Chapter 13

Vortex Spinning System and Vortex Yarn Structure

Gizem Karakan Günaydin and Ali Serkan Soydan

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/105882

Abstract

Studying the yarn formation with the swirling air concept arouse of interest of the researchers for a long time because it appears to be easy to understand as a spinning principle. These kinds of systems are known as the vortex yarn spinning systems. The air-jet spinning methods have been developed since it is possible to eliminate the movable elements as the spindle and the traveler in ring spinning or the centrifuge in rotor spinning. The success of Murata vortex spinning (MVS) system which is the newest system after all studies of air-jet systems has been much acceptable especially for the spinning ability of 100% cotton in high speeds (500 m/min) and the yarn structure resembling ring yarn structure rather than rotor yarns. This study summarizes the historical background of vortex spinning, the spinning principle and the structure of the yarn spun on this system, as well as the factors influencing the yarn quality and finally the developments in vortex spinning technology.

Keywords: vortex spinning system, vortex yarn, air-jet spinning

1. Introduction

There are many different spinning systems in textile technology. Some of them are in commercial use, many are still experimental and some of them have been withdrawn from the market. Certainly, the conventional ring spinning technique is currently the most widely used, accounting for an estimated 90% of the world market spinning machines [1]. Because of ring spinning, providing all fibers to be spun into a wide range of yarn count with the lowest rate of yarn faults with the best quality, this spinning technology is still the most widely used one in the market.

Compact spinning is one of the modifications of ring spinning process by the help of better integration of fibers into the yarn structure. The fiber bundle is condensed by air suction, and hence, this results better tensile properties for the same twist level, lower hairiness and better yarn evenness. Open-End rotor spinning is another most commonly accepted unconventional short-staple yarn spinning technology. It is a process in which the input material to the spinning system is highly drafted, ideally to the individual fiber state. The individual fibers are subsequently collected onto the tail end of a seed yarn that is rotated to twist the fibers into the yarn structure and thereby form a new length of yarn. The spinning is continuous as the input material is continuously collected onto the open end of a previously spun yarn [1].

In the early 1980s, air-jet spinning system was launched. Initially only the man-made fibers could be used as the raw material; later, it was improved for cotton yarn spinning as well. Although the developments aimed to produce 100% cotton yarns, the acceptable quality was provided with polyester/cotton blended yarns in terms of yarn strength. Today the latest development in air-jet spinning technology is the Murata vortex spinning (MVS) technology, which was firstly introduced at Osaka International Textile Machinery Show in 1997 (OTEMAS '97) by Murata Machinery Ltd [2].

2. Air-jet spinning systems

Airflows have been increasingly used in transporting, drawing, separating and deforming solid structures for the advantages with respect to high efficiency and economic benefits. Particularly in the polymer and textile processing industry, airflows have also been playing important roles in various processing methods such as melt-blowing, air-jet weft insertion, air-jet spinning and vortex spinning.

Many methods may be encountered with during the development of air-jet spinning process. But Goetzfried method is the first method where the air-jet flow is used as a twisting device. It is based on the Open-End spinning principle. The airflow is a main parameter for the control of spinning and twisting [1–3].

As a way of fascinated yarn production, there were many attempts for the air-jet spinning innovations such as "Dupont" in 1956, "Rotofil" in 1971, "Toyada" in 1983, "Toray" in 1985, etc. But these methods had little commercial success. A renaissance in the historical development of air-jet spinning started with the MJS machine of the Japanese company Murata Machinery Ltd (Murata Jet Spinner). The company introduced its first air-jet spinning machine, Murata Jet Spinner, MJS 801, at the American Textile Machinery Exhibition in 1982 (ATME '82). The machine contains a three-roll drafting system and is equipped with two air-jet nozzles that create air vortices rotating in opposite directions. In this system, the second nozzle creates false twist on the fiber bundle coming out of front roller. There is an air vortex between the front roller and the first nozzle which removes the twist and causes the edge fibers to be separated from the fiber bundle. So the edge fibers move to second nozzle in an untwisted form. However, the core fibers are directed to second nozzle in a twisted form. At the time of the second nozzle leaving, the core fibers are unwrapped and the edge fibers are twisted in the opposite direction. The system is stated to be suitable for processing man-made fibers and their

http://dx.doi.org/10.5772/105882

blends with cotton; however, it was not capable of spinning 100% cotton or rich blends of cotton yarn [3]. **Figure 1** displays the MJS yarn formation and the yarn structure in a detailed form.

2.1. Murata vortex spinning system

The latest concept in air-jet spinning developed by Murata Machinery Ltd. is known as the vortex spinning system which uses a modified single air nozzle. This system is claimed to be capable of producing 100% carded cotton yarns which have a ring spun-like appearance and higher tenacity due to higher number of wrapping fibers when compared with the previous air-jet spinning systems [3].

Murata has developed MVS 810, MVS 81T, MVS 851, MVS 861 and lastly the MVS 870 model spinning machines. Murata MVS 810 was the first vortex spinning machine exhibited at Osaka International Textile Machinery Show in 1997 (OTEMAS '97). The machine had a delivery speed of up to 400 m/min. The modified version of this machine, MVS 81T, was developed to produce twin vortex spun yarns. The yarns spun on two spinning units pass through the same yarn cleaning and waxing unit and are wound on the same package. These are twisted on a two-for-one twister to obtain a plied vortex yarn. Subsequently, Murata introduced the MVS 851 spinning machine. Apart from the previous machine, MVS 851 is not capable of spinning core yarns. Murata exhibited a new version of vortex spinning machine, the MVS 861, in 2003. This version allows the core yarns production with higher delivery speed of up to 450 m/min. The spinning system ensures uniform winding tension with a tension ruler with minimum energy consumption [3, 4]. **Figure 2** displays the general view of the MVS 861 machine and the yarn spinning unit.

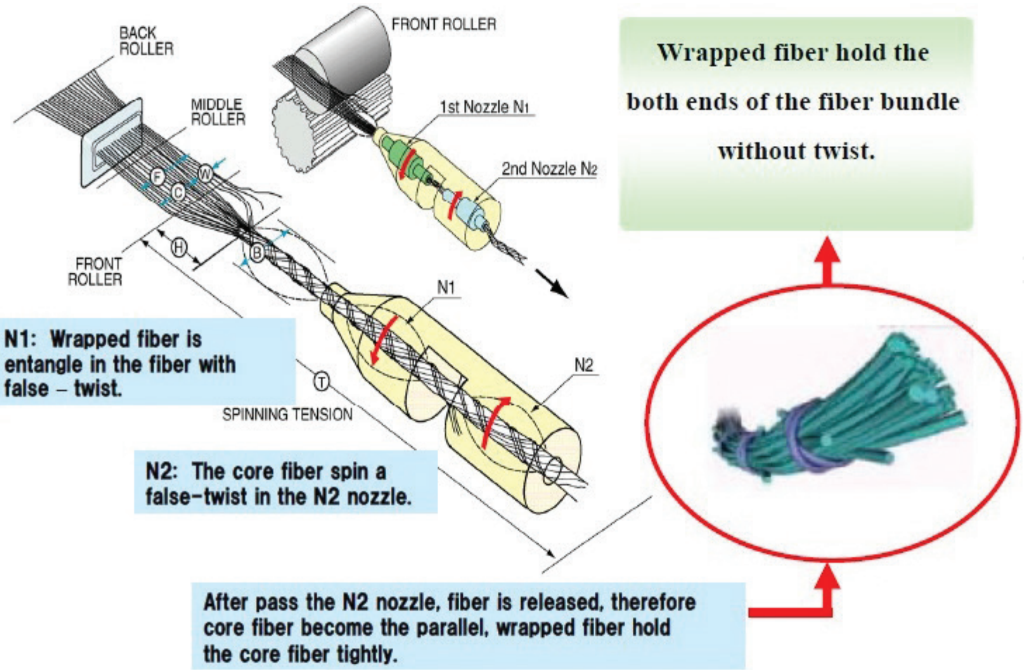

Figure 1. MJS yarn formation and the yarn structure [4].

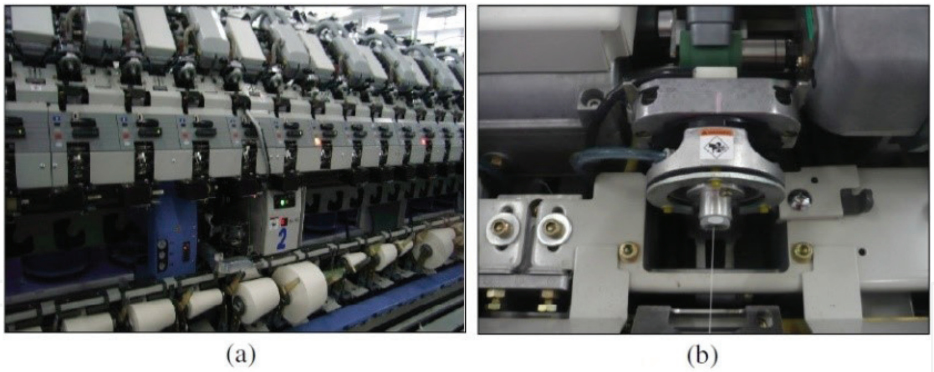

Figure 2. MVS 861 spinning machine: (a) the general view of the machine, (b) the yarn spinning unit.

