Textile & Leather Review

ISSN 2623-6281 | www.tlr-journal.com | 10.31881/TLR

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How to cite: Sayed MA, Uddin MB, Begum HA. Comparative Study of Cotton Yarn Properties Using Central-Fan and Multi-Fan for Vacuum Generation in Aerodynamic Compact Spinning Systems. Textile & Leather Review. 2022; 5:240-252. https://doi.org/10.31881/TLR.2022.28

How to link: https://doi.org/10.31881/TLR.2022.28

Published: 28 June 2022

Comparative Study of Cotton Yarn Properties Using Central-Fan and Multi-Fan for Vacuum Generation in Aerodynamic Compact Spinning Systems

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Article
https://doi.org/10.31881/TLR.2022.28
Received 2 May 2022; Accepted 21 June 2022; Published 28 June 2022

ABSTRACT
Today, aerodynamic compact spinning is the most widely used compact spinning method in which the vacuum (negative pressure airflow) is generated to compact the fibre strands. Different manufacturers use different vacuum generation systems, which can be divided into the following – a central fan system with combined duct and independent duct and a multiple fan system. The information on each system and its impact on yarn properties would be quite attractive for research. This empirical study investigated the properties of yarns manufactured on the aerodynamic compact spinning systems with widely-used different vacuum systems. To preserve neutrality, these systems were referred to as CFS (CDS and IDS) and MFS instead of using their commercial names. It was found that CFS was the most remarkable concerning yarn irregularity (U% and CVm%), imperfection index (IPI), and bundle yarn strength (CSP) in comparison with the MFS. Though the yarn hairiness in MFS was better than in IDS, overall quality parameters were not as comparable to IDS or CDS.

KEYWORDS
compact yarn, vacuum system, central fan system, multi-fan system, pneumatic compacting

