Investigation of the use of High Pressure Water for Spun-Like Textured Yarn Manufacturing

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Abstract— **The objective of this research work was to investigate the use of water in order to replace air in the production of spun-like textured yarn. An existing air-jet texturing machine was modified to supply either air or water to the texturing nozzle. A new texturing-jet was designed and developed to produce spun-like textured yarn using water. The texturing jet was further improved by incorporating capillary effect to suck air with water into the texturing zone to improve turbulence in the jet. The results show that water can be used to manufacture spun-like textured yarns.**

Index Terms— **Air-jet texturing, Water/air-jet texturing, spun-like textured yarn.**

I. INTRODUCTION

The objective of this paper is to investigate the use of water as an alternative fluid for air in the spun-like texturing. Preliminary trials were conducted to develop a method to produce textured yarns using water as a liquid fluid that is different to gas fluids such as air and steam.

The heart of the air-jet texturing process is the nozzle. This may vary in design and details, but has the purpose of creating a supersonic, turbulent and non-uniform airflow to entangle filaments and form them into loops and so generate stable textured yarns. The developments of air-jet texturing started approximately in 1951 with the patents of Du Pont and almost at the same time by the development of the Mirlan Jet in the Czechoslovakia. The progressive development in nozzle design, since the early 1950s, has considerably improved the productivity of the system. This has led; to the elimination of the need for pre-twisted yarn, to increased texturing speeds, to reduced compressed air consumption, to reduced energy and water consumption rates, to improved yarn quality, and to the development of a wider range of products[1].

In contrast with the earlier days of the process, a great numbers of texturing nozzles are available to be fitted to modern, purpose built texturing machines. Taslan nozzles by Du Pont and Hemajet nozzles by Heberlein dominate the nozzle supply to the air-jet textured yarn manufacturers. Demir and Wray have suggested, and seems very likely, that the development of the early nozzles were done on a trial and error basis [2]. In the early days there was no suggestion that wet yarn might be used, and the stability of entanglement was so poor that the yarn was generally down-twisted after texturing. A further development on the later Taslan nozzles were the provision of baffle elements at the exit with a flap. This addition has been claimed as improving process stability, but there is a strong division of opinion on this matter [3].

The principle drawbacks of the Taslan jets are high compressed air consumption and nozzle to nozzle variability. Such problems lead to a need for precise adjustment of both needle and the venturi. Frequent contamination of the venturi with spin-finish material washed away from the yarn surface is another problem. Because of it, regular cleaning and servicing needs are increased [2], [4]. In 1978 Heberlein Maschinenfabrik AG of Switzerland introduced air-jets of completely different design under the name of Hemajet to the market. The airflow into the yarn channel through either 1 or 3 fine bore air holes, meeting the overfed yarn at an angle (following the radial principle rather than the axial principle employed in needle/venturi jets) [5]. The yarn exit side of the yarn channel is widened to give a trumpet-shaped exit configuration and an adjustable spherical impact element is fitted just outside the yarn exit. Compared with the Taslan nozzles, the HemaJet is a very simple design requiring no adjustment after the initial setting. It therefore provides high levels of nozzle to nozzle consistency within the very tight limits of manufacturing tolerances. The straight geometry of the yarn channel facilitates self-cleaning, thus facilitating longer runs without stoppages[5].

However, the main advantage that made the Heberlein nozzles well accepted by the texturing industry was the economic factors, deriving from the reduced compressed air consumption, were significant. Furthermore, the Standard-core Hemajet was not the only nozzle developed by Heberlein. Improved nozzles for different purposes and for different feed yarns were also designed with many novel features such as: single, two or three inlet holes; a widened trumpet-shape exit section; a conical enlarged yarn inlet side of the main channel; and ceramic nozzles to reduce wear [2]. The design has a self-cleaning facility, as spin-finish constituents are washed away from the yarn surface because of the straight geometry of the main duct which is constantly in contact with the moving yarn [6].

