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Drop Hunter Isokinetic Probe for Cooling Tower Drift Measurement

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Abstract. This paper is devoted to the development of a new probe to measure a drift from cooling towers. The probe was named DPIK (Drop Hunter Isokinetic) and its development consists of a design of the aerodynamic and microelectronic part of the probe, verification methods, design and testing, verification tests in laboratory conditions and measurements on a model of the cooling tower. The paper deals mainly with the verification tools, as these methods are very closely related to the aerodynamic part of the probe design. Two options were chosen for verifying the probe principle. The first of these was the Interferometric Particle Imaging (IPI) method, the second was another optical method using similar experimental equipment Particle Image Velocimetry (PIV).

1 Introduction

Drift is the spectrum of water droplets released from cooling tower, created by the aerodynamic forces acting on droplets and films within the cooling tower and discharged into the environment. Typical drift droplet diameters range from 20 microns to 2000 microns. The cooling tower drift measurement is necessary, because the drift droplets contain both the chemicals and some biology species as the water circulating in the tower and this content could be potentially harmful and pathogenic (i.e. heavy metals and bacterium Legionella Pneumophila). Also, the drift causes considerable water loss. This loss can be 0,7-1,4 litres/m^2/hour, which represents a lower hundreds of cubic meters per one cooling tower per day (i.e. for an average nuclear power plant cooling tower).
Determining a drift rate from real cooling towers in operation becomes an important issue nowadays. Many states worldwide work on or already accepted legislation, which sets up required minimal drift eliminator (part of cooling tower capturing the drift) performance rate, e.g. for France 0.01 %, Spain 0.001 %. The drift eliminator efficiency is one of the two crucial characteristic parameters of it. The drift emission from a cooling tower is usually expressed as a percentage of the total circulating water flow rate. It can also be expressed as a mass per unit time related to water or air flow (as defined in [1]).

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There are various methods used for eliminators drift measurement (real world conditions methods, laboratory conditions methods): methods employing chemically sensitive materials (sensitive papers-based methods, sensitive surfaces), isokinetic extraction-based methods (with subsequent chemical analysis), holographic method, methods based on light diffusion, interference method and laser-induced fluorescence method. More on these methods could be find in [2], [3] and [4].

In general, nowadays the drift from the real towers can only be measured using relatively complex methods, where the so-called tracers (e.g. Lithium, Sodium, Magnesium) are mixed into the whole circuit. The measurements are then disproportionately expensive and also time-consuming as the sampling is followed up by subsequent external chemical analysis. That is why a new method developed with respect to the expense and testing time would be very useful for the whole industry.

Fig. 1. The model of DPIK probe used for electronic parts development.

2 Experiment description

The paper mainly deals with the development of a new probe. The probe was named DPIK (Drop Hunter Isokinetic) and is based on calorimetric principle. It operates as follows: a liquid phase (droplets with a size of 5 μm to approx. 150 μm) is separated from the flowing air for a certain period of time and it is captured. Then it is subsequently evaporated using a specially designed heated element located inside this isokinetic probe. Heating takes place by means of power regulation, with the temperature rise being monitored. The whole development consists of a design of the aerodynamic and microelectronic part of the probe (also consideration of the heating elements correct location inside the probe belongs here), verification methods, design and testing, verification tests in laboratory conditions and measurements on the model cooling tower. The paper deals mainly with the verification tools, as these methods are very closely related to the aerodynamic part of the probe design. Two options were chosen for verifying the probe principle. The first of these was the Interferometric Particle Imaging (IPI) method, the second was another optical method using similar experimental equipment Particle Image Velocimetry (PIV).

IPI is a non-invasive optical method providing mainly information on the size of individual droplets in the inlet channel and anywhere in the probe. The results obtained may include the integral value of the cooling tower drift as well as the efficiency of the eliminator, or the probe channel efficiency in the case of the probe shape development, according to particle size, correlation between particle size and even speed, etc. The great advantage of this method is that the minimum measurable droplet sizes are almost order of magnitude smaller compared to other methods.