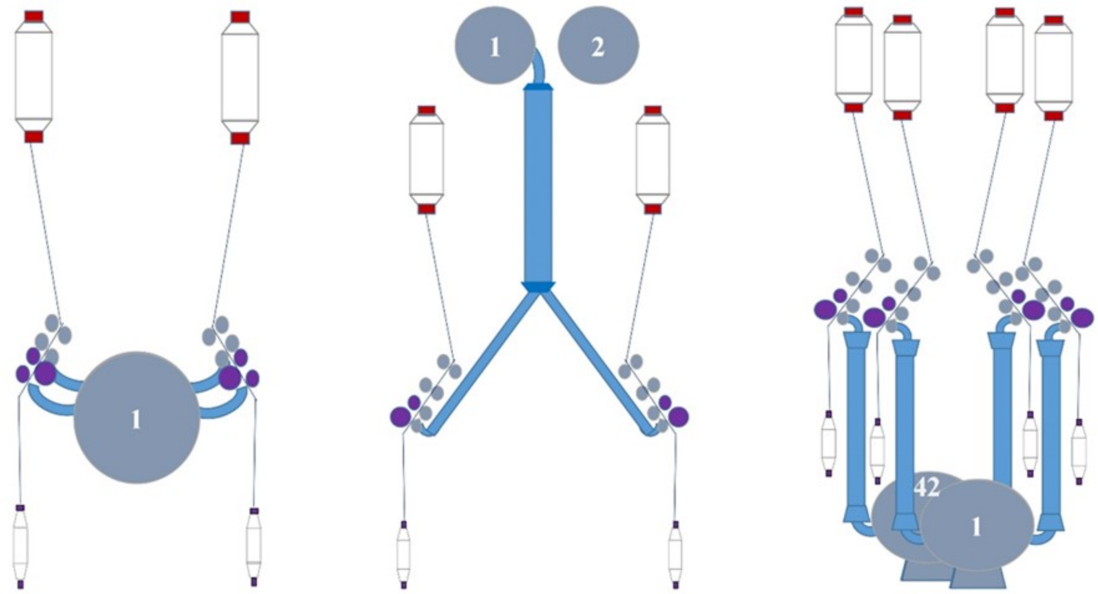
INTRODUCTION

There are a number of compact spinning systems for producing superior quality ring yarns, and aerodynamic compact spinning is the most popular system of these since its advent in the short-staple spinning industry. In a conventional ring frame, yarn hairiness or protruding fibres generate as the spinning triangle restricts the control of fibres, especially the selvage fibres [1]. In order to eliminate the spinning triangle, several manufacturers, such as Rieter, Suessen, Toyota, and Zinser, offer a variety of compact attachment designs based on the same compacting principle [2]. The compacting zone of most manufacturers comprises a vacuum system and a perforated apron or a perforated drum [3]. With the help of the vacuum system, the perforated drum or apron condenses the fibre strand after the main drafting zone of the ring frame and reduces the spinning triangle [4]. As the spinning triangle is greatly reduced, fibre strands are controlled properly and selvage fibres are easily bound into the yarn body [5]. As a result, the compact yarn shows less hairiness and improved strength and appearance than the conventional ring yarn [6-8]. Such compact yarn not only meets the customer's demand but also improves subsequent textile processing stages in terms of productivity [9].

In aerodynamic compact spinning systems, a substantial vacuum or negative pressure plays the most vital role in compacting the fibre strand before twisting [10]. If the vacuum pressure is varied, the compacting will not be regular and it will affect the yarn quality. Usually, suction fan/fans is/are used to create the vacuum, and it is provided for the condensing zone of each spinning position through the ducts [11]. There are different vacuum generation systems in the market from numerous manufacturers, and they can be divided into two systems: Central Fan System (CFS) and Multiple Fan System (MFS). These are described below.

CFS: it has only one central fan (CF) where vacuum generation is done centrally. A central fan serves throughout the whole spinning position using one or two central ducts with flexible hoses and or tubes. This can be further divided into the following:

a) Combined duct system (CDS) for ring and compact spinning
b) Independent duct system (IDS) for ring and compact spinning.



a) b) c)

Figure 1. Schematic diagram of (a) combined duct system, (b) independent duct system, and (c) multiple fan system

In CDS, as shown in Figure 1(a), the vacuum is provided throughout the machine using a central duct. The long central ducts are usually fitted under the spinning positions and connected to a central filter box. Each spinning position is connected to the central duct with two flexible tubes or pipes. One pipe is for compacting the fibre strand, and another is for the pneumafil suction [12].

In IDS, as shown in Figure 1(b), the vacuum for compacting is provided throughout the spinning positions by using one or two central ducts with flexible hoses, tubes, and a distributor, respectively. The long central ducts are usually fitted/retrofitted in the creel area and connected to a central filter box. One profile tube on the left and another profile tube on the machine's right are connected to the central ducts [13]. For pneumafil suction, a different duct is used here that is commonly seen in ring frames.

MFS: it has multiple fans (MF) where vacuum generation is done section-wise. A motor drives a shaft that reaches through the machine and drives the individual fans. Each fan usually serves a section of spinning positions through tubes with grommets and hoses [13]. For example, there will be 42 fans in a ring frame having 1008 spindles, where each fan serves 24 spinning positions. A representative schematic diagram of MFS is shown in Figure 1(c).

As mentioned above all the vacuum systems may have an impact on yarn properties, which would be of great interest. From that interest, however, the present study investigated the 100%-cotton yarn properties produced on the aerodynamic compact spinning frame equipped with different vacuum systems currently in common use in the cotton spinning industry. The authors believe this study will fulfil the research gap on vacuum generation systems and help spinners to produce better quality compact yarns.

EXPERIMENTAL

Materials

Cotton fibres (blend of India-80% and Greek-20%) with an average fineness of 4.2 micronaire value, upper half mean length (UHML) of 29.7 mm, and tenacity of 30.3 g/tex were used. Raw cotton properties evaluated through the High Volume Instrument (HVI) and Advanced Fibre Information System (AFIS) are shown in Table 1.

