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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

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- 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

EHD PUMPING

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- 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

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- simple design
- lightweight
- non-mechanical
- rapid control of performance
- low power consumption

ELECTRIC BODY FORCE

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$$\vec{F}_e = \underbrace{q\vec{E}}_{\text{Coulomb Force}} \underbrace{- \frac{1}{2}E^2\nabla\varepsilon + \nabla\left[\rho\frac{E^2}{2}\left(\frac{\partial\varepsilon}{\partial\rho}\right)_T\right]}_{\text{Polarization Force}}$$

Note: In an isothermal liquid, only Coulomb force can sustain a permanent EHD motion.

ELECTRIC CHARGE GENERATION

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- direct injection, not desirable
- induction, not feasible in isothermal liquid
- conduction

CHARGE GENERATION - CONDUCTION

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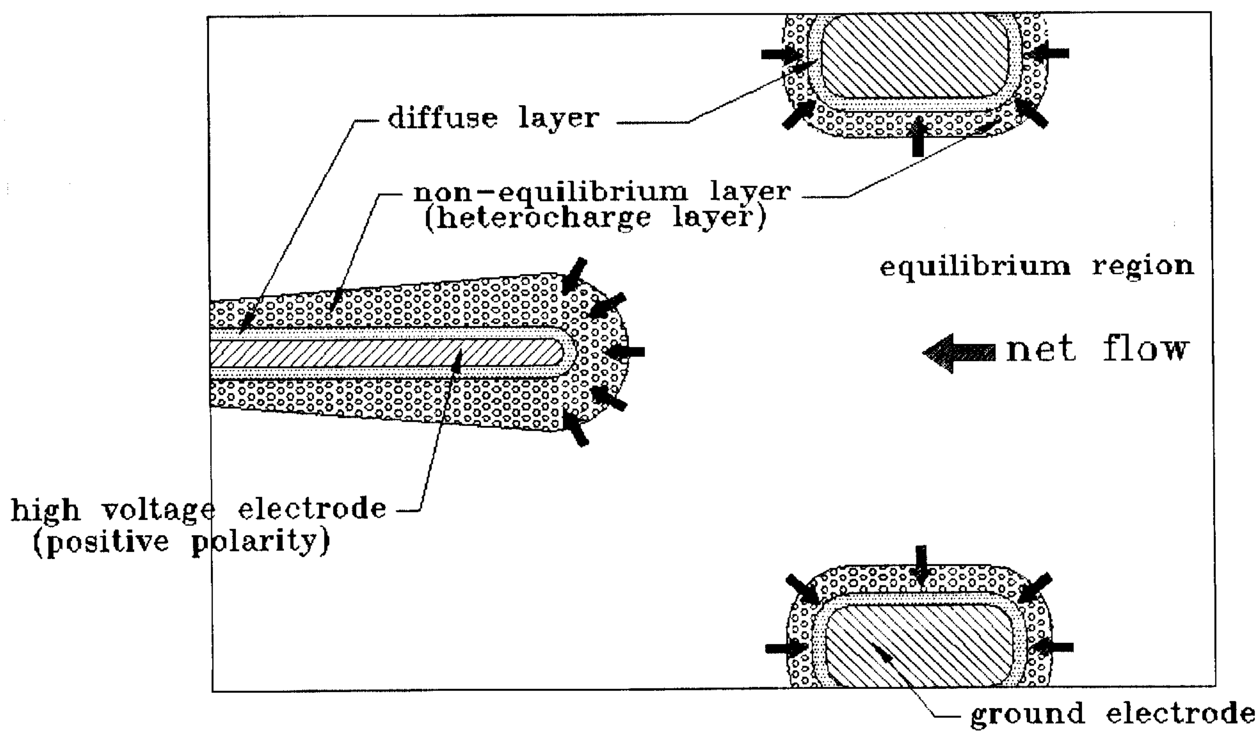
- heterocharge layers of finite thickness in the vicinity of electrodes



EHD CONDUCTION PUMPING

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- Atten and Seyed-Yagoobi (1999) presented a theory in point/plane geometry
- Jeong, Seyed-Yagoobi, and Atten (2000) experimentally investigated the phenomenon
- theory indicates $F_e \propto \varepsilon E^2$
- high electric field and permittivity are desirable

