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THE DESIGN AND AERODYNAMIC TESTING OF DPIK PROBE

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Abstract: *The isokinetic probe used to detect the liquid phase drift from the cooling tower is presented here. The main motivation is costs reduction that arises during standard drift measurements. The probe was developed in the framework of the grant project between private company 4Jtech and Institute of Thermomechanics. The aerodynamic design and optimization of this probe should fulfill one important criterion – to capture the droplets from the drift with maximal efficiency. Kalorimetric principle is then used to evaluate the amount of trapped water. Standard PIV (Particle Image Velocimetry) measurement technique and modified IPI (Interferometric Particle Imaging) methods were used to measure the flow field topology and the particle size distribution, respectively.*

Keywords: Isokinetic probe, Cooling tower, PIV, Droplet size.

1. Introduction

The requirement for the drift from cooling towers, to be as low as possible, is gradually turning into law worldwide. There are many reasons for this, and one of them is to eliminate the spread of bacteria Legionella Pneumophila. DPIK (Drop-Hunter Probe Izokinetic) is advanced probe which was developed by 4Jtech company in cooperation with Institute of Thermomechanics. This devise is to be applied as a novel method for in-field drift rate measurement inside cooling towers. This method should enable to determine the liquid phase drift from the space of the cooling towers in one moment via the net of the simple sampling probes working on calorimetric principle. The method will be able to capture the drift size equal to 0,0001% of the circulating water and will be applicable in the standard cooling tower within 8 hours. The price of measurement will be lower in comparison with classical methods.

The third variant of the model geometry is presented here. This one is optimized for maximum drift capture and, at the same time, for optimal assembly of heated elements and its microelectronic equipment. The goal of this article is to describe the geometry of the probe and to show some results from PIV measurements. Also the IPI measurement technique is shown in a non-standard configuration.

2. Experimental setup

The test stand, which was applied to mimic the real conditions of the cooling tower, was built up in the Laboratory of turbulent shear flows. It consists of an inlet part, a straight part, an elbow and an output. The fan is used and embedded into the inlet to deliver the flow with seeding particles through the whole stand. There is a honeycomb to homogenize the flow behind the elbow. The probe model is fixed directly behind the outlet orifice which has dimension 250 x 250 mm.

The model of the probe was designed with regard to use optical measurement techniques (PIV and IPI). The basic plate was made by 3D printing. The shape of the channel was created by a transparent foil which was inserted into grooves in printed plate. The front panel was made from plexiglass to allow optical access. The laser illumination was done through the transparent foils. The inner channel cross-sectional dimensions

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are 20 x 20 mm. The model of probe can be visible in Figure 1. The small fan is used as a part of the outlet to ensure the same flow velocity inside the probe as in the model of the tower.

Dynamic similarity of the flow field through the probe inner channel is given by Reynolds number and Stokes number. The Reynolds number is given by

$$Re = \frac{u \cdot L}{\nu} , \tag{1}$$

where u is the velocity value, L is characteristic dimension and ν is kinematic viscosity. The characteristic dimension is very often the inner diameter of the channel. Generally, the Re number gives us the rate between convective and viscous scales.

The motion of small droplet carried by the flow is given by the Stokes number. Reynold number of these particles is assumed as very small (very often below 1) and it is given by the particle diameter d_p:

$$Re_0 = \frac{u \cdot d_p}{\nu} . \tag{2}$$

The motion of the particle, which faithfully copies the flow, is given by Stokes number

$$S_{tk} = \frac{t_p}{t_f} = \frac{\rho_p \cdot d_p \cdot u}{18 \cdot \mu} , \tag{3}$$

which is practically the rate between relaxation time of the particle t_p and characteristic time of the flow t_f. ρ_d denotes particle density value, d_p is the particle diameter and μ is dynamic viscosity. Both non-dimensional numbers should be preserved for similarity.

