on yarn quality were examined. Experiments were carried out using 40/44 mm and 42/46 mm gauge settings in the production of 15 Tex (Ne 40) combed cotton yarn. The findings revealed that yarn defects (thin, thick places, and neps), unevenness (U %), and yarn strength varied depending on the bottom roller gauge settings. The 40/44 mm setting resulted in significant improvements in yarn quality, leading to the conclusion that proper gauge settings are critical for achieving high-quality yarn production. Ishtiaque et al. (2009) studied the effects of high-speed drafting frames and preparatory processes on the packing density and related structural characteristics of ring-spun yarn. The findings show that an increase in drafting speed and coil diameter leads to a reduction in helix twist, helix angle, and helix diameter, which in turn increases yarn packing density. However, an increase in card draft raises the helix twist and angle up to a certain point while reducing the packing density. Additionally, it was found that the packing density in the middle of the fiber was higher, indicating structural consistency. This article emphasizes the importance of process variables in yarn production. In the research carried out by Ramasamy et al. (2019), the modification of the drafting zone settings in the drawing frame was explored to enhance the quality of yarn. The study assesses the impact of various parameters involved in yarn production, particularly focusing on how drafting settings influence yarn quality. The authors noted significant improvements in fiber arrangement, packing density, and mechanical properties resulting from these modifications. The findings highlight the crucial role of optimizing process settings to achieve better yarn quality. This research offers practical strategies aimed at improving quality in yarn production. Kmansuri and Pathak (2022), emphasize the importance of yield percentage in the cotton spinning industry, noting that it directly influences performance and profitability. While the typical yield percentage is around 84%, even a slight increase of 1-2% can lead to significant profit gains. The study presents methodologies to enhance yield percentages, addressing the financial crises many spinning mills face due to their inability to meet quality standards, which adversely affects farmers, workers, and stakeholders in the industry. The research results indicate that ring yarns exhibit greater tenacity than rotor-spun yarns, although their elongation percentage is significantly lower. Additionally, hairiness tests reveal that rotor yarns are less hairy than conventional ring yarns. Ring yarns also show higher unevenness of mass and coefficients of variation compared to rotor yarns. Rotor-spun yarns have established strong applications in woven and knitted fabrics, particularly in home textiles such as terry products and upholstery fabrics, as well as in clothing items like socks and sweaters. Overall, enhancing yield and quality in cotton spinning is crucial for the industry's sustainability and economic impact.

The staple yarn spinning process comprises four critical stages: Blowroom, Carding, Drawing, and Spinning. Each stage plays a vital role in determining the final properties of the yarn, including its strength, uniformity, and overall quality. Cotton fibers arrive at the spinning mill's blowroom department in the form of bales packaged from the ginning plant. These fibers typically contain 1-15% impurities, which must be removed during processing. In the blowroom, the fibers undergo opening, cleaning, and blending processes to be properly cleaned, separated, and aligned to prepare them for yarn formation. The fibers are then pneumatically transported to the carding machine, where they undergo further opening, cleaning, and carding. The carded fibers are formed into slivers and placed in cans for entry into the drawing machine. The drawing machine is where the processes of doubling (folding the fiber slivers) and drafting (elongating and thinning the fibers) take place. By doubling, a homogeneous mixture is achieved. In the cross-section of the slivers coming from the carding machine, there are approximately 30.000 fibers. The drafting function of the drawing machine is to reduce this number to around 100 fibers, making the slivers thin enough to be suitable for spinning. This function is carried out by rollers in the drawing machine that rotate at different speeds to ensure uniform yarn formation. This is one of the critical tasks performed by the drawing machine, as a thin section in the sliver could result in a very thin and weak area in the final yarn (Elhawary, 2015). In order to reduce similar errors, the use of three-passage drawing frames in spinning methods such as vortex, which utilize long and relatively more costly fibers, demonstrates the significant impact these machines have on quality.

