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Empirical correlation for performance evaluation of electric/corona wind on natural convection

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ABSTRACT

The effect of the corona wind on the natural convection at a rectangular channel was investigated experimentally. The results indicate that the natural convection in the absence of electric/corona wind at obtuse angles outperforms than acute angles and keeps improving by increasing the angle. However, the efficiency of the electric/corona wind at acute angles is higher than obtuse angles. Generally, in the presence of electric/corona wind, heat transfer coefficient was increased. The effect of the electric/corona wind was decreased by raising heat flux. This mainly stems from the fact that the temperature gradient raises the thermal boundary layer and reduces the secondary flow power. Eventually, empirical correlation for the estimation of Nusselt number was achieved.

1. Introduction

As far as energy issue concerns, the human beings have looked for generating energies and transforming them to their benefits, one of which is heat energy. It plays a significant role in humankind's life cycle. Perhaps, in some cases, heat was a harmful phenomenon to them and they have tried to decrease and transmit the heat based on their needs. In accordance with developing humankind's needs and their progress in different fields especially in industries, their requests for inhibiting heat in a variety of industrial procedures, whether in large scales like power plants and condensers or small scales such as microchips and electronic components, have been increased. In recent decades, numerous attempts in the field of heat transfer increase and optimize have been made. Generally, these attempts could be classified in two categories: active methods and passive methods. In the inactive methods, developed surfaces along with creation of vortex thorough raised surfaces were more utilized. On the other hand, in active methods, external powers such as electrical and acoustic fields or surface vibration was frequently applied for heat transfer enhancement.

Using electrical fields account for a particular position amongst active methods. When the electrical current is low enough as to neglect the magnetic effect, electrical powers will have an impact on the hydrodynamic of the fluid, which is called electrohydrodynamics powers. The facility, high reliability, and short response time are among the advantages of this methodology. Therefore, in recent years these kinds of powers attracted scientists' attention.

Windischmann [1], investigated the temperature profiles of a flat plate in the presence of the corona wind and concluded that the effect of corona wind is more in Helium than in the air, Nitrogen, and Argon. Then Yabe et al. [2] presented the analytical and experimental model for corona wind. Moreover, it was demonstrated that the Coulomb force acting on the ions and treating between ions and neutral gas molecules forms corona wind. Furthermore, Velkoff and Godfrey [3] conducted a research on heat transfer from air fluid flow of flat plate with presence of corona discharge. Hutson and Franke [4] also investigated the effect of the electrical field, as one of natural convection approaches, on the fluid in the hollow vertical cylinder at constant temperature. They proved that the heat transfer ratio has approximately twice increased chiefly due to the presence of the corona wind.

Ohadi et al. [5] surveyed the effect of electrical discharge in forced convection with air fluid in the tube at Reynolds number ranged between $1000 < Re < 1500$, And zero Electrical potential

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Nomenclature

Ra	Rayleigh Number
Q''	heat flux (W/m^2)
β	thermal expansion coefficient (1/k)
α	thermal diffusivity
C_p	Specific heat at constant pressure (J/Kg K)
υ	kinematic viscosity (m^2/s)
H	length of plate (m)
K	thermal conductivity (W/m K)
T_{sx}	wall temperature (k)
T_{in}	bulk temperature (k)
V	voltage (V)
I	current (A)
D	degree of plate
X	distance (m)
g	standard gravity (m/s^2)
R	resistance of wire (Ω)
A	area of plate (m^2)

near the discharge was obtained practically when the arrangement of electrodes is single or double. The conclusions showed significant heat transfer in laminar and transient flow in single electrode case whereas in double electrodes arrangement, heat transfer prevails in turbulent flow. Tada et al. [6] investigated the heat transfer increase in the flow in terms of forced relocation by the electrical field and they detected the fluid behavior under the filed by using the smoke. They also experienced a pair reverse vortex due to fluid flow and the ionic wind interactions. In another study, Ngo and Lai [7] surveyed the effect of electrical fluid on natural convection at the bottom of the channel, which was heated in 2-dimensional and concluded that corona wind is effective at low Rayleigh numbers. Bhattacharyya and Peterson [8,9] worked on novel flow visualization as well as extensive and controlled heat transfer enhancement. The study was conducted in order to characterize the corona wind augmentation via natural convection process from a vertical copper plate subjected to a reversible polarity DC high-voltage electric field at various constant heating fluxes.

