Performance Evaluation and comparison of a Stainless Steel Heat Pipe with still Water Jacket

K D Chaudhari
Assistant Professor, Department of Mechanical Engineering
R C Patel Institute of Technology, Shirpur, Maharashtra, India

B Y Patil
Assistant Professor, Department of Mechanical Engineering
R C Patel Institute of Technology, Shirpur, Maharashtra, India

N P Salunke
Head, Department of Mechanical Engineering
R C Patel Institute of Technology, Shirpur, Maharashtra, India

Abstract- An experimental test rig is designed and manufactured to evaluate the performance of a stainless steel heat pipe (HP). The HP is a horizontal stainless steel pipe lined with a three-layer stainless steel mesh wick. The evaporator section of the heat pipe is surrounded by single band heater posing as the heat source. The condenser is still cooling water jacket. Part of the HP is insulated. The filling ratio is constant at 0.75. Heat input is varied. The results show that the stainless steel heat pipe efficiency is 800 times that of stainless steel pipe and 200 times that of a copper pipe while maximum thermal conductivity of the stainless steel HP is about 1000 times that of a stainless steel pipe and 250 times that of a copper pipe of the same size.

Keywords – Heat pipe, Stainless steel, Thermal conductivity.

I. Introduction

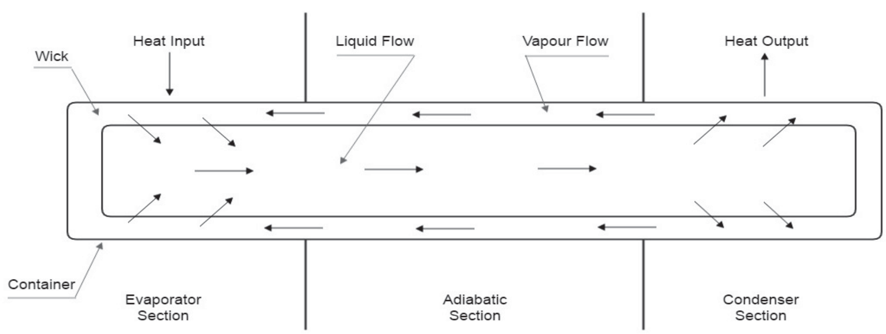

Figure 1. Schematic of a Heat Pipe.

The basic heat pipe is a closed container which contains a capillary wick structure and a small amount of working fluid. The fluid is saturated at operating conditions. The heat pipe uses a boiling-condensing cycle thus it transports heat in form of latent heat of vaporization. The capillary wick pumps the condensate to the evaporator. The vapor pressure drop between the evaporator and the condenser is very small; hence the boiling-condensing cycle is an isothermal process. Therefore, the heat pipe can be designed to transport large amount of heat between the heat source and the heat sink with very small temperature drop and small size- low weight structures. [1]

Heat pipes have been applied in cooling different electronics devices. Other applications include cooling of turbine blades, generators, motors. Heat pipes are used in heat collection from exhaust gases, solar and geothermal energy. In general, heat pipes have advantages over many traditional heat-exchange devices when heat has to be transferred isothermally over relatively short distances, low weight is essential and low maintenance is must. [2]

Heat pipes are also widely used in solar thermal water heating applications in combination with evacuated tube solar collector arrays and to dissipate heat alongside parts of the Qinghai–Tibet Railway where the embankment and track absorb the sun's heat. In heating, ventilation and air-conditioning systems, HVAC, heat pipes are positioned within the supply and exhaust air streams of an air handling system or in the exhaust gases of an industrial process, in order to recover the heat energy. Since the early 1990s, numerous nuclear reactor power systems have been proposed using heat pipes for transporting heat between the reactor core and the power conversion system. [3]

