DIGITAL PARTICLE IMAGE VELOCIMETRY (DPIV) CORRELATION ALGORITHM

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Abstract

This problem touches the aero-hydrodynamics issues deal with thermodynamic and floating processes within the heat exchangers. Modeling of these processes via dynamic fields of velocity and pressure visualizations is very useful for optimal design of mechanical constructions of equipments for many other applications [1, 2 etc.]. In this chapter the some aspects of digital particle image velocimetry (DPIV) based on vortex flows in quasi-regular heat-exchanging structures with the tracer-correlative technique are presented and considered. The classical shell-and-tube heat exchangers are commonly applied for heat transfer in flow [1, 3, 4].

Keywords: flow visualization, particle image velocimetry (PIV).

1 Digital Particle Image Velocimetry

In order to increase liquid flow velocity inside the shell – side, the flow is intensified by the use of sectional cross baffles, and minimizing superficies of heat exchangers. Two-phase mixture flow is characterized by significant fluctuations. Fluctuations are result of complicated geometry and oscillatory nature of two-phase flow in the shell-side. In case of two-phase flow, effects between phase boundaries appear simultaneously. Dynamics of gas-liquid system is significantly larger than in case of other systems. Mutual effects of gas-liquid system take turns at time and location, causing a change of two-phase profile and finally decides about distribution of velocity, pressure, and temperature fields. The shell-side defines the flow area of two-phase mixture, where velocity of flow is maximum in small passages of shell-side. The areas behind the tubes surface exhibit little fluctuations and became named "still zones" (Fig.1, 2) [4]. The velocity of flow and the gas void fraction in the still zones are considerably smaller than in passages of the shell-side. The shell-side decides about local disturbances of velocity fields, trajectories of gas flow, large area of all groups of gas particles concentration.

Quantitative measurements of the flow and turbulence characteristics are obtained using DPIV. This is a non-intrusive optical technique that measures fluid velocity by tracking the displacement of tracer particles added to the fluid [4] via capturing with a digital camera light which is scattered from particles. The displacement in a small region of the image is calculated by comparing consecutive images. The velocity is then calculated by dividing the displacement distance by the known time delay between the frames. The full size DPIV images are sub-divided between interrogation windows.

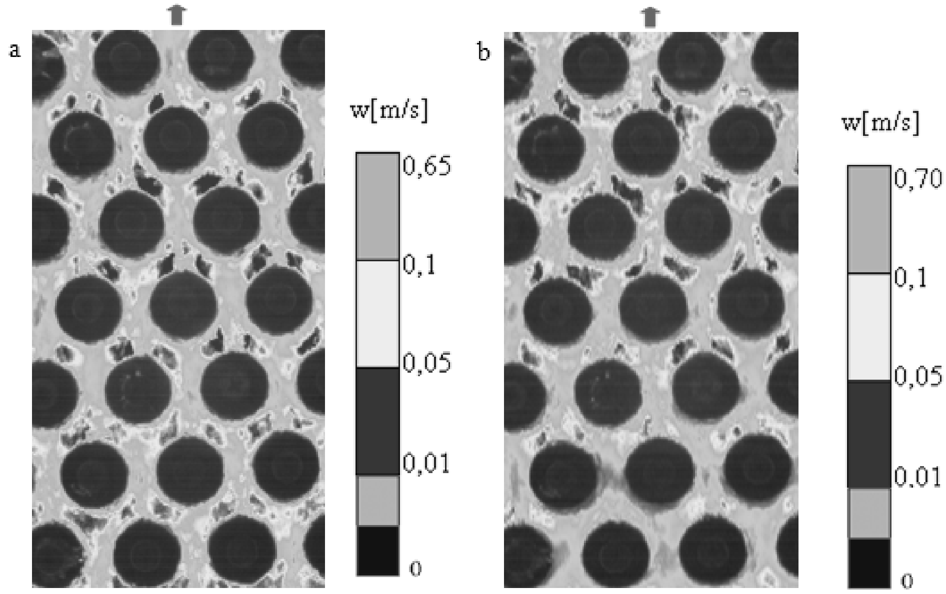

Fig.1: *Still zones visualization behind row of tubes for triangular - staggered arrangement [14]*

The calculation of the correlation function to determine the displacement vector for each window can be performed either in the spatial domain or in the frequency domain. The digital spatial correlation function R_{II} required the evaluation of the following expression [3]:

$$R_{II}(x_1, x_2) = \sum_{i=-K}^{K} \sum_{j=-L}^{L} I(i,j) I'(i + x_1, j + x_2), \qquad (1)$$

where *I(i, j)* represents the intensity value for the (*i, j*) pixel. This function statistically measures the degree of correlation between two samples *I(i,j)* and *I'(i',j')* for a given shift (x_1,x_2). The shift position where the pixel values align with each other gives the highest cross-correlation value, and represents the average displacement of the particles in a observed window.

The major drawback of this method is that it is highly computationally intensive since the number of computations necessary is proportional to the interrogation window size. Alternatively, the algorithm used to evaluate the particle displacements for this experiment was based on the frequency-domain correlation method. The images were divided into 24×24 pixel sub-windows with 50% overlap. The correlation plane was created by transforming the intensity function from the spatial to the frequency domain via DFT [3].

The cross-correlation was then realized by using FFT algorithm. The FFT cross-correlation method resulted in a single peak on the correlation plane that represented the average displacement of the particles in the window during the time delay between the illumination pulses. The position of the correlation peak was then estimated to sub-pixel accuracy by using a Gaussian-fit function. The displacement vector is defined by the location of the peak with respect to the center of the window. The finally algorithm is filtering the particles velocity vector fields. The vectors collected at a single spatial location were combined into a time record of velocity. Vectors that falling outside of predetermined value range are removed from the data set. A recursive filter was used to remove any vectors that lay beyond three standard deviations from the local time-average value. The time-average and standard deviation values were updated and the filtering procedure is repeated until zero vectors were removed in the final pass.