2.1.1. Principle of yarn formation in vortex spinning system

Murata vortex spinning (MVS) is based on the already existing air-jet spinning technology by Murata but essentially differs in principle from the MJS method because of the geometry of the air-jet twisting device used (US Patent 5,528, 895, 25 June 1996). This air-jet device includes a nozzle block with injectors for the generation of swirl flow, a needle holder, a hollow spindle and a guide member. **Figure 3** displays a detail view about the schematic diagram of the nozzle block of vortex spinning machine.

In MVS, a drawn sliver is fed to a four-line drafting system. After coming out of the front rollers, the fibers move to the air-jet nozzle. Although the fibers are oriented to be twisted with the pressured air effect, the twisting motion tends to flow upward toward the front rollers of the drafting unit; here, the guide member protruding from the fiber bundle passage prevents this upward during the yarn formation. The high-speed whirled air current arises in the vortex chamber into where the pressured air is injected. The preceding parts which will be core fibers later are drawn into the vortex spun yarn trail. However, the upper portions of some fibers separated from the nip point of the front rollers are kept open. After the departure of

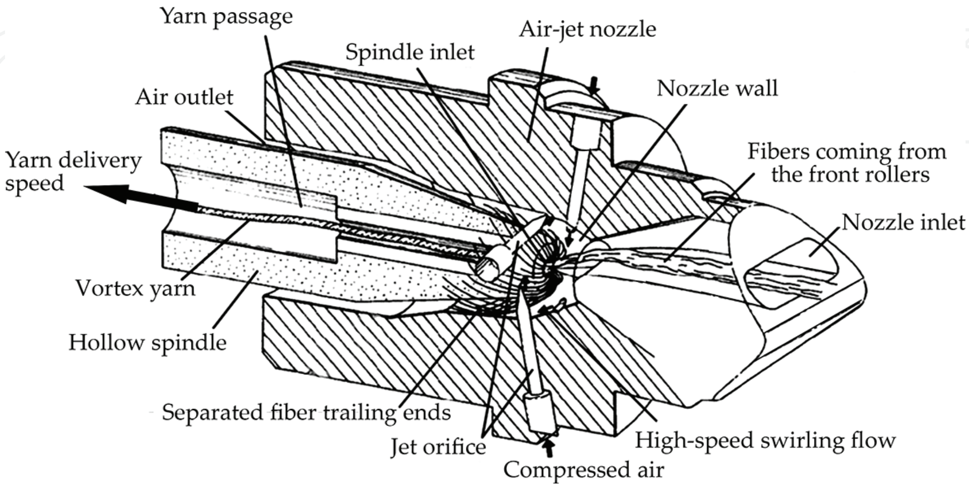

Figure 3. Schematic diagram of the nozzle block of vortex spinning machine [1].

trailing ends from the nip point, they pass through the spiral fiber passage, and they twine over the hollow stationary spindle due to the whirling force of air-jet stream and become the wrapping fibers [5]. **Figure 4** displays the yarn formation in Murata vortex spinning system.

2.1.2. Structure of vortex yarn

Vortex yarn has different yarn structure comparing the conventional yarn structures. Vortex spun yarn consists in two-segmented structure which includes core and wrapper fibers which covers the core part of the fiber grouping the yarn body. Since fiber separation occurs everywhere in the outer periphery of the fiber bundle, a higher number of wrapper fibers are obtained with jet-spun yarns. This leads to the production of a spun yarn with more of a ring-spun-type appearance and also with higher tenacity [2].

Basal (2003) studied yarn structure by using tracer fiber technique combined with the Image Analysis Application [5, 6]. The researcher captured the images of the tracer fibers which were transferred to a computer later. After evaluating the images, the researcher concluded that there were some variations along the vortex yarn length. The tracer fibers were grouped according to their configuration. It is emphasized that the percentage of straight, hooked (trailing) and hooked (both ends) is very close to each other and higher than the leading

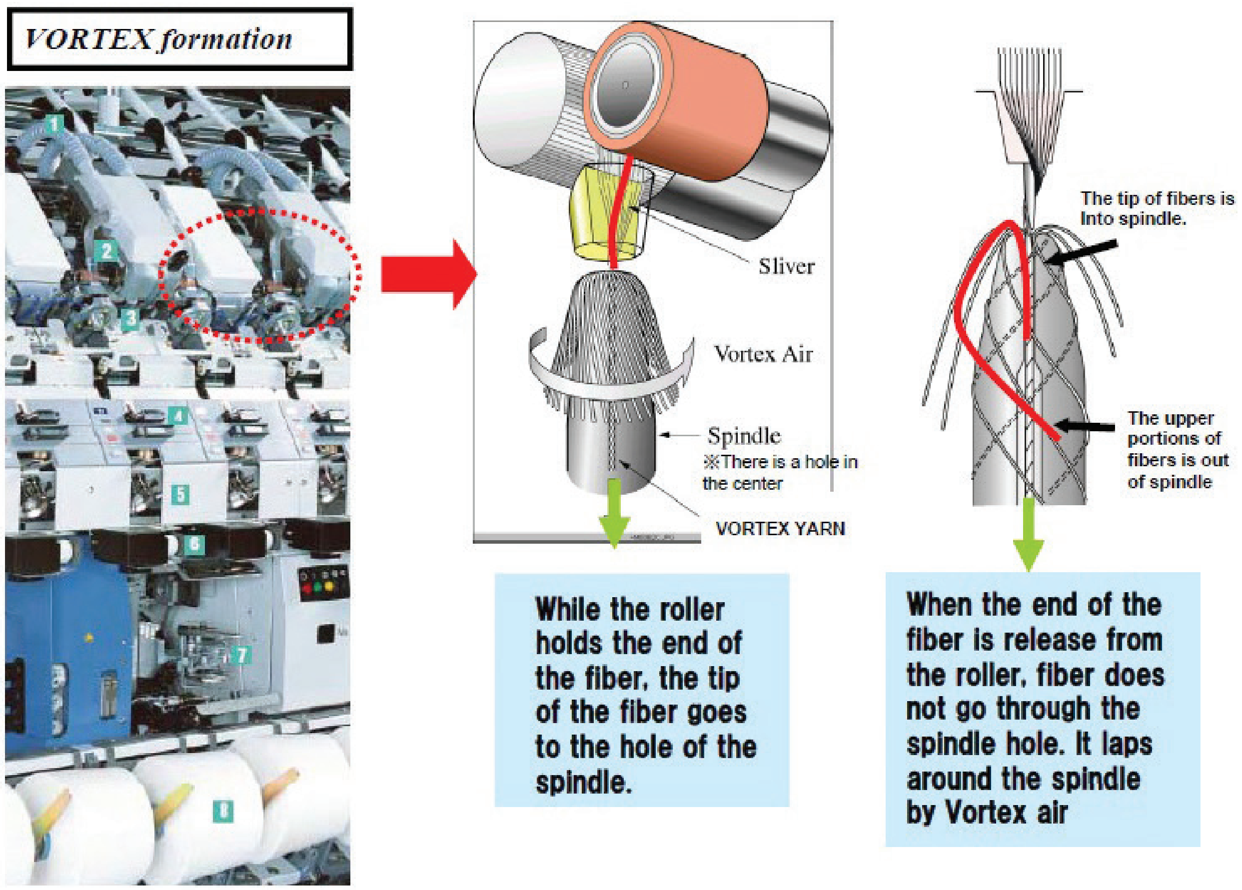

Figure 4. Yarn formation in Murata vortex spinning system [4].

hooked, entangled and looped fibers in vortex spun yarns (**Table 1**). It is concluded that the images revealed most of the tracer fibers tend to show first core fiber characteristics then wrapper fiber characteristic twining over the yarn core as described in the ideal case [5].

Soe also studied the structure of MVS Yarns and made a comparison with ring and Open-End yarns. By the help of the A Nikon SMZ 1500 microscope with a DXM 1200 digital camera, they investigated the side visual assessment of the yarn structures [7]. The fiber arrangements of the RS, OERS and MVS yarns, including the MVS yarn with the tracer fibers were observed carefully. They adopted the classification by Chasmawala et al. [8] and modified it for ring, Open-End and vortex yarns. Description of each classification depending fiber arrangement is explained below [7]:

1. **Core fibers:** These fibers may be straight or inclined. Core fibers constitute a major proportion of the yarn. Core fibers' orientation has a big impact on the stress-strain behavior of the yarn.

2. **Wild fibers:** These fiber groups randomly protrude from the main yarn body in any direction. Loops may also be observed along the yarn axis and these groups are also classified as wild fiber groups. The wild fibers increment leads to a more hairy yarn.

3. **Wrapper fibers:** The helix angle of wrapper fibers around the core fibers are considered similar. There might be some degree of inclination with respect to the yarn central axis.

4. **Wrapper-wild fibers:** These fibers wrap around the core fibers in a different direction from the regular wrapping fibers. The wrapper-wild fibers have a scattered appearance. There is no common angle for wrapper-wild fibers because of their disordered appearance.

