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Experimental and Comparison Study of Heat Transfer Characteristics of Wickless Heat Pipes by using Various Heat Inputs

N. Mukilarasan[1], M. Varistus Anto Romilton[2], S Ismath[3], I. Venkatraman[4], R Vignesh[5]
[1]*Assistant Professor,* [2,3,4,5]*Students , Mechanical Engineering,*
Jeppiaar SRR Engineering College, Padur, Chennai – 603 103, Tamil Nadu,

Abstract*: A wickless heat pipe is a heat transfer device which combines the principles of both thermal conductivity and phase transition without the usage of wick structure. The heat pipe generally consists of three sections namely evaporator section, adiabatic section and condensation section. An apparatus set up consisting of four heat pipes made up of different materials namely Copper, Aluminium, Brass and Stainless steel along with heater and cooling duct was designed and fabricated. Various working fluids such as Acetone, Toluene, Ethanol and Dichloro methane are used to determine which among the above working fluids can be used efficiently in heat pipes to improve its performance. The heat inputs are varied from 80 W to 460 W to determine the efficient heat input for the heat pipes. Thus the experiment was carried out to study the thermal efficiency of the heat pipes by using different materials, different working fluids and different heat inputs. At the end of the experiments, copper was found to be the material with high thermal conductivity when compared to the other materials. Dichloromethane was found to be one of the most efficient working fluid to be used in heat pipes at the heat input range of 160 W.
Keywords: Heat pipe, heat transfer characteristics, working fluid inventory

I. INTRODUCTION

Heat pipe is a heat transfer device which transports large quantities of heat with minimum temperature gradient without any additional power between the two temperature limits. It consists of three different sections namely evaporator, adiabatic section and condenser section. These three parts have equal importance and can significantly affect the performance of a heat pipe [1]. The heat input is added to the evaporator section of the container, the working fluid present in the wicking structure which is kept in the container is heated until it vaporizes. Since the latent heat of evaporation is large, considerable quantities of heat can be transported with a very small temperature difference from end to end. Thus, the structure will also have a high effective thermal conductance. The high temperature and corresponding high pressure in the evaporator section cause the vapour to flow to the cooler condenser section, where the vapour condenses and releases its latent heat of vaporization. The capillary forces existing in the wicking structure then pump the liquid back to the evaporator [2]. The evaporator and condenser sections of a heat pipe function independently, needing only common liquid and vapour streams.

A mathematical model and its numeric solution for the laminar two-phase flow of liquid and vapor of working fluid in the capillary structure of micro heat pipes was investigated by Garcia et al. [3]. The mathematical model is formulated for steady state, one-dimensional flow for the vapor and quasi-one dimensional flow for the liquid. The relation between the maximum heat transfer capacity and the capillary pressure is analyzed. To verify the mathematical models, the results obtained are compared with data reported in the specialized literature.

Overheating of integrated circuit (IC), microchip etc. is a potential threat to the electronic components. It is very important to facilitate optimum cooling of electronic components in a smaller electronic device because integrated circuit lifetime depends on it [4]. An increasing market demand on powerful gadgets in smaller and smaller cabinets creates a trade off situation: either to enlarge the package to accept additional cooling or to sacrifice IC lifetime. This is a great challenge in thermal design management. Among other cooling techniques heat pipes emerge as the most appropriate technology and cost effective thermal design solution due to its excellent heat transfer capability, high efficiency and its structural simplicity [5].The heat transfer capability of the all heat transfer devices including heat pipe is limited by the working fluid transport properties [6]. To overcome these limitations, the thermo physical properties of the working fluid have to be improved. The heat transfer rate of heat transfer devices can be improved by adding additives to the working fluids to change the fluid transport properties and flow features. One of the methods is to use the aqueous solutions of alcohols, with chain lengths longer than four carbon atoms.

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The phenomenon of reducing the vapor temperature and thus reducing the maximum rate of heat transfer occurs in MHP if the condenser is cooled excessively [7]. And there appear significant effects caused by the entire length of a heat pipe and the effect by the capillary limit among operating limits of a heat pipe. The selection of the proper heat pipe cooling solution is dependent upon the developer's specifications, design constraints and budget [8].

Hence it is understood clearly that the performance of heat pipes vary depending upon the pipe materials, working fluids and heat inputs.

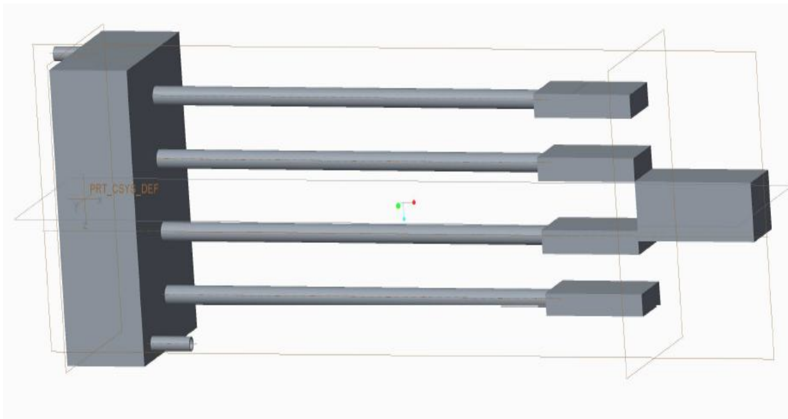

Figure 1 Schematic arrangement of experimental setup

II. DESIGN PARAMETERS

Outer diameter of pipe = 32 mm
Inner diameter of pipe = 29 mm
Thickness of pipe = 1.5 mm
Working fluids = Ethanol, Acetone, Toluene and Di chloro methane
Pipe materials= Copper, Aluminium, Brass and Stainless steel
Evaporator length = 100 mm
Condenser length = 100 mm
Adiabatic length = 800 mm
Cooling water temperature = 32^{o} C
Quantity of working fluid filled = 10 ml

III. EXPERIMENTAL PROCEDURE

The heat pipe generally consists of three sections namely, evaporating section, adiabatic section and condensation section. There are four RTDs in each pipes. One in the evaporating section, one in the condensation section and two in the adiabatic section. Thus the temperatures in the various sections of the pipes can be determined. In the evaporating section, band heaters are used to convert the working fluids into vapour. In the condensation section, water flow is used as the method to condensate the vapour into liquid. The rate of flow of water in the cooling duct is calculated. Also, the temperatures of the coolant at entry and exit are found out to determine the amount of heat transferred from the pipe to the cooling duct.

