



An Experimental Study of Thermal Performance of Concentric Annular Heat Pipe

Nishtha Vijra¹, Tejinder Paul Singh²

¹Assistant Professor, Mechanical Engineering Department, ²Director and Professor,
Symbiosis Institute of Technology (SIT), Symbiosis International University (SIU), Near Lupin Research Park,
Gram: Lavale, Taluka: Mulshi, Pune, Maharashtra - 412 115, INDIA

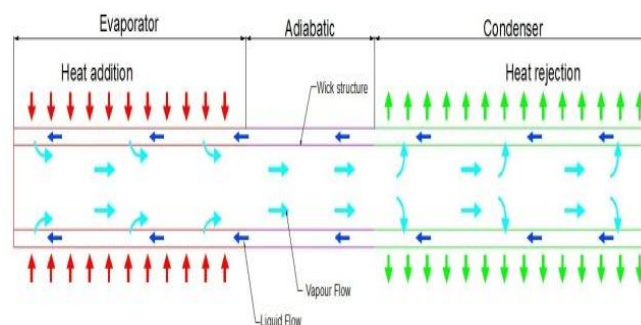
Abstract: Higher heat transfer rates and better cooling can be achieved by Concentric Annular Heat Pipes (CAHP) in comparison to conventional heat pipes due to increase in heat transfer area. Experiments were conducted to find the effect of variation in heat input and inclination angle on the performance of CAHP. SS304 was selected as the container material and water as the working fluid for CAHP. Inner surface of the outer pipe was covered with single layer of screen mesh wick. Surface and vapor temperatures were determined for various heat inputs and inclination angles at steady state conditions and isothermal characteristics of CAHP considering uniform heating application were found. Results concluded that with increase in heat input, the vapor temperature difference between the evaporator and condenser section decreases for all inclination angles of CAHP. The temperature difference between the evaporator and condenser end in axial direction is the least for vertical position of CAHP at all levels of heat input. This depicts the isothermal characteristic of concentric annular heat pipe. Thermal resistance decreased possibly due to enhancement in nucleate boiling activity and this improved the heat transfer with increase in heat input. Least thermal resistance was found at vertical position of CAHP.

Keywords: Concentric annular heat pipe; thermal resistance; inclination angle; isothermal characteristics

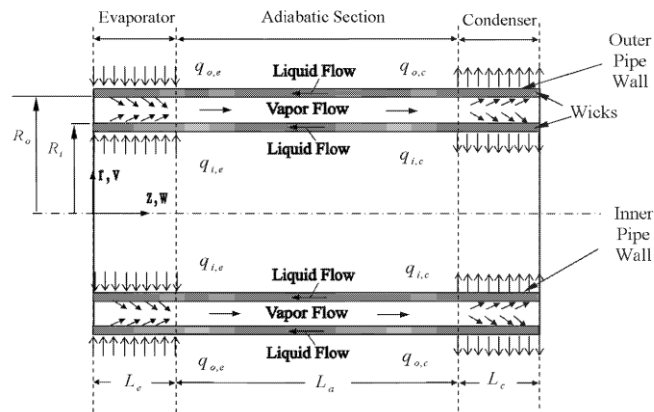
I. Introduction

Heat Pipe is a heat transfer device efficient enough to transfer heat even around 500 times higher than the best metal conductor available on earth [1]. A conventional heat pipe (CHP) consists of a sealed, evacuated, hollow, pipe like structure having wick material on the inner periphery of the container and working fluid sufficient enough to saturate the wick as shown in fig.1 (a). There are mainly three regions in a heat pipe. One end of the heat pipe is an evaporator region for heat addition, the other end is the condenser region for heat rejection and in between the two, is the adiabatic region [2]. Due to continuous heat addition, the working fluid gets converted to vapor using latent heat of vaporization and flows through the adiabatic section towards the condenser end. Here, the heat dissipation takes place in the form of latent heat of condensation and as a result the phase of the working fluid changes back to liquid. Wick plays a major role to transport the liquid back to the evaporator region by capillary forces. This cycle is repeated till the application of heat is continued. Of late, non conventional heat pipes (NCHP) have been used widely in many applications due to enhanced rate of heat transfer. Concentric Annular Heat Pipe (CAHP) is one such type of NCHP as shown in fig.1(b)[3]. As the name and figure suggest, CAHP has two concentric hollow pipes of different diameters sealed at their ends thereby forming an annular region where the wick structure is placed on the outer periphery of the inner pipe and on the inner periphery of the outer pipe. This enhances the heat flux due to increase in the overall area of the wick and the surface area of heat addition and heat rejection from the pipe [4].

