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The Fourth International Symposium on Engineering, Energy and Environment (4th ISEEE) is aimed at finding approaches and ideas toward an important question: "How can engineering research and practice help to create a sustainable society?" It serves as a forum for the presentation of technological advances and stimulating ideas to answer this challenging question. ISEEE 2015 is the fourth in the series which has been held since 2008. This year the symposium will be held in Pattaya, Thailand. The 2015 symposium will feature plenary talks by renowned speakers and parallel sessions which provide a platform for knowledge transfer and exchange.

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Effects of Electrode Position Respecting with Ground-Wire Positions on Efficiency of Hot-Air Drying Cooperating with Electric fields

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Abstract

This research aims to experimentally investigate the effects of electrode position respecting with ground-wire positions on the airflow pattern and drying rate of an unsaturated porous material subjected hot-air drying cooperating with electric fields. Eight electrode wires are suspended from the upper wall of wind tunnel, while a ground wire is installed across the direction of airflow. Gap between electrode and ground wires is fixed at 2.75 cm. Angles between electrodes and ground wires are varied in the range of $\theta = 0 - 180^{O}$. Moreover, the ground positions are varied in the vertical direction at G_y = 2.75, 11.00 and 19.25 cm far away from the lower wall where the material is installed. In experiments, the initial saturation (S_i) of the material is 0.5 and the electrical voltage is applied at 15 kV. In addition, the temperature and mean velocity of hot air before entering the test section are controlled at 60 ^{o}C and 0.35 m/s, respectively. The results show that when electric fields are introduced to airflow, the swirling flow clearly appears in the tunnel. The position and strength of swirling depends on the angle θ and ground wire position When G_y. = 19.25 cm, the drying rate is enhanced with the angle θ less than 90^{O}. When the ground wire is placed closer to the material surface, influence of electric force on flow near the lower wall becomes stronger. This causes the flow to be more turbulent and the drying rate to be enhanced with all angles more than normal flow. However, at position G_y=2.75 cm, the angle $\theta \geq 90^{O}$ gives the enhancement of drying rate more than $\theta \leq 90^{O}$due to higher velocity of near-well flow . Moreover, in this study, the drying rate can be enhanced approximately around 1.2 – 1.6 times of normal flow.

Keywords: High Voltage Electrical Fields, Hot-air Drying Efficiency, Porous Medium

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1. Introduction

Hot-air drying method is an important process in many manufactures, e.g. the pharmaceutical, food and furniture production, but this method consumes a large amount of energy and time. Therefore, this method is developed to work with the other heating processes, such as microwave [7], infrared [8], or electric field [1-6]. The using of electric field or Electrohydrodynamics (EHD) is an interesting process for enhancing the hot-air drying efficiency. The advantages are simple structure, no moving part, and easy to control the drying temperature. The principle of EHD is when the high voltage electric field is introduced to air, the charged air around electrode end moves forward the ground, meanwhile, with the shear flow effect, the uncharged air is induced to be a swirling flow. Consequently, this affect can enhance heat and moisture transfers on the surface of porous materials.

Chaktranond and Rattanadecho [1] use the electrode and ground wires, which are placed above the porous packed bed. The results show that the arrangement of packed bed with different porosity layers and the electrical voltages can enhance the rates of heat transfer rate and the moisture removal differently.

Saneewong Na Ayuttaya et al. [2] perform the numerical simulation to investigate the effects of the electric field on heat transfer in a channel flow. The results show that the heat transfer depends on the position of electrode and ground wires. When the hot-air drying process is cooperating with electric force, the surface temperature of the porous material rapidly increases.

Artana et al. [3] study the air flow control with the EHD principle. The results show that when the Reynolds number is low, the corona wind highly affects flow. In addition, this wind depends on the electrode positions.

In experiments of Lai et al. [4], the electrode wires and a ground plate are installed over and under a porous packed bed, respectively. The results show that the drying rate is increased when the electric voltage increases. However, the effect of the corona wind will drop when inlet air velocity increases.

Lai et al. [5] It is found flow that applying higher electric voltage affects the drying rate more than applying multiple electrode wires. In addition, the effect of corona wind becomes weaker when the moisture content in the porous packed bed is low.