The band heaters are connected in parallel to supply same amount of heat supply with help of auto transformer. Ammeter and Voltmeter are used to calculate the amount of heat input to the pipes. The auto transformer is used to alter the voltage. Thus the required amount of voltage can be supplied.

The four pipes are filled with any one of the working fluids. All the four pipes should contain the same amount of working fluid. Then the band heaters are used to heat the working fluids. The voltage is set to 60 V. After a certain limit, the working fluid will start to evaporate in the evaporating section and will condensate in the condensing section. Then the temperatures at all the RTDs are measured. Then the heat input can be changed to 70 V and 80 V. The heat transfer characteristics at various heat inputs are calculated. Then the working fluids can be changed and the heat transfer characteristics of the working fluids are compared.

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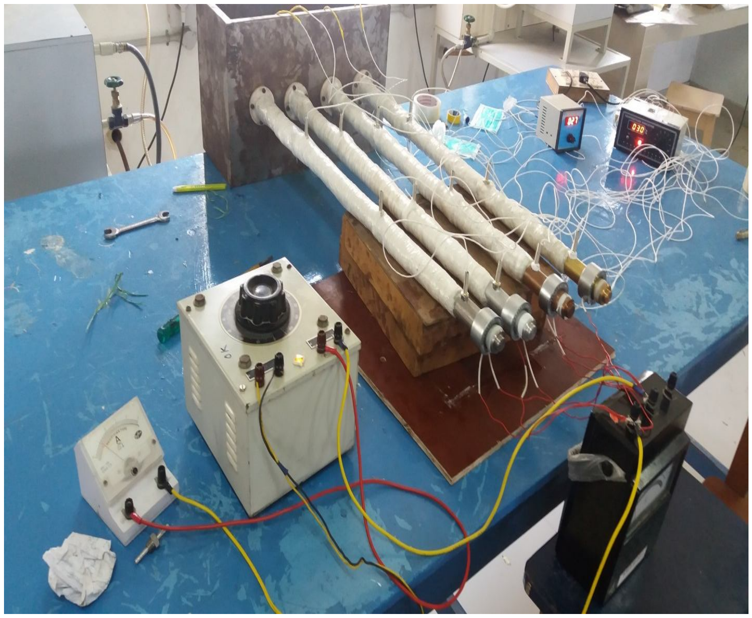

Figure 2 Experimental setup

IV. MATHEMATICAL EQUATIONS USED

Effectiveness of the heat pipe is indirectlybrought in terms of thermal resistance

R= $\frac{T_e - T_c}{Q}$ °C/W ------ (1)

And the overall heat transfer co-efficient is given by

h= $\frac{Q}{A(T_e - T_c)}$ W/m^2 °C ------- (2)

V. RESULTS AND DISCUSSION

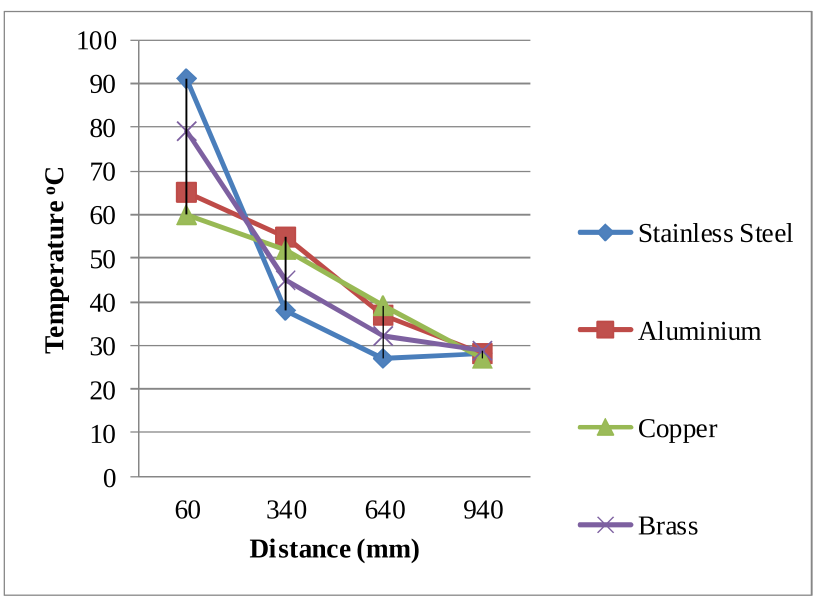

Fig. 3: Axial temperature profile of Ethanol at 80 W

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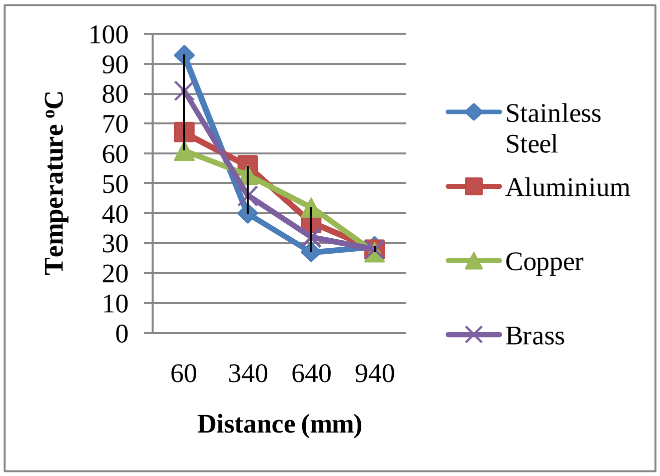