STATIC EHD CONDUCTION PUMP APPARATUS

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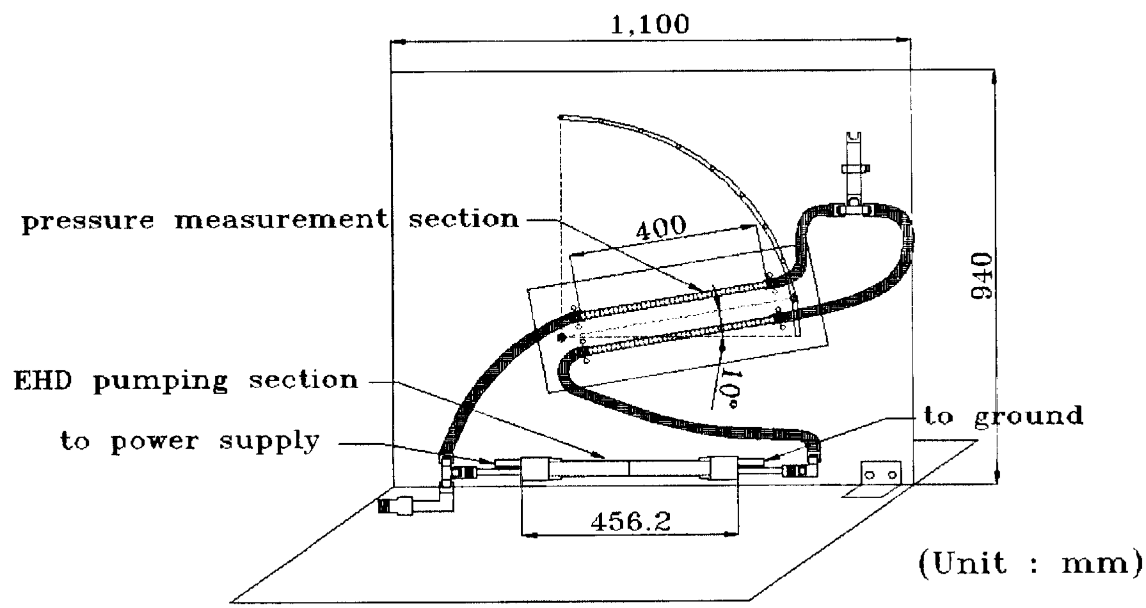

PRELIMINARY ELECTRODE DESIGN

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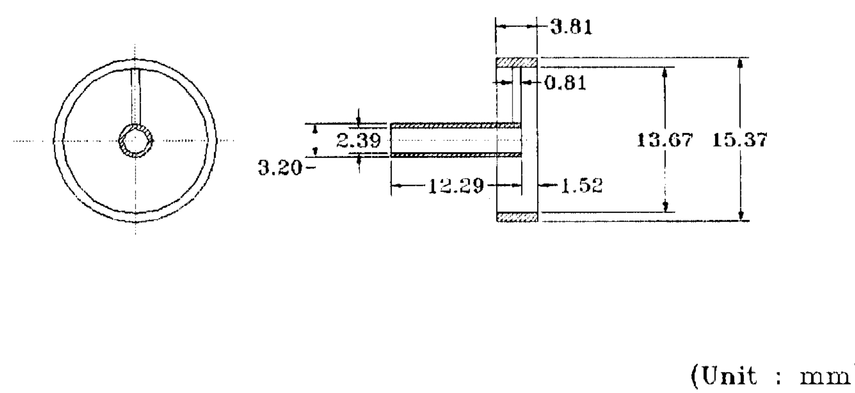

hollow tube (high voltage) electrode

PRELIMINARY ELECTRODE DESIGN (cont.)

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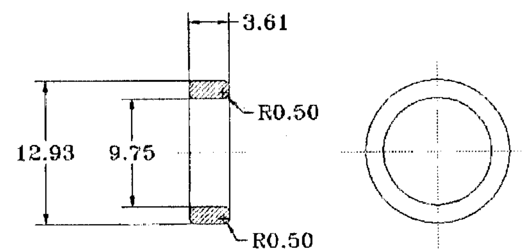

(Unit : mm)

ground electrode

ASSEMBLED HOLLOW-TUBE HIGH VOLTAGE ELECTRODE AND RING GROUND ELECTRODE

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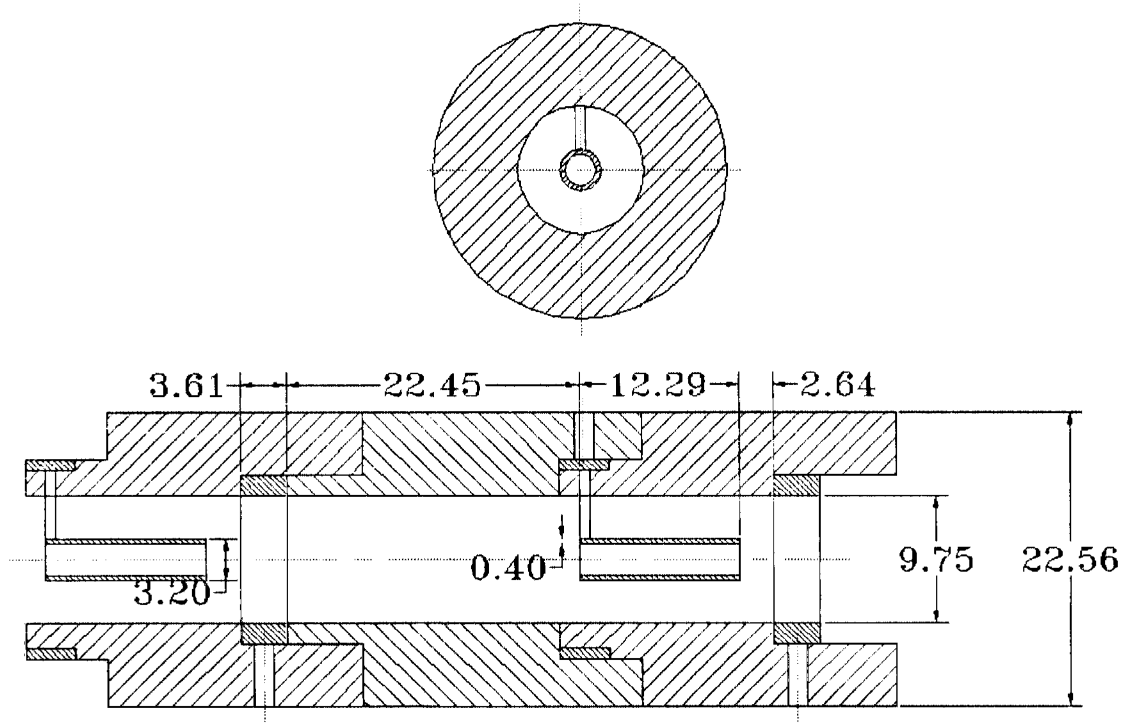

