Experimental Performance Analysis of Solar Heat Pipes

Mr. Nelakuditi Naresh Babu[1], P. Ravindra kumar[2]

Mr.K. Lakshmi prasad[3] Mr. N. Sudheer[4]

[1 & 4] PG Students (M.Tech),[2&3]Faculty, Department of Mechanical Engineering

[1,2 & 3]Lakireddy Bali Reddy College of Engineering, Mylavaram and [4]Gudlavalleru Engineering College, Gudlavalleru, Andhra Pradesh, India.

[1]Naresh338babu@gmail.com, [2]pasupuletirk@lbrce.ac.in, [3]klprasad1108@gmail.com
[4]nsudheer324@gmail.com

Abstract:

Solar Energy is the outstanding renewable energy source having the ability to meet the challenges faced by the world with high costs of electricity; deficiency of conventional energy sources generally fossil fuels; threat to climate; and it is cheap, available in very large quantities. Now-a-days the importance of usage of heat pipes in solar applications is drastically expanding its wings. Heat Pipes (HPs) are the simple heat transfer devices, used to convey or fetch the heat from one location to another, which integrates the concepts of both thermal conductivity and phase change by using an evaporation-condensation cycle. Since the development of HP in early 1960's, they served as effective heat transfer devices not only in mechanical but also most of the other engineering applications. This paper comprise of two parts. In the first part an exhaustive overview of heat pipes from historical developments to recent trends including principle of operations; types; working fluids and their operating temperature limits; wick designs and structures with compatible materials is presented. And the second part reviews the applications of heat pipes in solar systems such as solar thermal water heaters; solar building heating systems; solar cooking; solar drying systems; solar lighting systems and solar distillation. The experimental work shows the utilization of solar energy with the help of experimental setup consisting of parabolic trough collector which is of concentrating the solar energy on an evacuated tube heat pipe which transforms radiation energy into useful heat. The experiment is in the month of May 2018. Temperatures at the outlet are measured for both the system at different mass flow rate of heated water from the parabolic trough collector. From the experiment it was found that the solar aluminium heat pipe gave the good results in heat transfer aspect.

Key Words: Parabolic trough collector, heat pipe, heat transfer, thermocouple thermometer

Part-I: INTRODUCTION AND CLASSIFICATION OF HEAT PIPES

1.1. Introduction:

The first thought of Heat Pipe was considered in the year 1942 by R.S.Gaugler [1] in the year 1942 and he got the patent in the year 1944. G.M.Grover et. al [2] was first used the appellation "Heat Pipe" in their work in the year 1964, who basically developed it to move away heat from nuclear reactor which was used as power generating system in space crafts; but, in later decades the applications of heat pipes are darstically expanded to numerous fields such as Solarthermal energy conversion; Cooling of electronic equipments; Manufacturing; Cooling of machine tools and Metal cutting operations; Electric power generation; Aerospace and Aeronautics; Waste-heat recovery; Heat exchangers and Heat pumps; Cryogenic; Nuclear; Engines and Automotive industry; Ovens and Furnaces; Medicine and Human body temperature control; Air-conditioning and Geothermal applications, etc.[6-23].

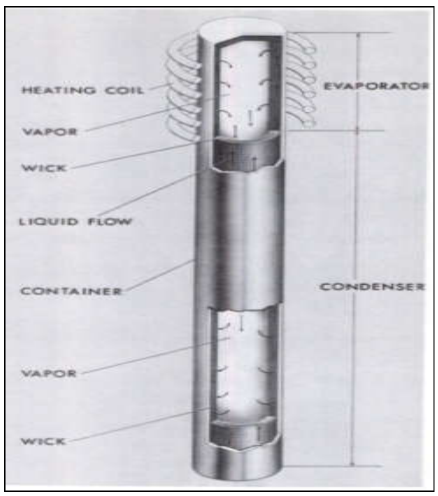


Fig.1.1.The "Grover's Heat Pipe"[3]

Heat pipes are highly efficient two-phase, passive devices to tranfer the heat at high rates over the distances millimeters to several meters long and these heat pipes are capable of high thermal conductances even than any metallic conductors[2-8]. The fig.1.1 shows model heat pipe used in the G.M.Grover et. al[2] research work[3]. These devices uses the latet heat of vaporization and differnce between the temperature of the two heat sourses is small, so they can capable of transfer of large quantities of heat. They permit the transportation of heat from the absorber plate of solar thermal collector to phase-changing fluid in pipe. The basic structure of heat pipe consists of a evacuated tube partly filled with a working fluid which has a phase changing nature. The most common physical configuration or shape of a heat pipe is a long, narrow or fine tube consists of a closed outer shell or cover, porous wick, and working fluid. Adequate working fluid is inserted or put into the heat pipe to wet the whole or entire or complete wick which is held tightly or firmly or securely and uniformly againt the inside wall of the heat pipe. The operating temperature of a heat pipe is determined by selection of working fluid operating pressures. Conceptually heat pipe operates at a single constant temperature. Because the boiling-condensing temperature is constant along the pipe. But in practically, a small temperature gradient is exists because of small vapour pressure and radial temperature gradients in thermal conduction between condenser and evaporator sections. The main reason for the super conductance of heat pipes is small temperature difference in Fourier's law of heat coduction due to the phase change at constant temperature.

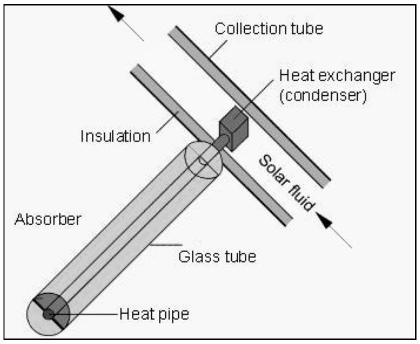


Fig.1.2. Heat pipe usage with solar collector

The Elements of a Heat Pipe are[6-8]:

- ✓ Container or tube (reqires high strength and high thermal conductivity);
- ✓ Working fluid (requires high latent heat of vaporization and high thermalconductivity); and
- ✓ Wick (or) capillary structure (needs to maintain its capillary function when it is bent or installed against the gravity).

1.2. Heat Pipe- Principle of Working:

Heat Pipe consists of mainly three parts viz., condensing, adiabatic or transport, and evaporating sections or regions. One can easily perceives that the working of heat pipe in cylindrical geometrical construction as illustated in the fig.1.3.