Fig. 4 Axial temperature profile of Ethanol at 108 W

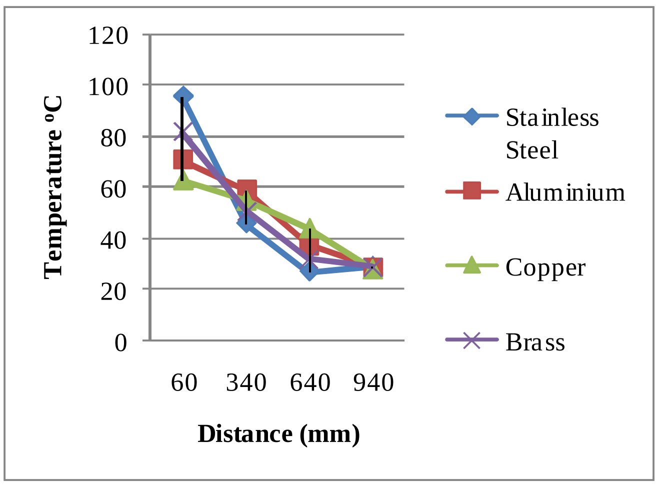

Fig. 5: Axial temperature profile of Ethanol at 140 W

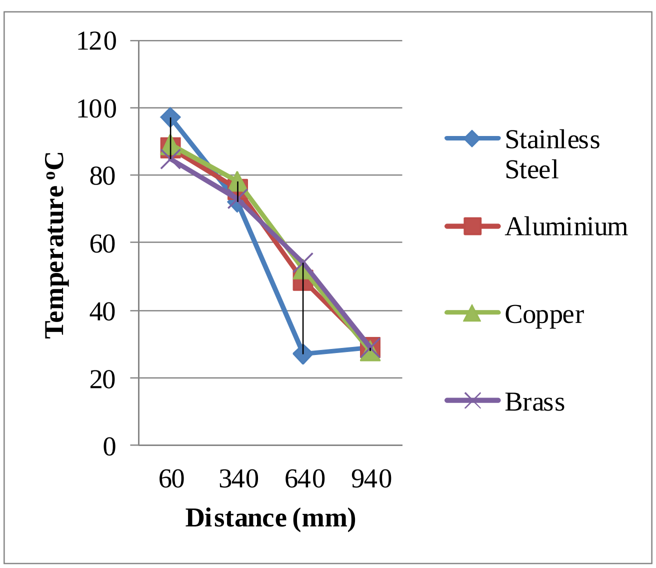

Fig. 6: Axial temperature profile of Ethanol at 176 W

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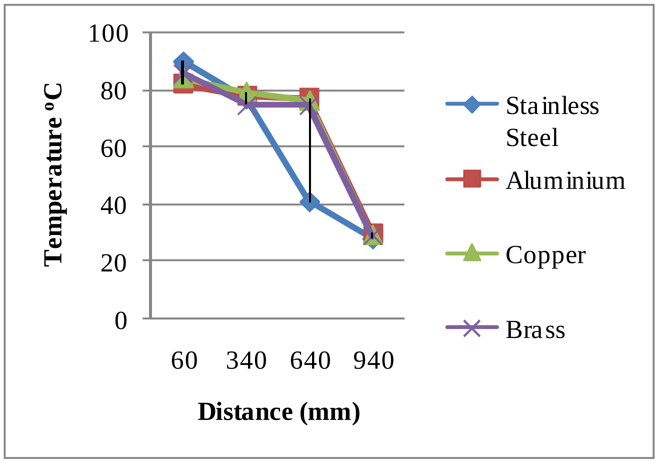