Rotor spinning system is also a spinning system in which more production is taken into account besides quality compared to other spinning systems due to its production method and raw material properties. In the rotor spinning system, the fiber length is limited due to the physical properties of the rotor. The length of the fibers used cannot exceed the rotor diameter for the spinning process to succeed, which leads to the use of shorter fibers in rotor spinning compared to other spinning methods. Since fiber length is one of the important parameters that directly affect yarn quality, yarns produced by the rotor spinning system are of lower quality in terms of physical properties when compared to yarns produced by other spinning systems. This situation is valid not only for the final yarn but also for the intermediate product, the slivers. Controlling shorter fibers is more challenging in mechanical processes compared to longer fibers, which results in slivers produced from the carding machine having more neps and drawing slivers being more uneven. Due to the limited fiber length, machine settings can only optimize the quality up to a certain point. Since the rotor spinning system is known for its production speed, the quantity of production takes precedence over quality expectations. As the last machine before yarn formation, drawing frames, especially in rotor spinning systems, must operate at high speeds to supply the spinning machines ahead of them. As speed increases, fiber control becomes more difficult, leading to lower quality. Therefore, the impact of the drawing frame on yarn quality in rotor spinning is lower than in other spinning systems. Additionally, as the number of fibers in the yarn cross-section increases, fiber control in mechanical processes becomes more challenging, leading to greater mass variation per unit length in thicker yarns compared to finer yarns. In light of this information, the aim is to produce yarn of the same quality in rotor spinning by using a single regulated drawing frame instead of two-passage drawing frames, especially for thick yarns with higher unevenness values. In addition to quality, reducing one machine from the production line will save energy and time, lower yarn production costs, and contribute to sustainability by preventing fiber waste that typically occurs in the first passage drawing frame.

In this study, two different types of yarn, Ne 10/1 and 20/1, were produced as four different samples in a rotor spinning production facility using a two-passage drawing frame and, unlike in the literature, a production line with a single regulated drawing frame. The unevenness and tensile strength values of the produced samples were measured, and their abrage characteristics were examined and compared. The hourly energy consumption of the removed drawing frame was also measured. Thus, the feasibility of production with a lower carbon footprint and reduced energy costs was evaluated.

2. Materials and Methods

The cotton fiber was used as the raw material for the rotor spun yarn samples. The cotton fiber properties, such as average fiber length, strength, elongation percentage, and micronaire value, were measured using the Uster HVI 1000 fiber testing device, and they were determined as 28 mm, 27 g/tex, 6.57%, and 3.47, respectively. The cotton, arriving at the blowroom in bales, went through the Rieter A12 model bale opener, A49 metal detector, B12 coarse cleaner, B76 mixer, B17 fine cleaner, and Uster Jossy foreign matter detector for opening, cleaning, and blending processes. The cotton fiber was then processed on a Rieter C70 carding machine with a licker-in speed of 1200 rpm, cylinder speed of 780 rpm, flat speed of 0.28 m/min, and an hourly production rate of 105 kg/h, resulting in a Ne 0.080 sliver after the carding process. The card slivers exiting in cans were then connected to the Rieter SB-D 45 first passage drawing frame in the normal production process with a doubling number of 6, draft adjustment of 37/41, and a production speed of 750 m/min, the first passage drawing frame produced slivers at Ne 0.100. These slivers were then connected to the regulated Rieter RSB-D 45 second passage drawing frame with a doubling number of 6, draft settings of 38/42, and a production speed of 750 m/min; sliver samples at Ne 0.100 were prepared by the second passage drawing frame. Using the same raw material and machine settings, sliver samples from the carding machine were directly connected to the second passage drawing frame, creating single-passage drawn sliver samples. The production lines used to prepare the samples are shown in Figure 1.

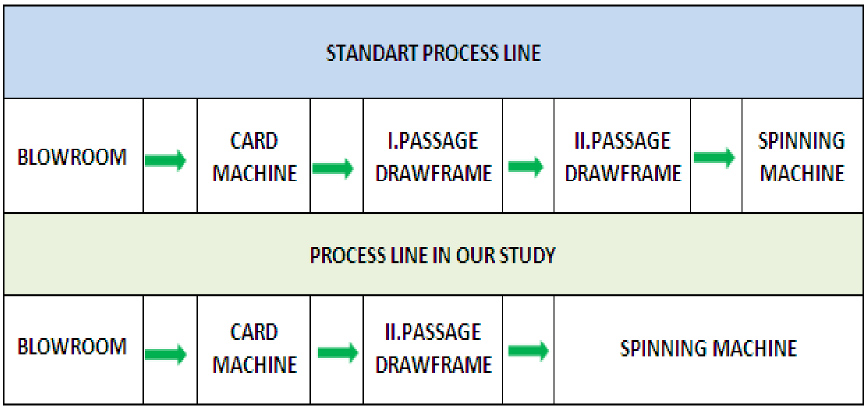

Figure 1. Production lines used in yarn sample production

Four yarn samples with Ne 10/1 and Ne 20/1 yarn counts were produced on the standard process line and study process line by using the same slivers with the parameters in Table 1. Yarn samples were produced with a Saurer Autocore 9 rotor spinning machine with Suessen spinning elements. Spinning elements used for sample production are given in Table 2.

