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Experimental Studies on Oscillating Heat Pipe using conventional and Nano Fluids

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ABSTRACT

Oscillating heat pipe (OHP) cooling is the new and emerging technique in the field of thermal management of electronics. In the present work, transient and steady state experiments are conducted on a multi turn closed loop OHP. Evaporator and condenser wall temperatures are measured. Copper is used as the capillary tube material in the evaporator and condenser sections with inner diameter of 1.5 mm and outer diameter of 3 mm. The total length of the closed loop pulsating heat pipe is 2040mm. The experiments are conducted in vertical orientation for different heat loads varying from 20 W to 40 W in steps of 5W. The OHP is tested with different working fluids viz. Acetone, water, SWCNT and Graphene. The performance parameters such as temperature difference between evaporator and condenser, thermal resistance and the overall heat transfer coefficient are evaluated. The experimental results demonstrate that SWCNT& Graphene particle based Nano fluid is the better working fluid among the working fluids considered in terms of lower thermal resistance and higher heat transfer coefficient. The multi loop OHP is found to perform better for all heat loads & working fluids considered.

Keywords: Nano fluids, oscillating heat pipe, experimental studies, thermal performance

I. INTRODUCTION

Thermal management is the challenge of the day in electronic product development. Presently, the chip heat flux level ranges between 40 to 120 W/cm^2. It is expected to increase to 200 W/cm^2 in the next few decades. Several cooling methods are employed to cool the electronic devices. Heat Pipe is being explored for electronic cooling devices with promising results. Even though the conventional heat pipes are excellent heat transfer devices their application ismainly confined to transferring small amount of heat over relatively short distances.

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Oscillating heat pipe (OHP) is a passive two-phase heat transfer device, which is a special category of wickless heat pipes. It has been invented by Akachi [1-3], it exhibits self-sustained oscillation of the working fluid and phase change phenomenon leading to enhanced heat transfer. Due to its simple design, light weight, low fabrication cost and very fast response at higher heat loads, OHPs have been considered as one of the compact heat transfer devices for various cooling applications such as electronics cooling, heat exchanger and space application, etc. Since the last two decades, many researchers have investigated its thermal performance experimentally and theoretically. These experiments reveal that the Closed Loop Oscillating Heat Pipe (CLOHP) performance is strongly affected by many parameters including geometrical, physical and operational parameters. Furthermore, it is mentioned that the problem of two phase flow oscillation in closed loop Oscillating heat pipe is very complicated because of many unstable variables and complexity of thermo-hydrodynamic operational characteristics. In the meantime, some visual studies have been performed using glass tube to understand the operational behaviour and considerable progress has been also achieved in these Attempts [4]. In recent years, improving thermal performance of CLOHP has become a demanding challenge and hot research topic due to rapidly increasing heat load and miniaturization of electronic devices. Based on existing experimental results the working fluid is the most important parameter in the CLOHP. At the same time, Nano fluids are viewed as advanced heat transfer fluids in heat transfer devices. In general, the nanoparticles suspended in the base fluid forming the Nano fluid are of size about less than 100 nm. The heat transfer performance of the base fluid is significantly improved due to increased surface area. In 1995, this concept was first proposed by Choi Since then, some researchers have focused on the heat transfer characteristics of Nano fluids such as thermal conductivity and viscosity in single-phase flow and also flow with phase change.

In recent years, the nanofluid, employed as a working fluid in the heat transfer device, is an emerging topic. In 2004, Tsai et al. [5] found application of nanofluids in the Conventional heat pipes using gold nanoparticle solution and there was a significant reduction noted in thermal resistance of heat pipe with nanofluid as compared to the one with DI water. In 2006, Ma et al. [6] conducted experiments under various operating temperatures and heat powers using water based diamond nanofluid in the CLOHP.