Figure 1(a) and (b)[3] showing working of CHP & CAHP



Researchers have carried out experiments on CAHP to analyze its performance under various combinations of parameters like material of pipes, their sizes, inclination angles, and working fluids and so on. Vasiliev[5] introduced coaxial heat pipe and analyzed its performance by variation in heat input in radial direction. Faghri[6] analyzed vapor flow characteristics for steady, 2D and incompressible flow in CAHP. Faghri and Parvani[7] continued their work to study copper – water CAHP vapor flow for 2D, incompressible model and concluded that elliptic model could provide more complete simulation of vapor flow than the parabolic model.



The performance characteristics were compared with identical simple heat pipe and an 80% increase was registered in heat flow of CAHP. Faghri and Thomas [8] conducted experiments to find the temperature distribution and analyze the capillary limit for different inclination angles and variable heat supply on Cu-H₂O CAHP. Theoretical analysis was done to predict the sonic limit. Layeghi and Borujerdi [9] worked on CAHP with partial heat transfers for laminar, 2D, steady and incompressible vapor flow for variable heat input to predict the pressure and velocity distribution. With increase in radial Reynold's Number (Re), the performance was increased. Borujerdi and Layeghi [10] also worked to analyze steady state vapor flow and heat transfer in CAHP. For symmetric cases for low to moderate Re , vapor pressure, temperature distribution, vapor reversal and transition to turbulence phenomenon were predicted and results were compared to be in fair agreement with available data. Boo and Park [11] studied the isothermal characteristics and thermal transient response of CAHP with uniform heating for different diameter ratios and different fill ratios. Increase in the diameter ratio resulted in better performance. Effect of fill ratio on thermal resistance was more significant than the diameter ratio variation. Jalilvand et.al. [12] studied the performance of Roll Heat Pipe(RHP) used in copy machines, xerox machines or laser printers. Transient thermal response and internal temperature distribution were observed and analyzed and results were compared with theoretical analysis. Effect of rotation of RHP was studied and comparison was made with existing heat roll of the fusing unit.

The review of literature shows that some work has been done on copper as container material and water as working fluid in concentric annular heat pipe for the vapor flow analysis, thermal analysis, prediction and analysis of sonic and capillary limit for variable heat input, variable inclination angle, different diameter and fill ratio and partial heat transfer condition. Certain computer programs have also been developed to analyze the model. In CAHP, literature in any other combination of container material and working fluid could not be seen. In the present study, experimental investigations have been done on stainless steel (SS304) as container material and distilled water as the working fluid in CAHP for determining the thermal performance with variation in heat input and inclination angle.

II. Experimental Set Up

The main objective of the experimentation was to estimate the effect of variation in inclination angle and variable heat input on the thermal performance of CAHP. Total length of CAHP was 900mm with 100mm evaporator section, 270 mm adiabatic section and 530 mm condenser section. The outer diameter of outer pipe was 53mm and of 2mm thickness and the outer diameter of inner pipe was 15.9mm and of 1.6 mm thickness. Both the pipes were sealed together to form an annulus. In the experiments performed on the copper –water combination by the researchers, almost similar sizes have been used. However, condenser section area has been increased to permit higher heat rejection [4]. The container material of CAHP was SS304. A single layer, 60 mesh screen wick of 36 gauge and 0.6 mm thickness of SS302 was used and the working fluid was distilled water. Glass wool of 2 inch thickness was used as an insulation material on the adiabatic section of CAHP. Ceramic band heater was the heating source on the outer periphery of the evaporator section of CAHP and cartridge type heater was inserted inside the inner pipe to supply heat. Total heat input was controlled by 4 ampere, closed type dimmer stat and was monitored by digital ammeter (0–5 amp.) and digital voltmeter (0–300V). SS316 thermo wells were welded in CAHP to permit insertion of K type thermocouples to measure the vapor temperature in axial direction. Five K type thermocouples were mounted at various distances along the

length of CAHP for surface temperature measurement. Two wooden stands were fabricated to hold CAHP in the horizontal and vertical/inclined positions. Fig. 2 represents the experimental set up for the horizontal, vertical and inclined positions of CAHP.