Legar et al. [10] investigated the fluid flow with low velocity along a flat surface in presence of DC discharge field. According to the characteristics of the electrical discharge, they indicated that the features are depended on the moisture and electrical geometry. Molki and Bhamidipati [11] examined the amount of heat transfer obtained from corona wind at developed zone in the tube experimentally. Based on the results, the maximum and average amount of local heat transfer coefficient are 8%, 23%, respectively.

Yan et al. [12] accomplished the mathematical and numerical model for natural convection in chambers with electro-hydrodynamic. They observed that in the same electrical field, heat transfer due to EHD has been changed by altering the electrical density injection. Using a non-uniform electrical field has given a better feedback in comparison with that of uniform electrical field. Heat transfer is dependent on Rayleigh number while the effect of EHD is mainly at low Rayleigh number. Kasayapanand and Kiatsiriroat [13] worked on the convection at wavy channels through EHD technique. They also surveyed various arrangements of electrodes. Their conclusions represented that the heat transfer increase is dependent on the quantity of electrodes and waves along the length of the channel. Molki and Harirchian [14] conducted a research on the effect of corona discharge on the natural convection heat transfer inside a rectangular channel. The results showed that increasing heat transfer for different Rayleigh numbers is within 1–4%. This increase occurred at $Ra = 3737$ and applied voltage was between 7 and 9 (kV). Kasayapanand [15] developed a study concerning the effect of EHD on the natural convection inside the chamber with different electrodes arrangement. He worked on the reciprocal effects of electrical field, fluid flow, and thermal field. More recently, Kasayapanand [16] investigated heat transfer increase by EHD technique inside a channel with numerous electrode arrangements in a numerical manner and it was seen that heat transfer coefficient in presence of electrical field increased by rising the applied voltage and decreased by increasing Reynolds number. They also found that the electrode arrangement in a row created more heat transfer in comparison with the checkered arrangement. Then, Kasayapanand and Kiatsiriroat [17] presented a numerical solution in surveying natural convective heat transfer in a vertical channel. Kasayapanand [18] investigated heat transfer increase in a solar chimney in a natural convection form in presence of EHD in the recent research. GO et al. [19] studied heat transfer increase in the forced convection through unique wind. They realized that the value of heat transfer is dependent on the distance between electrodes whereas the heat transfer coefficient is proportional to the fourth root of corona flow. Recently, Lakeh and Molki [20] conducted a numerical research on the impact of corona jet on heat transfer in rectangular channels with longitudinal and flat electrodes.

In this project, heat transfer from flat surface of rectangular channel, wherein there is active zone, was investigated experimentally through EHD technique. We studied how heat transfer mechanism operates in various fluxes and at different angles in presence and absence of the distinct electro-hydrodynamic fields. According to the obtained data, an equation is presented in order to calculate Nusselt number in terms of different parameters such as angle, flux, field, and Rayleigh number.

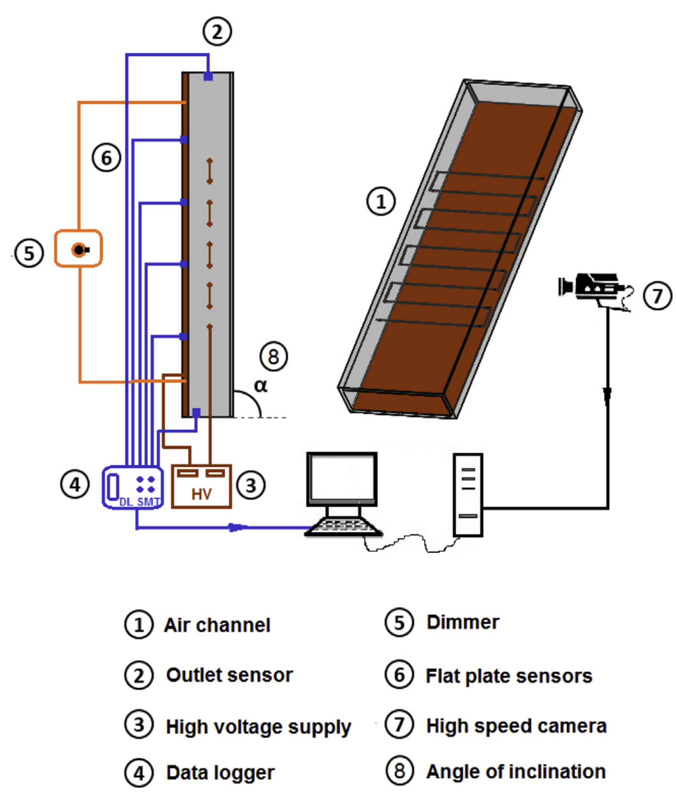

Fig. 1. Schematic of laboratory setup.