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An Experimental Study for Determination of Convective Heat Transfer Coefficients on Yarn Production Line

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Abstract. In this study, the convective heat transfer coefficient around small diameter circular wires is determined in an effort to obtain main parameters affecting quenching in melt fiber spinning. The different diameter wires and air velocities were employed for detailed research in parallel and cross flow by using a wind tunnel. These correlations were based on conditions used in monofilament yarn production line. The wire diameters which are used in the experiments were varied from 0,2 mm to 1 mm and air velocities were varied from 0,5 m/s to 5m/s. These wires were heated with power supply and cooled with specified air flows for the determination of convective heat transfer coefficients. A multimeter was used to measure the voltage and current values; and the resulting wire resistances were calculated for each wire surface temperature. The convective heat transfer coefficients were obtained from total electrical power consumption and formulas of convection heat coefficient and radiative heat transfer. The experiments were carried out with different Reynolds numbers. Finally, the resulting Nusselt correlations were compared to the correlations reported by Ohkoshi,, Glicksman, Copley, Kase and Matsuo, Churcill and Bernstein, Hilpert, Fand and Kesvani, and, Dito. The present results are in good agreement with literature and they are in the same range for these Reynolds numbers.

INTRODUCTION

Heat transfer (or heat) is thermal energy in transit due to a spatial temperature difference. The transfer of energy as heat is always from the higher-temperature medium to the lower-temperature one, and heat transfer stops when the two mediums reach the same temperature. Heat can be transferred in three different modes: conduction, convection, and radiation [1].

The heat transfer mechanisms used in this study are convection and radiation heat transfer mechanisms. These mechanisms are formed on the wires in the wind tunnel environment. The heat transfers with the radiation of the environment in which the wire is located is a size that cannot be negligible.

The regional convective heat flux of a fluid over a surface and total heat transfer are expressed as:

$$Q = h.\mathrm{A}.(\mathrm{Ts} - \mathrm{T}\infty) \tag{1}$$

where A is cross sectional area of heat surface, Ts and T∞ are the temperature of surface and environment fluid, respectively.

Heat transfer is a function of Reynolds Number,

$$\mathrm{Re} = \rho.v.\mathrm{L} / \mu \tag{2}$$

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where ρ is the fluid density, v is a bulk velocity, μ is dynamic viscosity. The Nusselt number (Nu) is the ratio of convective to conductive heat transfer across (normal to) the boundary [1].

$$Nu = h.\mathrm{L} / \mathrm{k} \tag{3}$$

Heat transfer coefficient h can be derived from (3) by placing the Nusselt number into the equation in which k is the fluid conductivity, and L is a characteristic length, such as a diameter.

In a study by Ravi and others in 2014, air flow and heat transfer in a two-dimensional circular cylinder unsteady flow regime were investigated. The effects of the Reynolds number on the drift and lift coefficients, the number of Strouhal, and the effect of a long circular cylinder on the heat transfer characteristic were investigated in the crossflow of Reynolds numbers from 50 to 180. At the same time CFD (Computational Fluid Dynamics) solver was also simulated using the Fluent program. The results obtained were consistent with the experimental / numerical data available for the circular cylinder in the literature. Nusselt number increased with increasing Reynolds number. At the same time, as the number of Reynolds increased, the drift coefficient increased. As a result, the relative drift coefficient for the specified operating range and the Nusselt number were obtained as a function of the Reynolds number [2].

In Manohar and Ramroop's experiment in 2010, the flow was made through two steel pipes of 34 mm and 49 mm in diameter along the air flow of 1.1 m/s and 2.5 m/s, with the horizontal axis at 30 and 60 degrees and heat transfer characteristics. These experimental studies are compared with literature. 30 ° slope and Nu values at an air velocity of 1.1 m / s were observed to agree well with the literature, however, considerable differences were observed at 60 degrees' slope and air velocity of 2.5 m/s. The experimentally determined Nusselt number for 30 degrees of inclination varied from 2% to 18% in the air velocity of 1.1 m/s and from 12% to 41% in the air velocity of 2.5 m/s. The experimentally determined Nusselt number for 60 degrees of inclination varied from 19% to 45% in the air velocity of 1.1 m / s and from 29% to 65% in the air velocity of 2.5 m/s [3].

