



The 4th International Symposium on Engineering, Energy and Environment

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The official one will available online
at <http://iseee.engr.tu.ac.th/Symposium.php>
on November, 16th 2015



Symposium Background

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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CONFERENCE TOPICS

Agricultural and food engineering
Biomedical engineering and engineering in medicine
Chemical processing
Diagnostic and monitoring System
Digital technology
Engineering and education
Environmental technology and management
Manufacturing and design
Materials engineering
Productivity improvement
Renewable energy and energy management
Resilient engineering
(Natural disaster, Infrastructure, Transportation, etc.)
Transportation and logistics
Other



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(Natural disaster, Infrastructure, Transportation, etc.)

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EHD-enhanced Heat Transfer of Fluid Flow related with Sample Size

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Abstract

The numerical analysis has been created to evaluate the Electrohydrodynamics (EHD) characteristics of fluid flow related with sample size. The finite element method is used for solving electrostatic, energy, continuity and incompressible Navier-Stokes equation in the channel flow. Temperature of inlet hot-airflow is controlled at 60°C and initial temperature of coarse beads ($d = 0.38$ mm, $\phi = 0.371$, $\kappa_s = 3.52 \times 10^{-11}$ m²) is specified at 20°C. High electrical voltage is varied from 0 - 30 kV and inlet velocity is varied from 0 - 1 m/s. By wire electrode and plate ground are installed above sample container. In addition, sample sizes are varied both of transverse and longitudinal direction. In this study, the characteristic of flow field and the temperature distributions of fluid flowing through a channel flow and with sample surface under electric field are evaluated. The results show that temperature distribution within sample is related with velocity of fluid flow within sample. Furthermore, average velocity and average temperature within sample are increased relate to increasing electrical voltage and inlet velocity. Finally, fluid flow characteristics with an EHD effect above sample surface is affect inside sample. The suitable sample size can provide an insight on the optimum fluid flow that maximizes heat transfer within coarse sample.

Keywords: Fluid Flow, Heat Transfer, Numerical Analysis, Sample Size, Coarse Beads

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1. Introduction

A porous medium is a material containing pores. The pores are typically filled with a fluid and the skeletal material is usually a solid. A porous medium is most often characterized by its porosity, other properties of the medium (e.g., permeability, tensile strength, electrical conductivity) can sometimes be derived from the respective properties of its constituents (solid matrix and fluid) and the media porosity and pores structure. Many natural substances such as biological tissues and food products can be considered as porous media. Also heat

and mass transfer formulations appearing in the food processing literature are synthesized in a systematic and comprehensive way, under the umbrella of transport in porous media [1]. The preservation of food products are an significant issue since they are perishable products. Therefore drying has been proven to be an efficient and inexpensive method of food preservation [2]. Drying process is the process of moisture removal from the product. The heated air drying process starts when the grain is heated (by conduction) when it comes in contact with the air. However higher velocity of airflow in heated air drying has the advantage of reducing the boundary layer of the grain, thereby increasing the heat transfer coefficient of the grain as well as increasing the rate of moisture movement from grain to the surrounding air. Therefore, the drying rate of a specific kind of grain is dependent on both air temperature and air flow rate.

At present, the conventional drying processes of food products include electric field has been developed. This technique is active method and deals with the interactions between electric field, flow field and temperature field. So it calls Electrohydrodynamics or EHD. Flow can be generated when air ions are accelerated through an interstitial atmospheric between electrode and ground area. As the ions are act upon by electric field, they collide and exchange momentum with the neutral air molecules [3]. These electrons collide with neutral molecules if the collision occurs at sufficiently high kinetic energy. However if the ionic wind is generated in the presence of a bulk flow, the ionic wind acts as a Coulombic body force on the bulk flow, adding momentum and disturbing the boundary layer. As a result, moisture from the products can remove. Fa et al. [4] studied the drying process with an EHD for okara cake. The results showed that the drying time under the high electric field condition reduced by 15–40% compared to the control at the final moisture content of 10% wb. In addition, the electric field also had an influence on the appearance of the okara cake. The okara cake after drying kept a whole shape and there was no cranny in the surface when the high electric field was supplied. Nevertheless there were some crannies and cracks in the surface of the control. However, the color of the sample exposed to the high electric field became distinctly browner than that of the control especially the part just under the needle electrode. Saneewong Na Ayuttaya [5] presented the influence of electrode and ground arrangement on behaviors of swirling flow driven by electric force and heat transfer enhancement in a saturated porous medium placed in a channel flow. The numerical results showed that when electric field was applied, fluid flow caused by shear flow effect was observed. When electrode was placed near ground electrodes, fluid flow was small but had a high strength. With occurrence of fluid flow, the convective heat transfer was totally higher than the case of conventional hot-airflow. Furthermore, effect of multiple grounds could induce electric force more than effect of single ground so the fluid flow to faster spread over the sample surface. This causes temperature within sample to rise faster than using single ground.