Similarly, the other optical method mentioned above - PIV - is a non-invasive method using the same laboratory equipment. In principle, PIV means taking two images of the same measured area within a very short time interval (in the order of hundreds of microseconds depending on the expected velocity in the measured area), the setting of which is the basic input parameter for obtaining relevant data. From these frames, the flow field in the probe can then be evaluated. The probe efficiency can be obtained from the subsequent purely mathematical processing after calculating the behavior of the two-phase flow.

The flow field was acquired using fast CMOS camera Phantom V611 with resolution 1280 x 800 pixels. Safex particles were illuminated using coherent light sheet of wavelength 527 nm from Laser New Wave Pegasus. The acquisition frequency of the recording was 100 Hz both for PIV and for IPI measurements. Only statistical evaluation of all quantities will be presented in this article.

The test stand (Fig. 2) is actually a model of a small cooling tower. It consists of an inlet part with an integrated fan, a straight part, an elbow and an output. There is a honeycomb in the outlet part to homogenize the flow entering DPIK probe. By means of the ventilator, desired speed of flow in the test stand can be set. The safex particles or water droplets are injected in front of the test stand inlet.

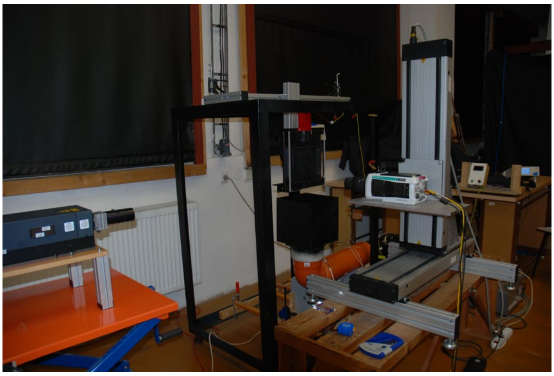

Fig. 2. Test stand in laboratory; PIV system, the DPIK probe and a cooling tower model.

Three individual models of DPIK probe were designed. There is a base case (A) in the figure 3a. The inner channel is branched into two symmetrical sections. The flow is divided just behind the inlet and it is mixed in front of the outlet section. The other two geometries utilize only one branch which significantly reduces the total size of the probe. The last variant (C) has short dead-end channel. The design of all three variants uses the same principle. The base plate is made using 3D printing (a puzzle from 4 pieces). The shape of the inner channel is defined using a transparent thin foil. The precise bending of the foil is very important since laser light is shining through it. The front panel (which is not visible in the figure 3) is used to cover and to seal the probe. It is also transparent to allow optical access for CMOS camera. The outlet section (red part) is a transition from rectangular cross-section 20 x 20 mm to circular one with second ventilator. The flow speed inside the probe is set according to the isokinetic condition.

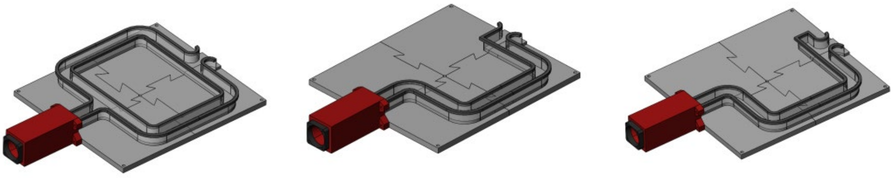

Fig. 3a, b, c. Three variants of inner channel geometry; branched channel (A) and two simple variant without (B) and with dead-end channel (C).

Dynamic similarity should be preserved to verify the efficiency of the probe. The model used for PIV and IPI measurement is twice bigger than the designed DPIK probe for real towers. It is very essential to keep the Reynolds and Stokes numbers, more details can be seen in [5]. For this model designed in scale 2:1, the flow rate is twice smaller than in reality and, on the other hand, the size of droplet should be twice bigger. Finally, we set the experiment so that the volume velocity is about 2 m/s and mean droplets size is about 30 microns.