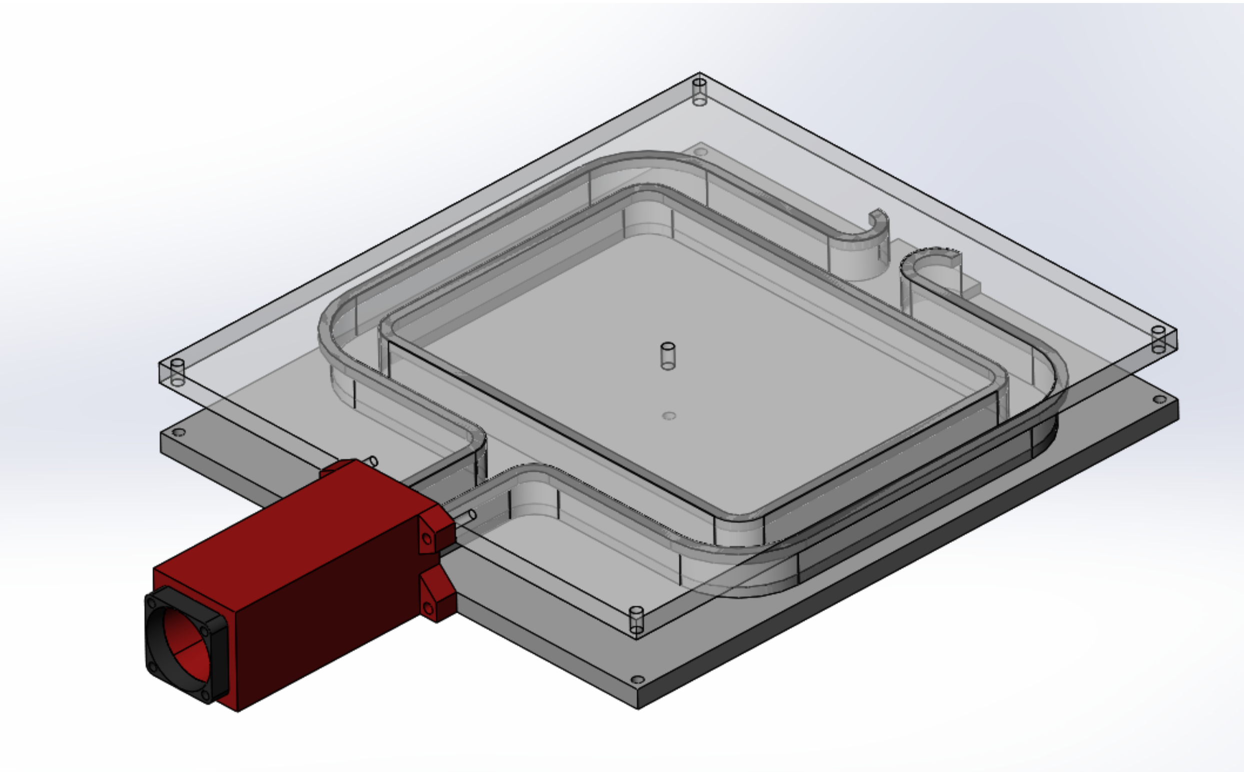

Fig. 1: Model of DPIK probe in scale 2:1.

The model of isokinetic probes is enlarged in scale 2:1, the model is twice bigger than real probe. To keep the dynamic similarity, we should use the velocity value twice smaller than in reality and on the other hand, the size of particles should be twice bigger. Since the particles in real cooling toward above the eliminators have diameter about 10-20 microns and the flow velocities vary between 3 and 4 m/s we used the particles with diameter approximately 30 microns and the fan revolutions were set to keep the volume velocity up to 2 m/s. Stokes number of the observed particles was then $S_{tk} = 4$ which was still satisfactory.

The flow topology was acquired by time-resolved Particle Image Velocimetry (TR PIV) which was supplied by Dantec company and it consists of a double-head laser and a fast CMOS camera. The maximal repetition frequency of the laser is 10 kHz while camera is able to acquire 3000 double-images per second.