They reported that the nanofluid could effectively enhance heat transfer due to occurrence of strong oscillatory motion of flow. Lin et al. [7] observed thermal enhancement of the heat pipe with water based silver nanofluid at very low mass concentration. Visualization

Experiments are carried out on two phase flows of the CLOHP using DI water and Nano fluid [8, 9]. Ji et al. [10] found improvement in the start-up performance of CLOHP due to alumina nanofluid. Jian Qu et al. [11] pointed out improvement or deterioration of the CLOHP performance due to different nanoparticle deposition behaviour with different nanofluids. A similar deterioration of heat pipe (thermosyphon) was found by Khandekar et al.

[12]. It is noticed from relevant literatures [5–12] that the improvement/deterioration of boiling performance in the heat pipes is due to the change in surface property. The small amount of the nanoparticle suspended on the base fluid cannot largely increase the thermal conductivity of the working fluid. However, the oscillating motion of the particles in the working fluids might have additional contribution to improvement of thermal performance of the CLOHP [6]. From the literatures [13–15], it is felt that the study of Nano fluids is still

promising and the overall understanding of two phase flow heat transfer with the CLOHP is at the beginning stage. Hence, exploratory researches in both fundamental and engineering systems are needed.

Further, it is noted that very little amount of work has been carried out with use of metal nanoparticles in the CLOHP. Therefore, the present study aims at experimentally investigating the thermal performance of the device using SWCNT & Graphene Nano particle based Nano fluid, Results of the present study are expected to help us understand and design more efficient Nano fluid-charged CLPHPs operational behaviour

II. EXPERIMENTATION

2.1 Material Selection & Fabrication

The basic components used in OHP are copper tubes, glass tubes, silicon rubber tubes, a non-return valve, a Mica heater and thermocouples. Copper is used as the tube material since it is an excellent conductor of heat. The tube is bent into a multi loop U turn with a radius of 35mm. The glass tube attached between the U turn copper tubes acts as the adiabatic section and provides the flow visualisation. The glass tube is made of borosilicate, which can resist temperature up to 1200°C. Silicon tubes are used as the connectors between glass and copper tubes. They can resist temperatures up to 400° C. In order to maintain unidirectional fluid flow, a non-return valve is used. Eight 'K-type' thermocouples are used for temperature measurement. Four thermocouples each are connected in the evaporator and condenser sections at equal distances. An Eight - channel digital temperature indicator is used to record the temperatures at different locations. A coil wound heater attached to evaporator section acts as the source of heat input. The experimental setup is worked with four working fluids viz., water, acetone, SWCNT and Graphene based Nano fluids. The Working fluid is injected into the heat pipe using a syringe

