EXPERIMENTAL STUDY OF THE HEAT TRANSFER FOR AN ISOLATED CYLINDER IN CROSS FLOW

H. NECULA[1], Elena Nineta GHIZDEANU[2]

În timp ce în domeniul ingineriei un mare interes îl prezintă transferul de căldură la curgerea prin țevi şi peste țevi, în mod egal trebuie să fie studiat şi transferul de căldură care poate avea loc la curgerea transversală peste un cilindru izolat, care constituie elementul de bază al fasciculului de țevi.

În acest articol este prezentat un studiu teoretic şi experimental asupra variației numărului Nusselt şi asupra variației coeficientului de transfer de căldură convectiv pentru diferite valori ale numărului Reynolds la curgerea transversală turbulentă peste un cilindru izolat.

While the engineer may frequently be interested in the heat – transfer characteristics of flow systems inside or/and over tubes, equal importance must be placed on the heat transfer, which may be achieved by a isolated cylinder in cross flow, which is the tubes bundle essential element .

In this paper it is presented a theoretical and experimental study on the variation of local Nusselt number for heat transfer from an isolated cylinder in the turbulent cross flow and the distribution of the local convective heat transfer on the surface for different Reynolds numbers.

Keywords: convective heat transfer, isolated cylinder, angular point, cross flow

Nomenclature:

a thermic diffusivity [$m^2.s^{-1}$];
C coefficient;
d_h hydraulic diameter [m];
m coefficient;
Nu Nusselt Number, $Nu = \dfrac{\alpha \cdot d_h}{\lambda}$;
Pr Prandtl Number, $\Pr = \dfrac{\nu}{a}$;
Re Reynolds Number, $\mathrm{Re} = \dfrac{w \cdot d_h}{\nu}$;

[1] Reader, Dept. of Production and Utilization of Energy, University POLITEHNICA of Bucharest, Romania;
[2] Assist. Dept. of Production and Utilization of Energy, University POLITEHNICA of Bucharest, Romania

t temperature [ºC];

Greek symbols:

α convective heat transfer coefficient [$W.m^{-2}K^{-1}$];
ν cinematic viscosity [$m^2.s^{-1}$];
θ angular coordinate [degree];

Subscripts symbols:

a air;
s surface.

1. Introduction

In the current era of large electronic computers, many complex problems in convection are being solved precisely by numerical solution of equations expressing basic principles, and fundaments of convection.

One of the fundaments of convection is the classic experiment on the average heat transfer rates from a single cylinder in cross flow. Starting from these experiments there are obtained predictions for the heat transfer rate to or from a bundle of surfaces in cross flow.

Moreover, heat transfer to or from a bundle of tubes in cross flow is relevant to numerous industrial applications such as steam generation in a boiler or air-cooling in the coil of an air conditioner.

In this paper it is presented and discussed the variation of local Nusselt number for heat transfer from a cylinder in turbulence cross flow and the distribution of the local convective heat transfer on the surface for different Reynolds numbers.

2. Theoretical correlations.

For an isolated cylinder in cross flow there are develop two types of convective heat transfer, these being laminar and turbulent.

In case of laminar flow, the fluid flows in filaments or streamlines that do not mix. Hence, heat transfer from a surface in laminar flow must occur by conducting through the fluid itself. Therefore, the rate of heat transfer will be low and highly dependent upon the thermal conductivity of the fluid.

In the case of turbulent flow, our case, mixing of the fluid occurs. Hence, a "packet" of fluid may at one instant be close to the heated surface and then rapidly transfer and dissipate in the stream, thus transferring heat very quickly to the bulk of the fluid. A Higher degree of turbulence implies a higher rate of the heat transfer.

For the turbulent flow, theoretical analysis and alternative methods are required in order to evaluate the surface heat transfer coefficients for general flow conditions.

In the case of external flow of a circular cylinder, the free stream fluid is brought to rest at the forward stagnation point, with an accompanying rise in pressure. From this point, the pressure decreases with the increase of the streamline coordinate, and the boundary layer develops under the influence of a favourable pressure gradient. The pressure must reach a minimum and toward the rear of the cylinder further boundary layer development occurs in the presence of an adversary pressure gradient.