Safex oil droplets were used as seeding particles. More information about PIV measurement in the small channels can be found in (Uruba et al 2021). The same measurement setup was used for Interferometric Particle Imaging (IPI). Generally, IPI can measure the size, distribution and the velocity of spray droplets in the air using laser illumination and a dual camera system with special optics. Within framework of this project, only one camera is used to measure particle size distribution using a special approach developed and described by Čížek (2010). A special software IPIDET is used to evaluate the size of droplets from the number of interferometric fringes and from other variables (e.g. the F-number, focal length etc.).

3. Results

To fulfill the condition of isokinetics, we set the revolutions of both fans individually. The flow topology inside the probe can be seen in Figure 2. The distribution of vector lines (red lines) can be seen in the left part of the probe. The origin of coordinate system is set to the center of the lower branch of the probe. The flow enters into the channel symmetrically and hit to the ceiling of the lower branch. This is the place where the biggest amount of the drift particles should be captured (this is the place where heated sensors will be installed). Two elbows follow. There is a moderate flow separation in the vicinity of the inner radius a little downstream. Finally, the flow enters the output section; left and right parts are mixed in front of the last straight part. Here, the flow topology demonstrates helical shape as it is sucked in by the ventilator.

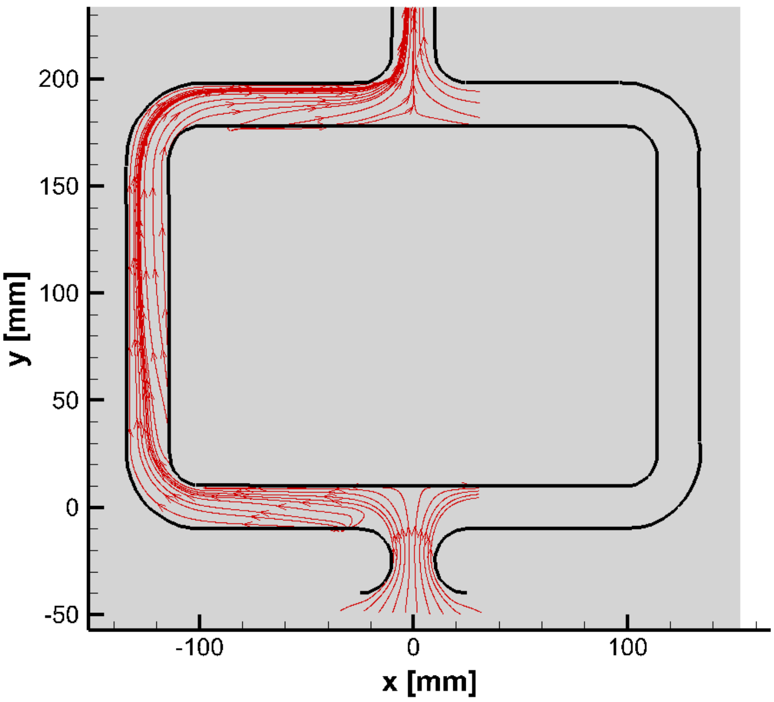

Fig. 2: Vector lines distribution in the left part of the model.

The most important part (the input and the output) was measured by PIV much more in detail. There is a velocity modulus distribution in Figure 3. The black arrows represent the velocity vectors in the plane of measurement (in the symmetry axis of the channel) and color is scalar (modulus). The flow enters the probe without any separation (a hemisphere is designed as the input wall). The flow is accelerated (red color) in the center of the nozzle and starts to separate on both sides. Vector lines are oriented still in the direction of the input for the center part (the drift particles are captured on the ceiling and start to create the water film). Further, the flow is divided to the left and right part of the branch relatively symmetrical. The separated flow is re-attached further downstream to the channel walls. The place, where both currents are mixed, is shown on the right-hand side of Figure 3. There is no flow separation in time averaged flow field; only singular point near the inner wall is present in the axis of symmetry. The fluctuation activity of the flow is most significant between both radii where the mixing effect is the strongest. Future measurements will show whether the straight part with rather low velocity will not be a place where drops will also stick.

