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Study on Hairiness reduction in Nozzle-Ring Spinning: Role of air drag forces and angle of impact of air current

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ABSTRACT

In this paper we report on the effect of axial angle of air inlets of air-nozzles on yarn hairiness reduction in Ring spinning. Simulation of airflow was carried out using Computational Fluid Dynamics Software (CFD) to compute drag forces acting on yarn and hairs. Nozzle-Ring yarns have lower hairs compared to control yarn in all hair-length groups. The drag forces play an important role in reducing yarn hairiness. It is observed that the angle of air inlets decides the direction of impinging of air on the hair and hairiness reduction.

1 Introduction

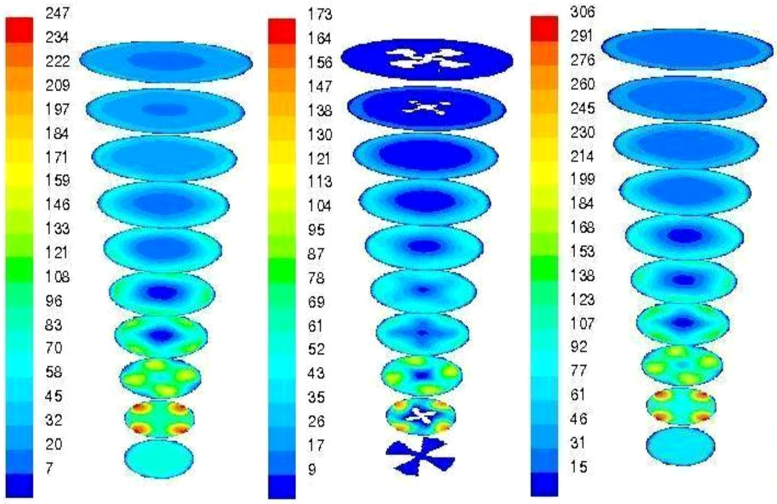
The hairiness of yarns can be controlled by placing an air-nozzle at winding machine or at ring frame[1-12]; the later is termed as 'Nozzle-Ring spinning'. Nozzle positioning, mechanism of hairiness reduction and effect of nozzle and process parameters on hairiness reduction are discussed in a series of papers [7-12]. In this study we report on the role of axial angle of air inlets on airflow velocity and their effects on hairiness using results of airflow simulation and experiments.

2 Experimental

Three divergent nozzles were used for the study. The axial angle of air inlets were: 40, 50 and 60°. Nozzle-housing was fixed in the spinning region of the ring frame without altering the yarn path significantly. 30 tex cotton yarns were spun with and without nozzle (control sample). Air pressure in the nozzle was kept at 0.5 bar (gauge).

2.1 Airflow Simulation

To analyze the airflow pattern, simulation of airflow was carried out using a fluid flow analysis package, Fluent 6.1[13, 14]. To solve the three-dimensional airflow field inside the nozzles, a CFD (computational fluid dynamics) model was developed. It is assumed that the airflow affects the yarn but the presence of yarn inside the nozzle has no effect on airflow. A typical mesh design of the nozzle is build of 50000 to 60000 finite volumes. The air velocity profiles are given in Fig. 1.



*White color shows velocity magnitude of -1 m/s for (b)

Fig. 1 Air velocity plots for a nozzle: (a) axial; (b) tangential; and (c) resultant velocity

2.2 Computation of Air Velocity and drag forces acting on yarn and hairs

A solid cylinder representing the yarn was superimposed on the air velocity profile to obtain air velocity acting on yarn surface. Airflow can be split into two mutually perpendicular directions: parallel to the yarn axis and perpendicular to it. The forces exerted on a body by the longitudinal (parallel to nozzle axis) and transverse (normal to nozzle axis) airflows are given by the respective longitudinal and transverse drag forces. In fluid dynamics, equations have been developed to quantify the drag forces on smooth circular cylinders which are analogous to yarns[15, 16]. The longitudinal drag force (F_l) or (LDY) on yarn is given by:

$$F_l = \frac{1}{2}\rho V_l^{\,2} S_l C_{Dl}$$

where, ρ = density of the air (kg/m^3);

V_l = the relative velocity between air (inside the nozzle) and yarn (m/s);

S_l = surface area of yarn, m^2 = $\pi\, d_y\, l$

l = length of the yarn (m).

C_{Dl} = drag coefficient related to Reynolds number as: $R_e = \dfrac{V_l\, d_y}{\mu/\rho}$

where, d_y = the diameter of the yarn (m);

μ = the viscosity of air (N s/m^2).

Similarly, transverse drag forces were also calculated.

3. Results and Discussion

3.1 Trajectory of Airflow in the Nozzles

The resultant air velocity (VR) is resolved into three components viz. axial (Va), tangential (Vt), and radial (Vr). Swirling of airflow is created by the tangential and axial velocity components of air velocity. All the four air holes lie on the same horizontal plane. Absence of staggering of air inlets helps to generate swirling airflow. Swirling intensity depends on the drag force and angle at which it acts on yarn or fibre, the former varies with the square of the resultant velocity of air and the later on the ratio of the tangential and axial velocity components of airflow.

