

Finite volume analysis of airflow field in the dual-feed and conventional rotor spinning unit

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Abstract. The paper compares the unsteady airflow field in the conventional and the new dual-feed rotor spinning unit. A 3D finite volume computation (with optional turbulence model) is adopted to simulate the airflow dynamics with a focus on the rotor interior. The equations are solved using Fluent 14.5 package. The airflow results reveal that the second transfer channel effect is significant, particularly in the rotor interior. Visualization of iso-surfaces and velocity magnitude in the two reveal a striking difference in the internal flow patterns and turbulent strength. Comparison of the yarn properties spun on the two systems shows improved tenacity, elongation, and yarn evenness. A Small variation in yarn hairiness of the respective spun samples is observed.

1. Introduction

The flow in the interior of the rotor spinning unit is a complex phenomenon involving fiber, air interaction and the negative pressure, rotating rotor among other rotor spinning conditions. Although 2D two-phase flow studies have provided more insight on the flow dynamics in the rotor interior in the rotor, the 3D two-phase model is still a mystery[1]. There are still many open questions regarding the fundamental aspects of the flow in the rotor interior which make it challenging to evaluate the flow dynamics in the interior of the rotor. Fundamental research regarding the application of computational fluid dynamics to study airflow dynamics has been significantly undertaken[2,3]. A recent trend in the implementation of numerical analysis has reported tremendous success in solving interdisciplinary problems[4–6]. The dual-feed rotor spinning concept is a new phenomenon that has revealed a fundamental potential in open-end yarn quality improvement as per previous literature[3,7,8]. The need to study intricate details of the dual-feed working principle is paramount in generating a reliable principle for mass commercialization. This paper reports the finite element analysis airflow in the interior of the novel dual-feed rotor spinning unit and the conventional unit and the dual-feed under similar conditions. Two computational fluid dynamic models are built and simulated using a commercial package (Fluent), visualization of the iso-surfaces and velocity magnitude is carried out. The yarn properties are examined too as well as consideration of related studies undertaken.

2. Methods and procedure

Computation and numerical solution of the model were achieved using FLUENT 14.5. The model was designed in solid works and implementation of meshing and refinement achieved in post processing



tool of Fluent. We applied tetrahedron meshing, and for accuracy and mesh independence tests; three grids were considered. The meshed models utilized in this study retained the boundary conditions similar to our previous works[3]. After analysis of residuals and comparison of airflow characteristics, one mesh was chosen for this study. Our main attention was mainly on velocity and Iso-surfaces inside the rotor.

In the simulation set-up, the pressure inlet was kept at the atmospheric pressure, pressure outlet set to -7000pa, inlet velocity magnitude of 20m/s, and the rotor speed was attuned to 100,000 r.p.m which is distinctive of commercial rotor spinning machines. The boundary conditions adopted were arrived at by comparison with the existing literature[9]. Figure 1 (a) and (b) illustrate the dual-feed and conventional rotor spinning unit.

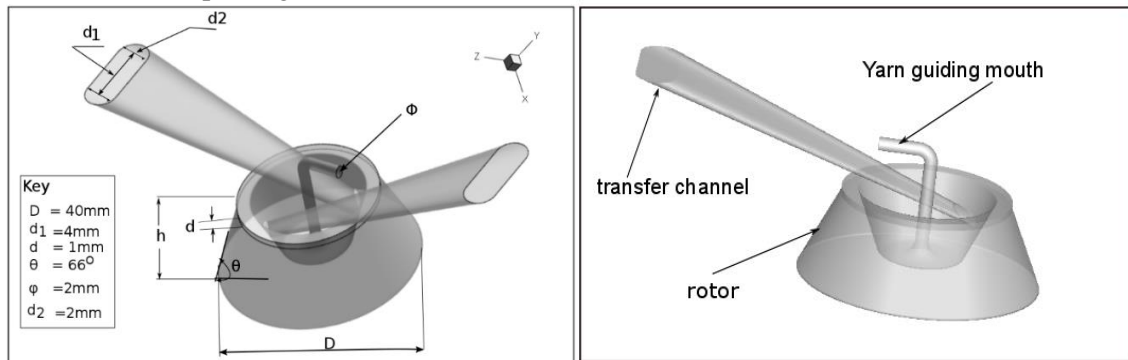


Figure 1. (a) Dual-feed rotor spinning unit

(b) Conventional rotor spinning unit.