The most important ambition, namely an increase in the texturing speed proved to be also the most difficult to achieve and was only fulfilled in 1997 by Heberlein after a long development. The Heberlein 'S' series jet core is claimed to increase the texturing speed by about 25% compared to their 'T' series. During air-jet texturing the formation of loops results from differential lengthwise displacement of the filaments relative to each other in the jet. The loops are formed from the excessive length of some of the filaments. The filament displacement is caused in the main by the angular impact of the airflow upon the yarn, emerging from one or three air holes. The higher the airflow velocity, the faster is the attainable texturing speed. In the case of the jet core series 'T' this velocity is equivalent to approximately Mach 1.5. With the help of special yarn channel geometry the

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velocity of the airflow in the jet core series ‘S’ has been increased to over Mach 2. Heberlein claim that the jet new core series furthermore consists of a new special ceramic with high strength [2].

Researches claim that in the air-jet texturing, filaments open-up and process by the shock waves. Theoretical investigation on nozzle parameters and air –flow on air-jet texturing was carried out by many researchers[7] [8][9][10][11]. However, actual behaviour of the filament during texturing in supersonic flow was not properly understood. However, it is understand that same technology cannot be applied for water. Water is non-compressible liquid and the sonic velocity is about 1500m/min which is quite outside the range of practical velocities of liquid flow. The study also opens up a debate whether shockwave is a must for texturing. However, it is understand that alternative methods have to be developed to get turbulence in the water flow in order to entangle core and effect filaments in the texturing process. The primary investigation of the water and water/air-jet texturing process are presented in this paper.

Since the introduction of the air-jet texturing by Du Pont de Nemours in early 1950’s, only air has been used as a fluid to produce spun-like textured yarns. Wickramasinghe and Foster [12], [13], [14] investigated the application of steam as an alternative fluid for air in spun-like textured yarn manufacturing. They concluded that steam can be used as an alternative fluid for air in air-jet texturing.

II. WATER-JET TEXTURING

A. Experimental Methodology

Due to the fact that water is not a compressible fluid, it does not behave like air in the nozzle outlet. But, the force created by the water is very high compared to a gas such as air and steam. During primary investigations with existing nozzles, it was observed that controlling the yarn against the shooting out and separating the yarn from water is a major obstacle to the texturing process with a liquid such as water. Therefore, a jet as shown in figure 1 was made using Perspex. A special baffle unit was designed to control the yarn flow, get more turbulence and to separate yarn and water. A labyrinth seal was used to remove water from the textured yarn.

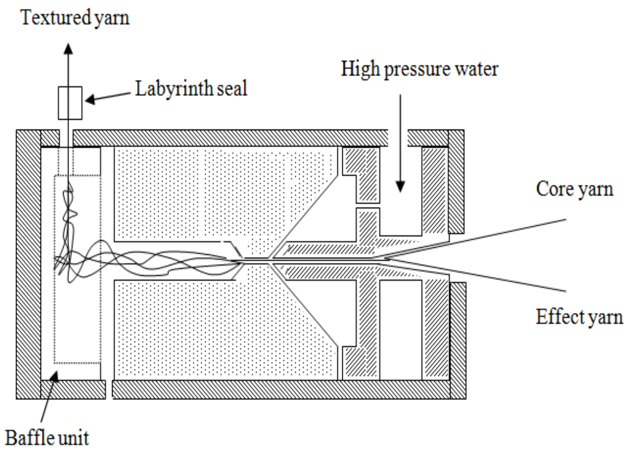

Figure 1. Schematic diagram of the water-jet texturing nozzle

However, over 100bar water pressure was needed to achieve good level of texturing. It was also noted that the core-yarn overfeed higher than 3% was not possible since the excessive overfed filaments created knots on the textured yarn. Unlike air, it seems water doesn’t bend core filaments and make loops although it entangle and make loops from effect filaments. That means core yarn filaments virtually undisturbed and has its straight form. However, this is an advantage in making high strength looped yarns but similar to air-jet textured yarns. Such yarns cannot make using air-jet, since it disturbed the core yarn filaments in the texturing/texturing process.