Table 1. Raw Cotton specifications from HVI & AFIS

	HVI					AFIS				
Raw cotton	SCI*	Micronaire	UHML (mm)	Tenacity (g/tex)	Elongation (%)	Neps (cnt/g)	SCN** (cnt/g)	SFC***(w)	SFC(n)	IFC**** (%)
India	145	4.1	30.3	30.5	6.2	228	24	13.7	34.2	5.9
Greek	132	4.3	29	30.1	7.6	246	9	9	24.1	8

*Spinning consistency index, **Seed coat neps, ***Short fibre content (w: by weight; n: by number), ****Immature fibre content

Methods

Preparation of roving from raw cotton

For the experimental study, a spinning mill named ‘SQUARE Textiles Limited, Bangladesh’ was selected, which is at the top of the local textile industry combining modern technology with skilled human resources. At first, cotton bales were processed through the Rieter blow room line (Unifloc-A11, Heavy Particle Separator, Uniclean-B12, Uster Jossi Combo Shield, Unimix-B72, Unistore-A79, Uster Jossi Magic Eye, Uster Jossi Vision Shield-2 and Condenser) that produced very small fibre tufts. The fibre tufts were then processed through a Rieter C-70 carding machine, and 4.9 ktex card sliver was produced with a delivery speed of 153 m/min.

Rieter SB-D-45 breaker draw frame (D/F) was used to convert the card slivers into breaker D/F sliver, and Rieter RSB-D-45 finisher D/F (with auto-leveller) was used to convert breaker D/F sliver into the finisher D/F sliver. The linear density of sliver, delivery speed, and doubling ratio for both D/F were 4.90 ktex, 500 m/min, and 8:1, respectively. Marzoli FT6 simplex machine was used to produce 0.66 ktex roving from the finisher D/F sliver where flyer speed was 1100 rpm, and roving TPI was maintained at 1.21.

Production of compact yarn by using different vacuum systems

Three ring frames with aerodynamic compact attachment were used to manufacture yarns where one had CDS, one had IDS, and another had MFS for vacuum generation. The same cotton roving was fed through the back roller of each ring frame to produce the 17.4 tex (34 Ne) hosiery grade compact yarns maintaining the same process parameters. The process parameters of the spinning frames are given in Table 2.

Table 2. Process parameters of yarn production using different vacuum systems

Parameters	Vacuum system		
	CDS	IDS	MFS
Roving linear density, tex	656	656	656
Yarn linear density, tex (Ne)	17.4 (34)	17.4 (34)	17.4 (34)
Twist Multiplier (TM)	3.61	3.61	3.61
Spacer, mm	2.8 (White)	2.8 (White)	2.8 (White)
Traveller type	5/0 UL udr (ISO-35.5)	5/0 UL udr (ISO-35.5)	5/0 UL udr (ISO-35.5)
Cradle load, kg	18 (Red)	18 (Red)	18 (Red)
Suction pressure, mbar	28-29	28-29	28-29
Spindle speed, RPM	15500	15500	15500
Drafting gauge, mm	44/65	44/65	44/65

Parameters	Vacuum system		
	CDS	IDS	MFS
Back draft	1.18	1.18	1.18
Main draft	40.3	40.3	40.3
Condensing system	Perforated drum	Perforated apron	Perforated apron

Testing Method of Produced Aerodynamic Compact Yarn Properties

Yarn properties were assessed by the following test methods, as shown in Table 3. Note that, for yarn sampling, 10 bobbins were taken from the same spinning position of 10 different sections (each section consisted of 24 spinning positions) of the ring frame in all cases. The test results were analysed by using one-way ANOVA and LSD tests in the SPSS software to find any statistically significant differences. For conditioning purposes, all yarn samples were kept in the testing laboratory for at least 24 hours under standard atmospheric conditions of 20 ± 2 °C and 65 ± 2 % relative humidity.

Table 3. Parameters and standards of yarn sample testing

Parameters measured	Name of testing instruments	Testing standard	Number of observations per sample
Yarn evenness (CV_m%, U_m%), hairiness and imperfections (+50%/km, -50%/km, +200%/km)	USTER® Tester-6	ASTM D1425/1425M-14(2020), Testing speed 400 m/min	10
Yarn fineness	USTER® Tester-6	ASTM D1907	10
Twist per inch (TPI)	Ordinary twist tester	ASTM D1422	10
Yarn bundle strength (CSP)	EleStretch XT Electronic Lea Strength Tester	ASTM D1578	10 (7 skeins taken for each sample)

RESULTS AND DISCUSSION

Table 4 summarizes the compact yarn properties, and Table 5 summarizes the ANOVA results. The post hoc LSD method was also performed to determine whether there was any significant impact of various vacuum generation systems on the compact yarn properties. The multiple-range test (LSD) results are summarized in Table 6 and discussed thoroughly.

Table 4. Properties of compact yarns.

