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# Numerical Computation of a Flow Field Affected by the Process Parameters of Murata Vortex Spinning

## Abstract

*In this paper, flow patterns, such as the velocity distribution along the radius of the nozzle block at section A-A and static pressure distributions along the nozzle block axis and its radius at section A-A, affected by the nozzle block's structure parameters and the velocity at the jet orifice exit in Murata vortex spinning are investigated by the method of numerical computation. The results show 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. 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.*

**Key words:** Murata vortex spinning, process parameters, airflow, numerical computation.

## Introduction

In Murata vortex spinning (MVS), the whirled airflow inside the nozzle block, formed by compressed air through the jet orifices, twists the open-trail-end fibres into MVS yarn, which is drawn out from the hollow spindle, as shown in *Figure 1* [1]. Previous studies have focused on the structure and properties of MVS yarns through experimental methods. Tyagi et al. and Basal et al. investigated the influence of the distance between the hollow spindle and front rollers, the jet orifice angle, nozzle pressure and delivery speed on the structure and characteristics of MVS yarns [2, 3]. Ortlek et al. discussed the effect of the hollow spindle diameter and spindle working period on the properties of 100% viscose MVS yarns and found that the various properties of MVS yarns are significantly affected by the spindle diameter and spindle working period [4]. Ortlek et al. also researched the influence of selected process variables, such as the delivery speed, nozzle pressure and elastane linear density, on the mechanical properties of core-spun vortex yarns containing elastane [5]. The viscoelastic behavior of MVS yarns was analysed by Zou et al. [6, 7] in which he

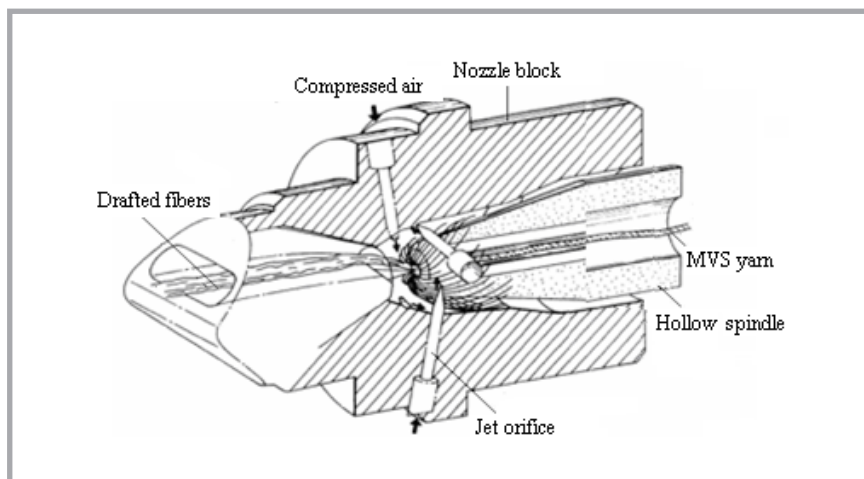
theoretically analysed the special fibre trajectory of MVS yarn with respect to the principle and process of yarn formation. He discovered that the fibre spatial configuration in vortex spun yarn consists of core fibre, migration wrapper fibre and regular wrapper fibre [8]. Soe et al. compared the structure and properties of MVS yarns with ring and rotor spun yarns and found that MVS yarn is mainly composed of core fibres and wrapper fibres [9].

The structure and performance of MVS yarn is mainly determined by the patterns of the flow field inside the nozzle block, which is simulated by constructing a Computational Fluid Dynamic (CFD) Model, Zou and Pei et al [10, 11]. Zou also investigated the twisted strength acting on vortex spun yarn from the whirled airflow [12]. The velocity of the whirled airflow will gradually attenuate in the

yarn formation process, flowing to the outlet of the nozzle block due to the air viscosity resistance, whose attenuated law was discussed by Zou and used to perform a force analysis of a separated fibre in the twist chamber which explained the generation of thin places in MVS yarn [13]. However, there are few studies that completely focus on the effect of the structure parameters of the nozzle block on flow patterns inside it. In this paper, the effects of the velocity at the exit of the jet orifice and structure parameters of the nozzle block on the characteristics of the flow field inside the nozzle block has been analysed, which offers the basis of a theory for designing the nozzle system and optimising the spinning process.