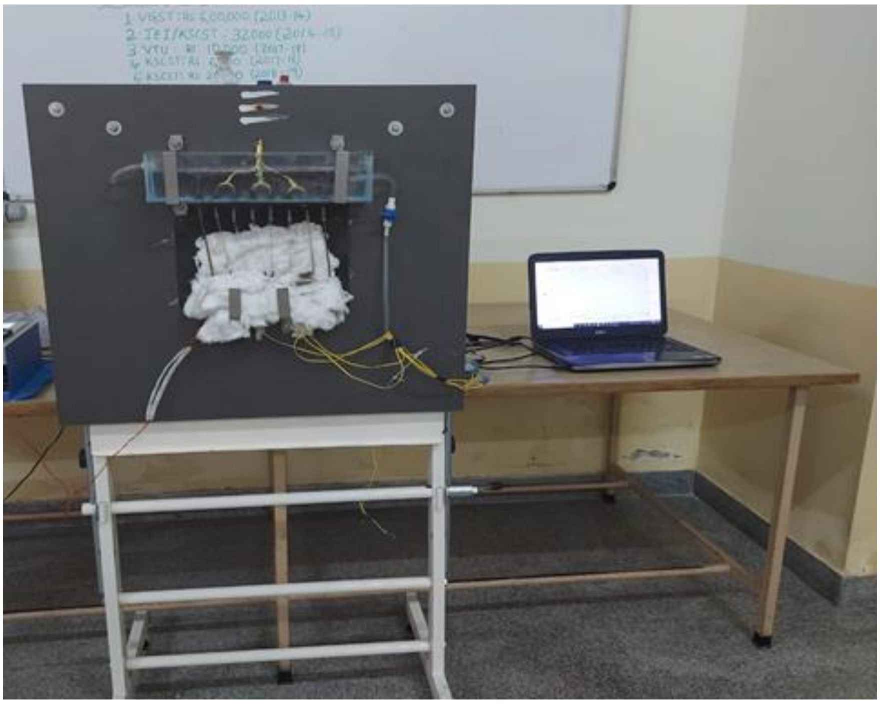

Figure. 1 OHP experimental setup

2.2 Experimental Procedure

Before conducting the experiment, it is ensured that there is no fluid inside the tubes. The required amount of working fluid is then filled through a syringe by opening one end of the non-return valve such that the fluid directly enters the evaporator section. Now the air is filled through the projection provided on the copper tube using another syringe. This is done to ensure simultaneous formation of liquid slug and vapour plug. The display unit is switched ON and the required wattage is set. A fan arrangement is used for cooling the fluid in the condenser section. The transient experiments are conducted and the various temperatures are recorded from the digital temperature indicator. The experiments are continued till SteadyState is reached.

The colloidal solution of SWCNT particle Nano fluids is prepared by using water as base fluid & graphene particle based Nano fluid is prepared by using acetone as base fluid and experimentation is carried out by varying the fill ratio as well as by varying the heat load input. The obtained values will be plotted against the graph through which the values of thermal resistance and heat transfer coefficient. The heat input and the variation of the temperature is noted with the aid of temperature data logger. The output of the temperature data logger with the help of the software is monitored in the computer. A typical output from the data acquisition system is as shown below,

Figure 2 Output of the Data Acquisition System

III. RESULTS AND DISCUSSION

Transient experiments have been conducted with different working fluids i.e., acetone, water, SWCNT and Graphene Nano particle based Nano fluid and variations of temperature with time are recorded. The experiments are continued till steady state is reached.

Fig 3 shows the variation of temperature difference between evaporator and condenser with time at different heat inputs for water at a fill ratio of 50%. It is observed that the temperature difference between evaporator and condenser is considerably less at lower heat input of 25 W

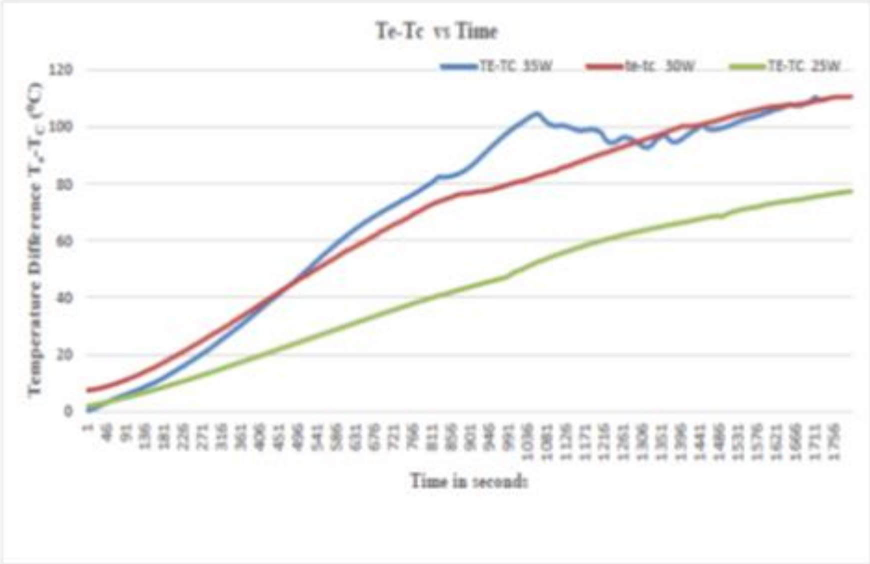

Figure 3 .Temperature Difference (Te -TC) Plot for water

Fig 4 shows the variation of temperature difference between evaporator and condenser with time at different heat inputs for SWCNT at a fill ratio of 50%. It is observed that the temperature difference between evaporator and condenser is considerably less at lower heat input of 25 W

