Experimental Analysis of Angle between Electrode and Ground on Electric Field Cooperating Hot-Airflow in Drying Process

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Abstract

This research aims to experimental analysis the enhancement of drying process in a porous medium with electric field cooperating hot-airflow. Therefore, high electrical voltage and average velocity of inlet hot-airflow are applied at 20 kV and 0.1 m/s, respectively. The angle between electrode and ground are varied in range of $\theta = 0 – 360^{o}$. Initial temperature in the rectangular duct flow and within the porous medium is controlled at 60 ^{o}C and 20 ^{o}C, respectively. However, the results show that electric field from various angles can induce the difference swirling flow pattern within the rectangular duct flow. This is because electric force influences shear flow in different directions. By fluid flow within porous medium is depended on the swirling flow and hot-airflow direction. Besides the shear flow effect, swirling flow is affected with temperature distribution. In addition, Electric force affects the swirling flow characteristics in relation with the heat and mass transfer enhancement. Therefore, it affects within the porous medium sample. Finally, swirling flow is obtained by smoke incense technique in order to clearly the flow visualization.

***Keywords**:* Angle between Electrode and Ground, Drying Process, Porous Medium, Electric Field, Flow Visualization.

1. Introduction

The heat and mass transfer enhancement is the one of the most important application subjects of the thermal engineering field which increases the effectiveness of the drying process in a porous medium. By promoting higher convective heat and mass transfer coefficient, the enhancement techniques are divided into two groups so called active and passive techniques. In which the Electrohydrodynamics (EHD) phenomenon is an active method and deals with the interactions between electric field, flow field and temperature field. The main advantage of EHD is that it directly converts electrical energy into kinetic energy without mechanical pieces. Moreover, the influence of EHD phenomena can change the pattern of airflow and enhances transport phenomena with lowering energy supplied. The flow in channel occupies an important place among the several heating systems. One way to achieve considerable improvement in thermal efficiency is to increase the convective heat transfer coefficient.

In order to improve convective heat and mass transfer in a porous medium, some researcher are mentioned EHD application for drying process [1-7]. Lai and Lai (2002) [2] studied the effect of electric field parameters on the drying rate in packed bed with wire to plate. The electrode wire and copper ground plate were installed at the top and bottom of packed bed, respectively. The results showed that drying rate could be greatly enhanced when electrical voltage applied. However, those results showed that in case of a cross flow with high velocity it seemed to be diminished the effect of Corona wind in the EHD drying process. Ramachandran and Lai (2010) [4] experimental studied effects of porosity on the performance of EHD-enhanced drying by using ground plate arrangement. Comparison with solid glass beads of various sizes were evaluated the dependence between the material structure (in terms of its porosity) and the effectiveness of corona wind in drying. The results showed that effect of porosity in the drying enhancement by corona wind. The drying enhancement of 5 mm perforated beads in some cases may exceed than 6 mm solid beads because the hole in a 5 mm perforated bed was straight through its center, the moisture path in 5 mm perforated beads may be more restricted than that of 6 mm solid beads. Chaktranond and Rattanadecho (2010) [5] experimental studied the heat and mass transfer enhancement in porous material subjected to electric field using ground wire. The results showed that the convective heat and mass transfer coefficient and drying rate were considerably enhanced with the strength of electric field influencing Corona wind. To improve the structure of the airflow in order to enhance heat and mass transfer in a porous medium, an alternative method based on a combination of electric field cooperating hot-airflow and flow pattern are very interested. In this study, angle between electrode and ground (θ = 0 – 360°) has been studied. Furthermore, flow visualization of experimental results are compared in order to that simulation has correctly presented.