## Numerical computation

A CFD model is constructed according to corresponding structure parameters of the



**Figure 1.** Schematic diagram of MVS yarn formation.

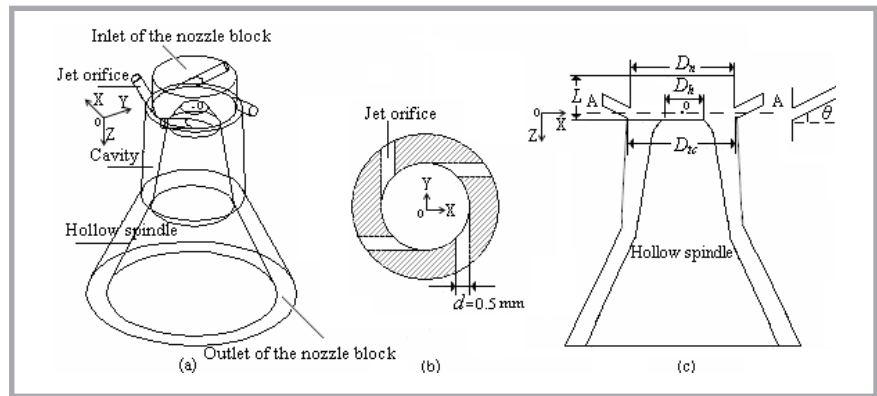
nozzle block of MVS No.861 (**Figure 2**). The flow field inside the nozzle block is computed numerically by applying the fluid flow analysis package (Fluent 6.2) and standard  $k-\varepsilon$  model of turbulence. It can be assumed that the flow inside the nozzle block is viscous, incompressible and isentropic. The planes at the inlet of the nozzle block and the hollow spindle are specified as the symmetry boundary. The exits of four jet orifices are defined as the velocity-inlet boundary, and the outlet of the nozzle block is termed the outflow. The inner wall of the nozzle block and exterior of the hollow spindle adopt non-slip boundary conditions.

There are many design parameters of the nozzle block, which influences the characteristics of the flow field inside it. These important parameters will be considered, hence the velocity  $u_0$  at exit of the jet orifices, the jet orifice angle  $\theta$ , the inner diameter at the inlet of the nozzle block  $D_n$ , the distance from the inlet of the nozzle block to the inlet of the hollow spindle  $L$ , and the outer diameter of the hollow spindle  $D_h$  have been selected for the numerical computation. Examples of numerical computation are shown in **Table 1**.

## Results and discussion

### Effect of the jet orifice angle on flowing patterns inside the nozzle block

The compressive air through the four jet orifices forms whirled airflow inside the nozzle block. The effect of the jet orifice angle  $\theta$  on the flow field inside the nozzle block is quite complex, and different  $\theta$  values result in variations in the tangential, axial and radial velocities. Velocity distributions of different  $\theta$  values at section A-A are shown in **Figure 3**.



**Figure 2.** Computational fluid dynamics (CFD) model; a) schematic model of the computational zone, b) projection of jet orifices at section, c) front view of the computational zone.

