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Influence of Nozzle Type on Yarn Quality in Open-End Rotor Spinning

Abstract
In this study we investigated the effect of the nozzle type as one of the most important parts of the open-end rotor spinning system on yarn quality. 100% Urfa Region cotton was used for the production of yarns of 20 tex. Experimental studies were made on ten spinning units of a Rieter R1 machine. Five different ceramic nozzle types were used: K4KK (plain with 4 grooves), K4KS (plain with 4 grooves and aggressive flute insert), K6KF (plain with 6 grooves), K8KK (plain with 8 groves), and KSNX (spiral with soft flute insert). Apart from the nozzle types, the yarn production conditions and machine parameters were kept the same. All production activities were realized under the same mill conditions. For yarn hairiness, yarn evenness and yarn imperfections, an Uster Tester 4SX and for yarn tenacity an Uster Tensorapid 3 tester were used. The test results were analysed using the one way-ANOVA statistical method of Design Expert 6.0.1. In one of the evaluations, it is clearly seen that the nozzle type mostly affects yarn quality and yarn tenacity.

Key words: *rotor spinning, nozzle type, yarn quality, yarn evenness, yarn hairiness, yarn tenacity.*

Introduction

In recent years, textile and apparel products from polyester, acrylic, viscose and modal have seen increased demand in international markets. However, cotton fibre continues to be the most basic and strategic raw material for the textile and apparel industry. In terms of the supply of raw materials, Turkey has the advantage of being one of the world's leading producers of cotton, being the eight largest after China, India, USA, Pakistan, Brazil, Uzbekistan and Australia, with 375 thousands tons of cotton production in the 2009/2010 season. By the year 2009/2010, the cotton production of Turkey was 375 thousand tons, while cotton consumption of Turkey was 1100 thousond tons [1].

When analysing the past 20 years, it is seen that Turkey has an important role in short-staple rotor spinning. At the beginning of 2005, Turkey had a capacity of 2.8 million tons of short staple spinning, with 70%. 60% of the 620 yarn spinning mills producing cotton yarns i.e. the whole short staple spinning industry of Turkey consist of ring and open-end rotor spinning system. 58% of the total capacity of short-staple spinning comprise the ring spinning system and 42% - the open-end rotor spinning system [2]. The open-end rotor spinning capacity of the world is as follows: Russia 26%, China 13%, USA 8%, respectively, followed by Turkey with a rate of 6% [3].

In the rotor spinning process, sliver is broken up so that individual fibres are fed by an air stream and deposited on the inner surface of a rotating device driven at high speed. As the fibres are drawn off, twist is inserted by the rotation of the rotor making a yarn [4].

The rotor spinning system offers the oppurtinity of determining the yarn parameters by changing drafting and twisting parameters, and can also be used as a versatile method for yarn production. In this system, by changing the rotor, spinning nozzle and opening roller elements, short staple yarn between 12 - 150 tex can be produced [5].

Various studies have been made on nozzle type, which has a significant effect on yarn structure, surface properties and yarn quality in rotor spinning.

A number of these studies [6 - 10] were made for 100% cotton fibre, as a result of which, it was found that nozzle types without grooves have an improving effect on yarn irregularity, hairness and strength. Two studies [11, 12] investigated the effect of nozzle type on yarn quality for waste cotton. In these researches similar results to those of the studies mentioned were observed. Another investigation [13] was performed for different raw material blends, such as cotton/polyester and polyester/viscose. In this study lower yarn hairness values were obtained for flat surface nozzles.

In this study, as a contribution to the literature, the effect of nozzle type, which is one of the most important elements in rotor yarn spinning, on yarn quality was investigated. 100% cotton raw material was converted to rotor yarn by using five different nozzle types. Yarn production was carried out for only knitting type yarns. As well as in earlier studies, yarns were produced in commercial mills to achieve the most accurate results.

Material and method

In the study, 100% Urfa cotton was used as raw material. Properties of the cotton was tested by an Uster HVI 900, and the results were evaluated on the basis of statistics [14]. Fibre and yarn samples were standard atmosphere conditioned, (temperature 20 ± 2 °C and relative humidity 65 ± 2%) based on EN ISO 139 standard, for 24 hours [15]. Collected from various parts of the blend used in the production of the cotton fibre sample, the results are the average of five measurements, given in ***Table 1***.