5. **Belly-band fibers**: These fiber groups are the main body wrapping fibers composed of either core or wrapper fibers. Belly band fibers are observed in the upright position with respect to the yarn central axis.

Figure 5 also displays the schematic diagram of yarn fiber types in the yarn structure.

According to the microscopic examinations, Soe et al. concluded that the highest proportion of core fibers were observed in ring spun yarn while MVS (Murata vortex spinning) yarn had the minimum ratio of oriented core fibers. The core fibers were helically embedded into the yarn. No

Tracer fiber configuration	Class	Percentage of fibers
	Straight	21.00
	Hooked (trailing)	20.50
	Hooked (leading)	6.4
	Hooked (both ends)	23.00
	Looped	11.50
	Entangled	10.25

Table 1. Tracer fiber configuration in MVS yarns [5].

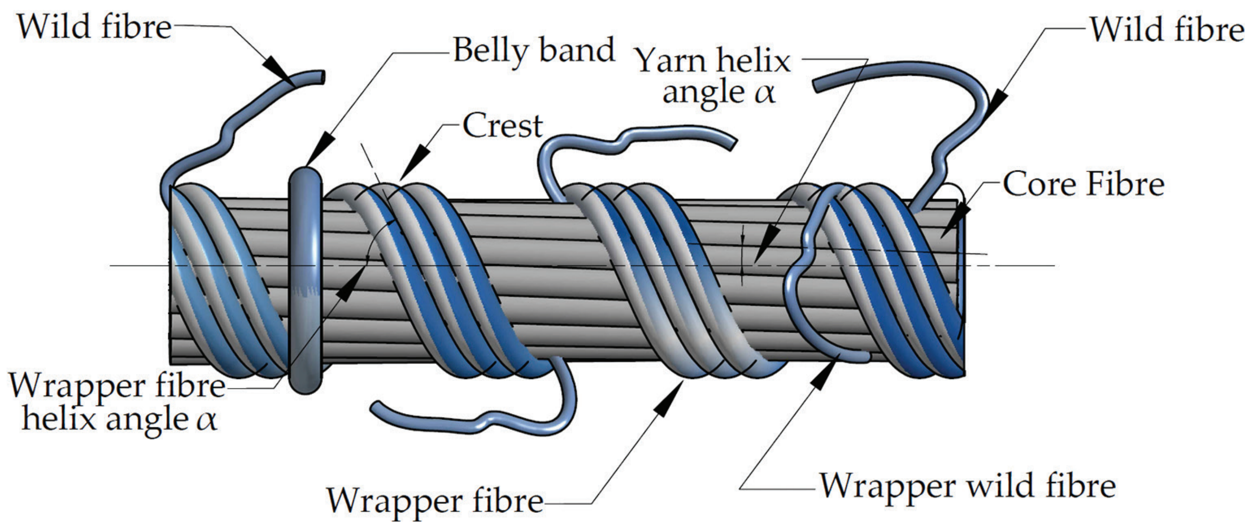

Figure 5. Schematic diagram of yarn fiber types in the yarn structure [7].

wrapper fibers were observed in the ring spun yarn structure. Belly-band fibers were mostly seen in Open-End rotor spun yarns followed by ring spun yarn. The highest wrapper fiber ratio of the three yarn types was obtained from MVS yarns. It can be emphasized that there was no twist in the core fibers of the vortex yarns which was a significant feature. The highest ratio of wild fibers in MVS yarns was observed in the wrapping fibers instead of the core fibers. This result is attributed to encirclement of the core fibers by the wrapper fibers. All forementioned fiber groups were observed in vortex spun yarn; however, belly-band fibers were hardly seen. Ideal yarn structures of ring spun, Open-End rotor and MVS yarn were illustrated in **Figure 6** [22].

There are also some studies related to comparison of air-jet spun yarns and vortex yarns. Since vortex yarn is the modified version of air-jet yarns, there are some features of vortex yarn expected to be much better. MVS spinning system uses only one air jet instead of two as in the air-jet spinning system. This directly affects the number of wrapping fibers between the vortex spinning system and air-jet spinning system. The fiber separation occurs everywhere in the outer periphery of the fiber bundle. Hence, the increasing number of wrapping fiber results with more ring-like appearance and higher tenacity [3]. **Figure 7** displays the yarn formation in MVS and MJS yarn spinning system.

Basal and Oxenham [9] produced vortex and air-jet yarns with different polyester/cotton blends as a raw material and compared the physical properties of vortex and air-jet yarns. They used variance analysis for determining the differences between the properties of the vortex yarn and the air-jet spun yarn. The results revealed that MVS yarns had fewer thick places, lower hairiness and better evenness values compared to MJS yarns. The higher tenacity values were obtained from the MVS vortex yarns for every blend ratio. But in 100% polyester yarn production, the MVS and the MJS yarn groups had the same strength. This was attributed to the higher proportion of wrap fibers because of the fiber separation from the bundle occurring everywhere in the entire outer periphery of the bundle. They also emphasized that higher proportion of wrap fibers leads to MVS yarns lower elongations because of the wrapping fibers restricting the yarn movement [9]. **Figure 8** displays the vortex and air-jet spun yarn together.

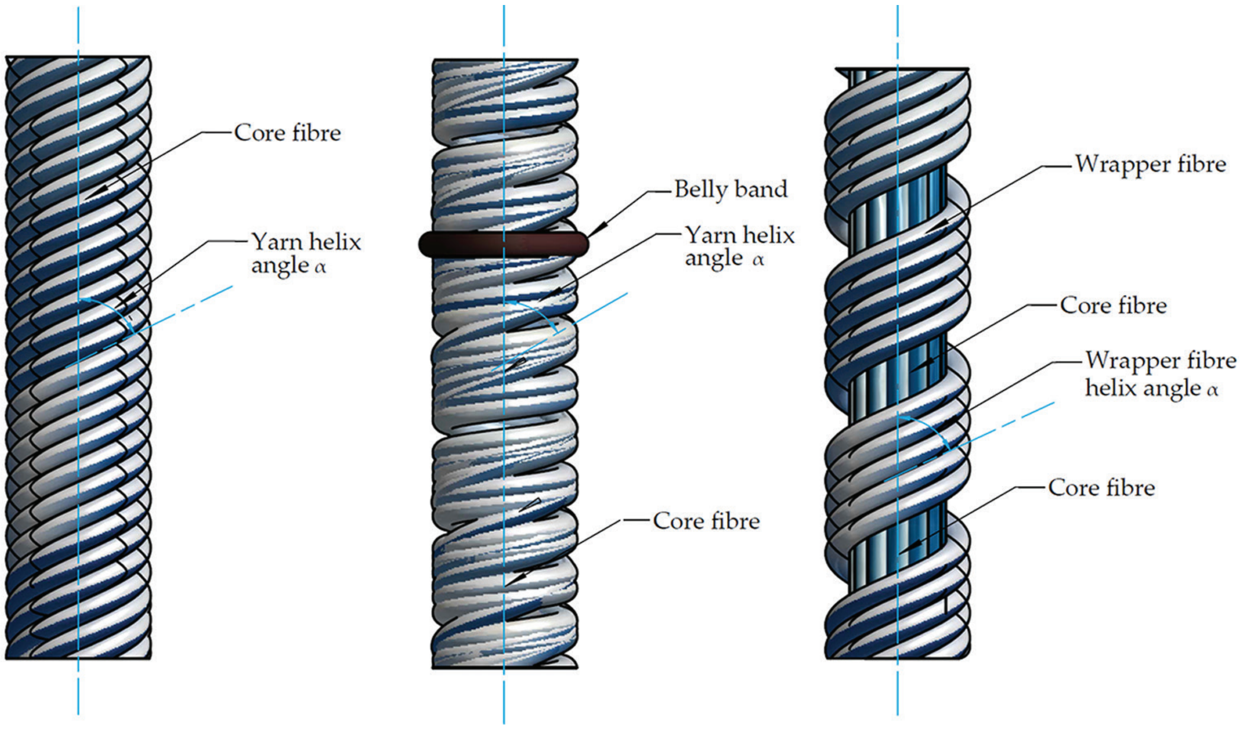

Figure 6. Ideal yarn structures of ring spun, Open-End and MVS yarn, respectively [7].