(Unit : mm)

Note: two pairs shown

HOLLOW TUBE - RING ELECTRODE DESIGN

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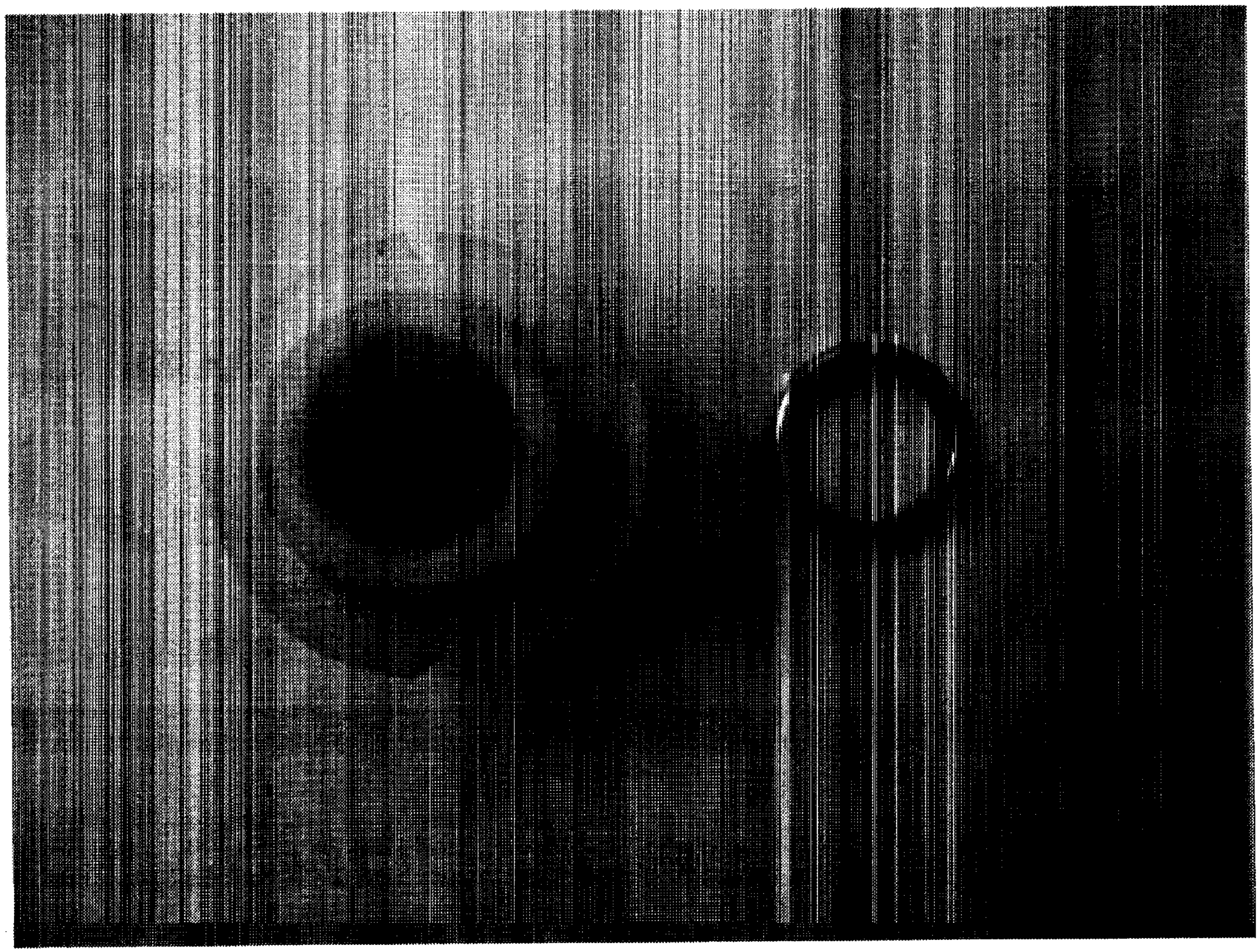