3 Results

First, all three variant were measured by means of Particle Image Velocimetry to study the flow field topology. The overall view of statistical quantities is composed of 12 individual fields of view. Then measurement of details especially for particle mean size detection (IPI) followed.

3.1 Overall view

There is a distribution of velocity modulus for all geometries in the figure 4. The maximal velocity is approximately 3 m/s (red color). The origin of the coordinate system is placed in the middle of the entrance section. The flow enters into the probe, hits the ceiling and it is divided into two symmetrical parts in the case of the very first model. Considering the flow branching, the flow velocity is half the value with respect to inlet or outlet parts. Two elbows follow and finally both streams are mixed before entering the output fan section. This mixing phenomena significantly increases the turbulence intensity (Fig. 8a), which was, together with demand for smaller build-in dimensions, the main reason to design two more variants (B, C).

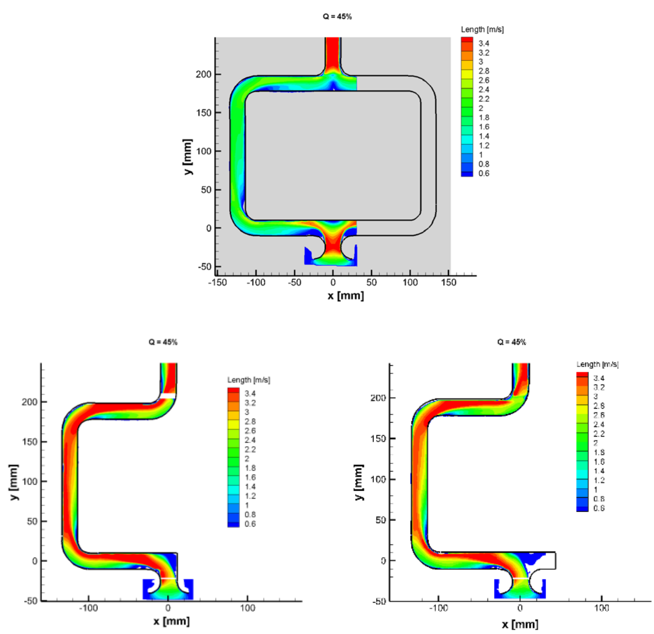

Fig. 4a, b, c. Mean flow fields of all variants; velocity distribution.

The flow enters the probe again from wide surroundings using two hemispheres. The velocity distribution is more regular – the volume flow rate is constant throughout the length of the probe. The flow separation can be seen behind each elbow. There is no mixing effect in front of the outlet part, however the velocity profile is not symmetrical across the output channel width compared to variant A.

The velocity vector lines can be seen in figure 5a, b, c. The presence of the dead-end channel seems to have no significant effect (Fig. 5c). The flow does not hit the ceiling but it is just turned to the left side in its entire volume.

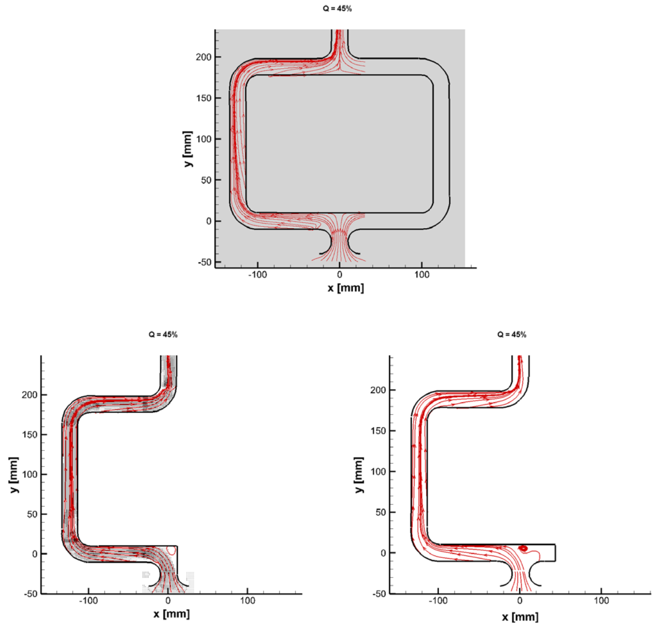

Fig. 5a, b, c. Mean flow fields of all variants; velocity vector lines distribution.