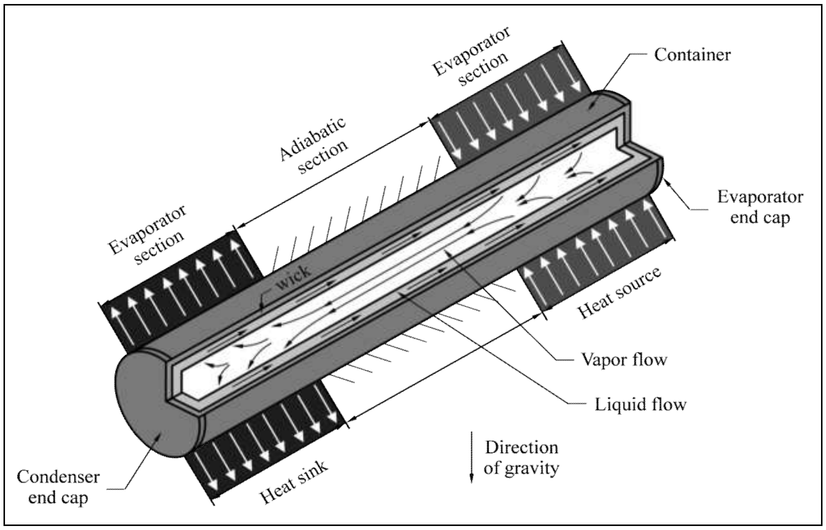


Fig.1.3. Schematic representation and principle of operation of conventional heat pipe[6]

In some times thermosyphon and heat pipe seems to be similar, but they are different. The distinction between thermosyphon and heat pipe is: in thermosyphon the liquid returned from condenser to evaporator depending on gravity but in heat pipe the working fluid in the liquid phase is returned from the condenser to the evaporator by surface tension acting in the wick. The fig.1.4. shows the schematic view for difference between thermosyphon and heat pipe.

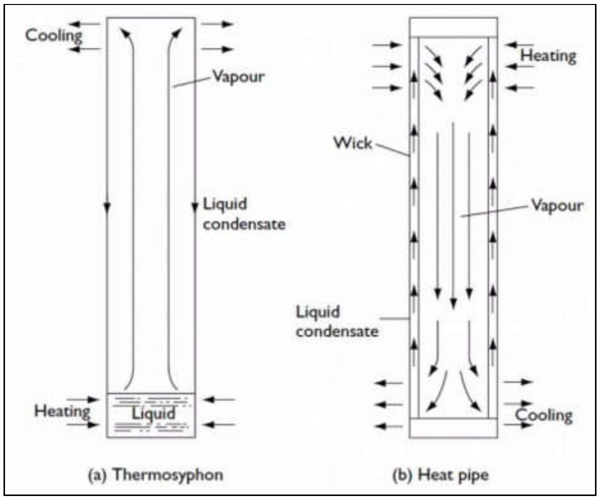


Fig.1.4. a) Thermosyphon and b) Heat pipe[7, 18, and 23]

1.3. Advantages of Heat Pipes:

- ✓ The construction of heat pipes is simple, robust.
- ✓ There are no moving parts and passive operation.
- ✓ No wear and tear as it doesn't have any moving parts and having longer life period.
- ✓ Low maintenance costs; and the prefered maintenance strategy is periodic cleaning.
- ✓ Flexible in size; they can also be manufactured in custom sizes to fit any required application.
- ✓ Suitable for wide range of temperature applications; and availability of number of compatible working fluids.
- ✓ Exhibiting Isothermality at high temperatures.
- ✓ Efficient in heat transfer at small temperature differences.

1.4.Classification of Heat Pipes:

Heat pipes have been designed and constructed at different sizes with various lengths and cross sectional areas as small as milli meters length(micro heat pipes) to as large as meters in length. In all heat pipes evaporator, condenser, and adiabatic sections common; and the evaporator and condenser sections are separated by the distance depending on the design retraints. Depending on the application heat pipe may have different multiple evaporators and condensers[24]. Because of ease in design and manufacturing most of the heat pipes are in cylindrical shape. Also there are other shapes such as rectangular(flat-heat pipes); conica(rotating heat pipes); corrugated or grooved(simple and flexible heat pipes); and nosecap(leading edge heat pipes) geometries[25]. The detailed classification of heat pipes is as follows:

1.5. Thermosyphons or Thermosiphons:

Thermosyphon is two-phase closed, gravity assisted wickless heat pipe in which the condenser section is positioned atop of the evaporator section lest the codensed vapor is come back by the assistance of gravity as shown in fig.1.5.[26]. The main constraint to the operation of two-phase garvity assisted wickless thermosyphon is flooding limit[27] which is interconnected with vapor velocity and is appreciable at low temperatures. The major cause for that is at low temperatures the vapor pressure and vapor density decreases. So it is necessary to increase the vapor velocity to avoid the flooding effect. To circumvent the flooding limit and to separate the vapor and liquid flows loop heat pipes are invented. At the flooding limit a sudden wall temperature and vapor pressure raises because the boiling limit in thermosyphons is due the phenomenon of film boiling on behalf of nucleate boiling in capillary-driven or wicked heat pipes.

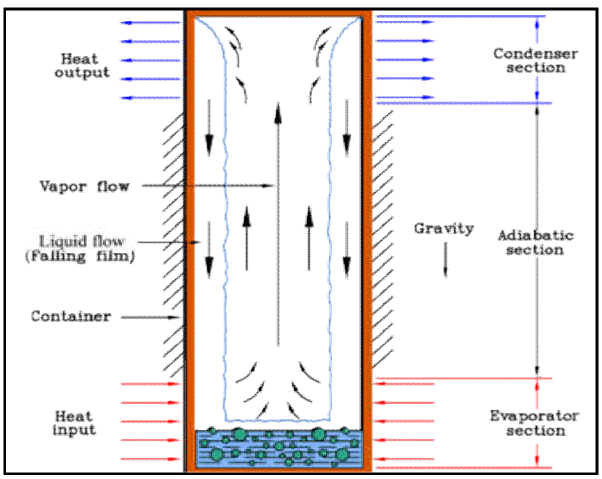


Fig.1.5.Two-Phase closed Thermosyphon[26]

1.6. Capillary-Driven or Wicked Heat Pipes:

`Capillary-driven heat pipe also known as conventional heat pipe consists of a closed container in which wick(porus lining) is positioned at the inner radius of the wall of heat pipe. The reason to place the wick in heat pipe is to provide capillary action to return the condensate from condeser to evaporator. The fig.1.6. shows the schematic representation of capillary driven wicked heat pipe[28].

