Effect of Nozzle Structural Parameters on Hairiness of Compact-Jet Yarns

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ABSTRACT
Hairiness significantly influences the appearance of yarns and fabrics. New methods and spinning systems have been offered to reduce it. Nevertheless, there is still the quest for easy, low-cost processes to produce good quality yarns with reduced hairiness. Therefore, due to its considerable importance for spun yarns, we worked on a new spinning method to decrease yarn hairiness. Many researchers have been studying the use of air nozzles in the spinning and also the winding processes, and they indicated that hairiness decreases by up to 40–50%. From this point, we investigated the use of an air nozzle on a compact spinning system and discussed the effect on yarn hairiness. The nozzle was positioned at the exit of the drafting system on a RoCoS compact spinning system and pressurized air was fed into the nozzle by the compressor during spinning. We called the combination of an air nozzle and a compact spinning system a Compact-Jet spinning system. In the literature, there are no such trials. At the end of the study, it was determined that a Compact-Jet spinning system truly improves hairiness by up to 40% in comparison to the compact spinning system and by up to 70% compared with the conventional ring spinning system. Regarding the nozzle structural parameters, the changes in hairiness indicate that the main hole diameter and nozzle outlet design make the most important contributions in reducing yarn hairiness; whereas the injector angle and nozzle head type show weaker effects. As a result, the Compact-Jet can be considered as an innovative spinning system providing the opportunity to produce less hairy yarn. Additionally, we believe that this study makes an important contribution to the research activities in the spinning field and its associated literature.

Keywords: Compact-jet, yarn hairiness, nozzle, compact spinning system, yarn properties.

INTRODUCTION
In modern technology, there are two main objectives: one to produce high quality products and the other to improve productivity. The hairiness of yarn is a parameter that appears frequently among the main yarn properties, as well as in yarn-quality indices and standards. [1] Hairiness is defined as the number of fibers perpendicular to the yarn surface projected from a unit length of the yarn or measured fiber length. [2] Yarn hairiness is, in most circumstances, an undesirable property for the end uses and downstream processes. In weaving and knitting, hairiness causes yarns to break and hence stoppages and processing costs increase. In addition, yarn hairiness contributes to hazardous fiber dust and fly generation. On the other hand, hairiness increases pilling tendency which mainly results in an unsightly fabric appearance. In dyeing, yarn hairiness leads to a differential dyeing effect. [3] Therefore, it is important to be able to control yarn hairiness.

Yarn hairiness became a measurable yarn property in the 1950s and many measurement techniques and instruments have been proposed since that time. Barella (1983, 1993) summarized these techniques and also described various instruments introduced to measure hairiness. [3–4] Nevertheless, the commonly used instruments today work on two different principles: one, to shine light onto the yarn and detect the rays of scattered light caused by fibers protruding from the main body of the yarn, the amount of scattered light being a measure of the yarn hairiness (H); the other counts the number of hairs at distances of 1 to 25 mm from the yarn edge.

There is ever increasing interest in the industry on the topic of yarn hairiness and its reduction. In order to decrease yarn hairiness, several modifications to spinning machines and also many processes, such as sizing, burning and two-folding, have been realized. [5–7] In addition, some new spinning systems were introduced. Compact spinning and solospun are the latest developments for least hairy yarn production.

Nowadays, an air nozzle, used in air jet spinning system, has been placed below the drafting system of the conventional ring spinning system to lessen the hairiness of conventional ring spun yarns. This spinning process has been termed Jetring or NozzleRing by the researchers. In the Jetring spinning system, the aim is to bind the projected fibers onto the yarn body by the swirling air flow in the nozzle. Many researchers found that the Jetring spinning system is capable of producing improved yarn hairiness compared to that of the conventional ring spun yarns [8–12] and hairiness decreases by up to 40–50%. [6, 13–14] Similar to the principle of the Jetring spinning system, we attached an air nozzle onto a compact spinning system to further improve the yarn hairiness. Due to the considerable importance of yarn hairiness, the main focus of this study was to offer easy and low-cost methods of producing less hairy yarns.

The nozzle was placed between the exit of the RoCoS compact unit and the yarn guide of the spinning system. This spinning process was called Compact-Nozzle or Compact-Jet since the system was based on the combination of a compact spinning system and the air nozzle of the Jetring spinning system.