Under the Uster statistics values for fibre properties, according to the HVI values, the irregularity of cotton fibre is regard-

Table 1. *Fibre properties.*

Fibre parameters tested	Symbol	Values measured
Upper half mean length, mm	UHML	14.33
Mean lenght, mm	ML	29.35
Microneire, μg/inç	Mic.	4.9
CVm, %	Unf.	48.8
Tenacity, cN/tex	Str	24.83
Elongation, %	El.	9.9
Yellow grade	+b	9.47
Brightness	Rd	76.60
Color grade	CG	21 - 4
Number of contamination, cnt/g	Dust	551

ed as „very good”, the strength value as „medium strength”, with a value of 9.9% elongation - as „very high”, a fibre fineness of 4.9 mg / inch Microner - as „medium fine”, and a fibre length of 29.35 mm as a „medium-length” group. A color diagram which identifies the colour scale value of 9.47 and brightness value of 76.60 correspond to 21-4 in the „white cotton” group [14].

During the production, five different nozzle types were used from the Rieter machine company: K4KK (plain with 4 grooves), K4KS (plain with 4 grooves and aggressive flute insert), K6KF (plain with 6 grooves), K8KK (plain with 8 groves), and KSNX (spiral with soft flute insert) [16]. In ***Table 2*** the end production and types of nozzles are shown. In this study 100% Urfa cotton was converted to a 5 900 tex count sliver. Slivers were fed through as pre-determined rotor spinning units and produced on an open-end rotor spinning machine. Spinning conditions and production parameters of the machine are given in ***Table 3***.

100% cotton yarn samples were produced by a rotor spinning machine with a rotor groove of type S and diamond coated rotor, which is suitable for knitting yarns. In order to minimise variations, the yarn production was done with pre-determined rotor units by just changing the nozzle type, while all other machine production parameters were kept constant.

For yarn evenness, faults and hairiness an Uster Tester 4SX test device was used and the results were evaluated according to Uster [17]. For each type of nozzle five bobbins were tested and ten measurements made for each bobbin. For yarn strength an Uster Tensorapid 3 tester was used according to EN ISO 2062, and for each type of nozzle five bobbins were tested. Five measurements were made for each bobbin [18].

Results and discussion

The effect of different nozzle types on yarn quality parameters are given in ***Table 4***.

Yarn evenness

The yarn evenness uniformity % Um and coefficient of mass variation %CVm values provide information about the %CVm. Uster statistics classify yarn

Table 2. *Nozzle types and characteristics.*

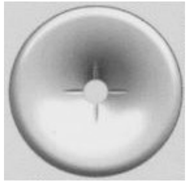
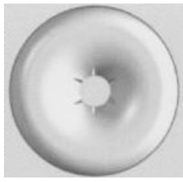
Nozzle type	Nozzle specification	Raw material	End use	Nozzle drawing
K4KK	plain with 4 grooves, ceramic	cotton, regenerate, viscose, polyester/acrylic, polyester/cotton	knitting and weaving	
K4KS	plain with 4 grooves and aggressive flute insert, ceramic	cotton	knitting	
		polyester/acrylic, polyester/cotton	knitting and weaving	
K6KF	plain with 6 grooves, ceramic	cotton, viskon, polyester/acrylic, polyester/cotton	knitting and weaving	
K8KK	plain with 8 groves, ceramic	cotton	knitting	
		viscose, polyester/acrylic	knitting and weaving	
KSNX	spiral with soft flute insert, ceramic	cotton	knitting and weaving	

Table 3. *Yarn and machine production parameters.*

Yarn parameters	Yarn count (Linear density), tex	20
	Sliver number, tex	5900
	Number of twist, t.p.m	840
	Twist factor, α_m	118.0
Machine parameters	Rotor type	32 SD
	Rotor diameter, mm	32
	Rotor speed, r.p.m	102,360
	Opening roller type	OB 20
	Opening roller speed, r.p.m	7,700
	Nozzle types	K4KK, K4KS, K6KF, K8KK, KSNX