The basic steps in the working of a wicked heat pipe are:

- ✓ The working fluid is vapourizes at evaporator due to the contact of heat pipe with external heat sourse. This fluid vapour creates the pressure difference.
- ✓ As the pressure difference is created in the pipe, the vapour flows towards cooler section i.e., condenser.
- ✓ In the condenser section the vapour gets cooled to form liquid by the loss of latent heat of vaporization.
- ✓ Again that condensed liquid flows towards the evaporator by the capillary action of wick structure or by the assistance of gravity. Although centrifugal; electrostatic; and osmatic force can also be employed to return the working fluid from the condeser region to evaporator region[13].

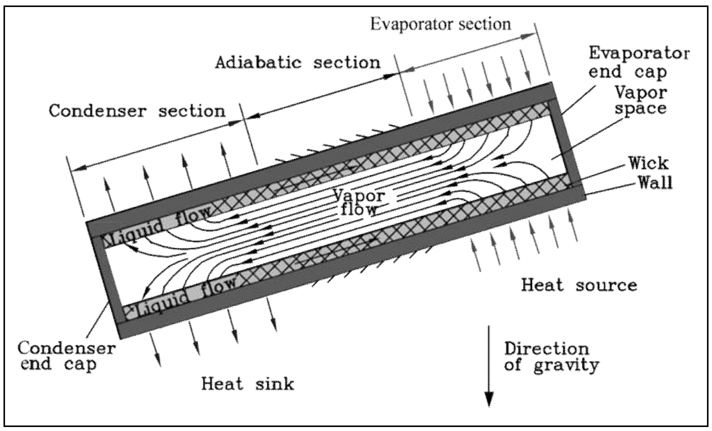
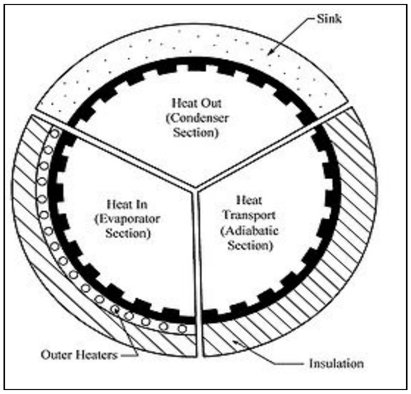


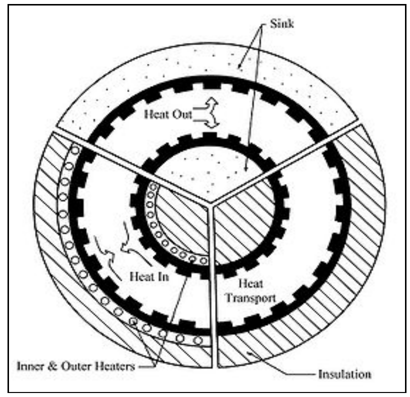
Fig.1.6. Capillary-Driven Heat Pipe[28]

Due to the two-phase nature of capillary-driven heat pipes, these are ideally suitable for transfering haet over large distances with negligible temperature drops and temperature stabilization near the surface. The most usual constraint for the operation of capillary-driven heat pipe is capillary limit which is due to the insufficiency of liquid flow through wick to the evaporator to maintain at it saturated state. If it is not happen, the evaporator wall suddenly experiences a temepertaure raise. These conventional heat pipes are now-a-days widely used in various commercial, industrial, and research applications.

1.7. Annular Heat Pipes (AHPs):

The annular heat pipes are mostly similar to conventional capillary driven heat pipes, but the difference in annular heat pipe is the cross section of the vapor space is annular instead of circular as in case of conventional heat pipes. In annular heat pipes the surface area of heat input and output is appriciably increased without increasing the size of the pipe[19, 29]. The fig.6 shows the design configurations of annular heat pipes i.e., conventional AHPs and Concentric AHPs(CAHPs). The Dry-out phenomenon[30, 31] of conventional heat pipes is effectively overcome by AHPs. AHPs are widely used to cool annular spaces in transformers, motors etc.





a) b)

Fig.1.7 . AHP designs- a) Conventional AHP; b) Concentric AHP[19]

1.8. Vapour Chambers(VCs) or Flat-Plate Heat Pipes:

Vapour chamber is palnar heat pipe used for heat spreading and isothermalizing. These are flat-plate type heat pipes having cross sections of rectangular or disk-shape[19]. Similar to conventional heat pipes, vapour chambers transport heat from heat sourse to heat sink with very small temperature gradients. Vapour chambers are usually used in high heat flux applications and when real two-dimensional spreading of heat over large area is required. Vapour chambers allow high heat fluxes than traditional metallic surfaces. VCs are extensively used in the cooling of electronic equipment[32]. The working principle of VCs is as shown in fig.1.8.

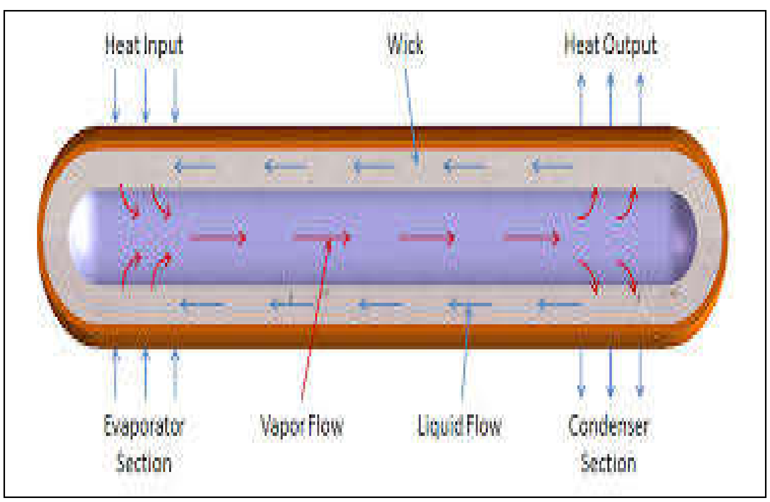


Fig.1.8. Working of Vapour Chamber[33]

1.9. Rotating Heat Pipes(RHPs):

In Rotating heat pipes, the heat tranfer process is doesn't depends on the gravity as in case of thermosyphons and conventional heat pipes. The natural convection type of heat transport is takes place from condenser section to evaporator section by the use of centrifugal force which is generated due to the rotational motion of pipe. So, instead of capillary action as in the case of conventional wicked heat pipes, centrifugar plays the main role. By having imperceptible internal taper in rotating heat pipe the pumping action of condensate takes place which consequences very thin condensate films on wall and higher heat transfer coefficients[34, 35]. The fig.1.9. shows a schematic rotating heat pipe.

