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# Simulation Approach to Investigate the Effect of the Jet Structure and Air Pressure on the Performance of Siro-jet Spinning

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**Abstract**
*In this paper, the effects of different parameters on the hairiness of siro-jet spun yarns, such as the nozzle pressure, the distance between the front roller nip and inlet of the nozzle, and jet structure were investigated. Using the Taguchi method, it was concluded that the factor air pressure has the strongest effect and the factor distance between the front roller nip and inlet of the nozzle does not have a significant effect on the performance of the siro-jet spinning system in reducing yarn hairiness. A computational fluid dynamics model was developed to simulate the airflow pattern inside the jets. The effect of air pressure and the jet structure was simulated using Fluent 6.3 software. The application of an air-jet nozzle reduces yarn hairiness by 40%.*

**Key words:** *air-jet, Taguchi method, siro- spinning, simulation, yarn hairiness.*

## Introduction

Hairiness will occur when some fibre ends protrude from the yarn body or some wild fibres appear on the yarn surface. Generally, long hairs are undesirable, while short hairs are desirable. The effect of yarn hairiness on different textile processes such as spinning, especially weaving and knitting, and its influence on the characteristics of the product obtained and on some fabric faults has led to attempts at reducing hairiness. Hairiness can be reduced by conventional techniques such as sizing and two-folding. In recent years, new technologies such as compact spinning [1], solo spinning [2] and jet-ring spinning [3 - 7] have been developed to reduce the hairiness of ring spun yarn. Jet-ring spinning combines the features of ring and air-jet spinning technology. The swirling air current inside the nozzle is able to wrap the protruding hairs around the yarn body, thereby reducing yarn hairiness [8 - 10]. Simulation of the airflow pattern by means of fluid dynamics inside the nozzle can provide a much better insight into the actual mechanism of hairiness reduction. Different nozzle parameters, such as the orifice angle and nozzle's main- and sub-hole diameter affect airflow characteristics and also the hairiness reduction of yarns of different linear density. This research focuses on the design and fabrication of two types of air jet nozzles for the siro-jet spinning system; the employment of these nozzles in the siro spinning system to be fitted in between the front roller nip and lappet hook of the ring frame, and a computational fluid dynamics model to evaluate the performance of these nozzles with respect to hairiness reduction.

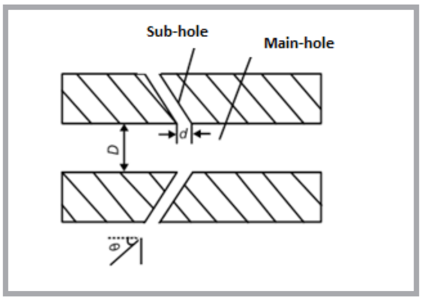

***Figure 1.** Structure of the air-jet nozzle.*

## Materials and methods

In the present study, Z-twisted carded cotton-polyester (35% - 65%) yarns with a linear density of 29.5 tex were produced. Cotton fibres (28 mm, 3.5 µg/inch) and polyester fibres (38 mm, 0.11 tex) were blended at the drawing stages. In order to produce a yarn with linear density of 29.5 tex, two roving of 1.18 hank were fed to the drafting system of a siro-spinning frame. Particulars of

***Table 1.** Setting parameters of siro-jet spinning.*

| Setting parameters | Value |
|---|---|
| Spindle speed, r.p.m. | 7000 |
| Total draft | 22 |
| Twist per meter | 580 |
| Ring diameter, mm | 60 |
| Traveler No., Iso | 90 |
| Roving No., Hank | 2 × 1.18 |
| Yarn No., tex | 29.5 |
| Air pressure, MPa | 0.05, 0.07, 0.11 |
| Distance between jet and front roller nip, cm | 3, 6, 9 |

***Table 2.** Geometric parameters of the nozzles.*

| Parameter | Jet A | Jet B |
|---|---|---|
| Main hole diameter D, mm | 2 | 3 |
| Numbers of sub-holes | 4 | 4 |
| Inlet and outlet shapes | circular | |
| Angles of sub-holes (θ), deg | 45 | 90 |
| Sub-hole diameter d, mm | 0.5 | 1 |

***Table 3.** Orthogonal array L9.*

| Trial No. | ($P_1$) Air pressure, MPa | ($P_2$) Distance, cm | ($P_3$) Jet type |
|---|---|---|---|
| 1 | 0.05 | 3 | A |
| 2 | 0.05 | 6 | B |
| 3 | 0.05 | 9 | B |
| 4 | 0.07 | 3 | A |
| 5 | 0.07 | 6 | A |
| 6 | 0.07 | 9 | B |
| 7 | 0.11 | 3 | A |
| 8 | 0.11 | 6 | B |
| **9** | **0.11** | **9** | **B** |

the machine setting for producing cotton-polyester spun yarn are shown in ***Table 1***.

