Parametric Study & Analysis of Pulsating Heat Pipe Using Pure Water

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Abstract- *Pulsating heat pipes (PHPs) are the new addition to the wick-less heat pipe family introduced by Akachi in 1990's, in last few decades this device acts as a promising source for cooling electronic devices where temperature difference between source and sink is very small. Pulsating heat pipes are highly acceptable devices due to its simple design, light weight feature and small size. Hence PHP is selected for analysis in this project. The working temperature range selected for this project is 40◦C to 150◦C. Within this working temperature range, various working fluids available for PHP are methanol, ammonia, water, naphthalene & various nano fluids such as CuO, Al2O3 & CuO2. Out of all these working fluids available, water is the cheapest working fluid, having highest Merit number as compared to others & easily available everywhere. Various researchers have studied & analyzed ethanol, CuO, Al2O3 & CuO2 as a working fluids & calculated their performances. Hence, in this project, analysis of pulsating heat pipe is carried out by using water as a working fluid. Various parameters such as heat transfer rate, thermal efficiency, thermal resistance of PHP, sensible heat & latent heat transfer in evaporator & condenser are calculated experimentally at different filling ratios. And the results at different obtained are compared with different filing ratios of water.*

Keywords- Pulsating heat pipes, closed loop pulsating heat pipes, Working Fluid, Thermal Resistance of PHP, Heat Transfer Rate, Filling Ratio.

I. INTRODUCTION

Electronic industry & space science is developing day by day. Hence very large equipment sizes are reducing day by day & becoming compact due to continuous development in it. As we can take examples of television, mobiles, computers, space equipments & many more. Cooling is most crucial part in electronic equipments because during the operation, they generate large amount of heat. Due to overheating, they may malfunction. Hence, method of cooling these equipments is also changing day by day & reducing in size of a cooling system. This project focuses on small size cooling system which will be used as cooling media for small sized electronic equipments & transfer the heat generated inside small equipments in very less time. In last few decades' rapid development in electronic industry forced researchers to do work on small size effective heat transfer devices for cooling of electronic components. Use of Phase change materials, jet cooling, two phase flow of fluid are the few methods used for cooling purpose. Heat pipes are widely used as one of the effective heat transfer device, researcher are working on different geometries and principle of fluid transport in heat pipes. The Components of heat pipe are Evaporator, Condenser & Wick structure. Adiabatic section is used to connect evaporator and condenser section. Heat pipe can be differentiate on the basis of wick structure as wick heat pipe and wickless heat pipes ,in wickless category there are Thermosyphon and Pulsating heat pipes .In this literature focus is on pulsating heat pipes (PHPs). [1] In Conventional Heat Pipe, Capillary force is responsible for liquid transport from condenser to evaporator, in Thermosyphon the position of evaporator is always below the condenser and liquid transport is due to gravity as driving force. PHPs are also providing the pump less system but the force which ensure the fluid transport is pulsating action of working fluid.

Pulsating heat pipe is new addition in wickless heat pipe family with promising heat transfer capacity introduced by Akachi in 90's. He further patent on PHP which is long meandering tube heated and cooled at two separate ends, the operation of PHP is depends on oscillation / pulsating action of working fluid inside the tube. [2] According to Akachi PHP is " When one end of the bundle of turns of the undulating capillary tube is subjected to high temperature, the working fluid inside temperature increases vapour pressure which causes the bubble in the evaporator zone to grow, this pushes the liquid column towards the low temperature end, the condensation at the low temperature end will further increases the pressure deference between the two ends, because of the interconnection of the tubes, motion of the fluid slug and vapour bubbles at one end section of the tube towards the condenser also leads to the motion of slugs and bubbles in the next section towards the high temperature end. This works as restoring force. The Inter-play between the driving force and restoring force leads to oscillation of the vapour bubbles and liquid slugs in the axial direction. The frequency and amplitude of the oscillation are expected to be depend on the shear flow and mass fraction of the liquid in tube".[3] Pulsating heat pipes are preferable for thermal control in different space applications due to its high thermal performance.

II. SELECTION OF WORKING FLUID

Heat pipes fluids are ranked by the Merit number:

$$N1 = \frac{\rho 1 \sigma \lambda}{\mu 1}$$

Where,
ρl = Liquid density
σ = Surface tension
λ = Latent heat
μl = Liquid viscosity

High liquid density and high latent heat reduce the fluid flow required to transport a given power, while high surface tension increase the pumping capability. A low liquid viscosity reduces the liquid pressure drop for a given power. The Merit number is derived below. The Merit number as a function of temperature is shown in Figure for a number of typical heat pipe working fluids. From the figure, it is very clear why water is chosen as the heat pipe working fluid whenever possible. Its Merit number is ~10 times higher than everything else except the liquid metals, meaning that it will carry ten times more power (in the proper temperature range) than other working fluids.