This research investigates the effects of the angles between electrode and ground wires, as well as, ground positions on the hot-air flow pattern and on the drying rate of porous material in a rectangular duct flow.

2. Experimental setup

Figure 1 and 2 show experimental diagram. Hot air is generated by a 4-kilowatt-electric heater, and then is introduced into the test section of 30 cm × 30 cm. Porous material is replaced with a porous packed bed of 7.5 cm wide × 15 cm long × 4 cm deep, and is placed on the bottom wall of wind tunnel. All walls of the packed bed is insulated with rubber sheets, except, the surface is exposed to hot-air flow. Eight electrode wires are suspended from the upper wall of the tunnel. While a ground wire is installed across the air flow direction and ground position (G_y) is tested at 2.75, 11.00 and 19.25 cm measured away from the lower wall. The angles between electrode and ground are tested in the range of 0 – 180 degree and distance between electrode and ground wires is fixed at 2.75 cm. Weight and temperature of the packed bed are measured through a load cell (accuracy ±0.5 g) and four fiber optic wires (Luxtron Fluroptic Thermo-meter, Model 790, Santa Clara, Canada, accuracy ±0.5 ^{O}C), respectively. The electrical voltage is generated by a high voltage power supply (Glassman, model FJ30R4, USA).

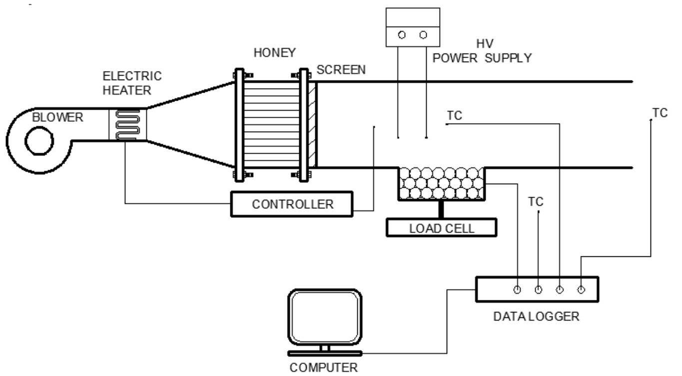

Fig.1 Schematic diagram of experimental setup

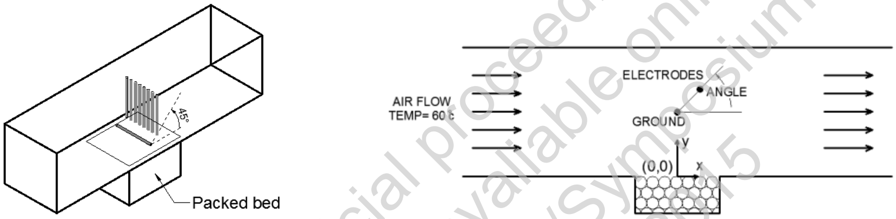

Fig.2 Positions of electrode and ground wires

3. Results and Discussion

In experiments, temperature and mean velocity of hot air before entering the test section is controlled at 60^{O}C and 0.35 m/s, respectively. In addition, high electrical voltage is applied at 20 kV. Packed bed has the initial saturation (S_i) of 0.5 dry based, and the porosity (ϕ) of 0.385. The results show air flow pattern, which is presented by incense smoke visualization, and drying efficiency depending on the position of ground and the angle between electrode and ground.

3.1 Effects of the ground position placing near the upper wall

When the electric fields are applied and G_y = 19.25 cm, as shown in Fig.3, the unstable flow is clearly observed near the lower wall. In addition, when the angle between electrode and ground is larger, flow near the lower wall looks more unstable and spread wider. This is because when the ground and electrode are installed far from the lower wall, the electric force conducts the air around electrode and ground to move faster. Especially, when $\theta > 90^{O}$, the electric force performs in the same direction as air flow, Consequently, air near the lower wall where velocity is low, is influenced by shear flow effect, resulting in occurrence of circulating flow.