Various levels of heat input were selected from 50W-300W with an interval of 50W. Inclination angle was varied at three different levels of 0°, 45° and 90° to the horizontal for each heat input. Condenser section was kept above the evaporator section in the vertical and inclined positions of CAHP. All the experiments for horizontal, inclined and vertical positions were conducted by keeping both the heaters in ON position and temperature readings

Figure 2: Heat pipe in Horizontal, Inclined and Vertical Position



were registered with 10 minutes interval till CAHP attained steady state condition. Thermal resistance (R_{th}) of CAHP was calculated from equation (1)

$$R_{th} = (T_{ave} - T_{avc}) / Q \quad (1)$$

Where, T_{ave} is the average evaporator temperature, T_{avc} is the average condenser temperature and Q is the total heat input.

III. Results and Discussion

Table I – Readings of Time Vs Temperature at different locations of CAHP for 200W heat input at horizontal position till achievement of steady state

Distance (m)	Time(min.) / Temp.(°C)	10	20	30	40	50	60	70	80	90	100	110	120
0.05	TV1	51	80	105	115	125	131	136	138	139	140	141	141
0.103	TV2	51	78	103	113	123	128	133	135	136	137	138	138
0.364	TV3	40	78	103	113	123	128	133	134	136	136	137	137
0.403	TV4	40	78	103	112	122	127	132	134	135	136	137	137
0.496	TV5	40	77	103	112	122	127	132	133	135	136	137	137
0.589	TV6	40	77	102	112	121	126	132	133	135	135	136	136
0.682	TV7	40	77	102	111	121	126	131	133	134	135	136	136
0.775	TV8	40	76	101	111	120	126	130	132	134	135	136	136
0.9	TV9	40	75	100	111	120	125	130	132	133	134	135	135
0.05	TS1	61	87	108	118	128	134	138	140	141	142	143	143
0.403	TS2	36	76	99	109	120	125	130	132	132	134	135	135
0.589	TS3	36	74	98	109	119	124	130	132	132	134	134	134
0.682	TS4	36	74	98	108	118	124	129	130	132	133	133	133
0.775	TS5	36	73	97	108	118	124	129	130	132	133	133	133

Table 1 shows the results of experimentation for 0° inclination angle (horizontal position) and power input of 200W in the evaporator section of CAHP. Vapor and surface temperature distribution along the length was plotted as shown in fig. 3 (a) and (b) with a time interval of 10 minutes. 0.05 meter axial distance indicated the centre of the evaporator region, 0.103 m. and 0.364 m. are the distances at the approximate entrance and exit of adiabatic region and rest of the zone is the condenser region. From the graphs of these figures, the following inferences can be made-(i)The temperature increased continuously with time till the achievement of steady state after 120 minutes from the evaporator till the condenser region at all times.(ii)For an initial period of 70 minutes the increase in the temperature was substantial which reflected that heat supplied was used to heat the working fluid where as with further increase of time, evaporation and condensation processes were clearly visible due to nearly uniform temperature in the respective zones.

Such experiments were conducted for different levels of heat input varying from 50W to 300W for horizontal, inclined and vertical positions of CAHP. The trend shown by graphs was found to be similar for all levels of heat input.