Table 4. *Test results of yarn properties.*

Parameters of yarn tested	Nozzle types				
	K4KK	K4KS	K6KF	K8KK	KSNX
Uniformity, % Um	12.67	12.72	12.79	12.75	12.29
Mass variation of coefficient, % CVm	15.95	16.03	16.13	16.08	15.51
Thin places (-% 50), 1/km	70.3	79.5	77.3	66.3	59
Thick places (+% 50), 1/km	111.8	117.5	115.3	111.3	76.8
Neps (+% 280), 1/km	22.8	63.8	21.0	24.3	10.8
Tenacity, cN/tex	10.43	8.86	11.7	10.34	10.24
Breaking strength, cN	205.3	174.5	230.4	203.6	201.7
Breaking work, cN/cm	269.5	212.3	312.3	256.5	266.5
Elongation, %	4.86	4.47	5.04	4.74	4.96
Uster hairiness index, H	5.16	7.12	4.99	5.30	5.34

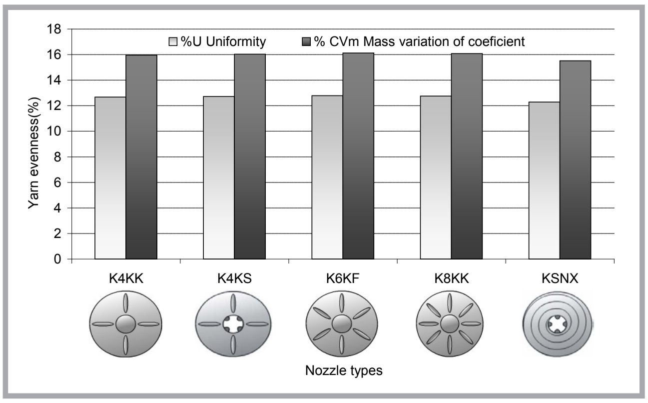


Figure 1. *Yarn evenness for different nozzle types.*

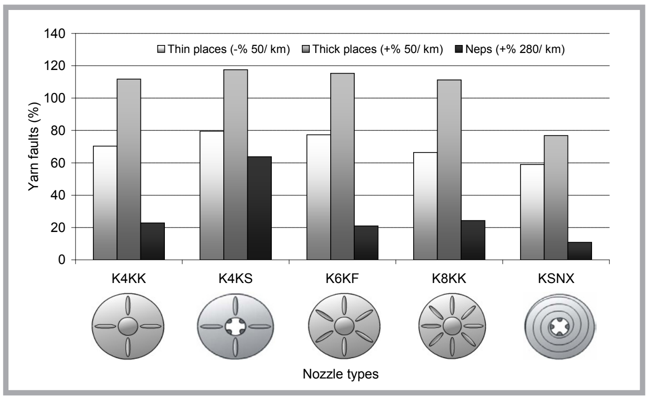


Figure 2. *Yarn faults for different nozzle types.*

quality values as less than 5%, 6 - 25%, 26 - 50%, 51 - 75% & 76 - 95%, up from 95%. The percentage increase in the value worsened the quality of yarn. The quality percentile value of Uster statistics was determined according to test results given in ***Table 4***. The CVm% for nozzle KSNX 15.51 with 60% Uster percentile was identified as the value of yarn quality. Other types of levels in terms of yarn quality for the values obtained from CVm% correspond to between 70 - 75% [17].

From ***Figure 1***, the best yarn irregularity is seen for KSNX nozzle. Therefore the irregularity value of the KSNX nozzle was taken as a basis for further calculations and the absolute relative difference between other nozzle types was calculated. Using the following expression, CVm_D refers to the values of CVm% for other nozzle types.

$$BF = \frac{|CVm_D - CVm_{KSNX}|}{CVm_{KSNX}} \times 100 \text{ in \% (1)}$$

Given ***Equation 1*** there is no relative difference in the type of expression levels in KSNX, other nozzle types can be calculated in the range 3 - 4%. Uster statistics for all levels in terms of CVm% were examined according to the types, with the quality of yarn ranging between 51 - 75% . According to these values, the nozzle does not have a significant effect on the value of yarn irregularity.

Yarn Faults

Yarn faults are expressed as thin places, thick places and neps. Using Table 4, with yarn quality values expressed as thin places (-% 50, 1/km), thick places (+% 50, 1/km) and neps (+% 280, 1/km), the quality percentile values of Uster statistics were determined and compared. The Uster quality percentile for thick places was calculated in the range 78 - 87% for all yarn types. For a number of thin places of 76.8 on the KSNX nozzle, corresponding to 32%, the Uster percentile for the other nozzle types is between 48 - 50%. For a nep value of 10.8 on the KSNX the value is 11%. For the K4KS the Uster percentile value was 77%. For the other types of nozzles for Neps values they were the worst, corresponding to 35 - 41% [17].

