Experimental Analysis of Heat Pipe with Acetone & Ethanol as a Working Fluid

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Abstract - *Thermal performance of the equipment's can be improved in many ways including two phase thermosyphon which is an efficient heat exchanger and can be used to enhance the heat transfer because of phase changes of working fluid .Thermosyphon have simple structure, low resistance, high efficiency and low fabrication cost.*

In this work two phase thermosyphon will be fabricated to investigate the effect of operating parameters on the heat transport capability. The system consist of evaporator section, adiabatic section, and condenser section with thermocouples located on the wall of thermosyphon. Electric heater will be fitted on the bottom of the evaporator section.

The experiments will conducted with three different thermosyphon with inner diameter of 12 mm, 9.5 mm and 6.7 mm. the variation of heat transport capability of the thermosyphon will studied for the input heat transfer rate ranging from 0 W to 1000 W for various filling ratio (30%, 60%, 90%) and with operating temperature (30^{0}C, 50^{0}C &70^{0}C) . Ethanol & Acetone use as working fluids.

Key Words: Thermosyphon, isothermalization, heat flux, Regression Analysis, Interaction Plot.

1. INTRODUCTION

Every day, cooling requirement in electronic industries increases abruptly due to greater functionality, faster operation, reduction in size and weight, and cost reduction of electronic products. Combination of faster operation and reduction in size resulted in high volumetric heat generation in electronic components leading to failure in the electronic device. Hence high performance heat dissipation devices are required to meet this demand. TPCT is one of the promising devices and hence, it is adopted for electronic cooling applications. Also the device is used in many applications such as energy storage system, thermoelectric power generators, power electronics, seasonal cooling load reduction of buildings, refrigeration systems, cooling super conducting bearings, boiler application, and heating and cooling applications. A thermosyphon is a two phase heat transfer device that transports heat from one point to another by phase change mechanism. In which the heat transfer takes place through evaporation and condensation processes, and the working fluid is re-circulated from the condenser to the evaporator by gravitational force. However, in some cases, the working fluid is re-circulated by capillary forces. Since the high performance weightless TPCTs are demanded in industries, many investigations have been performed by altering the design and working fluids.

1.1 Working Principles of Heat Pipe

The operation of a heat pipe is shown in Figure 1.1

The components of a heat pipe are a sealed container (pipe wall and end caps), a wick structure, and a small amount of working fluid which is equilibrium with its own vapor.

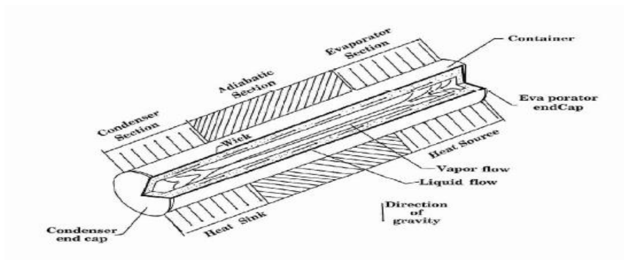


Figure 1.1 Schematic of a conventional heat pipe showing the principle of operation and circulation of the working fluid

The length of the heat pipe is divided into three parts: evaporator section, adiabatic (transport) section and condenser section. A heat pipe may have multiple heat sources or sinks with or without adiabatic sections depending on specific applications and design. Heat is applied to the evaporator section by an external source and it is conducted through the pipe wall and wick structure, where the working fluid vaporizes, The resulting vapor pressure drives the vapor through the adiabatic section to the condenser, where the vapor condenses, releasing its latent heat to the provided heat sink.

The condensed fluid is pumped back to the evaporator section by capillary pressure created in the wick pumps. So that, the latent heat of vaporization transport continuously from the evaporator section to thecondenser section. This process will be prolonged as long as enough capillary pressure is there to pump the condensate back to the evaporator.