Parameters	Vacuum generation system		
	CDS	IDS	MFS
Set count	34	34	34
Actual count	34.1	34.02	34.09
Count CV%	0.83	0.62	0.58
U%	13.2	13.4	14.5
CV_m%	16.9	17.3	18.6
CV_m (1m)%	5.28	4.72	5.20
CV_m (3m)%	4.12	3.79	4.13
CV_m (10m)%	3.23	2.90	3.13
Thin -30%	3210	3696	4802
Thin -40%	351	468	793
Thin -50%	14	16	38
Thick +35%	2014	2148	2668
Thick +50%	567	598	892
Neps +200%	931	927	1213
Neps +280%	210	179	257
IPI	1512	1541	2143
CSP	2360	2273	2249
Hairiness	4.83	5.57	4.85
Sh	1.35	1.47	1.27
Set TPI	21.06	21.06	21.06
Actual TPI	23.03	23.16	21.59

Table 5. Summary of statistical analysis results

ANOVA	Yarn properties	F value	Significance
Between groups	Bundle strength (CSP)	1.845	0.177
	Hairiness (H)	30.621	0.000*
	Mass variation (CV_m%)	117.288	0.000*
	Imperfection index (IPI)	80.975	0.000*

*Significant

Table 6. Summary of Post Hoc (LSD) test results

(I) Vacuum systems	(J) Vacuum systems	Hairiness (Sig. level)	Mass variation (Sig. level)	Imperfection index (Sig. level)
LSD				
CDS	IDS	0.000*	0.005*	0.606
	MFS	0.840	0.000*	0.000*
IDS	CDS	0.000*	0.005*	0.606
	MFS	0.000*	0.000*	0.000*
MFS	CDS	0.840	0.000*	0.000*
	IDS	0.000*	0.000*	0.000*

*The mean is significantly different at the 0.05 level.

Comparisons of yarn U% & CVm%

The yarn irregularity can be expressed either by yarn unevenness (U%) or the co-efficient of variation of yarn mass (CVm%). The USTER® evenness tester measures the yarn irregularity according to the capacitance principle. The lower the value of irregularity the better the quality of yarn [14].

The yarn U% and CVm% results are shown in Figure 2. The test results show that the CDS has the lowest irregularity, whereas the MFS has the highest irregularity, and the IDS has a medium irregularity level.

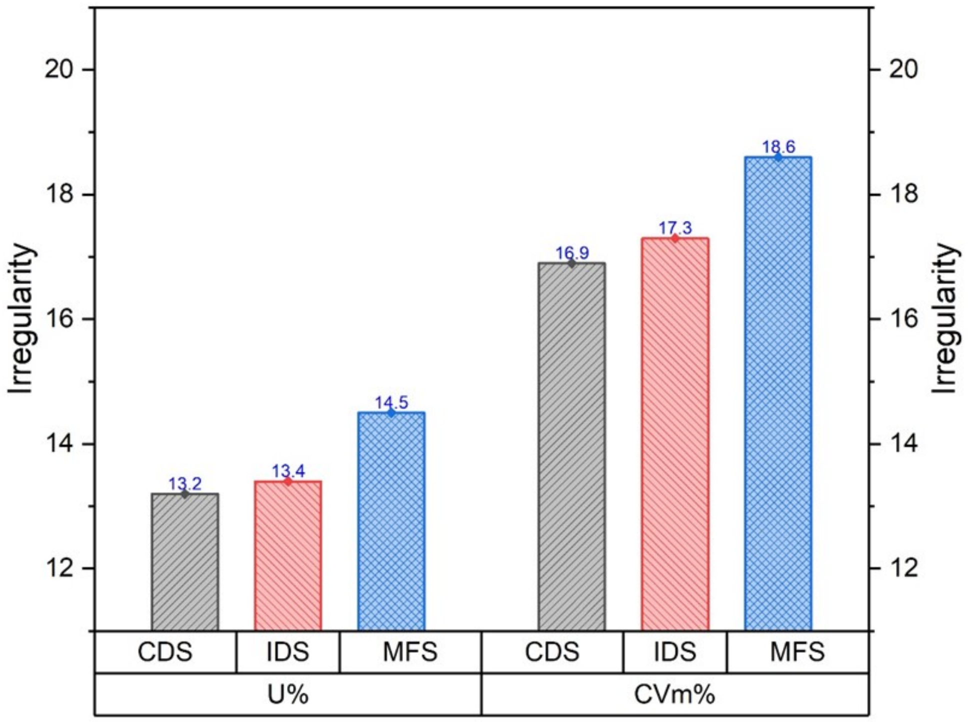


Figure 2. Comparisons of yarn unevenness and co-efficient of variation of yarn mass