As a result of this analysis, the yarn faults measured and Uster quality percentile evaluation of the quality categories, we can state that the KSNX nozzle gave the best results.

Figure 2 shows the yarn faults measured according to nozzle type. KSNX values were accepted as a starting point, and other relative differences between the values of the fault, respectively, thin places, thick places and neps for numbers (2), (3) and (4) were calculated using the equations.

$$BF = \frac{|I_D - I_{KSNX}|}{I_{KSNX}} \times 100 \text{ , in \%} \quad (2)$$

$$BF = \frac{|K_D - K_{KSNX}|}{K_{KSNX}} \times 100 \text{ , in \%} \quad (3)$$

$$BF = \frac{|N_D - N_{KSNX}|}{N_{KSNX}} \times 100 \text{ , in \%} \quad (4)$$

Taking expressions I_D, K_D and N_D, corresponding to the thin places, thick places and neps, except for KSNX nozzle, accordingly, relative differences were calculated as follows; for thin places 12 - 35%, for thick places 45 - 53% and for neps in the range of 95 - 490%.

As a result of this study, according to evaluations made using Uster statistics, we can state that nozzle type does not have a significant effect on thin places but has a moderate effect on thick places . Also nozzle type has a significant effect on the nep results, with higher yarn hairiness, leading to the deteriotion of yarn irregularity and nep values [9].

Yarn tenacity and elongation

In ***Table 4***, the yarn tenacity and elongation values are compared with test results of Uster statistics percentile in terms of quality. In terms of yarn tenacity the highest value of 11.7 cN×tex belongs to K6KF, with a 55% Uster percentile. This value is between 83 - 95% for other nozzle types. Elongation values for all nozzle types are in the range of 86 - 95% [17].

As presented in ***Figure 3***, the best yarn tenacity and elongation values were obtained for the K6KF nozzle. Therefore, nozzle K6KF's tenacity rating (M_{K6KF}) on the basis of levels for other types of tenacity values obtained from the relative differences between the absolute, BF in %, in the following number (5) was calculated using the expression. Here, M_D, represents the values of strength for other nozzle types.

$$BF = \frac{|M_D - M_{K6KF}|}{M_{K6KF}} \times 100 \text{ in \%} \quad (5)$$

The relative strength value of other nozzle types varies between 10.9 and 24.3%. Uster statistics are evaluated in terms of levels in other types of yarns from the class participated in a quality much worse. Nozzle type has a significant effect on the strength, as concluded in earlier studies [13, 14]. On the other hand, nozzle type does not have a significant effect on elongation.

Yarn hairiness

Table 4 gives the results of yarn hairiness. Uster yarn hairiness test results

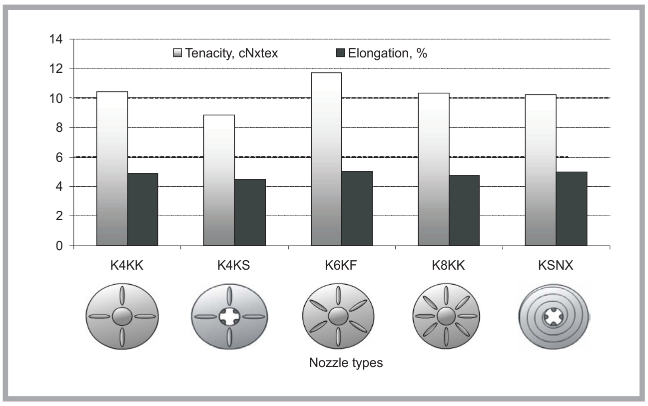


Figure 3. Yarn tenacity and elongation for different nozzle types.

