THERMAL CONTROL AND ENHANCEMENT OF HEAT TRANSPORT CAPACITY OF TWO-PHASE LOOPS WITH ELECTROHYDRODYNAMIC CONDUCTION PUMPING

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ABSTRACT
There are three kinds of electrohydrodynamics (EHD) pumping based on Coulomb force: induction pumping, ion-drag pumping, and pure conduction pumping. EHD induction pumping relies on the generation of induced charges. This charge induction in the presence of an electric field takes place due to a non-uniformity in the electrical conductivity of the fluid which can be caused by a non-uniform temperature distribution and/or an inhomogeneity of the fluid (e.g. a two-phase fluid). Therefore, induction pumping cannot be utilized in an isothermal homogeneous liquid. In order to generate Coulomb force, a space charge must be generated. There are two main mechanisms for generating a space charge in an isothermal liquid. The first one is associated with the ion injection at a metal/liquid interface and the related pumping is referred to as ion-drag pumping. Ion-drag pumping is not desirable because it can deteriorate the electrical properties of the working fluid. The second space charge generation mechanism is associated with the heterocharge layers of finite thickness in the vicinity of the electrodes. Heterocharge layers result from dissociation of the neutral electrolytic species and recombination of the generated ions. This type of pumping is referred to as pure conduction pumping.

This project investigates the EHD pumping through pure conduction phenomenon. Very limited work has been conducted in this field and the majority of the published papers in this area have mistakenly assumed that the electrostriction force was responsible for the net flow generated in an isothermal liquid. The main motivation behind this study is to investigate an EHD conduction pump for a two-phase loop to be operated in the microgravity environment. The pump is installed in the liquid return passage (isothermal liquid) from the condenser section to the evaporator section. Unique high voltage and ground electrodes have been designed that generate sufficient pressure heads with very low electric power requirements making the EHD conduction pumping attractive to applications such as two-phase systems (e.g. capillary pumped loops and heat pipes). Currently, the EHD conduction pump performance is being tested on a two-phase loop under various operating conditions in the laboratory environment. The simple non-mechanical and lightweight design of the EHD pump combined with the rapid control of performance by varying the applied electric field, low power consumption, and reliability offer significant advantages over other pumping mechanisms; particularly in reduced gravity applications.
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OBJECTIVES

Electrohydrodynamics Laboratory

- theoretical and experimental work to understand the EHD driven liquid flow
- EHD pump based on conduction phenomenon
- ground and microgravity environment
- with and without bubbles
- optimum electrode design
- EHD pump performance in single-phase and two-phase systems
BACKGROUND

- past microgravity studies with EHD dealt for example with bubble growth
- no work carried out to study an EHD driven flow in microgravity
- fundamental understanding of an EHD pump in microgravity needed
- pave the way for development of EHD technologies for heat transfer and mass transport systems in microgravity
interaction of electric fields and free charges in a dielectric fluid
Coulomb force main mechanism of this interaction
electric field and free charges required
EHD PUMPING ADVANTAGES

- simple design
- lightweight
- non-mechanical
- rapid control of performance
- low power consumption
\[ \vec{F}_e = q\vec{E} - \frac{1}{2} E^2 \nabla \varepsilon + \nabla \left[ \rho \frac{E^2}{2} \left( \frac{\partial \varepsilon}{\partial \rho} \right)_T \right] \]

Coulomb Force \hspace{1cm} \text{Polarization Force}

Note: In an isothermal liquid, only Coulomb force can sustain a permanent EHD motion.
direct injection, not desirable
induction, not feasible in isothermal liquid
conduction
CHARGE GENERATION - CONDUCTION

- heterocharge layers of finite thickness in the vicinity of electrodes
Atten and Seyed-Yagoobi (1999) presented a theory in point/plane geometry.

Jeong, Seyed-Yagoobi, and Atten (2000) experimentally investigated the phenomenon.

The theory indicates $F_e \propto \varepsilon E^2$.

High electric field and permittivity are desirable.
STATIC EHD CONDUCTION PUMP
APPARATUS

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(Unit: mm)
hollow tube (high voltage) electrode

(Unit: mm)
PRELIMINARY ELECTRODE
DESIGN (cont.)

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(Unit: mm)

ground electrode
ASSEMBLED HOLLOW-TUBE HIGH VOLTAGE ELECTRODE AND RING GROUND ELECTRODE

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(Unit: mm)

Note: two pairs shown
HOLLOW TUBE - RING ELECTRODE DESIGN

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PRESSURE GENERATION

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Pressure-Voltage (R123, TAMU 1 pair electrode)

- new electrode
- hollow-tube

Voltage (kV)

Pressure (psi)
CURRENT CONSUMPTION

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Current-Voltage (R123, TAMU 1 pair electrode)

- new electrode
- hollow-tube

Voltage (kV) vs. Current (A)
LONG TERM OPERATION

Pressure-Time (R123, 5 pairs hollow tube & ring electrodes)

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PRESSURE GENERATION - NEW ELECTRODE DESIGN

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Pressure-Voltage (R123, TAMU 1 pair electrode)

- new electrode
- hollow-tube

Voltage (kV)

P (psi)

NASA/CP-2000-210470
SIMPLIFIED NASA-GODDARD EHD TEST LOOP SCHEMATIC

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[Diagram of the EHD test loop with labels for Metered Valves, DP Cells, Test Sections (SH 1 and SH 2), Liquid Pump, Accumulator, and Condenser & Sub-cooler]
CONCLUSIONS

- several electrode designs considered
- EHD conduction pumping confirmed
- significant pressure head generated