Fig. 7 Axial temperature profile of Ethanol at 416 W

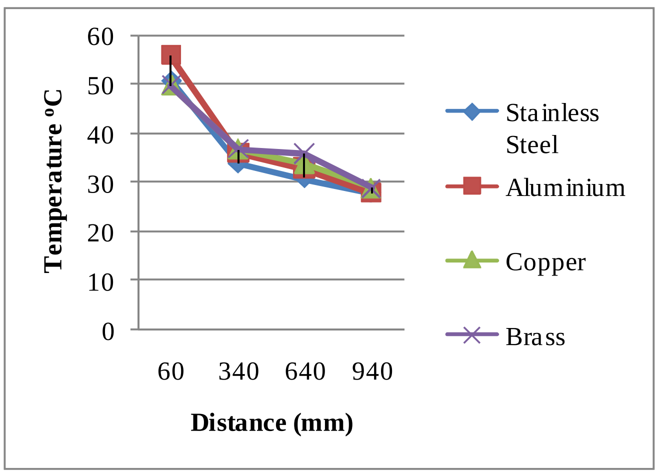

Fig. 8 Axial temperature profile of Dichloromethane at 80 W

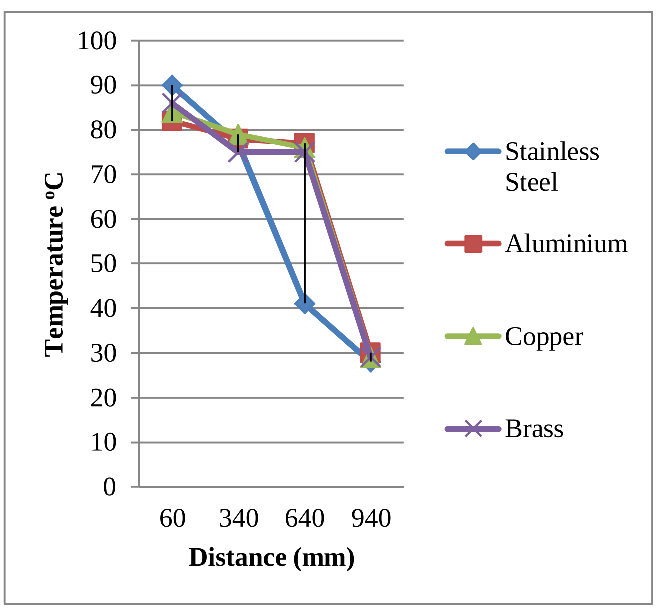

Fig. 9: Axial temperature profile of Dichloromethane at 108 W

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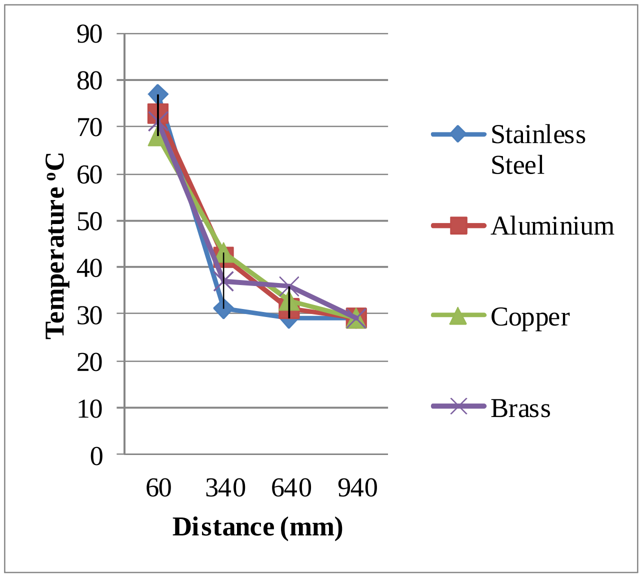