2. Experimental Analysis

2.1 Drying enhancement with swirling flow

When electrical is exposed to hot-airflow, it is created by ions generated in the corona discharge near the sharp electrode that drift to the ground. As a result, the momentum of hot-airflow is enhanced and primary flow is generated. The primary flow, ionized air, moves from electrode to ground in order to induce the shear flow or secondary flow. Shear flow is then appeared due to difference of fluid velocity between charged airflow (drift of ion) and uncharged airflow (flow of neutral molecules). Electric force, moreover, influences the characteristic and direction of flow pattern. This causes shear flow to become the swirling flow [8].

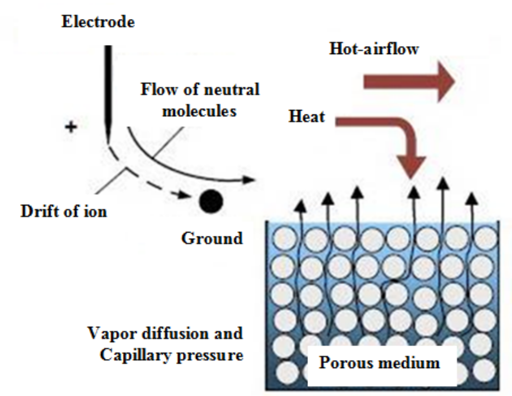


Fig. 1 Idea of heat and mass transfer enhancement with swirling flow [5]

For drying with hot-air flow, the idea of heat-and-mass transfer enhancement by utilizing EHD is shown in Fig. 1. When hot-airflow exposes to electric field, the flow is circulated. Then this secondary flow enhances the convective heat transfer and suppresses the influence of thermal boundary layer on the in a porous medium surface. This causes much of moisture on surface to vaporize towards the hot-air flow, and allows larger amount of heat to transfer into the porous sample. Consequently, the drying rate is substantially enhanced.

2.2 Electric field and flow field equation

As the airflow is appeared by the Coulomb force acting on the space charge density (q), the electric problem is then governed by Maxwell's equations of EHD (Eqs. (1)-(3)) and Ohm's law (Eq. (4)).

$$\vec{E} = -\nabla V \tag{1}$$

$$\nabla \cdot E = q/\varepsilon \tag{2}$$

$$\nabla \cdot \vec{J} + \frac{\partial q}{\partial t} = 0 \tag{3}$$

$$\vec{J} = qb\vec{E} + q\vec{u} \tag{4}$$

where E, V, ε and J are electric field, electrical voltage, dielectric permittivity and current density, respectively. t is time. The electric force per unit volume ($\vec{f}_E$) is the main driving force of corona-induced flow mixing. It is expressed as [10]:

$$\vec{f}_E = q\vec{E} - \frac{1}{2}\vec{E}^2\nabla\varepsilon + \frac{1}{2}\nabla\left[\vec{E}^2\left[\frac{\partial\varepsilon}{\partial\rho}\right]_T\rho\right] \tag{5}$$

For corona discharge is appeared at room temperature. Where T is uniform temperature and ρ is density. The continuity equation (Eq. (6)) and Navier–Stokes equation (Eq. (7)) which coupled with Coulomb force equation can be written in the following form:

$$\nabla \cdot \vec{u} = 0 \tag{6}$$

$$\rho\left[\frac{\partial\vec{u}}{\partial t} + (\vec{u}\cdot\nabla)\vec{u}\right] = -\nabla\vec{P} + \mu\nabla^2\vec{u} + q\vec{E} \tag{7}$$

where u is inlet velocity , P is pressure and μ is viscosity.