II. EXPERIMENTAL SETUP AND INVESTIGATION

A. Experimental Setup –

The apparatus has three pipes- Copper pipe, Stainless steel pipe and Heat pipe. Each pipe has outer diameter of 32 mm, inner diameter 28 mm and length of 340 mm. The heat pipe is lined with capillary structure of three layer stainless steel screen wire mesh. Each pipe is heated by electrical band heaters clamped on the evaporator. The heat input is varied using dimmer stat (300 V, 5 A). A Band heater (70 mm x 4 mm size, 230 Volt, 500 Watt each) is tightly mounted on outside surface of evaporator section of 100 mm. The heaters are surrounded by 20 mm thick wool cotton to reduce heat losses to the surrounding. Power input to heater is varied by variation of voltage in steps of 20 V from 60 V to 140 V. The heat input is evaluated from voltmeter and ammeter readings.

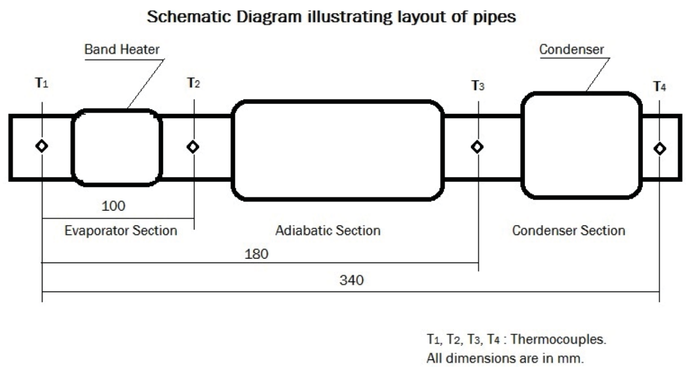

Figure 2. Schematic of a Heat Pipe.

Between the evaporator and condenser there is adiabatic zone. An adiabatic section is created using 20 mm thick layer of plaster of paris to stop heat losses. Other end of each pipe has still water tank of capacity 1 liter working as condenser. The heat output at condenser end is evaluated by using mass of water and recorded temperature of condenser water. Condenser water is stirred moderately for recording temperature. Calibrated chromel – alumel thermocouples of type K are used for temperature measurement. They are distributed around the entire length of each pipe. Four thermocouples are attached at each specified length on surface of the pipe. Each pipe thus has sixteen thermocouples. An electronic temperature indicator of range (0 - 300 ºC), with cold junction compensation is used to display temperature readings. All the observations of surface temperature are recorded with finite time interval till the arrival of steady state.

The heat pipe and mesh is cleaned with hydrochloric acid, acetone and distilled water, making perfect vacuum as far as possible. Calculated quantity of distilled water as working fluid is introduced in the heat pipe after cleaning the pipe is sealed after filling distilled water. Filling ratio used for this study is 75 %.

B. Experimental Investigations –

The Experimental work is conducted on Copper pipe, Stainless steel pipe and Stainless steel Heat Pipe at different heat input values. For each input temperature readings were recorded till steady state arrives. Average of four thermocouples at each junction like Heater end of pipe T_1, Evaporator section T_2, Adiabatic section T_3 and Condenser section T_4 is considered. Temperature of cooling water tank T_c is measured separately. For each set of readings, efficiency of each heat pipe is calculated as ratio of heat output at condenser tank to the heat input at evaporator end expressed as percentage. Thermal resistance of each pipe is calculated as the ratio of difference of temperature across evaporator and condenser to the heat input at evaporator in Kelvin per kilowatt.

III. Experiment Results

A. Temperature T_2 at Evaporator section against time for increasing heat input–

Following tables show Temperature T2 at Evaporator section against time for increasing heat input from 60 V to 140 V.