Fig. 10: Axial temperature profile of Dichloromethane at 140 W

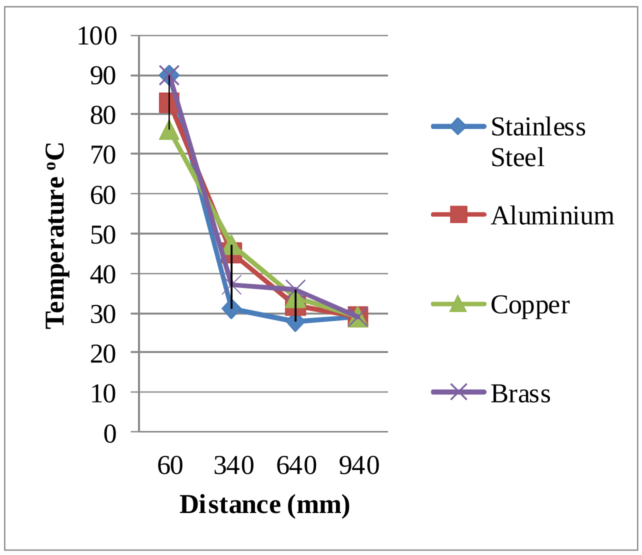

Fig. 11: Axial temperature profile of Dichloromethane at 165 W

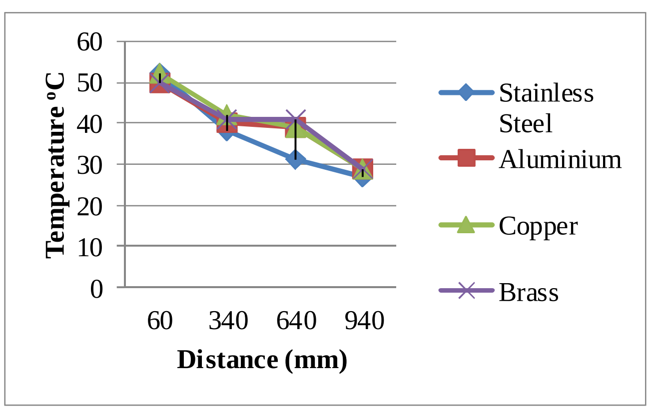

Fig. 12: Axial temperature profile of Dichloromethane at 416 W

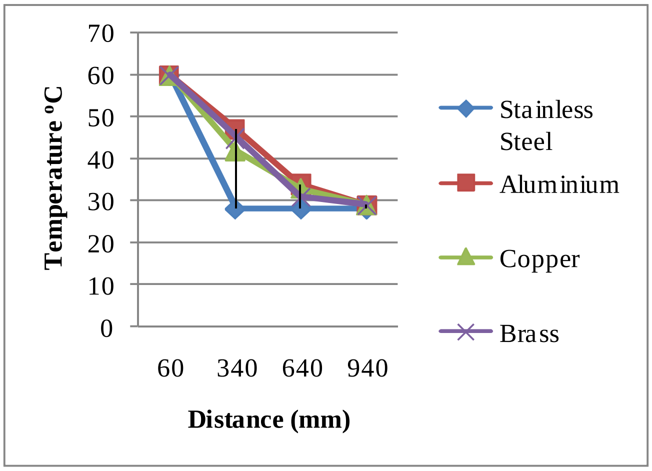

Fig. 13: Axial temperature profile of Acetone at 80 W

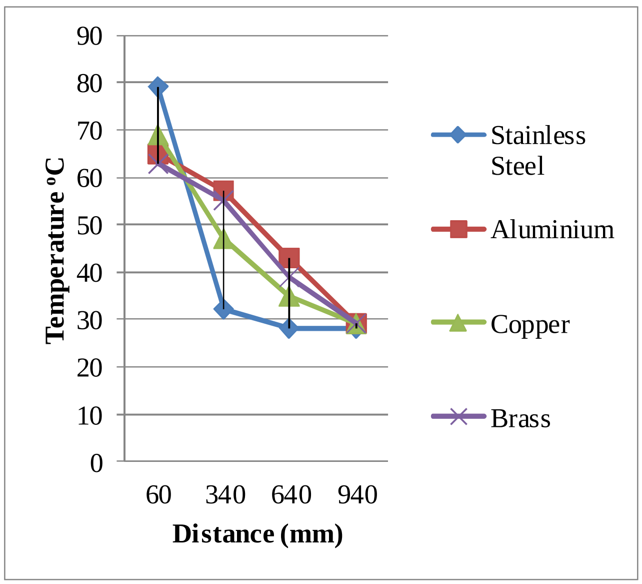

Fig. 14: Axial temperature profile of Acetone at 108 W

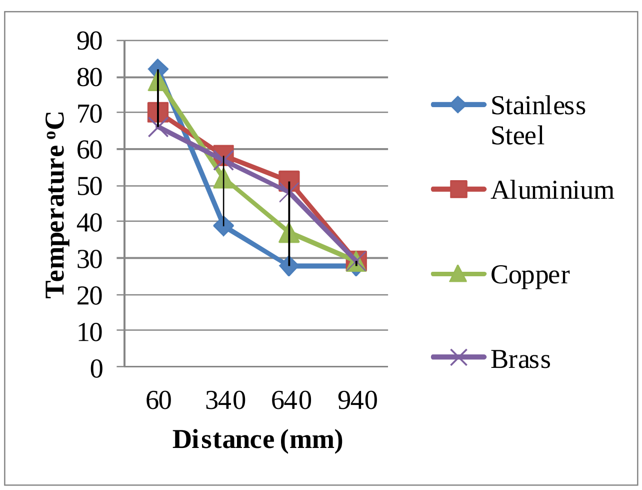

Fig.15: Axial temperature profile of Acetone at 150 W

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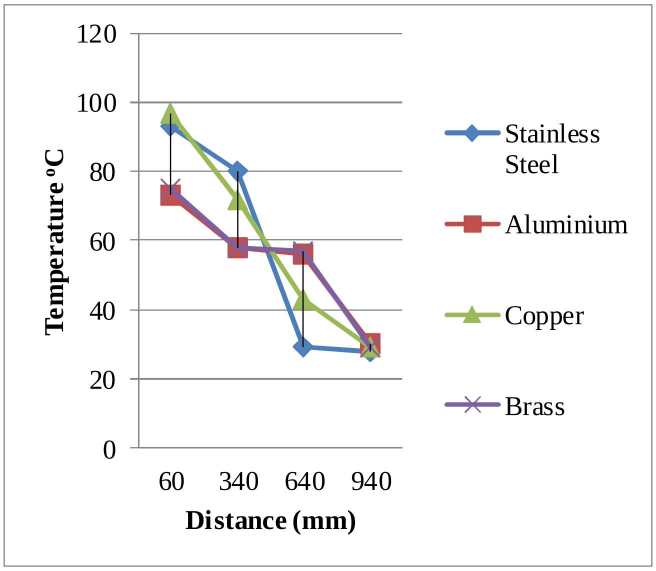