According to the LSD test results, shown in Table 6, CVm% of the MFS yarn is significantly different from the CDS and IDS yarn samples. The highest irregularity in the MFS may be due to the vacuum generation system used here. It is found that the effect of different vacuum systems on compact yarn irregularity at a 5% confidence level is significant. As reported by the manufacturers of MFS, the negative pressure is created section-wise it may vary between 25-33 mbar from section to section due to the use of multiple fans. As a result, mass per unit length of yarn will vary, resulting in higher irregularity of yarn in the MFS. On the other hand, as the negative pressure is created centrally by using one or two fans in the CFS, it will remain almost constant (27-28 mbar), and compacting will be similar to that in its neighbour spinning positions throughout the machine. As a result, mass per unit length of yarn will be more uniform in the CFS, and, for this consequence, there are less yarn irregularities, like U% & CVm%, in the CFS than in the MFS.

Comparisons of Imperfection Index (IPI)

The imperfection index (IPI) represents the sum of the yarn's thin places, thick places, and neps per kilometre at the sensitivity level +50%, -50%, and +200%, respectively. Lower values of IPI indicate a better quality yarn.

The IPI results are shown in Figure 3. The test results show that the MFS has the highest IPI among all others. It is found that at a 5% confidence level, the effect of different vacuum systems on compact yarn imperfection is significant.

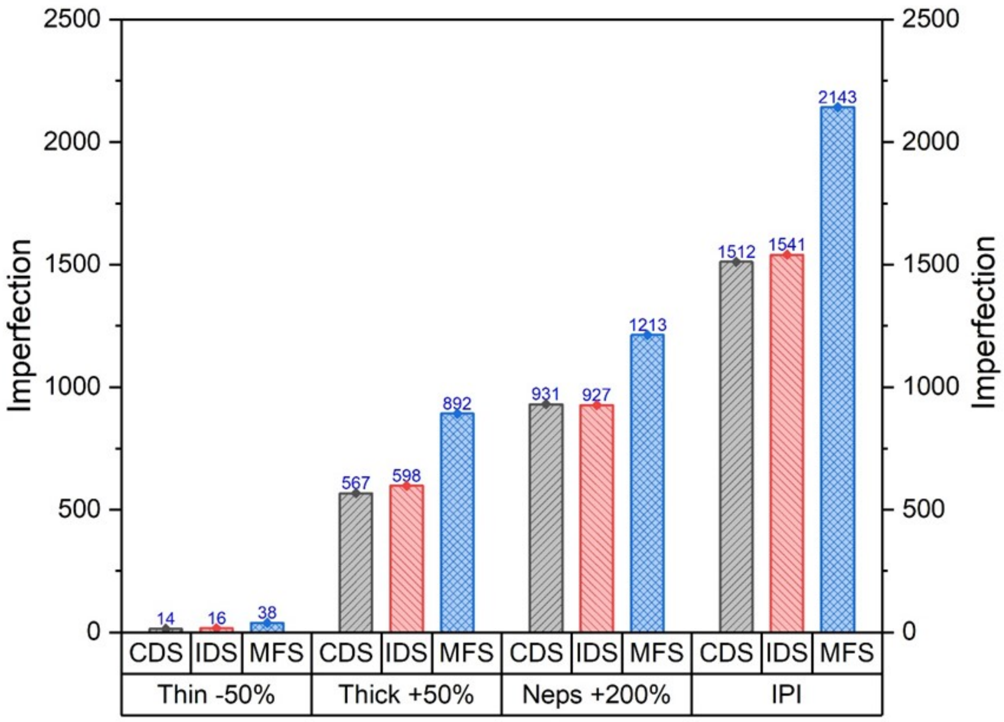


Figure 3. Comparisons of yarn unevenness and co-efficient of variation of yarn mass

According to the LSD test results, shown in Table 6, the IPI of MFS yarn is significantly different from the CDS and IDS yarn samples. All the corresponding values of IPI, such as thickness, thinness, and neps of the compact yarn produced by the MFS are found to be higher. As the negative pressure is created section-wise in the MFS, the pressure of every section will not be uniform. The negative pressure may vary from 25 to 33 mbar from section to section. As a result, where the negative pressure is higher, there will be more compacting, and where the negative pressure is lower, there will be less compacting. Due to such varied vacuum generation in the MFS, the compact yarn results in having more thick and thin places and more IPI overall than the CFS.