The air-jet nozzle consists of different components for the air suction channel, yarn inlet and outlet, and main and sub-holes. ***Figure 1*** shows the structure of the nozzle used. The structures of the nozzle, such as the diameters of the main and sub-holes, the number of sub-holes and angles of sub-holes ($\theta$) have a significant effect on the air-jet performance [3]. The two air jets have a different structure. Both nozzles produce an air vortex in the same direction as that of the air twist, i.e, in the Z direction. ***Table 2*** shows the geometric parameters of the two nozzles.

In this study, the effect of three factors: the air pressure, jet structure and distance between the delivery roller and installed jet structure on the siro-jet performance was also investigated using the Taguchi method. For the yarns produced with the two types of air jet nozzle, three different air pressures and distances between the delivery roller and installed jet were tested for hairiness. Because in this experiment the two controllable factors - the air pressure and distance between the front roller nip and nozzle inlet vary at three levels and the jet structure at two levels, an orthogonal array $L_{9,}$ shown in ***Table 3***, was chosen.

Samples were kept in standard testing conditions for 24 h prior to testing. For each sample, a 500 m length of yarn was tested on a Zweigle G 566 hairiness tester at a yarn speed of 50 m/min to obtain a number of hairs equal to or exceeding 3 mm in 1 meter of yarn. Thirty readings were taken for each sample to obtain average yarn hairiness values.

A nozzle placed in a nozzle-housing was mounted between the front roller nip and lappet at a distance of 3, 6 and 9 centimetres from the delivery roller's nip. Compressed air was supplied to the nozzles through pipes with a pressure- regulator and air-filter, entering the yarn channel through four sub-holes.

In the present study, the airflow inside the jets was simulated. A fluid flow analysis package, Fluent 6.10, which uses the finite volume method for flow simulation was applied. The following assumptions were considered for the simulation [10]:

1) The flow in the jets is turbulent, hence the standard k-ε model of turbulence was used.
2) Also it was assumed that the presence of yarn has no effect on the flow patterns, and hence the yarn was not modelled.
3) The high pressure and velocities of the air coupled with the very low volume of yarn compared to that of the jet chamber justify this assumption.
4) Although the high velocity of the air stream is a heat source that will increase the temperature in the jets, the jets are very short and the process occurs in a very short time.
5) For simplification, it is assumed that the process is adiabatic, i.e. with no heat transfer through walls.

***Table 4.*** *Analysis of variance for means.*

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| **Air pressure** | 2 | 253.6 | 321.6 | 160.8 | 7.63 | 0.06 |
| **Distance** | 2 | 140.9 | 16.7 | 8.4 | 0.40 | 0.70 |
| **Jet-type** | 1 | 69.1 | 69.1 | 69.1 | 3.30 | 0.17 |
| **Error** | 3 | 63.2 | 63.2 | 21.1 | | |
| **Total** | 8 | 526.8 | | | | |