For above mentioned reports, many researchers are seriously studied the conventional drying processes of food products include EHD. It can be seen that, the electrode arrangements and type of sample are important in the production but sample sizes are not investigated. In this numerical analysis, characteristics of fluid flow and heat transfer related with sample sizes (coarse beads) are studied. In addition, electrical voltage and inlet velocity are varied in order to achieve suitable sample sizes.

2. Numerical method

The computational domain is shown in Fig.1 and composes of main three parts: the first, second and third parts are electric field, fluid flow and heat transfer domains, dimensions of channel are 2.0 m long $\times$ 0.3 m high. The wire electrode is arranged above plate ground. Base on ground plate, the left, the middle and the right of electrode positions are shown in Fig. 1(a-c), respectively. The boundary condition is shown in Fig.2. In this simulation,

electrode is assumed to be a circle with a diameter of 0.5 mm and space charge densities (q_0) at the tip of electrode is considered from Griffiths [6]. Temperature of inlet hot-airflow (T_i) and initial temperature of coarse beads are controlled at 60°C and 20°C, respectively. High electrical voltage (V_0) is varied from 0 – 30 kV and inlet velocity (u_i) is varied from 0 – 1 m/s. By wire electrode and plate ground are installed above sample container. In order to study the suitable sample sizes, a saturated porous medium is installed within a channel, also sample size of coarse bead (S) is varied both of transverse (S_T) and longitudinal (S_L) direction. Fluid flow and coarse beads properties [7] are shown in Table 1 and 2, respectively.

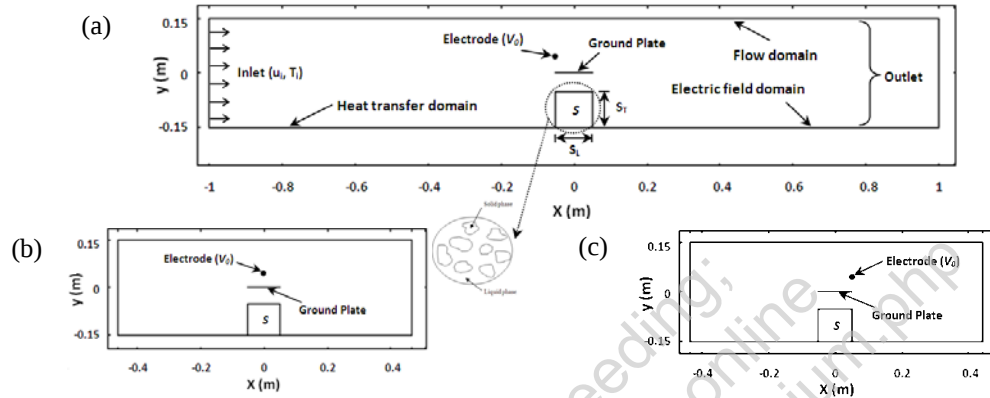


Fig.1. Computational domain in various electrode position (a) left position (b) middle position and (c) right position

