FACULTY OF MECHANICAL ENGINEERING CTU IN PRAGUE

Study Field: Thermomechanics and fluid mechanics
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Synthetic and continuous jets impinging on a circular cylinder: Flow field and heat transfer experimental study

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Aims of the dissertation

(1) Describe the behavior of synthetic jet (SJ) from the fluid mechanics point-of-view. Namely, to describe the behavior of a submerged SJ originating from a rectangular slot with small slot width (and associated Reynolds numbers), i.e., a (micro) SJ with a slot width below 1 mm.

(2) Describe the behavior of an SJ impinging onto a horizontal cylinder from the fluid mechanics and heat transfer point-of-view. Experimental comparison of SJs and continuous jets (CJs) based on a hypothesis of their similarity.

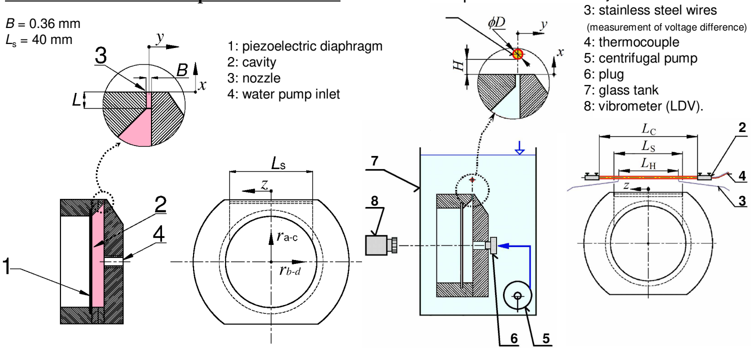
(3) Quantify experimentally the overall convective heat transfer rates in terms of the average Nusselt and Reynolds numbers, i.e., to propose a new correlation equation.

Experimental methods

LIF (Laser Induced Fluorescence) visualization, PIV (Particle Image Velocimetry) measurement, LDV (Laser Doppler Vibrometry) measurement of vibrating diaphragm surface, Temperature measurement (J-type thermocouples), Gravimetric method

Experimental setup

Schematic view of the experimental device — **The overall scheme of the experiment**

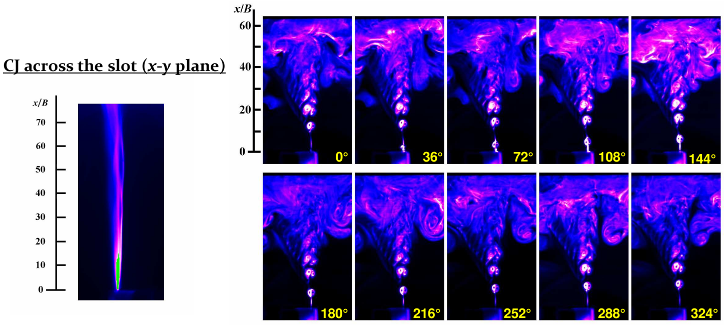


LIF visualization

free jets without cylinder

CJ across the slot (x-y plane)

SJ across the slot (x-y plane) at 10 phases of the working cycle



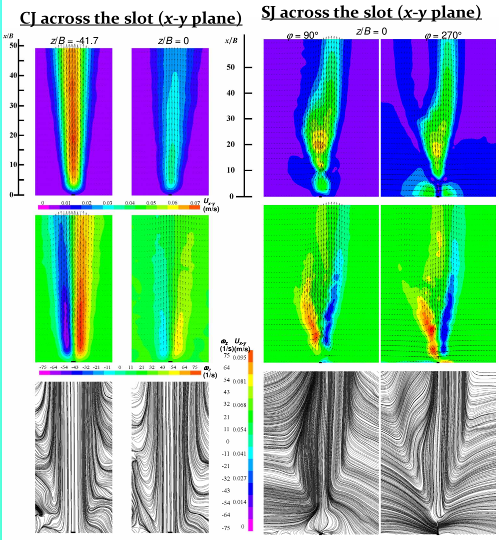
PIV measurement

free jets without cylinder

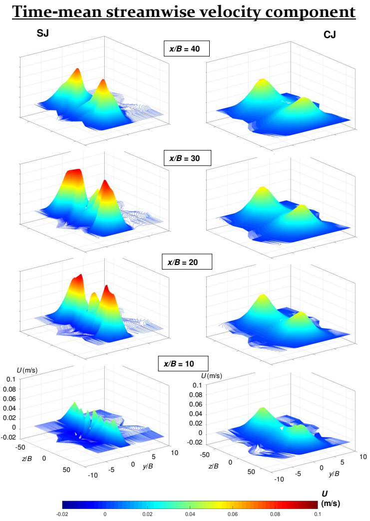
$Re_{SJ} = \frac{U_0 B}{\nu} = 67$ $\quad U_0 = \frac{1}{T}\int_0^{T_E} u_0(t)dt$ $\quad Re_{CJ} = \frac{U_m B}{\nu} = 40$

