Fabrication And Analysis Of Heat Pipe

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Abstract

The heat pipe is a device having a high thermal conductance which utilizes the transport of a vapours and rejection of latent heat to achieve efficient thermal energy transport. The theory of heat pipes is well developed. These are use in applications involving temperatures in the cryogenic regime, and with development units running as high as 2000 degrees C, shows that they can function over a large part of the temperature spectrum. Applications in spacecraft, electronics and die casting are few of the uses for these devices. Two types of heat pipes were studied experimentally using Ammonia as a working fluid, two aluminium pipes one with a wick and another with no wick. The wick used here is made of screen mesh. The heat pipes are positioned at same angles in the horizontal direction. Now the experimental analyses of the two pipes are done and finally the temperature distribution and heat transfer are submitted.

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1. INTRODUCTION

Heat transfer is a science that studies the energy transfer between two bodies due to temperature difference. There are three types or modes of heat transfer:
a. Conduction
b. Convection
c. Radiation

a. Conduction

Conduction is a mode of heat transfer that occurs when there is a temperature gradient across a body. In this case, the energy is transferred from a high temperature region to low temperature region due to random molecular motion – diffusion. Higher temperatures are associated with higher molecular energies and when they collide with less energetic molecules the transfer of energy occurs.

The simplest conduction heat transfer can be described as “one dimensional heat flow” depicted in Figure 1. In this situation, the heat flows into one face of the object and out the opposite face with no heat loss (flow) out the sides of the object. The surfaces 1 and 2 are held at constant temperature. Clearly, “in one dimensional heat flow,” the temperature of an object is a function of only one variable, namely the distance from either face of the object (face 1 or 2).

b. Convection

The convection heat transfer mode is comprised of two mechanisms: random molecular motion (diffusion) and energy transferred by bulk or macroscopic motion of the fluid. The convection heat transfer occurs when a cool fluid flows past the warm body as depicted in Figure 2. The fluid adjacent to the body forms a thin slowed down region called the boundary layer. The velocity of the fluid at the surface of the body is reduced to zero due to the viscous action. Therefore, at this point, the heat is transferred only by conduction. The moving fluid then carries the heat away. The temperature gradient at the surface of the body depends on the rate at which the fluid carries the heat away.

c. Radiation

All bodies emit energy by means of electromagnetic radiation. The electromagnetic radiation propagated as a result of a temperature difference is called thermal radiation. An ideal thermal radiator or a black body will emit energy at a rate proportional to the forth power of its absolute temperature and its surface area.

2. HEAT PIPE DESIGN

There are many factors to consider when heat pipe is designed. Compatibility of materials, operating temperature range, length and diameter of heat pipe, power limitation, heat transport limitation of the heat pipe, thermal resistance, effect of bending and flattening of the heat pipe and operating orientation are given high importance. However, the design issues are reduced to certain major considerations by limiting the selection to copper/water heat pipes for cooling electronics.

The main consideration is the amount of power the heat pipe is capable of carrying. Another aspect is the temperature range that the particular working fluid can operate. This working fluid needs a compatible vessel material to prevent corrosion or any chemical reaction. Table (a) illustrates the typical characteristics of heat pipe.

Entrainment/Flooding

This is where high velocity vapour flow prevents condensate vapour from returning to evaporator. The main reason is due to low operating temperature or high power input that the heat pipe is operating. To overcome this, the vapour space diameter or the operating temperature is increased.

Capillary

It is the combination of gravitational, liquid and vapour flow and pressure drops exceeding the capillary pumping head of the heat pipe wick structure. The main cause is the heat pipe input power exceeds the design heat transport capacity of the heat pipe. The problem can be resolved by modifying the heat pipe wick structure design or reduce the power input.

Viscous

Viscous force will prevent vapour flow in the heat pipe. This causes the heat pipe to operate below the recommended operating temperature. The potential solution is to increase the heat pipe operating temperature or operate with an alternative working fluid.

Temperature Range (°C)	Working Fluid	Vessel Material	Measured axial[θ] heat flux (kW/cm²)	Measured surface[θ] heat flux (W/ cm²)
-200 to -80	Liquid Nitrogen	Stainless Steel	0.067 @ -163°C	1.01 @ -163°C
-70 to +60	Liquid Ammonia	Nickel, Aluminum, Stainless Steel	0.295	2.95
-45 to +120	Methanol	Copper, Nickel, Stainless Steel	0.45 @ 100°C[X]	75.5 @ 100°C
+5 to +230	Water	Copper, Nickel	0.67 @ 200°C	146@ 170°C
+190 to +550	Mercury* +0.02% Magnesium +0.001%	Stainless Steel	25.1 @ 360°C*	181 @ 750°C
+400 to +800	Potassium*	Nickel, Stainless Steel	5.6 @ 750°C	181 @ 750°C
+500 to +900	Sodium*	Nickel, Stainless Steel	9.3 @ 850°C	224 @ 760°C
+900 to +1,500	Lithium*	Niobium +1% Zirconium	2.0 @ 1250°C	207 @ 1250°C
1,500 + 2,000	Silver*	Tantalum +5% Tungsten	4.1	413