1.2 Types of Heat Pipes

1.2.1 Two-Phase Closed Thermosyphon

A two-phase closed thermosyphon, a gravity-assisted wickless heat pipe.. The condenser section is placed above the evaporator so that the condensate is returned by gravity. When the thermosyphon is in steady operation, the internal flow is an annular, counter current and two phase flow. On the other hand, various fluid flow and heat transfer phenomena can prevent constant counter current, annular flow. Examples of such flow limiting phenomena are the dry out, burnout (or film boiling), and flooding limits.

1.2.2 Capillary-Driven Heat Pipe

The capillary-driven heat pipe consists of a sealed container, in which a wick is placed on the inner radius of the pipe wall. The need of the wick is to provide a capillary-driven pump for returning the condensate to the evaporator section. Working fluid is placed inside the sealed pipe to saturate the wick with liquid. Heat input to the evaporator section evaporates the liquid in the wick. The vapour then travels to the condenser section due to the high vapour pressure in the evaporator section. Heat is removed from the condenser and causes the vapour to condensate, and releases its latent heat of vaporization, the capillary force generated at the liquid-vapour interfaces of the pores in the wick makes the condensate to be pumped back to the evaporator section.

1.2.3 Annular Heat Pipe

The annular heat pipe is similar to the conventional capillary-driven heat pipe except that the cross section of the vapour space is annular instead of circular. The wick material can be placed both on the inside of the outer pipe and on the outside of the inner pipe. By this, the surface area for heat input and output can be increased significantly without increasing the outer diameter of the pipe. The annular heat pipe has been used as an isothermal fumes due to its temperature flattening capabilities and fast response time to a cold charge.

1.2.3 Loop Heat Pipe

The operating principle of loop heat pipe (LHP). At first, the liquid is loaded sufficiently to fill the condenser section, liquid line and vapour line and also enough liquid is filled in the evaporator and compensation chamber to saturate the wick. When a heat input is applied to the evaporator, fluid evaporates from the surface of the wick. Due to the high thermal resistance of the wick, the temperature and pressure within the compensation chamber is less than the evaporator. The capillary pressures developed in the wick prevent the flow of vapour from the evaporator to compensation chamber. When the pressure difference between the evaporator and compensation chamber increases, the liquid is moved from the vapour line and the condenser and return back to the compensation chamber.

2. Heat Pipe Applications

Heat pipe has been studied for a variety of applications, covering nearly the entire range of temperatures encounter in heat transfer processes. Heat pipes are used in a wide range of products like air-conditioners, refrigerators, heat exchangers, solar system, electronic cooling etc. It is also used in PC and laptops to reduce the working temperature for better performance.

2.1 Heat Exchangers

It is interesting to note that the energy conservation and renewable energy plays important role in energy efficient systems. Due to their high heat transfer capabilities with no external power requirements, heat pipes are being used in heat exchangers for various applications. In the power industry, heat pipe heat exchangers are used as primary air heaters in new and retrofit boilers. The major advantages of heat pipe heat exchangers compared to conventional heat exchangers are that they are nearly isothermal and can be built with better seals to reduce leakage. Heat pipe heat exchangers can serve as compact waste heat recovery systems which require no power, low pressure drop and are easy to install on existing lines.

2.2 Aerospace

Heat pipes are very likely attractive components in the area of spacecraft cooling and temperature stab due to their low weight penalty, zero maintenance, and reliability. Structural isothermalization is an important problem in regard to orbiting astronomy experiments due to the possible warp age from solar heating. During orbit, an observatory is fixed on a single point such as a star. Therefore, one side of the capsule will be subjected to intense solar radiation, while the other is exposed to deep space. Heat pipes have been used to transport the heat from the side irradiated by the sun to the cold side in order to equalize the temperature of the structure. Heat pipes are also being used to dissipate heat generated by electronic components in satellites.