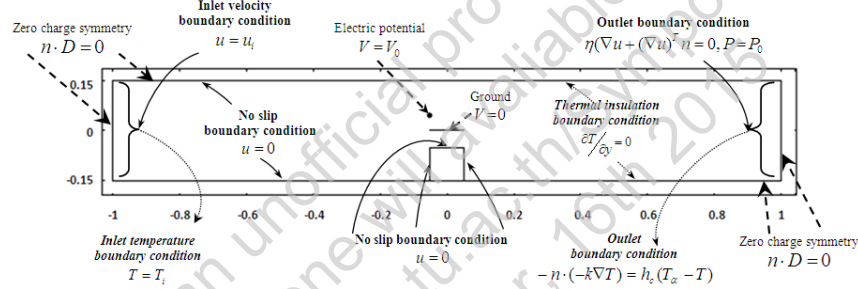


Fig.2. Boundary condition

Table 1 Fluid flow properties

Modeling parameter	Value
Ion mobility, b	$1.80 \times 10^{-4} \text{ m}^2 / \text{Vs}$
Dielectric permittivity, ϵ	$8.85 \times 10^{-12} \text{ F/m}$
Kinematics viscosity, η	$1.76 \times 10^{-5} \text{ m}^2 / \text{s}$
Density, ρ	1.060 kg/m^3

Table 2 Coarse beads properties [7]

Modeling parameter	Value
Porosity of solid, ϕ	0.371
Permeability of solid, κ_s	$3.52 \times 10^{-11} \text{ m}^2$
Density of solid, ρ_s	$2,500 \text{ kg/m}^3$
Specific heat of solid, C_{ps}	0.80 kJ/(kgK)
Density of liquid, ρ_l	$1,000 \text{ kg/m}^3$
Specific heat of liquid, C_{pa}	4.186 kJ/(kgK)

Electric force calculations refer to Eq.(1) to (4). The dielectric property is constant and the effect of magnetic field is negligible. Electric field distribution is computed from Maxwell's equations listed as below:

$$\nabla \cdot \varepsilon \vec{E} = q \quad (1) \quad \vec{E} = -\nabla V \quad (2)$$

$$\nabla \cdot J + \frac{\partial q}{\partial t} = 0 \quad (3) \quad J = qb\vec{E} + q\vec{u} \quad (4)$$

where E is electric field, t is time, q is the space charge density in the fluid, ε is dielectric permittivity, V is electrical voltage, J is current density, b is ion mobility and u is airflow velocity. Electric force (F_E) is computed by Coulomb force term as shown in Eq.(5). Fluid flow calculation refers to Eq.(6), Properties of fluids are assumed to be constant and evaporation effect is neglect. Fluid flow is computed through the continuity and incompressible Navier–Stokes equations.

$$\vec{F}_E = q\vec{E} \quad (5) \quad \rho \left[\frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \nabla) \vec{u} \right] = -\nabla \bar{P} + \mu \nabla^2 \vec{u} + \vec{F}_E \quad (6)$$

where P is pressure, ρ and μ are density and viscosity of fluid, respectively. The last term of Equation (6) is electric force per unit volume.

Heat transfer in a channel and within the sample are calculated from Eq.(7)-(9). The thermal property of the fluid is considered to be constant. The saturated porous medium is considered to be isotropic and homogeneous and saturation of porous medium is fixed at 1. Temperature distribution in a channel flow is calculated by energy equation,

$$\rho C_p \left[\frac{\partial T}{\partial t} + \vec{u} \cdot \nabla T \right] = k(\nabla^2 T) \quad (7)$$

where C_p is the specific heat capacity and k is thermal conductivity. The governing equations describing the heat transfer within the sample is calculated from Eq.(8) and effective thermal conductivity (k_{eff}) in a porous medium is computed by Eq.(9)[8].

$$\frac{\partial T}{\partial t} = \frac{k_{eff}}{(\rho_s C_p)_{eff}} \nabla^2 T, \quad (8) \quad k_{eff} = (1 - \phi) \kappa_s + \phi \kappa_l \quad (9)$$

where ϕ is porosity, κ is permeability. Subscript s and l are solid and liquid phase.

This study employs the commercial software; the finite element method is used for solving electrostatic, energy, continuity and incompressible Navier-Stokes equation. This convergence test leads to the mesh with approximately 9,000 elements. Higher numbers of elements are not tested due to lack of computational memory and performance.

3. Results and discussions

In order to evaluate the EHD-enhanced heat transfer of fluid flow related with coarse beads sample size, the maximum velocity in a channel flow (u_{EHD}), average velocity within sample (u_{avg}) and average temperature within sample (T_{avg}) are evaluated. Finally, transverse direction (S_T) and longitudinal direction (S_L) of coarse beads sample are investigated carefully.

