THERMAL SCIENCE, Year 2012, Vol. 16, No. 5, pp. 1414-1418

EXPERIMENTAL STUDY ON FIBER SUSPENSIONS IN A CURVED EXPANSION DUCT WITH PARTICLE IMAGE VELOCIMETRY

by

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Short paper
DOI: 10.2298/TSCI1205414L

The visualization measurement of internal flow field in a curved expansion duct is experimentally studied using particle image velocimetry technology and the influence of flow rate on flow field is analyzed. The streamline distribution and related performance curve in the internal flow field can be figured out through further analysis of experiment data. The results show that fiber orientation is mainly affected by velocity gradient, the fibers near the wall are aligned with the flow direction more quickly than the fibers in intermediate region, and the fibers near the concave wall are more quickly aligned with the flow direction than the convex wall. The larger inlet flow rate which will accordingly lead to increase inlet velocity enables the more quick adaptation and steady of fibers in flow direction.

Key words: *fiber suspensions flow, curved expansion duct, experiment study, particle image velocimetry, orientation*

Introduction

Fiber suspensions flow has widely applications in papermaking, chemical industry, medical treatment, environmental protection and other industries. The flow of fiber suspensions is divided into internal flow and external flow, and internal flow is further divided into simple flow and complex flow. Simple internal flow contains pipe flow, channel flow, wedged contraction flow and so on; and the typical case of complex flow is the flow in rotating impeller, what the complexity is that the rotation effect and the curvature effect of blade affect the flow simultaneously.

Over the past twenty years the fiber orientation distribution in the flow has been studied [1-5]. The main numerical methods for simulating the fiber orientation distribution include lattice Boltzmann method [6], the method of combining the slender body theory and the spectral method [7], and the Lagrangian method [8]. For the complexity of the problems, very few experimental studies focuses on the internal flow so far. You *et al*. [9] studied the stability of fiber suspension flow in channel. The results show that the fiber suspensions flow becomes unstable

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easily than the Newtonian flow under the same Reynolds number. The fibers in the suspension play a role of suppressing the instability of the flow. Yasuda *et al*. [10] reported their experimental results of flow-induced fiber orientation and concentration distributions in a concentrated suspension flow through a slit channel containing a cylinder. The flow regimes in closed channel flows of wood fiber suspensions was studied by Jasberg *et al.* [11]. Metzger *et al*. [12] investigated the instability of a sedimenting suspension of fibers. Only Zhang *et al.* [13] make a numerical simulation of the fibers orientation distribution in fiber suspensions flow in a curved expansion duct. The flow field is roughly divided into two areas, the near wall area and the central area. In the near wall area, the fiber orientation is close to local flow direction, but in the central area, congruence between the fiber orientation and local flow direction is not obvious. It shows that the fiber orientation is not easy to adapt to flow direction in weak shear area.

Experiment details

The experimental apparatus of fiber suspensions flow is illustrated in fig. 1. The power plant of test device, which is 60 W in power, 1 m in head and 400 ml/s in flow rate is a small self-priming pump, the flow rate is adjustable. Organic glass of the test section curved expansion duct is 50 mm in clear height. The both ends of duct is cemented by PMMA tube which is 40 mm in DN. The fiber in the present work whose density is 1.14 gcm^{-3} and diameter 0.019 mm and 0.0275 mm, respectively, is synthetic fiber-polyamide fiber (nylon 6.6). After the shearing, aspect ratio of nylon fiber ranges from 20 to 100. The particle image velocimetry (PIV) system produced by German Lavision company is consist of dipulse Nd:YAG laser, 2 CCD camera, synchronous controller and computer systems. It can samples up to 10~15 Hz and be able to measure transient flow field.

