International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 07 | July - 2022 Impact Factor: 7.185 ISSN: 2582-3930

DESIGN AND FABRICATION OF A LOOP HEAT PIPE USING ACTONE AS WORKING FLUID.

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Abstract

The growth and improvement of thermal heat transfer used in Engineering applications plays a beneficial role in recent days. Among these heat transfer devices such as heat pipes which are widely used in the fields of electronics, mechanical, refrigeration and air-conditioning, space crafts, boilers and so on are acting as a remedy to cool the devices which generates more heat transfer. Study about the thermal performance of any device working fluid, filling ratio, specific heat, thermal conductivity, material compatibility proves to be vital sources. This paper mainly highlights about the design and fabrication of heat pipe known as loop heat pipe and experimental investigation using traditional working fluid acetone to determine the heat transfer coefficient. Using acetone as working fluid the tthermal resistance at minimum heat input is 1.1 ^{o}C/w, and when heat input increased to 60watt, thermal resistance decreased to 0.2 ^{o}C/w. The heat pipe orientation and heat input are one of the parameters have significant effects on the thermal performance of the loop heat pipe. The results from the above investigation concludes that acetone is suitable working fluid to perform the thermal heat transfer operations, helps to transfer the heat and cool the devices.
Keywords**:** Working fluid, Copper, Acetone, Thermal Resistance, Thermal Conductivity.

1. Introduction

Loop Heat Pipes are one of the emerging technologies which is used to transfer heat from source to sink. The application of loop heat pipes (LHPs) [1] used in many electronic devices such as laptop cooling, locomotives and so on. Issues related to design, fabrication of loop heat pipe and use of hazardous working fluids such as ammonia are still a concern. Research work is being carried out using traditional working fluid and on nano fluids, hybrid nano [4,6] fluids as the thermal conductivity plays an important role. Different types of heat pipes exist, few of them are pulsating heat pipes, cylindrical heat pipes, loop heat pipes, rotating heat pipes and etc. Among them loop heat pipe is opted to design and study the thermal performance of the device. Loop heat pipe (LHP) a two-phase thermal management device, usually applied in the thermal control of satellites, space crafts, electronics and structures, and operates by acquiring heat from a source and dissipating it in a sink.

It is considered a reliable thermal control device as it can dissipate large amounts of heat while keeping a tight control of the heat source temperature. The components of an LHP are a capillary evaporator, condenser, liquid and vapor lines and a compensation chamber (or two-phase reservoir). In this project, it is proposed to design and fabricate a loop heat pipe (LHP) and investigate the thermal performance of the device using traditional working fluids acetone.

2. Heat Pipe and Its Types

A heat pipe is a heat-transfer device that employs phase transition to transfer heat between two solid interfaces. Working fluids are chosen according to the temperatures at which the heat pipe must operate, with examples ranging from liquid helium for extremely low temperature applications (2–4 K) to mercury (523–923 K), sodium (873–1473 K) and even indium (2000–3000 K) for extremely high temperatures [2]. Heat pipes are classified into different types based on the design, performance, applications. Loop Heat Pipes/Capillary Pumped Loop, Thermo syphon, Pulsating Heat Pipes, Micro-heat Pipes (MHPs), Constant Conductance Heat Pipes (CCHPs), Variable Conductance Heat Pipes (VCHP) [3]. In this paper a closed loop heat pipe is selected to determine the heat transfer coefficient for traditional working fluids.

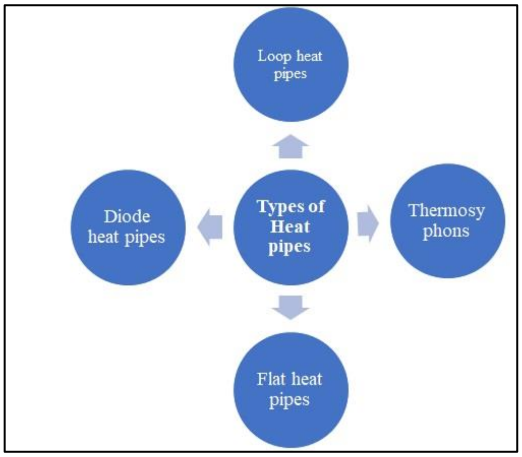

Figure 1: Types of Heat Pipes

2.1 Loop Heat Pipe Working

A loop heat pipe (LHP) is a passive two-phase transfer device related to the heat pipe. It can carry higher power over longer distances by having co-current liquid and vapor flow [2], in contrast to the counter-current flow in a heat pipe. This allows the wick in a loop heat pipe figure 2, to be required only in the evaporator and compensation chamber. Micro loop heat pipes have been developed and successfully employed in a wide sphere of applications both on the ground and in space.