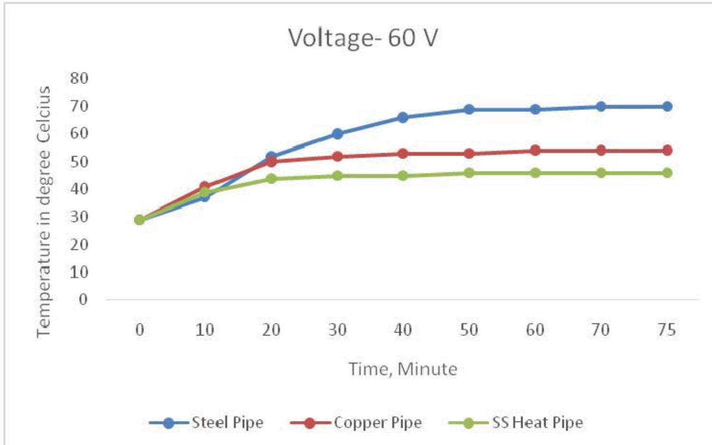

Table -1 Temperature T2 at Evaporator section against time for heat input at 60 V.

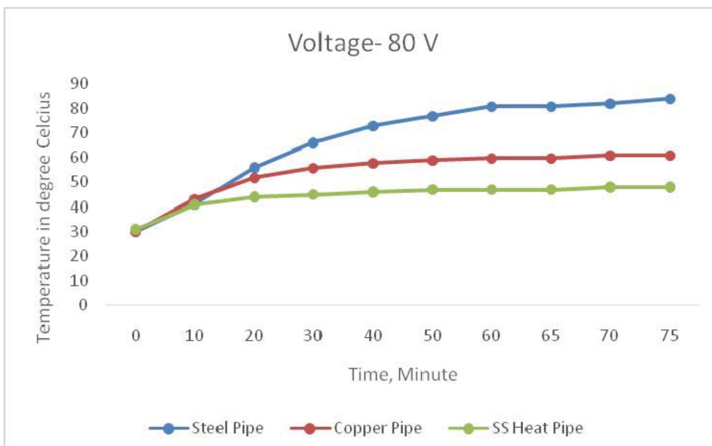

Table -2 Temperature T2 at Evaporator section against time for heat input at 80 V.

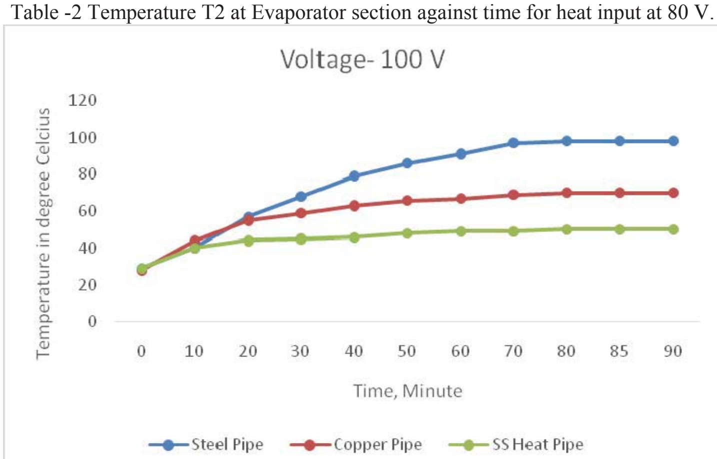

Table -3 Temperature T2 at Evaporator section against time for heat input at 100 V.

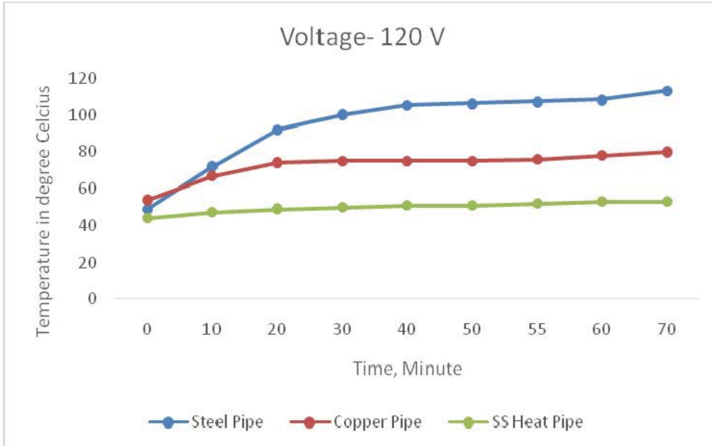

Table -4 Temperature T2 at Evaporator section against time for heat input at 120 V.

