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Electro Hydro Dynamic Enhancement of Heat Transfer by Different Working Fluids in a Forced Convection Loop

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***Abstract** The flow in channel occupies an important place among the several heating systems. At the same time there is a great need of maintaining and running the system effectively. There are several ways of improvement in thermal efficiency of a system, One of the ways by which we can improve thermal efficiency of the system is to take the advantage of electric field. In the present work the effect of electric field in combination with flow and temperature fields is studied experimentally in a vertical annulus, uniformly heated on the outer wall, a dielectric liquid is allowed to flow in the forced convection loop by using centrifugal pump in a channel. Sharp points are added perpendicular to the inner wire electrode and voltages are applied to it, while the outer wall is grounded. Experimental apparatus is fabricated to conduct the experiments with heat input, voltage supplied and mass flow rate of working fluid as the independent parameters. Flow and temperature distributions are affected by the supplied voltage at the wire electrodes, and effect is more when the fluid is flowing with low Reynolds number. Because of the advantage of considerable dielectric strength of the fluid and comparatively cheaper than silicone based dielectric fluids, transformer oil is selected as working fluid. It is seen from the experiments that the heat transfer coefficient in the presence of electric field increases in relation with the supplied voltage, but decreases with the Reynolds number. From the literature survey it can be concluded that there is a significant enhancement in the heat transfer from the heated surface to the working fluid.*

I. INTRODUTION

1.1 Heat transfer enhancement

1.2 The study of improved heat transfer performance is referred to as heat transfer enhancement, augmentation, or intensification. The heat transfer objectives can usually be stated as either a) removing large rates of energy generation through small surface areas with moderate surface temperatures rises or b) reducing the size of the equipment for a given rating. The heat transfer duty of heat exchangers can be improved by heat transfer enhancement techniques.

In general, these techniques can be divided into two groups; active and passive techniques. The active techniques require external forces, eg: electric field, acoustic or surface vibration etc. The passive techniques require no external forces, it require fluid additives or special surface geometries.

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Both the techniques have been used by researchers for 140 years for increasing heat transfer rate in heat exchangers. Over the past 70 years, the heat transfer enhancement by using a strong electric field has been continuously studied. The convective heat transfer enhancement technique utilizing electro hydrodynamic (EHD) force generated from the polarization of dielectric fluid can be one of the most promising methods among the various active techniques. The electro hydrodynamic (EHD) enhancement of heat transfer refers to the coupling of electric, flow and temperature fields in a dielectric fluid medium. In the presence of a sharp high-voltage (HV) electrode, free charge can build up in a single-phase liquid by ion injection at the metal-liquid interface. Electrophoretic forces acting on ions can generate strong convective motion, thus augmenting the heat transfer rate.

In the presence of an electric field, a dielectric fluid is subjected to body forces, which may readily be expressed as,

$$f_E = qE - (E^2 * \nabla\varepsilon)/2 + [\nabla < E^2 * (\partial\varepsilon / \partial\rho)_T * \rho) >]/2$$

Respectively, these forces are commonly identified as electrophoretic (or Columbic), dielectrophoretic, and electrostrictive.

The Columbic force is exerted by an electric field upon the free charge present in the fluid, while the other two forces act on polarization charges. In single phase liquids under D.C. fields, dielectrophoresis can be neglected with respect to the Coulomb force .Free charge can be created in the fluid by three mechanisms: Temperature gradients (which induce electrical conductivity gradients), field-enhancement dissociation of electrolytic species, and ion injection at the electrode/liquid interface via electrochemical reactions.

Ion injection is mainly controlled by the high field electrochemistry of the interface, which critically depends on the chemical nature of the dielectric fluid and on the shape, composition, and polarity of the electrode. A high heat transfer enhancement by ion injection can be obtained with fluids of low viscosity and low electrical conductivity. In fact, an increased viscosity of the fluid delays the onset of the electro hydrodynamic motion and the concurrent charge injection. Besides, with a high electrical conductivity, the ions in the liquid cross the space between the electrodes before they can thoroughly exchange their momentum with the neutral fluid molecules. This lack of momentum transfer decreases the induced velocity and thus the heat transfer augmentation.

1.3 EHD Phenomenon

The fundamental characteristic of electro hydrodynamic (EHD) phenomenon for an air application is described as follows.

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High voltage at the wire electrode is generated by the high voltage power supply. The ionic wind is induced by the ionization of a gas near the wire and the drift of positive ionized air molecules to the surface of grounded electrode. During movement of the ionized air molecules, they transfer energy from their momentum to the neutral air molecules by collisions, thus a movement of the flow field of molecules occurs. In a typical gaseous medium, energy is transferred from the free electrons to the gas molecules, and the latter moves towards a grounded surface to increase the heat transfer coefficient.