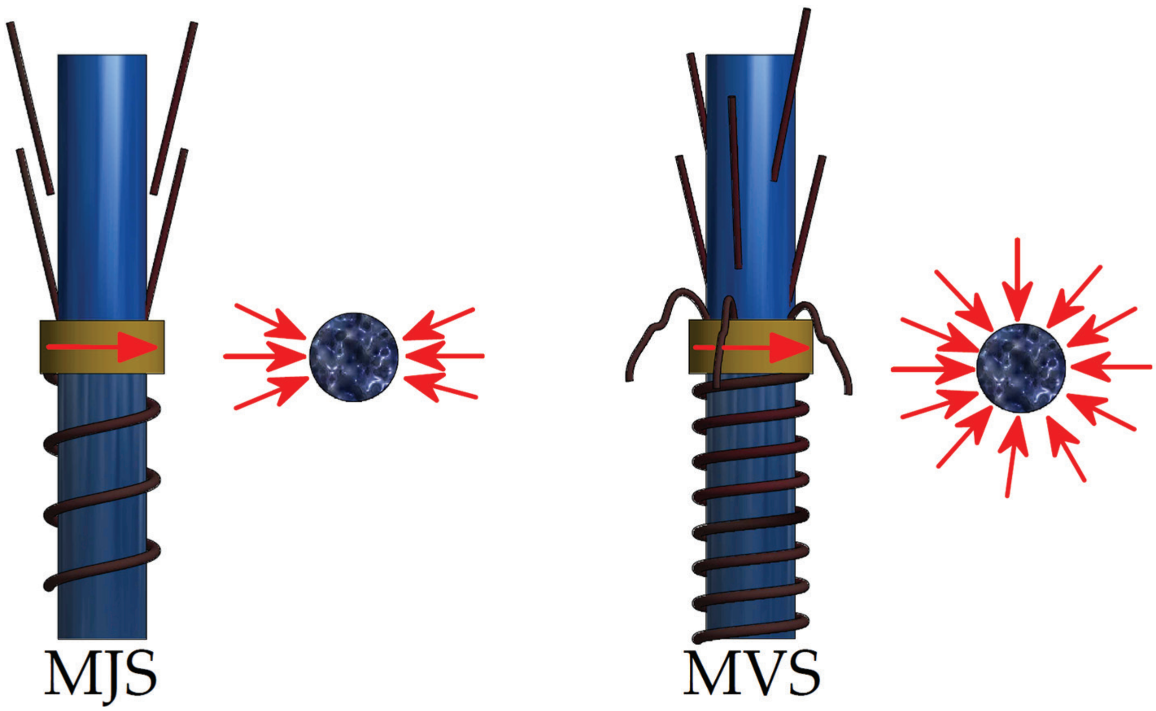

Figure 7. Comparison of yarn formation in MVS and MJS yarn spinning system [9].

http://dx.doi.org/10.5772/105882

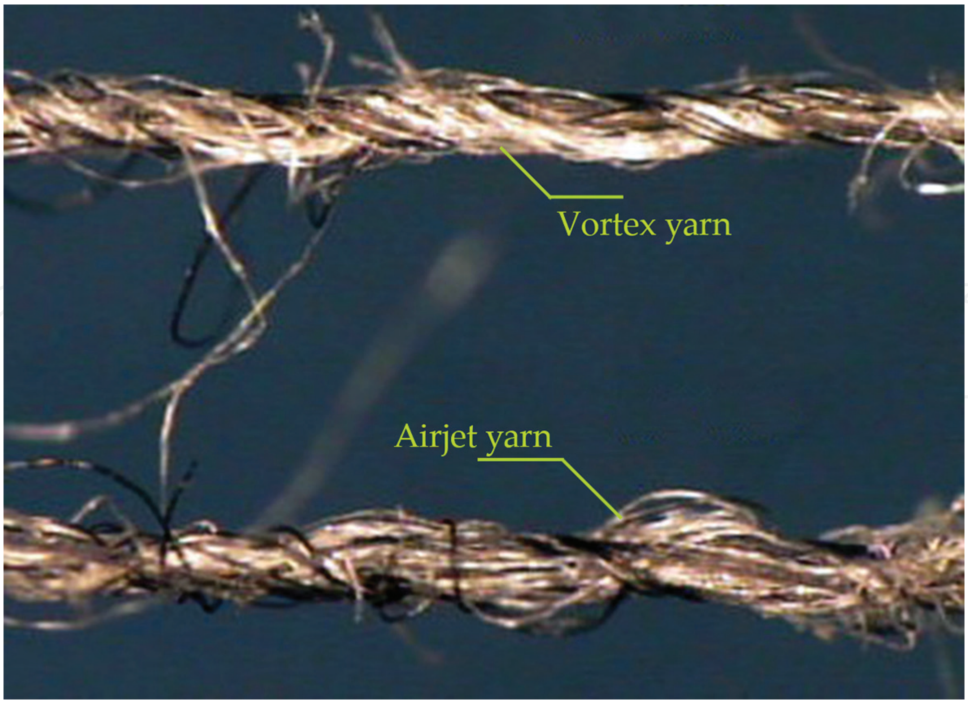

Figure 8. Vortex spun yarn versus air-jet spun yarn (28's Ne, 30/60 PES/Co) [9].

2.1.3. Effects of some parameters on structure and properties of vortex spun yarns

Previous studies proved that the structure and performance of vortex spun yarns were influenced by the effects of nozzle angle, nozzle pressure, spindle diameter, yarn delivery speed, yarn linear density, fiber composition and the distance between the front roller and the spindle [10, 11].

2.1.3.1. Nozzle pressure

There are many studies concerning the effect of nozzle pressure to the vortex spun yarn. These studies reveal that the nozzle air pressure directly influences the fiber configuration and the yarn structure. Basal and Oxenham investigated some process parameters including the nozzle pressure. It was observed that increasing the nozzle pressure led to the increment of the axial and tangential velocity The fiber bundling receiving higher twist with the pressured air caused the yarn becoming much stronger but stiffer [10]. Tyagi et al. reported that the changes in nozzle pressure influenced the tightness of wrapping fibers along the yarn strand as well as the amount of wrapping and the proportion of unwrapped sections. In their study, they observed that the increment of the nozzle pressure resulted in high level of tight wrapping ratio. However, they were inclined to turn into irregular wrappings at very high level of nozzle air pressure [12]. In the other study of Tyagi et al., they stated that lower hairiness was provided with the high nozzle air pressure up to a certain limit. But when the nozzle pressure reached the level of 6 kgf/cm^2, hairiness got worse due to the formation of the wild fibers. This was attributed to the rate of change in radial position of a fiber (mean migration intensity) becoming higher at the high nozzle pressure values [13].

Another study was conducted by Zou et al. which is related to theoretical analysis of vortex yarn formation. They revealed that the high nozzle pressure values caused an increase in the mean angular velocity of the free (open) end of the fiber. This provided the wrapping fibers whirling around the yarn core with the greater force. Hence, the proportion of tight wrappings increased. They added that when the nozzle pressure was too high, the separated fibers were easily taken out of the fiber bundle by the high-speed airflow which caused more fiber loss [14].

2.1.3.2. Yarn delivery speed

In vortex spinning system, yarn delivery speed may be up to 500 m/min in the latest version of MVS 870. The yarn delivery speed is important for the time of the fibers being exposed to the whirling force. It should be noted that at high delivery speeds, the fiber loss and the yarn quality problems may probably appear.

Basal and Oxenham investigated some process parameters, and they concluded that yarn delivery speed affects the yarn diameter since lower delivery speeds lead to regular tight wrapping fiber ratio increment [10]. Ortlek and Ulku investigated some process parameters in their study, and they observed that increasing the delivery speed causes more hairiness and leads to deterioration for the tensile properties of vortex yarns. They explained this with the result of less time for the wrapper fibers wrapping the parallel core fibers properly. Especially for the finer yarns, this may be an important problem which means vortex spinning is more appropriate for the coarser yarns [11]. Kuppers et al. investigated the spinning limits for the vortex spinning. They determined the ratio between the fiber guidance element and the yarn delivery speed depending on the yarn count. It is suggested that finer yarns require high ratio. At constant air speed, the delivery speed should be reduced [15].

2.1.3.3. Effect of draft ratio

Erdumlu and Ozipek investigated the effects of draft ratios on the properties of vortex spun in their study. Hundred percent viscose drawing slivers of three different counts (3.94, 3.19 and 2.68 ktex) were spun into yarns with a count of 14.76 tex while keeping all other spinning conditions constant. The yarn samples were evaluated on the basis of yarn irregularity and imperfections, as well as hairiness and tensile properties. In addition, a 3rd passage draw frame sliver with a yarn count of 3.19 ktex was spun into yarns of 14.76 tex using two different delivery speeds: 350 and 400 m/min. They concluded that while working with high levels of the total draft using a heavy sliver, the better yarn evenness and thin place values are obtained as the intermediate draft gets lower. Higher breaking elongation and work to break values were observed at the intermediate level of 2.5 with the highest total draft of 267. The results revealed that a high delivery speed deteriorated the physical properties of the yarns in terms of yarn evenness, thin places and tenacity. The lower the delivery speed, the better the yarn properties. Additionally, as the yarn delivery speed increased, hairiness also increased for both levels of intermediate draft [16].

http://dx.doi.org/10.5772/105882

2.1.3.4. The distance (L) between front roller nip point and the spindle

In many studies, the effect of distance between front roller nip point and the spindle was significantly important for the fiber loss and the number of wrapping fibers; Basal and Oxenham concluded that the short front roller to the spindle distance produced more even yarns with fewer imperfections and less hairiness. They also added that if the distance was short, the most of the fiber ends were tightly assembled, and there were fewer open-ended fibers. Hence, a yarn similar to MJS yarn with parallel core fibers mostly but fewer open-ended fibers was observed. In that case, yarn evenness and the imperfection results were more pleasing because of the minimum risk of losing control of fibers. Added to that in short distance between the front roller nip point and the spindle ensures less hairiness and leaner appearance [10]. Yarn formation zone in vortex spinning is shown in **Figure 9**. In that figure, L denotes the distance between front roller and the spindle.

