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Influence of electrode arrangements on Electrohydrodynamics and transport phenomenon within water and porous samples connected to rectangular duct

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ABSTRACT

A numerical study based on the concept of conjugate transport phenomena analysis has been developed for the investigation of heat transfer and fluid flow within a rectangular duct and a sample by Electrohydrodynamics technique. High electrical voltage and average velocity of inlet hot-airflow are applied at 20 kV and 0.1 m/s, respectively. Electrode arrangements or angle between electrode and ground are varied in a range of $\theta = 0–360°$. The effect of swirling flow on EHD-enhanced heat transfer is also examined. The results show that electric field from various angles can induce the difference swirling flow pattern. By fluid flow within the sample is depended on the swirling flow and hot-airflow direction. Besides the shear flow effect, swirling flow is affected by temperature distribution. Therefore, it affects the sample. Furthermore, fluid flow from swirling flow effect and sample properties is the main mechanism of natural convection and conduction modes, respectively. Finally, the comparison of heat transfer enhancement between water sample and porous sample are also presented.

1. Introduction

Conventional drying technique is usually involved high temperatures; this technique is widely used in food products. However, physical and chemical properties are changed due to produce undesirable. Furthermore, its drying period is long resulting in large energy consumption. The most important thing in industries except for producing the high-quality products, there is to increase productivity and reduce production cost. In fact, drying technique is involved with conventional heat transfer by air, it is the most common medium used to transfer energy in thermal food products. It is usually blown at the surface of the food to ensure by heat treatment since drying, chilling, boiling and freezing are the processes mainly concerned by these convective heat transfers [1–3]. The recent development trends in heat transfer technique are focusing on conventional or hot-air drying cooperating with other techniques such as microwave, vacuum, infrared and Electrohydrodynamics (EHD) [4–8]. In general, several techniques of industrial products are related to heat transfer technique either by using energy from other sources resulting in low production costs. The microwave heating technique takes place inside the material, the penetrated depth of which governs how strongly the microwave energy absorbed. However, it is known that the heat dissipated from the microwave technique depended on many parameters it is known that result in poor quality products when it is not properly applied [9]. In the vacuum, a technique can reduce operating times and higher end-product quality but fundamental of vacuum technique is the operating pressure to control of the product below a prescribed limit [10]. From infrared radiation, it is transmitted through water at a short wavelength while it is absorbed on the surface at a long wavelength [11]. One way to improve thermal efficiency is to extend heat transfer area and increase the flow velocity. The heat transfer enhancement technique utilizing electrostatic force generated from the polarization of dielectric fluid or EHD can be one of the most promising methods among various active techniques because of its several advantages. This technique deals with the interdisciplinary field with subjects concerning the interactions between electric and flow fields. When an electrical voltage is exposed to airflow, ions from a sharp electrode move forwards to the ground. An ionic wind or primary flow is formed when air ions are accelerated by an electric field and exchange momentum with neutral air molecules. It is because ionic winds can generate flow with no moving parts and have low power consumption. As a result, the momentum of airflow is enhanced [12]. Meanwhile, shear flow effect which is occurred by velocity difference between uncharged and charged air induces the uncharged air to become secondary flow or

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swirling flow.

In order to improve convective heat transfer, some researchers are studying seriously in EHD technique with flow control [13–19]. Dulikravich et al. [13] studied a mathematical model and an explicit finite-difference for two-dimensional laminar steady flow and solidification of an incompressible, viscous and electrically conducting. The system of governing EHD equations was derived from a combination of Maxwell's equations and the Navier-Stokes equations including thermally induced buoyancy, latent heat release, and Joule heating. The numerical results demonstrated the existence of strong electro-thermoconvective motion in the melt and quantify its influence on the amount of accrued solid, deposition pattern of the electrically charged particles inside the accrued solid and the melt/solid interface shape. Go et al. [17] analytically and experimentally studied of heat transfer from a flat plate. Corona discharges were generated between a steel wire and copper-tape electrode pair on a flat plate, perpendicular to the bulk flow direction such that the ensuing ionic wind was in the direction of the bulk flow. The magnitude of the corona current and the heat flux on the flat plate were varied. The result found that the heat transfer coefficient was shown to be related to the fourth root of the corona current and heat transfer enhancement was seen to be solely a hydrodynamic effect. Variation of the spacing between electrodes demonstrates that while the local peak enhancement was largely unaffected, the area of heat transfer enhancement was dependent on this spacing. Kasayapanand [18] numerical studied the electric field effect on natural convection in the square enclosures with the single fin and multiple fins. The interactions electric, flow and temperature fields were analyzed using a computational fluid dynamics technique. The parameters considered the supplied voltage, Rayleigh number, size of the enclosure, electrode arrangements, number of fins and fin length. The result shown that the flow and heat transfer enhancements were the decreasing function of Rayleigh number, the heat transfer coefficient was substantially improved by the electric field effect especially at the high number of fins and longfin length. In addition, the maximum average velocity and heat transfer enhancement occurred at the different electrode arrangements for the single fin and multiple fins.