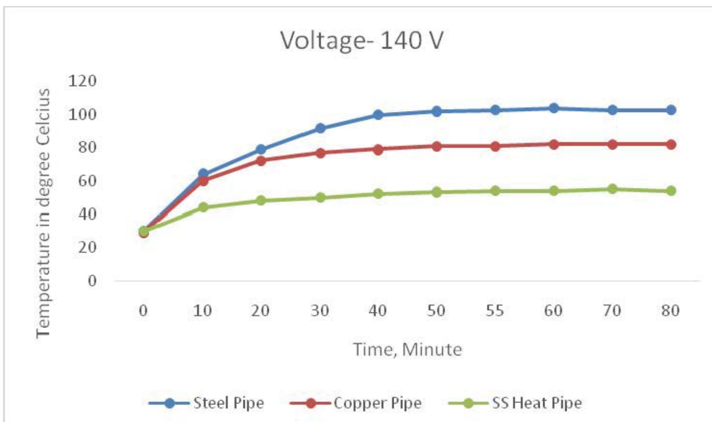

Table -5 Temperature T2 at Evaporator section against time for heat input at 140 V.

B. Temperature T_4 at Condenser section against time for increasing heat input–

Following tables show Temperature T4 at Condenser section against time for increasing heat input from 60 V to 140 V.

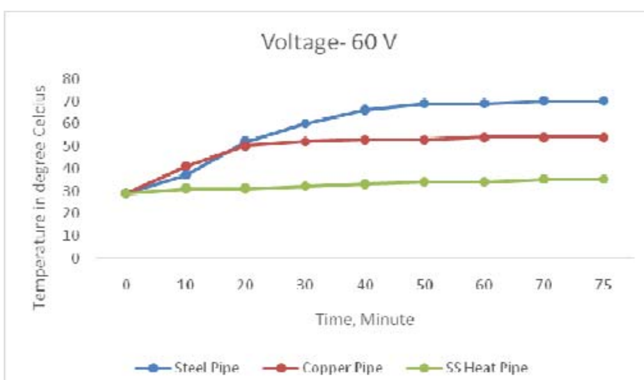

Table -6 Temperature T4 at Condenser section against time for heat input at 60 V.

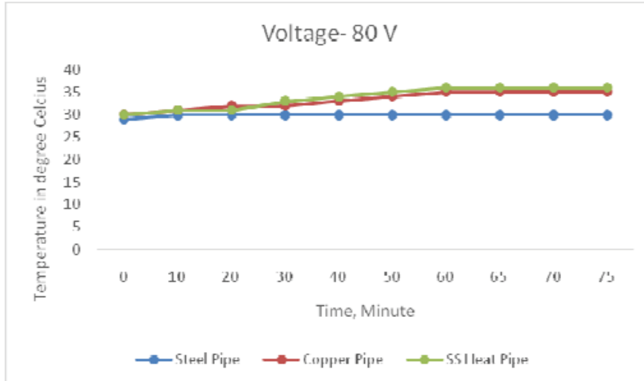

Table -7 Temperature T4 at Condenser section against time for heat input at 80 V.

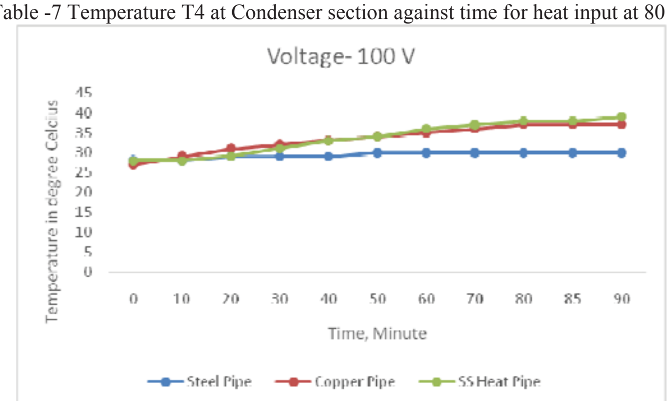

Table -8 Temperature T4 at Condenser section against time for heat input at 100 V.