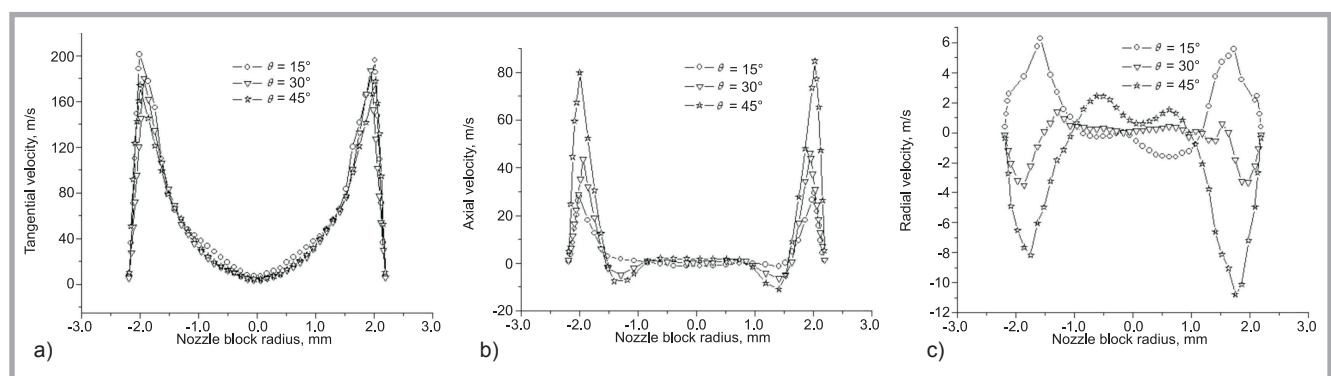
**Table 1.** Scheme of numerical computation.

Case	Velocity at the exit of the jet orifice $u_0$ , m/s	Jet orifice angle $\theta$ , deg	Inner diameter at the inlet of the nozzle block $D_n$ , mm	Distance from the inlet of the nozzle block to the inlet of the hollow spindle $L$ , mm	Outer diameter at inlet of the hollow spindle $D_h$ , mm
1	260	10	4.4	1.85	1.4
2	260	15	4.4	1.85	1.4
3	260	25	4.4	1.85	1.4
4	260	30	4.4	1.85	1.4
5	260	35	4.4	1.85	1.4
6	260	45	4.4	1.85	1.4
7	220	15	4.4	1.85	1.4
8	300	15	4.4	1.85	1.4
9	260	15	4.8	1.85	1.4
10	260	15	5.1	1.85	1.4
11	260	15	4.4	1.85	1.2
12	260	15	4.4	1.6	1.4
13	260	15	4.4	2.1	1.4
14	260	15	4.4	2.4	1.4

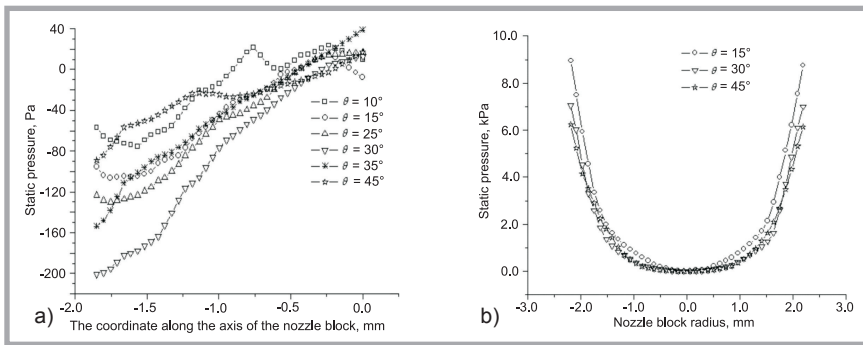
This shows that the tangential velocity decreases and the axial velocity increases along with an increasing  $\theta$  value. However, the distribution rule of the velocity does not change. The radial velocity influenced by the  $\theta$  value has an expanding effect on the fibre bundle, producing a large number of open-trail-end fibres, which also vary according to the  $\theta$  value. A higher tangential velocity twists open-

trail-end fibres expanded by the radial velocity, which will enhance the strength of the MVS yarn.

A change in airflow velocity will lead to a change in the airflow entrainment effect. The bigger the airflow entrainment effect, the higher the negative pressure at the inlet of the nozzle block will be. According to swirl-jet theory [14], the rela-



**Figure 3.** Velocity distributions with different  $\theta$  values along the radius of the nozzle block at section A-A; a) Tangential velocity, b) Axial velocity, c) Radial velocity.