3. Experimental Setup

Schematic diagram of experimental setup is shown in Fig. 2. The test section and apparatus is an open system. The hot-airflow is supplied from a blower an electric heater from High-voltage power supply. In order to control temperature of hot air, a thermocouple sensor (TC) is placed in front of the test section, where the cross-sectional area is 30 x 30 cm. The high voltage power supply (ACOPIAN model: NO30HP2M.-230) is used to create electrical voltage. A copper electrode wire is suspended from the top of rectangular duct and it is placed in the front of packed bed and a copper ground is suspended horizontally across the test section. The porous medium is composed of glass bead (d = 0.15 mm), water and air. The glass bead container is made of acrylic; the container is 12 cm (long) x 6 cm (high) x 7 cm (width). The upper surface of container is exposed to the hot-airflow; other sides are insulated by rubber sheet and the container is placed at the lower wall. In the experiments, the maximum electrical voltage is tested so that breakdown voltage will not occur. The detail of testing conditions and characteristics of glass bead water transport in porous medium is shown in Tables 1 and 2, respectively. In order to observe the motion of airflow subjected to the electric field, incense smoke technique is used from smoke generator (GUNT HAMBURG: HM 170.52). A spotlight of 500 W is placed at the outlet of rectangular duct flow and the light direction is opposite to the flow direction. The inlet velocity is 0.1 m/s. The motion of airflow is continuously captured by a digital video camera record (SONY: VCT-R640).

Table. 1 Test condition

Condition and symbol	Value
Initial moisture ($X_{db,i}$)	22-38%db
Drying temperature (T)	50-60 °C
Ambient temperature (T_a)	25 °C
Inlet velocity (u_i)	0.1 m/s
Electrical voltage (V)	0 and 20 kV
Drying time (t)	12 h

Table. 2 Characteristics of glass bead water transport in porous medium

Characteristics and symbol	Value
Diameter (d)	0.15 mm
Porosity(ϕ)	~ 0.38
Permeability (κ)	$\sim 8.41\times10^{-12}$ mm

4. Results and discussion

In this study, electrical voltage (V_0) and inlet velocity (u_i) are 20 kV and 0.1 m/s, respectively. The distance between electrode and ground (d) is 4 cm. The angle between electrode and ground are varied in range of $\theta = 0 – 360^{o}$.

4.1 Motion of airflow

The primary flow from electric field moves from electrode to ground in order to induce the shear flow. This causes shear flow to become the swirling flow or secondary flow. In various angles between electrode and ground (θ), it can induce the difference of swirling flow pattern, as shown in Fig. 3. When θ = 45^{o} (Fig. 3(a)), the swirling flow motion displays in the counterclockwise direction due to shear flow effect. The double cells are swirled for different direction, as shown in θ = 135^{o} (Fig. 3(b). The front cell and latter cell are swirled in the counterclockwise and clockwise direction, respectively. But two cells of swirling flow from θ = 225^{o} (Fig. 3(c)) are appeared in the different direction, the front cell and latter cell are swirled in the clockwise and counterclockwise direction, respectively. Due to electrode arrangements are installed in the different direction. From θ = 315^{o}