PRESSURE GENERATION

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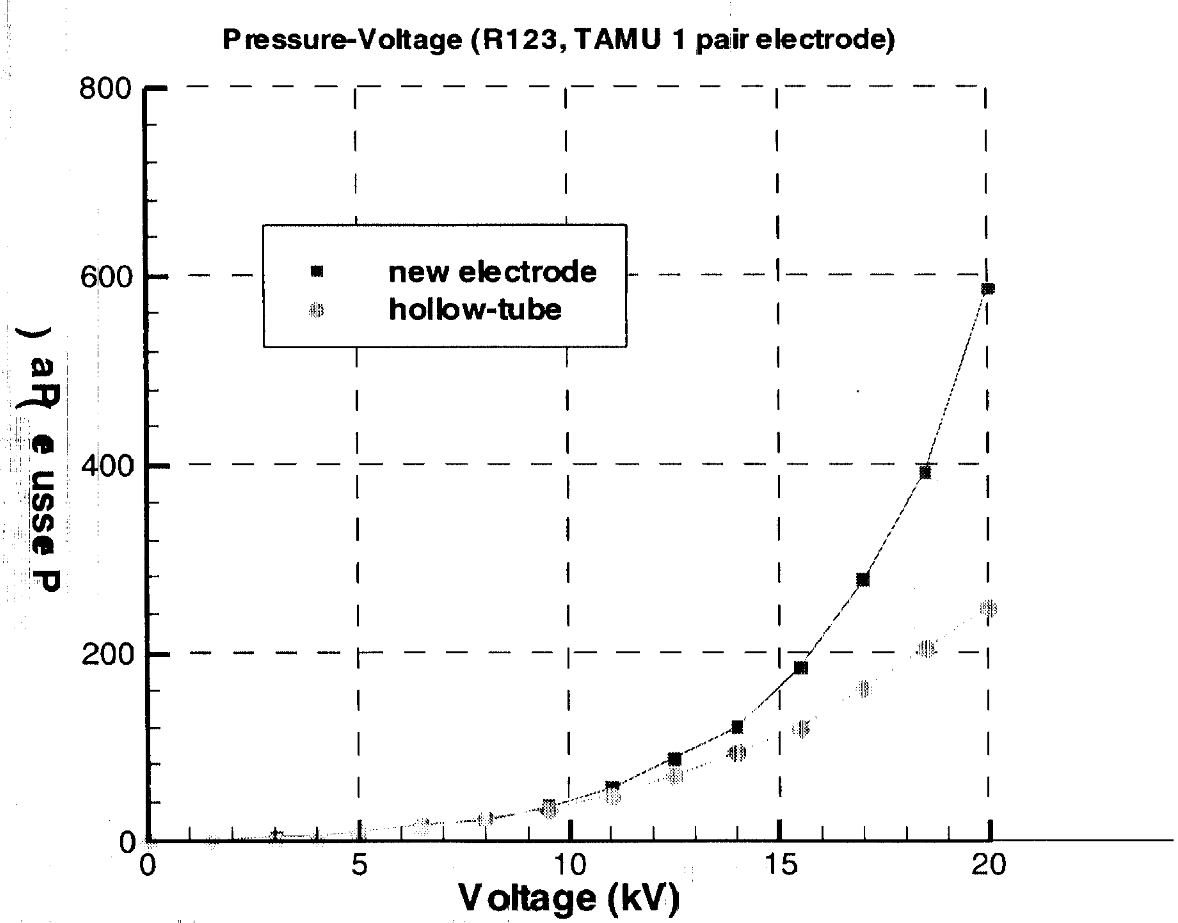

CURRENT CONSUMPTION

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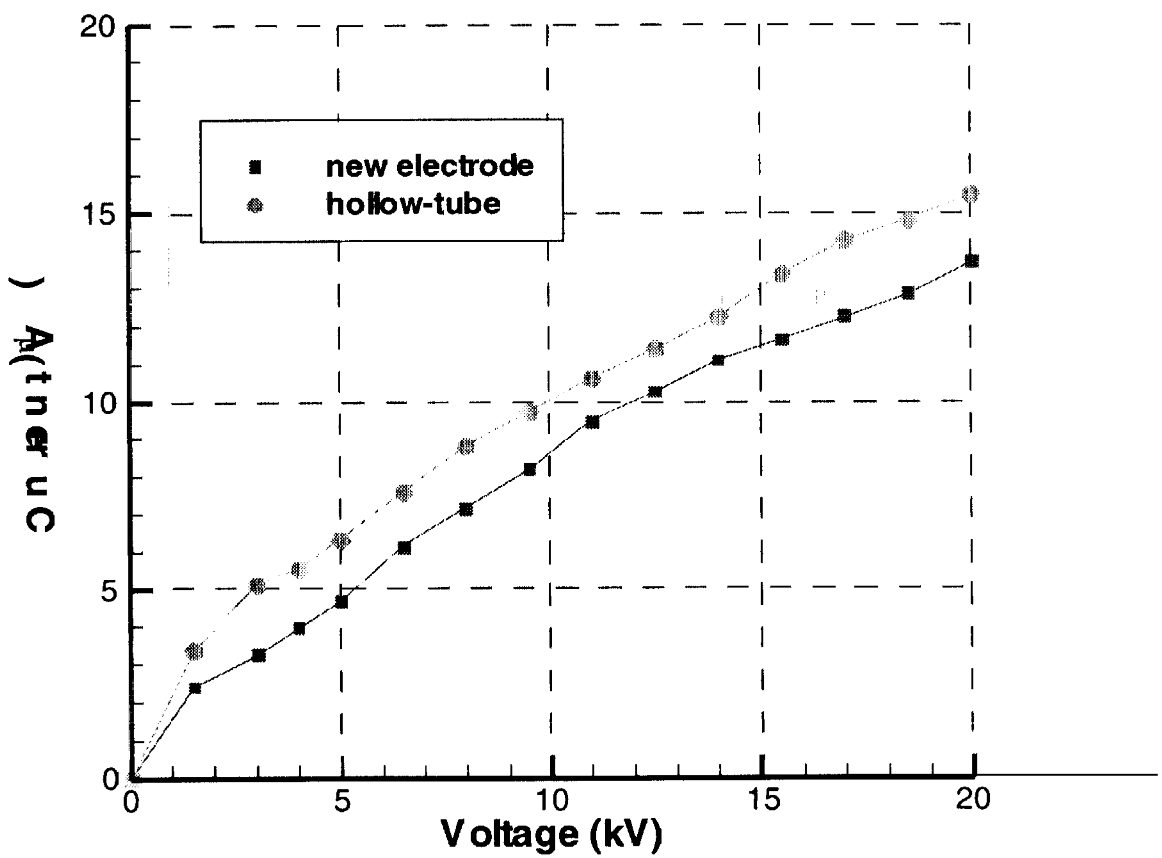
Current-Voltage (R123, TAMU 1 pair electrode)