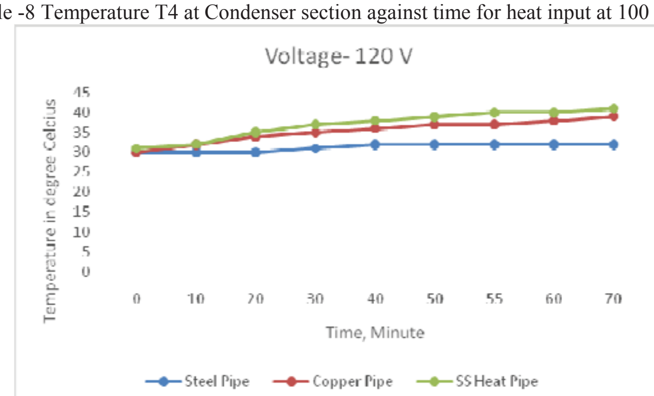

Table -9 Temperature T4 at Condenser section against time for heat input at 120 V.

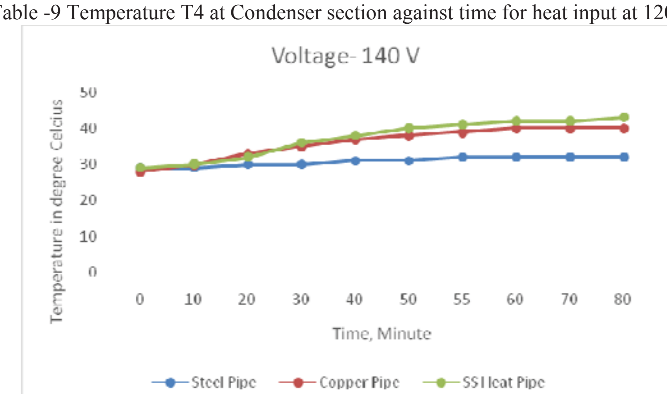

Table -10 Temperature T4 at Condenser section against time for heat input at 140 V.

C. Surface temperature distribution along het pipe for increasing heat input–

Following tables show Surface temperature distribution along length of heat pipe for increasing heat input from 60 V to 140 V.

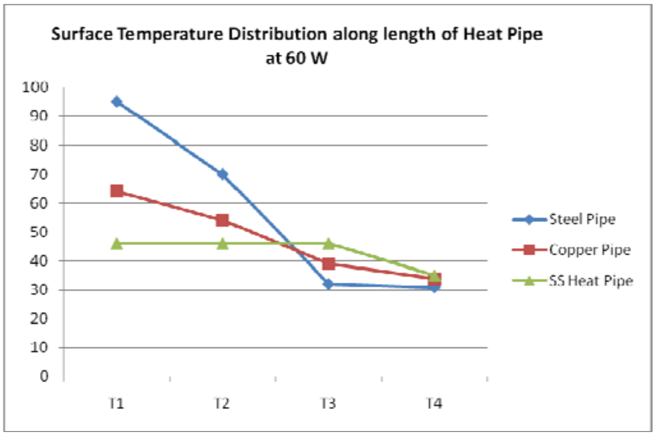

Table -11 Surface temperature distribution along length of heat pipe for heat input at 60 V.