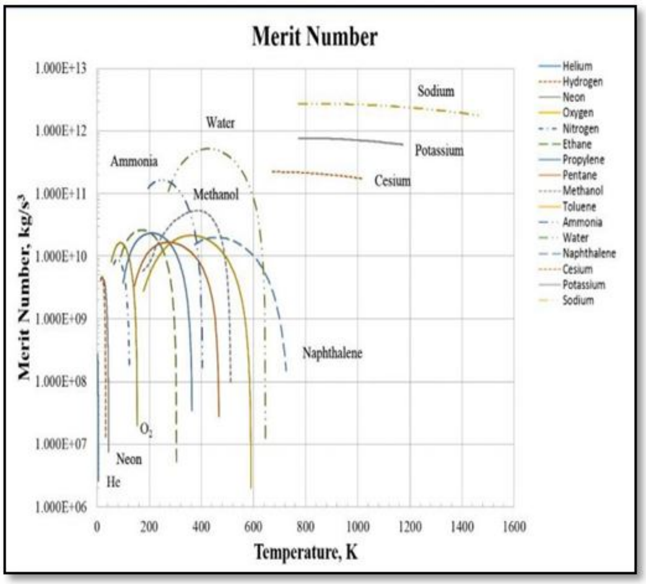

Chart.2.1 Temperature Range V/S Merit Number

Table 2.1 - Merit number of different working fluids [10]

Sr. No.	Working Fluid	Merit Number
1.	Ammonia	10^8 – 10^11
2.	Methanol	10^8 – 10^10
3.	Naphthalene	10^8 – 10^10
4.	Helium	10^7 – 10^10
5.	Ethanol	10^6 – 10^10
6.	Hydrogen	10^7 – 10^9
7.	Water	10^7 – 10^12

Thermo-Physical properties of different working fluids are as given in the table below

Table 2.2 Thermo-Physical properties of different working fluids [5]

Working Fluid	Satura -tion Temp, Tsat (◦C)	Specific Heat, Cp (KJ/kg◦ K)	Thermal Conductivity (KW/m◦ K)	Latent Heat, hfg (KJ/kg◦ K)
Methanol	64.7	2.48	0.212	1101
Ethanol	78.3	2.39	0.172	846
Acetone	56.2	2.35	0.170	523
Water	100	4.18	0.599	2257

- Cost of different Nanofluids is

Table 2.3 Cost of different Nanofluids[11]

Nanofluid	Costing(In Rs.)
Al_2O_3	4350/10gm
CuO	4850/10gm
CuO_2	5000/10gm
Pure water	20/liter
Silver	5000/10gm

(Note- Cost of different nanofluids are as per quoted by M/S. L. N. Chemical Industries , Andheri, Mumbai, Maharashtra.)

The selection of the working fluid used in pulsating heat pipes is dependent on a number of variables. The approximate temperature range the system will be exposed to be the most critical in determining the proper working fluid. Using an approximate temperature range of 50 to 150 degrees Celsius in turn means many potential working fluids are possible options. Additional requirements need to be examined as well and are listed below:

- Thermal stability
- Wet-ability
- Reasonable vapor pressure
- Compatibility with heat pipe materials
- High thermal conductivity and latent heat
- Low vapor and liquid viscosities
- Reasonable freezing point

For this experiment and various other experiments involving pulsating and oscillating heat pipes, distilled water is used as the working fluid. Water was chosen for its thermodynamic attributes that make it more appealing than others, such as methanol. It has a high latent heat of vaporization of 2260 kJ/kg which has the potential to spread significantly more heat with less fluid flow. Latent heat is defined as the heat required converting a solid into a liquid or vapor, or a liquid into a vapor, without a change in temperature.