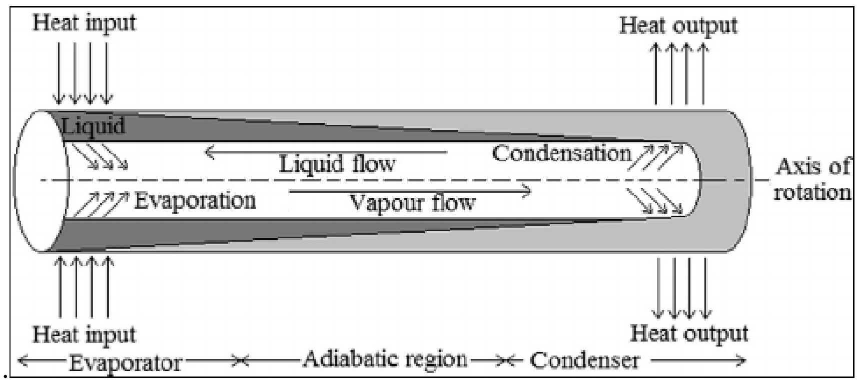


Fig.1.9. Rotating Heat Pipe[38]

S.H.Chan et al. [36] were developed an analytical solution to predict the rate of heat transfer of rotating wickless heat pipe which has the conical shape and which rotates about its longitudinal axis. T. A. Jankowski et al. [37] were developed and tested a prototype of curved rotating heat pipe to cool super conducting machines such as motors and generators.

1.10. Gas-Loaded Variable Conductance Heat Pipes (GVCHPs):

A GVCHP is similar to the conventional or traditional heat pipe but it has a reservoir along with a controlled amount of Non-Condensable Gas (NCG) inside the reservoir [17, 39]. During the functioning of heat pipe, the NCG drags towards the condenser end by the flow vapour of working fluid. The NCG then blocks or obstructs the flow of working fluid towards the condenser. The GVCHP mainly works on altering the condenser space available to the working fluid. These heat pipes are also known as Gas buffered heat pipes [7, 40]. The working of a GVCHP is as shown in fig.9.

Maryline liriche et al. experimentally and analytically studied the Variable Conductance Heat Pipe in the application of vehicle thermal management and also the effect of inclination angle on performance of VCHP was studied [41].

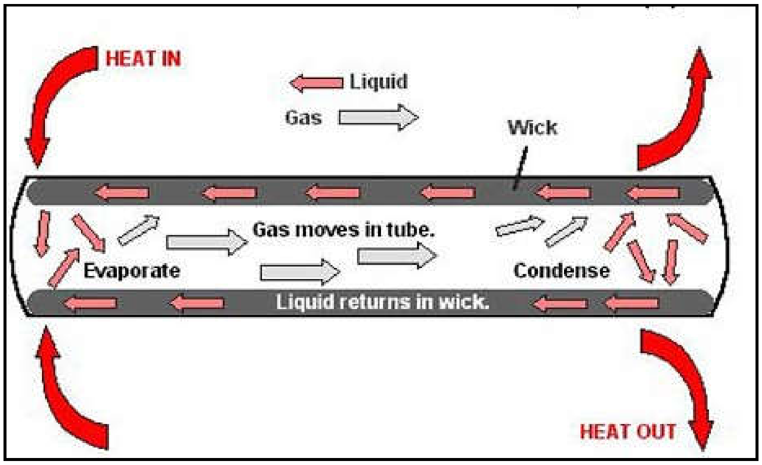


Fig.1.10.Working of GVCHP[39]

1.11. Loop Heat Pipes(LHPs):

Loop Heat Pipes(LHPs) are two-phase, passive heat carrying devices in which the working fluid is circulates by capillary action. LHPs are transformed from conventional heat pipes with the wick structure only at the evaporator section; the reason is to take the advantage of reducing hydraulic pressure loss in remaining portion of heat pipe[42, 43]. LPHs not only grabs all the advantages of conventional heat pipes but also advantageous in efficient heat transfer to many meters in length and any position in the gravity field. The prinple of working of a loop heat pipe is shown in fig.10.

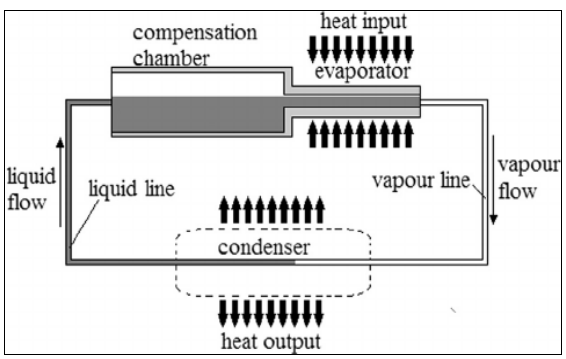


Fig.1. 11. Loop Heat Pipe[38]

1.12. HEAT PIPE OPERATION LIMITS

The heat pipe has four major operating regimes, each of which sets a limit of performance in either heat transfer rate (axial or radial) or temperature drop.

Vapour Pressure or Viscous Limit

At low temperature range of operation of the working fluid, especially at start-up of the heat pipe, the minimum pressure at the condenser end of the pipe can be very small. The vapour pressure drop between the extreme end of the evaporator and the end of the condenser represents a restriction in operation. The maximum rate of heat transfer under this restricted vapour pressure drop limit is given by:

$$\dot{Q}_V = \frac{D^2_V h_{fg} p_v \rho_v}{64 \eta_v l_{eff}}$$

Where D_v is the diameter of the vapour passageway, h_{fg} is the enthalpy of vaporization; p_v is the pressure, ρ_v the vapour density, and η_v the vapour dynamic viscosity.

$$l_{eff} = \text{effective heat pipe length} = \frac{l_e}{2} + l_a + \frac{l_c}{2}$$

Where, l_e is the length of the evaporator region, l_a the length of the adiabatic region and l_c the length of the condenser region.

Sonic Limit

At a temperature above the vapour pressure limit, the vapour velocity can be comparable with sonic velocity and the vapour flow becomes "choked". The recommended maximum rate of heat transfer, to avoid choked flow conditions (i.e., sonic limit) is given by

$$\dot{Q}_S = 0.474 A_V^2 h_{fg} (p_v \rho_v)^{\frac{1}{2}}$$

Where, A_v is the area of the vapour passageway.

