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Optimization Process Parameters for a Single Loop Pulsating Heat Pipe Heat Exchanger

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ABSTRACT-An experimental investigation on single loop pulsating heat pipe(PHP) is presented in this work. A closed pulsating heat pipe heat exchanger with a single turn is fabricated by brass tube with 2 mm diameter and408 mm long andtested. The un-steady and steady state experiments are conducted and operating temperatures are measured. The experiments are conducted for different working fluids, heat inputs and maintained filling ratio as constant (50%). The derivedparameters consist of thermal resistance and heat transfer coefficient of PHP. The outcomes of this experiments show in periodic movement of the working fluid at lower values of heat input. The evaporator temperature at steady state is raisehigher for ethanol (C2H5OH) compared to acetone (H3CHO) and methanol(CH3OH). The condenser temperature at steady state is form lesser for acetone compared to methanol and ethanol. The temperature difference between evaporator and condenser at steady state is creating lesser for acetone compared to the methanol and ethanol.Lower value of thermal resistance and higher value of heat transfer coefficient are realized in case of acetone compared to methanol and ethanol.

KEYWORDS*: *Pulsating heat pipe, Thermal performance, Working fluid, Thermal resistance.

NOMENCLATURE:

A_s	surface area of condenser (m^2)	R	Thermal resistance (K/W)
h	Heat transfer coefficient($W/m^{2\,0}C$)	T_e	Evaporator temperature(^0C)
Q	Heat input (W)	T_c	Condenser temperature (^0C)
PHP	Pulsating Heat Pipe	t	Time(s)

1.INTRODUCTION

Heat transfer management is the demanding of the day in the electronic product development presently, the chip heat flux level ranges between 50 to 150W/cm^2.It is expected to development 200W/cm^2 in the next coming few decades. Several cooling processes are employed to cool the electronic chips.The oscillating or pulsating heat pipe (PHP) is being research for cooling electronic components with talented results. The PHP is simple in design structure with a small diameter coil filled with working fluid in it and spread from the heat source to sink. Heat pipe heat exchangers are one of the most efficient devices for waste heat recovery.The heat pipe is a simple design device that can instantly transfer heat from one point to another point. They are often referred to as the “superconductors” of heat as they maintainan fantastic heat transfer capacity and with norate of heat loss.PHP uses the technique of bring the working fluid by means of differential pressure across liquid slugs and vapor plugs from the evaporator to the condenser and returns back. The fluid from the evaporator is forced towards the condenser in the form of discontinuous liquid slugs and vapor plugs.The rate of heat loss from a hot body is governed generally by Newton’s Law of Cooling – this states that the rate of loss of heat is proportional to the temperature difference between the hot body and the surroundings. The vapor gets moderately condensed at the condenser and loses the heat and arrival to evaporator to complete the cycle.The heat transfer in a PHP is due to the sensible and latent heat combination.Pulsating heat pipe first proposed by Akachi (1993,1996)) as a passive device is gaining attention of more investigators.

Zhang and Faghri (2003) studied numerically the pulsating flow in a PHP with arbitrary number of turns. The authors considered a vertical PHP with evaporator section at the top and condenser section at the bottom.The Governing mathematical statement are non-dimensionalised and the problem was analyzed with eight non-dimensional numbers. The effects of number of turns, length of the heating and cooling section were investigated. In the above works, heat transfer in PHP is investigated considering the pressure difference between evaporator and condenser as the dynamic force.A mathematical model which deals with the oscillating movement of the working fluid in a PHP was proposed by Ma et al. (2006) based on temperature difference between the evaporator and condenser as the dynamicforce.This model established the relation between oscillating frequency and geometry, thermal potential filling ratio, working fluid and operating temperature.The results of their study are used to understand the structure governing the pulsating phenomenon in a PHP. The authors describe the pressure difference using Clausius - Clapeyron equation. The model was determined for the displacement of the liquid slug and highlights the characteristics of the PHP in the saturation region.The authors treatedwater and acetone as the working fluid in their research.Rama Narasimhaet al.(2010) used the Ma et al.(2006) model and solved the governing equation for the displacement and the velocity of the vapor plug using explicit embedded Runge – Kutta formula, Dormand-Prince pair.Their results exhibit that the slug velocity is influenced by the filling ratio, the diameter of the tube, the operating temperature, the temperature difference between evaporator and condenser and the working fluid. They were investigated the flow characteristics of PHP with non-dimensional numbers viz. Poiseuille Number, capillary Number and Eckert Number.