III. EXPERIMENTAL SET UP

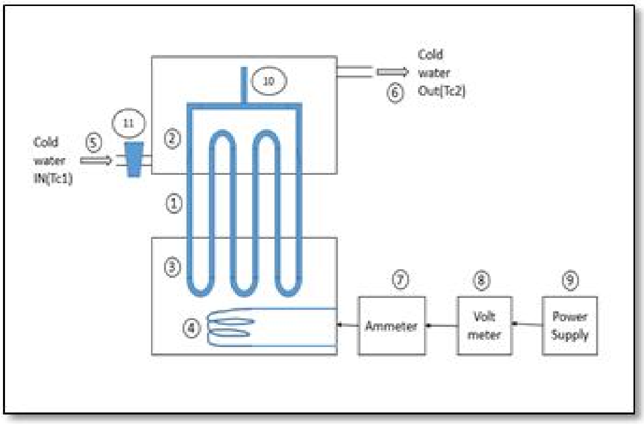

Figure 3.1 Schematic Diagram of Experimental set up

Where,

1 - Adiabatic section of PHP

2 – Evaporator

3 – Condenser

4 – Heater Coil

5 – Cold water Inlet of Condenser

6 – Hot water outlet of condenser

7 – Ammeter

8 – Voltmeter

9 – Power Supply

10 – NRV

11 – Rotameter

IV. EXPERIMENTAL PROCEDURE

1. Arrange the setup and make sure that all the connections are correct.
2. Start the water supply and wait for 15 minutes so that the flow of water is stabilized.
3. Once steady flow rate is achieved, switch on the power supply and adjust the dimmer stat to supply required power supply & achieve required evaporator temperature.
4. Note the temperatures on the PHP condenser, evaporator inlet and outlet of the water after 5 minutes of set up stabilization.
5. Note the steady state temperature readings once the temperatures stop rising for minutes (i.e. 4 temperature readings)
6. Repeat the process from 3 to 5 by increasing the mass flow rate.
7. By measuring the temperature difference between evaporator and condenser, and the power supplied, calculate the thermal resistance of the pulsating heat pipe.
8. From condenser inlet & outlet temperatures and input power supplied, efficiency of PHP can be calculated.
9. Repeat the same process from point no.1 to 8 for different water filling ratio in PHP.

V. RESULTS

5.1. Observations & Readings-

5.1.1- Readings at 30% Filling Ratio-

Sr. No.	Mass flow rate (LPH)	Te (◦C)	Tc1 (◦C)	Tc2 (◦C)	ΔT (◦C)	Qact (W)
1.	30	75	28.10	34.05	5.95	209.27
2.	40	75	28.15	32.80	4.65	218.06
3.	50	75	28.10	31.90	3.80	222.74
4.	60	75	28.12	31.22	3.10	218.02

Sr. No.	Mass flow rate (LPH)	Qth = V × I (W)	η	η_{avg}	Rth (◦C/W)
1.	30	299	69.98	72.56	0.1318
2.	40	299	72.92		0.1405
3.	50	299	74.42		0.1438
4.	60	299	72.91		0.1471

Sr. No.	Mass flow rate (LPH)	Te (◦ C)	Tc1 (◦C)	Tc2 (◦C)	ΔT (◦C)	Qact (W)
1.	30	75	28.12	34.42	6.3	232.20
2.	40	75	28.23	33.33	5.1	239.40
3.	50	75	28.15	32.35	4.2	246.20
4.	60	75	28.19	31.59	3.4	239.43

5.1.2- Readings at 40% Filling Ratio-

Sr. No.	Mass flow rate (LPH)	Qth = V × I (W)	η	η_{avg}	Rth (◦C/W)
1.	30	299	74.59	79.47	0.1243
2.	40	299	80.01		0.1328
3.	50	299	83.30		0.1376
4.	60	299	79.98		0.1402

5.1.3- Readings at 50% Filling Ratio-

Sr. No.	Mass flow rate (LPH)	Te (◦ C)	Tc1 (◦C)	Tc2 (◦C)	ΔT (◦C)	Qact (W)
1.	30	75	28.22	34.42	6.20	218.06
2.	40	75	28.15	32.97	4.82	226.03
3.	50	75	28.19	32.02	3.83	222.75
4.	60	75	28.12	31.37	3.25	228.61

Sr. No.	Mass flow rate (LPH)	Qth = V × I (W)	η	η_{avg}	Rth (◦C/W)
1.	30	299	72.93	74.87	0.1275
2.	40	299	75.59		0.1372
3.	50	299	74.49		0.1411
4.	60	299	76.46		0.1433

5.1.4- Readings at 60% Filling Ratio-

Sr. No.	Mass flow rate (LPH)	Te (◦ C)	Tc1 (◦C)	Tc2 (◦C)	ΔT (◦C)	Qact (W)
1.	30	75	28.02	33.82	5.80	203.10
2.	40	75	28.11	32.43	4.32	202.58
3.	50	75	28.10	31.58	3.48	203.92
4.	60	75	28.16	31.07	2.91	204.69

Sr. No.	Mass flow rate (LPH)	Qth = V × I (W)	η	η_{avg}	Rth (◦C/W)
1.	30	299	67.93	68.08	0.1350
2.	40	299	67.75		0.1437
3.	50	299	68.20		0.1472
4.	60	299	68.45		0.1505