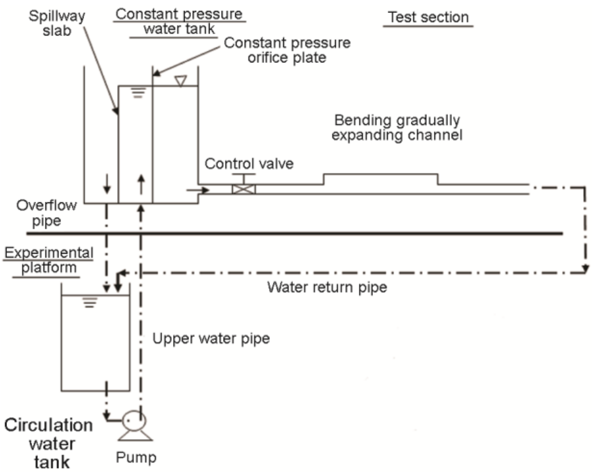

Figure 1. Test equipments

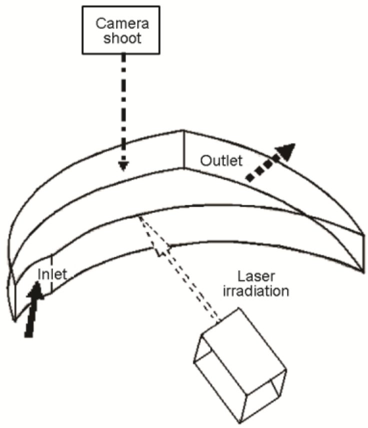

Figure 2. PIV working schematic diagram

CCD digital camera overhangs the right above the test section of curved expansion duct. Adjust the height, position and focal length to cover the shooting area and get clear imaging (as shown in fig. 2). Hollow glass beads used in experiment which is PIV special tracer particles, has particle size ranges from 1~5 micron, main chemical composition SiO_2 > 65%, and density approximate to pure water. Water is injected into the tank and constant pressure water tank contains spillway slab and constant-pressure orifice plate, and the spillway slab is 5 mm less than the top of the constant-pressure water tank.

Results and discussions

The density and dynamic viscosity of fluid medium is $\rho = 10^3$ kg/m^3 and $\mu = 10^{-3}$ Pa·s respectively. Reynolds number of inlet is $\mathrm{Re} = \rho Qd/A\mu$, where A is the inlet area; inlet radius is $R = 50$ mm. Time averaged pictures of flow field velocity vector, streamline, and vorticity are shown in figs. 3, 4, and 5, respectively, under different flow rate as shown in tab. 1. Figure 4 shows the fluid move along the concave surface steady after flow into duct. Thus, the fluid velocity near the concave surface is larger than others and local static pressure is lower, then the flow near outlet flow to the concave surface and a great vortex is formed near the convex surface at outlet. In addition, it can seem roughly from above diagram, the scale of the vortex is not large relative to flow rate. Figure 5 shows the vortex near the outlet has extrusion effect on flow in duct which make the velocity of flow in region 1 and region 2 greater, especially, velocity in region 1 is the greatest. Velocity in the center of the two regions will became larger as the flow rate of inlet increase.