For the local Nusselt number at the forward stagnation point (angular coordinate $\theta = 0^{\circ}$) for $Pr \geq 0.6$, the most utilised correlation is [3]:

$$Nu(\theta = 0^{\circ}) = 1.15 \cdot \mathrm{Re}^{1/2} \cdot \mathrm{Pr}^{1/3} \tag{1}$$

3. Description of the model.

Our experimental device presented in Fig. 1 consists in the air duct which is vertically mounted glass reinforced plastic duct with bell mouth intake at its upper end. The fan is mounted on an epoxy coated welded steel frame. Air duct is directly mounted on the frame and fan intake.

The heat element consists of a 22 mm plastic tube covered with an electrically conducting glass cloth of known dimensions. Around the top and bottom of the cloth / cylinder is a continuous electrical bus which allows a uniform low voltage current to be passed through the cloth, thereby heating it. Under the cloth and aligned with the 0° mark on the attached degree disc is a single thermocouple.

All electronic instrumentation and control is housed in a plastic coated steel console which consists of the digital electronic thermometer with 0.1 resolutions, which indicates element surface temperature and, via a biased switch, the duct air temperature and an analogue voltmeter indicating the voltage across the active element heater. The maximum voltage is 35 V.

The pressure is measured by 2 duct mounted inclined manometer recording intake depression one with the range from 0 to 70 mmH_2O and the second one from 0 to 30 mmH_2O.

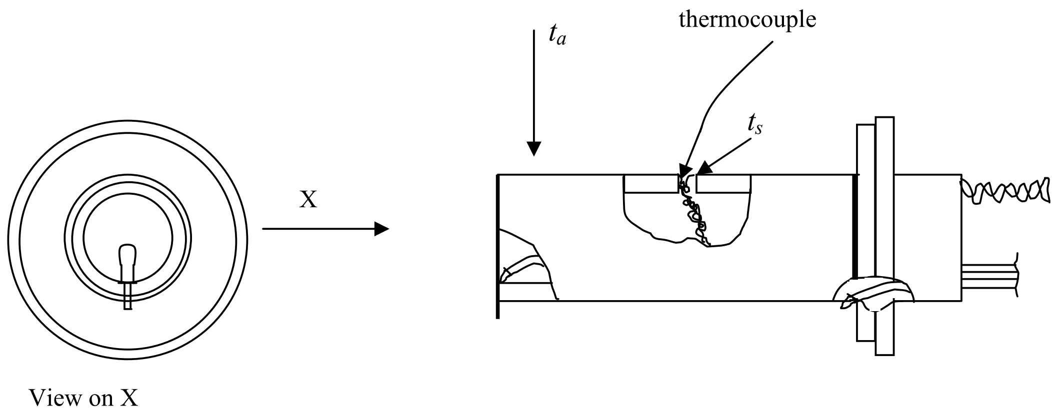

Fig. 1. Experimental setup

On this experimental device it can be made the following experiments:

- Determination of the Relationship between Nusselt and Reynolds Number for the Forward Stagnation Point on a Cylinder in Cross Flow using the Direct Heat Transfer Cylinder;
- Determination of the Variation in Convective Heat Transfer Coefficient around a Cylinder in Cross Flow.

The experimental study was realized with the device presented above. The cylinder was introduced carefully into the hole in the plate and retain with the spring clips with the zero line of the degree disc pointed upwards. In this position the thermocouple sensor is directly under the forward the stagnation point. The cylinder was plugged into the console and the voltage was switch to 35 volts.

The single tube plate consists of a thick plastic plate with a centrally drilled hole into which the active element may be placed.

The pressure tapping was connected to the tube of the upper manometer (0 – 700 mm) for the difference in level measuring.

With the fan running the iris damper was adjusted in conjunction with the manometer in order to obtain a moderate flow of air.

The voltage was increased in order to obtain a surface temperature of approximately 25°C.

When the stable conditions was occurred, indicated by a constant surface temperature, there was recorded the surface temperature t_s, the air temperature t_a, the difference of level, the voltage, and the angle θ.

After that, the cylinder was rotated with 20 degrees, and when the stable conditions was occurred there was recorded the same parameters.

The experiment was repeated for increasing values of θ until θ = 180°, when the thermocouple is situated under the downstream stagnation point, and for various air velocities.

4. Experimental results

The distribution of local Nusselt number for airflow normal to an isolated circular cylinder and the distribution of the local mean convective heat transfer coefficient of a cylinder in cross flow in air is carried out experimentally using the device presented above.