Initial experiments show that the water-jet can be used to texture core and effect filaments successfully. The main limitation of this process seems to be the knot formation due to very high turbulence and water-vortex created by the water. However, by adjusting the baffle unit it was possible to reduce the effect of water-vortex. Primary investigations revealed that unlike air-jet, higher core yarn over feed is not necessary to entangle core and effect filament using water-jet. It appears that very high force and turbulence generated by water entangle filaments effectively. Another main difference of water-jet textured yarn is it has less loop frequency and bigger loop size compared to the air-jet textured yarn. When the textured yarn heat set, loops shrink more compared to the air-jet textured yarn. Based on the initial trials, following process conditions were maintained and both air-jet and water-jet textured yarns were produced for comparison.

Texturing medium	**Air-jet** Compressed air	**Water-jet** High pressure water
Pressure (bar)	8	100
Jet type	Commercial texturing jet	New
Core-yarn (dtex)	415 f 48 POY Polyester	415 f 48 POY Polyester
Effect-yarn (dtex)	86 f 36 POY Polyester	86 f 36 POY Polyester
Core yarn draw ratio	2.19	2.19
Effect yarn draw ratio	1.75	1.75
Core overfeed (%)	2.9	2.9
Effect overfeed (%)	37.9	37.9
Production speed (m/min)	100	100

Table 1. Process conditions of the air-jet and water-jet textured yarns.

B. Experimental Results

	Air-jet	Water-jet
Count (Tex)	27.2	27.0
Strength (N)	11.1	11.8
Tenacity (cN/tex)	40.9	43.8
Elongation (%)	7.7	8.1

Table 2. Properties of air-jet and water-jet textured yarns

Properties of water-jet and air-jet are textured yarns are given in table 2. The results show that the water-jet textured yarns have higher strength than the air-jet textured yarns at same process conditions.

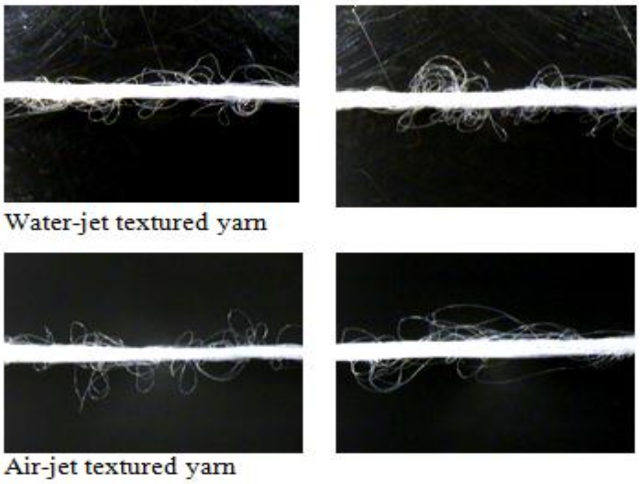

Figure 2. Water-jet and air-jet textured yarns

Figure 2 show the video microscopic images of water-jet and air-jet textured yarns produced using the process conditions given in table 1. Visual inspections using video and stereomicroscopes showed that the yarn produced using water-jet are adequately textured for textile applications. It was present author's opinion that the quality and production speed of the textured yarns produced using water-jet have to be improved to reach the present commercial levels. Author believed that the increase turbulent will improve the level of entanglement. Author attempted to change the jet design so as to make a jet to increase the turbulence of water. The design of the texturing jet so as to improve the turbulence and the results are presented bellow.

III. Water/Air-Jet Texturing

A. *Experimental Methodology*

It is known that according to burnoil's principle, high pressure-water flow has an ability to suck air through a capillary from outside atmosphere. The principle is going to apply to increase the turbulence in water by mixing air with water inside the texturing jet. Therefore further studies were carried out using a water-jet that sucks air from atmosphere. To differentiate the methods explain in section above, the method is defined as water/air-jet texturing. Figure 3 shows the water/air-jet nozzle that was designed by the authors. The jet was established by trial and error basis after series of jets were tested.