It took no effort to incorporate the compact spinning system and the nozzle of the Jetring spinning system in this manner. Therefore, the Compact-Jet spinning system can be considered to be a new application in the spinning field. In the literature, many researchers worked on air nozzle usage in the spinning and also the winding processes. In these studies, different fiber types and yarn counts were used. Similar to the spinning process, it was shown that nozzle usage improves the yarn properties, in particular yarn hairiness decreases significantly. [15–19]

MATERIALS AND METHOD

Yarn Production

To determine the effect of an air nozzle on the compact yarn properties, 100% combed cotton Compact-Jet yarns having Ne 30/1 yarn count were produced on a RoCoS compact spinning system. In addition to Compact-Jet yarns, compact and conventional ring spun yarns were produced with the same rovings used for the Compact-Jet yarn production.

In all the yarn productions, the same spinning parameters, namely, twist multiplier, draft, spindle speed and traveller type, were used (*Table I*).

TABLE I. Spinning particulars.

Parameters		**Values**
Roving count (Ne)		0.85
Yarn count (Ne)		30/1
Twist (t/m)		797
α_e		3.7
Mean spindle speed (rpm)		10,000
Take up speed (m/min)		12.5
Traveller		SFB 2.8 PM udr
Traveller ISO No		31.5
Ring diameter (mm)		36
Draft	Break draft	1.181
	Total	37.05

To minimize any possible variation, we used the same spindles for all the experiments. Yarn tests were carried out on Zweigle G566 hairiness tester. In this tester, the hairiness measurement is based on counting the number of hairs and the hairiness is characterized by an s3 value. The Zweigle s3 parameter is the total number of protruding hairs having 3 mm and upper lengths in 100 meters of yarn. Three samples were tested for each spinning system and parameter analysis.

Compact Spinning System

As can be seen in *Figure 1*, in the RoCoS spinning system, the bottom roller (1) supports the front roller (2) and delivery roller (3). The magnetic compactor (4), having a specially designed slit, is pressed permanently and the clearance between the magnet and the bottom roller is completely enclosed. Accordingly, a compression chamber is generated through the bottom roller surface. The fibers are guided into the magnetic compactor slit and condensed throughout the magnetic compression chamber.

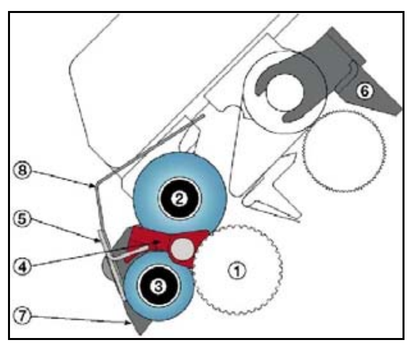


FIGURE 1. Main elements of RoCoS compact spinning system (1: Bottom roller, 2: Front roller, 3: Delivery roller, 4: Compactor equipped with magnet, 5: Supporting bridge, 6: Roving guide, 7: Top roller holder, 8: Weighting spring) [20].

Air Nozzle

The main component of the Compact-Jet spinning system is the nozzle. It was placed between the exit of the RoCoS compact unit and the yarn guide (*Figure 2)*.

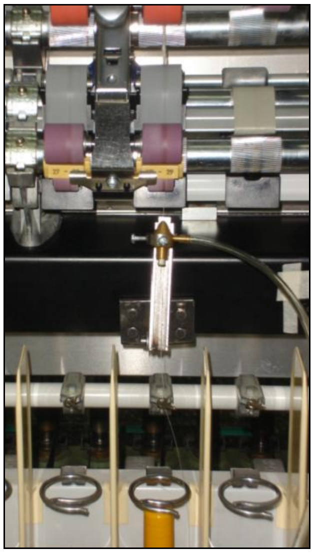
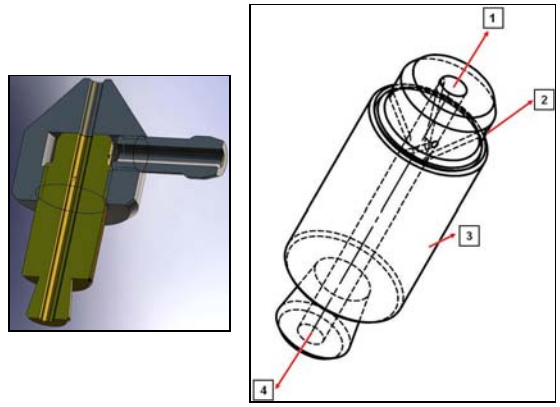


FIGURE 2. Application of an air nozzle on the RoCoS compact spinning system in terms of supporting device.

The nozzle was positioned about 6 cm below the delivery roller of the RoCoS compact unit. Pressurized air was fed into the air nozzle by the compressor.