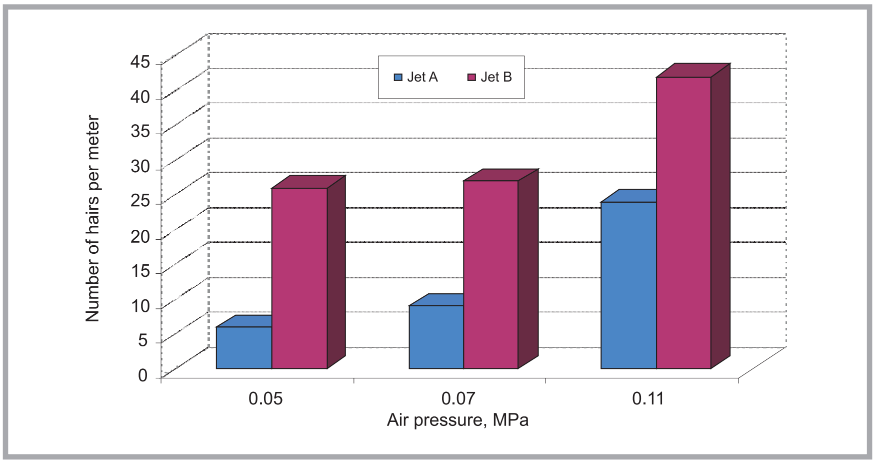

***Figure 2.*** *Effect of jet structure and air pressure on the yarn hairiness level.*

## Results and discussion

Level average analysis was adopted to interpret the results. This analysis is based on combining the data associated with each level for each factor. ANOVA analysis was made to investigate the significant effect of the three factors. ***Table 4*** shows the results of this analysis. The highest P-value is related to the strongest effects of that particular factor. Accordingly, factor $P_1$ (air pressure) shows the strongest; Factor $P_3$ (jet structure) is second, followed by factor $P_2$ (distance). The finding shows that the factor distance between the jet and delivery roller's nip line has no significant effect on the hairiness level of the yarn produced. Thus the effect of the other factors was investigated using the simulation technique. This result also confirms the findings of Cheng and Li [3], who investigated the effect of different parameters on the reduction in yarn produced on the Jet-ring spinning system. Wang et al. [8] explained the mechanism of hairiness reduction as follows: The upward swirling air current against the movement of yarn and twist loosens the fibre strand, during which the tucking of fibres on the body takes place. As the yarn comes out of the nozzle, the loosened fibre strand gets tightened by the flow of twist from the mechanical twisting agency, during which the binding of the tucked fibres takes place. The effect of the jet structure and air pressure on the yarn hairiness level is shown in ***Figure 2***.