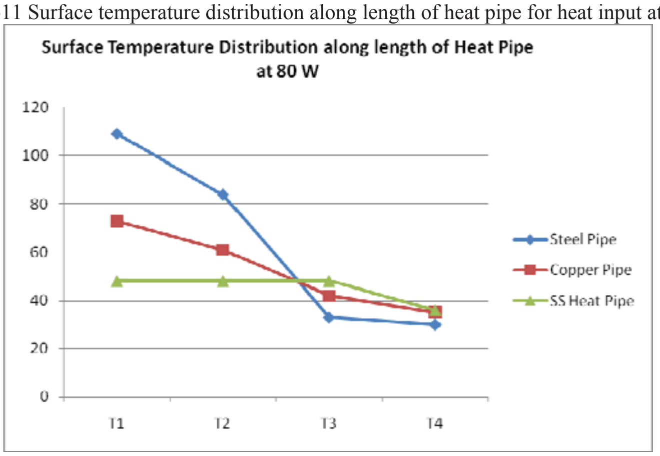

Table -12 Surface temperature distribution along length of heat pipe for heat input at 80 V.

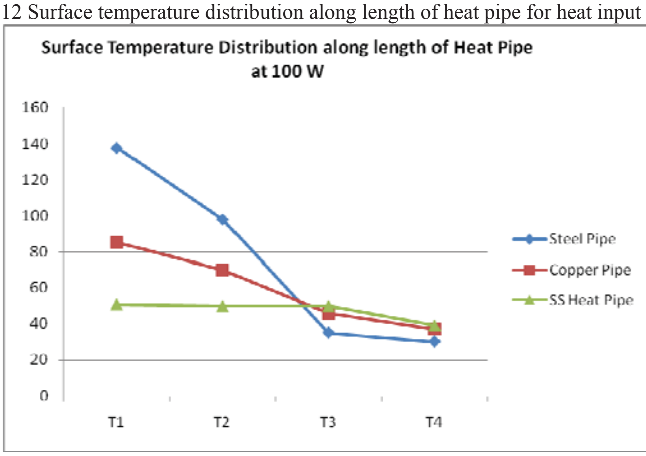

Table -13 Surface temperature distribution along length of heat pipe for heat input at 100 V.

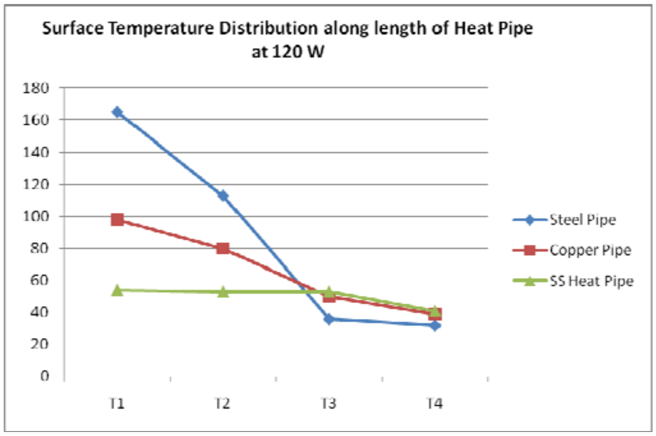

Table -14 Surface temperature distribution along length of heat pipe for heat input at 120 V.

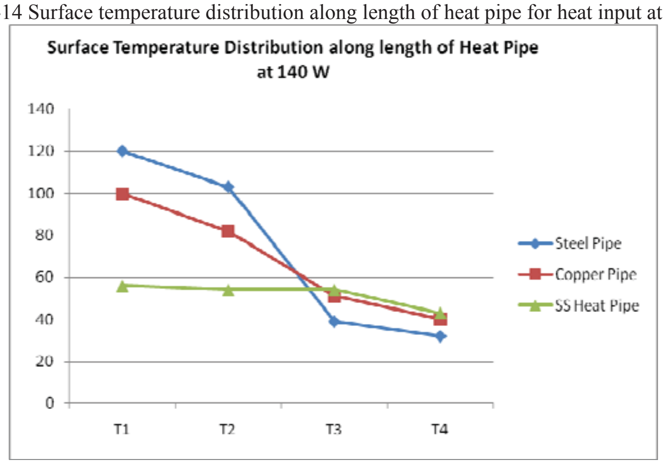

Table -15 Surface temperature distribution along length of heat pipe for heat input at 140 V.