[θ]Varies with temperature
[X]Using threaded artery wick
*Tested at Los Alamos Scientific Laboratory
*Measured value based on reaching the sonic limit of mercury in the heat pipe
Reference of "Heat Transfer", 5th Edition, JP Holman, McGraw-Hill

Table.1 Typical Characteristics of Heat Pipe

3. FABRICATION OF HEAT PIPE

A typical heat pipe consists of a sealed hollow tube, which is made from a thermo conductive metal such as copper or aluminum. The pipe contains a relatively small quantity of "working fluid" (such as water, ammonia, ethanol or mercury) with the remainder of the pipe being filled with vapor phase of the working fluid. On the internal side of the tube's side-walls a wick structure exerts a capillary force on the liquid phase of the working fluid.

This is typically a sintered metal powder (sintering is a method for making objects from powder, by heating the material until its particles adhere to each other) or a series of grooves etched in the tube's inner surface. The basic idea of the wick is to soak up the coolant. Heat pipes contain no moving parts and require no maintenance and are completely noiseless. In theory, it is possible that gasses may diffuse through the pipe's walls over time, thus reducing this effectiveness.

The vast majority of heat pipes uses either ammonia or water as working fluid. Extreme applications may call for different materials, such as liquid helium (for low temperature applications) or mercury (for extreme high temperature applications).

The advantage of heat pipes is their great efficiency in transferring heat. They are actually a better heat conductor than an mass of solid copper.

The heat pipe is similar in construction of the thermo siphon but in this case, a wick constructed from a few layers of wire gauge, is fixed to the inside surface and capillary forces return condensate to the evaporator. In the heat pipe evaporator position is not restricted and it may be used in any orientation.

The heat pipe is aluminum seamless tube with 32 mm outer diameter and 25 mm inner diameter and 300 mm in length. Screen wick is used as a wick. With all heat pipes cleanliness is of prime importance to ensure that no incompabilities exist and to make certain that the wick and wall will be wetted by a working fluid. When the heat pipe is vacuum tight, the requisite amount of ammonia is fed in to it.

Basic components of a heat pipe

The basic components of a heat pipe are

1. The container
2. The working fluid
3. The wick or capillary structure

Container

The function of the container is to isolate the working fluid from the outside environment. It has to be there for leak proof, maintain the pressure differential across the walls, and enable transfer of thermal energy to take place from and into the working fluid.

Working fluid

The first consideration in the identification of the working fluid is the operating vapor temperature range. Within the approximate temperature band, several possible working fluids may exist and a variety of characteristics must be examined in order to determine the most acceptable of these fluids for the application considered.

Wick

The wick structure in a heat pipe facilitates liquid return from the evaporator from the condenser. The main purposes of wick are to generate the capillary pressure, and to distribute the liquid around the evaporator section of heat pipe. The commonly used wick structure is a wrapped screen wick.

Specifications	**Dimensions**
Length of pipes	300mm
Outer diameter of pipes	32mm
Inner diameter of pipes	25mm
Capacity of heaters	250KW
Material of heat pipe	Aluminium
Wick Material	Screen mesh
Working fluid	ammonia

Table.2 Specifications of heat pipe

Fig.1 (a) Fabricated Heat Pipe with valve

Fig.1 (b) Fabricated Aluminium Pipe

Fig.2 (c) Illustrated view of two pipes

4. ANALYSIS AND EXPERIMENTAL CALCULATIONS

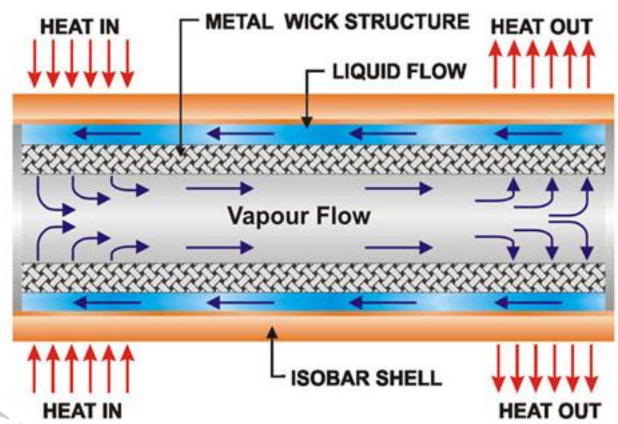

Fig 2 Operating Principle of heat pipe

The aluminum heat pipe is a super-thermal conductor that transmits thermal energy by evaporation and condensation of the working fluid. The working fluid inside the heat pipe is in equilibrium with its own vapour as the container tube is sealed under vacuum. Thermal energy applied to the external surface of the heat pipe causes the working fluid near the surface to evaporate instantaneously. Vapour thus formed absorbs the latent heat of vaporization and this part of the heat pipe becomes an evaporator region.