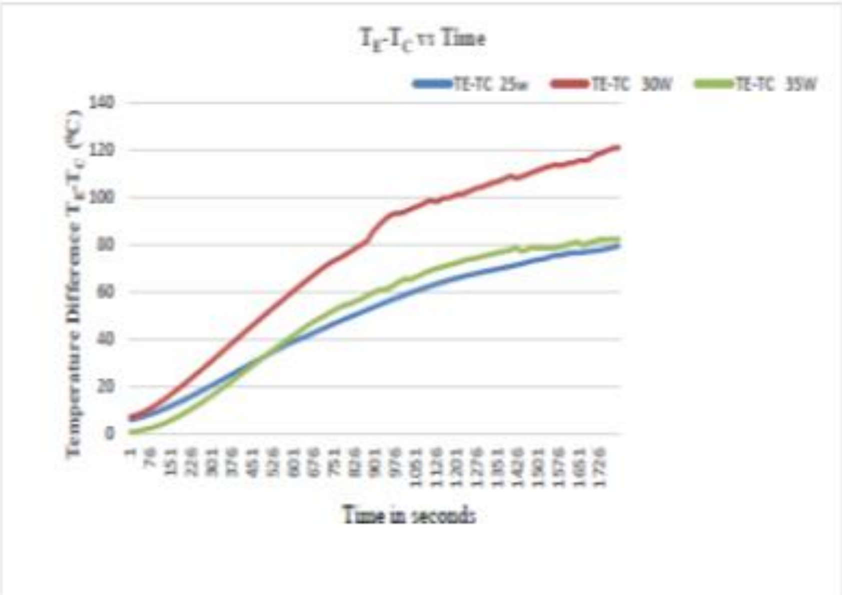

Figure 4.Temperature Difference (Te –TC) Plot for SWCNT

Fig 5 shows the variation of temperature difference between evaporator and condenser with time at different heat inputs for Graphene at a fill ratio of 50%. It is observed that the temperature difference between evaporator and condenser is considerably less at lower heat input of 25 W

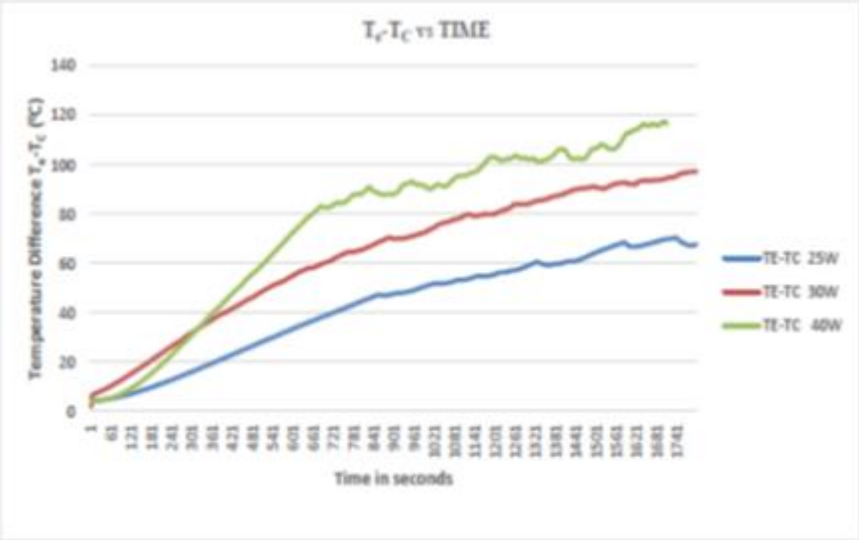

Figure 5.Temperature Difference (Te –TC Plot for Graphene

Fig 6 shows the variation of temperature difference between evaporator and condenser with time at different heat inputs for Graphene at a fill ratio of 50%. It is observed that the temperature difference between evaporator and condenser is considerably less at lower heat input of 25 W