Entrainment Limit

The vapour velocity increases with temperature and may be sufficiently high to produce shear force effects on the liquid return flow from the condenser to the evaporator, which cause entrainment of the liquid by the vapour. The restraining force of liquid surface tension is a major parameter in determining the entrainment limit. Entrainment will cause a starvation of fluid flow from the condenser and eventual "dry out" of the evaporator.

The entrainment limit is given by

$$\dot{Q}_E = \mathrm{A_V} h_{fg} \sqrt{\frac{\rho_v \sigma}{x}}$$

Where σ is the surface tension of the liquid, x is the characteristic dimension of the wick surface (≡$2r_\sigma$, where r_σ = effective radius of pore structure).

Circulation Limit

The driving pressure for liquid circulation within the heat pipe is given by the capillary force established within the wick structure, namely

$$\Delta P_\sigma = \frac{2\sigma}{r_\sigma} = \text{(i.e., maximum capillary presure)}$$

Circulation will be maintained provided:

$$\Delta P_\sigma \geq \Delta P_l + \Delta P_v + \rho_l g l \cos\phi$$

Where ΔP_l is the frictional pressure drop in liquid and ΔP_v is the factional pressure drop in the vapour.

Part-II

2.1 Selection of Working Fluids & Materials for Heat Pipes:

The working fluid selection in heat pipes mainly depends on operating temperature range and the properties of working fluid. The properties of working fluid effects both rate of heat transfer and the compatibility with pipe and wick materials. The commonly used working fluids in heat pipes and their melting & boiling points at atmospheric pressure and useful operating temperature range in ºC shown in Table.2.1. The factors considered while selecting working fluid are[10, 48]:

- ✓ Compatibility with pipe and wick materials
- ✓ Good thermal & chemical stability
- ✓ High latent heat of vaporization
- ✓ Wettability to wick and pipe materials
- ✓ High thermal conductivity
- ✓ Low viscosities in liquid and vapour phases
- ✓ High surface tension.

Table 2.1. Different working fluids used in Heat pipes[10, 48]

Working Fluid	Melting point at atmospheric pressure(^{0}C)	Boiling Point at atmospheric temperature(^{0}C)	Operating temperature Range(^{0}C)
Helium	-272	-269	-271 to -269
Nitrogen	-210	-196	-203 to -160
Ammonia	-78	-33	-60 to -100
Freon 11	-111	24	-10 to -120
Pentane	-130	28	-20 to -120
Freon 113	-35	48	-10 to -100
Acetone	-95	57	0 to -120
Methanol	-98	64	10 to 130
Ethanol	-112	78	0 to 130
Heptane	-90	98	0 to 150
Water	0	100	30 to 100
Thermex	12	257	150 to 395
Mercury	-39	361	250 to 650
Sulphur	385.9	717.8	530 to 947
Caesium	29	670	450 to 900
Rubidium	312.7	959.2	800 to 1275
Potassium	62	774	500 to 1000
Sodium	98	892	600 to 1200
Lithium	179	1340	1000 to 1800
Calcium	1112	1762	1400 to 2100
Lead	600.6	2013	1670 to 2200
Indium	429.7	2353	1800 to 2300
Silver	960	2212	1800 to 2300

The effective performance and life of heat pipes depends on selection of pipe & wick materials and their compatibility with the working fluid. Incompatibility results failures in the heat pipe walls and some times solubility of pipe material in working fluid may also occur. The anthology of comaptible metals with working fluids is shown in Table.2.2.

Table: 2.2. Information about Compatibility of metals with Working fluids [10, 19, 48]

S.No.	Working Fluid	Compatible Material	Incompatible Material
1.	Water	Stainless Steel, Copper, Silica, Nickel, Titanium	Aluminium, Inconel
2.	Ammonia	Aluminium, Stainless Steel, Cold rolled Steel, Iron, Nickel	Copper
3.	Methonal	Stainless Steel, Iron, Copper, Brass, Silica, Nickel	Aluminium
4.	Acetone	Aluminium, Stainless Steel, Copper, Brass, Silica	
5.	Freon-11	Aluminium	
6.	Freon-21	Aluminium, Iron	
7.	Freon-113	Aluminium	
8.	Heptane	Aluminium	
9.	Dowtherm	Stainless Steel, Copper, Silica	
10.	Lithium	Tungsten, Tantalum, Molybdenum, Niobium	Stainless Steel, Nickel, Inconel, Titanium
11.	Sodium	Stainless Steel, Nickel, Inconel, Niobium	Titanium
12.	Cesium	Titanium, Niobium, Stainless Steel, Nickel-based super alloys	
13.	Mercury	Stainless Steel	Molybdenum, Nickel, Tantalum, Inconel, Titanium, Niobium
14.	Lead	Tungsten, Tantalum	Stainless Steel, Nickel, Inconel, Titanium, Niobium
15.	Silver	Tungsten, Tantalum	Rhenium

Marian Jobb et. al [49] studied the impact of working fluids on the performnce of heat pipes. In their studies it is evident that the performnce of a heat pipe depends on material selection; dimensions of heat pipe; type and amount of working fluid; gravity and angle of inclination of heat pipe; and working temperature.

Junjie Gu et. al [50] experimatally investigated effects of garvity on the heat transport characteristics of pulsating heat pipe made up of aluminium and R-114 as working fluid.