Table 1. Flow rate flow parameters

Item	A	B	C
Q [mls^{-1}]	400	300	200

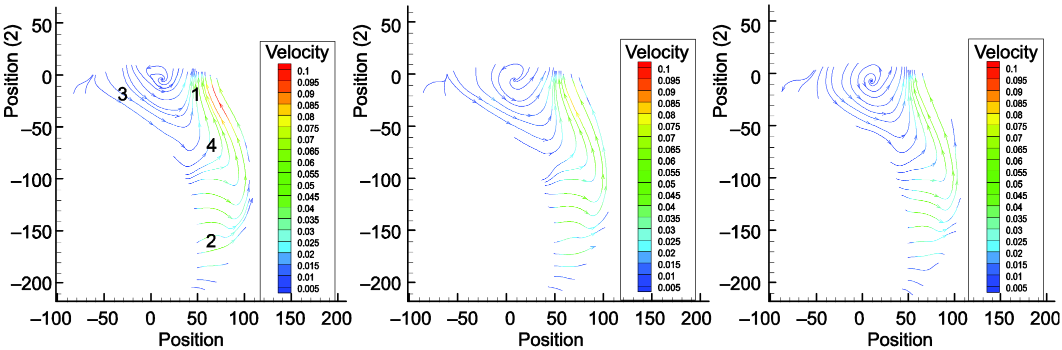

Figure 3. Time averaged pictures of streamline in different flow rate

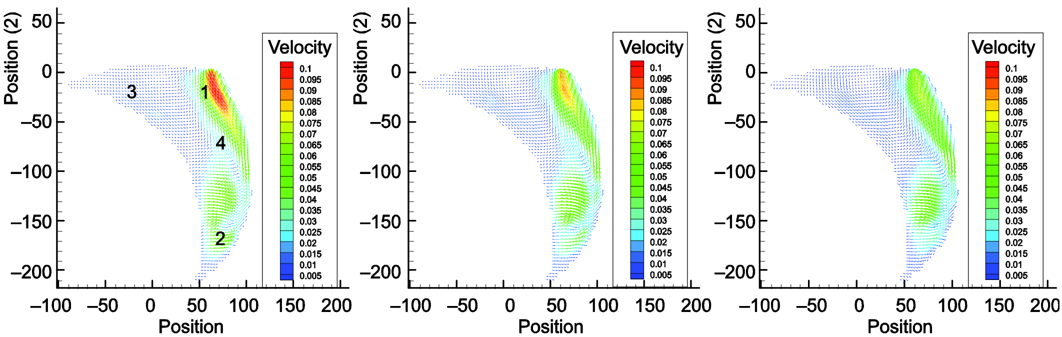

Figure 4. Time averaged pictures of velocity vector in different flow rate

It can seem from vorticity diagram, there is a narrow strong vorticity band between region 1 and region 2. Strong positive vorticity and strong negative vorticity are distributed like a

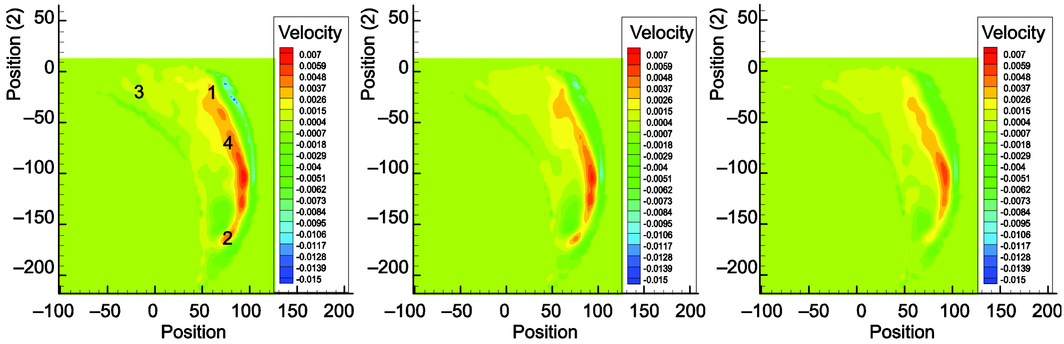

Figure 5. Time averaged pictures of vorticity in different flow rate

band near the concave wall, and between the strong positive vorticity and strong negative vorticity there is a narrow weak vorticity band, the wide weak vorticity band is close to convex wall. As the flow rate increases, the strong positive vorticity and strong negative vorticity develop to outlet of channel. Moreover, the largest vorticity intensity is distributed in the intersection of outlet and concave wall where has largest velocity and velocity gradient.

Conclusions

Fluid from inlet directly impact the concave surface and attach to it steady. Velocity of fluid in concave surface near the outlet is greater and its corresponding static pressure is smaller, which leads the surrounding fluid flow to concave surface and generate a big vortex near the convex wall at outlet.

The vortex could block the effective flow area of bend channel to a certain extent and fluid accumulated close to convex wall at inlet. The fluid accumulation in region 1 and region 2 also has greater velocity gradient. The fibers near the wall are aligned with the flow direction more quickly than the fibers in intermediate region. And the fibers near the concave wall are more quickly aligned with the flow direction than the convex wall. The larger inlet flow rate which will accordingly lead to increase inlet velocity enables the more quick adaptation and steady of fibers in flow direction.

Acknowledgment

This work was supported by the Scientific Project of Zhejiang Province (2008C01024-4).

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Paper submitted: August 1, 2012
Paper revised: September 5, 2012
Paper accepted: September 12, 2012