The overall velocity distribution in the probes suggests that most droplets will be captured in probe A on the wall just immediately opposite the inlet. Probes B and C will rather capture the droplets rather further in the channel.

3.2 The details - inlet and outlet parts

The most important part is the entrance section with the ceiling where we expect the droplet capturing and heated elements should be mounted (white arrows in the figure 1). There are velocity vectors for all three variants in the figure 6. The color denotes the value of velocity modulus, respectively distribution of velocity variations in the figure 7. The entrance is made by using two hemispheres so the flow enters this region regularly. The separation bubble(s) is present in the direct part of the channel (dark blue color). The separation is more significant for branched geometry. The vectors are oriented directly against the ceiling for the base case variant A which should be more suitable for capturing of the water droplets. Variants without junction do not capture so much water. Unfortunately, the effect of the dead-end on the flow field is almost negligible (compare B and C).

Variant A contains more fluctuation activity in the straight part behind the entrance section (green color in the figure 7a). Two variants without junction have rather regular flow with warp shear layers.

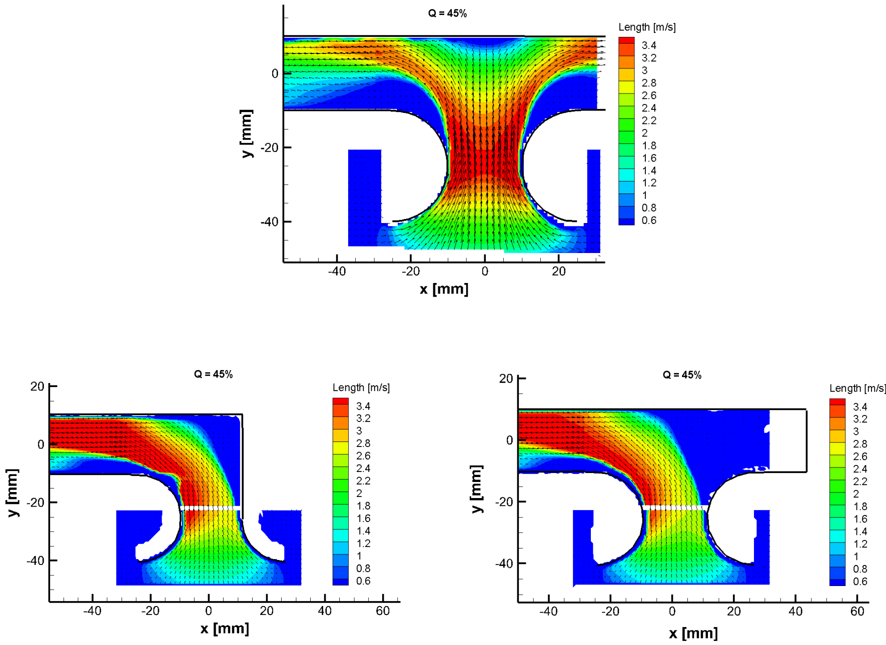

Fig. 6a, b, c. The inlet section; velocity distribution.