Due to the pressure gradients thus created within the heat pipe by the rapid generation of vapour near the surface, the excess vapour is forced to a remote area within the heat pipe having low temperature and pressure. The vapour then travels to the other end of the pipe where the thermal energy is removed causing the vapour to condense into liquid again, thereby giving up the latent heat of the condensation. This part of the heat pipe works as the condenser region. The condensed liquid then flows back to the evaporator region to be reused, thus completing a cycle.

Heat is removed from the external surface of the condenser region by conduction, convection or radiation. The heat pipe works continuously in a close-loop condensation or evaporation cycle and thus, the capillary pumping force is established within the wick structure that returns the working fluid from the condenser region to the evaporator region. The transfer efficiency level of each heat pipe is 99%.

CALCULATIONS FOR ALUMINIUM HEAT PIPE

Mass of water (M_w) = 0.5 kg
Specific heat of water (Cpw) = 4187 j/kg-k
Initial temperature of water (Twi) = 36 °C
Final temperature of water (T_{wo}) = 42 °C
Temperature at distance 50 mm on heat pipe
(T_1) = 115 °C
Temperature at distance 100 mm on heat pipe
(T_2) = 95 °C
Temperature at distance 150 mm on heat pipe
(T_3) = 74 °C
Temperature at distance 200 mm on heat pipe
(T_4) = 52 °C
Amount of Heat Transfer =MwCpw (Two-Twi)
=0.5*4187(42-36)
=12567 J

CALCULATIONS FOR ALUMINIUM PIPE

Mass of water (M_w) = 0.5 kg
Specific heat of water (Cpw) =4187 j/kgk
Initial temperature of water (Twi) = 36 °C
Final temperature of water (T_{wo}) = 40 °C
Temperature at distance 50 mm on aluminum pipe
(T_5) = 130°C
Temperature at distance 100 mm on aluminium pipe
(T_6) = 106 °C
Temperature at distance 150 mm on aluminium t pipe
(T_7) = 82 °C
Temperature at distance 200 mm on aluminium pipe
(T_8) = 58 °C
Amount of Heat Transfer Q =MwCpw(Two-Twi)
=0.5*4187(40-36)
=8374J

5. RESULTS

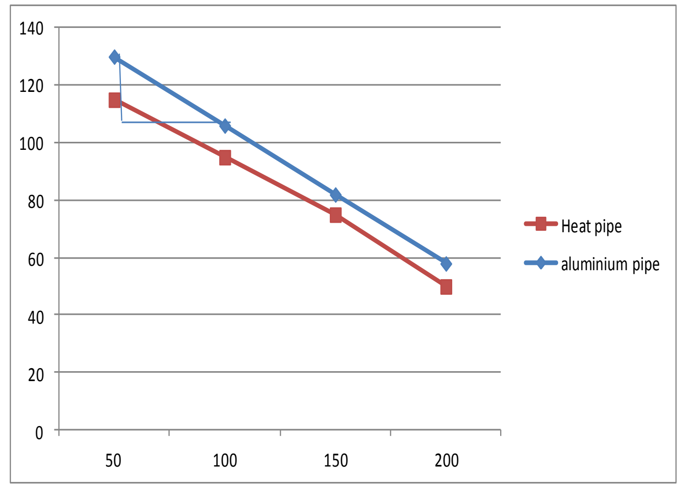

Fig 3 Comparison of aluminum pipe and heat pipes with temperature gradient

From graph for aluminum pipe dT = 25 °C

Scale:

For aluminium pipe dX=50 mm on x-axis 1 unit
=50 mm

Now dT/dX = - 0.5°C/m on y-axis 1 unit
=20 mm

From graph for heat pipe dT = 17 °C

For heat pipe dX =50 mm

Now dT/dX = -0.34°C/mm

6. CONCLUSION

Two types of heat pipes were studied experimentally using Ammonia as a working fluid, two aluminium pipes one with a wick and another with no wick. The wick used here is made of screen mesh. The heat pipes are positioned at same angles in the horizontal direction. Now the experimental analyses of the two pipes are done and finally the temperature distribution and rate of heat transfer are obtained.

The amount of heat transfer (Q) for heat pipe is 12567 J The amount of heat transfer (Q) for aluminium pipe is 8374 J From graph for heat pipe temperature gradient is - 0.34°C/mm. From graph for aluminium pipe temperature gradient is - 0.5°C/mm Hence the heat transfer for heat pipe is more when compared to the aluminium pipe and the temperature gradient is less for heat pipe when compared to the aluminium pipe

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