Zou et al. [17] investigated the twisted strength acting on the vortex spun yarn by the whirled airflow by an analytical model based on simulating the flow field inside the nozzle block. The results showed that the twisted strength acting on the yarn by the vortex is also affected by the distance from the inlet of the nozzle block to the inlet of the hollow spindle. The strength twisted by the whirled airflow was weaker when the distance from the inlet of the nozzle block to the inlet of the hollow spindle was bigger. When the distance "L" increased, the number of the open-trail end fibers also increased which caused a decrease in the tangential velocity inside the nozzle block [17].

Zou et al. [18] studied the fiber spatial configuration in another research. The spatial configuration and the influenced factors were analyzed. They declared that the fiber spatial

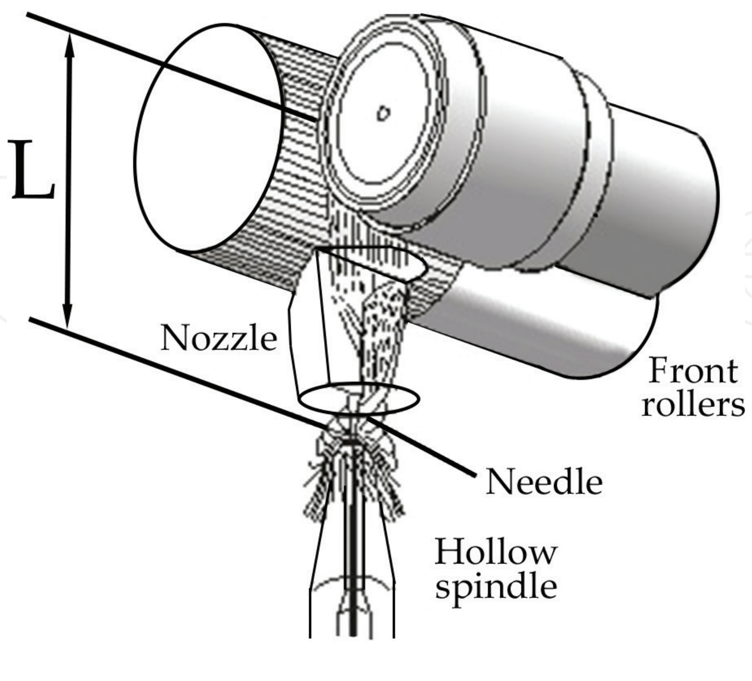

Figure 9. Yarn formation zone in vortex spinning [10].

configuration in vortex spun yarn was affected by the distance between the front roller nip point and the hollow spindle. As the distance between the front roller nip point and the inlet of the hollow spindle increased, it was observed that the open trailing ends' critical angular velocity decreased which mean the length decreasement of fiber embodies into the vortex. This was explained as a risk for the leading end of the fibers to be more easily pulled out from the vortex spun yarn and for the fiber loss and more thin places in the yarn [18].

Tyagi and Sharma studied the influence of processing variables delivery speed, nozzle distance, yarn linear density and yarn composition on the structural parameters of polyester/cotton yarns spun on Murata Vortex Spinner (MVS). It is observed that MVS yarns have about 50–60% core fibers and remaining as wrapper or wild fibers. The structure of MVS yarns has been classified into four main categories: tight wrappings, long wrappings, irregular wrappings and unwrapped. They concluded that increase in nozzle distance causes an increase in long regular wrappings and number of wrapper fibers due to increase in the amount of fibers with Open-End configuration, while decrease in tight regular wrappings. And the resultant yarn was more hairy with longer hairs [12]. The tensile characteristics increased as the nozzle distance increased. But a reduction in yarn tenacity was observed at very high nozzle distances [13].

Murata Machinery Ltd. also suggests that the short front roller to the spindle is favorable for less fiber waste. The even yarns with fewer imperfections and lower hairiness are obtained. But it is also added that when the distance is too short, both ends of fibers are tightly held, and there occurs fewer fibers with open trailing ends. So the yarn is mostly composed of the parallel fibers as in the air-jet yarns [4].

2.1.3.5. Nozzle angle

There are also some investigations verifying the nozzle angle's effect on the swirling air during vortex yarn formation. Zou et al. [14] made a study concerning numerical computation of a flow field affected by the process parameters of Murata vortex spinning. They observed that the tangential, axial and radial velocities inside the nozzle block are significantly affected by the jet orifice angle and velocity at the exit of the jet orifice as well as by the diameter at the inlet of the nozzle block. They explain the effect of the jet orifice angle "θ" on the flow field inside the nozzle block is quite complex, and different "θ" values result in variations in the tangential, axial and radial velocities. Along with an increasing "θ" value, the axial velocity increases, and the tangential velocity decreases. The radial velocity influenced by the "θ" value has an expanding effect on the fiber bundle. This produces a large number of open-trail end fibers. A higher tangential velocity twists open-trail end fibers expanded by the radial velocity which enhances the strength of the MVS yarn. Static pressure distributions inside the nozzle block are significantly affected by the jet orifice angle, the velocity at the exit of the jet orifice, the outer diameter of the hollow spindle and the distance from the inlet of the nozzle block to the inlet of the hollow spindle [14]. Schematic model of nozzle block and projection of the nozzle with jet orifices at section respectively is shown in **Figure 10**.

http://dx.doi.org/10.5772/105882

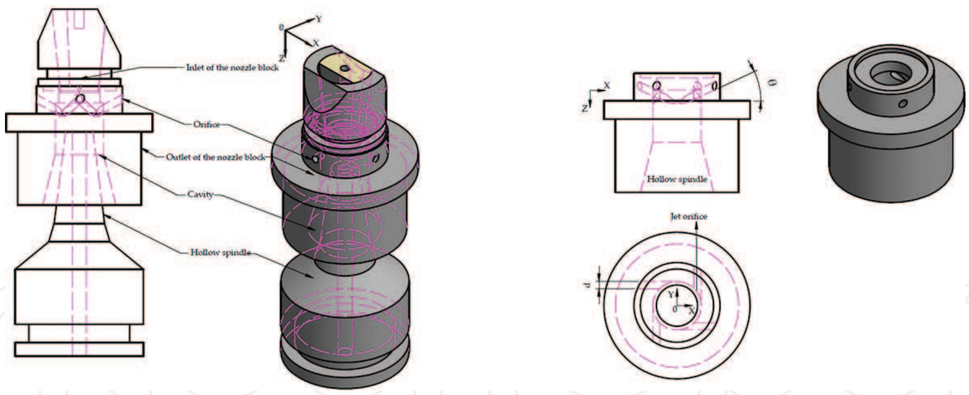

Figure 10. Schematic model of nozzle block and projection of the nozzle with jet orifices at section, respectively.

Basal and Oxenham also suggested that the nozzle angle had significant impact on yarn hairiness and evenness. They claimed that a high nozzle angle leads to higher tangential velocity, and in turn to higher twist which means more even and less hairy yarns. The interaction of a high nozzle angle and short front roller to the spindle provided better evenness.

According to the same study, low hairiness values were obtained from the high nozzle angles. It was explained with the belief that the increment of the nozzle angle and pressure caused the fibers being integrated more tightly into the yarn structure [10].

2.1.3.6. Spindle diameter and spindle working period

The studies on vortex spun yarn related to spindle diameters claim that the tightness of wrapping on vortex spun yarn is significantly affected by the spindle diameter. A smaller spindle does not give so much freedom for the fibers expanding. Hence, there occurs the tight wrapping with higher twist which means less hairy yarns. When the spindle has large diameter, the fiber bundle movement is not restricted, and wrappings become looser which means more hairy yarns.

Ortlek et al. [19] investigated the effects of various spindle diameters and the spindle working period on the properties of 100% viscose MVS yarns. MVS yarn samples produced with four levels of spindle diameter: 1.1, 1.2, 1.3, 1.4 mm and five levels of the spindle working period: 0, 1, 2, 3, 4 months were evaluated on the basis of unevenness, hairiness, elongation at break, tenacity and work-of-break (B-work) values. They concluded that a large spindle diameter resulted in high hairiness, as well as low unevenness and tenacity values. Especially, a decrease in spindle diameter from 1.3 to 1.2 mm resulted in a significant increase in the yarn unevenness value. The explanation for that was the possibility of the fibers having much more place to arrange themselves in larger spindle diameters. When it comes to spindle working period, Ortlek et al. [19] also concluded that spindle wear was a major problem as it negatively affects MVS yarn properties. The wear of the spindle increased with an increasing working period. Spindle wear mainly occurred in the tip zone and the whole surface of the spindle. The tenacity, elongation at break and B-work values of MVS yarns produced with a spindle that had 4 months working period were significantly lower than those of yarns produced with spindles which had other working periods [19]. SEM images of spindle wear versus spindle working period for different spindle diameters were shown in **Figure 11**.