An experimental study on PHP was carried out by Zhang et al. (2004) with FC-72, ethanol and water used as working fluids. The experimental set-up mainlyconsists of copper tubes of inner diameter 1.17 mm and also the number of turns was 3. The authors were realized that the amplitude of thermal pulsations reported was small for FC-72. Comparedto water and ethanol due to its lesser surface tension. The pulsation movement in the channels was found to be faster in case of FC-72 compared to the other fluids. This quick movement of FC-72 in the channels was associated to its low latent heat value. They recommended water as the better working fluid beyond a minimum heat input. They also showed that FC-72 is more suitable for low heat flux situations.Khandekar (2004) prove the existence of multiple quasi-steady state in a PHP by promoting an experimental test rig of a single loop PHP made of copper tubes of inner diameter 2 mm and outer diameter 3 mm. The experiments were conducted for heat inputs of 10 W, 15w and 20 W with ethanol as the working fluid at 60% filling ratio and continuous online data were recorded for 12 hours.The multiple quasi steady states observed were named as steady state 1, 2 and 3. The flow in steady state 1 was unidirectional with back upfluid flow movement. Higher value of thermal resistance was observed in steady state 1.In steady state 2 a tendency of liquid hold – up was observed in the condenser section which made the evaporator region drier and hotter. Extremely poor thermal performance was reported in steady state 2. In steady state 3 resulted unidirectional flow pattern with no stop-over leading to thermal resistance.

2. EXPERIMENTAL SETUP

Figure 1 shows the schematic diagram of the experimental setup. In this setup, brass is used as the tube material with inner diameter of 2 mm and outer diameter of 2.5 mm. In order to vision the fluid flow in the PHP, the glass tube is linked to the brass tubes for a length of 60 mm. In this present research borosilicate glass of inner diameter 2 mm and outer diameter 3 mm is employed. Silicon rubber tubes of 2 mm inner diameter and 4 mm outer diameter are used as connecters between glass and brass tubes, both in the evaporator and condenser section.The silicon rubber tubes are occupied as connectors because they are thermal insulators and can resist high temperatures up to 400^0C.They are leak proof and enlarge at higher temperatures. As the glass tube is connected to the brass tubes both in evaporator and condenser sections through these silicon rubber tubes, the brass tube is not in direct contact with the glass tube. Since the thermal conductivity of the glass tube is extremely low compared to brass tube, very little heat will be flowing through the glass wall. Thus glass tube can be considered as adiabatic which many authors have used in the earlier literature (Khandekar 2004).It is also observed during the experiments that the glass section is very slightly warmer and can be comfortably touched by hand.The purpose of the glass tube is to check the flow configuration.

A tape heater of heating capacity 0-50W is used to heat the working fluid. T-type thermocouples are used for the temperature measurement. The operating temperature range of these T-type thermocouples is -50^0C to 400^0C with maximum error of $\pm 0.1^0$C. In the present setup totally eight thermocouples are used, four in the evaporator section and four in the condenser section.The thermocouples are fixed to the brass tube by drilling a small indention on the brass tube and fixing the beed into the indentation by force fit. A Krypton tape is wound on the thermocouples beed and the thermocouple wire. A temperature data logger is used for recording the temperature values. The temperature values are recorded with a frequency of 1 Hz.The glass wool is uniformly apply throughout the entire setup so as to ensure that the experimental setup is well insulated. The experimental setup is operated with three different working fluids viz., acetone, methanol and ethanol.