Table 1. Yarn production parameters

Sample	Count(Ne)	Twist Per Meter	Twist Coefficient(α)	Rotor Speed (Revolution/Meter)	Production Rate (Meter Per Minute)
Yarn Samples with Single Drawframe					
1	10	505	4	103.000	204
2	20	860	4.9	146.000	170
Yarn Samples with Double Drawframe					
1	10	505	4	103.000	204
2	20	860	4.9	146.000	170

Table 2. Spinning elements

Sample	Drawframe	Rotor	Opening Roller Solidring	Torque Stop	Navel
Ne 10/1	I. Passage	T 633 BD	B 174 DN	GREEN	KSK4-A
Ne 10/1	II. Passage	T 633 BD	B 174 DN	GREEN	KSK4-A
Ne 20/1	I. Passage	G 628 BD	B 174 DN	GREEN	KSSA
Ne 20/1	II. Passage	G 628 BD	B 174 DN	GREEN	KSSA

The physical properties of yarn samples were measured after production. Yarn count measurements were done according to TS 244 EN ISO 2060 standard. Yarn unevenness measurements were done with Uster Tester 6 test device. Yarn strength measurements were done according to TS EN ISO 2062:2010 standard via Uster Tensorapid 4. Abrage control was made over the yarn bobbins under the UV light. Energy consumption of the eliminated drawframe was measured from energy monitoring system over the machine and calculated for 8 hours.

3. Results and Discussion

Yarn physical test results were given in Table 3 and they were analyzed in Figure 2.

Table 3. Yarn unevenness and tenacity results

Draw Frame	Yarn Count (Ne)	CVm	Thin Places -40%	Thin Places -50%	Thick Places +35%	Thick Places +50%	Neps +140%	Neps +200 %	Neps +280 %	Hairness	Tenacity (Rkm)
Double	10	11.25	8	0	80	3	108	5	0	5.43	12.61
Singe	10	11.00	13	0	70	0	54	0	0	5.43	12.36
Double	20	13.14	131	5	381	24	1046	88	5	4.53	12.47
Single	20	13.00	125	4	368	16	1068	60	4	4.58	12.85