Figure 3(a) Vapor temperature distribution and (b) Surface temperature distribution w.r.t. time for 200W heat input in horizontal position

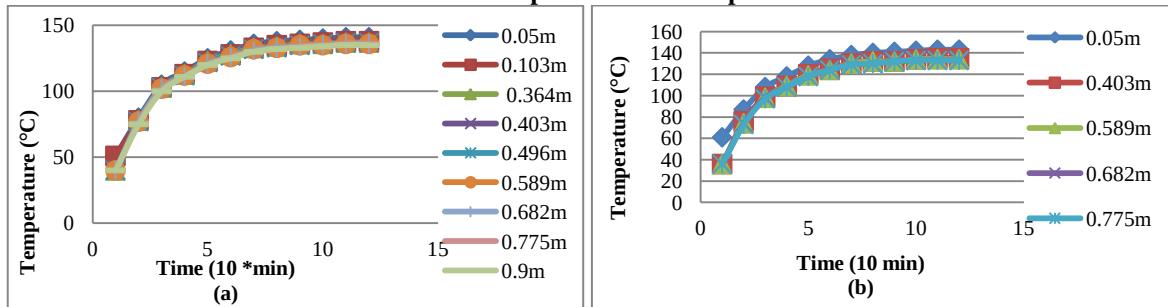


Fig.4 (a) depicts steady state temperature distribution of the vapor and figure 4 (b) of the surface with axial distance of CAHP. It is seen that-(a) Surface temperature of the evaporator region was higher than the vapor temperature due to heat supply from the surface whereas surface temperature of the condenser region was lower than corresponding vapor temperature due to heat rejection.(b) The temperature decreased continuously from evaporator to condenser region.(c) Adiabatic region showed almost constant temperature due to no heat loss condition. (d) The difference in surface and vapor temperature of the evaporator section was 2°C and condenser section was 3°C at same axial distance. This can be due to very high thermal conductivity of CAHP. (e) For all other levels of heat input a similar phenomenon was observed. (f) Vapor temperature difference from the evaporator to condenser region was only 6°C which showed nearly isothermal behavior of CAHP due to very high heat transfer coefficient during evaporation and condensation. It was of the similar order for all other levels of heat input except for 50W where this was 10°C. This reflected that the size of CAHP was large enough for 50W in horizontal position and it could handle higher heat input. (g) Due to natural convection used for the present experiment, surface heat transfer coefficient was low which was due to the resistance to heat rejection to the surroundings and this was indicated by the almost uniform surface temperature of the condenser region.

Figure 4 (a) Steady state vapor temperature distribution and (b) Surface temperature distribution w.r.t. axial distance for 0° inclination angle

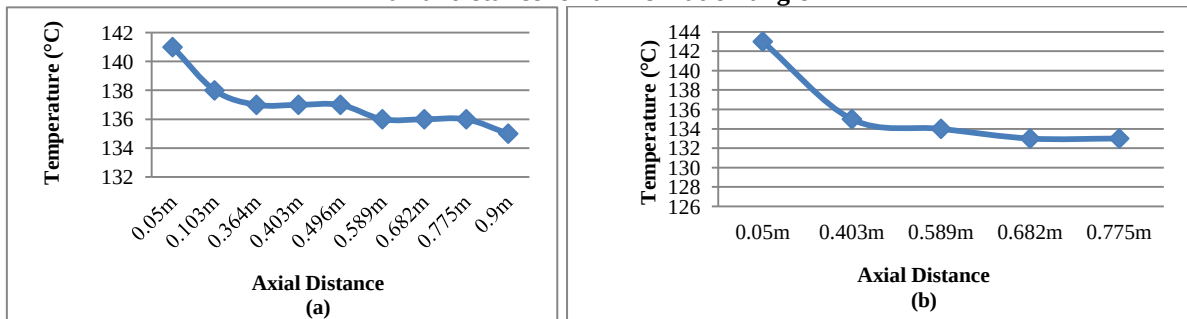


Table II – Readings of Time Vs Temperature at different locations of CAHP for 200W heat input at inclined (45°) position till achievement of steady state

Distance (m)	Time(min.)/T _{emp} (°C)	10	20	30	40	50	60	70	80	90	100	110	120
0.05	TV1	58	80	96	113	128	138	140	144	146	147	148	148
0.103	TV2	57	79	95	112	127	137	139	143	145	146	147	147
0.364	TV3	57	79	95	112	127	137	139	143	145	146	147	147
0.403	TV4	50	79	95	112	127	137	139	143	145	146	147	147
0.496	TV5	50	79	95	112	127	137	139	142	144	146	147	147
0.589	TV6	45	78	94	111	126	136	139	142	144	145	146	146
0.682	TV7	45	78	94	111	126	136	138	141	144	145	146	146
0.775	TV8	40	77	93	110	125	135	138	141	143	144	146	146
0.9	TV9	40	75	91	108	123	133	137	140	141	142	145	145
0.05	TS1	66	88	100	115	130	140	142	146	148	149	150	150
0.403	TS2	40	77	93	110	125	135	138	141	143	144	145	145
0.589	TS3	40	76	92	109	124	134	138	140	142	143	144	144
0.682	TS4	40	76	92	109	124	134	137	140	142	143	144	144
0.775	TS5	38	75	91	108	123	133	136	140	140	142	143	143