D. Performance characteristic of heat pipe –

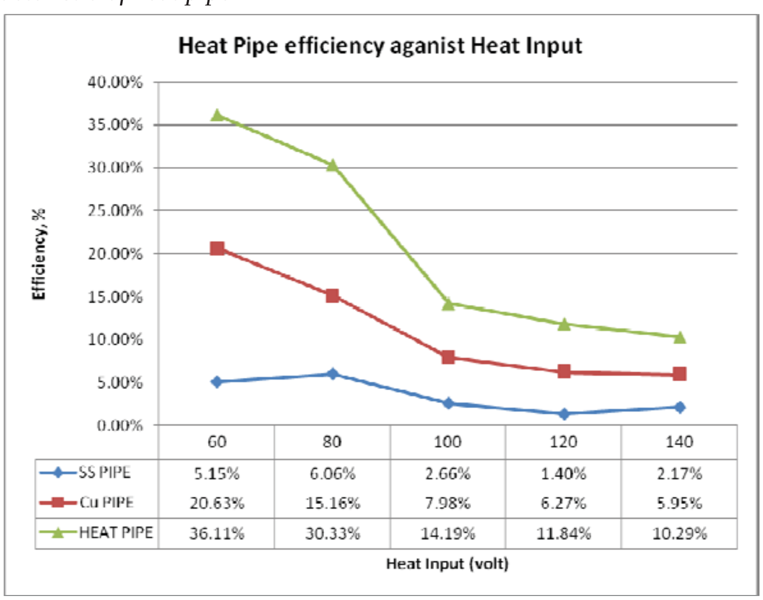

Table -16 Heat pipe efficiency against increasing heat input.

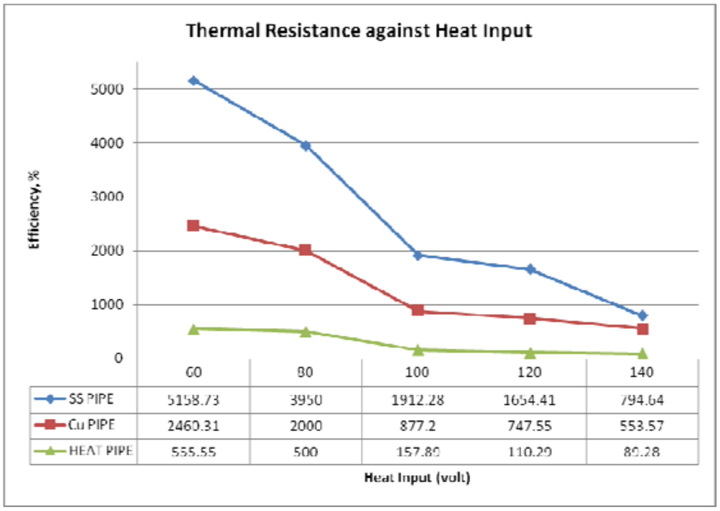

Table -17 Thermal resistance of Heat pipe against increasing heat input.

IV.CONCLUSION

From the present work, the following conclusions can be extracted:

1. The time required for achievement of steady state in terms of surface temperature distribution increases with the heat input. This time required is observed to be the minimum for stainless steel heat pipe.
2. The temperature distribution along the HP wall in the evaporator section is almost isothermal. The measured temperature along the condenser section shows lower values. This drop of temperature is expected because of the internal resistances due to boiling and condensation.
3. For all heat inputs it is found that the average temperature drop between evaporator and condenser sections is the maximum for stainless steel heat pipe.
4. The experimental results indicate that the stainless steel heat pipe efficiency is 800 times that of stainless steel pipe and 200 times that of a copper pipe under similar conditions. Maximum thermal conductivity of the stainless steel HP is about 1000 times that of a stainless steel pipe and 250 times that of a copper pipe of the same size.

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