LONG TERM OPERATION

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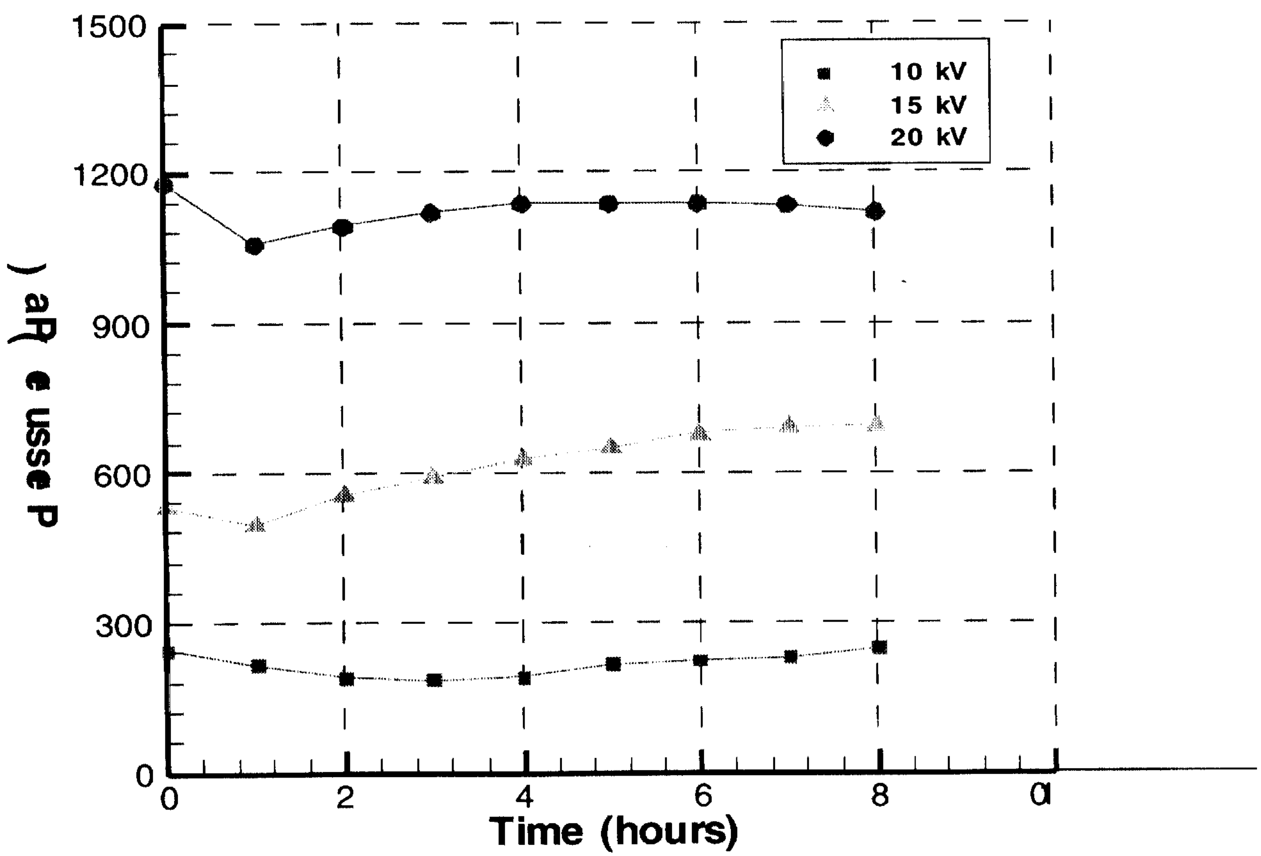
Pressure-Time (R123, 5 pairs hollow tube & ring electrodes)



LONG TERM OPERATION (cont.)