Fig.2. 1 Experimental setup

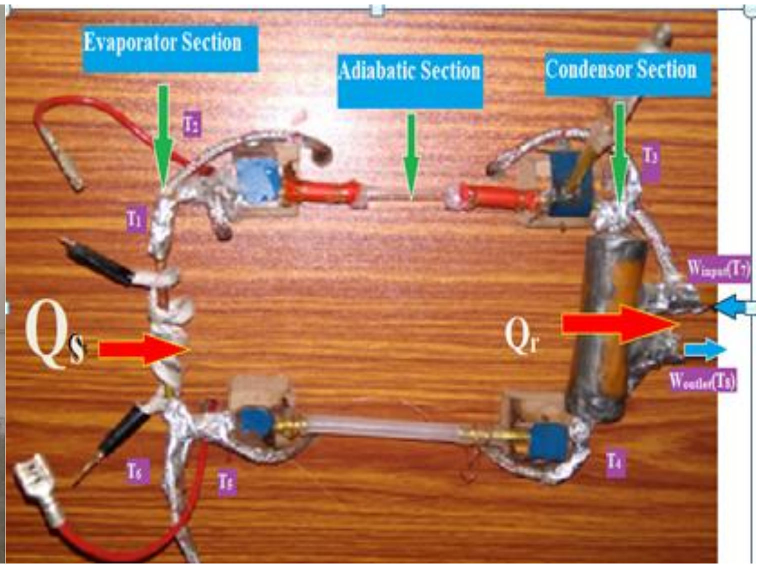

Fig 2.2 Single loop pulsating heat pipe`

3. EXPERIMENTAL PROCEDURE

The experimental setup shown in fig. 2.1 is used for experimentation and the following procedure is adapted during the present transient experiment:

Step1: Before filling the working the fluid, it is ensure that there is no other fluid exists inside the tube of heat pipe so clean the PHP using the de-ionized water injected by a small injector.

Step2: In the present work,the experiments were carried out with only at atmospheric condition (1 bar) considering the boiling point of the fluids used at this pressure.

Step3: The working fluid of desired quantity that is filling ratio (50%) is then filled keeping one end of the filling valve using a syringe.So that the fluid directly enters the evaporator section. Literature studies of Khandekar et.al reveal that true pulsation flow in PHP could be seen for the fill ratios between 20% to 80% with 50% filling ratio is stated to be optimum one. Hence in the present work experiments are conducted for the fill ratios ranging from 50 to 80%.

Step4: The cooling water is passed to the condenser section of PHP from the constant height of water bath and the amount of cooling water is controlled in such way that the temperature rise of cooling water in the condenser is always between 1^0C to 2^0C

Step5: The temperature data logger is then switched on to record the temperature readings is adapted to 1 Hz

Step6: The required wattage is set using the power supply unit. In this present work, the experiments were conducted by varying the heat inputs from 8 W to 12 W in steps of 1 W

Step7: The un-steady experiments are conducted along with different working fluids are acetone, methanol and ethanol and the various temperatures are directly recorded with the help of data logger. The experiments are continued till up to the steady state is reached.

4. RESULTS AND DISCUSSION

4.1 Effect of Heat Input on Temperature

As there is a regular pressure pulsation during the flow in a PHP, there will be variation in both the evaporator and condenser temperatures even at steady state. Mainly four thermocouples mounted in the evaporator and four in the condenser and hence the uncertainty in the evaporator temperature and condenser temperature U_e and U_c are evaluated respectively as

$$\%U_e=\sqrt{\left(\frac{\Delta T_1}{T_1}\right)^2+\left(\frac{\Delta T_2}{T_2}\right)^2+\left(\frac{\Delta T_5}{T_5}\right)^2+\left(\frac{\Delta T_6}{T_6}\right)^2} \quad (1)$$

$$\%U_c=\sqrt{\left(\frac{\Delta T_3}{T_3}\right)^2+\left(\frac{\Delta T_4}{T_4}\right)^2+\left(\frac{\Delta T_7}{T_7}\right)^2+\left(\frac{\Delta T_8}{T_8}\right)^2} \quad (2)$$

The maximum uncertainty obtained in the temperature readings using Equations. (1) and (2) is about 5%.A typical transient fluctuations showing the deviation of evaporator wall temperature with time at the atmospheric pressure for acetone is shown in fig. 4.1. It can be seen that the variation of evaporator temperature with respect to time is intermittent in nature at steady state.As there is a repeated pressure pulsation during the flow in a PHP, the evaporator temperature versus time curve is repeated in nature.It is also observed that the variations in the evaporator temperature are high at higher heat input of 12 W due to intermittent motion of the working fluid.It is also observe that the system taking more time to reach the steady state condition at lower heat input of 8 W.