3.1 Effect of fluid flow and heat transfer in a channel flow and with sample when no inlet velocity

When no inlet velocity, no sample and EHD effect, fluid flow is swirled in the channel flow due to shear flow from electric field induces the neutral airflow so secondary flow or recirculation is appeared. Recirculation of the left and the right of electrode position are appeared in clockwise and counterclockwise, respectively and 4 cells of the middle of electrode position are circulated because shear flow direction is different. Fig.3 shows fluid flow in various electrode position when no inlet velocity and $V_0 = 10$ kV. When sample container is installed in the channel flow, fluid flow is still swirled within the channel flow

but it avoids sample container. Recirculation of fluid flow from Fig.3(a-c) is distorted when it is compared to no sample container. When no inlet velocity, $V_0 = 10$ kV and $t = 1800$ sec, temperature distributions in the channel flow from Fig.4 is supported with fluid flow from Fig.3. Disturbance of temperature zone is related with fluid flow characteristic. The influence of fluid flow from Fig.3(a)-(c) resulting the temperature distribution of Fig.4(a)-(c).

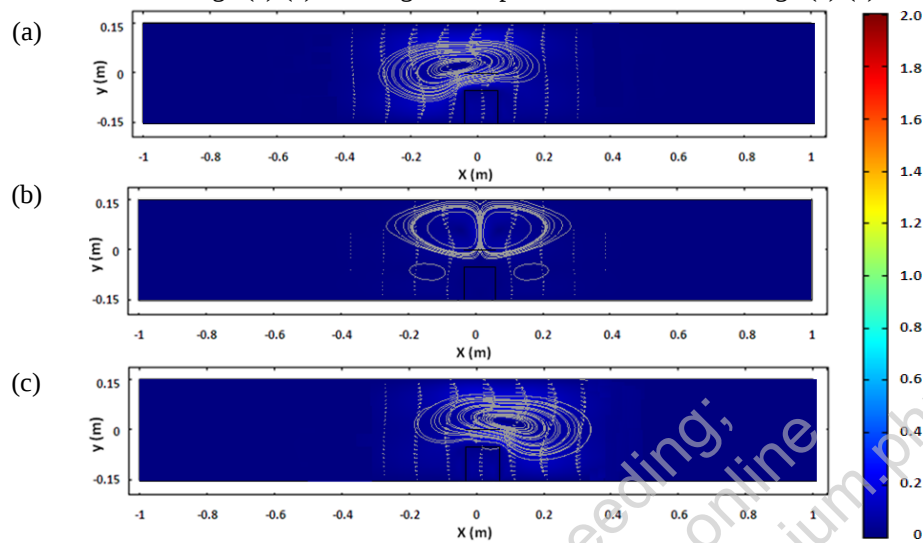


Fig.3. Fluid flow in the channel flow and within the sample in various electrode position (a) left position (b) middle position and (c) right position when no inlet velocity ($u_i = 0$ m/s) and $V_0 = 10$ kV

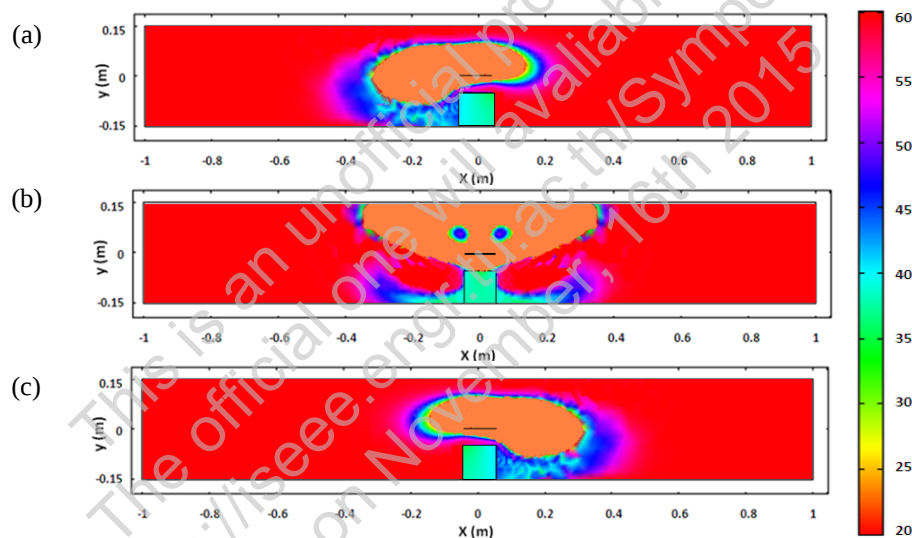


Fig.4. Temperature distribution in the channel flow and within the sample in various electrode position (a) left position (b) middle position and (c) right position when no inlet velocity ($u_i = 0$ m/s), $V_0 = 10$ kV and $t = 1800$ sec