Fig. 16: Axial temperature profile of Acetone at 209 W

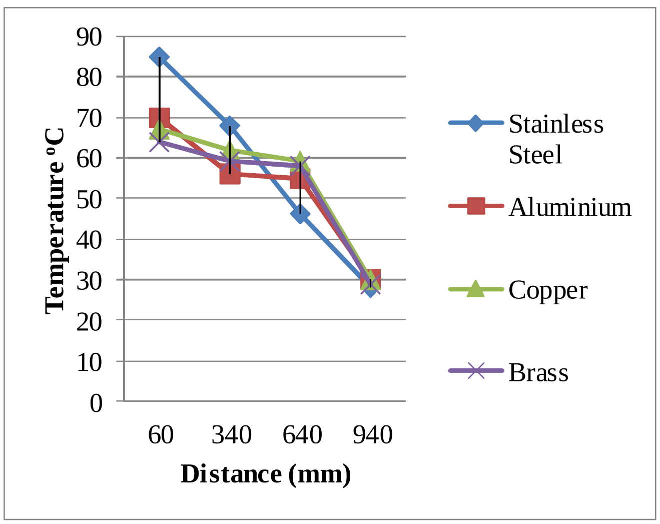

Fig. 17: Axial temperature profile of Acetone at 448 W

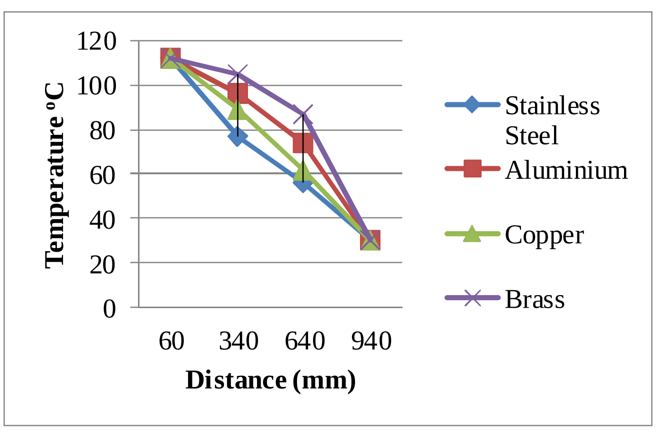

Fig. 18: Axial temperature profile of Toluene at 416 W

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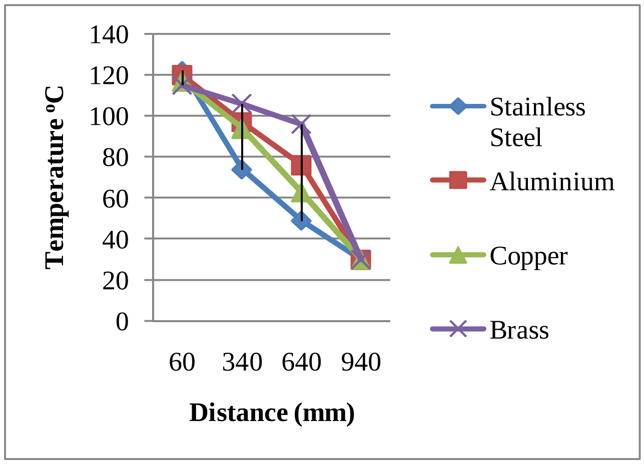

Fig.19: Axial temperature profile of Toluene at 476 W

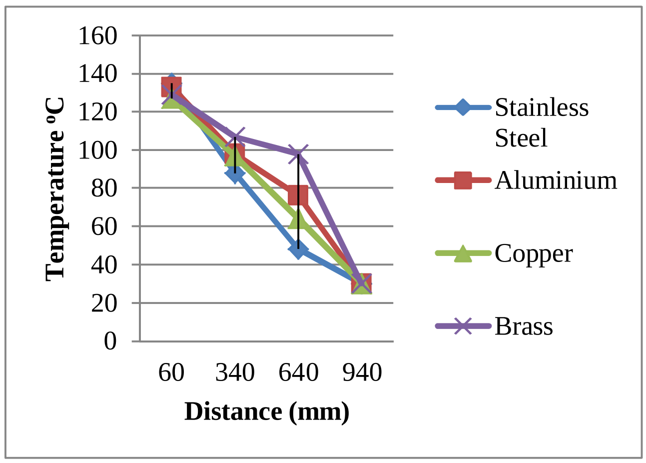

Fig. 20: Axial temperature profile of Toluene at 540 W

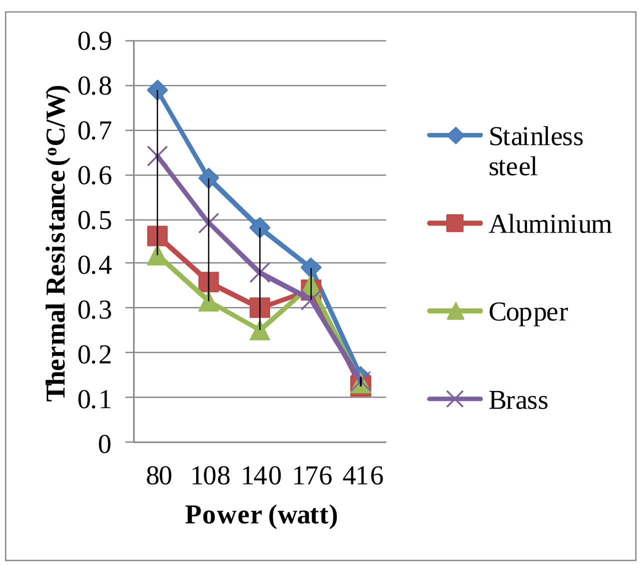

Fig.21: Variation of thermal resistance with different heat inputs while using ethanol as working fluid

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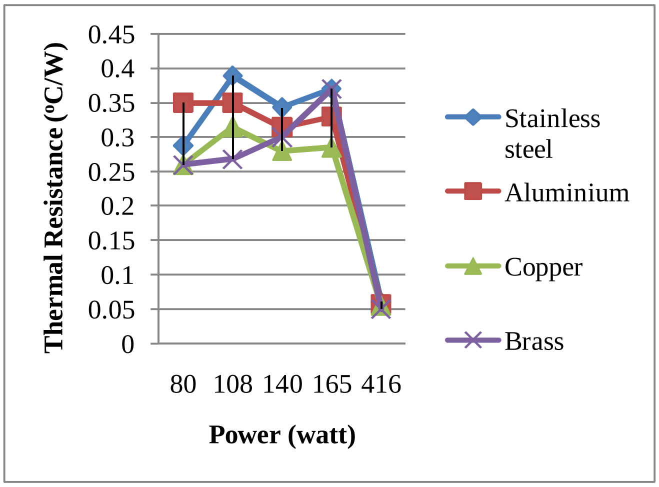

Fig. 22: Variation of thermal resistance with different heat inputs while using Dichloromethane as working fluid

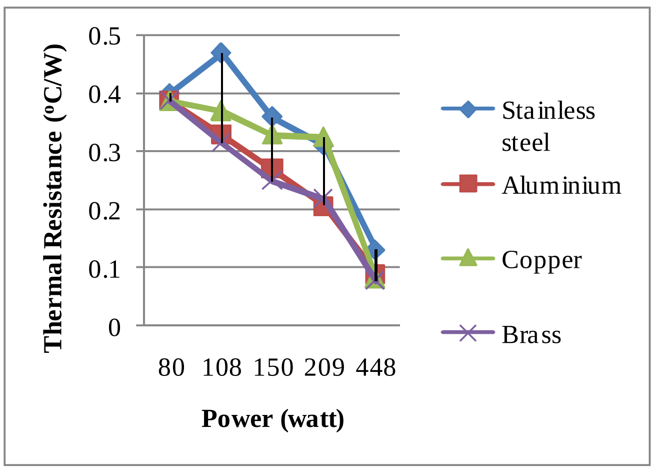

Fig. 23 Variation of thermal resistance with different heat inputs while using Acetone as working fluid