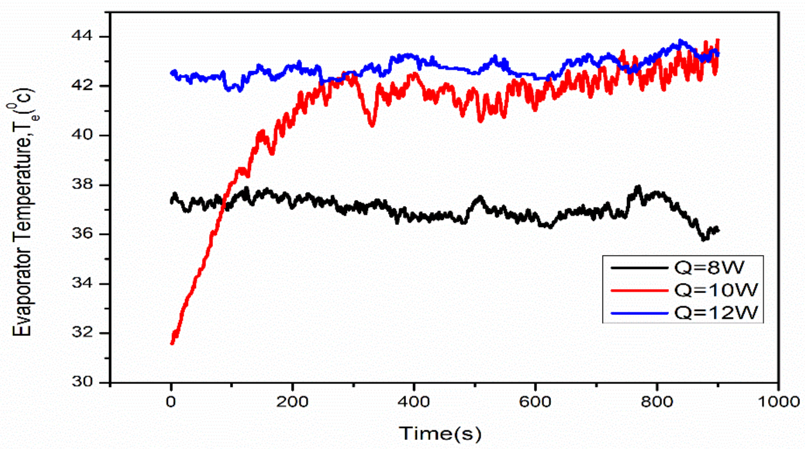

Fig. 4.1 Effect of the heat input on evaporator temperature

Figure 4.2 shows the fluctuation of condenser temperature wall temperature with respect to the time at different heat inputs for acetone. It is clear from fig. 4.2 that the fluctuation of condenser temperature is less at lower heat input of 8 W compared to higher heat input of 12 W. This is because of the very slow and periodic motion of the working fluid at lower heat input. Mainly the flow of the working fluid is slow at lower heat input due to lower energy layers. The hot fluid takes more time to reach the condenser from the evaporator.

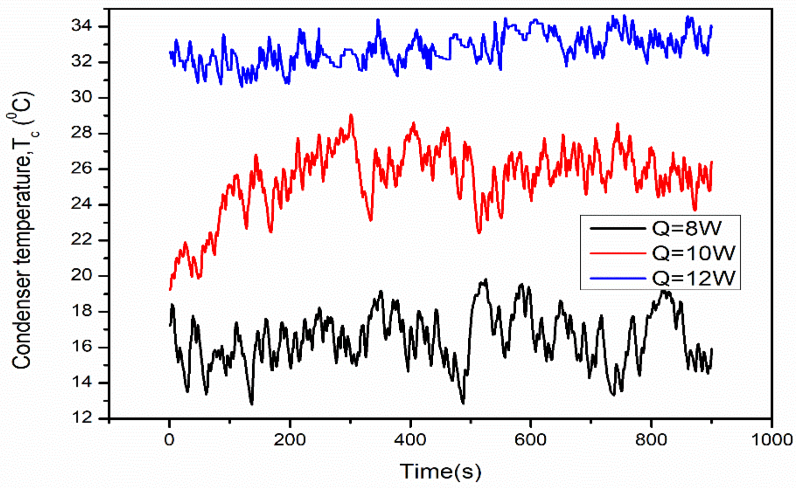

Figure 4.2 Effect of the heat input on condenser temperature for acetone.

Figure 4.3 shows the plot of temperature difference with respect to the time for acetone at different heat inputs. From Fig. 4.3 it is visible that temperature difference between evaporator and condenser decreases with increase in heat input. As the movement of the fluid is very slower at low heat input which is correlated with lot of variations, the temperature difference between evaporator and condenser is higher at lower heat input.