Thermal diodes have been proposed for use in cooling low temperature sensors, such as an infrared detector in low sub solar earth orbits. This type of heat pipe was proposed because of its characteristic of being able to cool the instrument during normal operation, but effectively insulating it when exposed to an external to an external heat flux. One type of thermal diode uses a liquid reservoir at the evaporator end of the heat pipe which does not communicate with the wick structure, Dulling normal operation the reservoir is empty, but if the condenser is subjected to an external heat flux, the working fluid condenses in the reservoir, causing the wick to dry out. This results in the heat pipe becoming an insulator, because heat can only be conducted axially through the thin pipe wall.

2.3 Electronic Equipment Cooling

Miniaturization of electronic components is accompanied by increased demands on heat dissipation systems due to the increased density of the components. For example, the digital computer has evolved from a massive system that filled an entire room to a unit which can be stored in a brief-case. However, the overheating problems associated with the dense packing of heat-generating integrated circuit chips used in the computer have escalated dramatically. Since the reliability of these and other types of electronic components are sensitive to their operating temperature, steps have been taken to improve heat dissipation by using heat pipes. Other applications to electronic cooling have included rectifiers, transistors, traveling wave collectors, audio amplifiers and high density semiconductor packages.

2.4 Solar Systems

Nowadays, more interest has been shown on the use of heat pipes to collect solar energy. Solar energy is absorbed stored in a ank for later use. Dulling the night, the thermosyphons essentially act as thermal diodes, since the only way heat can be transferred from the interior to the outside is by axial conduction through the pipe walls, a similar design can be used for desalinating sea water using solar energy. In this application, however, a heat pipe would be positioned at the focal point of a trough-shaped parabolic reflector in order to generate the high temperatures and heat fluxes necessary for desalination.

2.5 Air Conditioning

In an air conditioning system, the colder the air as it passes over the cooling coil (evaporator), the more the moisture is condensed out. The heat pipe is designed to have one section in the warm incoming stream and the other in the cold outgoing stream. By transferring heat from the warm return air to the cold supply air, the heat pipes create the double effect of pre-cooling the air before it goes to the evaporator and then re-heating it immediately. Activated by temperature difference and therefore consuming no energy, the heat pipe, due to its pre-cooling effect, allows the evaporator coil to operate at a lower temperature, increasing the moisture removal capability of the air conditioning system by 50-100%. With lower relative humidity, indoor comfort can be achieved at higher thermostat settings, which results in net energy savings.

2.6 Laptop Cooling

One end of the heat pipe is attached to the processor with a thin, clip-on mounting plate. The other is attached to the heat sink, in this case, a specially designed keyboard RF shield. This approach uses existing parts to minimize weight and complexity. The heat pipe could also be attached to other physical components suitable as a heat sink to dissipate heat. Because there are no moving parts, there is no maintenance and nothing to break. Some are concerned about the possibility of the fluid leaking from the heatpipe into the electronics. The amount of fluid in a heat pipe of this diameter is less. In a properly designed heat pipe, the water is totally contained within the capillary wick structure and is at less than 1 atmosphere of pressure.

2.7 Heat Pipes in Energy Storage Systems

Heat pipes have been used widely in a variety of energy storage systems. Because of their high effective thermal conductivity heat pipes are suited for thermal storage systems, in particular, in the role of heat delivery and removal. As aids to temperature stratification in hot water storage tanks, to their incorporation in stores for heat or cool using phase change materials (PCMs), the unique properties of heat pipes can permit systems to operate in a manner not generally possible using conventional heat exchangers. Heat pipes and thermosyphons are used where heat transfer from or into the ground has been essential. These were the applications of heat pipe in various fields.