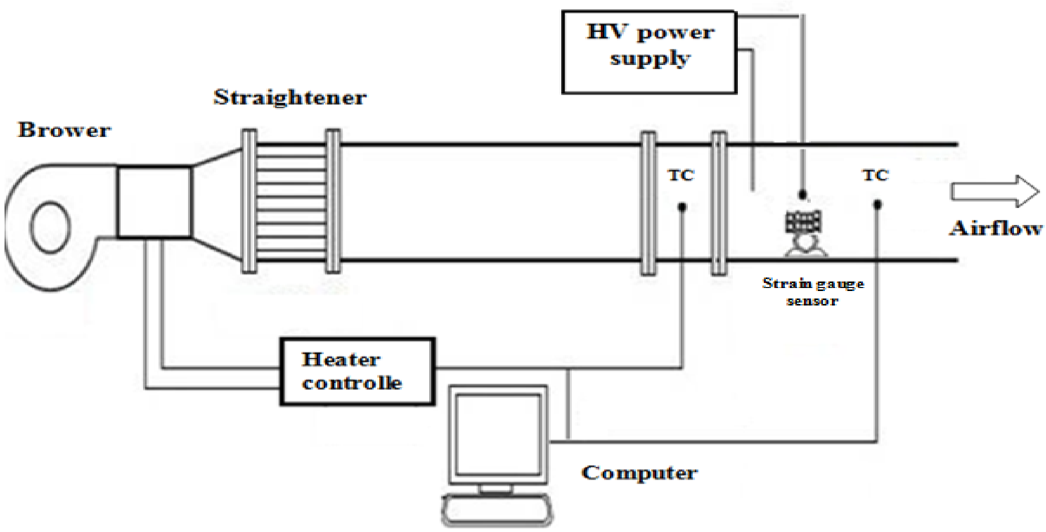
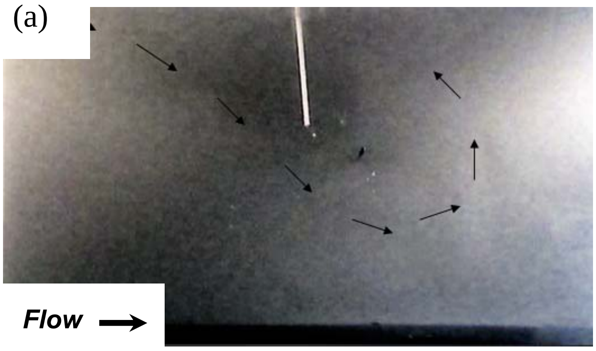


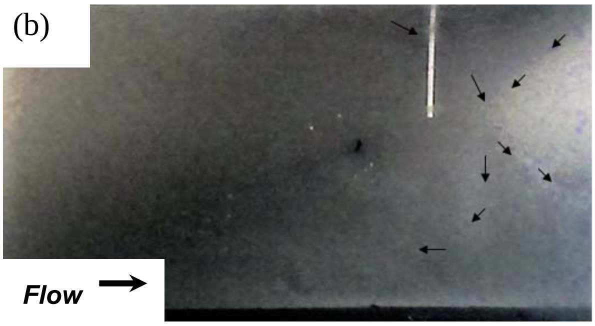
Fig. 2 Schematic diagram of experimental setup

(Fig. 3(d), the swirling flow is circulated in clockwise direction when inlet airflow is supplied from the left to the right direction. Due to angle between electrode and ground are varied, it can be seen that the differences of swirling flow are appeared in another patterns. This is because electric field induction airflow induces shear flow in the different direction. By the arrangement of θ = 45^{o} is supported from the inlet airflow, so the swirling flow is clearly swirled and concentrated more than the other cases.

(a)



(b)



(c)

(d)

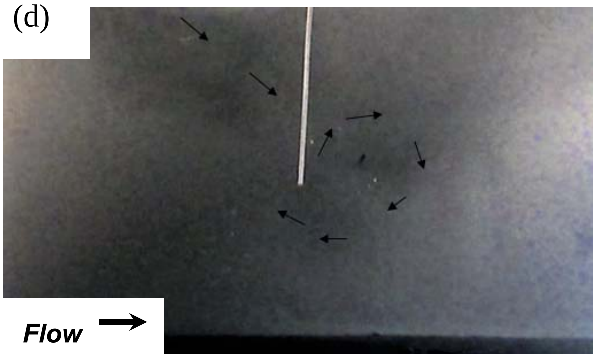


Fig. 3 Flow visualization in various θ : (a) θ = 45^{o} (b) θ = 135^{o} (c) θ = 225^{o} and (d) θ = 315^{o}