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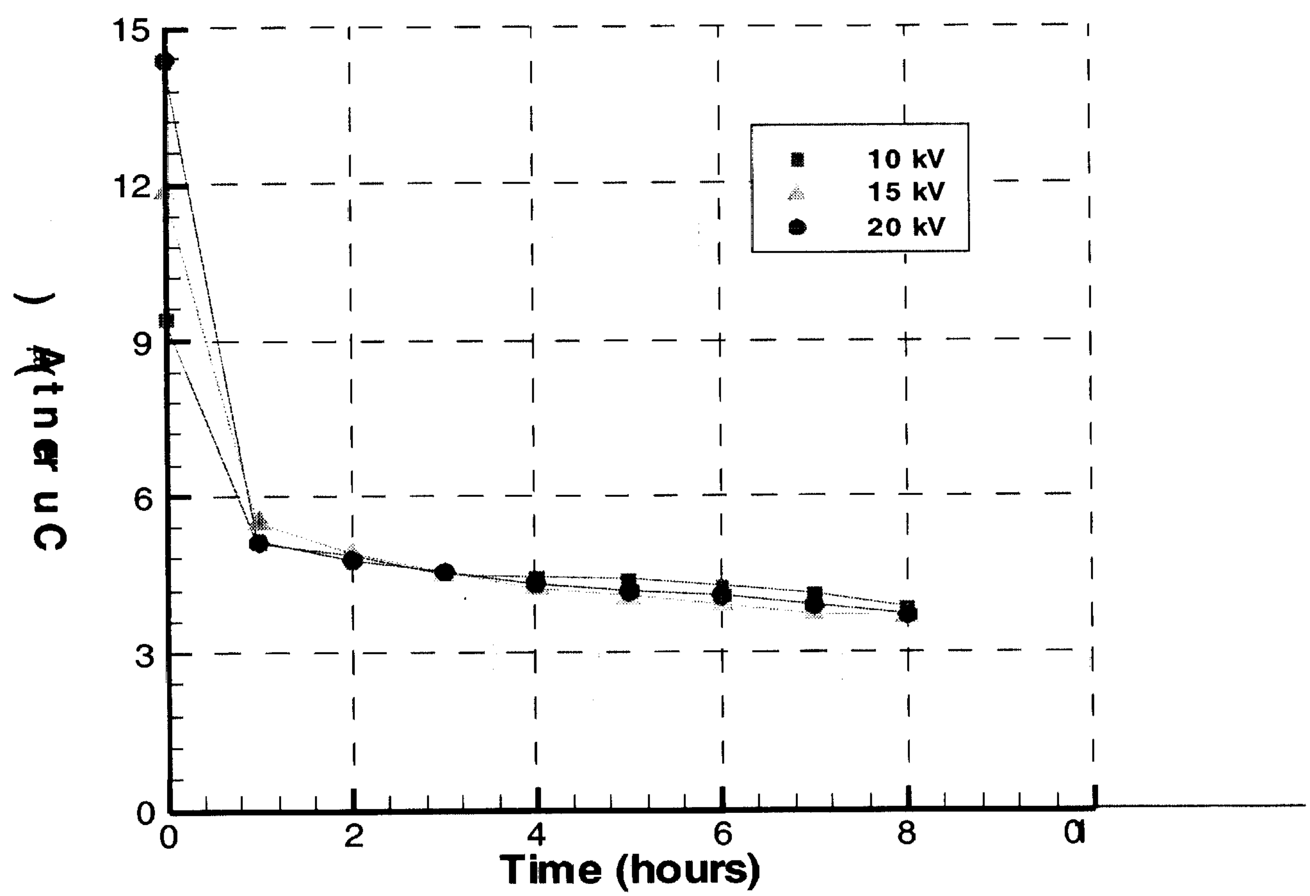
Current-Time (R123, 5 pairs hollow tube & ring electrodes)