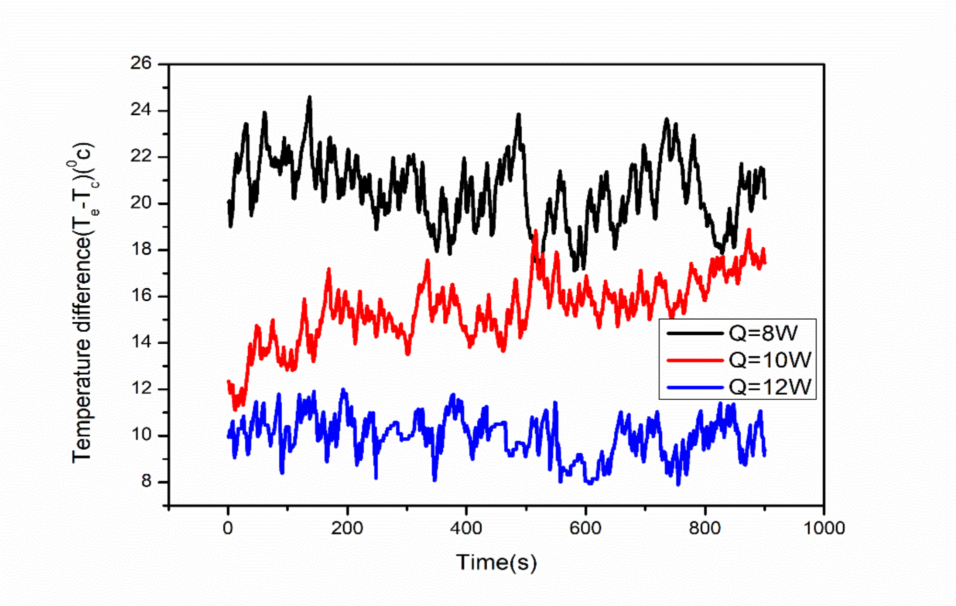

Fig4.3 Effect of heat input on temperature difference for acetone

4.2 Effect of working fluid on temperature

The fluctuation of evaporator wall temperature with respect to the time for different working fluids at the atmospheric pressure and at a heat input of 12 W is shown in fig 4.4 .From the figure 4.4 it can be seen that the evaporator wall temperature is more in case of ethanol and less in the case of acetone due to greater saturation temperature for ethanol. It is also observed that the system takes more time to reach the steady state condition in case of ethanol compared to acetone. More deviations are observed in evaporator wall temperature of ethanol in view of its high latent heat.

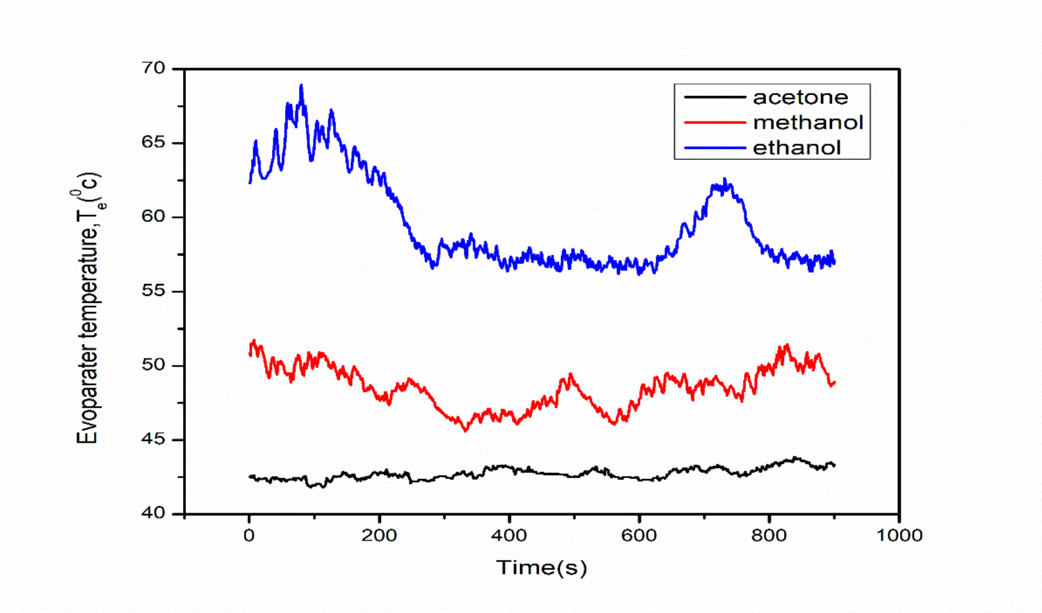

Fig 4.4 Effect of working fluid on evaporator temperature at Q=12 W

The variation of condenser wall temperature with the time for different working fluids at an atmospheric pressure and at a heat input of 12 W is reported in the fig 4.5.Fromfig 4.5. It is clear that the variations in the condenser wall temperature are much lowered compared to the wall temperature of evaporator (fig. 5). It is also clear that the condenser wall temperatures are lower for ethanol and higher for acetone. As there is an presence of less vapor while entering into the condenser in case of ethanol, only a small amount of heat will be liberated due to latent heat. This outcomes in higher condenser wall temperature for acetone and lower condenser wall temperature for ethanol.