The measurements were made for different air velocities which implied different Reynolds numbers.

The results are presented in Fig. 2 and Fig. 3.

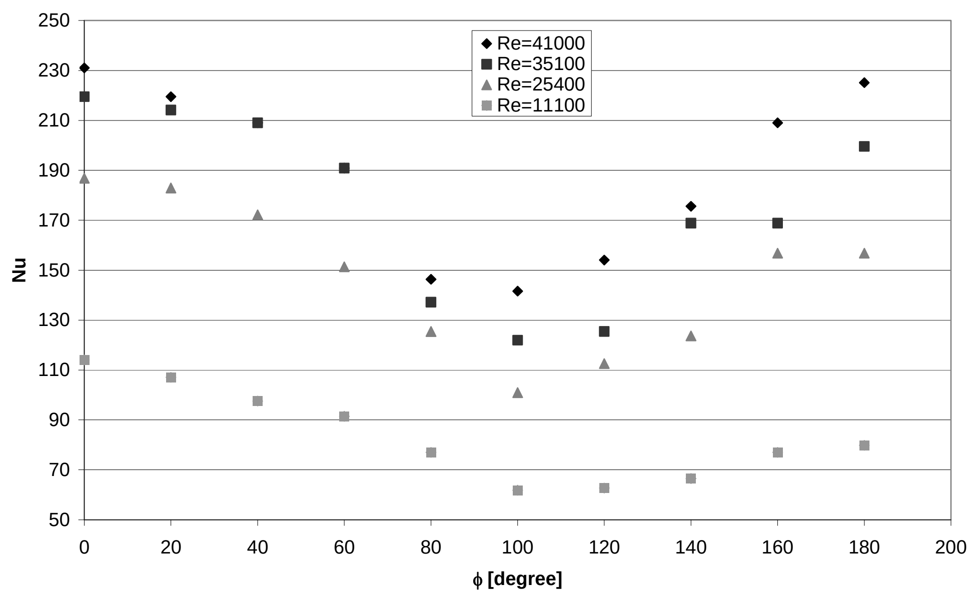

Fig. 2. The local Nusselt number for airflow normal to a circular cylinder

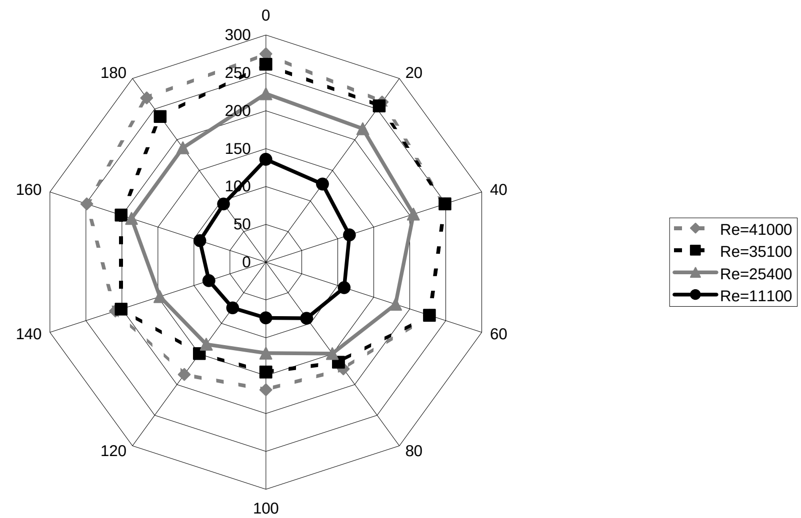

Fig. 3. The distribution of the local mean convective heat transfer coefficient of a cylinder in cross flow in air

5. Conclusions

At the lower Reynolds number from Fig. 2 it results that the local Nusselt number decreases initially along the surface from the forward stagnation point to a minimum which is reach at θ ≈ 100 as a result of laminar boundary layer development. When the minimum is reach the separation occurs and Nusselt number starts to increase with θ due to boundary layer transition to turbulence.

Moreover, for the Reynolds number range analysed, there is observed twofold heat transfer intensification (increase of Nusselt number) with the 3.7-fold turbulence intensification (increase of Reynolds number).

The local Nusselt number is based on the local heat transfer coefficient and the cylinder diameter (Fig. 3.).

There were calculated and verified the correlation described in equation (1) and the relative errors range obtained was between (5 ÷ 12) %.

R E F E R E N C E S

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