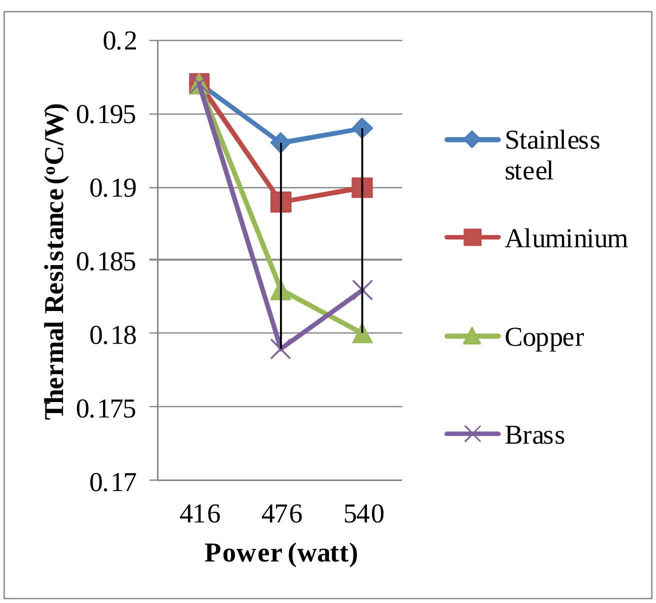

Fig. 24 Variation of thermal resistance with different heat inputs while using Toluene as working fluid

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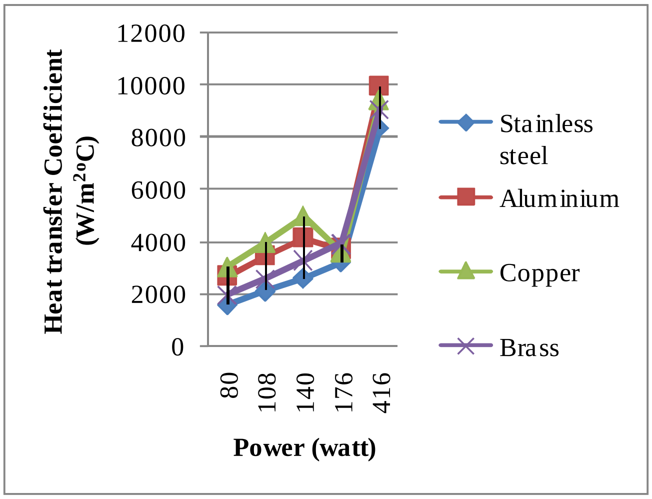

Fig. 25: Variation of heat transfer coefficient with different heat inputs while using Ethanol as working fluid

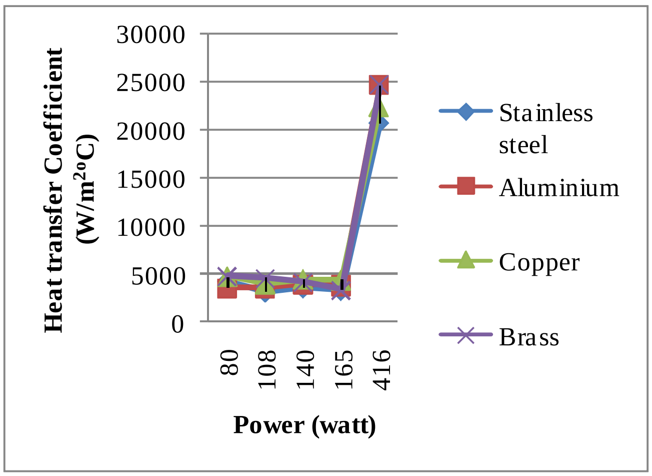

Fig. 26: Variation of heat transfer coefficient with different heat inputs while using Dichloromethane as working fluid

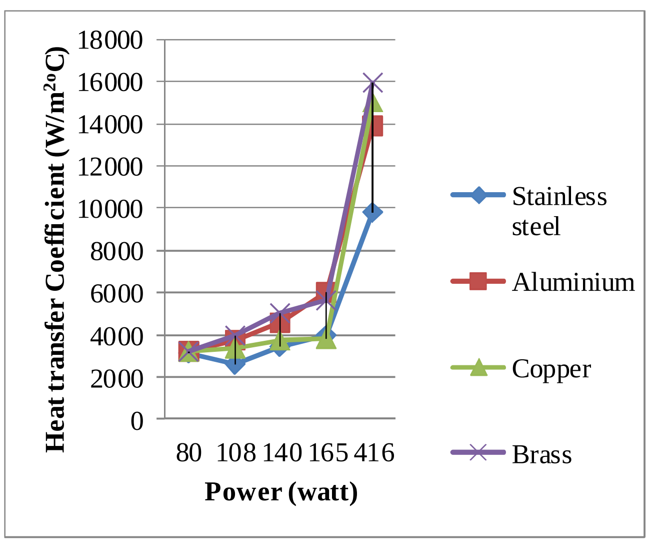

Fig. 27: Variation of heat transfer coefficient with different heat inputs while using Acetone as working fluid