$Re_{SJ,D} = \frac{U_0 D}{\nu} = 225$ $\quad f = \frac{1}{T} = 46\ \text{Hz}$ $\quad Re_{CJ,D} = \frac{U_m D}{\nu} = 135$

CJ across the slot (x-y plane) — **SJ across the slot (x-y plane)**



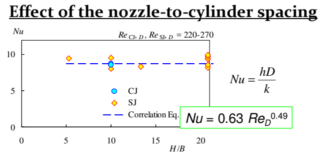
Time-mean streamwise velocity component



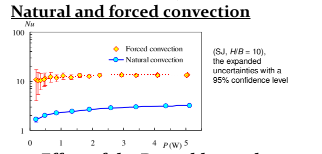
Visualization and temperature measurement

jets impinging onto heated cylinder

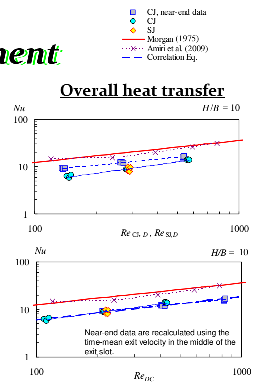
Effect of the nozzle-to-cylinder spacing



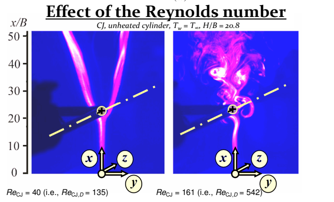
Natural and forced convection



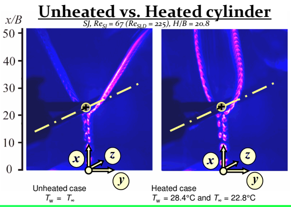
Overall heat transfer



Effect of the Reynolds number



Unheated vs. Heated cylinder



Conclusions

The results of the thesis contribute to

- deepening the basic knowledge of synthetic jet behavior from a fluid mechanics and heat transfer point-of-view,
- establishing more precise background for future investigations of potentially suitable cooling alternatives (e.g., highly loaded up-and-coming electronic components).

1. The synthetic jet was investigated, the highly 3D nature of the initially rectangular jet was revealed. The strong variation of the velocity magnitude along the nozzle span was observed. The existence of streaky-like patterns in the velocity/vorticity field was confirmed. The present results are in good agreement with data from available literature.
2. The continuous jets were investigated, the highly 3D nature of the initially 2D jet was revealed. The dependence of the velocity field on the spanwise location was identified. Saddle back velocity profiles were observed - as expected. The results agree with the literature for common macro jets. On the other hand, no gradual merging of the peaks or axis switching was revealed in this case. Moreover, some findings relate to the micro-size of the present jet, thus neither large coherent structures nor break-up effects were identified. The low mixing intensity and a slow axis velocity decrease were found.
   - The synthetic jet was compared to continuous (steady) jets and several similarities were found in terms of the time-mean characteristics: highly 3D character of the jet issuing from a rectangular slot, highly non-uniform velocity distribution along the span and an absence of the axis switching phenomenon. Visualization of both continuous and synthetic jets impinging onto a circular cylinder confirms the expected flow-field similarity in this case, i.e., both jets are split into two halves after hitting the cylinder surface.
   - The overall heat transfer characteristics were evaluated for both the continuous and synthetic jets impinging onto the cylinder. The average Nusselt numbers are commensurate in both cases.
   - To determine synthetic jets, the Reynolds number was defined from the extrusion stroke of the cycle. The suitability of this approach for fluid mechanics and heat transfer components of the problem was confirmed.
3. The enhancement of the average Nusselt number, using both continuous and synthetic jet, against natural convection was found to be 4.2–6.2 times. The influence of the nozzle-to-cylinder distance on the average Nusselt number was found to be negligible. The Nusselt number obtained for the present microjet was lower than the Nusselt number for conventional macro jet. A new correlation equation for the present range of parameters was proposed: $Nu = 0.63\ Re_D^{0.49}$.

Publications

- Z. Broučková, Z. Trávníček, T. Vít, Synthetic and continuous jets impinging on a circular cylinder. Heat Transfer Eng. 40 (13–14) 2019 (in press; on line version will be available in 2018).
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- Z. Broučková, T. Vít, Z. Trávníček, Laser Doppler vibrometry experiment on a piezo-driven slot synthetic jet in water. EPJ Web of Conferences 92 02007 (2015). (Experimental Fluid Mechanics 2014, Český Krumlov, Czech Republic).
- Z. Broučková, S.-S. Hsu, A.-B. Wang, Z. Trávníček, Water synthetic jet driven by a piezoelectric actuator - LIF and PIV experiments. Advanced Materials Research 1104 (2015) 45-50. (Spring Int. Conf. on Material Sci. and Technology 2015, Beijing, China).
- Z. Broučková, Z. Trávníček, Visualization and heat transfer study of a synthetic jet impinging on a circular cylinder. In: Proc. of 12th Int. Conf.on Heat Transfer, Fluid Mech. and Thermodyn. /HEFAT2016/, Costa del Sol, Spain, 11-13 July 2016, pp. 1791-1796.