Table 2 shows the readings for 45° inclination angle (inclined position) and a power input of 200W in the evaporator section of CAHP. Although, steady state has been achieved in same period of time as for the horizontal position but the temperatures for the inclined position are slightly higher than those for the horizontal position, which depicts that gravity assists in heat transfer.

Figure 5 (a) Vapor temperature distribution and (b) Surface temperature distribution w.r.t. time for 200W heat input in inclined (45°) position

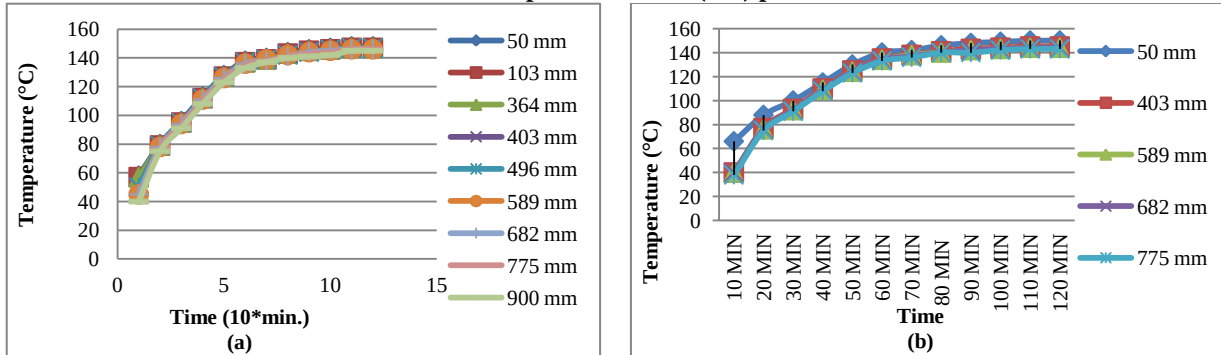
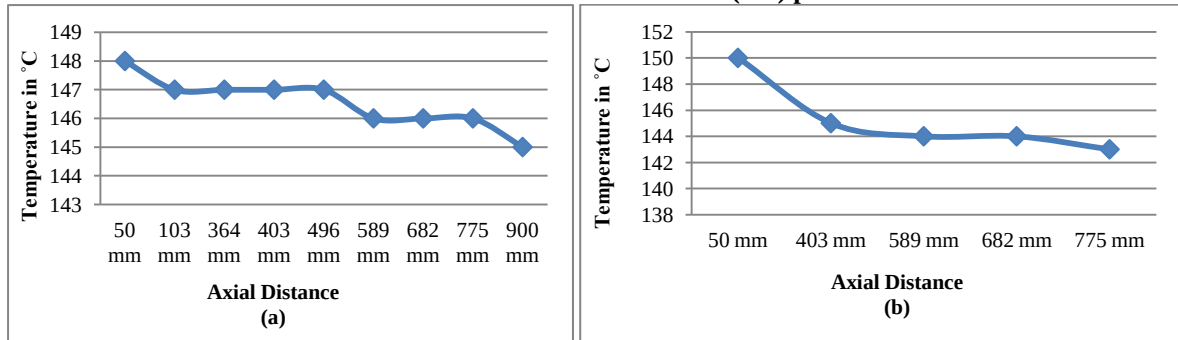


Fig. 5 shows similar graphs for the position of CAHP inclined at 45° to the horizontal. Time required to achieve steady state was the same as for the horizontal position. At all levels of heat input for inclined position, similar pattern of graphs was obtained.