Figure 4 shows that when θ= 45^{O}, the drying rate is higher. In this case, direction of electric force is opposite to air flow and inclines to bottom wall. This result induces swirling flow which influences the near-wall flow to circulate violently. Therefore, moisture removal can be enhanced. But when θ > 90^{O}, electric force is in that same direction of air flow. It will increase the air velocity around electrode and ground wires. Then effect of shear flow will induce the unstable flow on bottom wall.

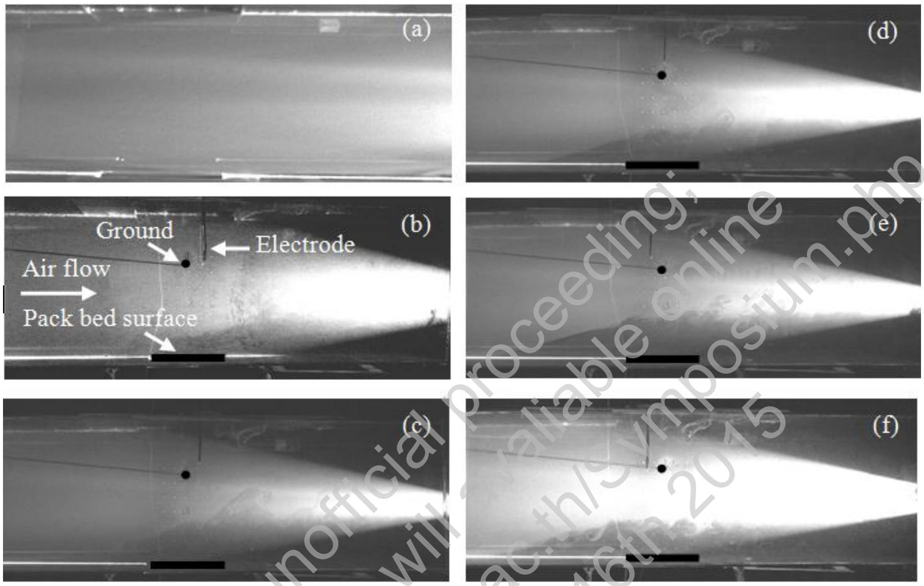

Fig. 3 Effect of angles θ when G_y = 19.25 cm:
(a) NO EHD, (b) 0^{o}, (c) 45^{o}, (d) 90^{o}, (e) 135^{o}, and (f) 180^{o}.

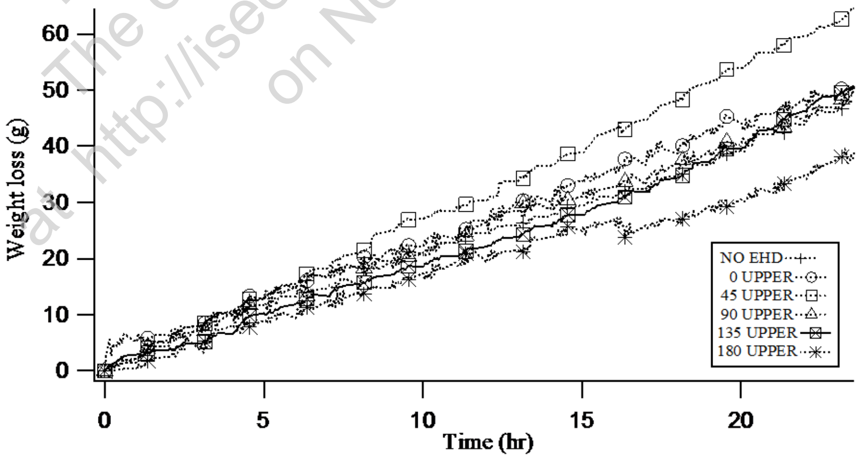

Fig. 4 Comparisons on moisture removal from packed bed in various angle when G_y = 19.25 cm.

As shown in Fig. 5, the unsteady flow regions become larger when the ground is moved closer the lower wall, influence of electric force on flow near the lower wall becomes stronger. This causes the flow to be more turbulent and the drying rate to be enhanced shown in Fig. 6.