The nozzle used in this study consists of a nozzle head and a nozzle body. The nozzle body has a cylindrical cross section consisting of the main hole (1), the injectors (2), the twisting chamber (3) and the nozzle outlet (4) (*Figure 3)*. The main hole lies between the nozzle inlet and the nozzle outlet and the nozzle has a constant diameter. Injectors are positioned at certain angles with respect to the nozzle axis and so they lie tangentially to the twisting chamber. The nozzle inlet can be considered to be an opening in which airflow can occur as an inflow or outflow depending on the injector angle and the air pressure level.



(a) (b)

FIGURE 3. Nozzle (a) and nozzle body (b) (1: Main hole, 2: Injectors, 3: Twisting chamber, 4: Nozzle outlet).

The nozzle head transfers the pressurized air coming from the compressor into the nozzle body by means of the injectors. The pressurized air goes out of the nozzle inlet and outlet.

In the Compact-Jet spinning system, the objective is to attain lower hairiness values in comparison to compact and conventional ring spun yarns. To realize this aim, changes were done on the structural parameters of the nozzle, such as the injector angle, main hole diameter etc. (*Table II)*.

TABLE II. Nozzle variables.

Structural Parameters	**Values**			
Axial angle of injectors (˚)	15		45	
Main hole diameter (mm)	2.0		2.5	
Nozzle head type	Conical		Spiral	
Nozzle outlet type	Normal (No hole)		2 holes	
Air pressure (MPa)	0.25	0.5	0.75	1.0

The angle profile of the injectors (θ) is shown in *Figure 4*. In this study, we used two different injector angles which were 15º and 45º; meaning that air enters at an angle of 15º or 45° to the main hole. Most of the studies concerned with nozzle usage focused on the 40–50° injector angle range. [10, 14, 16, 18, 21, 22] For that reason, we selected the 45° injector angle. In addition to 45°, differing from the literature, we also focused on 15°.

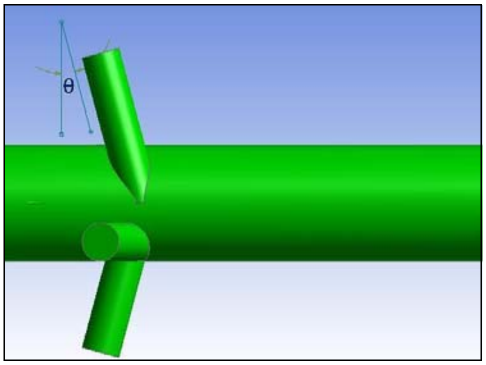


FIGURE 4. Angle profile of the injectors.

RESULTS AND DISCUSSION

Effect of Injector Angle and Air Pressure

To determine the effect of the injector angle on yarn hairiness, Compact-Jet yarns were produced with the nozzles having different injector angles (15° and 45°) at different pressures when the other structural parameters of the nozzle were kept constant. The air pressures were 0.25, 0.5, 0.75, and 1.0 MPa. The Zweigle hairiness (s3) results of the Compact-Jet yarns are given in *Figure 5*.

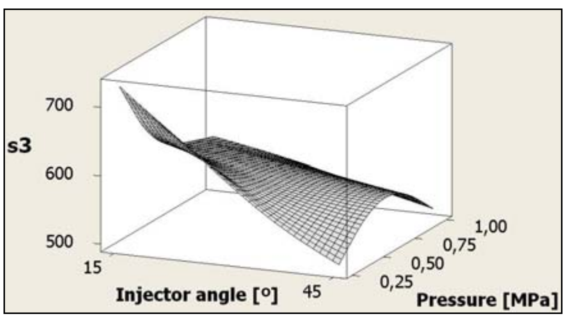


FIGURE 5. The effect of injector angle and air pressure on hairiness of Compact-Jet yarns.

The hairiness results of the Compact-Jet yarns display different trends depending on the injector angles. The injector angle of 45° especially gives the least hairiness values. Nevertheless, the difference in hairiness values of the yarns decreases when the air pressure increases. Statistical analysis results also show that there is no statistically significant difference in the s3 values of the yarns produced with different injector angles at 0.5 MPa and higher pressure levels (*Table III*). As a result, both injector angles produce yarns with similar hairiness values at 0.5 MPa and upper pressure levels.

TABLE III. Anova test results for 15° and 45° nozzle injector angles.