Figure 6 (a) Steady state vapor temperature distribution and (b) Surface temperature distribution w.r.t. axial distance of CAHP for inclined(45°) position



The conclusions that can be drawn from the fig. 6 (a) and 6 (b) are -The difference in the surface temperature and vapor temperature of the evaporator section was 2°C and condenser section was 3°C at the same axial distance as that of the horizontal position. The difference in vapor temperature of the evaporator section and condenser section was found the least as 3°C of all the heat inputs. At all other levels of heat input this was 4°C to 5°C. This was comparatively lower than that for horizontal position. This could be due to gravity assisting working fluid flow inside CAHP.

Table III– Readings of Time Vs Temperature at different locations of CAHP for 200W heat input at 90° inclination angle till achievement of steady state

Distance (m)	Time(min.)/Temp.(°C)	10	20	30	40	50	60	70	80	90	100	110	120
0.05	TV1	55	80	110	122	133	138	140	142	143	144	145	145
0.103	TV2	55	80	110	121	131	137	140	142	143	144	145	145
0.364	TV3	50	79	109	121	131	137	139	141	142	143	144	144
0.403	TV4	50	79	109	121	131	137	139	141	142	143	144	144
0.496	TV5	45	79	108	120	130	136	138	140	141	142	143	143
0.589	TV6	45	78	108	120	130	136	137	140	141	142	143	143
0.682	TV7	45	78	108	120	130	135	137	139	140	141	142	142
0.775	TV8	45	78	107	119	128	135	137	138	139	140	141	141
0.9	TV9	45	77	107	119	128	134	136	138	139	140	141	141
0.05	TS1	61	87	112	124	136	140	142	144	145	146	147	147
0.403	TS2	45	77	107	119	129	135	137	139	140	141	142	142
0.589	TS3	40	76	106	118	128	134	135	138	139	140	141	141
0.682	TS4	40	76	106	118	128	134	135	137	138	139	140	140
0.775	TS5	40	76	106	117	127	134	135	136	138	138	139	139

Table 3 shows the results of experimentations carried out for 90° inclination angle (vertical position) and power input of 200W in the evaporator section of CAHP. Although the range of temperature at steady state is highest for inclined position as depicted from all of the above readings shown in table (1), table (2) and table (3), but still the temperature difference between the evaporator and condenser end in axial direction is the least for vertical position of CAHP at all levels of heat input.

Figure 7 (a) Vapor temperature distribution and (b) Surface temperature distribution w.r.t. time for 200W heat input in vertical (90°) position

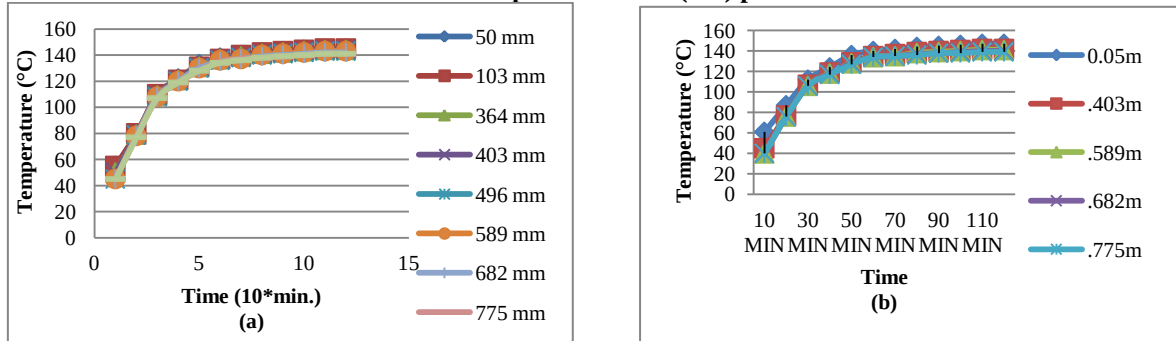
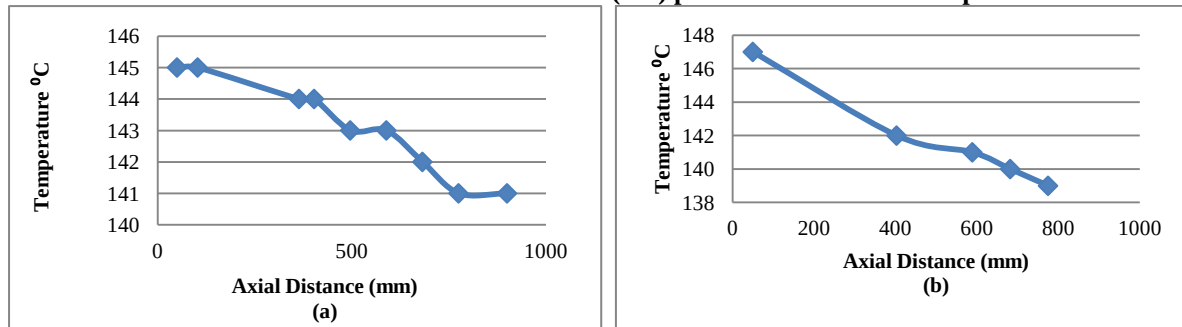