Generation of results for analysis was considered on the x - y plane at $z=0.00018$ by extracting the three-dimensional view of the slice layer cutting across the yarn guiding mouth and part of the transfer channel regions. Along the x - z plane at $y=0.003$ m, velocity contours were also extracted because this region locates at the rotor groove where the slivers are laid during the spinning process. The airflow visualization obtained at this region provides clear contour regions and areas of velocity fluctuations which provide a clear-cut pattern of in the rotor interior. The iso-surfaces colored and filled by the velocity magnitude were also extracted to supplement the airflow study further.

3. Mathematical model and numerical procedure

Classical modeling of turbulence is founded on the Reynolds concept, which for incompressible and Newtonian fluids yields the following equations (see Equations 1-5). The principal equations, which include mass conservation equation and the momentum conservation equation viz;

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{v} = 0 \quad (1)$$

Where ρ the fluid density and \mathbf{v} is a velocity vector. This equation implies that, the sum of the time-dependent change of density ρ and the three-dimensional of the current density $\rho \mathbf{v}$ is zero.

$$\frac{\partial(\rho u_i)}{\partial t} + \text{div}(\rho u_i \mathbf{u}) = \text{div}(\mu \text{grad} u_i) - \frac{\partial p}{\partial x_i} + S_i \quad (2)$$

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \quad (3)$$

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_j} = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k - \rho \varepsilon \quad (4)$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial(\rho \varepsilon u_i)}{\partial x_j} = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + \frac{C_{1\varepsilon}}{k} G_k - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k} \quad (5)$$

The equation terms and empirical constants have been well articulated in our previous works[10]. The k - ε model is derived using a statistical technique called the renormalization group theory. Boundary conditions on the rigid walls were set in the form of non-equilibrium wall functions. Numerical simulation of airflow for the conditions identical to both the dual-feed and conventional

rotor spinning unit were performed using FLUENT software commercial package. A strict, non-uniform mesh was generated for the computational domain. Grid independence test was performed to ensure that the grid size does not influence the accuracy of the solution. A grid of 494,257 elements was assumed after the grid independence test.

4. Results and discussion

This work evaluates characteristics of the airflow field by visualizing the iso-surfaces in the two models. The velocity magnitude in the rotor interior and the iso-surfaces and a precise analysis of pressure distribution in the rotor interior were undertaken. A detailed evaluation of the yarn quality characteristics is also revealed.

Extraction of the velocity profiles in the two models was achieved in Tecplot CFD Visualization tool. The iso-surfaces clearly show the flow field and the airflow patterns, the effect of the second dual-feed is vividly observed as the flow in the rotor interior significantly changes (see Figure 2). The dual-feed concept is anticipated to have a positive impact on the way fibers are oriented in the final yarn structure. The primary reason for introducing a dual-feed concept was to facilitate blending, facilitate better fiber opening, effective trash removal and hence improve the yarn quality.