When $V_0 = 10$ kV, maximum velocity in various inlet velocity is showed in Fig.5. For low inlet velocity, high shear flow is induced for the middle of electrode position and shear flow is appeared between electrode and ground area so maximum velocity is high. For middle to high inlet velocity, maximum velocity is a little difference. Fig.6 shows maximum velocity in various electrical voltage when absence inlet velocity. For the middle of electrode position, high shear flow is induced so maximum velocity is higher than maximum velocity of the left

and right of electrode position. So the maximum velocity is increased when increasing the inlet velocity and electrical voltage.

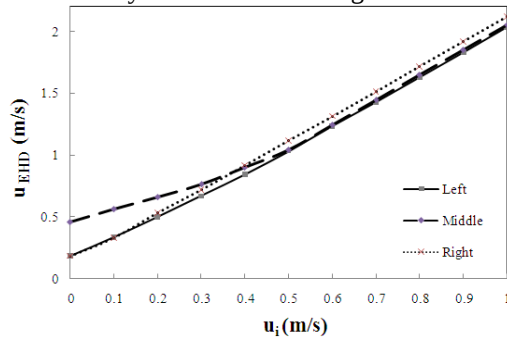


Fig.5. Maximum velocity in various inlet velocity and electrode position when $V_0 = 10$ kV

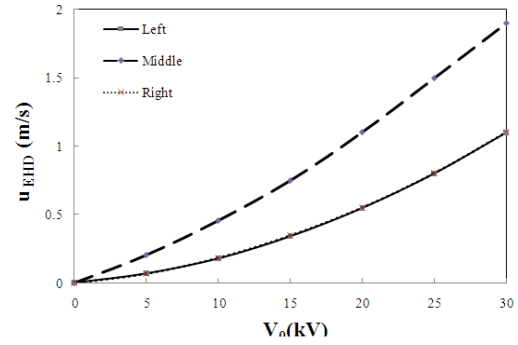


Fig.6. Maximum velocity in various electrical voltage and electrode position when $u_i = 0$ m/s

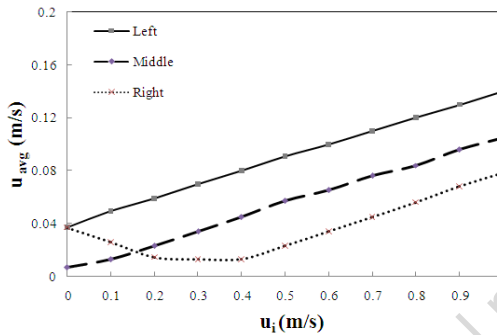


Fig.7. Average velocity within sample in various inlet velocity and electrode position when $V_0 = 10$ kV

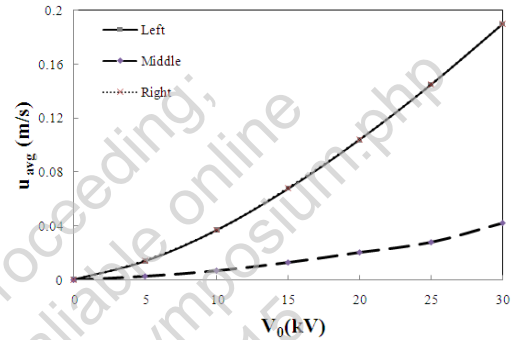


Fig.8. Average velocity within sample in various electrical voltage and electrode position when $u_i = 0$ m/s

