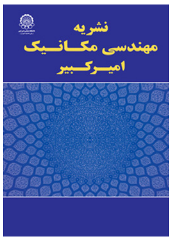

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Analysis of Corona Wind Effect on Mass Transfer and Energy Consumption in Drying of Moist Object

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ABSTRACT: In this paper, drying of the moist object is numerically investigated in the forced convection with and without the electric field. Finite volume method is used to solve governing equations of electric, flow, temperature, and the concentration fields in flow phase, as well as the temperature and the moisture fields in the moist object. In this study, the effect of applied voltage and the arrangement of the emitting electrode are evaluated. The results indicated that in presence of electric field, the increment of the applied voltage for 18 kV to 24 kV, the mass transfer from porous object 3.78 times and power consumption 7.96 times are increased. It is also found that the drying rate is increased by decreasing the distance between the emitting and collecting electrodes. According to numerical results, the mass transfer enhancement is usually accompanied by penalty of electric energy consumption. Therefore, the specific energy consumption has been evaluated as final criterion. It is shown that the specific energy consumption of the electrohydrodynamic drying process has been remarkably affected by the changing of the emitter arrangements. Finally, an optimum arrangement has been introduced as the affordable arrangement.

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1- Introduction

Drying is a moisture removal from a solid object including evaporation and mass transfer of the moisture to the solid surface and the surrounding air as well. In order to achieve the desired mass transfer with minimum energy consumption, different techniques have been used. Electrohydrodynamic (EHD) as an active technique can be used to enhance the heat and mass transfer. In this method, a high voltage is applied to the discharge electrode to induce a secondary air flow which is known as corona wind. Chen and Barthakur [1] experimentally studied the EHD drying technique to dehydrate potato slabs with different thicknesses. They used a single point-to-plate corona discharge. Their results demonstrated that the EHD flow enhanced the average rate of evaporation by a factor of 2.5 for 2 mm and 4 mm slabs, and 2.1 for the 8 mm slab. Some researchers conducted a set of EHD experiments on Japanese radish [2], carrot slices [3], mushroom slices [4], and etc. All of them concluded that the drying rate highly is affected by EHD flow. Moreover, some studies reveal that the EHD drying gives superior quality in physiochemical properties as color, shrinkage, and nutrient content [5]. Amanifard and Haghi [6] numerically studied the mass transfer through a porous body. They revealed that the flow velocity is proportional to the moisture removal rate in Reynolds range of 50 to 1000. The purpose of the present work is to investigate the drying process through and over a porous body with the EHD-induced flow in different emitting electrode arrangements. Finally, to gain a more general conclusion, the Specific Energy Consumption (SEC) of all cases is evaluated.

2- Geometry

Fig. 1 represents a schematic view of the computational domain used for the present study.

3- Governing Equations

The governing equations of the flow, thermal, and species fields including continuity, momentum, concentration and

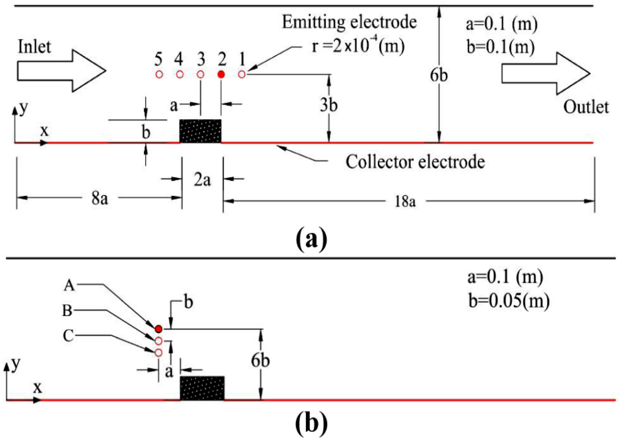

Fig. 1. Schematic view of the computational domain, (a) Horizontal arrangements of emitting electrode; (b) Vertical arrangements of emitting electrode.

Corresponding author, E-mail: hmohaddesd@guilan.ac.ir energy equations as well as transport equations of k and ε, are as follows.

$$\frac{\partial\left(\rho u_i\right)}{\partial x_i}=0 \tag{1}$$

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial\left(\rho u_i u_j\right)}{\partial x_i}= -\frac{\partial P}{\partial x_j}+\frac{\partial}{\partial x_i}\left[\left(\mu+\mu_t\right)\frac{\partial u_j}{\partial x_i}\right]+\vec{f}_b \tag{2}$$

with $\mu_t/\rho=C_\mu k^2/\varepsilon$

$$\frac{\partial(\rho c_p T)}{\partial t}+\frac{\partial\left(\rho u_i T\right)}{\partial x_i}=\frac{\partial}{\partial x_i}\left[\left(\frac{\mu}{\Pr}+\frac{\mu_t}{\Pr_t}\right)\frac{\partial T}{\partial x_j}\right] \tag{3}$$

$$\frac{\partial(\rho c_p C)}{\partial t}+\frac{\partial}{\partial x_i}(\rho c_p u_i C) =\frac{\partial}{\partial x_j}\left[(D+\frac{\mu_t c_p}{\Pr_c})\frac{\partial C}{\partial x_j}\right] \tag{4}$$