5.1.5- Readings at 70% Filling Ratio-

Sr. No.	Mass flow rate (LPH)	Te (◦ C)	Tc1 (◦C)	Tc2 (◦C)	ΔT (◦C)	Qact (W)
1.	30	75	28.07	33.37	5.30	186.40
2.	40	75	28.16	32.28	4.12	193.20
3.	50	75	28.22	31.43	3.21	187.58
4.	60	75	28.19	30.85	2.66	187.12

Sr .No.	Mass flow rate (LPH)	Qth = V × I (W)	η	η_{avg}	Rth (◦C/W)
1.	30	299	62.34	63.07	0.1385
2.	40	299	64.61		0.1469
3.	50	299	62.73		0.1501
4.	60	299	62.58		0.1538

5.2 Calculations-

5.2.1 Heat Transfer Rate through Condenser-

The temperature change of the condenser section's inlet water & outlet water was measured to calculate heat transfer rate of PHP. The heat transfer rate of PHP at condenser section can be calculated by,

$$Qact = mCp(Tc1 - Tc2)$$

5.2.2 Input Power supplied to Evaporator-

The input power is supplied to evaporator through electrical heater, hence input power is given by,

$$Q = V \times I$$

Here, V = Voltage = 230 V……….(Reading taken from Voltmeter)
& I = Current = 1.3 A…………(Reading taken from Ammeter)

$$Q = 230 \times 1.3$$
$$Q = 299\ W$$

5.2.3 Efficiency of PHP-

The efficiency of pulsating heat pipe can be calculated by using formula,

$$\eta = \frac{Qact}{Qinput}$$

5.2.4 Heat Flux of PHP-

The heat flux rate of pulsating heat pipe can be calculated as,

$$q = \frac{Q}{\pi\ DLcN}$$

5.2.5 Thermal Resistance of PHP-

Thermal Resistance of pulsating heat pipe can be calculated as,

$$Rth = \frac{Te - Tc}{Qinput}$$

5.2.6 Volume of PHP-

Volume of PHP = No. of turns × Area of PHP × Length

= n × ∏Dc × L
= 6 × ∏ × 0.003 × 0.250
= 0.01415 m3

5.3. Results –

5.3.1 Graph of actual heat transfer in condenser V/S mass flow rate at different F.R.-

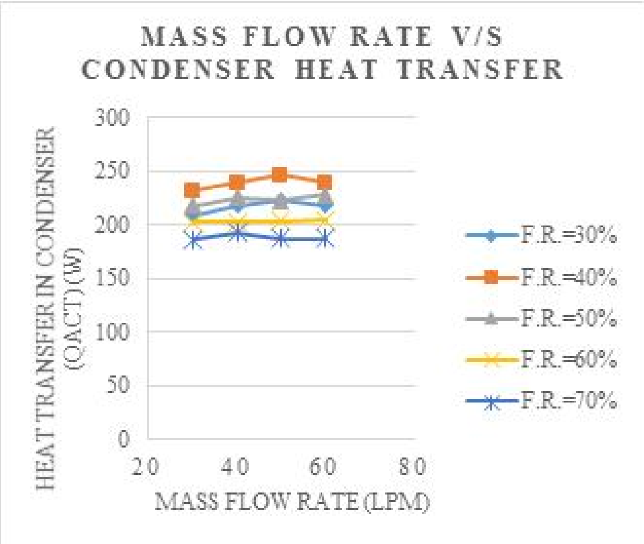

Figure 5.3.1 Graph of actual heat transfer in condenser V/S mass flow rate at different F.R

Above graph shows the relationship between mass flow rate & heat transfer in condenser at different filling ratios. It shows that heat transfer rate in condenser is maximum at 40 % filling ratio of water inside pulsating heat pipe. Minimum heat transfer is observed at 70 % filling ratio.

Hence it is very clear that optimum heat transfer occurs at 40 to 50 % filling ratio of water inside heat pipe.

5.3.2 Graph of efficiency V/S different mass flow rate at different F.R.-

Below graph shows relationship between efficiency of PHP at different mass flow rate of cooling water inside the condenser. Comparison of efficiencies at different filling ratio is carried out. It is observed that maximum efficiencies occur at 40 to 50 % filling ratio.