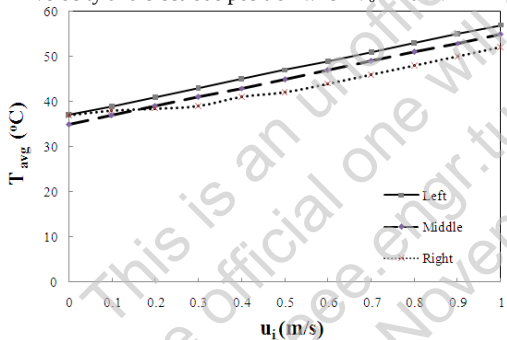


Fig.9. Average temperature within sample in various inlet velocity and electrode position when $V_0 = 10$ kV and $t = 1800$ sec

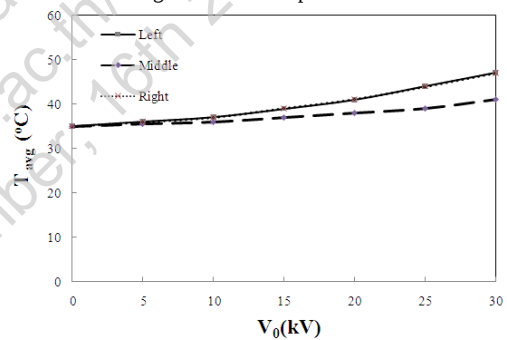


Fig.10. Average temperature within sample in various electrical voltage and electrode position when $u_i = 0$ m/s and $t = 1800$ sec

From Fig.7, average velocity within the sample is increased with increasing inlet velocity when consider the left and the middle of electrode positions. When the right of electrode position is investigated, average velocity within the sample is decreased when inlet velocity is 0 to 0.4 m/s and it is increased when inlet velocity is more than 0.4 m/s. From Fig.8, average velocity within the sample is increased with increasing electrical voltage. By the left and the right of electrode positions, average velocity within the sample is clearly increased. For $t = 1800$ sec and $V_0 = 10$ kV, trend of average temperature within sample (Fig.9) is related with trend of average velocity within sample (Fig.7). Furthermore, for absence inlet velocity and t

= 1800 sec, trend of average temperature within sample (Fig.10) is related with trend of average velocity within sample (Fig.8). It can be seen that temperature distribution within sample is not related with maximum velocity in the channel flow but it is related with velocity of fluid flow within sample so inlet velocity direction and disturbance of fluid flow above sample surface are influenced with average velocity within the sample and it is affect inside coarse sample.

3.2 Effect of fluid flow and heat transfer when $u_i = 0.1$ m/s

In order to consider in the channel flow and within the sample, Fig.11 and 12 show fluid flow and temperature distribution in various electrode position, respectively.

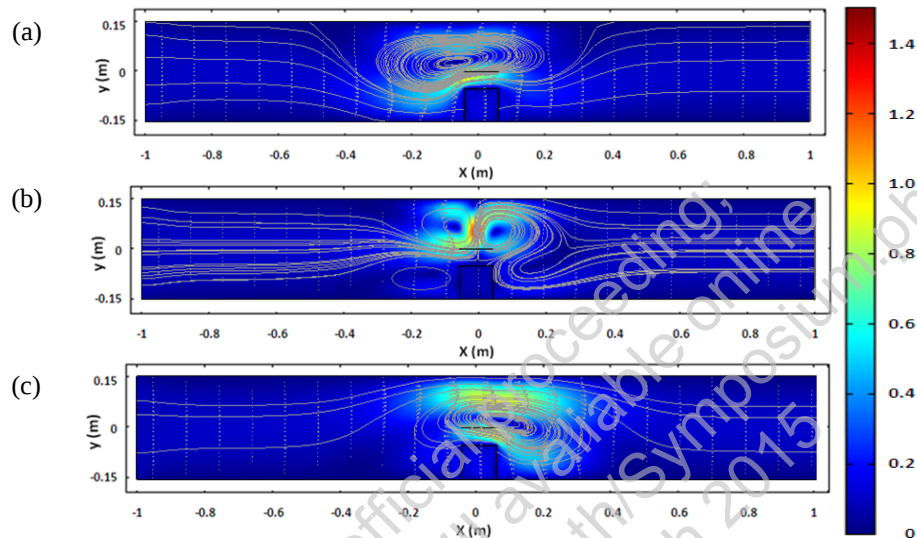


Fig.11. Fluid flow in the channel flow and within the sample in various electrode position (a) left position (b) middle position and (c) right position when $u_i = 0.1$ m/s, $V_0 = 30$ kV.