1.4 Experimental Procedure

Every test has to be run under constant volumetric flow rate and heat input, and steady state condition is awaited, with or without the electric field. The temperatures measured by thermocouples are retrieved by connecting them to a mill voltmeter. Once the thermocouple readings are steady (i.e. steady state is achieved) we will note down all the temperatures read by thermocouples located at different locations over the test section. Then using these temperatures by data analysis we will calculate the amount of heat transferred from the tube wall to the working fluid.

Then we will adjust the valve to change the volume flow rate to next desired value and in the same way we will vary input voltage for attaining desired output heat and electric field for performing next test in a experiment, then after all this adjustments again we wait for steady state condition and we take the thermocouple readings. In this way we will repeat the process till the completion of experiment.

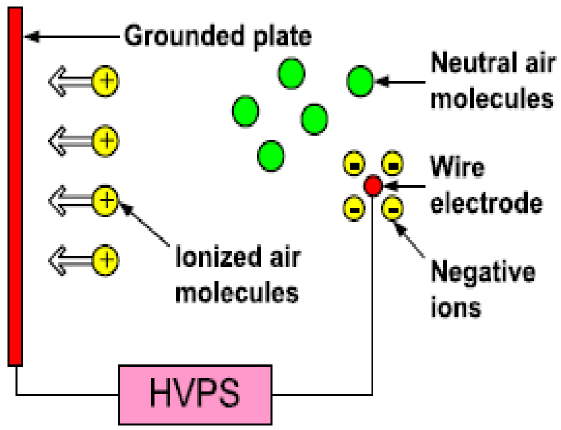

Fig 1, Schematic view of the EHD phenomenon ofair molecules

1.5 Objectives of the work

The aim of the project is fabrication of an forced convection loop having vertical channel with a wire electrode placed axially to the channel with proper insulation. Because of the advantage of good dielectric strength of the fluid transformer oil is used as a working fluid. In this work we examine the effect of an A.C electric field in a heated vertical annulus with sharp points added perpendicularly to the inner electrode at various longitudinal locations. The experiments will be conducted with heat input, flow rate and supplied voltage as the independent variables. The effect of electric field (A.C) is observed.

II DESIGN AND FABRICATION OF TEST SECTION

2.1 Introduction

This chapter gives the details of design and fabrication of the experimental set up, including the details of the working fluid.

2.2 Experimental apparatus

In the present work we examine the effect of an A.C. electric field in a heated vertical annulus with sharp points added perpendicularly to the inner electrode at various longitudinal locations with the help of forced convection loop shown below.

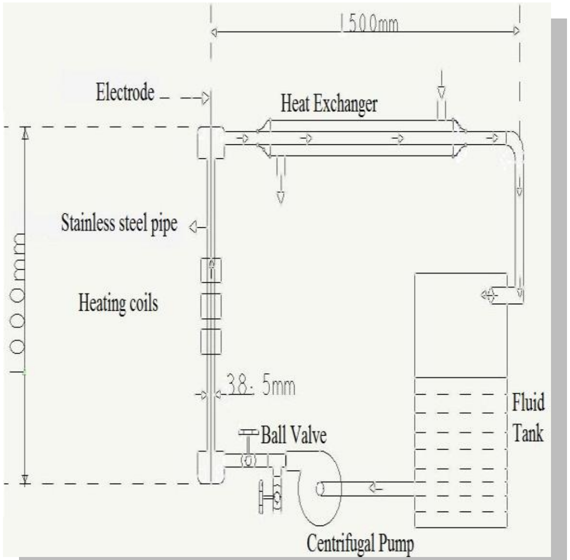

Fig. 1 (Block diagram of Experimental setup)

Fig.2 (Schematic view of Experimental setup)

2.3 Specifications of test loop

Length of the channel	= 1000mm
Inner diameter of tube	= 34mm
Type of thermocouples	= T (10in number)
Thickness of the channel	= 2mm
Heating length	= 210mm
Heat supplied	= up to 500Watt
Maximum surface temperature	= 1800c
Length of each heating element	= 70mm

2.4 Heating element

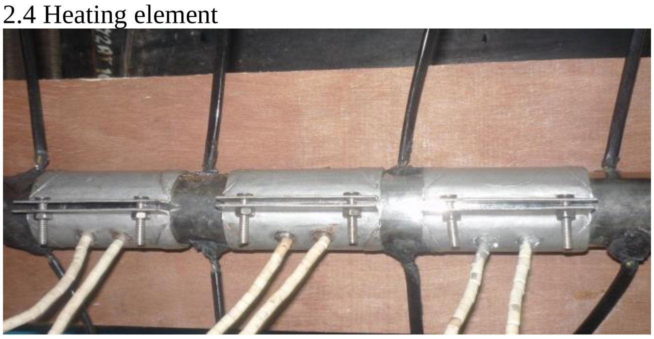

Fig. 3

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2.5 Inner wire electrode

It consists of 3mm stainless steel rod of required length. Metallic points (copper wire) were welded perpendicularly to the inner wire electrode by braze welding technique. The metallic points were simply copper wires of diameter 0.9mm (20gauge) and length 10mm.