Experiments by Yuge in 1960 to find convection heat transfer for the sphere were carried out in the range of 1.44x105 to 3.5 x 105 Reynolds number and 1 to 105 Grashof number. Empirical formulas for forced, natural and combined convection heat transfer have been obtained and compared with other experiments in the literature. The results obtained are consistent with literature studies [4].

EXPERIMENTAL STUDY

A schematic figure of Wind Tunnel Test Apparatus is shown in **FIGURE 1**. The experimental test apparatus comprises tunnel, fan, power supply, digital multimeter, flow meter, frequency converter and wires with diameters between 0.2 mm to 1.0 mm. These are used to represent monofilament yarns. The model of the wires is Resistohm 30 and their chemical compositions is Ni-Cr-Fe alloy which is in conformity with ASTM B 344.



FIGURE 1. Wind Tunnel Test Apparatus

Air passes over around the wires and it is cooled. Air flow rate is adjusted with a frequency converter and measured with Testo 435 model flow-meter with a full scale accuracy of 1.0%. Wires holder is used to keep the wires stable during air flow. The cylinder position for cross flow is 90 degrees as shown in **FIGURE 2**.

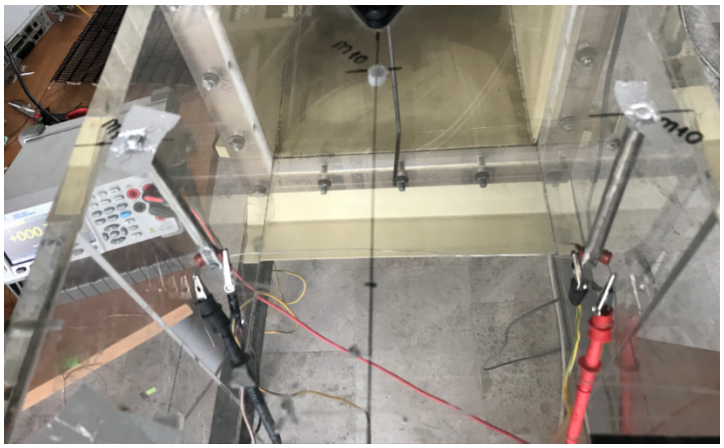


FIGURE 2. Wire and Wire Holder for Cross Flow

Before testing, uncertainty of measurement test was realized. Repeatability and reproducibility of testing system was analyzed. Test system can recognize differences stemming from changes in different parameters on test. Also it gives repetitive results for the same inputs. Test system provides significant results according to uncertainty of measurement analysis. Tests are carried out at air velocities from 0,5 to 5 m/s and with wires having diameters varying from 0,2 to 1,0 mm. All parameters were selected to simulate monofilament yarn production line.

RESULTS

Wind Tunnel Test Apparatus was used to determine Nusselt and Reynolds numbers correlations to calculate convective heat transfer coefficients around circular wires with small diameters. Parallel and cross flow type air was used for these experiments to represent quenching process of monofilament yarn. Analysis of the results and drawing of the graphics were done using Minitab Software.

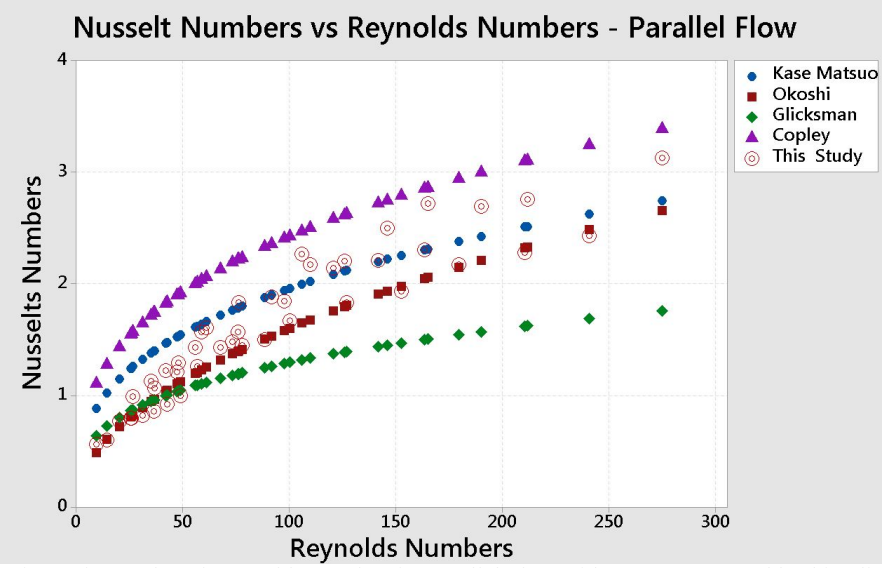


FIGURE 3. Comparison of Nusselt and Reynolds Number for Parallel Flow with Kase Matsuo, Ohkoski, Glicksman, Copley