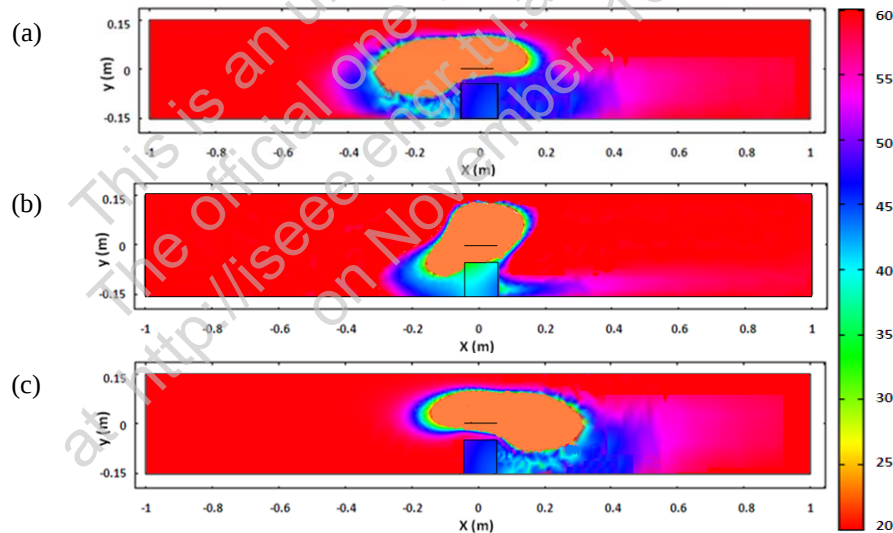


Fig.12. Temperature distribution in the channel flow and within the sample in various electrode position (a) left position (b) middle position and (c) right position when $u_i = 0.1$ m/s, $V_0 = 30$ kV and $t = 1800$ sec

From Fig.11 and 12, electrode position, inlet velocity and electrical voltage are influenced with fluid flow and temperature distribution but fluid flow is not depended on time various. Fluid flow from Fig.11 ($u_i = 0.1$ m/s, $V_0 = 30$ kV and $t = 1800$ sec) is stronger than fluid flow from Fig.3 ($u_i = 0$ m/s, $V_0 = 10$ kV and $t = 1800$ sec) because influence of inlet velocity and electrical voltage as a result, it affects with temperature distribution. Within the sample is considered, fluid flow of Fig.11(b) is lower than fluid flow of Fig.11(a) and (c) due to strength of fluid flow in the channel flow is not swirled above sample surface so temperature distribution of Fig.12(b) is lower than temperature distribution of Fig.12(a) and (c). Fig.13 shows comparison between average velocity and average temperature in various electrode positions. Trend of average velocity within sample is related with average temperature within sample. When the right of electrode position, average velocity and average temperature within the sample is highest because it can store airflow in the channel and it can induce airflow above sample surface.

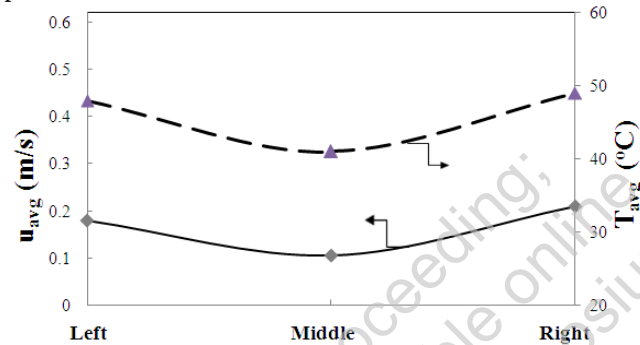


Fig.13. Comparison between average velocity and average temperature within sample in various electrode position when $u_i = 0.1$ m/s, $V_0 = 30$ kV and $t = 1800$ sec

3.3 Effect of fluid flow and heat transfer with various sample size

When $u_i = 0.1$ m/s, $V_0 = 30$ kV and $t = 1800$ sec, with various sample from longitudinal direction (S_L) is evaluated from Fig.14 and 15. With various sample from transverse direction (S_T) is evaluated from Fig.16 and 17.

