Features of flow and heat transfer near a pair of circular cylinders

V V Seroshtanov, A S Vlasov, V V Suchok* and N A Zhidkov

Peter the Great St.Petersburg Polytechnic University,
Russia, 195251 St.Petersburg, Politekhnicheskaya ul., 29

suchok.va@gmail.com

Abstract. Synchronous flow and heat transfer study of in a single-phase medium is one of the important engineering and thermophysical problems. To solve this problem, the simultaneous use of PIV and gradient heatmetry is proposed. The investigated model is a pair of heated circular cylinders. Constant cylinders’ surface temperature is ensured by heating with saturated steam. The studies were carried out at various Reynolds numbers and inert-tube distance $S$, ranging from $0.5d$ to $4d$. The use of gradient heatmetry made it possible to estimate the heat flux pulsations at the second cylinder and then, to compare them with the instantaneous velocity fields obtained using the PIV. The distributions of the heat flux and heat transfer coefficient over the cylinder surface were obtained for the range of Reynolds numbers from $4.8 \times 10^3$ to $48 \times 10^3$. The results are consistent with the data of other authors and show the prospects for the proposed methodology. Moreover, the results on the heat transfer augmentation the same models and in the same modes are presented.

1. Introduction

The study of processes in convective heat exchangers has attracted the attention of researchers for a long time. So, since the 30s of the last century, the numerous flow and heat transfer studies have been conducted. In particular, heated tubes of various cross-sections, streamlined with water or air, are often considered. For example, in [1], the distribution of the heat transfer coefficient (HTC) over the circular cylinder’ surface was studied. In the work [2], the authors tried to reveal the influence of non-cross flow on the heat transfer rate.

Another line of this type of research is an attempt to increase HTC at the cylinder’ surface in various ways. The authors of the study [3] do this by turbulizing the free stream (so-called active methods). An increase in the average heat transfer of the cylinder is shown at assistance of forced nonstationarity of the flow. The local HTC increase occurs behind the aft cylinder area, while the average HTC in this variant is 14.7% higher in comparison with the stationary flow.

The most famous author in the heat transfer enhancement is the Igarashi research team. They increase heat takeoff in a different way: flow turbulization occurs due to the installation of additional geometric barriers (dimples, caverns, etc.). In the field of their research also lies the measurement of aerodynamic forces, after increasing the heat transfer rate [4].

All the described works are united by the fact that the tubes were heated by electric heating, which does not quite correspond to real heat exchangers. This is due to the poor prevalence of heat flux sensors. Therefore, researchers are stimulated to use thermocouples in their research and then, to
recalculate the heat flux per unit area and HTC according to the signals. It should be added that the thermocouples response time (ms) does not allow us to estimate the HTC fluctuation and almost all studies refer to some average values.

On the other hand, despite the huge pool of studies, most of them are done for a single cylinder. Studying the effect of cross-section area reduction, longitudinal and transverse pitch, etc. requires a significant design complication (in natural experiments) and a computing power increase (in numerical simulating). At the same time, the problem becomes multifactorial, which increases the error in measurements and calculations.

All of the above motivated us to study of the flow and heat transfer near a pair of cylinders using modern PIV and unique gradient heat measurement.

2. Experimental details

A series of experiments was carried out in a subsonic wind tunnel of the Research and Education Center «Energy Thermophysics». The wind tunnel is completed a water-air heat exchanger to maintain constant flow temperature. The tube is equipped with a variety of measuring devices, including a shadow device, as well as a PIV system by POLIS. The operation principle and features of our system are described in detail in the paper [5]. Next, we will analyze particularly the aspects of the experiment that are important, in our opinion.

2.1. Experimental models

In wind tunnel experiments all models are based on hollow models and steam heating. From there, the temperature of the heat exchange surface is constant (close to 100 °C), which, as mentioned above, is more consistent with the heat exchangers operation. Surface temperature were controlled by the infrared measuring using FLIR P640 infrared camera. Figure 1 shows a scheme of the experimental model.

![Experimental scheme model](image)

**Figure 1.** Experimental scheme model.

Two heated circular cylinders a length of 600 mm and diameters of 66 mm for gradient heatmetry and 25 mm for PIV are spaced apart at a distance $S$ from each other. The cylinders are made of steel
with a thickness of 0.1 mm. Gradient heat flux sensor (GHFS) is mounted at the second cylinder, and the cylinder itself can rotate around an axis at an angle $\varphi = 0...180^\circ$ with a step of $\Delta \varphi = 10^\circ$. The distance $S$ varied from $0.5d$ to $4d$, where $d$ is the diameter of the cylinders.

2.2. Gradient heatmetry

In our experiments we measured the heat flux per unit area using the methods of gradient heatmetry. Gradient heatmetry, based on the use of GHFSs, was developed in Peter the Great St. Petersburg Polytechnic University and is being actively integrated in laboratory and industrial experiments [6, 7]. The principle of GHFS operation is based on the transvers Seebeck effect. The GHFS theory and detailed description is described in the monograph [8]. Here we just note that when the heat flux passes through the GHFS, a thermoEMF is generated in it, proportional to the passing heat flux. In this series of experiments, we used a GHFS based on monocrystalline bismuth with dimensions of $2 \times 2 \times 0.2$ mm. The sensor was calibrated using the absolute method on a special bench, its volt-watt sensitivity $S_0 = 5 \text{ mV/W}$.