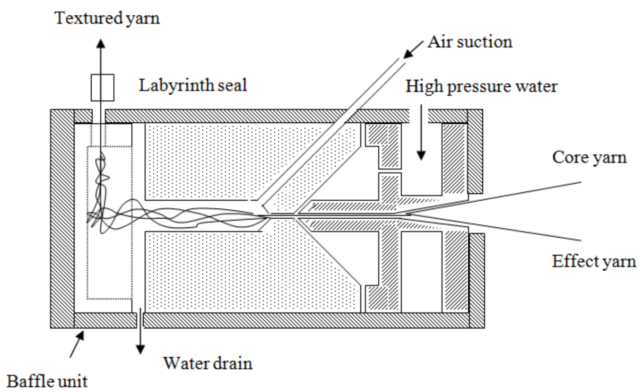

Figure 3. Schematic diagram of the Water/air-jet texturing nozzle.

It was also observed that the shape of the baffle unit inside is important for successful texturing as well as to stop the water vortex effect. As an example circular baffle leads to the twisting yarn and therefore texturing was not possible. Water twist core-yarn and effect-yarns before it enters in to the texturing-jet and therefore break the feeder yarns. It also create snarl on the yarn and cause problem pulling it through labyrinths. Therefore, rectangle baffle cross section was used.

Polyester 596 f 60 POY white core yarn and Polyester 120 f 34 POY black effect yarn was used in this study. It was observed that it is easy to see the textured yarn structure when white core yarn and black effect yarn were used. The process conditions as shown in the table 3 were used to make textured yarns.

	Air-jet	Water/air-jet
Texturing medium	Compressed air	High pressure water
Pressure (bar)	8	100
Jet type	Commercial jet	New (Fig. 4)
Core yarn (dtex)	596 f 60 Polyester POY	596 f 60 Polyester POY
Effect yarn (dtex)	120 f 34 Polyester POY	120 f 34 Polyester POY
Core yarn draw ratio	2.19	2.19
Effect yarn draw ratio	1.75	1.75
Core overfeed (%)	2.9	2.9
Effect overfeed (%)	37.9	37.9
Production speed (m/min)	200	200

Table 3. Process conditions of the air-jet and water/air-jet textured yarns.

B. *Experimental Results*

	Air-jet	Water/air-jet
Count (tex)	39.4	39.2
Strength (N)	14.9	15.8
Tenacity (cN/tex)	33.9	35.1
Elongation %	7.8	8.2

Table 4. Properties of air-jet and Water/air-jet textured yarns

Table 4 shows the comparison of the air-jet and water/air-jet textured yarn properties produced. Results show that the water/air-jet textured yarn structure is similar to the air-jet textured yarn structure. However, as shown in the figure 3, the water/air-jet textured yarn has more entangled structure than the air-jet textured yarn structure for low core-yarn overfeed percentage of 2.9.

Water/air-jet textured yarn.

Air-jet textured yarn.

Figure 3. water-air-jet textured yarn and air-jet textured yarn.

IV. CONCLUSIONS

From the above primarily investigations, it can be concluded that water can be used for core and effect texturing. Use of air suction to improve turbulence in the texturing jet proves effective. It was possible to produce successful textured yarn samples using less core-yarn overfeed. Therefore, the water/air-jet textured yarn has higher strength than the conventional air-jet textured yarns which use higher core-yarn overfeeds. It can also be recommended that further studies to be carried out to improve the water/air-jet texturing process by improving the water turbulence. It is also important to study the effect of surface tension of water and filaments on texturing. One of the limitations of the water-jet and water/air-jet texturing is its very high pressure. Therefore, further research has to be done to optimise the process while reducing water pressure and consumption.

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