3.2 Process of hairiness reduction

When a yarn enters the nozzle, a hair may bend over the yarn depending on the magnitude of the transverse drag forces acting on it. This may happen at any of the normal planes. A long hair can bend more easily than the shorter ones. This would be accompanied by wrapping of hair around the yarn. Once the hair is bend and laid over the yarn surface, drag forces (LDH) due to the resultant velocity of air on yarn surface would wrap it around yarn body (if they are sufficient). So, bending of a hair can be considered as a prerequisite for it to be wrapped over the yarn surface, and hence, reduction in yarn hairiness. Bending and wrapping of hairs are most likely to take place at planes 0 to 1 due to the presence of high magnitude of forces.

3.3 Hairiness of yarns

Table 1 shows the hairiness values of control (without nozzle) and Nozzle-Ring cotton yarns processed with upward airflow direction with nozzles having air inlets of different axial angles. Nozzle-Ring yarns have lower hairs compared to control yarn in all hair- length groups. Nozzle having air inlets with axial angle of 40º produces yarn with least hairiness, followed by 50º and the least performing one is 60º.

Table 1 Hairiness values of yarns

	Number of hairs/100 m length of yarn						
Sample code	N1	N2	N3	N4	N6	N8	S3
Control	2810	275	84	43	10	1	138
40	2642	253	43	17	5	0	65
50	2612	269	48	17	7	0	72
60	2729	259	55	23	7	0	85)

3.4 Air drag and angle of impact on hairiness

The resultant velocity of air and transverse drag forces acting on hairs for the nozzle with 40º are higher than that of the nozzles 50º and 60º at 0- and 1- planes (Fig. 2 and 3) where bending of many hairs might take place, followed by wrapping them around the yarn body, hence the nozzle-40º could achieve a higher hairiness reduction than the rest.

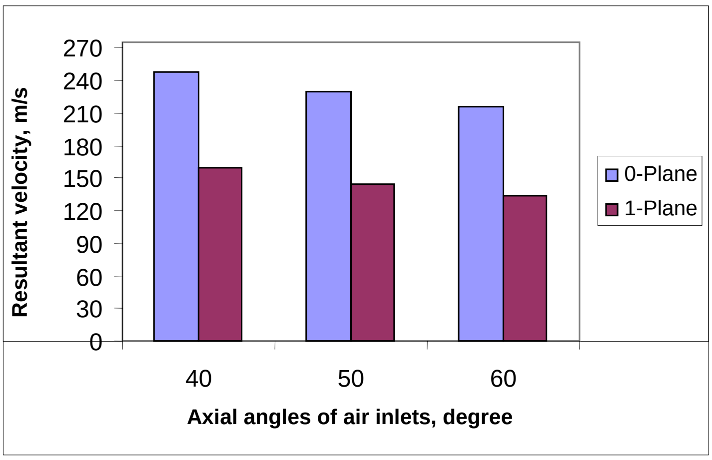


Fig. 2 Resultant air velocity on hairs (Angles: 40, 50, and 60º)

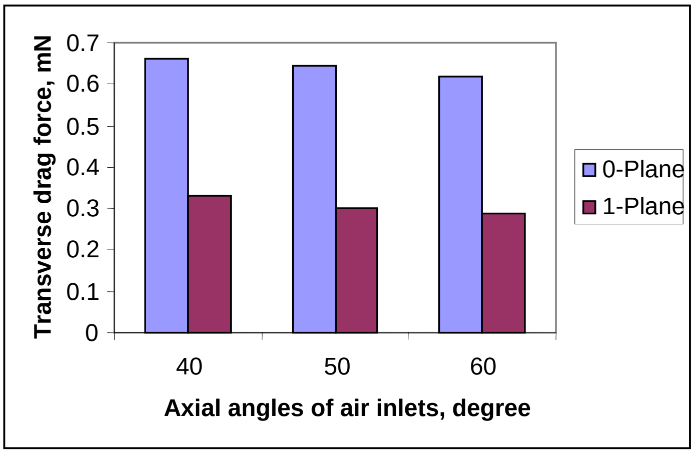


Fig. 3 Transverse drag forces acting on hairs (Angles: 40, 50, and 60º)

The values of the angles of impact of air on hair at 0-plane are 52, 35 and 17º for nozzles with angle of air inlets 60, 50 and 40º respectively. When the impact angle is higher as in the case of the nozzle with large axial angle of air inlets (nozzle-60º), curving of fibres occurs during folding of hairs; and the wrapping of the curved fibres would be difficult. When the impact angle is less as in the case of nozzles (40º and Z50º), hairs may fold without much curving and wrapping would become easier. This may be another reason (apart from the air drag forces) for more hairiness reduction observed in the case of nozzle Z40 compared to others.

4. Conclusions

Three divergent types of nozzles varying in axial angles of air inlets were investigated for their effectiveness in reducing yarn hairiness during ring spinning. Using CFD, airflow inside the nozzles is simulated to get the air velocity profile, from which longitudinal and transverse drag forces acting on yarn surface and hairs were calculated for different nozzles. Nozzles reduce long hairs (S3) by 40-50%. The hairiness reduction is due to folding and wrapping of the hairs during untwisting of the yarn followed by re-twisting of the yarns. Nozzle having axial angle of air inlets 40º reduces the hairiness the most, followed by the nozzles with 50º and 60º. The hairiness reduction is influenced by the level of air drag forces acting on the hairs. Nozzle having large axial angle of air inlets produces airflow with very high impact angle, leads to fibre curving during fibre folding and hence poor wrapping and consequently less hairiness reduction.

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