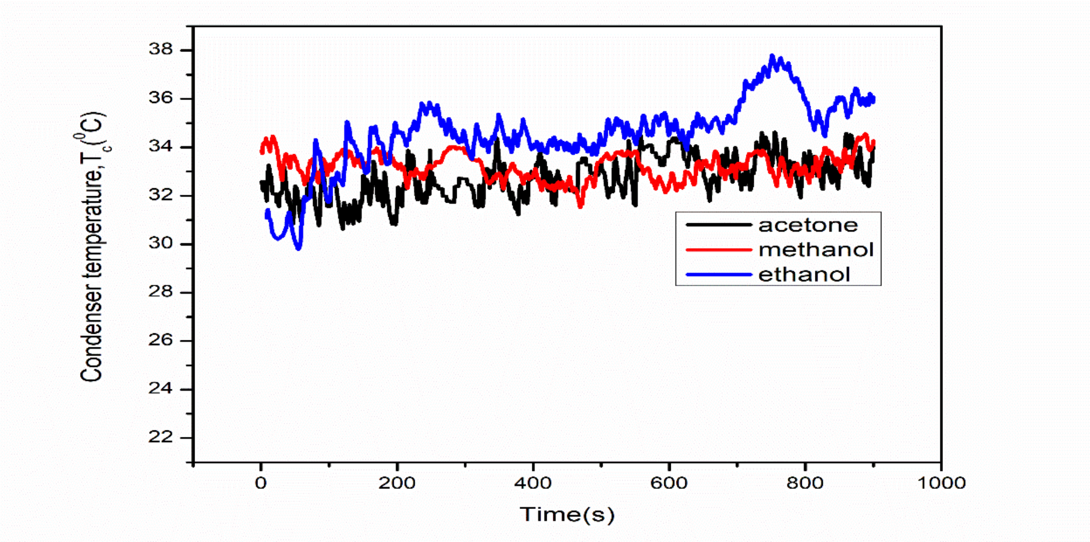

Fig 4.5. Effect of working fluid on condenser temperature at Q=12 W

Figure 4.6 shows the fluctuation of temperature difference between evaporator and condenser with time for different working fluids at heat input of 12W. It is seen that the temperature difference between the evaporator and the condenser is less for acetone and more for ethanol. This is due to the fact that the saturation temperature of acetone is lower compared to ethanol. The fluctuations in temperature difference values are much lower for acetone compared to ethanol due to higher vapor contents in case of acetone. This shows that acetone can transfer heat with less temperature difference compared to ethanol. The temperature difference value between evaporator and condenser for the acetone is found to be around 12℃ and for the ethanol it is around 37^{0}C.