PRESSURE GENERATION - NEW ELECTRODE DESIGN

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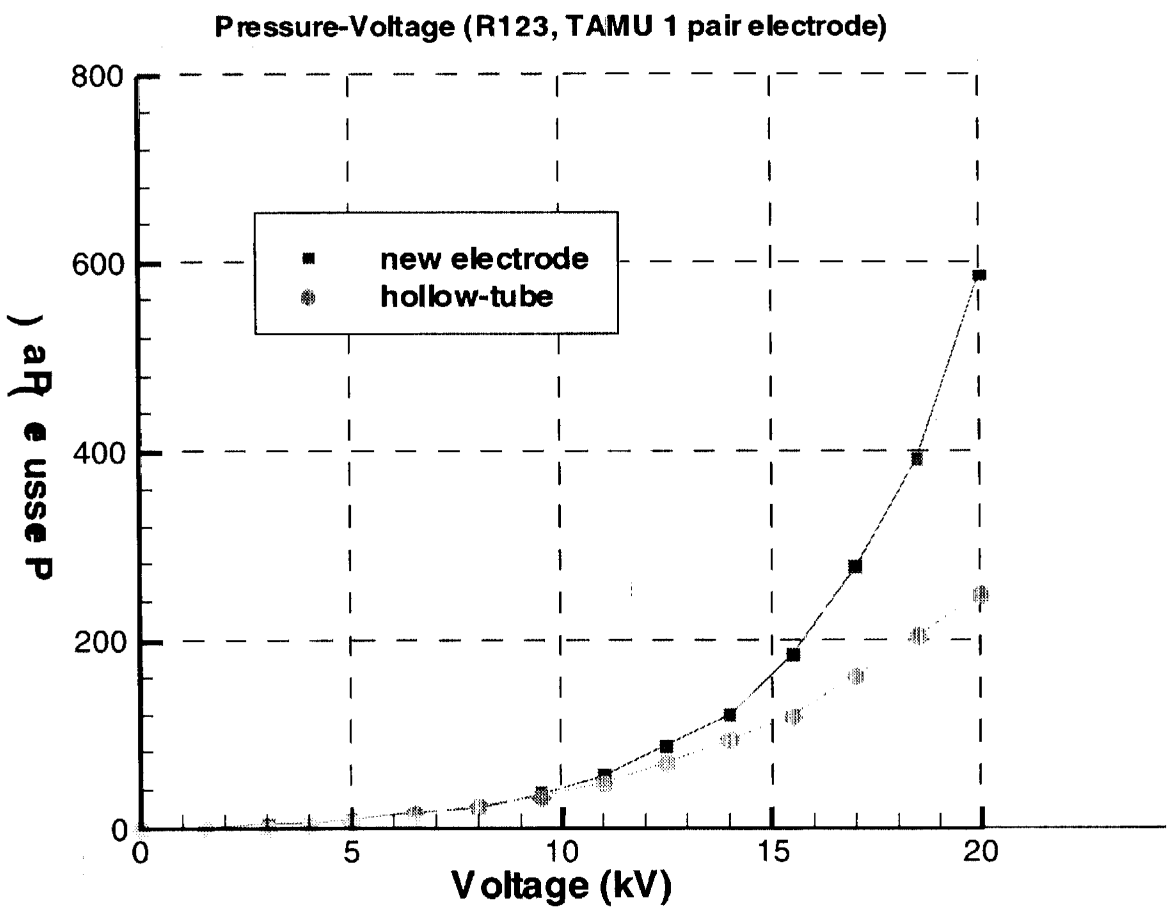

CURRENT CONSUMPTION - NEW ELECTRODE DESIGN

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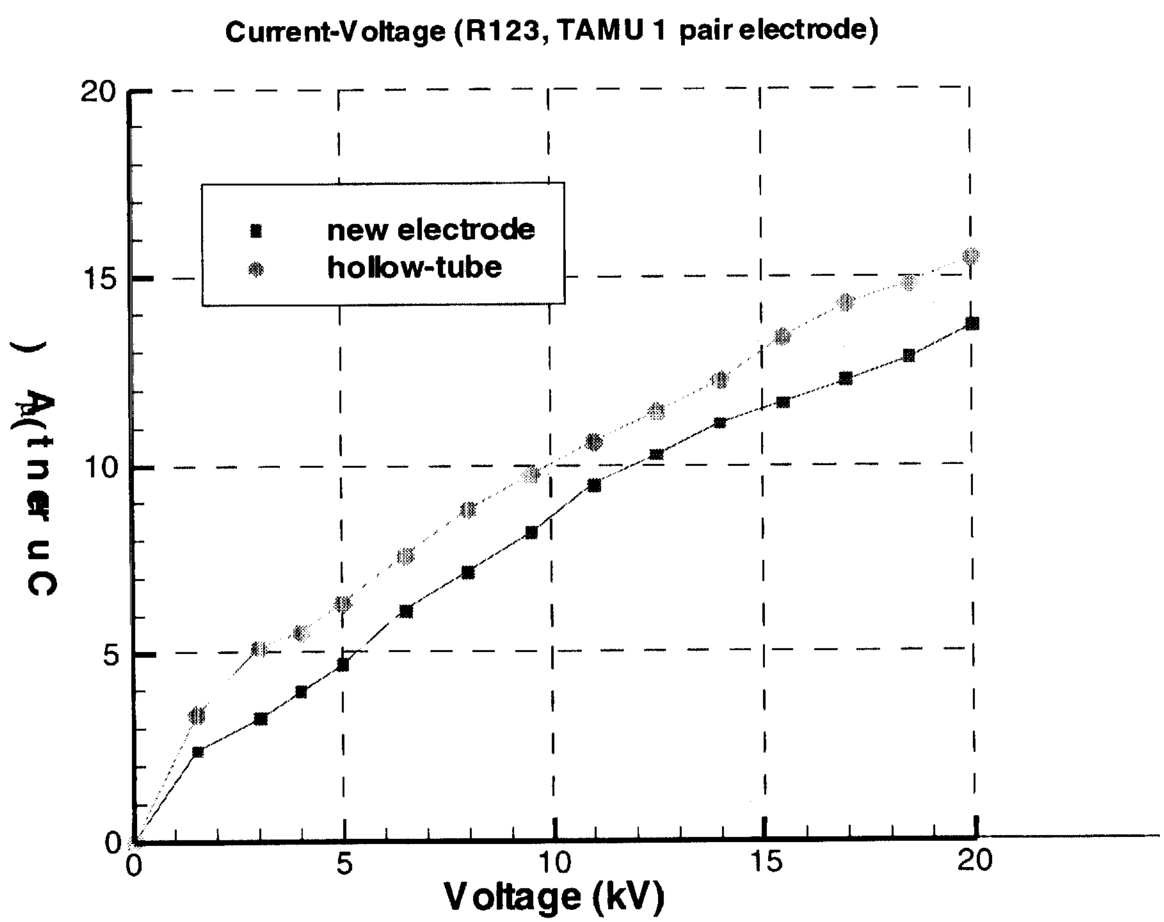