**Figure 4.** Static pressure distributions with different  $\theta$  values along the nozzle block axis and its radius at section A-A: a) static pressure distributions along the nozzle block axis, b) static pressure distributions along the nozzle block radius at section A-A.

relationship between the airflow entrainment effect  $\frac{dm}{dx}$ , the airflow thrust  $G_t$  and the degree of swirl  $S$  of the jet-flow is

$$\frac{dm}{dx} = f \left[ (\rho G_t)^{\frac{1}{2}} S^q \right] = f \left[ (\rho G_t)^{\frac{1}{2}} \left( \frac{u_t}{u_a} \right)^q \right]$$

Where  $u_t$  and  $u_a$  are the tangential and axial velocity, respectively;  $q$  is a constant.

When the  $\theta$  value is fixed, the static pressure along the axis of the nozzle block gradually increases. Moreover, the static pressure value initially rises but then diminishes with an increasing  $\theta$  value, as shown in **Figure 4.a**. When the  $\theta$  value is no more than 30 degrees, increasing the  $\theta$  value will strengthen the airflow entrainment effect. The reason for this is that the enhance value of the thrust  $G_t$  is larger than the decreasing value of the degree of swirl  $S$ . When the  $\theta$  value is more than 30 degrees, the decreasing value of the degree of swirl  $S$  is dominant, which makes the entrainment effect weak and results in negative pressure at the inlet of the nozzle block, which decreases with an increase in the  $\theta$  value. Thereby the negative pressure is maximal when the jet orifice angle is 30 degrees. A higher

negative pressure at the inlet of the nozzle block allows the fibre bundle to successfully enter the inlet of the hollow spindle, and vice versa. The static pressure along the radius of the nozzle block decreases with an increasing  $\theta$  value, as shown in **Figure 4.b**, because enhancing the  $\theta$  value makes the tangential velocity diminish.

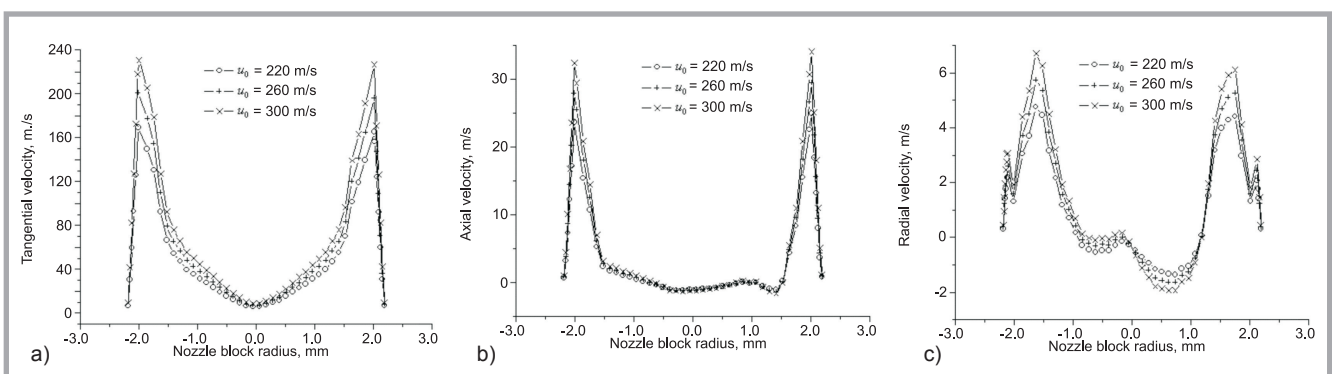
#### Effect of the velocity at the exit of the jet orifice on flow patterns inside the nozzle block

According to the hypothesis of isentropic flow, the fixed nozzle pressure  $p_0$  corresponds to the only velocity  $u_0$  at the exit of the jet orifice, and  $u_0$  increases with an increasing  $p_0$  when the velocity at the exit of the jet orifice is no more than the sonic speed [15]. Discussing the influence of the velocity at the exit of the jet orifice on flow characteristics inside the nozzle block means to describe the effect of the nozzle pressure on flow characteristics inside the nozzle block.