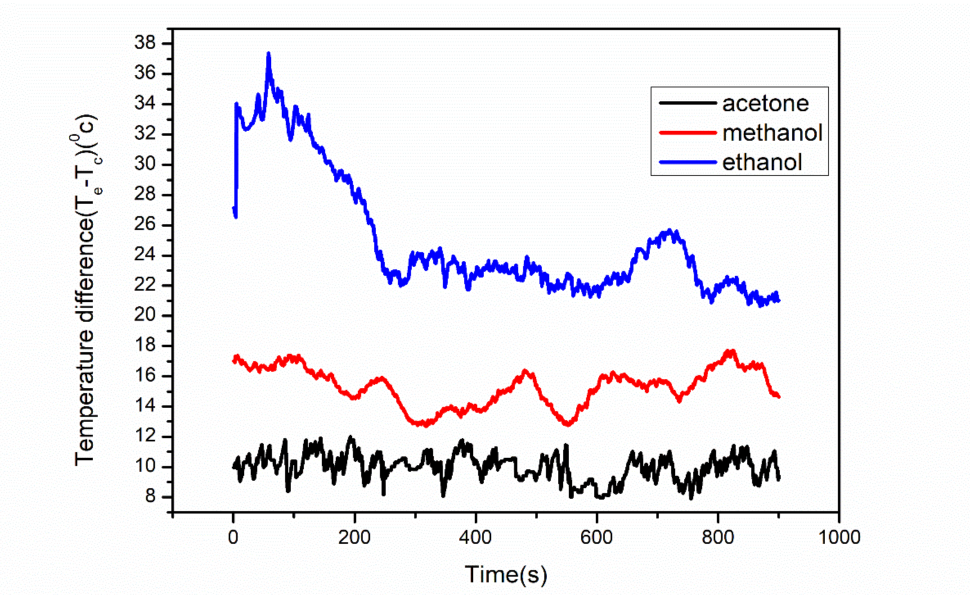

Fig 4.6. Effect of working fluid on temperature difference at Q=12W

4.3 Effect of working fluid on thermal resistance

The Thermal Resistance of Pulsating heat pipe is given by $R=\frac{T_e - T_c}{Q} \quad (\frac{K}{W})$ (3)

Figure 4.7 shows the variation of thermal resistance with varying heat input for the different working fluids under the atmospheric pressure conditions. From the figure it is clearly the thermal resistances of different working fluids aredecreases with increases in heat input at atmospheric conditions. Further, it is observe that acetone display low values of thermal resistance compared to the other working fluids of methanol and ethanol.This is mainlydue to lower values of temperature difference between evaporator and condenser in the presence of acetone. The lower values of thermal resistance of acetone indicate that acetone has better heat transport capacity compared to the other working fluids considered.

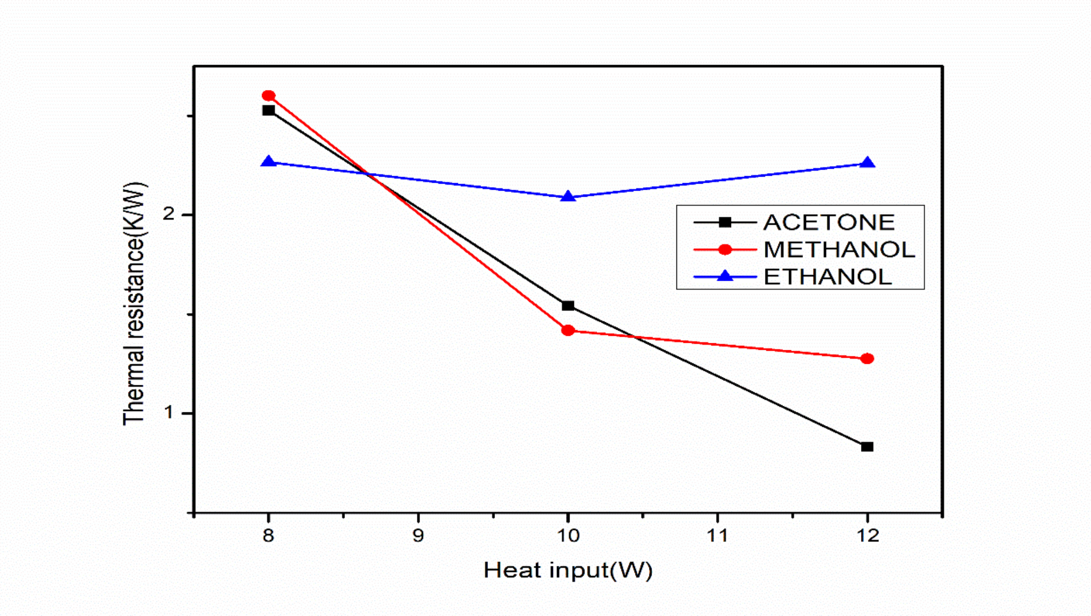

Fig 4.7. Effect of working fluids on thermal resistance

4.4 Effect of working fluid on heat transfer coefficient

The heat transfer coefficient of a Pulsating Heat Pipe is given by (Faghri 1995)

$$h = \frac{Q}{As(Te - Tc)} \text{ (W/m℃)} \qquad (4)$$

Figure 4.8 shows the deviation of heat transfer coefficientwith varying heat input for different working fluids at atmospheric conditions.From figure 4.8, clearly it shows that the heat transfer coefficient values increases along with increase in heat input for all the working fluids considered. The fluid acetone shows high heat transfer coefficient value compared to the other working fluids assumed. This is mainly due to the lower values of temperature difference between evaporator and condenser for acetone.