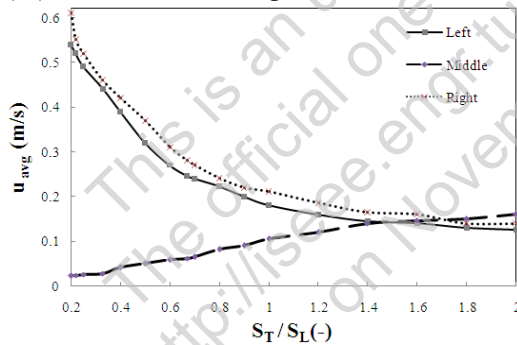


Fig.14. Average velocity within sample in various electrode position and S_L when $u_i = 0.1$ m/s, $V_0 = 30$ kV, $t = 1800$ sec and $S_T = 10$ cm

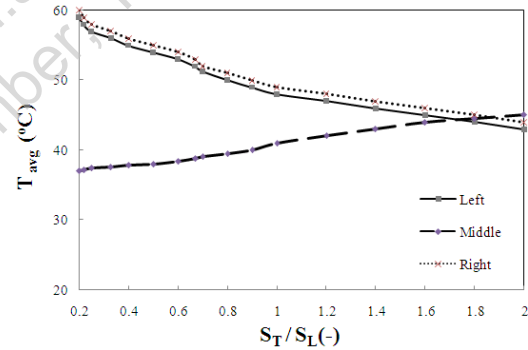


Fig.15. Average temperature within sample in various electrode position and S_L when $u_i = 0.1$ m/s, $V_0 = 30$ kV, $t = 1800$ sec and $S_T = 10$

When $S_T = 10$ cm, average velocity within the sample and S_T/S_L is showed in Fig.14. For the left and the right of electrode position, trend of average velocity is clearly decreased but the middle of electrode position, trend of average velocity is increased. Furthermore, trend of average velocity within sample is related with average temperature within sample, as shown in Fig.15. When $S_L = 20$ cm and various S_T/S_L , average velocity and average temperature

within sample are similar trend in the all cases, as shown in Fig.16 and 17, respectively. It can be seen that suitable sample sizes can support maximum velocity and maximum temperature within sample so the optimum fluid flow that maximizes heat transfer within coarse sample.

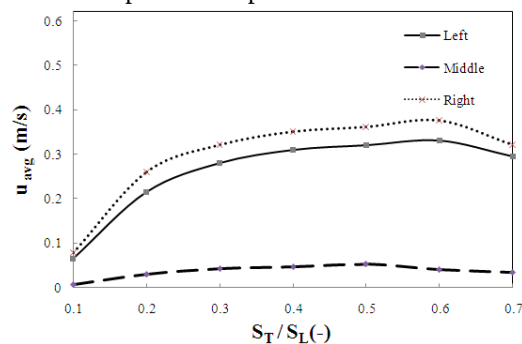


Fig.16. Average velocity within sample in various electrode position and S_T when $u_i = 0.1$ m/s, $V_0 = 30$ kV, $t = 1800$ sec and $S_L = 20$ cm

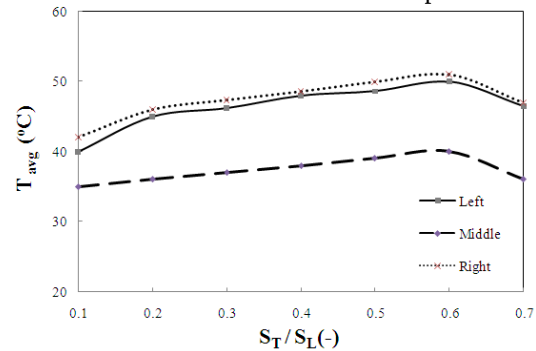


Fig.17. Average temperature within sample in various electrode position and S_T when $u_i = 0.1$ m/s, $V_0 = 30$ kV, $t = 1800$ sec and $S_L = 20$ cm

4. Conclusions

The numerical analysis has been created to evaluate the EHD characteristics of fluid flow and heat transfer related with sample size. The following main conclusions can be highlight:

1. Inlet velocity direction and disturbance of fluid flow above sample surface are influenced with average velocity and temperature distribution within sample
2. Average velocity and average temperature within sample are increased with increasing electrical voltage and inlet velocity.
3. The suitable sample sizes can support maximum velocity and maximum temperature so the optimum fluid flow that maximizes heat transfer within sample

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