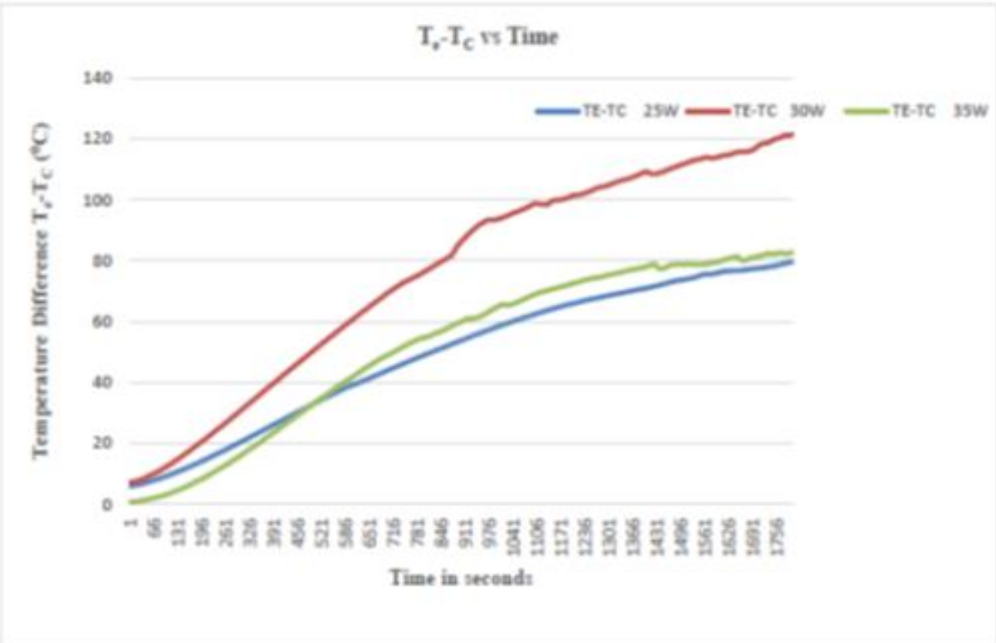

Figure 6.Temperature Difference (Te -TC) Plot for Acetone

Finally the effectiveness of the heat pipe is indirectly brought in terms of thermal resistance and convective heat transferco-efficient.

The thermal resistance is computed as,

$$Rth = \frac{Te - Tc}{Q} \text{ --------}{}^0C/W \qquad \text{------(1)}$$

Convective heat transfer co-efficient is given by

$$h = \frac{Q}{As\ (Te - Tc)} \text{---- } W/m^2 C \qquad \text{----- (2)}$$

Where Te = Evaporator temperature in ^0C

Tc = condenser temperature in ^0C

A_s = surface area of the condenser section of heat pipe in m^2

h= Heat transfer coefficient W/m^2 C

R_{th} = Thermal resistance $^0C/W$

Fig.7 &8 shows the variation of thermal resistance and heat Transfer coefficient with heat load at steady state for Water and SWCNT at a fill ratio of 50%. It is observed that the thermal resistance decreases with increase in heat load & heat Transfer coefficient increases with increase in heat load for both Water and SWCNT. However, it is clear that the magnitude of thermal resistance is lower for SWCNT compared to Water. As the temperature difference between evaporator and condenser is less for SWCNT, the thermal resistance is also