3.6 The working fluid

The dielectric fluids chosen for the experimental campaign is two grades of transformer oil, water, which are having widely varying properties. Transformer oil has a low viscosity and an extremely low electrical conductivity, thus being really suitable for EHD processes. The physical properties of the working fluids are as follows,

Working fluid-I:

- Dielectric strength(as delivered):62 kV
- Kinematic viscosity@ 27oC:12.28 cSt
- Density at 29.5oC kg/m3: 815
- Flash point: 156oC
- Pour point: - 36oC

Working fluid-II:

- Dielectric strength(as delivered): 74kV
- Kinematic viscosity@ 30oC: 10.20 cSt
- Density at 29.5oC kg/m3: 865
- Flash point: 142oC
- Pour point: - 48oC

3.7 Schematic of section:

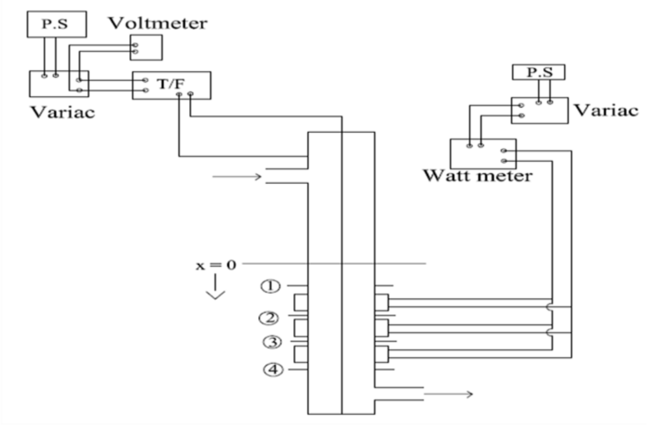

Fig.4 Block diagram of test section

EXPERIMENTATION ON THE TEST SECTION

3.1 Introduction

This chapter gives the details of the experimental procedure, including calculations of the heat transfer coefficients and Nusselt number.

3.2 Test procedure and data analysis

In a preliminary operation, the dielectric strength of the medium is tested. Slowly increasing the applied voltage, it is observed that electrical break down occurred at 20KV, which is called as break down voltage, above which there exist a continuous arc between the two electrodes.

Every test was run under constant volumetric flow rate and heat flow and a steady state condition was awaited, with or without the electric field. The mass flow rate of the working fluid which is flowing through the channel was measured by knowing the time taken to fill one lit. at the outlet section. As the terminals of thermocouples are connected to the end terminals of micro voltmeter, the output can be finally converted into temperature from the calibration curve available.

The two outer wall surface temperatures are to be averaged to get the outer wall surface temperature at each of the four sections. The bulk mean temperature of the fluid at a given axial position was calculated considering a temperature of adiabatic mixing for the examined cross section, assuming a linear trend, from the inlet to the outlet temperature, on the heated length. The temperature of the inner side of the wall was obtained from the ones measured on the outer side, properly accounting for one dimensional heat conduction within the wall thickness.

3.3 Measurement of supplied voltage

Generally the output voltage (high voltage) of a transformer is measured by using electrostatic voltameters, which works on the principle of electrostatics. In another way we can also measure the output voltage by knowing the transformer K-factor, which is the ratio of output voltage to the input voltage of the transformer.

Table 1: Calculation of transformer K-factor :

K Average = 25.88

i.e. Output voltage = input voltage x KAvg

3.3.1 Data processing

The heat transfer performance of flowing fluids was defined

S No	Input voltage(V1)	Output voltage(V2)	'K' factor= V2/V1
1	5	132	26.4
2	10	262	26.2
3	15	384	25.6
4	20	518	25.9
5	25	638	25.52
6	30.5	790	25.90
7	35	885	25.28
8	40	1050	26.25

in terms of the following convective heat transfer coefficient (h) and the Nusselt number (Nu):

$h(x) = q/(T_w(x)-T_f(x))$ (3.1)

$Nu(x) = h(x)D/k_f$ (3.2)

Where q is the heat flux, Tw and Tf are the wall and fluid temperatures respectively, D is the tube diameter, kf is the fluid thermal conductivity, and x represents axial distance from the entrance of the test section. The fluid temperature profile in the test section was obtained through the energy balance:

$T_f(x) = T_{in}+qSx/\rho c_p u A$ (3.3)

Where cp is the heat capacity, ρ is the fluid density, Tin is the inlet temperature of the fluid entering the test tube, A and S are the cross-sectional area and perimeter of the test tube, and u is the average fluid velocity. Eq. (3.3) is based on an assumption of zero heat loss through the insulation layer.

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The deviation to this assumption was assessed by comparing the measured temperature difference between inlet and outlet of the test section with the theoretical value calculated by Eq. (3.3).

Traditionally, the Nusselt number is related to the Reynolds number defined as $Re = (u*D)/\nu$ and the Prandtl number defined as $Pr = \nu / \alpha$, where ν is the fluid kinematic viscosity, α is the fluid thermal diffusivity, and μ the fluid dynamic viscosity.

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