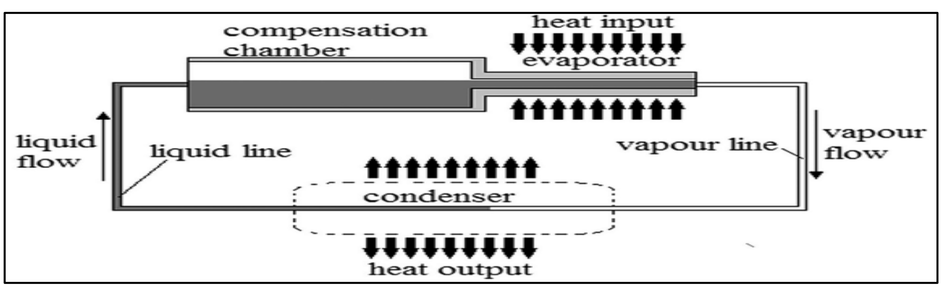

Figure 2: working of Loop Heat Pipe

The operation of a LHP is based on the same physical processes as those of conventional heat pipes. The LHP [3] consists of a capillary pump (also called evaporator), a compensation chamber (also called reservoir), a condenser, and vapor and liquid transport lines [4]. Only the evaporator and the compensation chamber contain wicks the rest of the loop can be made in smooth tubing.

3. Design and Fabrication of Loop Heat Pipe (LHP)

3.1 Experimental Investigation of Loop Heat Pipe

3.1.1 Selection of Materials For LHP

By taking thermal conductivity and specific heat of metal as a parameter, the metals are selected. Thermal conductivity [2] of different material are given in the table 1 below. From the table we can choose copper as a base material.

Table 1 - Material selection

Solid/Liquid	Material	Thermal Conductivity (W/mk)
Metallic Solid	Silver	429
Metallic Solid	Cooper	401
Metallic Solid	Aluminum	237
Non-metallic solid	Diamond	3300
Non-metallic Liquid	Carbon nanotube	3000
Non-metallic Liquid	Silicon	1458

From the above table 1, copper is considered as base material, since copper is having highest thermal conductivity and low specific heat.

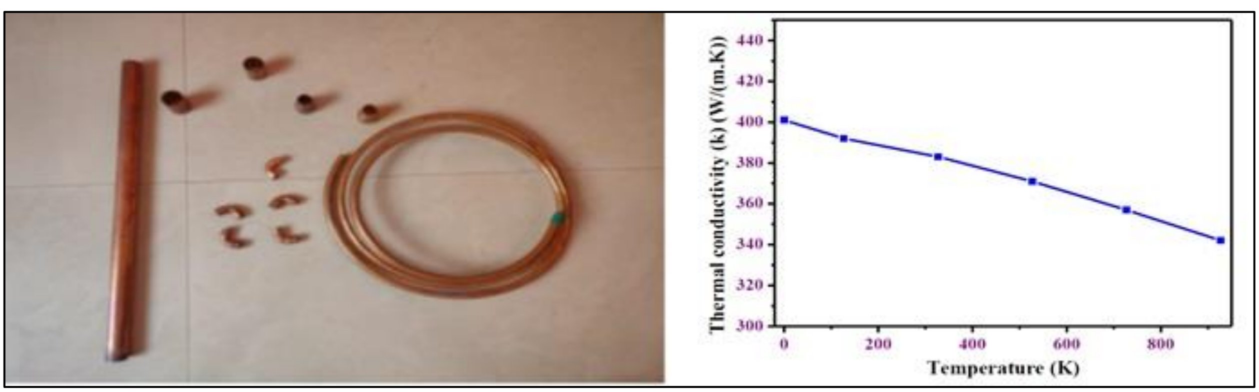

Figure 3: Copper Material Selection Based on Thermal Conductivity

3.1.2 Selection of Wick Structure

Loop heat pipe requires two wick structures. primary wick structure and secondary wick structure:

PRIMARY WICK STRUCTURE

Material Type: Copper

Thermal conductivity: 401w/mk

Specific Heat: 390J/kgK

Wire Diameter: 0.1143mm

SECONDARY WICK STRUCTURE

Material Type: Stainless Steel

Thermal Conductivity: 16 w/mk

Specific Heat: 502 J/kgK

Wire Diameter: 0.1143mm

3.1.3 Selection of Working Fluid

The selection of the working fluid determines the thermal performance of the heat pipe. For the desired operating temperature range several potential working fluids may exist, so other factors have to be taken into consideration in order to choose the most acceptable fluid [4] for the given application. Parameters such as heat transfer capabilities, good thermal stability, wettability, optimum vapor pressure, high latent heat and the compatibility of the fluid [5] with the case and wick material of the heat pipe play a significant role in the determination of the appropriate working fluid. The last factor has to be carefully considered as non-compatibility of materials can decompose the working fluid, which will lead to corrosion and chemical reactions of the non-condensable gases causing the failure of the heat pipe. The Working Fluids are Categorized into Two Types they are Traditional Working Fluids and Nano Fluids. The working fluid compatibility of the heat pipe is shown in the table 2.

Table 2: Heat pipe compatibility and Working Fluid Selection

Working Fluid	**Compatible Material**	**Incompatible Material**
Water	Stainless steel, Copper, Silica, Nickel, Titanium	Aluminium ,Inconel
Ammonia	Aluminium, Stainless steel, Cold rolled steel, Iron, Nickel	Copper
Methanol	Stainless steel, Iron, Copper, Brass, Silica, Nickel	Aluminium
Acetone	Aluminium, Stainless steel, Copper, Brass, Silica,	
Freon-11	Aluminium	
Freon-21	Aluminium. Iron	
Freon-113	Aluminium	

Heptane	Aluminium	
Dowt berm	Stainless steel, Copper, Silica	
Lithium	Tungsten, Tantalum, Molvbdenum, Niobium	Stainless steel, Nickel, Inconel, Titanium
Sodium	Stainless steel, Nickel, Inconel, Niobium	Titanium
Cesium	Tantalum, Niobium	Molybdenum, Nickel, Tantalum, Inconel, Titanium, Niobium
Mercury	Stainless steel	Stainless steel, Nickel, Inconel, Titanium, Niobium
Lead	Tungsten, Tantalum	Stainless steel, Nickel, Inconel, Titanium, Niobium
Silver	Tungsten, Tantalum	Rhenium

From the above table it is understood that the acetone is suitable as a working fluid to investigate the heat transfer coefficient, since the boiling point of acetone is very less when compared to the water. Acetone or propone, is an organic compound with the formula $(CH3)_2CO$. It is the simplest and smallest ketone. It is a colorless, volatile, flammable liquid with a characteristic odor. Acetone is miscible with water and serves as an important solvent in its own right, in industry, home, and laboratory.

4. EXPERIMENTAL LOOP HEAT PIPE WITH ACETONE AS WORKING FLUID

4.1 Working Fluid Properties of Acetone

The working fluid selected is further estimated to determine the thermal resistance at a particular heat applied, and time with respect to temperature at varying heat input.

Table 3: Properties of Acetone Working Fluid

Property	Value	Unit	Value	Unit
Auto ignition temperature	738	K	465	°C
Boiling Point	329.2	K	56.08	°C
Critical density	4.70	mol/dm^3	273	kg/m^3
Critical pressure	4.69	MPa=MN/m^2	46.9	Bar
Critical temperature	508.1	K	235.0	°C
Critical volume	213	cm^3/mol	0.00366	m^3/kg
Density	13507	mol/m^3	784.5	kg/m^3
Flammable, gas and liquid	Yes			

Gas constant, individual – R	143.2	J/kg K	0.03977	Wh/(kg K)
Specific heat capacity Cp (gas)	75.0	J/mol K	1.29	kJ/kg K
Specific Heat capacity, Cp (liquid)	124.5	J/mol K	2.14	kJ/kg K
Specific Volume	0.0000740	m^3/mol	0.00127	m^3/kg
Surface tension	23.1	dynes/cm	0.02308	N/m
Thermal Conductivity	0.18	W/m °C	0.104002	Btu/hr ft °F

4.2 Design Considerations of Loop Heat Pipe

The loop heat pipe design considerations are as mentioned in the table 4 below

Table 4: Properties of Acetone Working Fluid

Working Fluid	**Acetone**
Designed Temperature range	5 to 75 °C
Evaporator	Copper
Heated Length	100 mm
Wall Thickness	1 mm
Primary Wick	Copper wire mesh
Outer Diameter	22 mm
Inner Diameter	21 mm
Length	110 mm
Compensation chamber	copper
Inner diameter	21 mm
Length	40 mm
Vapor line	Copper
Line inner diameter	7 mm
Line length	30 mm
Wall thickness	1 mm
Liquid line	Copper
Line inner diameter	7 mm
Line length	30 mm

4.2.3 Loop Heat Pipe, Thermal Resistance vs. Temperature

On increasing the heat input i.e., by increasing the temperature the thermal resistance is going todecreased.