3. Experimental Setup and Methodology

3.1 Design Principles of Thermosyphon

The design of a thermosyphon includes the following processes,

- Selection of Working fluids
- Selection of Container Material.
- Evaluation of performance limits
- Evaluation of the actual performance

Tube sizes are selected for a lab size system suitable for making reliable measurements. Working fluids such as ethanol and acetone are selected because of useful range of operating temperature for waste heat recovery applications in the temperature range of 100 to 250°C

3.2 Selection of working fluids

The working fluids are selected such that the melting point temperature is below and the critical point temperature is above the thermosyphon operating temperature. The most important properties of the working fluid for a thermosyphon are as follows

- High surface tension
- High liquid density
- High latent heat of vaporization
- Low liquid viscosity
- Maximum vapor pressure
- High thermal conductivity
- High heat transport capability

3.3 Experimental Arrangement

The experimental setup will use for the research work is shown in Figure 3.1. The test rig consists of a heater, a liquid reservoir for charging, a thermosyphon (wickless heat pipe), a cooling section and also measuring instruments. The upper part of the thermosyphon was equipped with a seal valve for connection to a mechanical vacuum pump and to the working fluid charging line. A mechanical vacuum pump capable of up to 0.5 Pa used for partial elimination of the non-condensable gases (NCG) from the thermosyphon. Complete extraction of NCG was achieved by purging.

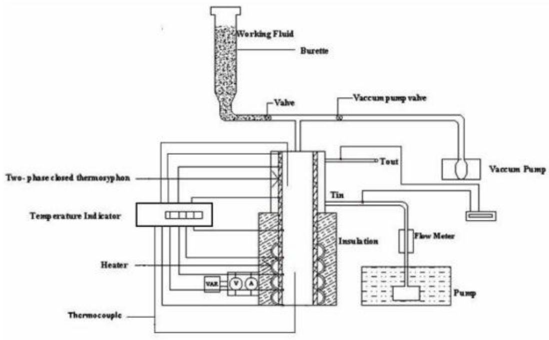


Figure 3.1 Schematic of the test rig

In the experiment three different dimensions of 12mm, 9.5 mm and 6.7mm thermosyphon use. An electrical resistance of a nominal power range of 0 to 1200 W wrapped around the evaporator section, which will be used to heat the evaporator. To prevent the heat loss to the atmosphere, the electrical elements were insulated by glass wool having a thickness of 65mm. The heat will remove from the condenser section by the water jacket as described in the introduction.

The power supplied to the evaporator section monitoring the applied voltage and current with accuracy of ± 2%. The accuracy of flow measurement around ±2 %. A variable voltage controlled the rate of heat transfer the evaporator. Temperature distribution along the thermosyphon will measureusing thermocouple. The upper surface of thermocouple will fully insulated and the vacuum pressure will be measured by using the vacuum pressure gauge. In order to find out the effects of maximum heat transfer capability on the thermal performance of the thermosyphon a series of test will be carried out according to the following Design of Experiment Method

Three Level Full Factorial Design

In the present study the factors and their levels have been decided by study of various research paper.

The details of are shown in table

Research Design Variable

The design variables are described as follows.

- **Input parameters include:**
  - a. Filling Ratio (%)
  - b. Operating Temperature (ºC)
  - c. Inner Diameter of pipe (mm)
- **Output parameters (Response) include**
  - a. Heat Rejected (W)
- **Working Fluid**
  1. Acetone
  2. Ethanol

Table 3.1 Parameters and their levels

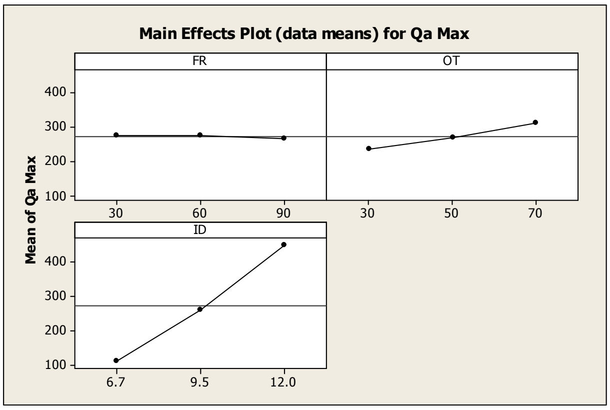
Parameters	Levels		
	Level 1	Level 2	Level 3
Filling Ratio(%)	30	60	90
Operating Temperature(oC)	30	50	70
Inner Diameter of pipe (mm)	6.7	9.5	12