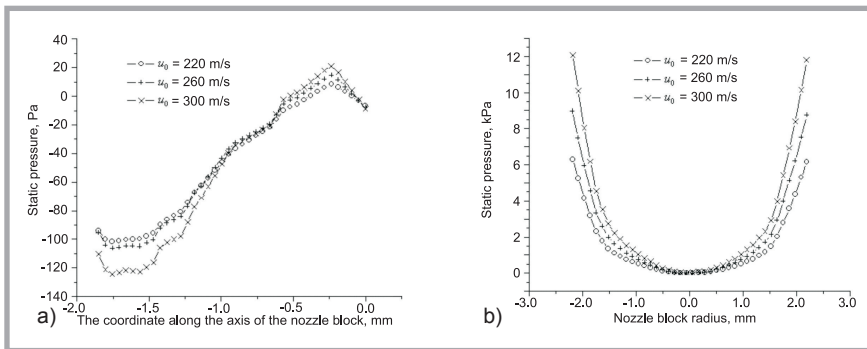
As shown in **Figure 5**, the tangential, axial and radial velocities inside the nozzle block increase with an increase in the velocity at the exit of the jet orifice (namely an increase in the nozzle pres-

sure); however, the distribution rule of the velocity does not change, still matching the theory of swirling flow [16]. The change in point from the potential swirling zone to the rigid swirling zone slowly closes at the center of the nozzle block. Increasing the nozzle pressure results in a radial velocity increase, which reinforces the expanding effect on the fibre bundle, producing more open-trail-end fibres. Wrapper fibres are produced by the twist effect of tangential velocity. Enhancing the tangential velocity can increase the efficiency of twisting open-trail-end fibres. As a result, the MVS yarn can gain better tensile properties. However, when the nozzle pressure is too high, the separated fibres are easily taken out of the fibre bundle by the high-speed airflow, which produces more wild and waste fibres and deteriorates the uniformity of the vortex spun yarn, as discussed by Zou et al. [13]. Improving the axial velocity easily makes open-trail-end fibres twine over the hollow spindle, the twisting efficiency thus being improved. These results are in accordance with Tyagi's experimental results [17].

Static pressure distributions with different  $u_0$  values along the nozzle block axis and its radius at section A-A are shown in **Figure 6**. The negative pressure at the inlet of the nozzle block increases with an increasing velocity  $u_0$  at the exit of the jet orifice (i.e. increasing the nozzle pressure). Increasing the negative pressure at the inlet of the nozzle block strengthens the suction effect, which allows the fibre bundle to enter the twisting chamber successfully. Furthermore, the extreme negative pressure allows the fibre bundle to enter the twisting chamber rapidly and makes the fibre bundle stay in the twisting chamber shorter, which lowers the tenacity of MVS yarn. Static pressure distributions along the radius of the noz-



**Figure 5.** Velocity distributions with different  $u_0$  values along the radius of the nozzle block at section A-A: a) tangential velocity, b) axial velocity, c) radial velocity.



**Figure 6.** Static pressure distributions with different  $u_0$  values along the nozzle block axis and its radius at section A-A; a) static pressure distributions along the nozzle block axis, b) static pressure distributions along the nozzle block radius at section A-A.

zle block at section A-A increase with an increasing  $u_0$  value because the nozzle pressure is enhanced.

### Effect of the diameter at the inlet of the nozzle block on the flow patterns inside the nozzle block

Velocity distributions inside the nozzle block change markedly when the diameter  $D_n$  at the inlet of the nozzle block is changed (Figure 7). However, the static pressure distributions are little affected by the diameter  $D_n$ . Tangential and axial velocities at the same radius of the nozzle block decrease with an increasing diameter  $D_n$ , while changes in the tangential and axial velocity at the center as well as in the radial velocity are not obvious. At the same radius of the nozzle block, when the diameter  $D_n$  is smaller, the tangential velocity is higher, which can improve the twisting efficiency. It should be emphasised that diameter  $D_n$  should match diameter  $D_{ic}$ , otherwise the dissipation of turbulent kinetic energy will augment. If diameter  $D_n$  decreases, diameter  $D_{ic}$  should likewise decrease. Hence, a comparatively small value of diameter  $D_n$  should be selected to obtain the highest velocity inside the nozzle block, where it can be required

that the twisting process of open-trail-end fibres not be impacted.