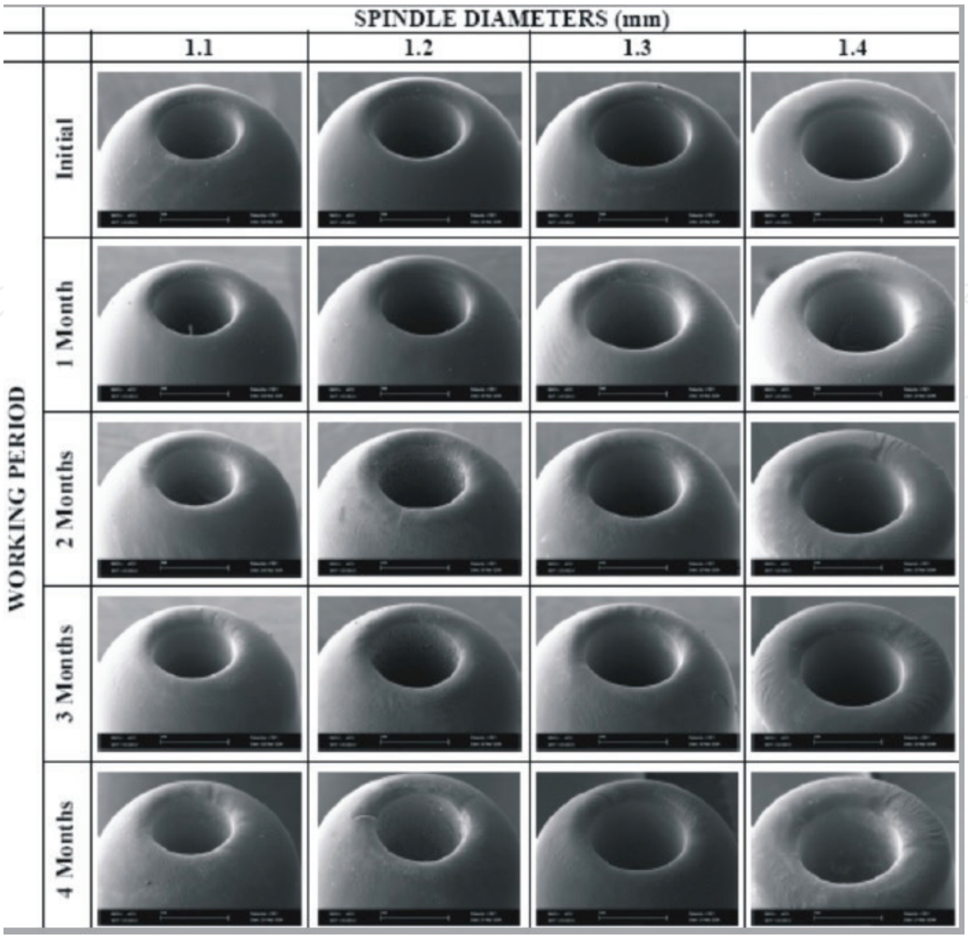

Figure 11. SEM images of spindle wear versus spindle working period for different spindle diameters [19].

2.1.3.7. Yarn count

As it is observed in the other yarn spinning systems, the yarn evenness and the imperfection results get worse also in Murata vortex spinning system. Although Murata Machinery claims, the yarn tenacity results improve as the yarn gets finer. The most studies reveal that coarser vortex spun yarns have better tenacity as well as the yarn evenness and the number of imperfections.

Ortlek and Ulku studied the some process parameters' effects on the properties of vortex yarns. The delivery speed, nozzle pressure and yarn count were the main variables on the Murata vortex spinning system. According to the experimental results, yarn evenness, imperfections, tensile properties and hairiness were all affected significantly from the parameters. They concluded yarn count was also highly correlated with the vortex yarn properties. Generally, coarser yarns yielded better yarn properties in terms of yarn evenness, imperfection values, hairiness and tensile properties [20]. Tyagi et al. also claimed that the finer MVS yarns have less proportion of core fibers than the coarser ones. So it is more difficult for the core fibers to bear the loads which results as the low tenacity [13]. In another investigation, Leitner et al. also concluded that coarser yarns have higher tenacity and breaking elongation. In addition, they stated that there aren't major changes in tenacity and breaking elongation values of fine count vortex spun yarns [21].

2.1.3.8. Fiber Composition

Several fiber properties govern the successful application of the air-jet process in vortex spinning system. In order of importance, these properties are as follows:

- Fineness (fiber micronaire or denier).
- Cleanliness.
- Strength.
- Length and length irregularity.
- Friction coefficients: "fiber-to-fiber" and "fiber-to-nozzle".

The fiber fineness has a vital effect for the yarn quality in vortex spinning. As the number of fibers in the cross section increases, the yarn break ratio during spinning also the yarn faults will be in a decreasing tendency. On the other hand, the use of finer fibers increases the number of core fibers at the expense of the wrap fibers, which decreases the yarn strength. Generally, fibers with higher strength should be used for spinning air-jet and vortex yarns. However, the elongation of the fibers also has to be considered since the high strength fibers have very low elongation for tight wrapping of the yarn core. The fiber length and length distribution influence the fascinated structure. There will be more wrapping fibers when the fiber is longer which results as a stronger yarn [22].

There are some studies examining the vortex and air-jet yarns made from different fibers. Basal and Oxenham investigated the difference between the properties and structure of the MVS and MJS produced with different blends of cotton and black polyester. The trial of MJS yarn production of pure cotton and the polyester/cotton blend with 83% of cotton ratio was not successful. Moreover, they declared that when the blend ratio of polyester was less than 50%, many difficulties appeared during the MJS production. They succeeded to produce yarns from 100% polyester and polyester/cotton blends with the MVS system; however, MVS yarn production with the 100% cotton was not possible. They explained this with the high short fiber content of cotton slivers. They also added that there is not an apparent tendency of cotton or polyester fibers to become either wrapper or core fibers in blended yarns [9].

Kılıç and Okur investigated the properties of cotton Tencel® and cotton ProModal® blended yarns in count of 30 Ne spun in different spinning systems (conventional ring, compact and vortex spinning system). They examined the effects of different blend ratios on a yarn's structural, physical and mechanical properties by using 100% cotton, 100% regenerated cellulosic fiber and 67–33, 50–50, 33–67% cotton-regenerated cellulosic fiber blended yarns. It was observed that the increasing ratio of regenerated cellulosic fiber content increases the hairiness values of vortex spun yarn. It is obvious that as the ratio of regenerated cellulosic fiber increases, the length of wrapping fibers will increase depending on the increased mean fiber length. So there is a dilemma here with the explanation of increasing wrapping length prevents fiber ends protruding from the yarn body. The increasement ratio of regenerated cellulosic fiber also provides better results for yarn unevenness, reduction in the number of thin-thick places and neps. They added that increasing ratio of the regenerated cellulosic fiber content has also contributes positively for the tenacity, breaking elongation values, roundness [23].

Tyagi et al. concluded that percentage of each fiber type in polyester/cotton blended vortex spun yarns has impacts on various yarn and fabric properties. Yarns with higher proportion of cotton fiber are less even and have high number of imperfections. Moreover, the yarns with higher proportion of cotton content are more hairy on account of the higher bending and torsional rigidity of cotton fiber, and flexural rigidity and abrasion resistance are considerably higher in yarns with higher polyester content [24].

Tyagi and Sharma [25] evaluated the thermal comfort characteristics air permeability, water vapor diffusion, absorbency and thermal insulation of scoured and finished fabrics made from polyester/cotton MVS yarns. Related to the fiber composition, they concluded that higher cotton content is very effective improving absorbency and thermal insulation properties but decreases the air permeability. They explained this with relation to the change in yarn bulk and hairiness, since higher cotton content results in a larger yarn diameter and more hairiness [25].

Gordon made a survey related to the short fiber content and neps on Murata vortex spinning. Darling Downs cotton was used as the raw material for the bales. But the cotton of each bale had different fiber length distributions and neps levels since different conditions with respect to moisture conditions in storage and heat conditions were applied for the each treatment. He summarized the results as dry seed cotton and hot air in the ginning increased the short fiber ratio and neps and reduced the fiber tensile. Deterioration of fiber values led to higher fiber loss in spinning, lower yarn tenacity, high hairiness, high number of imperfections and bad spinning efficiency. On the other hand, less fiber loss with high yarn quality and better spinning efficiency was obtained from the cotton fibers stored in higher moisture and treated with less heat in ginning [26].