2.2 Wick Structures:

There are different types of wick structures have been developed in order to optimize the performance of wicked heat pipe. [40],

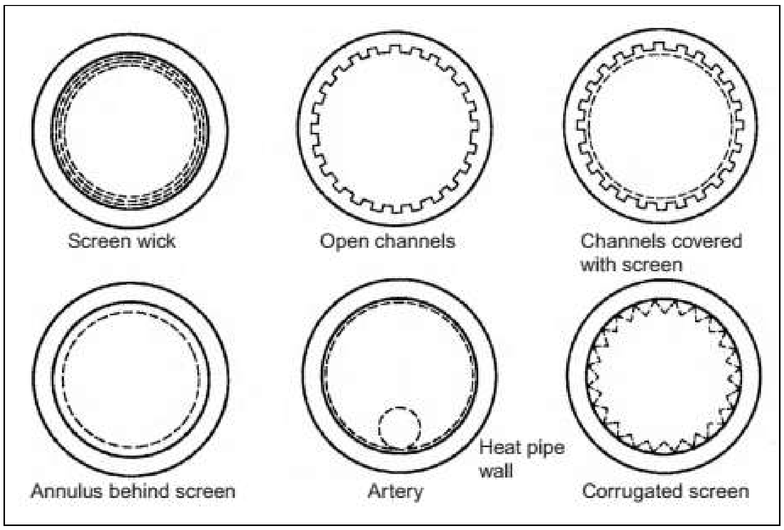


Fig.2.1. Different Types of Wick sections[11]

Table.2.3. Overview of several solar applications of heat pipes

References	Application	Details
Heat pipes in Solar Applications		
Name of Researcher(s)	Area of Application	Analysis
M.Akyurt [9], 1984	Solar water heater	An exhaustive research and testing of various heat pipes in solar water heater over one year was done.
W.Chun et al. [52], 1999	Solar water heater	An experiment is conducted on copper heat pipe water heating system for different working fluids.
K.S.Ong et al. [53], 2012	Solar water heater	This paper details the application of heat pipes in evacuated solar collectors for solar water heating systems.

2.3. Solar Water Heating (SWH):

The first found application of heat pipes among solar applications is Solar Water Heaters (SWHs). SWH is the most famous application of solar thermal technologies. Solar water heating system basically consists of a solar collector and a water storage tank. The most used solar collectors are flat-plate collectors and evacuated-tube collectors. The collector absorbs the radiation energy from sun and transfers it to the water in storage tank. There are two ways for transfer of heat to water in SWHs: a direct transfer of heat to water through collector; and an indirect way in which a heat-transfer fluid (working fluid), circulating in collector transfers the heat to the water. The applications of solar water heaters includes domestic household water heating; commercial applications such as hotels, hospitals, hostels, swimming pools and dormitories; and industrial applications like food and beverages, processing, textile industries, and preheating of boiler feed water, etc [51].

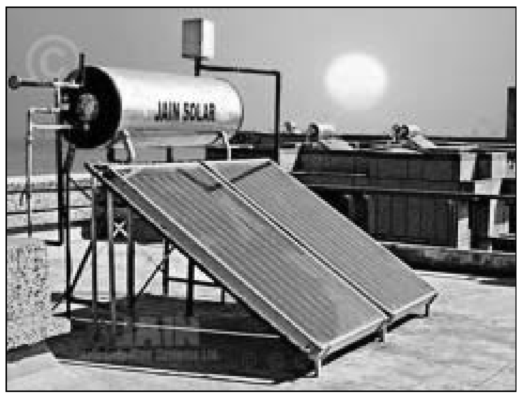


Fig.2.2. Flat Plate Type Solar Water Heater [51]

M.Akyurt [9] tested the heat pipe in solar water heater and he found that the isothermal behaviour of heat pipe and believed the potential future of heat pipes in solar applications. The schematic experimental set-up used in his study is shown in fig.6.

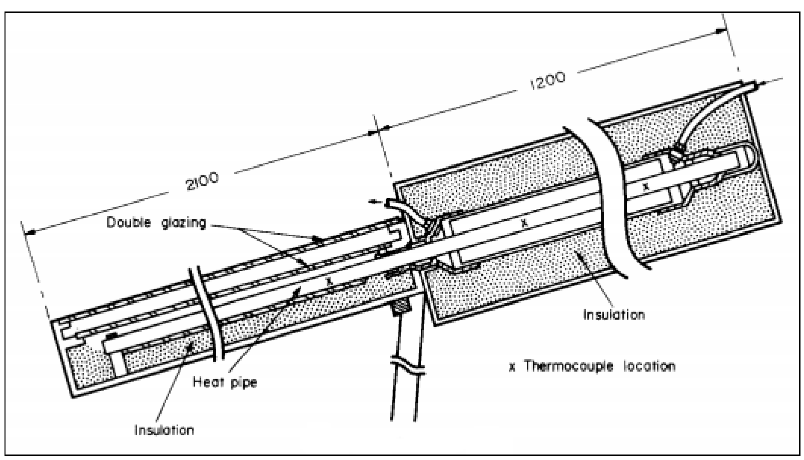


Fig.2.3. The Schematic Experimental Set-up of Heat Pipe [9]

W.Chun *et al.* [52] carried out an experimental study on the utilization of heat pipes in solar water heaters. They carried out the experiments on thermosyphon and wicked heat pipe with water, methanol, acetone, and ethanol as working fluids; and they studied the system at two different storage tank capacities.

K.S.Ong *et al*. [53] experimentally studied the system performance with U-tube and heat pipes in solar water heaters under the conditions of natural and forced convections. Among their experimentations, they found that the heat pipe system shows over other.

K.S.Ong *et al.* [54] experimented on U-tube type thermosyphons in solar water heaters with vertical and inclined panels and studied the performance at different times of the year. They found the better performance with inclined collector than vertical collector.

J.Xinian *et al.* [55] presented a coreless horizontal heat pipe vaccum tube collecter for solar water heaters which is having the facility to install in balcony.

2.4. Solar space heating and cooling:

Solar space heating is a thermal thecnology the solar energy from sun is collected and used to heat the air which is very useful for heating commercial industrial spaces and such sort of system is known as solar thermal system. Solar heating technologies are usually classified into passive and active solar heating technologies depending on the usage of active mechanical and electrical devices.Solar cooling technologies mainly desires refrigeration and dehumidification requirements.

If we consider heat pipe as a thermodynamic system ; according to first law of thermodynamics the difference in thermal energies at input and output locations of the heat pipe gives some amount of energy[15] as:

$q_e - q_c = L$

The effectiveness of thermodynamic cycle of a gheat pipe is givenby,

$\eta_T = (q_e - q_c)/ q_e$

Based on thermal efficiency the heat pipes are classified as three types[15]. They are:

(i). $\eta_T \geq 0$; heat pipes used to transform the thermal energy into other forms of energy,

(ii). $\eta_T = 1$; heat pipes used mostly for thermal energy transport, and

(iii). $\eta_T \leq 0$; heat pipes used for systems requiring cooling effect.

Now-a days the heat pipes are have their greater utilization in solar applications such as solar distillation; solar cooking; solar space and water heating; solar cooling; electricity generation; aerospace and other solar thermal applications. A Solar collector is a unique energy exchanger which converts the irradiation energy of sun into either thrmal energy of working fluid or to direct electric energy[6,]. Solar collectors can be classified mainly as two types. They are non-concentrating and concentrating. The difference between these two is that the non-concentrating collectors have same sizes of both interceptor and absorber while concentrating collectors have the bigger interceptor size than the absorber.

