

Experimental Study of the Effects of Fluid Physical Properties and Working Temperature on Heat Transfer in Conduction Pump

Moharram Jafari^{1*}, Esmail Esmailzadeh^{2,3}, Navid Farrokhi⁴

¹Assistant Professor, Faculty of Mechanical Engineering, University of Tabriz

²Professor, Faculty of Mechanical Engineering, University of Tabriz

³Professor, Department of Mechanical Engineering, Tabriz Branch, Islamic Azad University

⁴ PhD Student, Faculty of Mechanical Engineering, University of Tabriz

ABSTRACT

In the current paper, heat transfer in conduction pumping of n-hexane and n-decane dielectrics (as working fluids) using flush electrodes is investigated by conducting experimental tests. The Study has been carried out for different fluid film thicknesses and variable applied electric voltage, and the effects of various parameters such as physical properties (ion mobility difference, density and viscosity), as well as fluid working temperature on heat transfer performance of the conduction pump have been investigated. The results show that higher ion mobility difference, as well as lower density and viscosity, increases the flow rate and heat transfer in the conduction pump, due to the improvement of the vortices formation in the vicinity of the electrodes. Moreover, it significantly increases the heat transfer in the pump by creating turbulent flow around the electrodes. On the other hand, higher operating temperatures enhance the flow rate and heat transfer due to decreasing density and viscosity and also increasing the temperature gradient between the source and the destination of heat transfer. The intense heat transfer enhancement by using the conduction phenomenon compared to the ordinary fluid flow pumping through a simple duct (having no electrodes) is seen for all film thicknesses and working temperatures. Maximum observed enhancement of Nusselt number for n-hexane and n-decane are equal to 1041% and 568%, respectively.

KEYWORDS

Electrohydrodynamic, Electrical conduction pump, Ion mobility difference, Pump characteristics

* Corresponding Author: Email: mjafari@tabrizu.ac.ir

1. Introduction

Applying electric field to a dielectric fluid medium causes mechanical body-force, which can create fluid flow at some conditions. This phenomenon can be used in many applications such as mass transport, heat transfer, liquid film pumping and electronic device cooling. Electrohydrodynamic (EHD) pumps are mostly categorized in three types based on the way they form free charges: ion-drag pumps, induction pumps and conduction pumps. Conduction pumping phenomenon is based on the dynamic equilibrium of molecules dissociation and recombination of the ions generated from dissociation, which is a suitable pumping mechanism for homogeneous and isothermal fluids. Eq. 1 shows the mentioned dynamic equilibrium for conduction pumping [1]



where k_d , k_r are constants of dissociation and recombination rates, respectively.

From the different types of electrohydrodynamic (EHD) pumps, Conduction pumping is a relatively new field among EHD topics. Jeong and Seyed-Yagoobi [2] began the studies about pumping of dielectric fluids by conduction phenomenon, and investigated conduction pumping performance. Atten and Seyed-Yagoobi [3] presented a simple model of conduction with its corresponding numerical model. They used different electrode types and dielectrics. Yazdani and Seyed-Yagoobi [4] numerically investigated the effects of conduction on flow of liquid film. They observed that for the flush electrodes, difference between the width of the electrodes leads to net flow of liquid. Hemayatkhah et al. [5] experimentally investigated the flow pattern of the electrical conduction pump with flush electrodes, and presented their results about the location and situation of eddies creation in the vicinity of the electrodes. Nourdanesh and Esmailzadeh [6] experimentally investigated heat transfer in electrical conduction pump with flush electrodes for kerosene. They reported that by applying electrical field heat transfer was enhanced significantly. Gharraei and Esmailzadeh [7] numerically simulated conduction pump with flush electrodes, and compared the results with the experimental results, which showed proper conformity.

To the best of the authors' knowledge, there has been no study working on the simultaneous effects of changing working temperature and using different dielectric fluids on heat transfer and heat transfer enhancement in conduction pumps. In the current study, effect of parameters such as working temperature of the system and applied voltage for two different dielectric

liquids (n-hexane and n-decane) on heat transfer enhancement of the conduction pump with flush electrodes is experimentally investigated. It is obvious that using electrical conduction pumps can be very useful because of their unique characteristics such as the lack of moving parts. On the other hand, these pumps can be used in certain applications to enhance heat transfer. The combination of good hydrodynamic performance and excellent heat transfer characteristics will make conduction pumps more applicable in future.

2. Methodology

The setup has a loop-shaped channel with its floor made of polyethylene and walls made from plexiglass. The loop consists of two direct sections and two curved sections. One of the direct sections has the flush electrodes mounted on it, while the other one is the place where measurements of flow velocity are performed. Under the surface of the two curved sections, heaters are embedded to create the ability of changing fluid temperature. Average temperature of the fluid in the channel is measured by using PT100 temperature sensors. Measurements accuracy for temperature, film thickness, applied voltage and electrical current are $\pm 0.03^\circ\text{C}$, $\pm 0.2\text{mm}$, $\pm 1\text{V}$, $\pm 1\text{nA}$, respectively.