4.2 Effect of heat and mass transfer on porous medium sample

Fig. 4-7 shows the temperature variations and elapsed times with respect for different drying methods. Furthermore, the influences of EHD on temperature of porous medium sample in various depths are considered. When electric field is applied, the temperature of porous medium sample rise up steadily when warm-up period. Later, they remain constant. Moreover, EHD influences the surface temperature more than the inside so the surface temperature increases rapidly and it is higher than temperature in the other layers due to capillary pressure effect. In case of convective heat transfer, as the surface is dried while the interior is still wet, the dry layer offers a resistance to the heat transport resulting in a reduction of the evaporation rate as well as drying rate, causing non-uniform heating. This is because the swirling flow above porous medium sample enhances the heat and mass transfer and it can destabilize the boundary layer on the surface. Within the sample, the electric field attenuates owing to energy absorption. Thereafter the absorbed energy is converted to the thermal energy, which increases the sample temperature. By θ = 45^{o} (Fig. 4) and θ = 315^{o} (Fig. 7), the surface temperature (z = 0 cm) is increasing much higher than in case of z = 2 and 4 cm. With θ = 135^{o} (Fig. 5) and θ = 225^{o} (Fig. 6), difference of surface temperature and inside is very small. From Fig. 8, the most case of the surface temperature is θ = 45^{o} because this arrangement can support from the inlet airflow more than the other cases. From the first period times of No EHD case, surface temperature is increased. This is because air from ambient is more influence than evaporation within porous medium sample, air from ambient moves into porous medium so heat and mass from porous medium is increased.

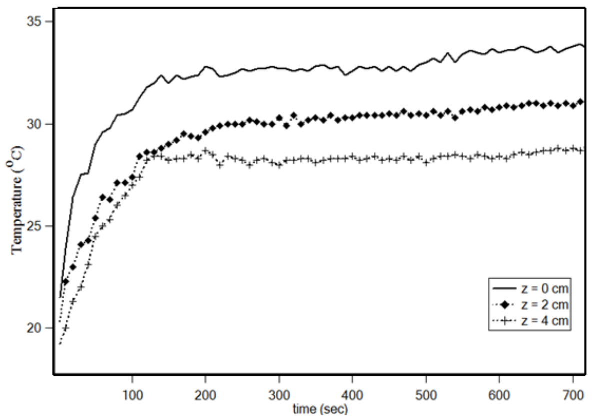


Fig. 4 Temperature of porous medium sample with $\theta = 45^{o}$ in various depths

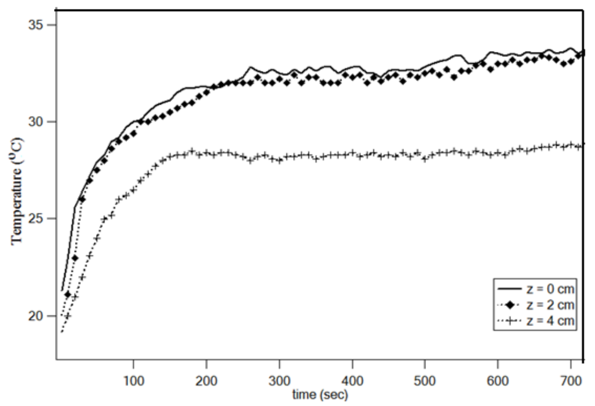


Fig. 5 Temperature of porous medium sample with $\theta = 135^{o}$ in various depths

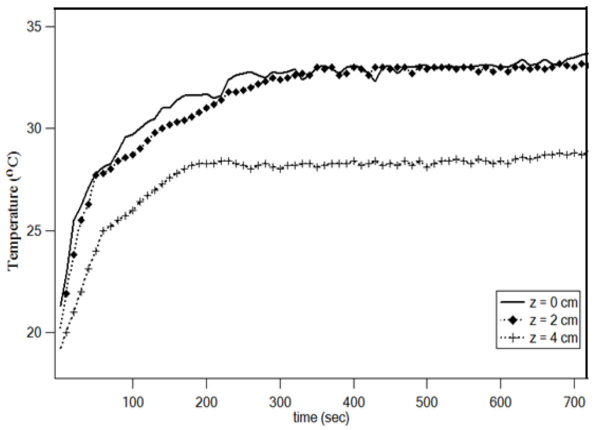


Fig. 6 Temperature of porous medium sample with $\theta = 225^{o}$ in various depths