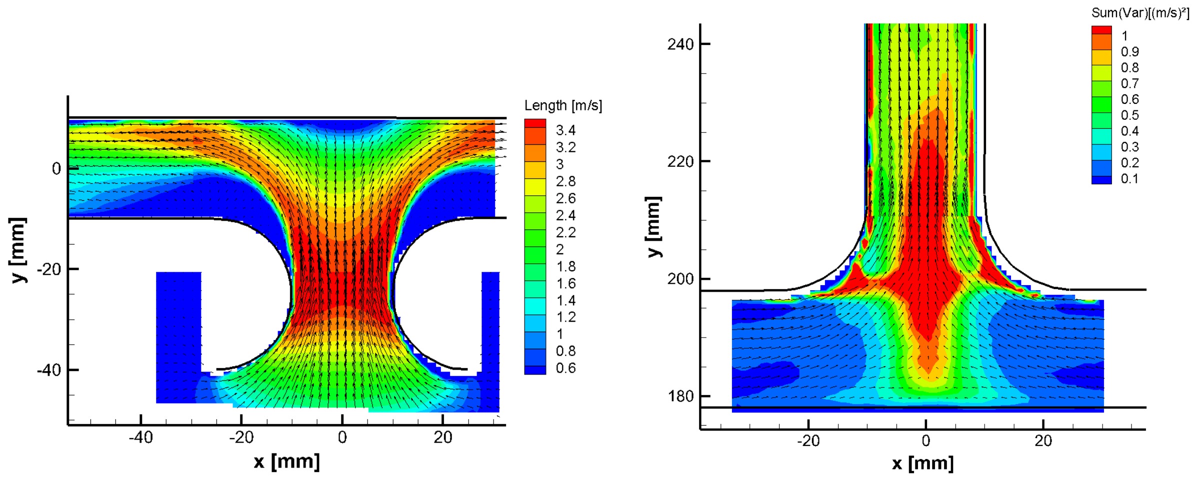

Fig. 3: Velocity modulus distribution of the probe inlet and velocity fluctuations in front of the outlet.

The efficiency of the probe will be measured as the rate between amount of the droplets detected in the output section and in the inlet part. IPI measurement requires special treatments and until this time only limited IPI images were acquired. As an example, interferometric fringes of the water particles can be seen in Figure 4. This snapshot was taken in the outlet section and it contains about 15 droplets. The number of fringes varies from 4 to 10 which corresponds to particle diameter about 10 or 20 microns. Apparently, the bigger particles were captured by the probe ceiling. During future work, the newly developed IPIDET software will be utilized to determine the droplet size spectrum and to specify the efficiency of the probe.

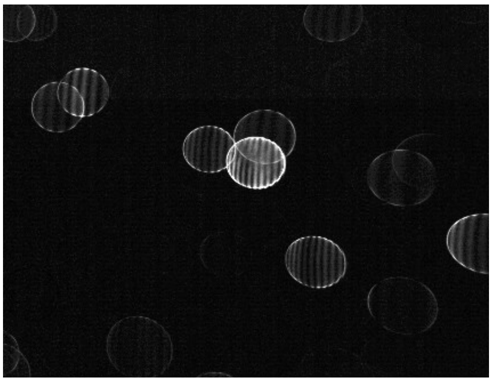

Fig. 4: Interferometric fringes detected using IPI method.

4. Conclusions

Time-resolved PIV method was used to optimize the shape of isokinetic probe for liquid drift detection. Advanced IPI algorithm is to be used to track the water droplets. The optimal place, where the heated detector should be placed, was identified. It seems that this geometry variant is quite satisfactory concerning the efficiency of droplets capturing on one side and concerning the shape which is appropriate for heated element assembly on the other side.

Acknowledgement

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