Comparisons of yarn hairiness

Hairiness is calculated by the total length of the protruding fibres in unit length of one centimetre [15]. A value of below 6 indicates a better quality of yarn in the case of the 100%-cotton process [16]. Figure 4 shows the hairiness (H) and the standard deviation of hairiness (sh) value of compact yarns.

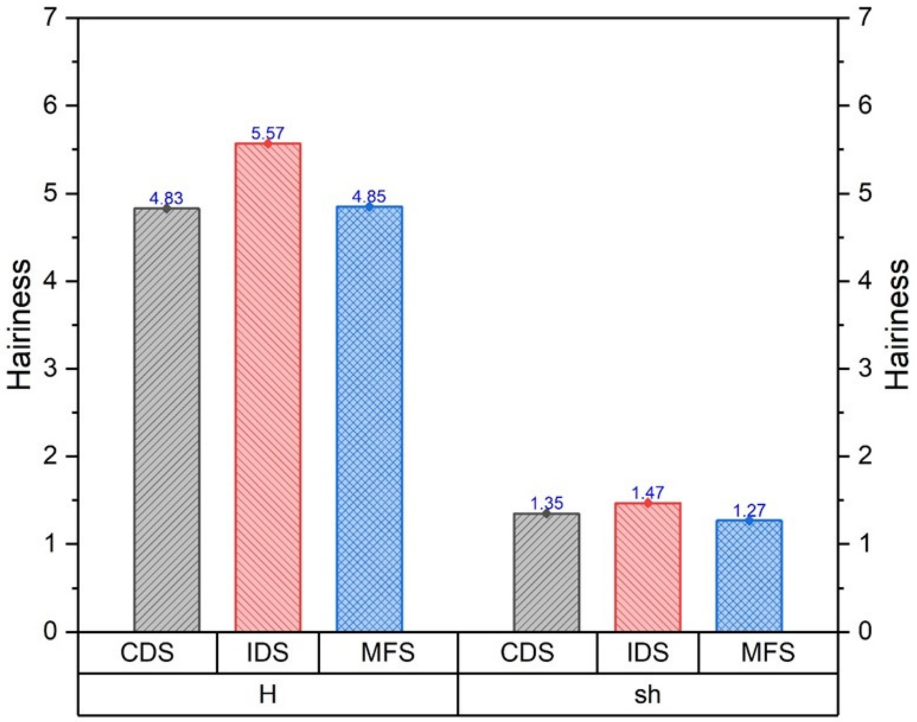


Figure 4. Comparisons of yarn H and sh value

The test results depict that CDS provides the least, whereas IDS provides the highest yarn hairiness. It is found that the effect of different vacuum systems on compact yarn hairiness at a 5% confidence level is significant. According to the LSD test results, shown in Table 6, the hairiness of the CDS yarn is significantly different from the IDS one. This is attributed to the use of a perforated drum instead of a perforated apron in the CDS for condensing the fibre strand. This statement is supported by a previous study [2].

Comparisons of bundle strength (CSP) of yarn

Count Strength Products (CSP) is the product of English count and the strength of yarn in pound is the expression of bundle strength of the yarn. The strength of yarn gives us an idea about how much load we can apply to it and indicates how good or bad the yarn quality is. Yarns need to withstand applied load at subsequent textile processing stages. In the case of hosiery, it is considered that yarns having a CSP of less than 1800 are bad or weak; 1800-2200 is considered average and greater than 2200 is considered strong [16].