There are different types of working fluids, such as acetone, methanol, ammonia, sodium and even water can be used as the working fluid in heat pipes based on operating temperature. Several studies are performed on the performance of heat pipes with different working fluids [1]; fill ratios [1]; and orientations [1]. Hari krishnan S.S., and Vinod Kotebavi [1] tested the heat pipes with Methanol, Acetone and Water as working fluids; with fill ratios of 25%, 50%, 75%, and 100%. They were carried out the experiments at 60^0, and 35^0 inclinations of heat pipes. And also some experimental investigations are performed by number of researchers on the performance of heat pipes in solar water heaters and parabolic trough concentrators with nano fluids [2, 3].

2.5. Experimental Analysis on Solar Heat Pipe:

The experimental set up is shown in the figure.1., In which main components are condenser, evaporator, and three heat pipes made up of materials stainless steel, galvanized iron, and aluminium.

Fig2.4.Arrangement of Heat Pipes

Each heat pipe consists of porous wick structure and working fluid filled by ammonia solution. These heat pipes are placed in between condenser and evaporator. Three heat pipes are of same diameter. The experimental setup with solar parabolic collector is shown in figure.2.5.

Fig. 2.5.Experimental setup with Solar Parabolic Collector

The heat pipes setup is attached to a supporting table for experimentation. The inlet and outlet valves for condenser and evaporator are provided. Condenser is filled with cold water and evaporator is filled with hot water taking from solar parabolic through collector. Then heat will be transferred from heat pipes to the ammonia and it is evaporated in evaporator section. And in condenser section it is converted to liquid state by means of cooling water. The working fluid continuously recirculated by variation of temperature. The cooling water is measured by measuring flask. By continuously varying the mass flow rate, the readings are taken using attached thermocouples on three heat pipes. In which we are use the thermocouple thermometer. The heat pipes are maintained vacuum inside space is created by vacuum pressure gauge.

2.6. Experimental Readings at different Mass Flow Rates:

Experimental readings were taken at different flow rates of cold water entering in to the condenser. The heated coldwater from the parabolic concentrating collector entering to the condenser of solar heat pipes.

These solar heat pipes are placed parallel to the ground at certain height. Initial and final temperature readings were recorded with the help of thermocouple thermometers connected at evaporator side. With the help of temperature readings attained are used to calculate the heat transfer in various solar heat pipes.

Table.2.4. Heat Transfer at Mass Flow of 1000 ml

Type of Heat Pipe	Temperatures of Heat Pipes		Amount of Heat Transfer, Q (W)
	Initial Temp. T_1 (^oC)	Final Temp. T_2 (^oC)	
Aluminium	40.2	41.3	42
Galvanized Iron	39.1	39.5	15.27
Stainless Steel	38.2	39.2	38.18

It was found that maximum temperature is attained in the Aluminium solar heat pipe for different flow rates of hot water shown in table 1.

Table.2.5.Heat Transfer at Mass Flow of 1500 ml

The heat transfer is calculated at a mass flow of 1500 ml and time is also recorded.

Type of Heat Pipe	Temperatures of Heat Pipes		Amount of Heat Transfer, Q (W)
	Initial Temp. T_1 (°C)	Final Temp. T_2 (°C)	
Aluminium	35.8	39.5	103.6
Galvanized Iron	32.1	34.2	58.8
Stainless Steel	32.5	36.1	100.8

Table.2.6.Heat Transfer at Mass Flow of 2000 ml

Type of Heat Pipe	Temperatures of Heat Pipes		Amount of Heat Transfer, Q (W)
	Initial Temp. T_1 (°C)	Final Temp. T_2 (°C)	
Aluminium	33.4	35.5	56.36
Galvanized Iron	31..6	32.2	16.1
Stainless Steel	31.9	33.4	40.25

Table.2.7. Heat Transfer at Mass Flow Rate of 2500 ml

Type of Heat Pipe	Temperatures of Heat Pipes		Amount of Heat Transfer, Q (W)
	Initial Temp. T_1 (°C)	Final Temp. T_2 (°C)	
Aluminium	31.5	32.8	33.29
Galvanized Iron	29.8	30.4	15.36
Stainless Steel	31.3	32.2	23.05

2.7. Results and Discussion:

The amount of heat transfer in various solar heat pipes for different flow rates of hot water is presented in three Cases.

The figures indicate the amount of heat transfer for three materials viz., aluminium, galvanized iron, and stainless steel are shown in case: I, case: II, case: III, and case: IV for various mass flow rates.

Case I: Hot water flow of 1000 ml through solar heat pipe of different materials

Hot water is passed in to the solar heat pipe in condenser section and temperature is also recorded in evaporator section.

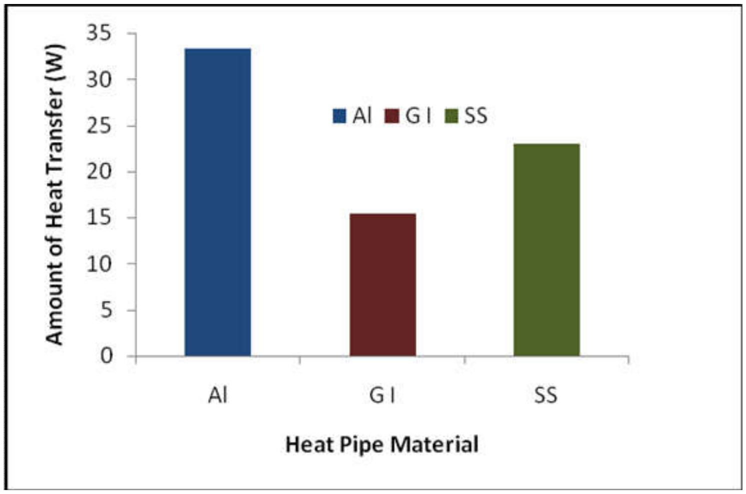


Fig.2.6.Amount of heat transfer in solar heat pipes

The experimental setup is placed parallel to the ground and various thermo couples readings are recorded for a flow of water at 1000 ml. It shows that more heat transfer is occurred in case of Aluminium heat pipe because of having high thermal conductivity. The second largest heat transfer is occurred in stainless steel.

Case II: Hot water flow of 1500 ml through solar heat pipe of different materials shown in figure 2.7.