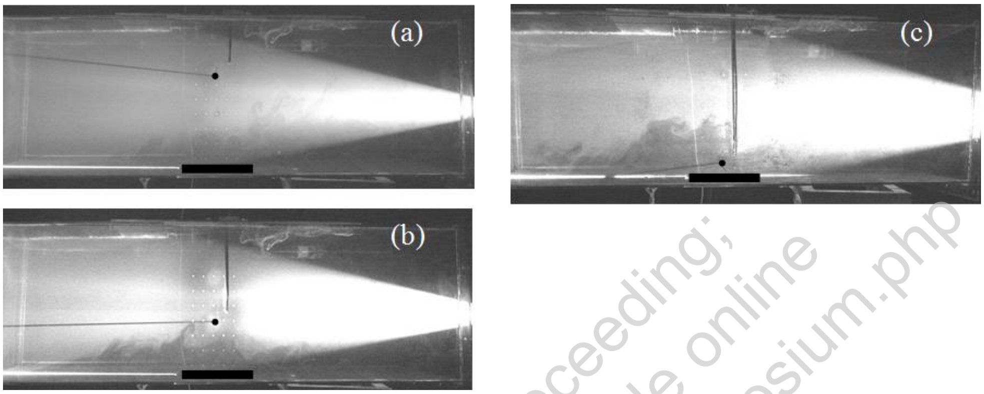

Fig. 5 Effect of ground elevation G_y when θ=45^0:
(a) 19.25 cm, (b) 11.00 cm, and (c) 2.75 cm.

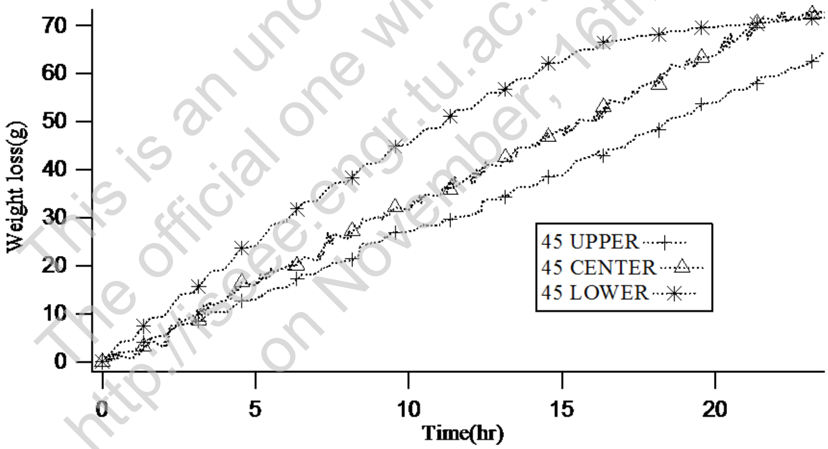

Fig. 6 Comparisons on moisture removal from packed bed in various G_y when θ=45^0.

3.2 Effects of the ground position placing near the lower wall

Figure 7 shows that when the ground is installed near the lower wall (θ_y=2.75 cm) and angle $\theta \leq 90^O$, the unstable region becomes bigger. This is because the effect of electric force is much higher than that of fluid force. In addition, the direction of electric force is against that of the fluid inertia force. Therefore, this conducts the shear flow effect to be stronger. Moreover, when θ = 90^O, the electric force performs normal to fluid force charged flow impinges on the pack bed surface. This enhances the heat and mass transfer on the packed bed surface. As shown in Fig. 8, the rate of moisture removal is high. The drying rate of this case is 1.6 times higher than that of normal flow (no EHD).