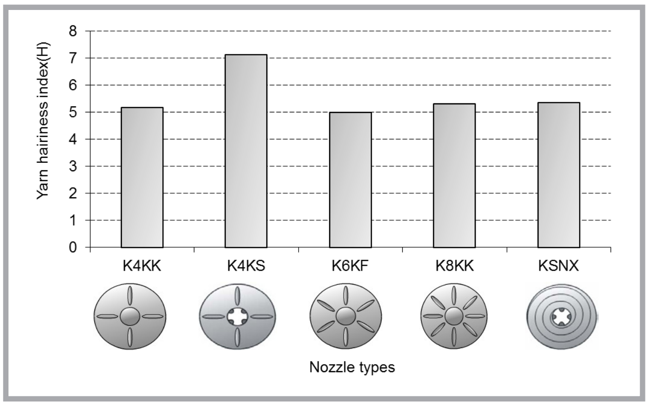


Figure 4. Yarn hairiness index for different nozzle types.

measured with statistics and comparing the percentage levels were determined according to the nozzle types in terms of the quality of the yarns. The minimum level of yarn hairiness was achieved by the K6KF nozzle with a value of 4.99, representing 63% of the yarn quality percentile; for the K4KK nozzle the yarn quality percentile value is 69%, and for the KSNX and K8KK nozzles, the yarn quality values are 75% and 76%. The lowest yarn quality values were achieved by the K4KS nozzle, which was around 95% [17].

$$BF = \frac{|H_D - H_{K6KF}|}{H_{K6KF}} \times 100 \quad \text{, in \% (6)}$$

Figure 4 shows that the best yarn hairiness value was obtained by the K6KF nozzle. For this reason, for the K6KF nozzle (H_{K6KF}), the absolute relative difference between the hairiness values, *BF* in %, in the following ***Equation 6*** was calculated using the expressions. Here, hairiness values H_D refer to the other nozzle types.

The relative difference calculated for the other nozzle types varies between 3.4% and 42.7%. The type of nozzle has a significant effect on yarn hairiness, keeping the Uster statistics in mind.

Statistical significance analysis

The results of these experimental studies were evaluated by a Design-Expert 6.0.1 statistical software package with one-way analysis of variance (ANOVA), where for factor F a level of significance of α = 0.05 was preferred. ***Table 5*** summarises the results of the statistical analysis. Here a P value less than 0.05 is considered to be the result of factors that show no significant effect on the value. We evaluated the results based on the F-ratio and the probability of the F-ratio (prob > F). The lower the probability of the F-ratio, the stronger the contribution of the variation and the more significant the variable.

Conclusions

In this study, yarn evenness, yarn faults, yarn strength and yarn hairiness values were tested and yarn quality values were classified according to nozzle types with Uster statistics. The findings of the study and the results are summarised in the following items.

1. In terms of the comparative value, the KSNX nozzle obtained the best yarn irregularity. The absolute relative difference of the other nozzle types are between 3 - 4%. The Uster quality percentile value of the yarn types range between 51 - 75%. Thus the effect of nozzle type on yarn irregularity was not significant.
2. With respect to yarn faults measured (thin places, thick places and neps) and Uster yarn quality in terms of a comparative evaluation of the quality categories, the KSNX nozzle gave the best result. As a result of this study, according to the evaluations made using Uster Statistics, it can be concluded that nozzle type does not have a significant effect on thin places, whereas for thick places there is a moderate effect. Also the nozzle type has a significant effect on neps, resulting in higher yarn hairiness, which leads to a deteriotion of yarn irregularity and nep values.
3. The best yarn tenacity and elongation values were obtained for the K6KF nozzle type. Uster statistics are evaluated in terms of levels in other types of yarns from the class participated in a quality much worse. The nozzle type has a significant effect on the tenacity, as concluded in earlier studies. On the other hand, the nozzle type does not have a significant effect on elongation.
4. The best yarn hairiness value was obtained for the K6KF nozzle. The type of nozzle has a significant influence on hairiness.

Within the scope of the study, it was observed that the structure of the nozzle has a significant effect on thick places, neps, tenacity and hairness values of the yarn in open-end rotor spinning. An important issue from this study is that the selection of the nozzle has an effect on yarn quality and specification.

Table 5. *Levels in the statistical analysis of the effect on the type of yarn properties.*

Yarn properties	F value	P value	R^2	Level of effect, %
Uniformity, % Um	7.43	0.0001	0.3976	39.76
Mass variation of coefficient, % CVm	8.21	<0.0001	0.4217	42.18
Thin places (- % 50)	2.95	0.0301	0.2077	20.77
Thick places (+ % 50)	5.90	0.0007	0.3440	34.40
Neps (+ % 280)	17.44	<0.0001	0.6079	60.79
Hairiness (H)	215.9	<0.0001	0.9505	95.05
Tenacity, cN/ tex	6.39	0.0018	0.5609	56.10
Elongation, %	3.10	0.0389	0.3825	38.25

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