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MEASUREMENT OF CONVECTIVE HEAT TRANSFER COEFFICIENT FOR A HORIZONTAL CYLINDER ROTATING IN QUIESCENT AIR

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ABSTRACT

The present paper deals with convective heat transfer from a horizontal cylinder rotating in quiescent air, experimentally. The average convective heat transfer coefficients have been measured by using radiation pyrometer, which offers a new method. According to the experimental results, a correlation in terms of the average Nusselt number and rotating Reynolds number has been established. The equation, $\overline{Nu} = 0.318\ Re_r^{0.571}$, has been found valid for a range of the rotating Reynolds number from 2000 to 40000. The average Nusselt number increased with an increase in the rotating speed. Comparison of the results, with the previous studies, have been showed a good agreement with each other.

Introduction

Heat transfer from a rotating cylinder is one of the problems, which is drawing attention due to its wide range of engineering applications. The application areas vary from the space vehicle technology to the rotating machinery. Convective heat transfer from a horizontal cylinder rotating in quiescent air was studied experimentally by Anderson and Saunders [1], Etemad [2], Dropkin and Carmi [3], Kays and Bjorklund [4], Becker [5] and Shimada et al. [6].

Anderson and Saunders found that the average Nusselt number, $\overline{Nu}$, was independent of the rotating Reynolds number, Re_r, up to a critical value. The critical rotating Reynolds number was found to be equal to $(Re_r)_{cr} = 1.09\ Gr^{1/2}$. Above this critical value, it was found that the average Nusselt number increased with the rotating Reynolds number. They derived an expression by using heated horizontal plate analogy above the critical rotating Reynolds number. Etemad found that the laminar Couette motion broke down at a critical rotating Reynolds number by making interferometry observations. Secondary flow above the critical value was steady up to a rotating Reynolds number of 14500. Above this value the flow was turbulent. Dropkin and Carmi determined the heat transfer rate from horizontal rotating cylinder to ambient air for rotating Reynolds numbers up to 433000. Kays and Bjorklund measured heat transfer from a horizontally rotating cylinder in air and investigated the case by means of the momentum and heat transfer analogy. Becker , first , studied the heat transfer from a horizontal cylinder rotating in water. Then , he extrapolated the data collected for water to a Prandtl number , Pr , of 0.72 valid for air . Schimada measured local and average coefficients of heat transfer from a rotating cylinder under with and without flow conditions by Mach-Zehnder interferometer.

Convective heat transfer from rotating bodies in quiescent air was investigated , theoretically , by Dorfman and Serazetdinow [7] , Dorfman and Selyavin [8] , Sherstyuk [9] and Suwona [10] . Due to the mathematical difficulties and wide variations of the geometries , theoretical studies are scarce in this field . In this study, convective heat transfer from a horizontal cylinder rotating around its own axis in quiescent air has , experimentally , been investigated by using a radiation pyrometer. As a result of the data , an equation which the average Nusselt number could be predicted has been correlated for a range of the rotating Reynolds numbers from 2000 to 40000 and compared with the previous ones.

Experimental Apparatus and Procedure

A schematic view of the experimental apparatus is shown in Fig.1. The copper test cylinder was mounted horizontally and driven by a variable speed DC motor. The range of rotating speed was between 0 and 1700 rpm. But the measurements below 100 rpm were not carried out because of fluctuations occurred in the rotating speed. The copper cylinders were 95 , 66 , 54 mm in outer diameters each 500 mm in length. Rotational speed of the cylinder was measured by an optical transducer and a speed pulse amplifier. A rotometer was used for measuring flow rates. The heating of the cylinder was accomplished by using a circulated heating bath. In order to let the heat transfer to be only from lateral surface , bilateral front surfaces of the cylinder were well insulated. Copper-constantan thermocouples were used measuring the inlet and outlet water temperatures of the copper test cylinder. The ambient air temperature was measured by means of four thermocouples placed equally around the rotating cylinder. The surface temperature of rotating cylinder was measured by a radiation pyrometer . The measurements were repeated at three different points located on the cylinder.

The average Nusselt number was obtained by using the average outer convection coefficient , $\overline{h_o}$, which was determined by equating the heat transfered to the cylinder

$$Q = m\, c_p\, (T_i - T_o) \qquad (1)$$

and the heat transfer between the ambient air and cylinder surface

$$Q = \frac{2\pi L(T_s - T_\infty)}{\dfrac{1}{\overline{h_o} r_o}} \tag{2}$$

Thermophysical properties of the water and air were taken at arithmetical means of the inlet and outlet water temperatures and the surface and ambient air temperatures.

Functional dependence of the average Nusselt number is

$$\overline{Nu} = f(Re_r, Pr) \tag{3}$$

Since the Prandtl number of 0.72 constant for air, the functional dependence is reduced to

$$\overline{Nu} = f(Re_r) \tag{4}$$

Because of the low surface temperature and relatively high rotating speed, respectively, radiation and natural convection effects were ignored.