2.2. The latest developments in vortex spinning technology

Rieter has developed Rieter J10, J20 and J26 model spinning machines working with the same principle with Murata vortex spinning system. These are double sided machines with 100 spinning units with delivery speed up to 500 m/min. The machine application range covers 100% polyester, combed cotton, cellulosic fibers, microfibers and different blends including man-made fibers in the yarn count range from Ne 20 to 70. In this spinning, system fibers that leave the drafting zone are guided through the fiber feeding element (FFE) by means of negative pressure into a spinning nozzle. The front part of the fibers enters the tube of the spinning tip and creates the core of the yarn. The four air jets in the twist element create a whirlwind air-jet stream. The air stream drifts the loose fiber ends around the yarn core. In this system, there is also a regulator connected for adjusting the compressed

http://dx.doi.org/10.5772/105882

air pressure to the set value. One of the distinctive features of the system from the Murata vortex spinning system is the connection of sliver condensers, nozzle and the yarn quality sensor with the traversing device. Hence, this becomes an advantage for the stable yarn quality, less wear on rollers. By this way, sliver/yarn is moved slowly over the defined range. The yarn produced by this system is called Comforjet®. Lower spinning air pressure and higher delivery speed result in soft yarns which maintain low hairiness, good pilling and high abrasion resistance. One of the decisive features from the other air-spun systems is the profiting from the minimal fiber fly. But unlike the Murata vortex spinning system, it is not possible to produce core-spun yarns in Rieter air-jet spinning [27]. Yarn formation in Rieter air-jet spinning machine and Rieter automated air-jet spinning machine is shown in **Figures 12** and **13**, respectively.

Murata Machine has also developed a new vortex spinning model MVS 870 at ITMA 2011 Barcelona. There are some little innovations compared to the previous models. The spinning speed has increased to 500 m/min, faster than before. A friction roller is adopted instead of the nip roller in the mechanism which draws the yarn from the spinning nozzle. Frictional force is generated between yarn and roller by winding a preset amount of yarn onto the friction roller. This frictional force contributes to draw the yarn from the spinning chamber with the roller rotating [28]. Eldessouki et al. made a study about the structure and comparison between Murata vortex, Reiter and Open-End rotor yarns and their mechanical behavior under dynamic stresses [29]. **Figure 14** displays scanning electron microscope pictures for the longitudinal view of Rieter, Murata vortex and Open-End rotor spinning.

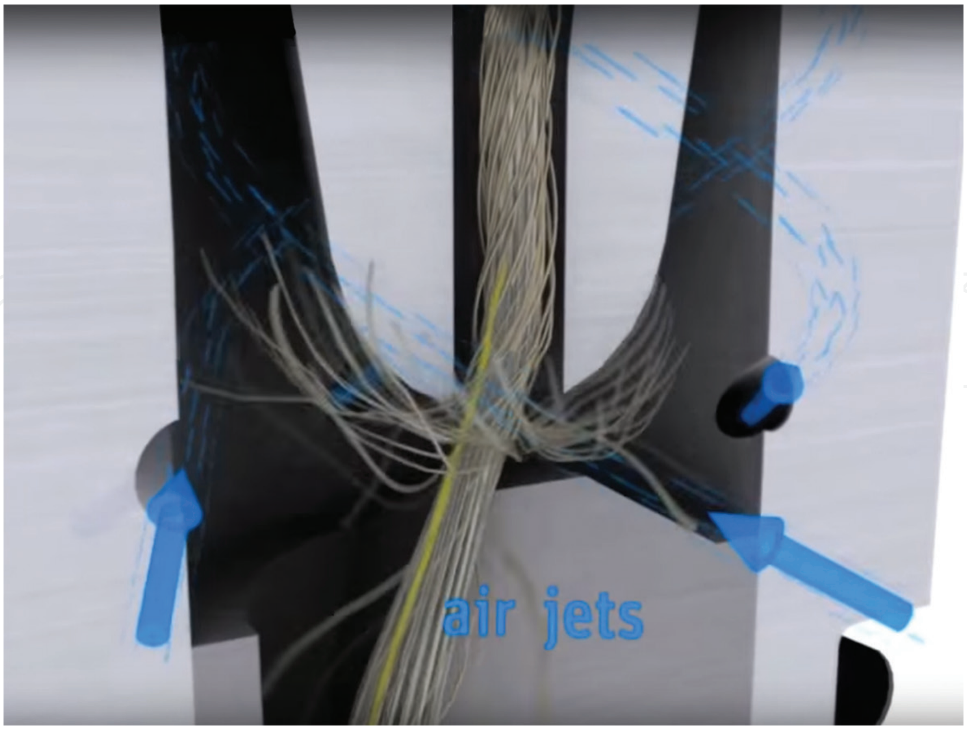

Figure 12. Yarn formation in Rieter air-jet spinning machine [27].

Figure 13. Rieter automated air-jet spinning machine [27].

http://dx.doi.org/10.5772/105882

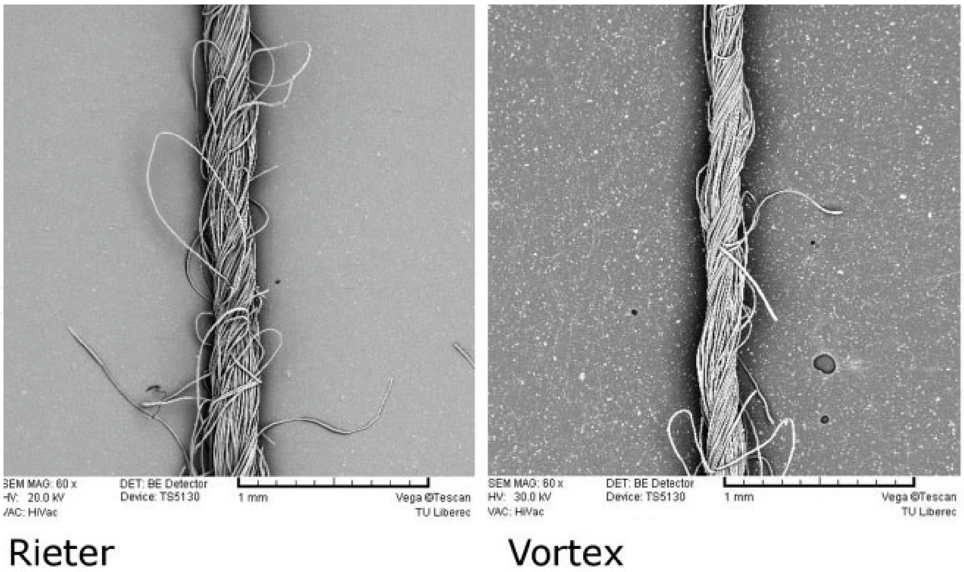

Figure 14. Scanning electron microscope pictures for the longitudinal view of Rieter, Murata vortex and Open-End spinning [29].

2.3. Numerical simulation studies concerning vortex spinning theory

Some researchers have pointed out that the dynamic behavior of the fiber in the airflow field inside the nozzle plays an important role in the twist insertion process of vortex spinning. Since the internal airflow field inside the nozzle is very complex, there aren't many studies on investigating the dynamic behavior of the fiber experimentally. With the development of computer-aided technology, computational fluid dynamics (CFD) have provided an important means of predicting the flow field under different design and operating conditions. In recent years, computational fluid dynamic approaches have been used to investigate the airflow characteristics in the vortex spinning nozzle [30–32].

Zeng and Yu [30] made a research about developing a computational fluid dynamic (CFD) to simulate the airflow patterns inside the nozzle of an air-jet spinning machine. The nozzle design parameters' effect to the flow characteristics and its reflection to the yarn was mostly discussed. The nozzle pressure increment led to the higher axial and tangential velocity in the nozzle which resulted better tensile properties of the yarn. But they emphasized that after a certain nozzle pressure, there might be some deteriorations for the yarn. The researches added that the selection of jet orifice angle which should be comprised of several factors also affected the flow characteristics. At the end of the study, they concluded that the nozzle design was a very significant factor for the vortex formation hence the yarn quality. And for further researches in order to improve vortex yarn quality, CFD can be used for optimizing the nozzle design [30].

Liu and Xu [31] studied a simple analytical formulation for the forces that determine the strength of the air vortex twist acting on the yarns during air-vortex spinning as a function of nozzle pressure, flow rate, the radius of the main nozzle in the horizontal plane, nozzle pressure, jet orifice angle, the number of the orifices, jet orifice angle, diameter of the jet orifice, and from the top of the twisting chamber to the spindle. They used FLUENT to simulate the flow fields of air vortex spinning machine. They obtained the relationship between the velocity and the radius of the main nozzle. In the study because of the high velocity and high

Reynolds number in the nozzle, airflow is accepted as a turbulent flow. The standard k-Ɛ turbulence model was used to study the air stream field of the main nozzle, and the standard wall-function approach was introduced to deal with flow near the walls. The researchers focus on the yarn formation area. Considering the distance from the top of the twisting chamber to the spindle (h) and ignoring the energy loss, the momentum formulation in the horizontal direction was calculated [31].

Pei and Yu [32] discussed the principle of yarn formation mechanism in vortex spinning system by developing a three-dimensional CFD model to simulate the airflow characteristics inside the air nozzle. A three-dimensional grid and the realizable k-ε turbulence model are used in the simulation. A streamline starting from the nozzle inlet is also acquired. Based on the simulation, the principle of yarn formation of MVS is discussed. They stated that a negative pressure zone appears in the center of the twisting chamber causing two air currents flowing into the twisting chamber through the nozzle inlet and the yarn passage of the hollow spindle, respectively. The investigators approve the simulation results with the yarn formation theory [32].