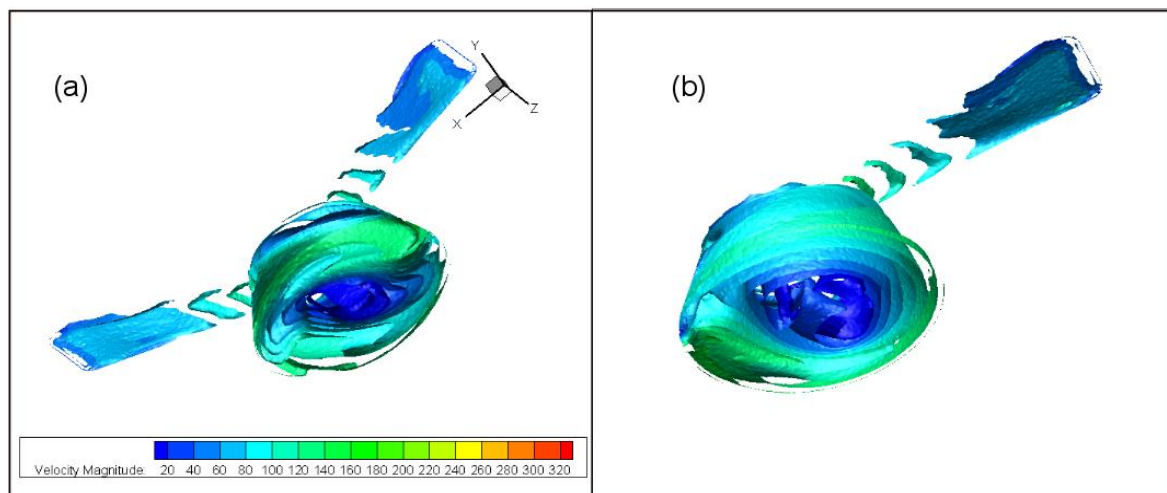


Figure 2. Iso-surfaces of velocity profiles in the interior (a) dual-feed (b) Conventional rotor spinning unit.

The overall velocity magnitude observed, shows that the second feed resulted into substantial fluctuations in the airflow dynamics. The velocity profiles in the dual-feed model predict a significant shift in the way fibers can be arranged inside the rotor. The balanced velocity flow profiles characterized extreme sections of the rotor interior compared to the single channel. Our simulation results anticipate improved fiber alignment. However, this should be proved experimentally. Our recent works on the evaluation of drag force and other turbulence properties agree quantitatively with the findings in this paper. In figure 3 and 4, the velocity profiles are viewed in different perspective, and a clear difference in the two models is visible.

The results support the hypothesis that as fibers flow through the rotor unit, they adopt an airborne state, the velocity profiles show the clear paths and velocity variation, which can be used to predict the manner of fiber movement. The difference in iso-surface patterns is significant implying a change in the fiber configuration process. Two cotton yarn samples of the 58tex count were spun on the two machines under similar conditions for the purpose of comparing the mechanical properties. The tenacity of the dual-feed spun yarn increased by 16%, elongation by 10%, and CVm(%) improved by 13%. Thin places were greatly reduced with the proposed model (33% reduction of thin places). Hairiness and thick places were not significantly improved.

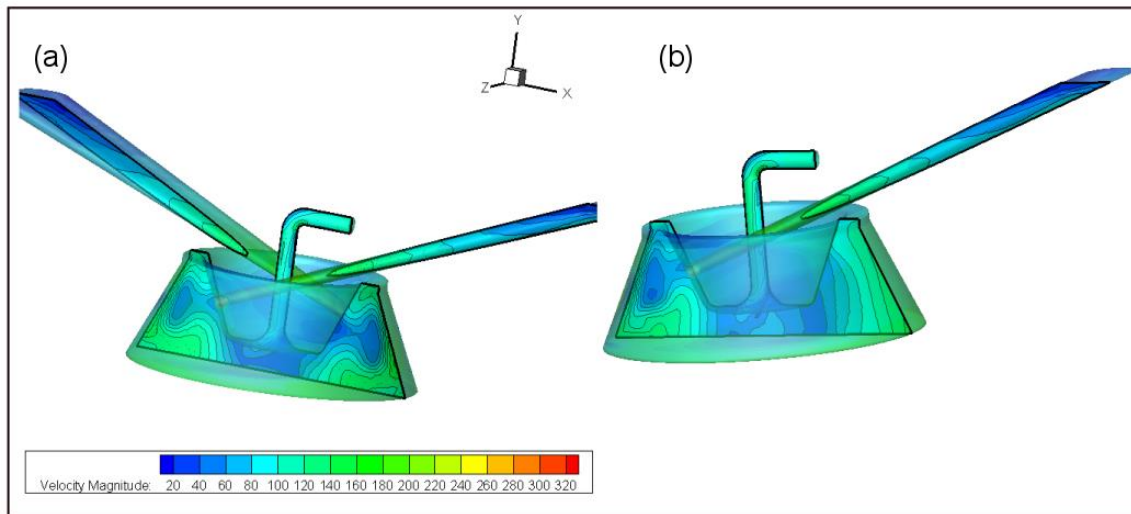


Figure 3. Visualization of velocity magnitude at $z=0.00018\text{m}$. (a) dual-feed (b) conventional rotor spinning unit.