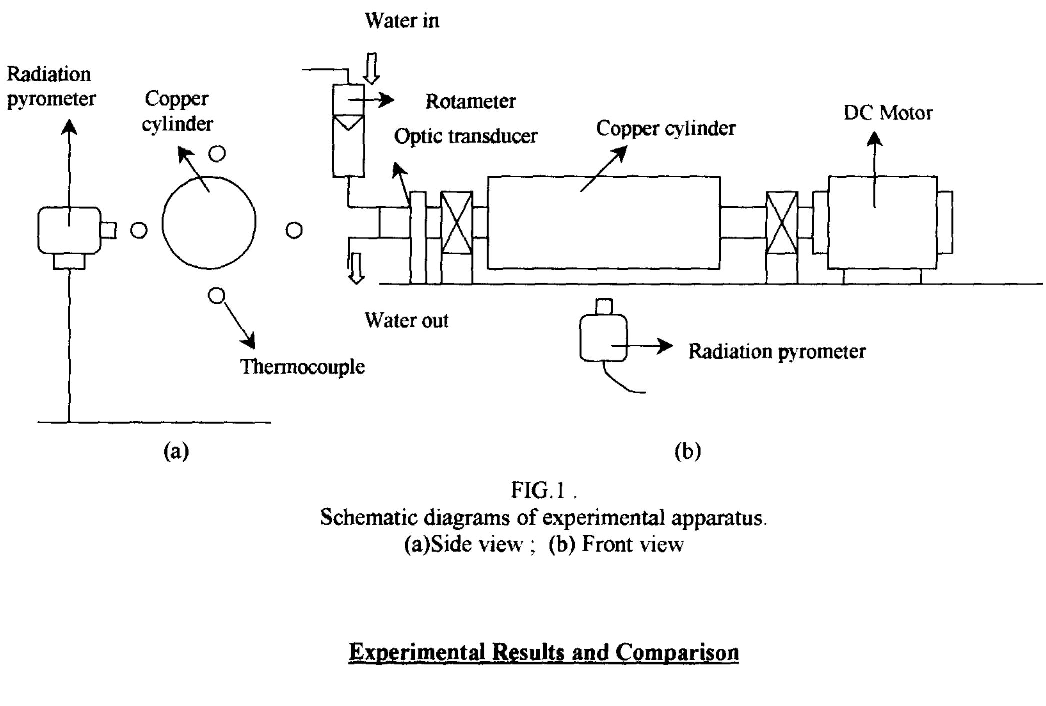

FIG.1.
Schematic diagrams of experimental apparatus.
(a)Side view ; (b) Front view

Experimental Results and Comparison

Figure 2 shows the relationship between the rotating Reynolds number and average Nusselt number.The correlation obtained as a result of regression analysis is

$$\overline{Nu} = 0.318\,(\mathrm{Re_r})^{0.571} \tag{5}$$

The coefficient of determination , R^2 , that belongs to the correlation expressed above is 0.810. This equation is compared with the other ampirical equations obtained from previous studies in Figure 3 .

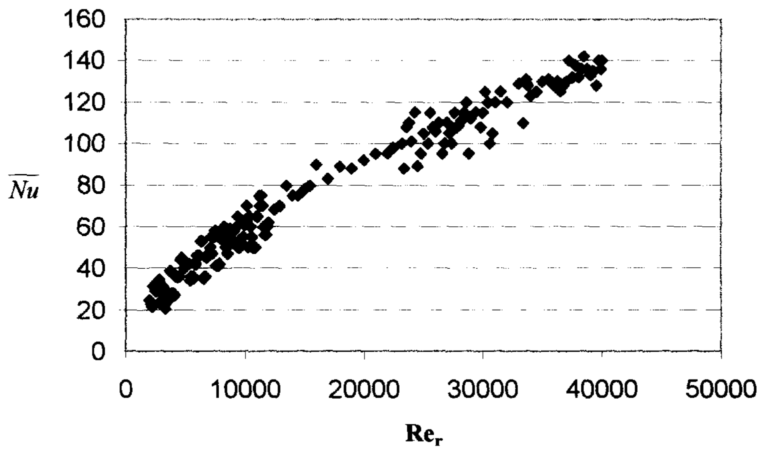

FIG.2.
Relationship between rotating Reynolds number and average Nusselt number.

A comparison of the available equations is given in Table 1.