Production parameters		Sig.
15° - 0.25 MPa	45° - 0.25 MPa	0.001*
	45° - 0.5 MPa	0.006*
	45° - 0.75 MPa	0.006*
	45° - 1.0 MPa	0.030*
15° - 0.5 MPa	45° - 0.25 MPa	0.035*
	45° - 0.5 MPa	0.184
	45° - 0.75 MPa	0.179
	45° - 1.0 MPa	0.553
15° - 0.75 MPa	45° - 0.25 MPa	0.130
	45° - 0.5 MPa	0.505
	45° - 0.75 MPa	0.494
	45° - 1.0 MPa	0.921
15° - 1.0 MPa	45°- 0.25 MPa	0.221
	45° - 0.5 MPa	0.724
	45° - 0.75 MPa	0.711
	45° - 1.0 MPa	0.678

*: The mean difference is significant at the 0.05 level.

For the 15° injector angle, the hairiness results of the yarns significantly decrease as the air pressure increases (*Table IV*). But, the amount of reduction in hairiness decreases lower with increased air pressure, and it was found that there are no significant differences in the results at 0.5 MPa and upper pressure values. Therefore, Compact-Jet yarns obtained at 0.5 MPa and higher air pressures have similar yarn hairiness values.

TABLE IV. Anova test results of the nozzle with the 15° injector angle.

Production parameters		Sig.
0.25 MPa	0.5 MPa	0.025*
0.25 MPa	0.75 MPa	0.005*
0.25 MPa	1.0 MPa	0.002*
0.5 MPa	0.75 MPa	0.304
0.5 MPa	1.0 MPa	0.148
0.75 MPa	1.0 MPa	0.629

*: The mean difference is significant at the 0.05 level.

With regard to the 45° injector angle, the hairiness of the yarns shows an increasing trend up to a certain pressure level. Thereby, it is decreasing at 1.0 MPa. In spite of the changes in yarn hairiness with respect to the air pressure level, there are no statistically significant differences in the results of the 45° injector (*Table V*). Therefore, all air pressure levels give similar yarn hairiness values.

TABLE V. Anova test results of the nozzle with the 45°injector angle.

Production parameters		Sig.
0.25 MPa	0.5 MPa	0.489
0.25 MPa	0.75 MPa	0.497
0.25 MPa	1.0 MPa	0.215
0.5 MPa	0.75 MPa	0.989
0.5 MPa	1.0 MPa	0.552
0.75 MPa	1.0 MPa	0.543

*: The mean difference is significant at the 0.05 level.

According to the findings in the literature regarding the influence of air pressure on yarn properties, it was stated that the tangential and axial components of air velocity, and so the resultant velocity, increase with the air pressure. [10–11, 21] Increasing the swirling airflow intensity gives rise to bend and wrap the projected fibers around the yarn body and decreases the yarn hairiness. [8, 10, 18] However, when the pressure exceeds certain values, it was determined that fluid flow becomes unstable, hairiness decreases in smaller amounts and spinning deteriorates. [23–24] Therefore, lower pressure levels, such as 0.5 MPa, should be used from the point of view of yarn properties and also production costs.

Effect of Main Hole Diameter

In the second set of the experiments, the effect of the main hole diameter on yarn hairiness was analysed. The main hole diameter was selected as 2.0, and 2.5 mm when the other structural parameters of the nozzle were kept the same. The injector angle was fixed at 15° and the injector diameter was taken as 0.8 mm. Compact-Jet yarns were produced at 0.5, and 0.75 MPa, since, as mentioned above, air pressures higher than 0.25 MPa give similar hairiness values. In addition to the 0.5 MPa pressure level, yarn production was carried out at 0.75 MPa to eliminate any possible variation and to achieve the real results. The Zweigle hairiness (s3) results of the Compact-Jet yarns are shown in *Figure 6*.

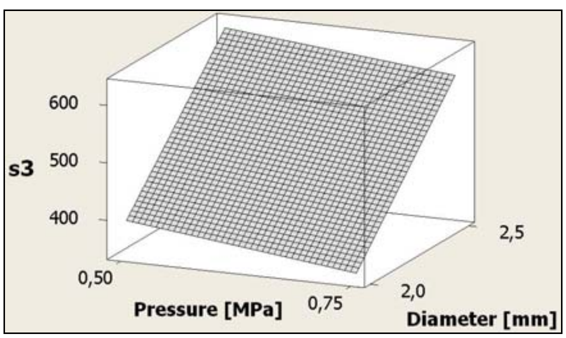


FIGURE 6. The effect of main hole diameter on hairiness of Compact-Jet yarns.

It is clearly seen in *Figure 6* that the s3 hairiness values increase with the main hole diameter. A 2.0 mm main hole diameter gives significantly lower hairiness values than a 2.5 mm at both air pressure levels *Table VI*. This case can be explained by the weakening swirling airflow and the lower false twist efficiency resulting from the larger main hole. [22, 25]

On the other hand, the differences in the hairiness results of the yarns produced at 0.5, and 0.75 MPa are statistically insignificant when the main hole diameter is kept the same. Therefore, both air pressure levels give close yarn hairiness values.