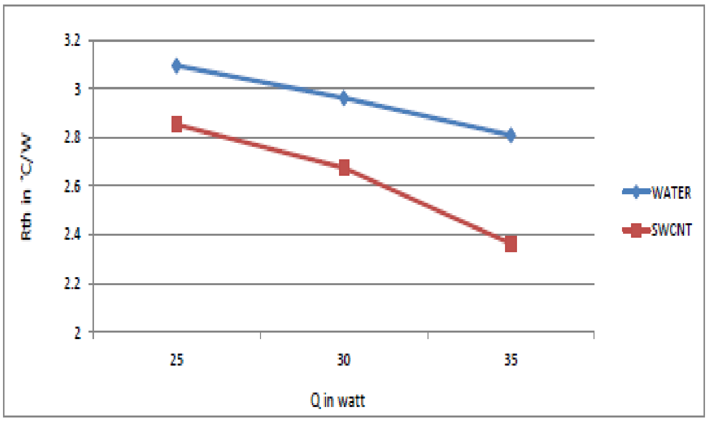

Figure 7. Thermal Resistance vs heat input

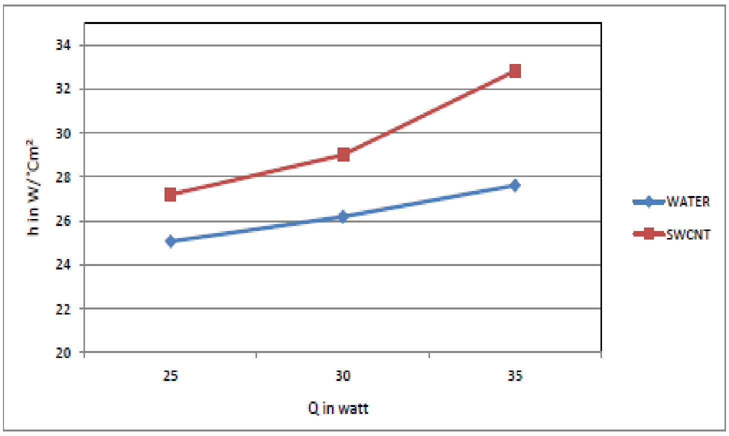

Figure 8.Heat transfer coefficient vs heat input

Fig.9 & 10 shows the variation of thermal resistance and heat Transfer coefficient with heat load at steady state for Acetone and Graphene at a fill ratio of 50%. It is observed that the thermal resistance decreases with increase in heat load & heat Transfer coefficient increases with increase in heat load for both Acetone and Graphene. However, it is clear that the magnitude of thermal resistance is lower for Graphene compared to Acetone. As the temperature difference between evaporator and condenser is less for Graphene, the thermal resistance is also less.

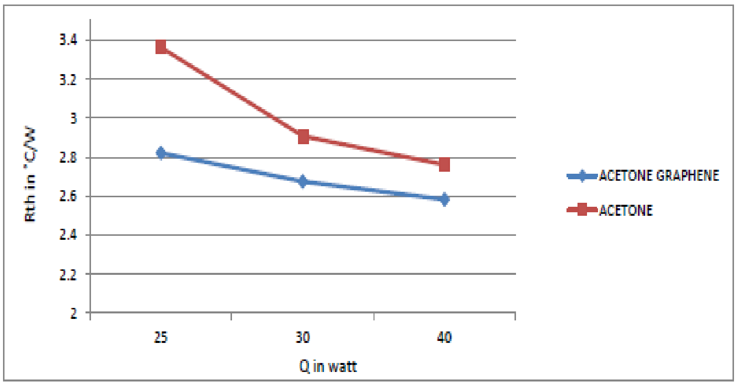

Figure 9.Thermal Resistance vs Heat input

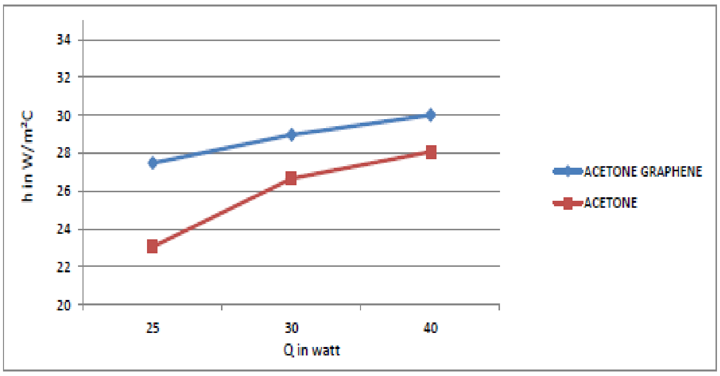

Figure10. Heat transfer coefficient vs Heat input

Figure 11. Shows the variation of thermal resistance with heat input for different working fluids at 50% fill ratio. The figure indicates that the thermal resistance decreases with increase in heat input in case of both the working fluids considered .Further it is seen that SWCNT exhibits lower values of thermal resistance compared to Water and Graphene. This is due to lower value of temperature difference between evaporator and condenser in case of SWCNT .The lower values of thermal resistance of SWCNT indicate that SWCNT has better heat Transport capability compared to Water and Graphene