TABLE 1
Comparison of the available equations

Author	Equation	Remark & Referance
Anderson & Saunders	$\overline{Nu} = 0.1\,\mathrm{Re_r}^{2/3}$	Analogy solution [1]
Etemad	$\overline{Nu} = 0.076\,\mathrm{Re_r}^{0.7}$	$8000 \leq \mathrm{Re_r} \geq 65400$ [2]
Etemad	$\overline{Nu} = 0.11\,[(0.5\,\mathrm{Re_r}^2 + \mathrm{Gr})\,\mathrm{Pr}]^{0.35}$	$1000 \leq \mathrm{Re_r} \geq 8000$ [2]
Dropkin & Carmi	$\overline{Nu} = 0.073\,\mathrm{Re_r}^{2/3}$	$15000 \leq \mathrm{Re_r} \geq 433000$ [3]
Dropkin & Carmi	$\overline{Nu} = 0.095(0.5\,\mathrm{Re_r}^2 + \mathrm{Gr})^{0.35}$	$1000 \leq \mathrm{Re_r} \geq 15000$ [3]
Kays & Bjorklund	$\overline{Nu} = \dfrac{Re\,Pr\,\sqrt{(f/2)}}{5\,Pr + 5\,ln(3\,Pr + 1) + \left[1/\sqrt{(f/2)}\right] - 12}$	Analogy solution [4]
Becker	$\overline{Nu} = 0.119\,\mathrm{Re_r}^{2/3}$	$800 \leq \mathrm{Re_r} \geq 100000$ [5]
Shimada et al.	$\overline{Nu} = 0.046\,\mathrm{Re_r}^{0.7}\,(1+8\,\mathrm{Gr}/\mathrm{Re_r}^2)^{0.95}$	$300 \leq \mathrm{Re_r} \geq 3000$ [6]
Özerdem	$\overline{Nu} = 0.318\,\mathrm{Re_r}^{0.571}$	$2000 \leq \mathrm{Re_r} \geq 40000$, this study

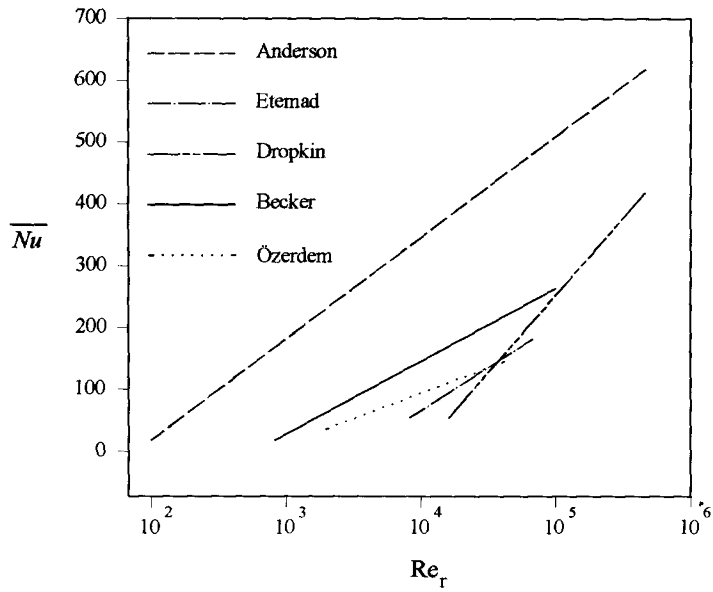

FIG. 3.
Comparison of experimental studies.

Conclusions

An experimental study of convection around a rotating horizontal cylinder has been completed . In this paper , a new method of radiation pyrometer is used to measure average outer convection coefficients for a horizontal cylinder rotating in ambient air. All the measurements have been obtained in the region where the natural convection effect was negligible. Therefore , heat transfer rate is assumed to depend on the rotational Reynolds number only. As a result of the experimental data the average Nusselt number has been correlated for a range of the rotating Reynolds numbers from 2000 to 40000 . The value of the average Nusselt number increased with an increase in the rotating speed . The data agreed well with the previous studies.

Nomenclature

c_p heat capacity , kj / kg °C

D_o outer diameter of cylinder , m

f friction coefficient , dimensionless

g gravity , m / s^2

Gr Grashof number , dimensionless $= \dfrac{gd^3 \beta \Theta \rho^2}{\mu^2}$

$\overline{h_o}$ average outer convection coefficient , W / m^2°C

k conduction coefficient , W / m °C

L length of cylinder , m

m mass flow rate , kg / s

$\overline{Nu}$ average Nusselt number , dimensionless $= \dfrac{\overline{h_o} D_o}{k}$

Pr Prandtl number , dimensionless $= \dfrac{\mu c_p}{k}$

Q heat flow , W

Re_r rotating Reynolds number , dimensionless $= \dfrac{\Omega D_o^2 \rho}{2\mu}$

r_o outer radius of cylinder , m

T_i inlet temperature of water , °C

T_o outlet temperature of water , °C

T_s surface temperature of cylinder , °C

T_∞ ambient temperature , °C

ß coefficient of thermal expansion , °C^{-1}

μ dynamic viscosity of air , kg / m s

Ω angular velocity of cylinder , s^{-1}

ρ density of air , kg / m^3

θ temperature difference between surface and ambient , °C

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