SIMPLIFIED NASA-GODDARD EHD TEST LOOP SCHEMATIC

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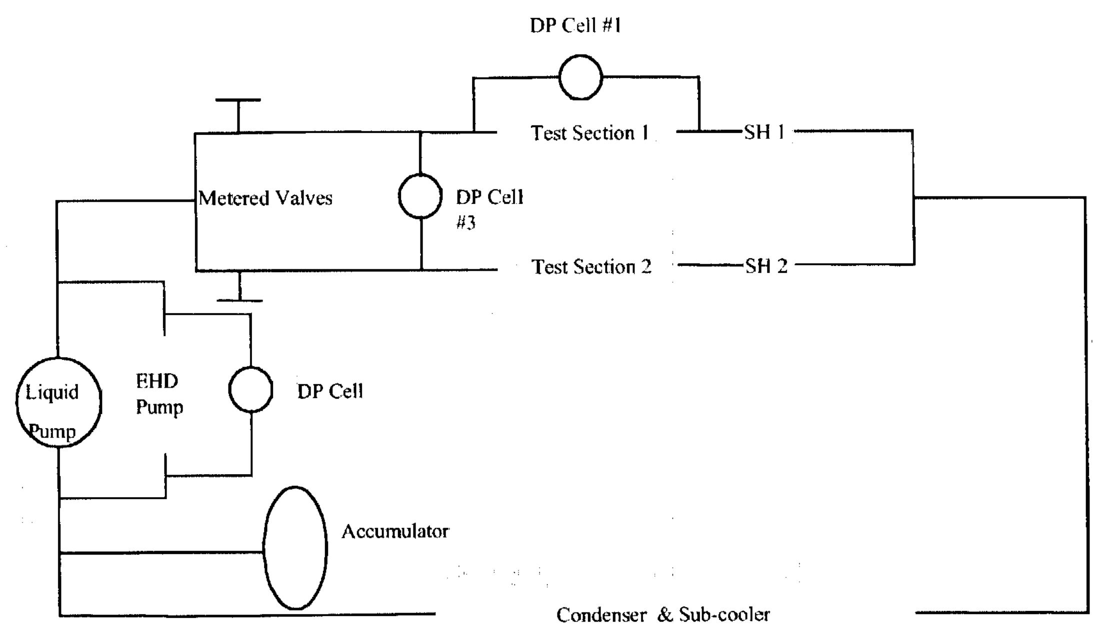

SIMPLIFIED TEST LOOP SCHEMATIC

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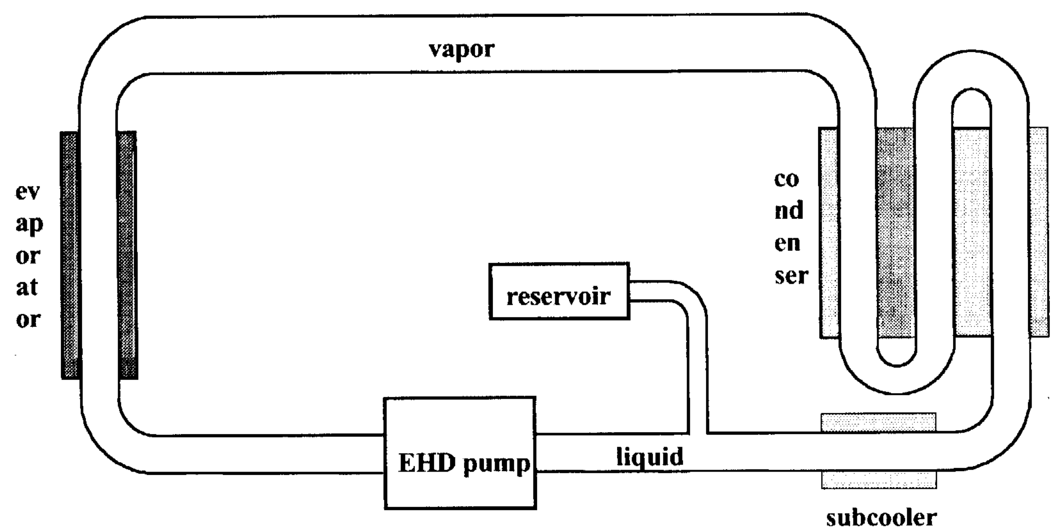

CONCLUSIONS

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