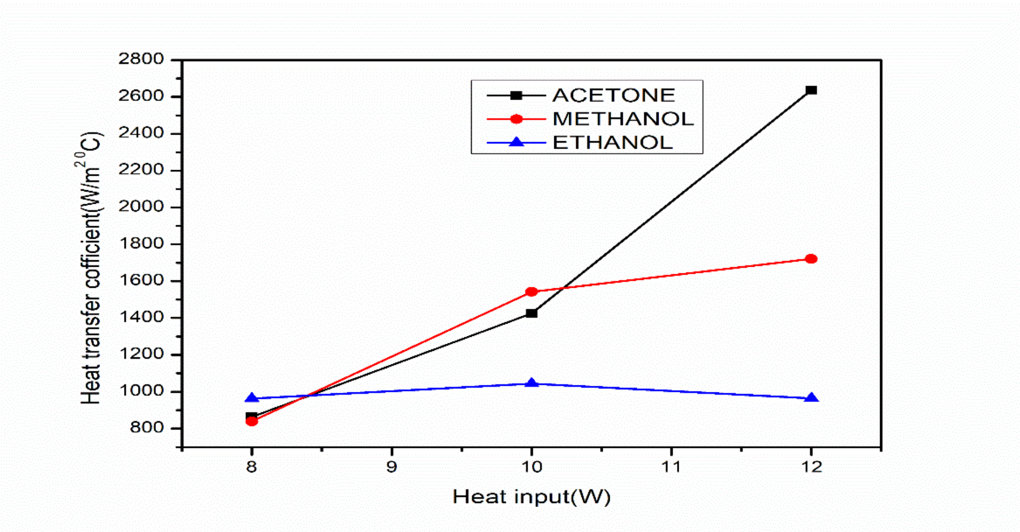

Fig 4.8. Effect of working fluid on heat transfer coefficient

5. CONCLUSION

1. The transient fluctuations of pulsating heat pipe are conferred exclusively in this present work. The effects of heat input, thermal resistance and heat transfer coefficient on the achievement of PHP are examined through experimentation.
2. The results of the present study are summarized as follows:
3. The temperature difference values between evaporator and condenser at steady state is form to be lesser for acetone compared to the working fluids ofmethanol and ethanol.
4. Higher variations are realized in wall temperature for ethanol compared to the other working fluids.
5. Lower values of thermal resistance are observed for acetone comparing to the other fluids.
6. Higher values of heat transfer coefficient are realized for acetone compared to the other fluids.
7. Acetone is observed to be most suitable working fluid for the PHP operation.

REFERENCES

1. Akachi, H. (1996). Structure of heat pipe. US Patent,5490558.
2. Akachi, H. (1993). Structure of heat pipe. US Patent,5219020.
3. Faghri, A. (1995). Heat Pipe Science and Technology. Taylor and Francis, Washington.
4. Khandekar, S. (2004). Thermo hydrodynamics of Pulsating Heat Pipes. Ph. D. Dissertation, University of Stuttgart, Germany.
5. Rama Narasimha, K., S.N. Sridhara, M.S. Rajagopal, and K.N. Seetharamu (2010). Parametric studies on pulsating Heat Pipes. International Journal of Numerical Methods for Heat and Fluid Flow 20(4), 392-415.
6. Rama Narasimha, K., S.N. Sridhara, M.S. Rajagopal (2008) .Experimental studies on Pulsating Heat Pipe. . International Journal of Mechanical Engineering 1 (1) ,46 – 49.
7. Xu, J.L., and X. M. Zhang (2005). Start-up and steady thermal oscillation of a Pulsating Heat Pipe. Heat and Mass Transfer 41,685-694.
8. Zhang, X. M. Xu and Z.Q. Zhou(2004). Experimental study of a Pulsating Heat Pipe using FC-72, Ethanol and Water as working fluids. Experimental heat Transfer 17,47-67.
9. Zhang, Y., and A. Faghri (2003), Oscillatory Flow in Pulsating Heat Pipes with Arbitrary number of turns. Journal of Thermo Physics and Heat transfer 17(3), 340-347.
10. ZhangY. and A. Faghri (2002).Heat Transfer in a pulsating heat pipe with open end .International Journal of Heat and Mass Transfer 45(4), 755-764.