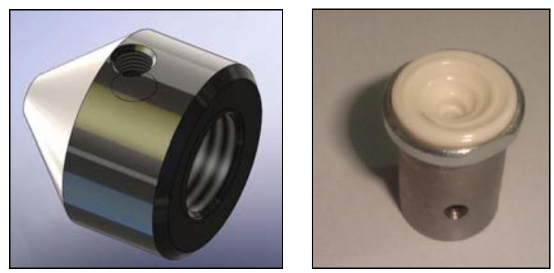
TABLE VI. Anova test results of the nozzles with different main hole diameters.

Production parameters		Sig.
2.0 mm - 0.5 MPa	2.0 mm - 0.75 MPa	0.059
2.0 mm - 0.5 MPa	2.5 mm - 0.5 MPa	0.000*
2.0 mm - 0.5 MPa	2.5 mm - 0.75 MPa	0.000*
2.0 mm - 0.75 MPa	2.5 mm - 0.5 MPa	0.000*
2.0 mm - 0.75 MPa	2.5 mm - 0.75 MPa	0.000*
2.5 mm - 0.5 MPa	2.5 mm - 0.75 MPa	0.110

*: The mean difference is significant at the 0.05 level.

Effect of Head Type

In the study, two distinct nozzle heads produced from different materials were used. The heads have conical and spiral forms (*Figure 7*).



(a) (b)

FIGURE 7. Conical (a) and spiral (b) type of nozzle heads.

The nozzle head with the conical form was produced from brass due to its easy processing and low-cost properties (*Figure 7a*). In the second type, a ceramic spiral part was positioned onto a metal body to eliminate the increase in hairiness due to rubbing and friction between the yarn and the head surface when the yarn passed into the nozzle (*Figure 7b*). We call this type of nozzle head spiral form. Compact-Jet yarns were produced with both head types at 0.5, and 0.75 MPa with the nozzle body kept the same. The nozzle particulars were 15° injector angle, 2.5 main hole diameter and 0.8 mm injector diameter. The s3 hairiness results of the Compact-Jet yarns are given in *Figure 8*.

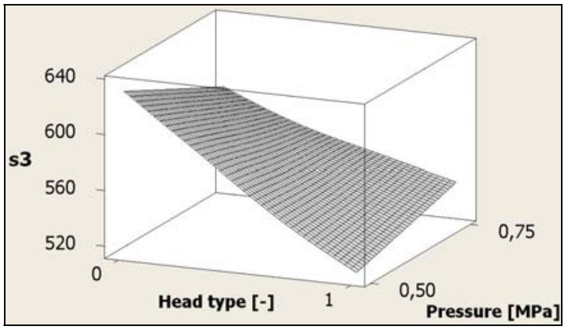


FIGURE 8. The effect of nozzle head type on hairiness Compact-Jet yarns (0: Conical head, 1: Spiral head)

According to *Figure 8 and Table VII*, the ceramic head with the spiral form mostly gives significantly lower hairiness values as compared to the conical head form at both pressure levels. This result may be due to friction at the nozzle inlet. The ceramic part of the head with the spiral form may enable the yarn to pass smoothly and decrease the rubbing between the yarn and the nozzle inlet. Therefore, the spiral nozzle head produces Compact-Jet yarns with better hairiness values.

TABLE VII. Anova test results for different nozzle heads.

Production parameters		**Sig.**
Conical - 0.5 MPa	Conical - 0.75 MPa	0.174
Conical - 0.5 MPa	Spiral - 0.5 MPa	0.003*
Conical - 0.5 MPa	Spiral - 0.75 MPa	0.009*
Conical - 0.75 MPa	Spiral - 0.5 MPa	0.024*
Conical - 0.75 MPa	Spiral - 0.75 MPa	0.092
Spiral - 0.5 MPa	Spiral - 0.75 MPa	0.412

*: The mean difference is significant at the 0.05 level.