The equation for moisture conservation is given by [6]:

$$\frac{\partial M}{\partial t}=(D_{tl}+D_{tv})(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}) +(D_{ml}+D_{mv})(\frac{\partial^2 M}{\partial x^2}+\frac{\partial^2 M}{\partial y^2}) \tag{5}$$

The energy equation for the porous body is obtained as:

$$(c_0+m_l c_l+m_v c_v)\frac{\partial T}{\partial t}= (\frac{k}{\rho_0}+h_{fg}D_{tv})(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2})+(h_{fg}D_{mv})(\frac{\partial^2 M}{\partial x^2}+\frac{\partial^2 M}{\partial y^2}) \tag{6}$$

The governing equations for the electric field as following:

$$\nabla^2 V=-\frac{\rho_c}{\varepsilon} \tag{7}$$

$$\frac{\partial \rho_c}{\partial t}+\nabla\cdot\left(-\rho_c\beta\nabla V\right)=0 \tag{8}$$

4- Results and Discussion

The average moisture content in different emitting electrode positions is shown in Fig. 2. It indicates that average moisture content is remarkably influenced by the position of the emitting electrode. It is found that arrangement 5 has maximum moisture removal.

The average moisture for three configurations is represented in Fig. 3. The results confirmed that shorter distances between corona wire and collector electrodes intensify the strength of vortices and increases the deviation of flow toward the moist object.

The SEC for each case is presented in Table 1 and Table 2. The results show that SEC is significantly sensitive to the vertical gap size and the arrangemets of emitting electrode.

It is noticed that when arrangemet *B* is used, the specific energy consumption has the minimum value and it can be concluded that this arrangemet may be affordable.

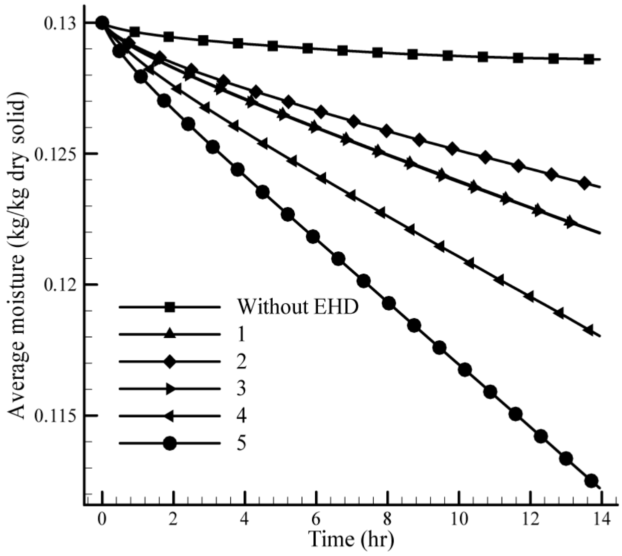

Fig. 2. Average moisture content in different electrode positions.

5- Conclusions

The convective drying rate of a porous body through a smooth channel is numerically studied when it is affected by corona wind. It is found that the drying rate is increased by decreasing the distance between the emitting and collecting electrodes. According to numerical results, the mass transfer enhancement is usually accompanied by penalty of electric energy consumption. Therefore, the SEC has been evaluated as final criterion. It is shown that the SEC of the EHD drying process has been remarkably affected by the changing of the emitter arrangements. Finally, an optimum arrangement has been introduced as the affordable arrangement.

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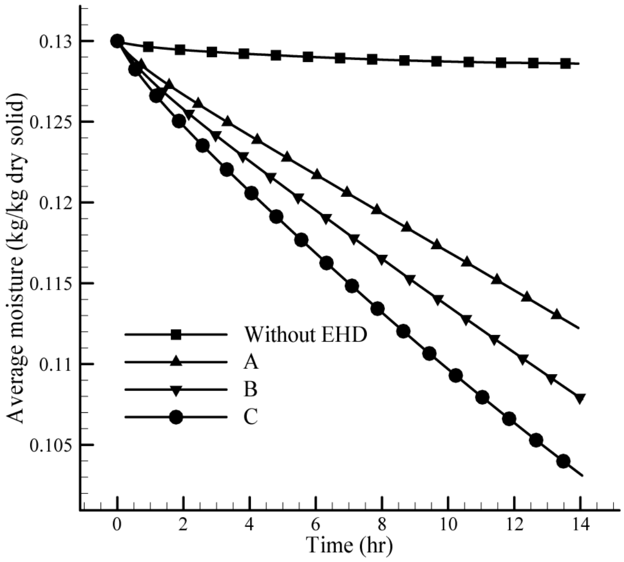

Fig. 3. Average moisture content in vertical arrangements

Table 1. Specific energy consumption of EHD drying in horizontal arrangements

No. arrangements	*P*, W	Moisture removal, kg/kg dry solid	SEC, kJ/kg
1	0.016352	0.0080201	102.62
2	0.007733	0.0062722	62.139
3	0.009496	0.0080373	59.549
4	0.010333	0.0119608	43.539
5	0.019459	0.0177672	55.201

Table 2. Specific energy consumption of EHD drying in vertical arrangements

Arrangements	*P* (W)	Moisture removal (kg/kg dry solid)	SEC (kJ/kg)
A	0.019459	0.017767	55.201
B	0.021407	0.021016	48.817
C	0.039065	0.026820	73.412

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