### Effect of the hollow spindle on flow patterns inside the nozzle block

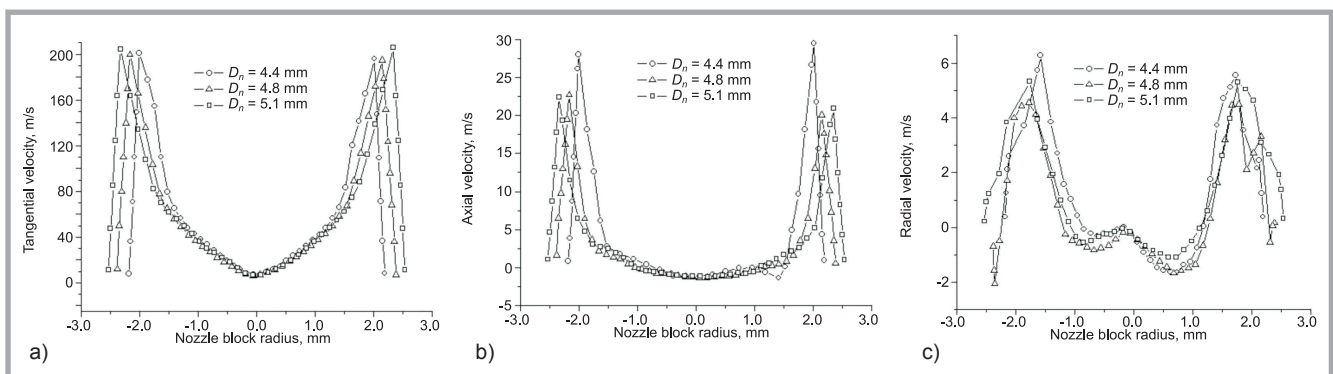
#### Effect of the outer diameter of the hollow spindle on flow patterns inside the nozzle block

The effect of the outer diameter of the hollow spindle on flow characteristics inside the nozzle block is discussed in cases 2 and 11. The result of numerical computation shows that the velocity of airflow inside the nozzle block is little affected by the outer diameter of the hollow spindle, the reason for which may be that the difference in the outer diameter of the hollow spindle in cases 2 and 11 is quiet small. However, the negative pressure at the inlet of the nozzle block is significantly affected by the outer diameter of the hollow spindle. The negative pressure at the inlet of the nozzle block with a smaller outer diameter of the hollow spindle is higher than that with a larger outer diameter of the hollow spindle (Figure 8). Therefore, the power for sucking fibres into the twisting chamber is strengthened when the outer diameter of the hollow spindle becomes smaller, which allows fibres to successfully enter

the hollow spindle, contributing to the parallelism and straightness of separated fibres.

### Effect of the position at the inlet of the hollow spindle on flow patterns inside the nozzle block

In Murata vortex spinning, the position at the inlet of the hollow spindle is quite an important parameter. In practical spinning, it can be assumed that the distance from the front rollers to the inlet of the hollow spindle is fixed. The distance from the front rollers to the hollow spindle becomes large when the  $L$  value (the distance from the inlet of the nozzle block to the inlet of the hollow spindle) increases. Hence, the  $L$  value becomes one of the factors significantly affecting the properties of vortexspun yarn. When the  $L$  value is larger, the negative pressure at the inlet of the nozzle block is higher, which allows the drafted fibre bundle to successfully enter the twisting chamber (Figure 9, see page 43). What is more, the space of the twisting chamber is larger when the  $L$  value is greater, permitting the twisting of open-trail-end fibres. However, the leading ends of the fibre bundle in the twisting chamber are easily disturbed by high speed airflow when the  $L$  value is excessive, which results in the waste fibre rate being extremely large, forming more thin places. The tangential velocity inside the nozzle block is smaller when the  $L$  value is larger (Figure 10, see page 43), but the difference in velocity is small when the variance of difference of the  $L$  values is small. Decreasing the tangential velocity results in weakening the twisting effect of open-trail-end fibres. Therefore, the property of vortex spun yarn first increases and then deteriorates along with an increasing  $L$  value. These results are in accordance with Liu's results [18].