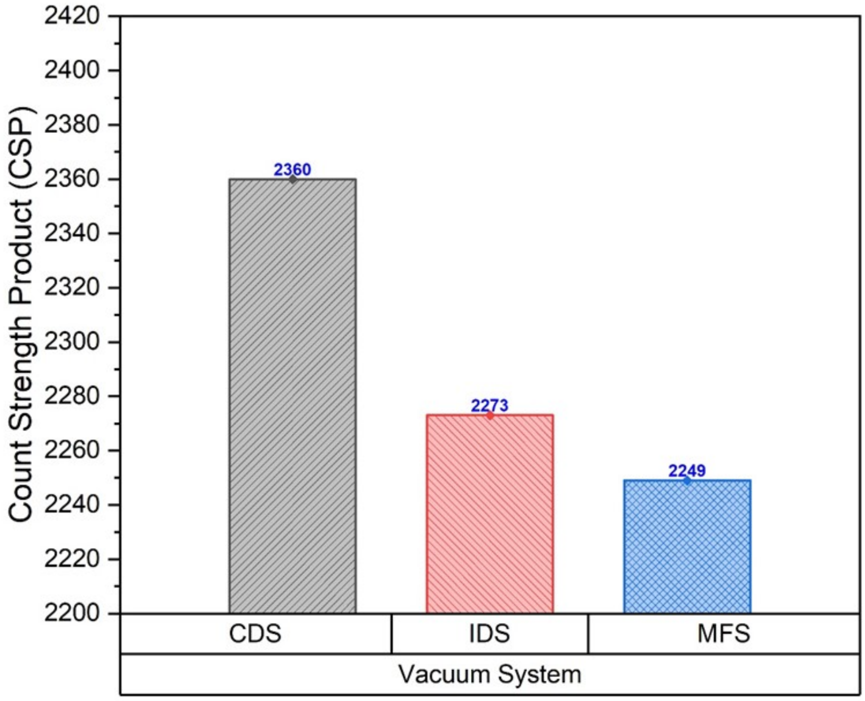


Figure 5. Comparisons of yarn bundle strength

As shown in Figure 5, the CSP of yarns in the CDS, IDS, and MFS fulfil the required value for the hosiery process. Compact yarns produced by the CFS (both CDS and IDS) show more than the value of CSP needed for the hosiery process. From ANOVA analysis, as shown in Table 5, it is found that at a 5% confidence level, the use of different vacuum systems on the CSP value of the yarn is not significant, and they are not statistically different from one another. As the CSP is higher than the required value in CFS systems, the spinners can reduce the TM of yarn for this system during manufacturing, which will ultimately increase the speed of the ring frame as well as the production rate. In the case of MFS, more irregularities and imperfections in the yarn are due to variable negative pressure in different sections of the ring frame (previously described), which indicates it has more weak places in the form of U%, CVm%, thick, thin & neps. As the yarn has more weak places in MFS yarns, they cannot withstand many loads like CFS; thus, the CSP value was found to be somewhat lower than in the CFS (both CDS and IDS).

CONCLUSION

In this study, 100%-cotton yarn properties were compared by using commonly used different vacuum generation systems in aerodynamic compact spinning. To preserve impartiality, all the systems were categorized as a CFS (CDS and IDS) and MFS instead of using their brand names.

It is found that the CFS showed noticeably lower yarn irregularity (U% and CVm%), imperfection index (IPI), and remarkable higher bundle yarn strength (CSP) compared to the MFS. This is attributed to the uniform suction pressure, as it is done centrally and, therefore, the negative pressure remains constant throughout the spinning positions.

Though the yarn hairiness in the MFS is better than in the IDS, the overall quality parameters are not as good as those of the IDS or CDS. This is attributed to the varied suction pressure as it is done section-wise and, therefore, the yarn quality differs due to the varying negative pressure within the neighbouring sections.

Based on the overall outcome of this study, it is concluded that the vacuum generation system has a great impact on the quality parameters of the compact yarn and the CFS shows overall better results than the MFS.

Author Contributions

Conceptualization – Conceptualization – Sayed MA, Uddin MB; methodology – Sayed MA, Uddin MB; formal analysis – Sayed MA, Uddin MB; investigation – Sayed MA; writing-original draft preparation – Sayed MA, Uddin MB; writing-review and editing – Sayed MA, Uddin MB, Begum HA; supervision – Uddin MB, Begum HA. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Funding

This research received no external funding.

Declaration of interest

The authors report there are no competing interests to declare.

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