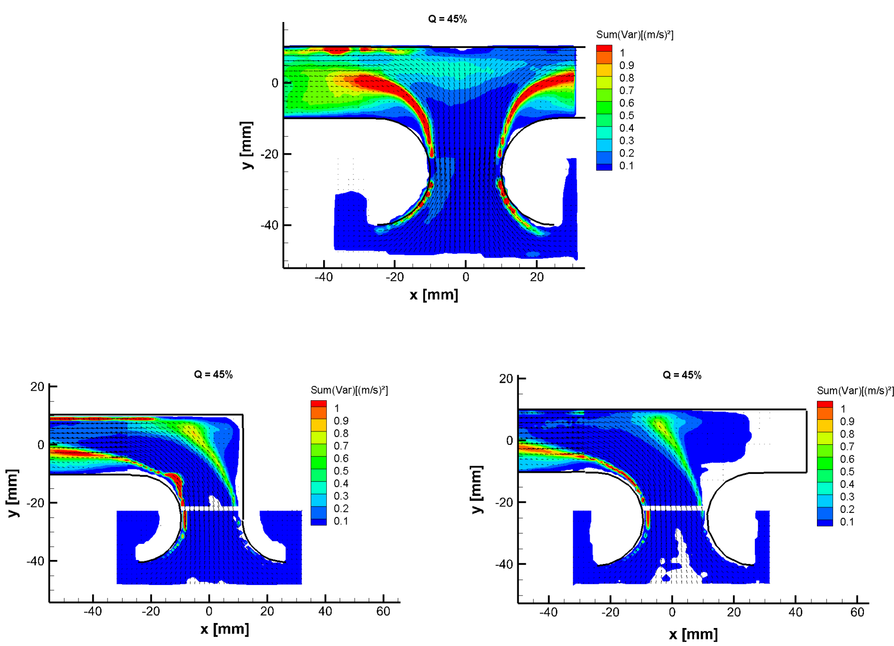

Fig. 7a, b, c. The inlet section; velocity variations (TKE) distribution.

Both streams are mixed in the T-junction of the first variant which results in high fluctuation activity (Fig. 8a). There is only small shear layer connected with tiny separation for the second and third variant equipped just with the last elbow. Future IPI measurement will show if this region also will have effect on droplets sticking.

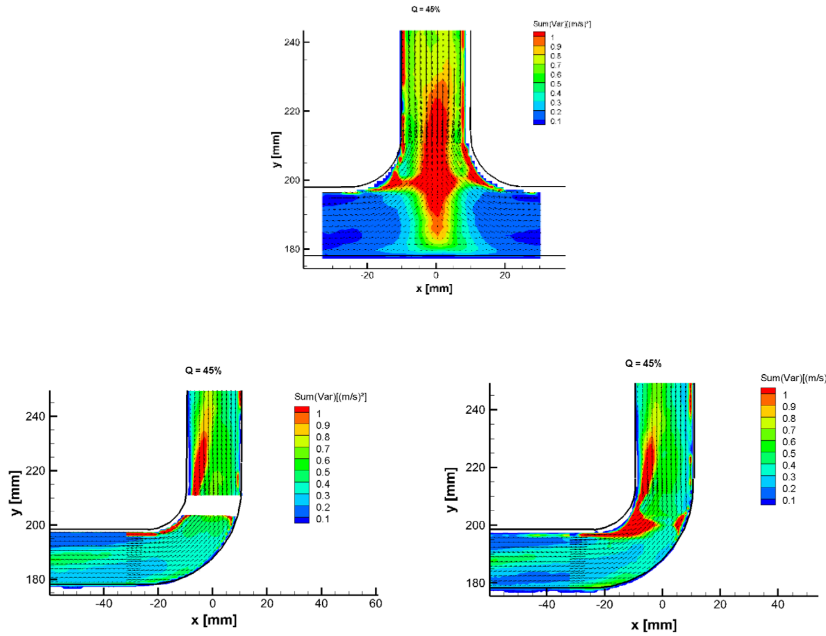

Fig. 8a, b, c. The outlet section; velocity variations distribution.

3.3 Particle detection

To evaluate the size and amount of water droplets, the IPIDET software was used. This algorithm is written in Python language as in-house software. The main purpose is to calculate the number of interferometric fringes of each defocused image of the droplets. There are IPI images acquired for entrance section (Fig. 9a) and inside the first elbow (Fig. 9b) taken for the base case variant A. As the size of the particle image is the same due to defocusing, the number of fringes gives us the information about the droplet size. The droplets are entrained at a velocity that is not very different from that of the volume velocity. The droplets in the inlet section contain more fringes (3-9) which means that droplets of different size enter the probe. Many droplets were captured as inside the elbow only droplets with 3 or 4 fringes are present.