Pei and Yu made a research about the airflow characteristics and the fiber dynamic behavior by using a two-dimensional numerical model consisting of the airflow-fiber interaction and the fiber-wall contact. The effects of nozzle structure parameters such as jet orifice angle, jet orifice diameter, the distance between the nozzle inlet and the hollow spindle were investigated to analyze the dynamic behavior of the fiber in order for a whole understand of yarn structure and tensile properties detailed. The researchers declared that the best yarn tenacity was obtained when the jet orifice angle was 70°, the jet orifice diameter was 0.4 mm, and the distance between the nozzle inlet and the hollow spindle was 14 mm [33].

In another study of Pei et al.'s [34], the fiber motion simulation under the aerodynamic effects inside the vortex spinning was investigated. The researchers made a solution of coupling between the fiber and airflow together with the fiber-wall contact. The numerical model was based on the motional characteristics of some fibers (cotton, viscose rayon, Lyocell and polyester fibers) inside the vortex spinning nozzle. The wrapping effects of different types of fibers were obtained by the numerical simulation and compared with the view of vortex yarn structure under the scanning electron microscope [34].

3. Conclusions

The swirling air has been used frequently for twisting the fibers instead of using mechanical parts in the recent years. Vortex spinning has become a modern alternative method to ring and rotor spinning. Compared to commonly used ring yarns, the vortex yarn is less hairy, which leads to less fabric pilling and high abrasion resistance, high moisture absorption, color fastness, fast drying characteristics. However, there are many parameters influencing this twisting system consequently the vortex yarn. Hence for the whole understanding of the system, each factor has to be investigated in detail.

http://dx.doi.org/10.5772/105882

The design of the nozzle as well as the airflow characteristics has a significant influence on the yarn character. The number of jet orifices and the diameters of orifice directly affect the vortex magnitude. The airflow characteristics depending on the nozzle pressure reflect to the ratio of the wrapping fibers to the core fibers which cause many changes in yarn properties. The ratio of wrapping fibers to core fibers is a very decisive factor for the yarn fineness. The decrease of the core fibers in the yarn structure may lead deterioration in the yarn properties as the yarn gets finer. It is thought that the possibilities of fine count vortex yarn production with newly developed fibers such as microfibers at higher speeds are good to be investigated further for softer fabric handle. Also airflow-fiber-nozzle interactions at the yarn formation area have to be analyzed carefully for the quality improvement of vortex yarn spinning.

Author details

Gizem Karakan Günaydin[1]* and Ali Serkan Soydan[2]

*Address all correspondence to: ggunaydin@pau.edu.tr

1 Buldan Vocational Training School, Pamukkale University, Denizli, Turkey

2 Department of Textile Engineering, Faculty of Engineering, Pamukkale University, Denizli, Turkey

References

[1] Lawrence C., Editor. Fundamentals of Spun Yarn Technology. USA: The Textile Institute, CRC Press; 2003. 523 p. ISBN:1-56676-821-7

[2] Erdumlu N. An Approach to Investigate Spinnability of Fine Count Yarns on Vortex Spinning System [thesis]. Istanbul,Turkey: İstanbul Technical University; Institute Of Science And Technology. 154 p.

[3] Erdumlu N., Ozipek B., Oxenham W. Vortex spinning technology. Textile Progress. 2012;**44**(3–4):141–174. doi:10.1080/00405167.2012.739345

[4] Murata Textile Machinery. MVS 861 Catalogue [Internet]. 20.05.2006. Available from: www.muratec.net [Accessed: 10.04.2016].

[5] Basal G. The Structure and Properties of Vortex and Compact Spun Yarns [thesis]. USA: North Carolina State University; 2003. 180 p.

[6] Morton W., Yen K.C. The arrangement of fibers in fibro yarns. Journal Textile Institute. 1952;**43**(T60–T66).

[7] Soe A.K., Takahashi M., Nakajima M., Matsuo T., Matsumoto T. Structure and properties of MVS yarns in comparison with ring yarns and Open-End rotor spun yarns. Textile Research Journal. 2004;**74**(9):819–826.

[8] Chasmawala S.M., Jayaraman H., Jayaraman S. Structure and properties of air jet spun yarns. Textile Research Journal. 1990;**60**(2):61–69.

[9] Basal G., Oxenham W. Vortex spun yarn vs air-jet spun yarn. Autex Research Journal. 2003;**3**(3):96–101.

[10] Basal G., Oxenham W. Effects of some process parameters on the structure and properties of vortex spun yarns. Textile Research Journal. 2006;**76**(6):492–499.

[11] Ortlek H.G., Ulku S. Effects of some variables on properties of 100% cotton vortex spun yarn. Textile Research Journal. 2005;**75**(6):458–461.

[12] Tyagi G.K., Sharma D., Salhotra K.R. Process-structure-property relationship of polyester-cotton MVS yarns: Part I-influence of processing variables on the yarn structural parameters. Indian Journal of Fiber & Textile Research. 2004;**29**:419–428.

[13] Tyagi G.K, Sharma D., Salhotra K.R. Process-structure property relationship of polyester-cotton MVS yarns: Part II-influence of processing variables on the yarn characteristics. Indian Journal of Fiber & Textile Research. 2004;**29**:429–435.

[14] Zou Z., Liu S., Zheng S., Cheng L. Numerical computation of a flow field affected by the process parameters of Murata Vortex Spinning. Fibers & Textiles in Eastern Europe. 2010;**18**(2):35–39.

[15] Kuppers S., Muller H., Ziegler K., Heitmann U., Planck H. Spinning Limits at vortex spinning at the processing of 100% cotton. Melliand English. 2008.

[16] Erdumlu N., Ozipek B. Effect of draft ratio on vortex spun yarn properties. Fibers & Textiles in Eastern Europe. 2010;**18**(3 (80)):38–42.

[17] Zou Z.Y., Cheng L.D., Xue W.L., Yue J.Y. A Study of the twisted strength of the whirled airflow in Murata Vortex Spinning. Textile Research Journal. 2008;**78**(8):682–687.

[18] Zou Z.Y., Yu J.Y., Xue W.L., Zhu Y.D., Wu J.M., Cheng L.D. Analysis of the fiber spatial trajectory in vortex spun yarn. Textile Research Journal. 2009;**79**(10):924–929.

[19] Ortlek H.G., Nair F., Kilik R., Güven K. Effect of spindle diameter and spindle working period on the properties of 100% viscose MVS yarns. Fibers and Textiles in Eastern Europe. 2008;**3**(68):17–20.

[20] Ortlek H., Ulku S. Effect of some variables on properties of 100% Cotton Vortex spun yarn. Textile Research Journal. 2005;**75**(6):458–461.

[21] Leitner H., Schwippl H., Baldischwieler O. Air-jet spinning-yarns & fabrics compared to established spinning systems. In: XIIth International Izmir Texitile & Apparel Symposium; October 28–30; Izmir, Turkey. 2010.

[22] Lawrence C., editor. Advances in Yarn Spinning Technology. Philadelphia, New Delhi: The Textile Institute Woodhead Publishing; 2010. 431 p.

[23] Kılıc M., Okur A. The properties of cotton-tencel and cotton-promodal blended yarns spun in different spinning systems. Textile Research Journal. 2011;**81**(2):156–172.

[24] Tyagi G.K., Sharma D. Performance and low-stress characteristics of polyester-cotton MVS yarns. Indian Journal of Fiber & Textile Research. 2004;**29**(September):301–307.

[25] Tyagi G.K., Sharma D. Thermal comfort characteristics of polyester-cotton MVS yarns fabrics. Indian Journal of Fiber & Textile Research. 2005;**30**:363–370.

[26] Gordon S. The effect of short fiber and neps on Murata Vortex Spinning. The Australian Cotton Grower: http://www.greenmountpress.com.au/cottongrower/Back%20 issues/231jfcot02/28 Effect.tif. 2002;**23**(1 (January-February)):28.

[27] RIETER. rieter.com/en/machines-systems/products/j-26-air-jet-spinning-machine [Internet]. 20.03.2015. [Accessed: 21.06.2016].

[28] MURATEC. muratec.net/tm/products/vortex/vortex_001.html [Internet]. 02.11.2015. [Accessed: 10.05.2016].

[29] Eldessouki M., Ibrahim S., Farag R. Dynamic properties of air jet yarns compared to rotor spinning. Textile Research Journal. 2015;85(17):1827–1837.

[30] Zeng Y., Yu C. Numerical simulation of air flow in the nozzle of an air-jet spinning machine. Textile Research Journal. 2003;**73**(4):350–356.

[31] Liu Y., Xu L. Controlling air vortex in air-vortex spinning by Zeng-He model. International Journal of Nonlinear Sciences and Numerical Simulation. 2006;7(4):389–392.

[32] Pei Z., Yu C. Study on the principle of yarn formation of Murata vortex spinning using numerical simulation. Textile Research Journal. 2009;**79**(14):1274–1280.

[33] Pei Z., Yu, C. Prediction of the vortex yarn tenacity from some process and nozzle parameters based on numericals. Textile Research Journal. 2011;81(17):1796–1807.

[34] Pei Z., Hu B., Diao C., Chongwen Y. Investigation on the motion of different types of fibers in the vortex spinning nozzle. Polymer Engineering & Science. 2012;**52**(4):856–867.