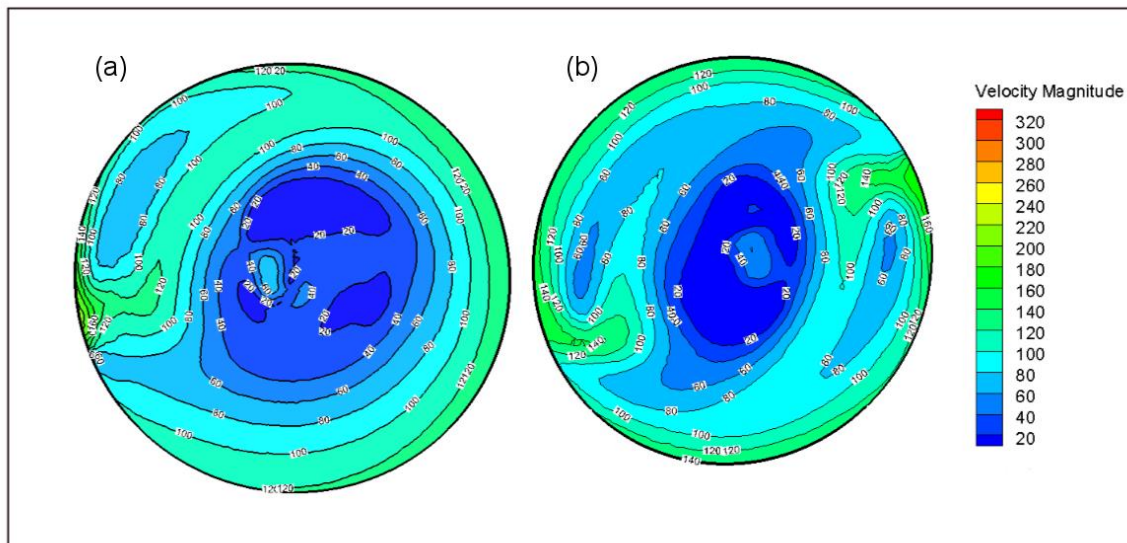


Figure 4. Velocity magnitude contour at $y=0.003\text{m}$ located near the rotor groove position

Figure 4 extracts the velocity contours located at the position where slivers are processed during the spinning process. The velocity contours were numbered by magnitude to find out regions of higher velocities. It is noticed that despite the clear difference in the flow patterns were imbalanced velocities were depicted in the conventional rotor spinning unit. The higher velocities were observed at the contours on the extreme layer near the presumed rotor groove. The variation between the two models is somewhat minute implying that the second channel doesn't necessarily create more unpredictable chaotic flow in the rotor. Rather, a balanced pattern is observed hence accounting for the extensively reported improvement in the yarn properties of yarns spun on this system. The results show that the new prototype leads to more orderly flow with minimal eddies which is anticipated to have a positive influence on fiber processing and consequently the resulting yarn quality characteristics.

Figure 5 illustrates the pressure distribution in the rotor of the conventional and modified rotor spinning process. The region opposite the transfer channel outlet of the conventional model was

exhibited by pressure ranging from -8000 to -6000pa with the center largely dominated by -8000pa. On the contrary, the pressure distribution in the modified model is evenly distributed with the transfer channel exit positions occupied by traces of positive pressure of up to 6000pa. The pressure difference in internal flow system is a very fundamental parameter due to its influences the forces and moments such as drag and lift forces. The effect generated by pressure difference eventually influences the airflow dynamics and hence the production process. Relatively evenly distribution pressure profiles achieved through additional transfer channel significantly stimulates the fiber processing mechanics.