Effect of Nozzle Outlet Design

As mentioned in the literature, airflow constitutes a vortex at the nozzle outlet since air pressure changes suddenly at the outlet due to the pressure difference in the nozzle body and the atmosphere. This phenomenon disturbs the characteristic structure of the airflow. [24] To eliminate the negative effect of the disturbances in airflow, two holes were drilled into the nozzle having the 15° injector angle, 2.5 mm main hole diameter and 0.8 mm injector diameter. These holes were positioned symmetrically to the nozzle outlet and their diameters were 0.8 mm. To analyse the effect of the nozzle with holes on yarn hairiness, Compact-Jet yarns were produced at the 0.5–0.75 MPa pressure range. Hairiness results of the yarns were compared with the yarns produced with the nozzle having the same structural parameters, but just no holes at the nozzle outlet. The hairiness results of the Compact-Jet yarns are indicated in *Figure 9.*

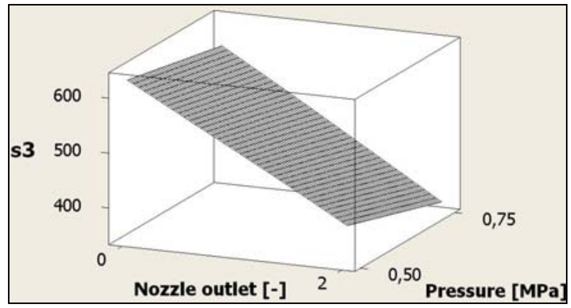


FIGURE 9. The effect of nozzle outlet design on the hairiness of Compact-Jet yarns (0: Normal nozzle without hole, 2: Nozzle with two holes).

As can be seen in *Figure 9 and Table VIII*, the nozzle with the holes at the outlet produces yarns with significantly less hairiness in comparison to the normal nozzle.

TABLE VIII. Anova test results of the nozzles with different outlet designs.

Production parameters		**Sig.**
Normal - 0.5 MPa	Normal - 0.75 MPa	0.219
Normal - 0.5 MPa	Holes - 0.5 MPa	0.000*
Normal - 0.5 MPa	Holes - 0.75 MPa	0.000*
Normal - 0.75 MPa	Holes - 0.5 MPa	0.000*
Normal - 0.75 MPa	Holes - 0.75 MPa	0.000*
Holes - 0.5 MPa	Holes - 0.75 MPa	0.082

*: The mean difference is significant at the 0.05 level.

As a consequence of the studies concerning the nozzles used in the Jetring and air-jet spinning systems, it was shown that the airflow in the nozzle has different flow characteristics upstream and downstream of the nozzle injectors. [14, 25–26] Guo et al. (2007) stated in one of their studies that there is a swirling balloon because of the reversal flow region near the upstream wall of the injector. This causes vortex breakdown downstream of the nozzle injectors. In addition to the effect against sudden changes in the air pressure, the holes at the nozzle outlet may also help to protect the yarn against the negative effect of vortex breakdown in the nozzle.

Effect Level Analysis of Nozzle Structural Parameters

We adopted average level analysis to interpret the effect of the nozzle structural parameters on yarn hairiness. In this analysis, we followed the method mentioned in one of the works of Cheng and Li (2002). According to this analysis, the difference was calculated between the highest and lowest hairiness results for each of the nozzle structural parameters studied in the work. Each difference value was accepted as a measure of the effect strength for the concerned parameter. As the difference increases, the effect of the parameter on yarn hairiness becomes stronger. The results of the effect level analysis are given in *Table IX.*

TABLE IX. Effect level analysis results of nozzle structural parameters

Parameters	0.5 MPa	0.75 MPa
Injector angle	76.9	38.8
Main hole diameter	233.2	242.1
Nozzle outlet design	221.6	240.8
Head type	111.9	50.1

According to *Table IX,* the main hole diameter, followed by nozzle outlet design, have the strongest effect on the hairiness of the Compact-Jet yarns at both air pressure values due to their greatest difference in values. The injector angle exhibits the weakest effect as a result of its lowest difference in value. When the air pressure increases, the effect of the injector angle and the nozzle head type, both weaker nozzle parameters, are reduced by half. In short, the main hole diameter and the nozzle outlet design are the strongest parameters, while the nozzle head type and then the injector angle are the weakest, in relation to less-hairy yarn production.

Comparison of Hairiness of the Conventional Ring, Compact and Compact-Jet Yarns

To display the influence of the nozzle on yarn hairiness, the hairiness results of the yarns produced on the Compact-Jet, compact and conventional ring spinning systems were compared. In the comparison, the results obtained from two types of nozzle having the strongest effect on yarn hairiness were taken into account. Compact-Jet (1) yarns were produced with a nozzle with a 2.0 mm main hole diameter and Compact-Jet (2) yarns were obtained using the nozzle with holes at the nozzle outlet. Both nozzle types were different from each other regarding the main hole diameter and nozzle outlet design.