FIGURE 3 shows that Nusselt and Reynolds numbers changes which they were calculated from experimental results for parallel flow. The experiments were carried out in the range of Reynolds numbers from 9 to 275, with an r^2 value of 0,93. The convective heat transfer coefficients were found from 24 to 160 W/m^2.K. The results were compared with the ones reported by Kase and Matsuo, Ohkoshi, Glicksman and, Copley [5-8].

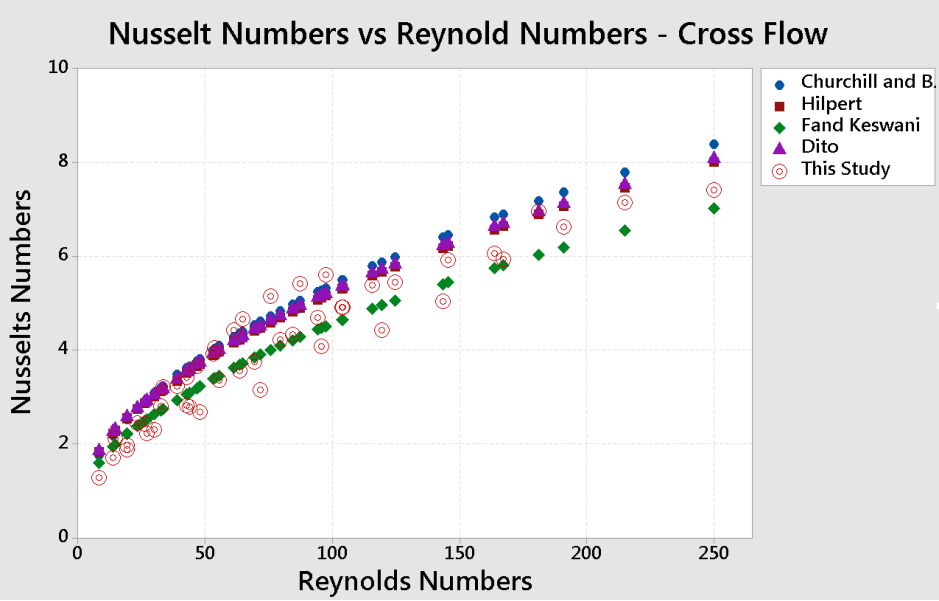


FIGURE 4. Comparison of Nusselt and Reynolds Number for Cross Flow with Churchill and B., Hilpert, Fand and Keswani, Dito

The cross flow experiments were carried out in the Reynolds numbers range from 8 to 250, with an r^2 value of 0,93. The Nusselt correlations which are determined from the experiments were compared with the ones reported by Churcill and Bernstein, Hilpert, Fand and Kesvani, and, Dito on **FIGURE 4** [9-12].

CONCLUSIONS

In this paper, wires with different diameters and air velocities were used by using a wind tunnel. These parameters play an important role on convective heat transfer coefficient. The results showed that the higher diameter value of wire provides a greater forced convection heat transfer for the same air velocity. For the same experimental conditions and wires, the convective heat transfer coefficient increases with air velocity.

For parallel flow, the experiments were carried out in the Reynolds numbers ranging from 9 to 275. The correlations were compared with the ones reported by Golzar, Ohkoshi, Zieminski, Glicksman, Copley, Brünig and, Kase and Matsuo. For cross flow, the experiments were carried in the Reynolds numbers ranging from 8 to 250. The Nusselt correlations which are determined from experiments were compared with the correlations of Churcill and Bernstein, Hilpert, Fand and Kesvani and Dito. The present results are in good agreement with literature and they are in same range for these Reynolds numbers. These present correlations give the Nusselt numbers for various flow conditions and the heat transfer coefficient *h* is found.

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