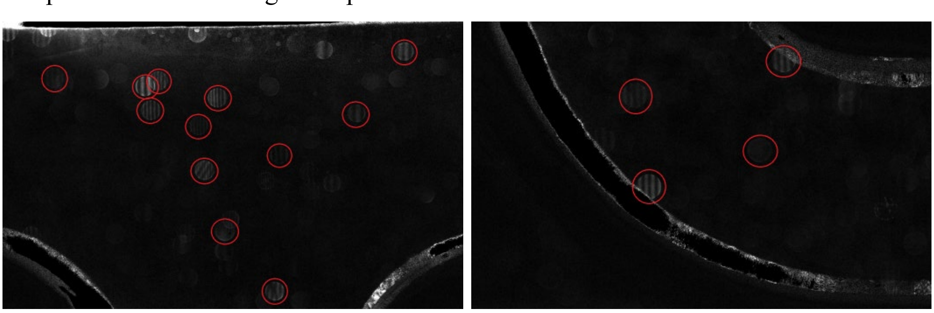

Fig. 9a, b. IPI images for inlet section and first left elbow.

Two histograms are plotted in figure 10. These histograms are calculated from 500 snapshots of IPI images. It is total amount of particles which were present in the flow for distinct number of fringes. The efficiency of used probe can be established using comparison of both histograms. Since droplet feeding is not constant in time, this information has rather qualitative character.

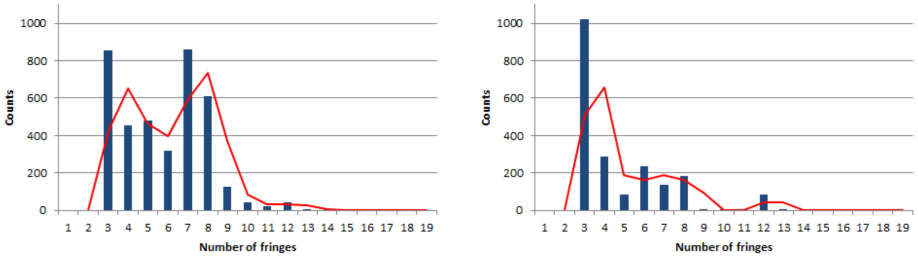

Fig. 10a, b. Calculated histograms of particles incidence for inlet section and first elbow.

4 Conclusions

Time-resolved PIV and IPI (both optical non-intrusive methods) were utilized to compare the design of three distinct DPIK probes.

Unfortunately, the geometry without branching channel is not able to capture sufficient amount of particles because the velocity vector are not oriented perpendicularly to the ceiling where heated element should be placed.

As we are not able to fulfil the repeatability of all measurements (feeding of droplets are not constant in time), during future experiments, we plan to make an acquisition using two fast cameras in the same instants.

The variant A is the most effective according to water droplets capturing. This geometry captured almost 50 % of the total number of particles present in the inlet (evaluated to the first elbow). However, the amount of captured water is even greater because especially large droplets were taken.

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References

1. CTI Bulletin BUL-109: Nomenclature for Industrial Water-Colling Towers, (2019).
2. J. Čížek, L. Nováková, J. Nožička, Reducing Liquid Phase Drift from Cooling Towers, Gradient, Prague, (2009).
3. J. Čížek, L. Nováková, New methods for drift eliminators performance evaluation, CTI, TP11-11, (2011).
4. A. Roffman, L. D. Van Vleck, The State-of-the-Art of Measuring and Predicting Cooling Tower Drift and its Deposition, Journal of the Air Poll. Contr. Assoc. 24:9, 855-859, (1974).
5. P. Procházka, V. Barraclough, V. Skála, V. Uruba, The design and aerodynamic testing of DPIK probe, Engineering Mechanics 2022, Vol. 27/28, (2022).