4. Results and Discussion

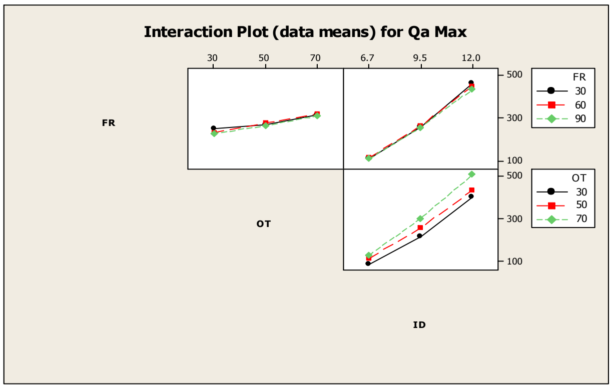
4.1. Working Fluid:- Acetone

4.1.1 Regression Analysis for Maximum Heat Transport Capability When Working Fluid used as Acetone.

The analysis of Maximum heat transport capability when working fluid used as Acetone is carried out using regression method in which the influences of each input parameters on convective heat transfer coefficient are obtained and which are listed in table 4.1. Also estimated effect and coefficient are obtained and listed in table 4.1, by using these coefficients regression equation is obtained for convective heat transfer coefficient. Also parameter influence is plotted on main effects plot for each parameter and normal plots of the standardized effect.



Graph 4.1 Main Effects Plot (Data Means) For Qa max



Graph 4.2 Interaction Plot (Data Means) For Qa max

Graph 4.1 shows the main effect plots for maximum heat transport capability when working fluid used as Acetone which indicates the variation of heat transport capability with respect to each input parameter. Maximum heat transport capability when working fluid used as Acetone increases with increase in inner diameter of pipe(ID) also increases with increase in operating temperature (OT), at 60% filling ratio results in maximum heat transport capability.

4.1.2 Model Analysis for Maximum Heat Transport Capability When Working Fluid used as Acetone.

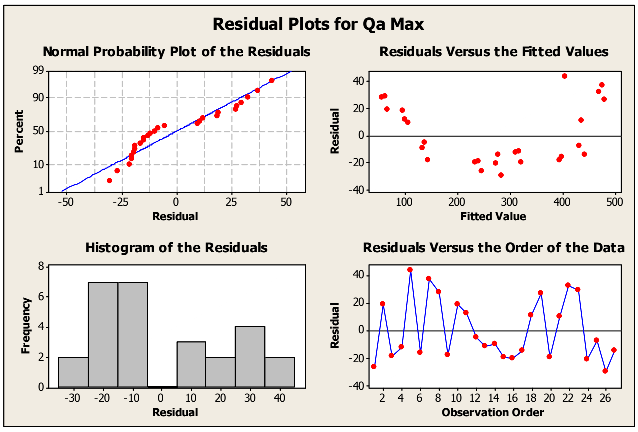
The coefficients of model for maximum heat transport capability are shown in table 4.1. The parameter R^2 describes the heat transfer capability with respect to input factors. R^2 = 97.7% indicates that model is able to predict the response with high accuracy. Adjusted R2 is modified R2 that has been adjusted for the number of terms in the model. If unnecessary terms are included in model, R2 can be artificially higher, but adjusted R^2 = 97.30% may get smaller. The standard deviation of errors in the modeling is S = 23.6934. The comparison of p-value with a commonly used α-level equals to 0.05, it is found that if p-value is less than or equal to α, it can be concluded that, the effect is most significant as shown bold in table 4.1, otherwise it is not significant.

Table 4.1: Estimated Effects and Coefficients for maximum heat transport capability

Term	Coef	SE Coef	T	P
Constant	-410.53	27.06	-15.17	**0.000**
Filling Ratio (FR)	-0.1796	0.1861	-0.96	**0.345**
Operating Temp.(OT)	1.9139	0.2792	6.85	**0.000**
Inner Diameter (ID)	63.501	2.106	30.15	**0.000**
S=23.6924				
R-Sq=97.7%	**R –Sq (adj)=97.3%**			

The regression equation is obtained using coefficient listed in table 4.1. The regression equation for convective heat transfer coefficient as follows.