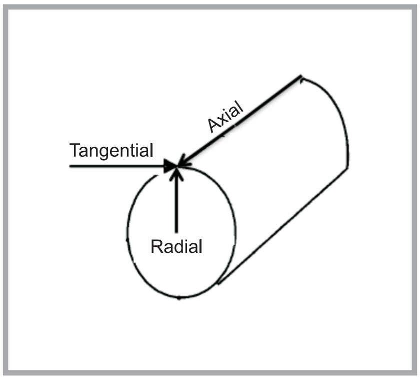

***Figure 3.*** *Three components of air velocity in the nozzle jet.*

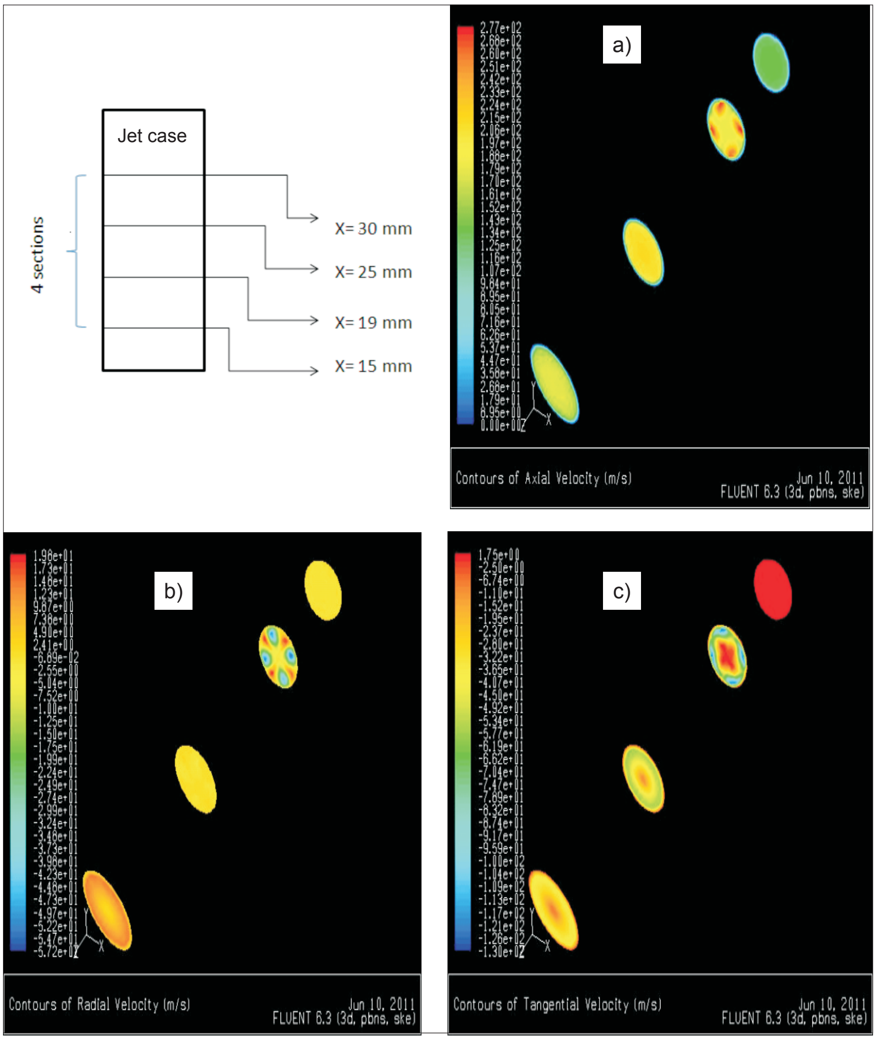

***Figure 4.*** *Four cut sections at different positions of the jet. Contour of the (a) axial velocity (b) radial velocity and (c) tangential velocity of Jet A.*

## Effect of air pressure on airflow in the nozzle

The air pressure was controlled by a suction pump at three different levels. As mentioned before, the air pressure plays the most important role in reducing the yarn hairiness. To investigate the effect of air pressure on the yarn hairiness, the airflow along the nozzle was simulated. The air velocity along the nozzle is divided into three components: the axial, tangential and radial velocity (***Figure 3***, see page 47).

The distance of the jets was divided into four sections, tacking the yarn inlet of the jet as the origin. ***Figure 4*** indicates that the jet is cut into 4 sections along the axial height of the jet. For example, cut section 'X = 15' means that the section has been plotted at a distance of 15 mm from the yarn inlet. ***Figures 4.a, 4.b & 4.c*** show the contour of the axial, radial and tangential velocity in 4 plotted cut sections of jet A.

Furthermore the variation in the axial, radial and tangential velocity along the distance from the main-hole center to the main-hole wall was investigated. ***Figure 5*** shows these variations for jet B at a pressure of 0.05 MPa in the cut section 'X = 19'. The results show that the axial, radial and tangential velocities increase from the main-hole's center toward the main-hole's wall and experience a maximum point near the main-hole's wall. The mechanism of hair reduction was explained at this radial position, in which the three components of the air velocity have a peak point. ***Figure 6.a***, ***6.b*** & ***6.c*** shows three stages of hair wrapping around the yarn. The hair which is projected from the yarn surface is folded and lies on the yarn surface along the direction of total velocity, which is composed of the axial and radial velocity. Then the hairs wrap around the yarn due to the existence of the tangential velocity of airflow. The swirling air current in the nozzle twists the yam strand in the reverse direction due to the false twisting effect. Higher tangential velocity produces more wrapping hairs and, hence, fewer hairy yarns.

The results of the simulation show that while the air pressure increases, the axial, radial and tangential velocities, which are responsible for wrapping the protruding surface hairs around the yam body, increase. Normally this would lead to more wrapping fibre ends and thus less hairiness. But the results show a different trend (***Figure 6.d*** & ***6.e***).

The maximum axial, radial and tangential velocity at different pressures in the two jet structures is shown in ***Figures 7***.