In addition, at different testing conditions (EHD and No EHD cases), mass loss is increased with time increasing, as shown in Fig. 9. In EHD case, the mass loss profile of the porous medium samples continuously rises while the mass loss profile of No EHD case gradually decreases with respect to elapsed time and it continuously rises after 100 sec. The most case of the surface temperature is $\theta = 45^{o}$ so mass transfer is related with heat transfer. From above data, the shear flow induces in another direction due to the difference of angle between electrode and ground so surface temperature is affect with swirling flow in rectangular duct flow and it affect with mass transfer.

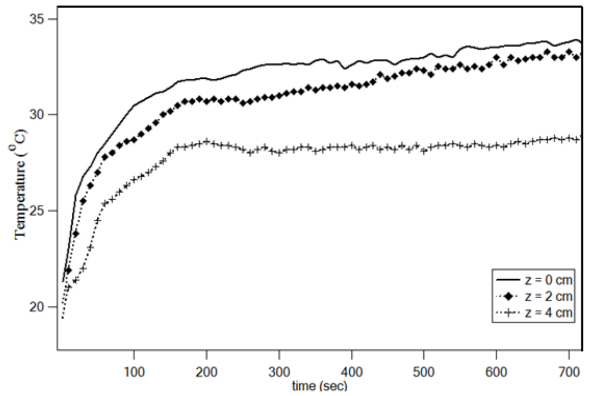


Fig. 7 Temperature of porous medium sample with $\theta = 315^{o}$ in various depths

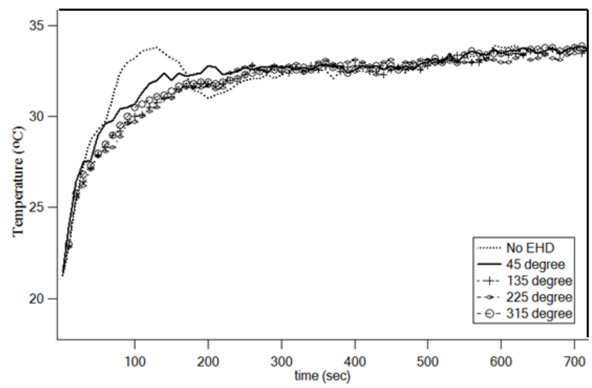


Fig. 8 Surface temperature (z = 0 cm) of porous medium sample in various θ

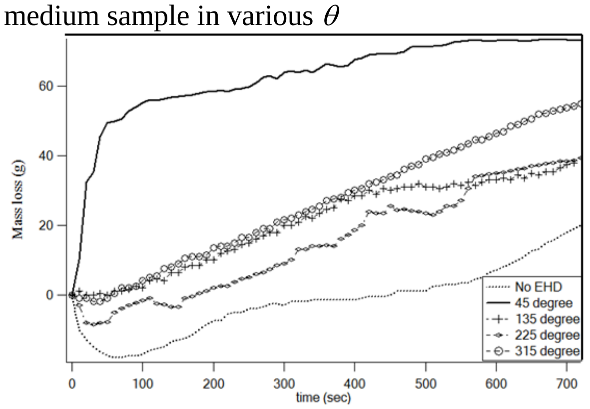


Fig. 9 Mass loss in case of porous medium sample in various θ

5. Conclusions

On electric field cooperating hot-airflow, effect of angle between electrode and ground on heat and mass transfer in porous medium sample are experimental investigated and analyzed for drying process. The following paragraph summarizes the conclusions of this study:

1. Effect of swirling flow circulating above porous medium sample enhance the convective heat transfer coefficient on sample surface exposed to hot-airflow, resulting in enhancement the heat and mass transfer in sample.
2. The disturbance strength of swirling flow above sample surface is depended on shear flow from various angles between Electrode and ground.

6. Acknowledgement

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7. References

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