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Experimental Study of the Effects of Fluid Physical Properties on Conduction Pump Performance

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ABSTRACT: In the current study, the performance of a conduction pump with flush electrodes has been experimentally investigated using two dielectrics (n-hexane and n-decane) as the working fluids. The study is conducted for different liquid film thicknesses, and effects of changing the magnitude of applied electrical voltage, and other different parameters such as fluid physical properties (ion mobility difference, density, and viscosity) and working temperature of the liquids on the performance and efficiency of the pump are investigated. Results show that while higher ion mobility difference increases the electrical power consumption of the pump, since it leads to higher flow velocity, significantly enhances flow rate and efficiency. Therefore, using liquids with higher ion mobility difference is more appropriate in industrial applications due to the simultaneous enhancement of flow rate and efficiency. On the other hand, although increasing the applied voltage decreases the pump efficiency, it raises the flow rate, which is an important pump characteristic and even more important than efficiency for conduction pumps. Furthermore, it is observed that increasing the liquids temperature enhances the pump efficiency due to the reduction of fluids density and viscosity.

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1- Introduction

Applying an 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. Electro Hydrodynamic (EHD) pumps are mostly categorized into 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]

$$A^+B^- \underset{k_r}{\overset{k_d}{\longleftrightarrow}} A^+ + B^- \qquad (1)$$

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

From the different types of 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 the flow of the liquid film. They observed that for the flush electrodes, the difference between the width of the electrodes leads to a 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 Esmaeilzadeh [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 Esmaeilzadeh [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 the performance characteristics of conduction pumps. In the current study, the effect of parameters such as the working temperature of the system and applied voltage for two different dielectric liquids on the performance and applicability of the conduction pump with flush electrodes is experimentally investigated.

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

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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. The average temperature of the fluid in the channel is measured by using temperature sensors. Measurements accuracy for temperature, film thickness, applied voltage and electrical current is $\pm 0.1°C$, $\pm 0.2mm$, $\pm 1V$, $\pm 1nA$, 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 efficiency as one of the performance characteristics of the pump is discussed. The pump efficiency is expressed as [8]

$$\eta = \frac{pump\ output\ power}{power\ consumption} = \frac{\rho g Q h}{VI} \qquad (2)$$

where h is the specific energy of open channel flow.

The effect of the fluid average temperature on the conduction pump efficiencies for the film thickness is shown in Fig. 1. Increasing the average temperature of the fluid increases the pump efficiency. Since the two fluids have lower density and viscosity values at higher temperatures, the motion of the formed vortices and also fluid flow in the channel becomes easier. This raises the output power as well as diminishing the power consumption, leading to higher efficiencies. It is demonstrated that n-decane has lower efficiency as well as lower flow rates in comparison with n-hexane which is a limiting factor to use it as the operating fluid, while it has advantages such as higher flash point temperature. Also, it is seen that increasing the film thickness shows more significant effect on the efficiencies of n-hexane in comparison with n-decane, which can be due to the easier formation of more effective vortices at the vicinity of the electrodes because of higher ion mobilities and rather lower density and viscosity values. It should be mentioned that in some applications such as cooling electronic devices, the film thickness is the limiting design factor, and has to be considered.

4- Conclusions

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

- Although conduction pumping efficiency reduces with increasing applied voltage since it is accompanied by higher flow rates, especially for n-hexane it is of the lower order of importance. On the other hand, efficiency reduction with voltage for n-hexane shows faster rates, and finding an optimized range of applied voltage may be needed for some applications.

- Increasing the working temperature of fluids raises efficiency due to reducing the viscosity of both of them. For the n-hexane effect of increasing temperature is more obvious.

- Despite showing a higher flow rate and efficiency values for n-hexane, it should be concerned that the last mentioned hydrocarbon has rather lower flash point temperature in comparison with n-decane and heavier hydrocarbons. This parameter, especially at higher operating temperatures, becomes very important which can be a limiting factor about using it as the working fluid of the conduction pumping system. References.

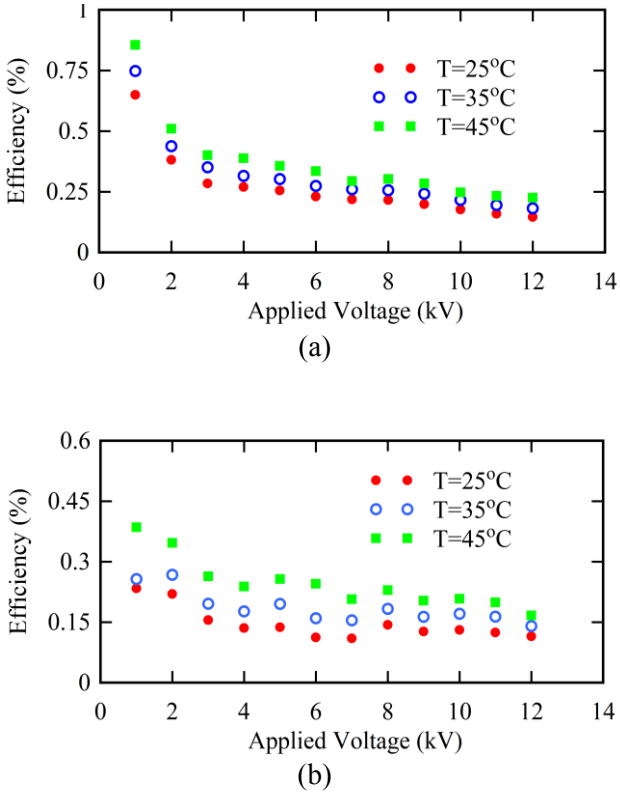

Fig. 1. Efficiency variations with applied voltage for film thickness $d = 6mm$: (a) n-hexane, (b) n-decane

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