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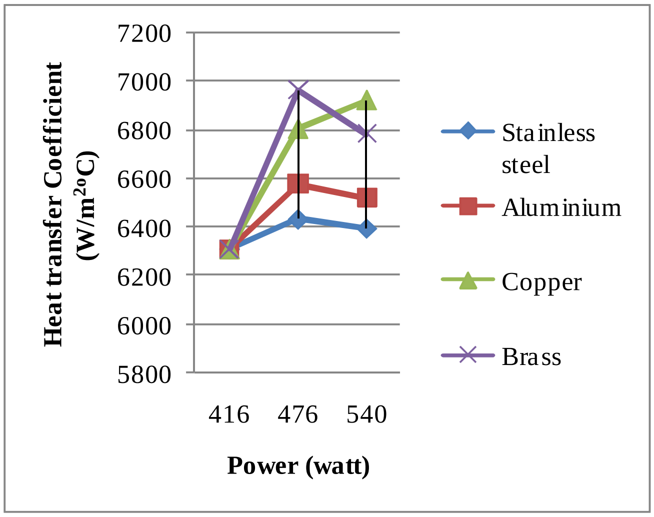

Fig. 28: Variation of heat transfer coefficient with different heat inputs while using Toluene as working fluid

VI. CONCLUSION

A setup consisting of four heat pipes made up of different materials has been successfully developed, fabricated and tested. Different operating characteristics are presented at different heat inputs from 80 W to 460 W. From the
investigation, the following findings are obtained:

A. The overall heat transfer coefficient of heat pipe increases with increase in heat input, in the range of inputs tested for Dichloromethane.
B. The pipe made up of copper shows better characteristics when compared to other materials.
C. The heat input of 160 V is proved to be the heat input where the heat pipe can work efficiently.
D. Aluminium is found to be the effective heat pipe while using Ethanol and Dichloromethane as the working fluids.
E. Brass is found to be the effective heat pipe while using Acetone as the working fluid.
F. Copper is found to be the effective heat pipe while using Toluene as the working fluid.

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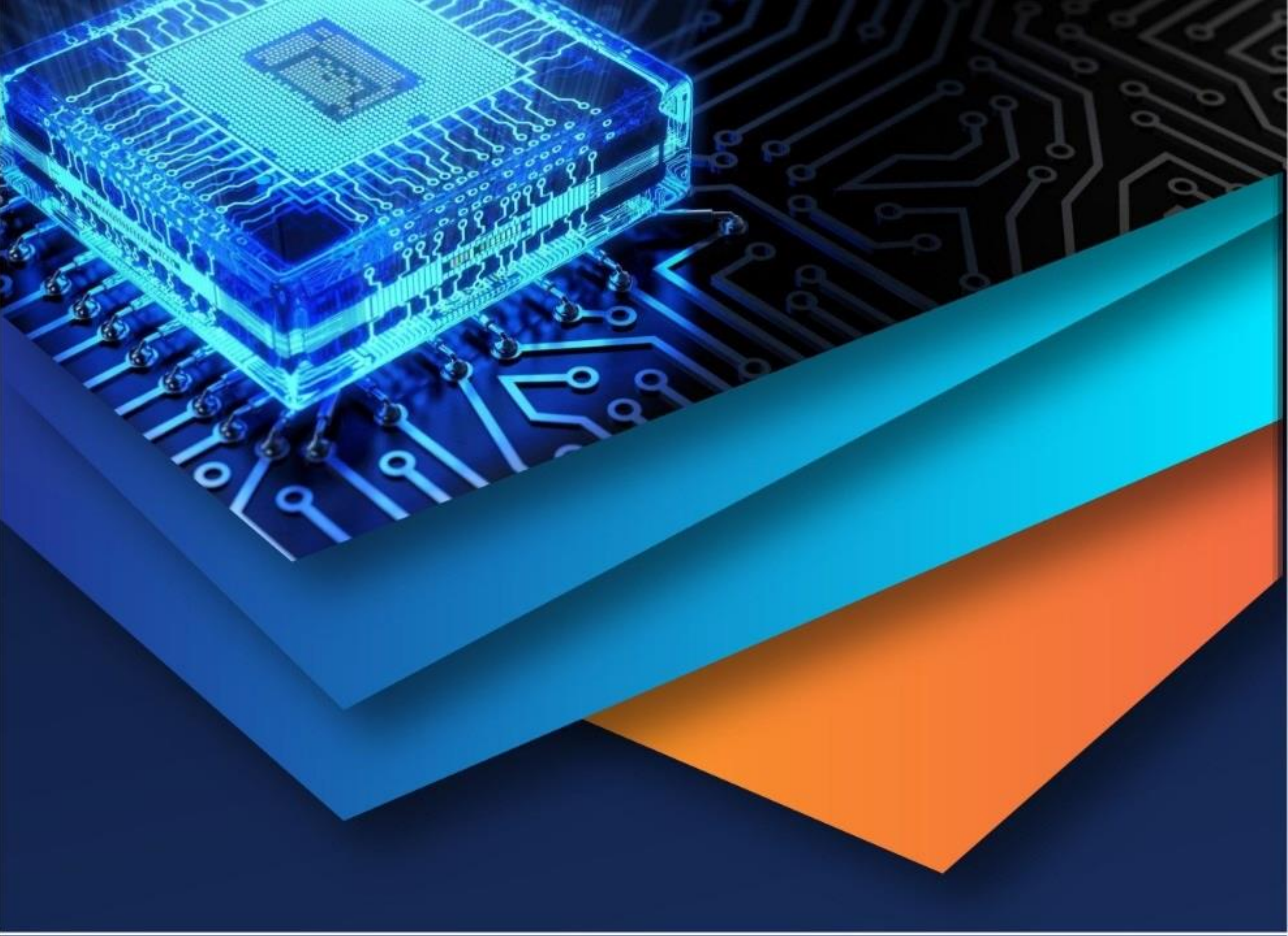

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