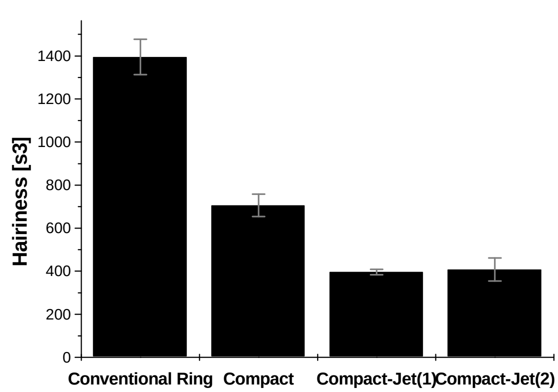


FIGURE 10. Zweigle hairiness (s3) values.

It can be clearly seen in *Figure 10* that both Compact-Jet yarns have considerably lower s3 hairiness values than those of the compact and conventional ring spun yarns. On the other hand, conventional ring spun yarns are more hairy than the other yarns. The differences in the hairiness results of the Compact-Jet, compact and conventional ring spun yarns are statistically significant (*Table X*). The Compact-Jet spinning system improves hairiness by up to 40% in comparison to the compact spinning system in which the aim was to produce less hairy yarn. On the other hand, Compact-Jet (1) and Compact-Jet (2) yarns are not statistically different from each other in spite of their different nozzle structural parameters. From this point, we concluded that the nozzles produce Compact-Jet yarns with similar hairiness results, even though they are different from each other with regard to the main hole diameter and nozzle outlet design.

TABLE X. Anova test results of yarn hairiness.

Spinning Systems		Sig.	
		s3	s1+s2
Conventional Ring	Compact-Jet (1)	0.000*	0.000*
Conventional Ring	Compact-Jet (2)	0.000*	0.005*
Compact-Jet (1)	Compact	0.000*	0.000*
Compact-Jet (2)	Compact	0.000*	0.002*
Compact	Conventional Ring	0.000*	0.005*
Compact-Jet (1)	Compact-Jet (2)	0.805	0.081

*The mean difference is significant at the 0.05 level

In addition to the s3 results of the yarns, we also analysed the number of hairs in 1 mm (s1) and 2 mm (s2) hair length groups expressing the short hairiness. To interpret the short hairiness, s1 and s2 values were summed indicating the number of hairs in 1 mm and 2 mm hair-length groups.

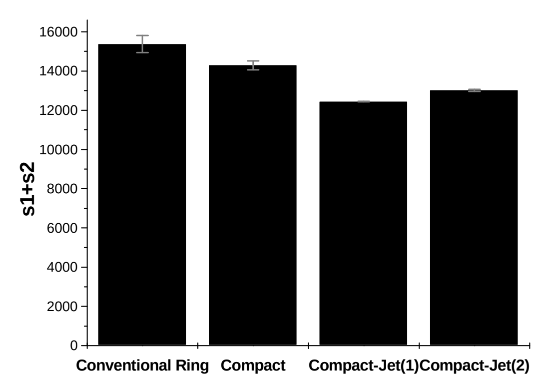


FIGURE 11. Total number of hairs shorter than 3 mm.

According to these overall values, similar to the s3 results, Compact-Jet yarns have the lowest values while conventional ring spun yarns have the highest (*Figure 11).* Therefore, Compact-Jet yarns have less long and short hairs than those of the other systems.

As mentioned previously, a swirling airflow was produced in the nozzle depending on the nozzle geometry and air pressure. [6, 8] Yarn hairiness results indicate that this swirling airflow in the nozzle wraps the long hairs onto the yarn body, so covering some of the short hairs. Therefore, there is a reduction in the number of hairs in all length groups.

Yarn Hairiness Results after the Winding Process

As is well known, yarn hairiness increases after winding resulting from the rubbing of fiber ends with various machine parts such as the tensioner, clearer, yarn guide, splicer and the grooved winding drum. Therefore, to examine the effects of the winding process on yarn hairiness, all yarn types were wound onto bobbins by the Murata Process Coner winding machine. The winding speed was adjusted to 1500 m/min for all experiments. After the winding process, the hairiness of the yarns was measured on the Zweigle G566 hairiness tester and the results are given in *Figure 12.*

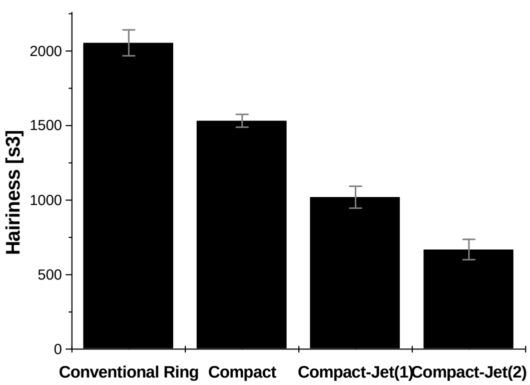


FIGURE 12. Zweigle hairiness (s3) values after winding.