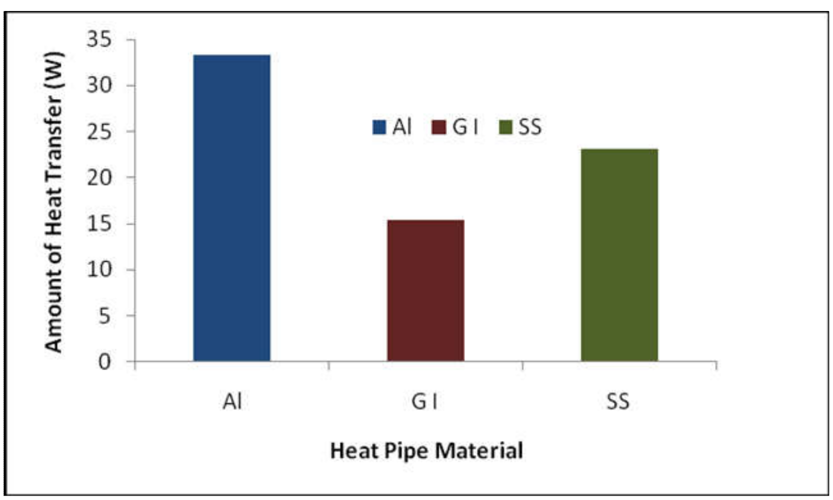


Fig.2.7. Amount of heat transfer in solar heat pipes

The experimental analysis is conducted again for different water flow rate of 1500 ml. placed parallel to the ground and various thermo couples readings are recorded for a flow of water at 1500 ml. It also shows that more heat transfer is occurred in case of Aluminium heat pipe but the percentage of heat transfer improvement is 12%. The second largest heat transfer is occurred in stainless steel.

Case III: Hot water flow of 2000 ml through solar heat pipe of different materials

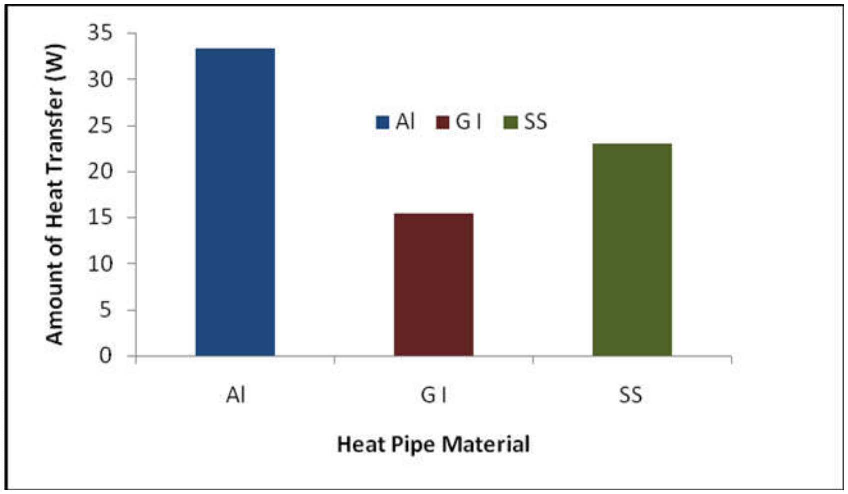


Fig.2.8.Amount of heat transfer in solar heat pipes

The experimental setup is placed parallel to the ground and various thermo couples readings are recorded. The experimental analysis is conducted again for different water flow rate of 1500 ml. placed parallel to the ground and various thermo couples readings are recorded for a flow of water at 1500 ml. It also shows that more heat transfer is occurred in case of Aluminium heat pipe but the percentage of heat transfer improvement is 12%. The second largest heat transfer is occurred in stainless steel.

Case IV: Hot water flow of 2500 ml through solar heat pipe of different materials shown in figure 2.9.

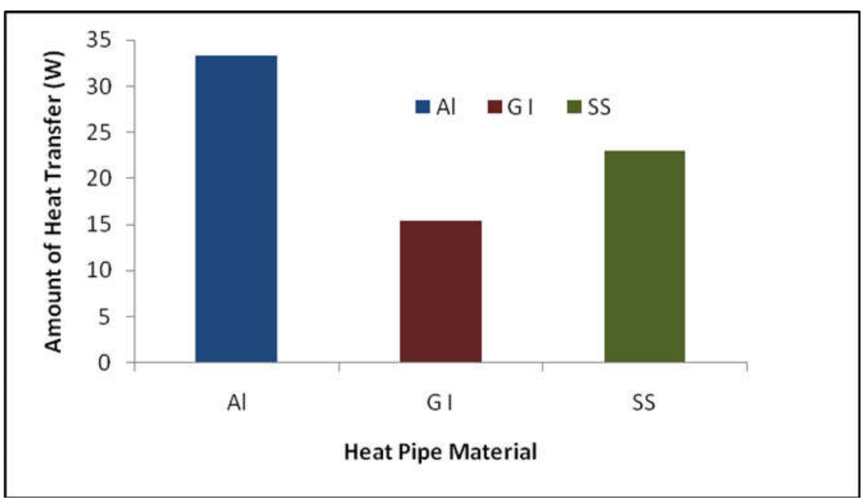


Fig.2.9. Amount of heat transfer in solar heat pipes

The experimental setup is placed parallel to the ground and various thermo couples readings are recorded.

2.8. Conclusion

The heat pipe in its basic form, as well as the various modified versions, is a highly versatile engineering structure. It is endowed with the quality of acting as an efficient heat transfer element. Heat pipes seem to have great potential in the field of solar energy applications, apart from the many industrial applications. Commercial models have yet to be developed although the principles and concept are well-understood. It is time the energy-conscious industries attempted to reap the benefits of this valuable tool. The results obtained from experimental study and performance of solar heat pipe, in which for different mass flows, the heat transfer is calculated for three materials of heat pipes. Among these three heat pipes aluminium pipe shows more heat transfer. Finally galvanized iron pipe maintain low heat transfer rate compared to aluminium and stainless steel. The following conclusions can be drawn as follows from the experminetation.

1. From the above experimental analysis, it shows that more amount of heat transfer is occurred in case of Aluminium heat pipe than compared to Stainless and GI.

2. It also indicates that maximum value of heat transfer is occurred to an Aluminium heat pipe for an optimum flow of 1500ml.

3. The percentage of heat transfer improvement is found to be more in case of Aluminium compared to other heat pipe materials for different flow of hot water.

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