**Figure 7.** Velocity distributions with different  $D_n$  values along the radius of the nozzle block at section A-A; a) tangential velocity, b) axial velocity, c) radial velocity.

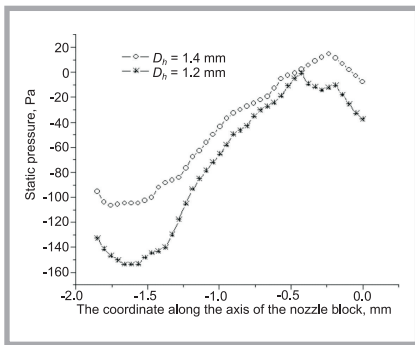


Figure 8. Effect of the outer diameter of the hollow spindle on static pressure.

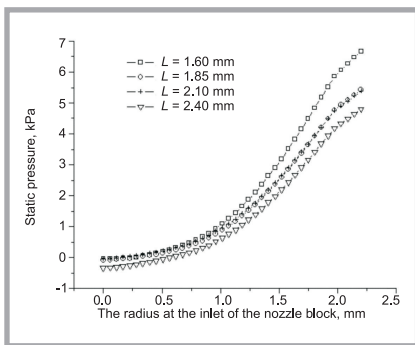


Figure 9. Static pressure distributions with different  $L$  values along the radius at the inlet of the nozzle block

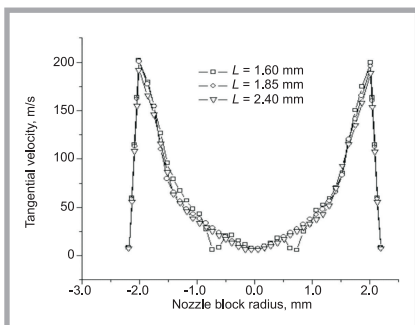


Figure 10. Tangential velocity distributions with different  $L$  values along the radius of the nozzle block at section A-A

## Conclusions

By numerical computation and analysis, the following conclusions can be drawn: The tangential velocity decreases with an increasing jet orifice angle, whereas the axial velocity increases with an increasing jet orifice angle. The radial velocity affected by the jet orifice angle follows no obvious rule. The negative pressure along the axis of the nozzle block first increases and then diminishes with an increasing jet orifice angle, its maximal occurring when the jet orifice angle is 30 degrees.

The tangential, axial and radial velocities as well as the negative pressure along the

axis of the nozzle block all increase when the velocity at the exit of the jet orifice rises. The higher the radial velocity, the bigger the expanding effect on the fibre bundle is, producing more wrapper fibres in the MVS yarn. Increasing the tangential velocity benefits the twisting of open-trail-end fibres. However, extreme high-speed airflow easily removes fibres separated from the fibre bundle, producing more wild and waste fibres, as well as deteriorating the uniformity of the vortex spun yarn. The axial velocity makes open-trail-end fibres twine over the hollow spindle, improving the twisting efficiency.

The tangential and axial velocities at the same radius of the nozzle block are smaller when the diameter  $D_n$  is larger, hence a comparatively small value of diameter  $D_n$  should be selected. The outer diameter  $D_h$  of the hollow spindle rarely affects the velocity inside the nozzle block, but the smaller the outer diameter  $D_h$ , the higher the negative pressure at inlet of the nozzle block will be.

With an increasing distance  $L$  between the hollow spindle and the inlet of the nozzle block, the airflow velocity inside the nozzle block diminishes, but the negative pressure at the inlet of the nozzle block increases. However, an excessive  $L$  value will result in producing more waste fibres, forming more yarn thin places.

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## Editorial note

This article has been presented at a conference

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