As can be seen in *Figure 12 and Table XI*, Compact-Jet yarns are still significantly the least hairy yarn type after winding, while conventional ring spun yarns are the most hairy. This finding is similar to the hairiness results prior to the winding process. Consequently, the Compact-Jet spinning system enables less hairy yarn production before winding and also after the winding process.

TABLE XI. Anova test results of yarn hairiness.

Spinning Systems		Sig.
Conventional Ring	Compact-Jet (1)	0.000*
Conventional Ring	Compact-Jet (2)	0.000*
Compact-Jet (1)	Compact	0.000*
Compact-Jet (2)	Compact	0.000*
Compact	Conventional Ring	0.000*
Compact-Jet (1)	Compact-Jet (2)	0.000*

*The mean difference is significant at the 0.05 level

CONCLUSIONS

Hairiness is a key yarn property for spun yarns. The present study attempted to develop a new spinning method to reduce yarn hairiness and tested the system performance. The spinning system which is based on a nozzle attachment to the compact spinning system was called a Compact-Nozzle or Compact-Jet. The nozzle was positioned at the exit of the drafting system on a RoCoS compact spinning system and pressurized air was fed into the nozzle by the compressor during the spinning. In Compact-Jet spinning, the objective is to achieve lower yarn hairiness values in comparison to compact and conventional ring spun yarns. To realize this aim, we attempted to optimize the nozzle design with regard to yarn hairiness. Basically, we focused on the influence of the injector angle, main hole diameter, nozzle head type and nozzle outlet design.

The following conclusions can be drawn from the study:

(1) Concerning the injector angle, it was determined that 15° and 45° injector angles give statistically similar hairiness values at air pressure levels higher than 0.25 MPa, although they have different effects on Compact-Jet yarn hairiness. Therefore, both injector angles produce yarns with similar hairiness values at 0.5 MPa and upper pressure levels.

(2) As the air pressure increases, the reduction in yarn hairiness decreases due to vortex breakdown at the higher air pressure levels. Therefore, it is not sensible to increase the nozzle pressure to a very high level. From the perspective of yarn properties and production costs, it should be worked at lower pressure levels such as 0.5 MPa.

(3) As the main hole diameter increases, s3 hairiness values deteriorate because of the weakening swirling airflow and lower false twist efficiency.

(4) On the other hand, the ceramic head with spiral form and the nozzle with holes at the nozzle outlet give significantly lower hairiness values in comparison to the other head and nozzle types.

(5) The changes in hairiness values indicate that the main hole diameter and then the nozzle outlet design represent the most important attributes in reducing yarn hairiness, whereas the injector angle and nozzle head type show a weaker effect.

(6) In addition to the analysis of nozzle structural parameters, the hairiness of the Compact-Jet yarns was compared with that of the compact and conventional ring spun yarns to interpret the effects of the nozzle on yarn hairiness. It was determined that Compact-Jet yarns have significantly lower s3 hairiness values than those of the compact and conventional ring spun yarns. The Compact-Jet spinning system improves the hairiness by up to 40% in comparison to compact yarns and by 70% in comparison with the conventional ring spun yarns.

In the literature, many researchers studied air nozzle usage in the spinning and also the winding processes. However, there was no effort to incorporate the air nozzle and compact spinning system in this manner. Therefore, the Compact-Jet spinning system is a new application in the spinning field. It was proved that the Compact-Jet spinning system enables the production of considerably less hairy yarn at even lower air pressure levels in comparison to the compact and conventional ring spinning systems. Interestingly, the yarns produced with an air nozzle on the compact spinning system are still less hairy than the other yarns after the winding process. From the perspective of being a new application and the yarn hairiness results, it seems that Compact-Jet spinning will attract attention in the spinning field. In addition, this system will be noted as an innovation for less-hairy yarn production.

ACKNOWLEDGEMENT

This work is supported by grants from the Unit of Scientific Research Projects of Isparta in Turkey (Project No: 1795-D-09) and The Scientific and Technological Research Council of Turkey (Project No: 109M372). The authors also wish to express their thanks Ekrem Gülsevincler for his collaboration, the firms of Isparta Mensucat San. Tic. A.Ş. and YUMAK Tekstil San. Tic. A.Ş. for offering testing services and contributions to the study and also Technician Ufuk Korkmaz and other staff in the laboratory for their generous help.

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