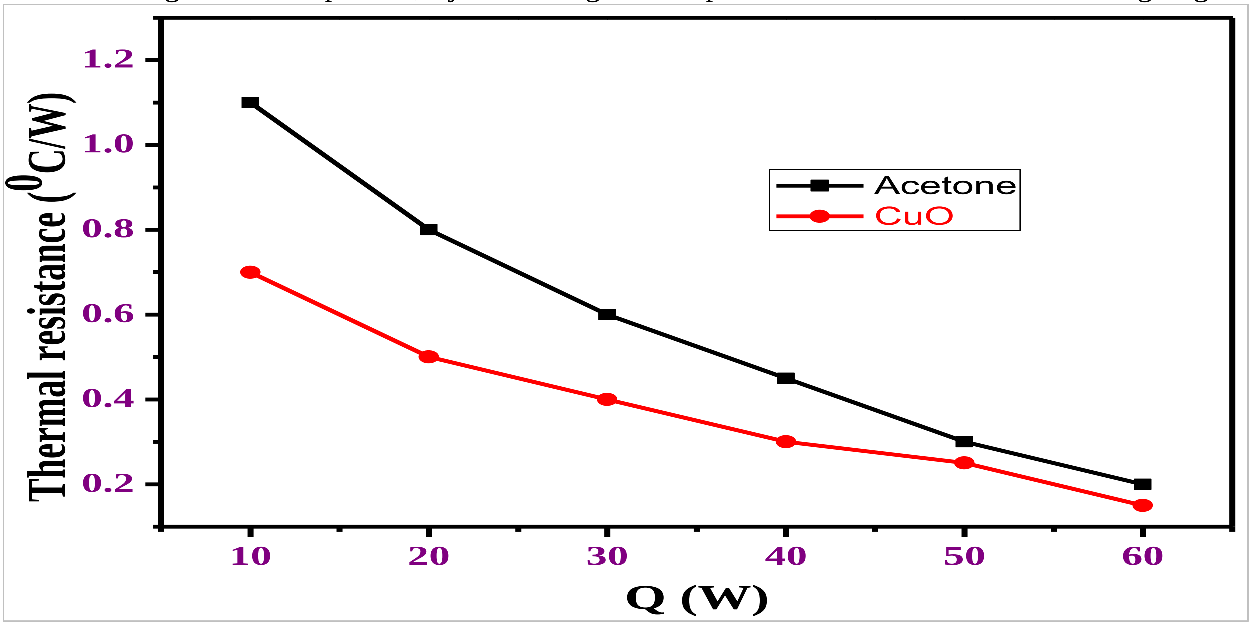

Fig 4: Heat input(Q) vs Thermal resistance (R)

From the above graph (fig.4) it was observed that, increase in heat input causes the decrease in thermal resistance, it means heat input and thermal resistance are inversely proportional to each other. When acetone is used as working fluid thermal resistance at minimum heat input is 1.1 ^{o}C/w, and when heat input increased to 60watt, thermal resistance decreased to 0.2 ^{o}C/w.

5. Acknowledgement
This article made possible with the support of the Department of Mechanical Engineering, Thermal Engineering laboratory. I would also like to thank the institute Raghu Engineering College (Autonomous) for giving permission to design and fabricate the loop heat pipe in heat transfer laboratory. Overall our heartful thanks to Raghu educational institutions for providing its best sources to carry our research-oriented experimentations and supported us to carry out the work.

6. Conclusions
The traditional working fluid acetone was opted investigated experimentally by varying with thermal conductivity and thermal resistance. It is observed that LHP which is filled with acetone as working fluid is compatible with copper, and the boiling point is also in the margin. The graphs represent that the using acetone as working fluid the tthermal resistance at minimum heat input is 1.1 ^{o}C/w, and when heat input increased to 60watt, thermal resistance decreased to 0.2 ^{o}C/w. The heat pipe orientation and heat input are one of the parameters have significant effects on the thermal performance of the loop heat pipe. As the heat input is increased, the temperature differential is also increased. However, the thermal resistance, thermal conductivity and heat transfer varies with the change in heat inputs. The results from the above investigation concludes

that acetone is suitable working fluid to perform the thermal heat transfer operations, helps to transfer the heat and cool the devices.

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