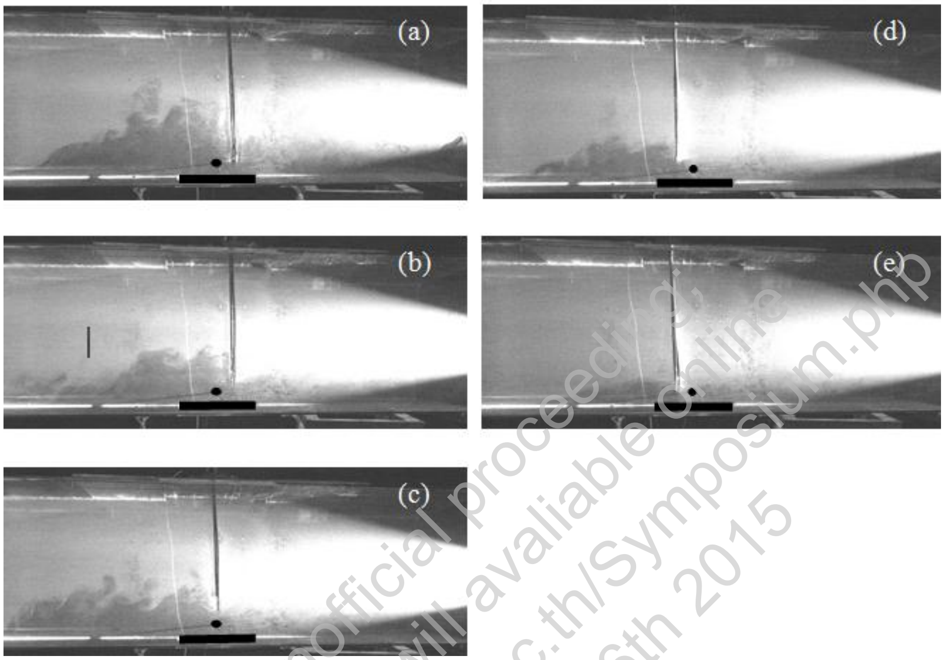

Fig. 7 Experiment result of swirling flow in various θ when G_y = 2.75 cm: (a) 0°, (b) 45°, (c) 90°, (d) 135°, and (e) 180°.

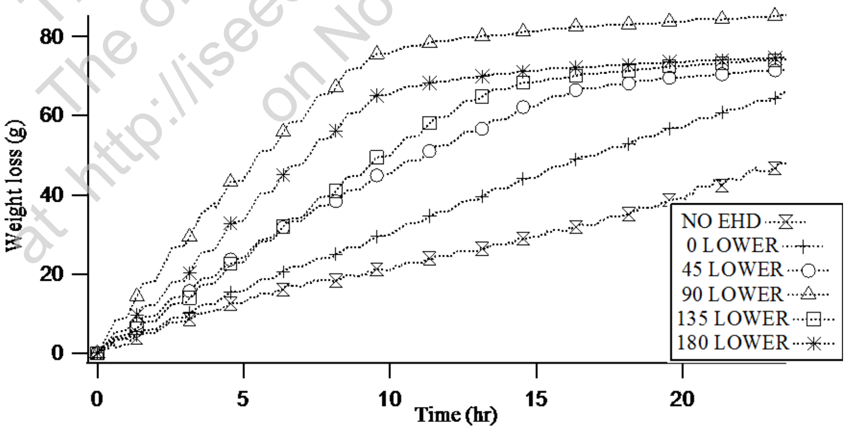

Fig. 8 Comparisons on moisture removal from packed bed in various θ when G_y =2.75 cm.

4. Conclusions

This study experimentally investigates the enhancement of hot-air drying efficiency with utilizing the high voltage electric fields. We focus on the effect of the position of the ground wire (G_y) and the angle (θ) between electrode and ground positions. The following paragraph summarizes the conclusions of this study:

1. The position of ground affects the flow pattern above the surface of porous packed bed. When the ground is placed near the upper wall, the direction of electric force in the same direction of fluid flow ($\theta > 90^O$) increases the fluid velocity around electrode and ground wires then shear flow effect creates the unstable flow near the surface of packed bed. High moisture removal occurs when $\theta = 45^O$. The electric force induces the swirly flow. Then, swirly effect conduct for near flow to circulate violently. In addition, when the ground is placed closer the lower wall, the unstable flow is obviously stronger.
2. When the ground is placed near the lower wall, the electric force is stronger than the fluid force. This causes the near-wall fluid to move faster when $\theta \geq 90^O$. Therefore moisture can move towards to main flow quickly. Moreover when $\theta = 90^O$, the air is strongly induced to impinge on the bottom wall and the drying rate is enhanced around 1.6 times.

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