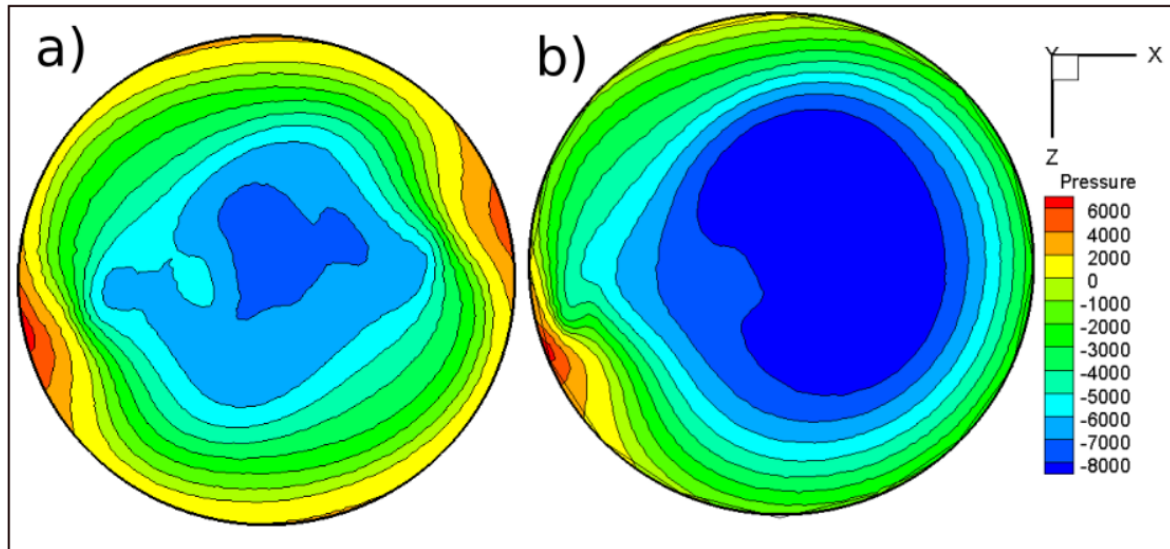


Figure 5. Pressure distribution contours at $y=0.003\text{m}$ located near the rotor groove position

5. Conclusion

The validation of any turbulence model remains a crucial step in the fully justified application. In this paper, two equation k-epsilon turbulence model was tested through the implementation of finite volume analysis to study the airflow in the two rotor spinning models. The results attained provided a striking difference in the flow domain in the two cases. The yarn quality properties from yarns made on a few reported dual-feed concepts revealed the potential of the dual-feed concept. The present works provide the tangible foundation of numerical results that can be validated via experiment in future. Experimental measurement of the airflow parameters in the two models would provide valuable assessment for the model. Nevertheless, the model arrived at in this work revealed fundamental insights. We conclude that the second channel introduced imparts a huge difference on the flow mechanics. The velocity and pressure inside the rotor of the new model appeared evenly distributed compared to the conventional one. This effect is anticipated to improve fiber configuration, and alignment since one of the challenges in rotor spinning is maintaining the fiber alignment as the fibers are conveyed to the rotor surface.

Acknowledgments

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References

- [1] Kong L X and Platfoot R A 1997 Computational two-phase air/fiber flow within transfer channels of rotor spinning machines *Text. Res. J.* **67** 269–78
- [2] Akankwasa N T, Lin H and Wang J 2017 Evaluation of the dual-feed rotor spinning unit based on airflow dynamics and blended yarn properties *J. Text. Inst.*
- [3] Akankwasa N T, Lin H, Zhang Y and Wang J 2016 Numerical simulation of three-dimensional airflow in a novel dual-feed rotor spinning box *Text. Res. J.* 4051751667723
- [4] Lin H, Bergadà J M, Zeng Y, Akankwasa N T, Zhang Y and Wang J 2017 Rotor spinning transfer channel design optimization via computational fluid dynamics *Text. Res. J.* 4051751769898
- [5] Szmyd J, Branny M, Karch M, Wodziak W, Jaszczur M and Nowak R 2013 Experimental and Numerical Analysis of the air Flow in T-Shape Channel Flow / Eksperymentalna i numeryczna analiza przepływu powietrza przez skrzyżowanie kanałów w kształcie litery T *Arch. Min. Sci.* **58** 333–48
- [6] Šidlof P, Müller B and Horáček J 2011 Numerical Analysis of Airflow in Human Vocal Folds Using Finite Element and Finite Volume Method *M* 917–9
- [7] Peyravi A, Eskandarnejad S and Moghadam M B 2014 Dual-feed rotor spinning of cotton fiber: trash separation and yarn properties *J. Text. Inst.* **105** 377–82
- [8] Nicholus Tayari Akankwasa, Lin H and Wang J 2017 Evaluation of drag and lift in the internal flow field of a dual rotor spinning unit via CFD *2nd International Conference on Mechanical, Manufacturing, Modeling and Mechatronics, University of Gent* (Matec Web of Conferences) p 1-6
- [9] Lin H T, Zeng Y C and Wang J 2016 Computational simulation of air flow in the rotor spinning unit *Text. Res. J.* **86** 115–26
- [10] Nicholus Tayari Akankwasa, Lin H and Wang J Evaluation of the dual-feed rotor spinning unit based on airflow dynamics and blended yarn properties *J. Text. Inst.*