For several years our research group tried to increase the convective heat transfer subject to EHD technique [20–22] such as Chaktranond and Rattanadecho [20] experimentally investigated the influences of electrical voltage on the heat and mass transfer in porous packed bed subjected to EHD drying. The results showed that the heat and mass transfer rate in the packed bed was increased when using EHD. Furthermore, the convective heat transfer coefficient and drying rate were considerably enhanced with the strength of electric field influencing swirling flow. Saneewong Na Ayuttaya et al. [21] studied electric field distribution, characteristics of swirling flow and effect of inlet velocity. The numerical results showed that the difference of electrode and ground arrangements influenced the swirling flow behavior dominantly due to the characteristics of Coulomb force or electric body force which was affected by the electric field. The strength of swirling flow was decreased when inlet velocity was increased because inertial force was superior to the electric body force. Moreover, the idea behind this work can be used as guidance for the special design of EHD application processes in the future. It can be seen that our group studies flow phenomena under electric field in order to increase the swirling flow. The benefit of swirling flow is directly related to heat transfer enhancement within a sample. Various types of sample occur in many industries such as food, ceramic and wood. The most of sample is the porous material or porous medium. The porous medium is a material that consists of a solid matrix with an interconnected void. Based on the complexity of interface problem, the heat transfer and swirling flowing past it is a conjugate transport phenomenon. The heat transfer between a body and a fluid flowing past it is a conjugate problem, because the heat transfer inside the body is governed by the elliptical Laplace equation or by the parabolic differential equation, while the heat transfer inside the fluid is governed by the elliptical Navier-Stokes equation or by the parabolic boundary layer equation. The solution of such problem gives the temperature and heat flux distributions on the interface, and there is no need for a heat transfer coefficient.

From the literature review of conjugate approach [23–27], it is essential to simulate all of this electric field, flow field and temperature field systematically but there are few studied on EHD technique with the conjugate approach. In this study, a rectangular duct flow model is used to simulate the swirling flow and heat transfer enhancement in the specified domain. Moreover, electrode arrangements are varied the angle between electrode and ground, in order to study the suitable arrangements for enhancing the fluid flow and temperature distribution within sample. The natural convection or fluid flow within sample has been studied. Finally, comparison of heat transfer and fluid flow within water sample and water porous sample are presented.

2. Modeling analysis

This rectangular channel comprised of main three parts, the first, second and third parts are the electric field, fluid flow, and heat transfer models, respectively. The dimension of rectangular channels is 2.8 m (long) × 0.3 m (high). In order to study effect within the sample, it is placed at the lower of rectangular duct and the top surface is exposed to the hot-airflow. By sample is connected to the rectangular duct. The dimension of the sample is 10 cm × 5 cm, as shown on Fig. 1. Furthermore, the interface between hot-airflow and sample is investigated by the concept of conjugate approach. Within the rectangular duct, electrode and ground are 0.5 mm (diameter). The position of the ground is always fixed at x = 0 m and y = 0 m. The displacement between electrode and ground is d = 4 cm. The angle between electrode and ground (θ) is varied in clockwise direction from 0 to 360°. A subdomain is used for the entire simulation space which made up the inside a rectangular duct. By using the electrical, charge transport, temperature and fluid equations are solved, the classical properties of hot-airflow, water and solid are shown in Table 1 [21 and 28] and the thermal properties of hot-airflow, water and solid are shown in Table 2 [21 and 28]. In this study, the porous sample is a saturated porous packed bed; it consisted of single size glass beads with only water in voids.

3. Model approach

A numerical modeling based on conjugate approach has been formulated to predict the fluid flow and temperature distribution within the rectangular duct and predict the transport phenomenon with the sample. Three boundary conditions of the electric field, fluid flow, and heat transfer models are shown in Fig. 2.

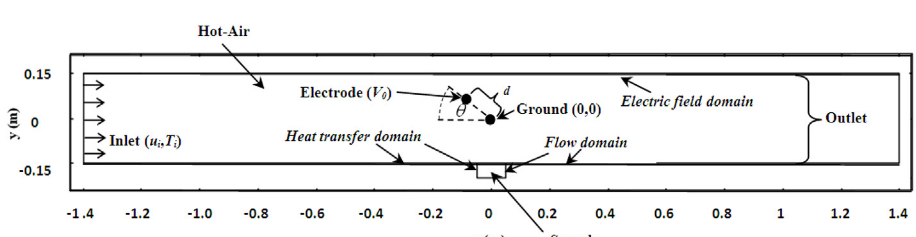

Fig. 1. Model geometry for analysis.