Qa Max = - 411 - 0.180 FR + 1.91 OT + 63.5 ID



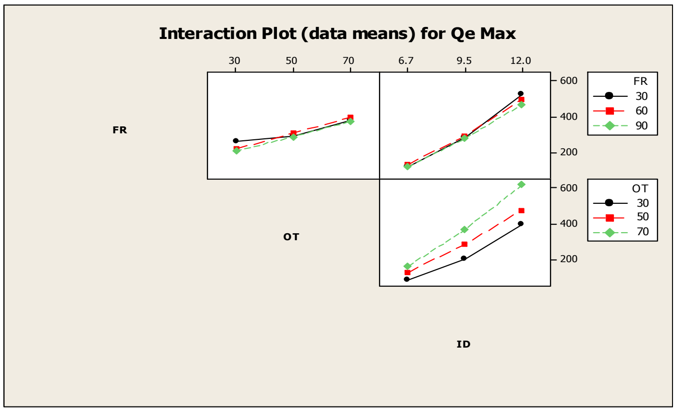
Graph 4.3-Residual Plots for Qa Max

The model listed above can be used to predict the Qa max, and Graph 4.3 displays the normal probability plots of the residuals for maximum heat transport capability. Notice that the residual generally falling on straight line, which means error are normally distributed. Further it indicates that the developed regression mathematical model can yield very accurate results.

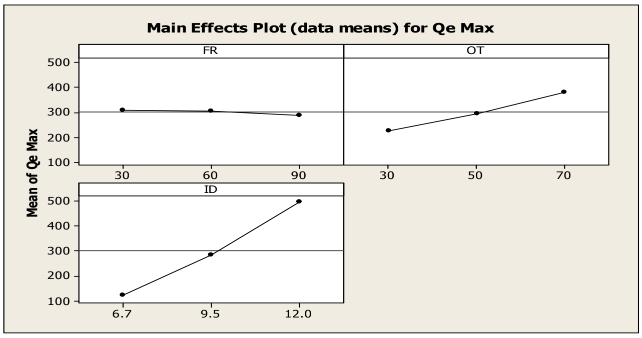
4.2. Working Fluid:- Ethanol

4.2.1 Regression Analysis for maximum heat transport capability when working fluid used as Ethanol.

The analysis of Maximum heat transport capability is carried out using regression method in which the influences of each input parameters on convective heat transfer coefficient are obtained and which are listed in table 4.2. Also estimated effect and coefficient are obtained and listed in table 4.2, by using these coefficients regression equation is obtained for convective heat transfer coefficient. Also parameter influence is plotted on main effects plot for each parameter and normal plots of the standardized effect.



Graph 4.4 Interaction Plot (Data Means) For Qe max



Graph 4.5 Main Effects Plot (Data Means) For Qe max

Graph 4.5 shows the main effect plots for maximum heat transport capability when working fluid used as Ethanol. Which indicates the variation of heat transport capability with respect to each input parameter. Maximum heat transport capability of Acetone increases with increase in inner diameter of pipe(ID) also increases with increase in operating temperature (OT), at 60% filling ratio results in maximum heat transport capability.