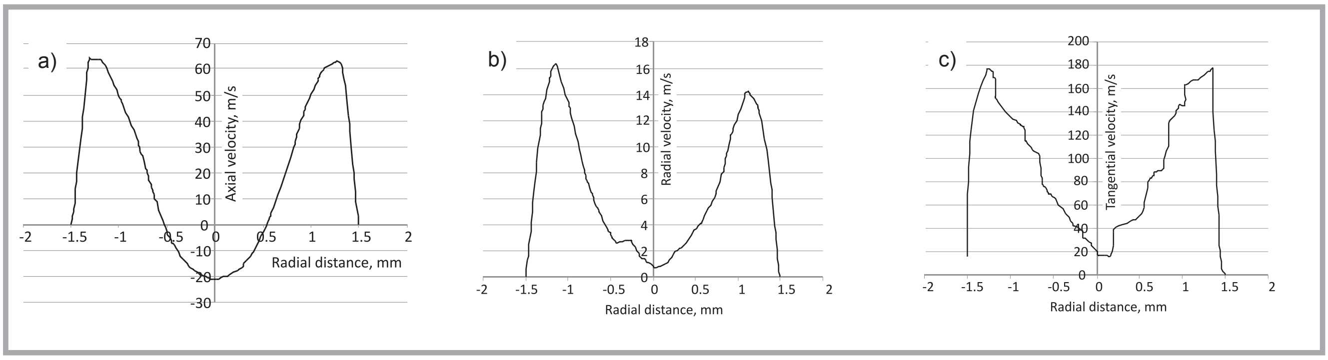

***Figure 5.*** *Variation in radial, axial and tangential velocities along the cross section of the main-hole at a pressure of 0.05 MPa.*

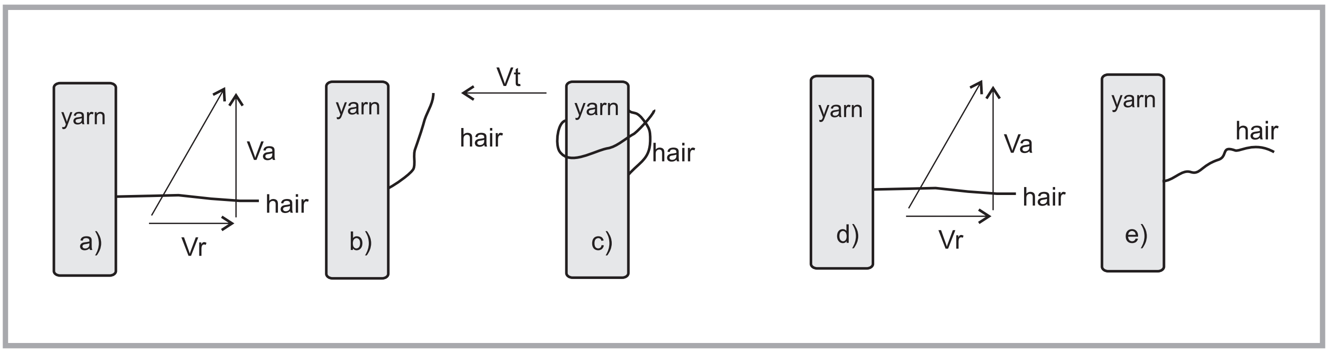

***Figure 6.** Laying of the hair on the yarn surface in three stages (a, b & c) and fibre curving at high axial velocity (d & e(; Vr - radial velocity, Va - axial velocity, Vt - tangential velocity.*