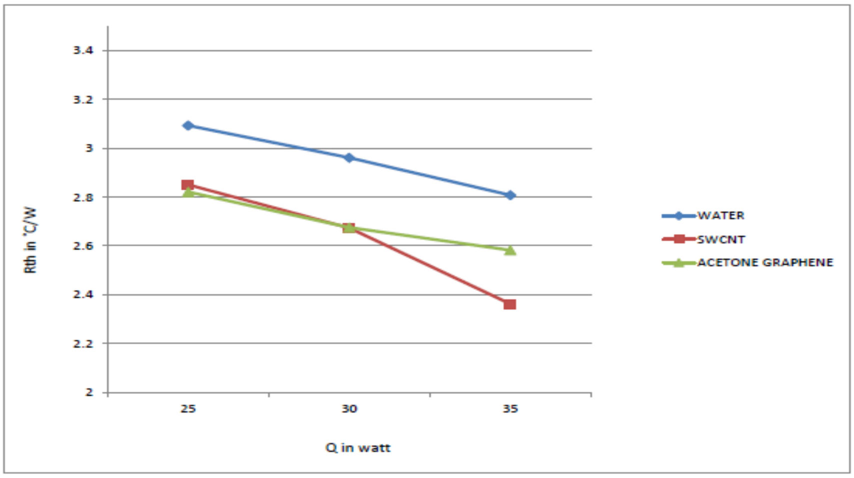

Figure 11. Thermal resistance plot for different fluids

The variation of Heat transfer coefficient with respect to heat input for different working fluids at a fill ratio of 50% is shown in Fig.12 It is seen that the Heat transfer coefficient increases with increase in heat input for the working fluids considered. SWCNT shows higher heat transfer coefficient values compared to water & Graphene. This is due to the lower values of temperature difference between evaporator and condenser for SWCNT

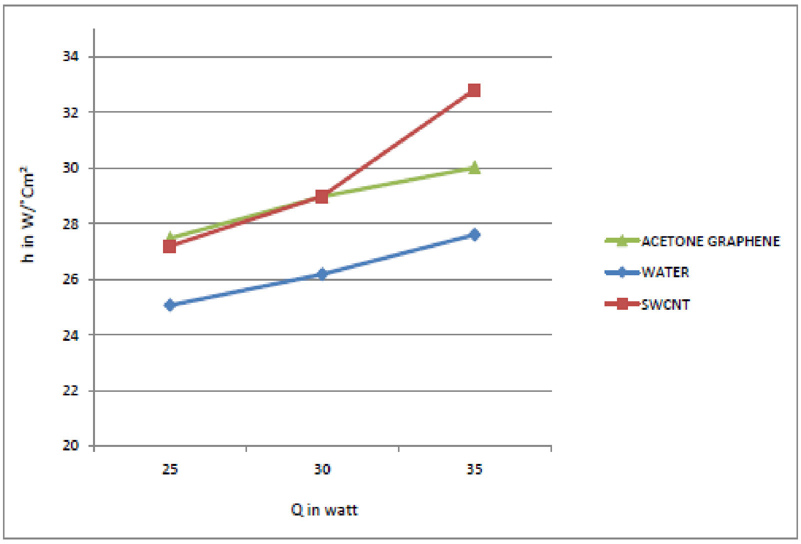

Figure 12. Heat transfer coefficient plot for different fluids

IV. CONCLUSION

In the present work, the experimental investigations are carried out on a multi turn loop OHP. The effects of heatinput, working fluid and fill ratio on the performance of OHP are studied.

Following conclusions are drawn from the present experimentation:

1. The variation of temperature difference between evaporator and condenser wall with time is found to be periodic.

2. The temperature difference between evaporator and condenser at steady state is found to be less for SWCNT compared to water & Graphene.
3. SWCNT and Graphene are observed to be more suitable working fluid for OHP operation under different operating conditions.
4. The results indicate that SWCNT can transfer more heat with less temperature difference and less thermal resistance. Thus SWCNT can be considered as more suitable working fluid for OHP operation.

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