An important feature of the GHFS is their response time of 10 ns. This phenomenon, its possible causes and a physical description can also be found in [8]. In our study, such a high response time made it possible to estimate not only the average heat flux, but also its fluctuations.

3. Results and discussion

The experiments were carried out in the range of the Reynolds number $\text{Re} = (4.8...48) \times 10^3$. Reynolds number is calculated as:

$$\text{Re} = \frac{Wd}{\nu},$$

where $W$ free stream air velocity, m/s; $\nu$ air viscosity, m$^2$/s.

Figure 2 shows the averaged velocity fields behind the first and near the second cylinder, obtained by the PIV. 1000 pairs of photographs were used for averaging. The color indicates the velocity value, and the arrows show the direction of flow.

It is seen that the low-energy zone also grows with increasing distance $S$ between the cylinders. We can also see the acceleration of the flow near the first cylinder. The vortex street opening angle increases with increasing $S$.

Gradient heatmetry and free-stream airflow temperature measurements under conditions of constant cylinder temperature (steam heating) made it possible to calculate the local HTC.
Gradient heatmetry and free-stream airflow temperature measurements under conditions of constant cylinder temperature (steam heating) made it possible to calculate the local HTC. The HTC distribution by the rotation angle $\varphi$ of the cylinder is shown in figure 3. Note that the HTC extremum is in the region $\varphi = 60\ldots90^\circ$ for high Reynolds numbers. The deviation of the local HTC from the average does not exceed 30%, which is less than the same deviation for a single cylinder [9]. This fact suggests that the first cylinder stabilizes the flow near the second cylinder. The effect is more pronounced for high Reynolds numbers and for larger distance $S$. 

Figure 2. Average velocity field for: a $S = d$ and b $S = 3d$; Re = 4800.
Figure 3. Local HTC distribution over the surface of the second cylinder for $S = 4d$.

In the next experiments series, we investigated the heat transfer enhancement. In paper [9], we found that a thin rod-turbulizers (see figure 1) installed at the single cylinder surface can increase the average HTC by 14%. We were interested in the influence of the rod-turbulizers installation on the first cylinder for the heat transfer of the second. We took the geometric parameters of the turbulizers from [9]. The results of the experiments are presented in figure 3. The plots of HTC versus $\varphi$ are shown in dimensionless form: $h$, W/(m$^2$×K) average over the cylinder surface HTC.

Figure 4. Comparison of the dimensionless heat transfer coefficient distribution for $S = d$: a – Re = 0.48×10$^3$, b – Re = 9.60×10$^3$.

Turbulizers installed on the first cylinder, the effect on the heat transfer at the second cylinder is ambiguous. When the distance $S = 2d$, the average HTC increases in the entire investigated regimes. For the distance $S = d$, the average HTC remains practically unchanged (the difference does not exceed 5%).

The nonlinear dependence can be explained by the flow in the wake behind the first cylinder (figure 5).
Figure 5. Instantaneous velocity field; the first cylinder has two turbulizers. Re = 9600.

The formation of a vortex is observed near the second cylinder, which intensifies heat transfer. In addition, the vortex street behind the second cylinder has become shorter and smaller.

4. Conclusions
The results of studying the flow and heat transfer near a pair of cylinders are presented. The combination of gradient heatmetry and PIV made it possible to study the features of the flow around a pair of cylinders and directly measure the heat flux per unit area. Distributions of local HTCs over the second cylinder surface depending on the mode and distance are obtained. The influence of turbulizers on heat transfer near the second cylinder is estimated.

References
[1] Achenbach E 1975 Total and local heat transfer from a smooth circular cylinder in cross-flow at high Reynolds number Int. J. Heat Mass Transfer 18 pp 1387 – 1396.
[2] Manohar K, Ramroop K 2010 A comparison of correlations for heat transfer from inclined pipes International Journal of Engineering 4.
[3] Mikheev N, Molochnikov V, Mikheev A, Dushina O 2017 Hydrodynamics and heat transfer of pulsating flow around a cylinder Int. J. Heat Mass Transfer 109 pp. 254-265.
[4] Nakamura H, Igarashi T 2004 Unsteady heat transfer from a circular cylinder for Reynolds numbers from 3000 to 15,000 Int. J. of Heat and Fluid Flow 25 pp 741–748.
[5] Mityakov V, Gusakov A, Seroshtanov V, Grekov M 2018 Investigation of flow and heat transfer at the circular fins MATEC Web Conf 245 06001
[6] Sapozhnikov S, Mityakov V, Subbotina V 2019 Gradient heat flux measurement in study of unsteady water film boiling at the surface of the sphere Journal of Physics: Conference Series 1382
[7] Mityakov V, Mityakov A, Vintsarevich A, Gerasimov D 2018 Gradient heat flux measurement as monitoring tool for the diesel engine. MATEC Web of Conferences 245
[8] Sapozhnikov S, Mityakov V, Mityakov A 2020 Heatmetry (Springer International Publishing)
[9] Gusakov A 2015 Flow rate and heat transfer for transverse flow around a cylinder: combination of PIV and gradient heat flux measurement Ph.D. Thesis (St. Petersburg State Polytechnical University).