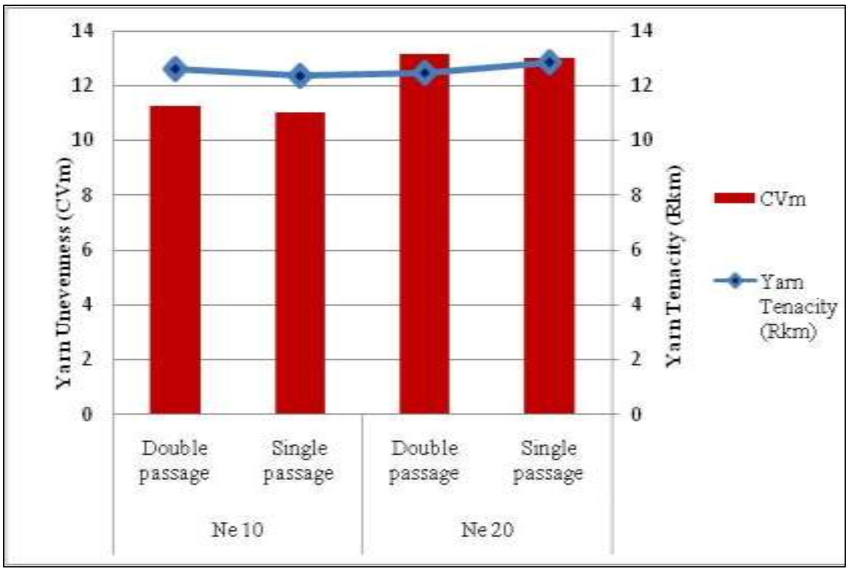

Figure 2. Yarn unevennessand tenacity results

IPI (imperfections) in yarn samples refers to the preference for defects or irregularities. IPI includes thick places, thin places and neps values. When the IPI results of the yarn samples were analyzed (Table 1), it was seen that fewer yarn irregularities were obtained with a single passage draw frame for both yarn counts. As seen from Figure 2, the unevenness values (CVm) of the single and double passage draw frame applications are close to each other for both yarn counts, but the single passage samples have slightly lower CVm values, so they have better yarn quality. The tenacity values are nearly the same and fallwithin the acceptable standard. Similar to unevenness (CVm) results, the Ne 20/1 yarn sample produced from the study process line has a higher tenacity value according to the double passage sample. Single passage samples for Ne 10/1 have shown slightly less tenacity.

In order to see the effect of passage number and yarn count on yarn tenacity (Rkm) and unevenness (CVm), multivariate analysis (ANOVA) was performed (Table 4). According to the multivariate analysis (ANOVA), it is seen that passage number has no significant effect on yarn tenacity (Rkm) ($p > 0.05$) and no significant effect on yarn unevenness (CVm) ($p < 0.05$). The same results were also obtained for the yarn count parameter.

Table 4. ANOVA results of the production parameters

Tests of Between-Subjects Effects						
Source	**Dependent Variable**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Passage Number	Rkm	0.011	1	0.011	0.308	0.594
	CVm	0.110	1	0.110	11.990	0.009
Yarn Count	Rkm	0.092	1	0.092	2.484	0.154
	CVm	11.310	1	11.310	1230.485	0.000
Passage Number * Yarn Count	Rkm	0.298	1	0.298	8.047	0.022
	CVm	0.009	1	0.009	0.987	0.350
Error	Rkm	0.296	8	0.037		
	CVm	0.074	8	0.009		
Total	Rkm	1898.013	12			
	CVm	1767.97	12			
Corrected Total	Rkm	0.697	11			
	CVm	11.503	11			

a. R Squared = 0.575 (Adjusted R Squared =0.416)
b. R Squared = 0.994 (Adjusted R Squared = 0.991)

Since there was no significant difference between the two parameters in terms of tensile strength, similar Rkm values were obtained in both passage applications. Considering energy consumption and waste, the use of a single-passage drawing frame can be recommended. In terms of unevenness, as it has a significant effect, it presents a preferable option depending on the passage. As seen from Figure 2, when taking energy savings and waste reduction into account, the unevenness values of the single-passage are better, and the process provides higher quality yarn for both yarn counts.

The values of energy consumption and working conditions are taken by the machine energy monitoring system. This drawframe use 2.63 Kw/h electricity seen in Table 5, for 8 hours (one working shift) if the machine work with 780 rpm speed with 72.3 % efficiency.

Table 5. Energy consumption values of the eliminated drawframe for 8 Hours

Model	**Efficiency For 8 Hours (%)**	**Speed(Rpm)**	**Output Sliver Number (Ne)**	**Energy Consumption In %100 Efficiency (Kw/H)**
Rieter SB-D 45	72.3	600	0.100	2.63

Ne 10/1 yarn bobbin image under UV light is given in Figure 3. The yarn inside the red circular is produced from a normal process line, which contains a double drawframe and Ne 10/1 yarn. Outside of the red circular is the Ne 10/1 yarn produced from the study process line. It is obviously seen in Figure 3 that there is no abrage between the yarns from two different process lines.