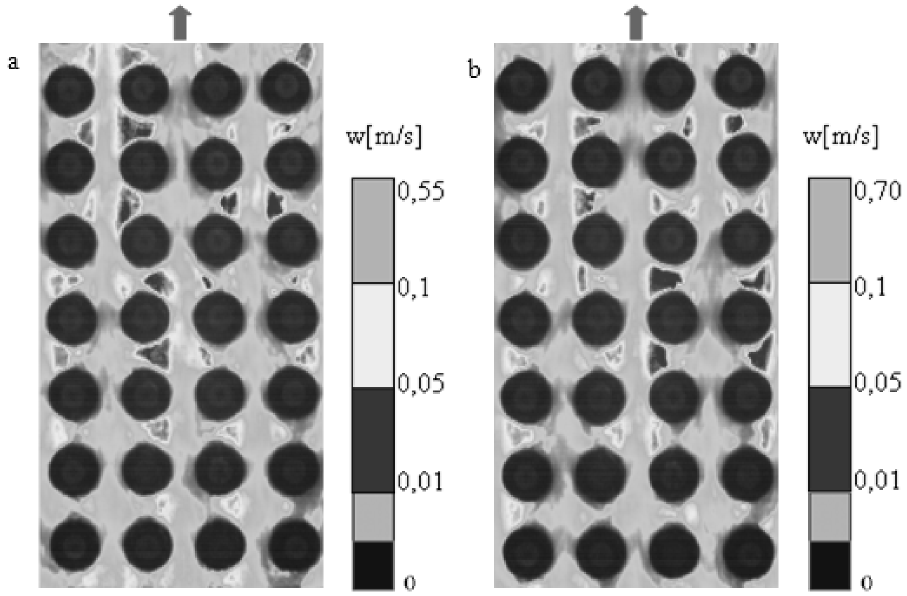

Fig.2: *Still zones visualization behind row of tubes for square in-line arrangement [14].*

The integral length scale of the flow was calculated by measuring the area under the spatial correlation function [3]:

$$L_{ij} = \int_0^\infty f(r_j)\,dr_j \tag{2}$$

The spatial correlation function is defined as:

$$f(r_j) = \frac{u_i'(x+r_j)u_i'(x)}{u'_i(x)u'_i(x)}, \tag{3}$$

where x is an arbitrary location, u_i indicates the fluctuation of the i-velocity component, and r_j is the distance in the j direction between the velocity measurements.

Visualization of liquid flow in the shell – side enables analysis of flow parameters by the used image processing and analysis methods. Images were recorded with frequency of 100Hz by the use of digital high speed CMOS camera. The bubbles of gas in shell-side are particle markers The recording sequences of flow were conducted for two-phase gas-liquid flow across tube bundle, which were placed in triangular-staggered and square in-line arrangement for bubbles pattern. The sequence of consecutive images was recorded during two-phase flow in shell-side, next were determined velocity fields of liquid using the cross-correlation DPIV method (Fig. 3) [4]. Dislocation of markers floating through liquid, in given interval of time, makes possible to receive the flow parameter, which characterizes velocity of liquid flow. Distributions of velocity fields in dependence of geometry of tubes arrangement, staggered either in-line, has decided about values of heat transfer coefficient. Trajectories of particle markers motion were designed for the flow pattern estimation.

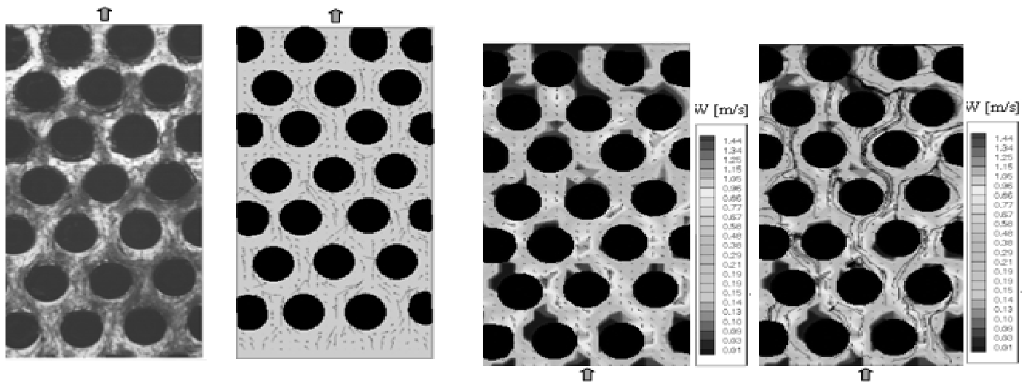

Fig.3: *Liquid velocity fields and particles motion in the shell-side for triangular – staggered and square in-line arrangement (DPIV correlation algorithm) [4].*

3 Conclusions

The results of flow visualization and digital processing methods allowed to receive detailed conclusions to the point of the hydrodynamic of two-phase flow in an area of shell-side, which are following:

- Optical techniques of measurement, based on correlation algorithms, allow accurate determination of stabilization of velocity fields for the whole field of flow in shell-side,

- The velocity of field stabilization is following between fifth and sixth row of tubes, but stabilization of velocity field is ensured much closer, with reference to an initial shell-side for in-line than staggered arrangements.

- On the basis on distribution of velocity fields have been ascertained that staggered arrangements, which are applied in heat exchanger, are more efficient with regards to the flux of heat transfer. The triangular arrangement in actual heat exchangers is equivalent to the staggered arrangement.

4 References

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