3. Results and discussion

In this section, electrical conduction pumping of two different dielectric liquid films in an open channel using copper flush electrodes is investigated, and the effect of liquid physical properties and temperature of the dielectric liquid on heat transfer enhancement of the pump is discussed. With the heat transfer coefficient known, the Nusselt number is obtained as follows:

$$\bar{Nu} = \frac{\bar{h}d_h}{k} \quad (2)$$

where \bar{h} , d_h and k are heat transfer coefficient, hydraulic diameter of the channel and the thermal conductivity of the dielectric fluid, respectively.

The Nusselt number variations for the film thickness $d = 4\text{mm}$ are shown in Fig. 1. As can be seen, the applied voltage increases the Nusselt number. In almost all cases, n-hexane exhibits a higher Nusselt number than n-decane, which is due to its physical properties. As explained earlier, higher ion mobility differences and lower viscosity and density cause n-hexane to form stronger vortices near the electrodes. The created vortices, in addition to creating the flow in the channel, also increase the heat transfer due to their turbulent nature. Maximum observed enhancement of Nusselt number for n-hexane and n-decane for the film

thickness $d = 4\text{mm}$ are equal to 677.6% and 568.2%, respectively. Moreover, higher operating temperatures increase the Nusselt number further. For a thickness of $d = 4\text{mm}$ at the operating voltage of 6 kV, increasing the temperature from 35°C to 45°C increases the Nusselt number for n-hexane and n-decane in case C2 by 133.1% and 104.7%, respectively.

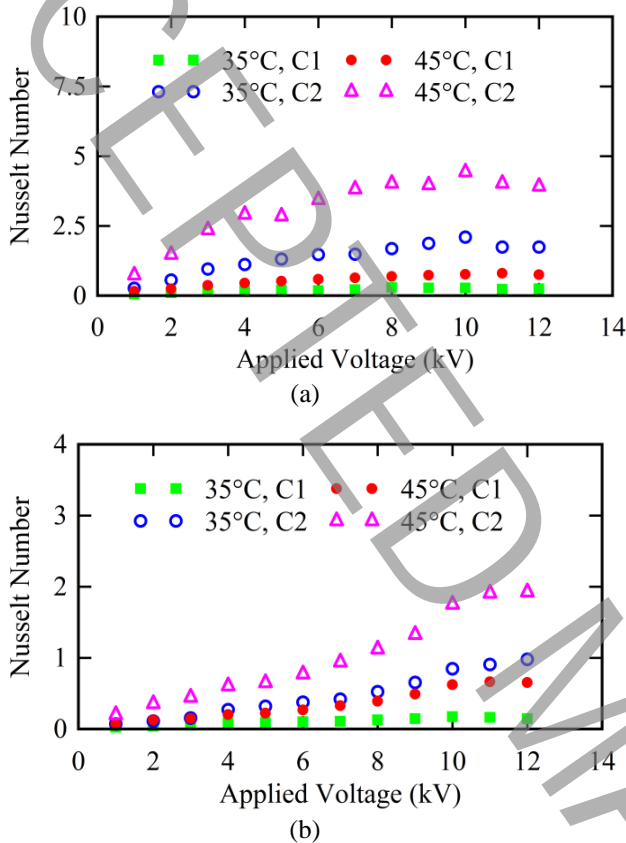


Fig. 1. The Nusselt number changes with applied voltage for film thickness $d = 4\text{mm}$: (a) n-hexane, (b) n-decane

4. Conclusion

The current study experimentally investigated enhancing heat transfer by using electrical conduction pumping of two hydrocarbon dielectric having different properties such as ion mobility, density and viscosity. Results show that:

- At a given voltage, flow rate and heat transfer in the channel are higher for n-hexane. This is due to the higher value of ion mobility difference for n-hexane which improves the vortex formation in the vicinity of the electrodes. For n-decane, higher density and viscosity also act as decreasing agents.

- It is observed that increasing the operating temperature increases the flow rate. Due to the decrease in density and viscosity at higher temperatures, the

increased temperature facilitates the vortex motion (which results in fluid flow in the channel) in the vicinity of the electrodes. It is also evident that heat transfer at higher temperatures increases due to the higher temperature difference between the heat source and the surroundings.

- The Nusselt number is significantly increased for all different thicknesses of the fluid film and also operating temperatures by the use of electrical conduction pumps, which is due to the creation of turbulence in the vicinity of the electrodes. For a thickness of $d = 4\text{mm}$ at the operating voltage of 6 kV, increasing the temperature from 35°C to 45°C increases the Nusselt number for n-hexane and n-decane in case C2 by 133.1% and 104.7%, respectively.

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