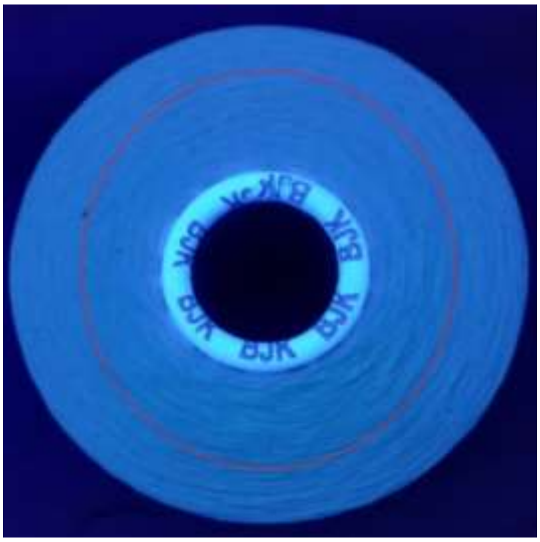

Figure 3. Image of the Ne 10/1 yarn bobbin under UV light

Ne 20/1 yarn bobbin image under UV light is given in Figure 4. The yarn inside the red circular produced from normal process line which contains double drawframe also Ne 20/1 yarn. Outside of the red circular is the Ne 20/1 yarn produced from study process line. It is obviously seen in Figure 4 that there is no abrage between the yarns from two different process line.

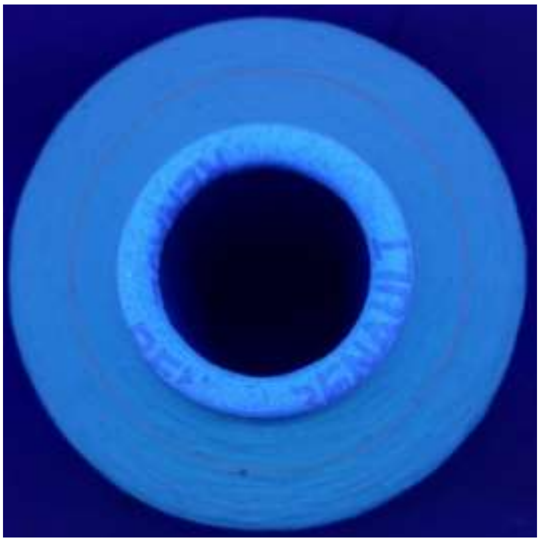

Figure 4. Image of the Ne 20/1 yarn bobbin under UV light

4. Conclusion

According to the European Green Deal announced in 2019 and European Union strategies for reducing greenhouse gas emissions and being carbon neutral, manufacturing enterprises need to follow strategies that will reduce carbon emissions in a short time. Energy is one of the big parameters that affect carbon emissions. This study aims to reduce carbon emissions by targeting energy saving by making process improvements. Furthermore, working with fewer machines means less waste. Saving raw materials significantly contributes to sustainability.

In this study, a machine used in the yarn production process was removed from the production line, and the settings of the other machines were optimized to produce the same quality yarn. At the same time, thanks to the machine removed from the production line, energy saved, waste material prevented and carbon emissions were reduced compared to standard production. The produced yarn was compared with the yarn properties produced in the standard process in terms of evenness and strength. Considering both test results, the yarns produced in the study gave better results in many respects. Based on the results of the multivariate analysis (ANOVA), the passage number has a major influence on unevenness but no significant effect on yarn tenacity. For the yarn number parameter, the same outcomes were likewise observed. Similar tenacity values were found in both passage applications because the two parameters' tensile strengths did not differ significantly. It may be advised to utilize a single-passage drawing frame in regard to waste and energy usage. It offers a better choice in terms of unevenness, depending on the passage, because it has significant consequences. Since the machine removed from production has an important role in the raw material mixture, the yarn produced as a result of the study was checked under UV light to see if there was a problem in terms of the mixture, and it was observed that the yarn produced in the study has no difference from the yarn produced in the normal process. Owing to the machine being removed from the production line, 2.63 kW of energy was saved in 1 hour and approximately 1800 kW in 1 month. Considering that there is an approximate use of between 40-50 of these machines in a rotor spinning mill with an average daily production of 60-70 tons, the amount of energy that will be saved is significant. Saving this amount of energy will help reduce serious carbon emissions. When the operational data for the eliminated drawing frame were examined, the calculated waste amount was 0.6%. Considering this, for a facility producing 60-70 tons of yarn daily, the amount of cotton saved from being wasted annually is approximately 4 tons.

Ethics Permissions

This paper does not require ethics committee approval.

Conflict of Interest

Authors declare that there is no conflict of interest for this paper.

Authors Contribution

Methodology, investigation and supervision were made by the author Halil İbrahim ÇELİK. Data curation, formal analysis, investigation and writing were made by the author Ali Osman HAN. Raw material supply, yarn production and performance tests were done by Gökhan TANDOĞAN.

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