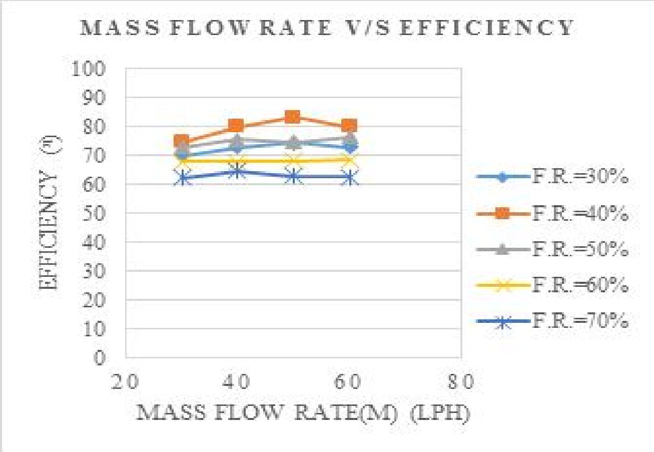

Figure 5.3.2 Graph of efficiency V/S different mass flow rate at different F.R

It is the optimum range of heat transfer to get desirable results.

5.3.3 Graph of average efficiency V/S mass flow rate at different F.R.-

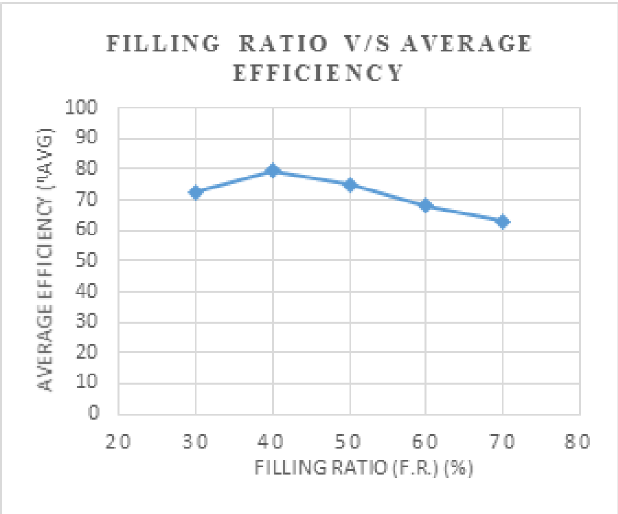

Figure 5.3.3 Graph of average efficiency V/S mass flow rate at different F.R

Above graph shows the relationship between average efficiency at different filling ratio of water inside PHP. It is observed that maximum efficiency upto 79.47 % is observed at 40 % filling ratio of water. Hence we can say that 40 % filling ratio is optimum filling ratio for pulsating heat pipe. Minimum efficiency 63.07 % is observed at 70 % filling ratio.

5.3.4 Graph of Thermal Resistance V/S mass flow rate at different F.R.-

The graph shown below explains the change of thermal resistance of pulsating heat pipe when mass flow rate of cold water inside condenser is changed. Readings are taken at filling ratios of 30%, 40%, 50%, 60% & 70 %. When graph of readings is plotted, it is seen that minimum thermal resistance of pulsating heat pipe is observed at 40 % filling ratio of water & maximum thermal resistance is offered by pulsating heat pipe at 70 % filling ratio.

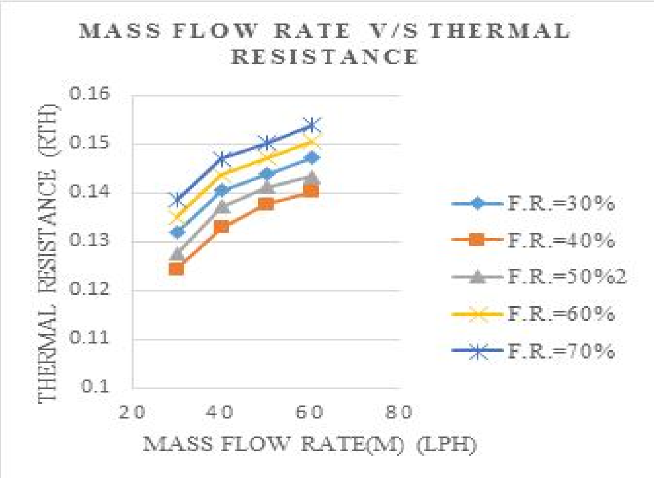

Figure 5.3.4 Graph of Thermal Resistance V/S mass flow rate at different F.R

VI. CONCLUSION

1. It is concluded that best results are obtained at 40% filling ratio in closed loop pulsating heat pipe by using water as working fluid.
2. Heat transfer rate increases as mass flow rate through condenser decreases.
3. Thermal resistance of PHP is minimum at 40% FR and maximum at 70% F.R.
4. Water is cheapest working fluid for PHP at working temperature range of 40◦C to 150◦C & easily available.

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