4.2.2 Model Analysis for maximum heat transport capability.

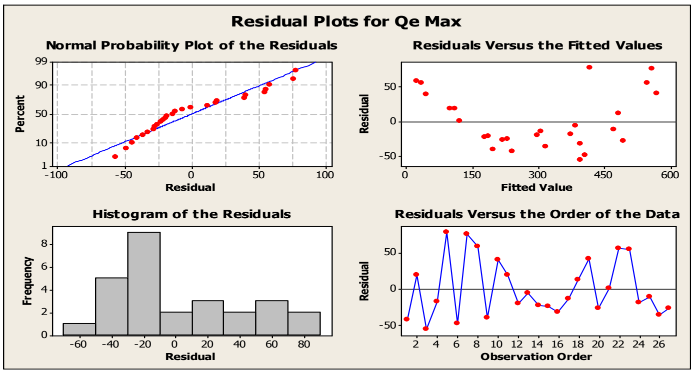
The coefficients of model for maximum heat transport capability are shown in table 4.2. The parameter R^2 describes the heat transfer capability with respect to input factors. R^2 = 94.7% indicates that model is able to predict the response with high accuracy. Adjusted R2 is modified R^2 that has been adjusted for the number of terms in the model. If unnecessary terms are included in model, R^2 can be artificially higher, but adjusted R2 = 94.00% may get smaller. The standard deviation of errors in the modeling is S = 42.26. The comparison of p-value with a commonly used α-level equals to 0.05, it is found that if p-value is less than or equal to α, it can be concluded that, the effect is most significant as shown bold in table 4.2, otherwise it is not significant.

Table 4.2: Estimated Effects and Coefficients for maximum heat transport capability

Term	Coef	SE Coef	T	P
Constant	-528.28	48.27	-10.96	**0000**
Filling Ratio (FR)	-0.3481	0.3320	-1.05	**0.035**
Operating Temp.(OT)	3.8333	0.4981	7.70	**0000**
Inner Diameter (ID)	70.113	3.757	18.66	**0000**
S=42.26				
R-Sq 94..7%	**R –Sq (adj)=94%**			

The regression equation is obtained using coefficient listed in table 4.2. The regression equation for convective heat transfer coefficient as follows.

Qe Max = - 529 - 0.348 FR + 3.83 OT + 70.1 ID



Graph 4.6-Residual Plots for Qe max

The model listed above can be used to predict the Qa max, and Graph 4.6 display the normal probability plots of the residuals for maximum heat transport capability. Notice that the residual generally falling on straight line, which means error are normally distributed. Further it indicates that the developed regression mathematical model can yield very accurate results

4.3 Influence of Filling Ratio on Maximum Heat Transport capability

The increase in diameter of thermosyphon from 6.7 mm to 12 mm clearly increases the heat transport capability at any operating temperature and filling ratio, for the same working fluid. The variation in operating temperature also positively influences the heat transport capability of thermosyphon, the variation of heat transport capability of working fluid at any operating temperature has only marginal influence on heat transport capability as shown in graph 4.4 & 4.5. As the diameter of thermosyphon increases, the variation of heat transport capability decreases, clearly indicating the uniformity and effectiveness of the process.

4.4 Influence of Operating Temperature on Maximum Heat Transport Capability

The operating temperature is another influential parameter on the heat transport capability of thermosyphon. It is observed that the increasing temperature increases the heat transport capability at all filling ratios as shown in graph 4.1, 4.2, 4.4 & 4.5 It is because of the fact that when the size of the thermosyphon increases, the amount of the working fluid also increases for the same filling ratio. Increased size also provides increased heat transfer area.

4.5 Influence of Size of the Thermosyphon on Maximum Heat Transport Capability

A large size thermosyphon provides better heat transport capability. When the operating temperature is 70 degree C, the heat transport capability found 378 W for 9.5 mm and 636 W for 12 mm at 60% filling ratio when ethanol used as working fluid. As the dimension of the inner diameter of the thermosyphon increase the variation in heat transport capability decreases as shown in graph 4.1, 4.2, 4.4 & 4.5.

5. CONCLUSIONS

According to series of experimental tests and observations as well as analysis the following conclusion comes out.

1) The maximum heat transport capability showed an increasing trend with increasing operating temperature. The effect of filling ratio on heat transport capability was only marginal for all fluids.

2) Maximum heat transport capability was found to strongly depend on the operating temperature and size of the thermosyphon.

3) The increase in the inner diameter of the thermosyphon for the same length increases the heat transfer capability.

4) The increase in diameter of the thermosyphon offers not only increase in surface area but also increased quantity of working fluid for the same filling ratio.

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