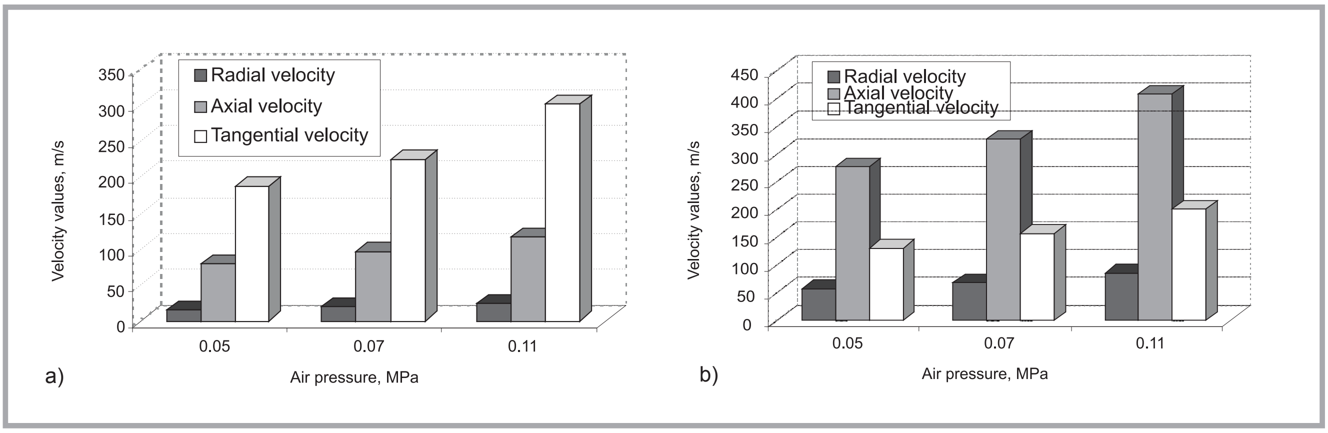

***Figure 7.** Maximum values of the axial, radial and tangential velocity of : a) Jet B and b) Jet A.*

The maximum axial, radial and tangential velocities will be reached where the four sub-holes join the main-hole., which is due to the presence of air streams from four sub-holes' inlet, which mix with air coming through the yarn inlet, creating a swirling effect. In the case of jet A, the optimum air pressure was found to be 0.05 MPa. At pressures higher than 0.05 MPa, the axial velocity increases significantly, which is a potential source of fibre curving (***Figure 6***), thus it impedes the wrapping of the protruding fibre ends [12]. Therefore at pressures higher than 0.05 MPa, the performance of the jet in reducing the hairs will be lower.

In the case of jet B, in comparison with the axial and radial velocity, due to the presence of the air stream from the four sub-holes, the tangential velocity will increase with a higher slant. The tangential velocity at a pressure of 1.1 reaches a velocity of 300 m/s. A high tangential velocity may create an unsteady motion in the yarn, resulting in an eccentric placement of the yarn inside the nozzle and yarn ballooning. Due to this ballooning action, yarn positioning at the center of the nozzle would be difficult and the wrapping of surface fibre would also suffer [12]. Also, in this case, the yarn rubs with the wall of the nozzle, thereby raising the hairs from the yarn body.

### Effect of the jet structure on air velocity and yarn hairiness

It is believed that the performance of Siro-jet spinning processes depends on the design of the nozzle [11]. ***Figure 7.a*** & ***7.b*** shows the effect of different jet structures at the same pressures (0.05 MPa) on the air tangential velocity at the four cut sections. In the case of jet B, the maximum tangential and axial air velocity will be 208.4 and 000.0 m/s. The diameter of the main and sub-holes in Jet B are larger than in jet A. It is expected that an increase in the hole diameter decreases the axial and radial air velocities experienced by the yarn throughout the jet. Jeon [3] reported that the number of hairs longer than or equal to 3 mm from yams spun through a nozzle with a smaller sub and main-hole diameter significantly decreases the number of hairs, which can be due to weakening air suction resulting from larger main- or sub-holes, which may lose the air pressure necessary to hold the fibre ends. Therefore the resultant air velocity will be lower in jet B. Thus, due to the fact that the hairs are folded and lying on the yarn surface along the direction of the total velocity, which is composed of the axial and radial velocity, jet B cannot lay the hairs on the yarn surface effectively. Due to a higher sub-hole slant, jet B produces a higher tangential velocity in comparison to jet A. In the case of jet B, the maximum tangential air velocity will be nearly 300 m/s. Therefore it seems that there is not enough axial and radial velocity to fold and lay the hairs on the yarn surface. On the other hand, the high tangential velocity produced in a jet with a higher sub-hole slant will produce an unsteady motion and yarn ballooning, which can reduce the performance of jet B.

## Conclusion

Using the Taguchi method, the performance of the Siro-jet spinning system in the reduction of hairiness and the effects of different parameters, such as the nozzle pressure, distance between the front roller's nip and inlet of the nozzle, and the nozzle structure were investigated. It was concluded that the factor distance between the front roller's nip and inlet of the nozzle does not have a significant effect on yarn hairiness. A computational fluid dynamics model was developed to simulate the airflow pattern inside the jets. Application of a jet with a higher sub-hole slant produces a higher tangential velocity, which can result in an unsteady motion, yarn ballooning and a reduction in jet performance. The effect of the air pressure was also investigated, in which it was found that an increase in air pressure can lead to a higher radial, axial and tangential velocity. The intensity of this increase will depend on the jet structure. The results shows that a jet with a lower sub-hole slant and main- and sub-hole diameter at a pressure of 0.5 bar provides optimum conditions for higher jet performance.

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