Figure 8 (a) Steady state vapor temperature distribution and(b)Surface temperature distribution w.r.t. axial distance of CAHP for vertical(90°) position for 200W heat input



For the vertical position of CAHP also similar trends were observed as shown in fig. 7(a), 7(b), 8(a) and 8(b).The difference in the vapor temperature of the evaporator section and condenser section was 4°C and was of the same order for all other levels of heat input also. The trend of difference in the vapor temperature was found to decrease from the horizontal position which depicted that gravity effect assisted the flow of working fluid.

Thermal resistance of CAHP was calculated and compared for all the three positions as shown in fig.9. The results that the graph reflects are– (i) with increase in heat input, thermal resistance of the CAHP decreased and heat transfer was more effective. Enhancement of boiling technique could be a possible reason for this as improvement in nucleate boiling activity with increase in heat input in the evaporator region could be reducing the thermal resistance and hence the overall thermal resistance. (ii) Vertical position depicted minimum thermal resistance at all levels of heat input followed by inclined and then the horizontal position of CAHP. (iii) It also depicted that with increase in inclination angle with horizontal, gravity plays an effective role even for heat pipes with wick.(iv) Transportation of the heat flow rate under the driving temperature difference was found to improve with increase in inclination angle due to decrease in thermal resistance.

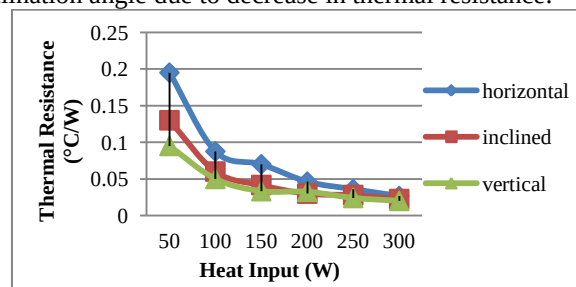


Figure 9 Thermal resistance for various heat input at different inclination angles

IV. Conclusions

The experimental analysis of an air cooled, concentric annular heat pipe was carried out to determine the thermal performance for various levels of heat input from 50W to 300W with an interval of 50W under steady state condition for three inclination angles and the results were plotted. Stainless steel container material with

water as a working fluid was tested up to 300W, 150°C for CAHP which was not seen in the literature earlier. CAHP attained steady-state nearly after 110-120 minutes of operation for various levels of heat input in the evaporation section. The variation of temperature along the length of heat pipe at various time intervals explained the process of evaporation and condensation inside CAHP for different stages of operation. The difference in the vapor temperature of the evaporator and condenser region decreased with increase in heat input for all inclination angles and minimum temperature difference of 3°C was found between the evaporator and the condenser section. This depicts the isothermal characteristic of a heat pipe. With increase in heat input in the evaporator the operating temperature of CAHP also increased due to surface convective resistance of the condenser region. With increase in heat input, heat transfer improved as thermal resistance decreased for all positions of CAHP. One of the possible reasons could be due to improvement in boiling technique. Thermal resistance was found to be the least for vertical position due to the gravitational forces assisting the process of heat transfer.

Encouraging results of the experiments suggest that stainless steel container material with water as a working fluid combination for CAHP can be used for various industrial applications.

In the present case with natural convection using air as the cooling medium in the condenser section, low surface convective heat transfer coefficient was the influencing resistance that affected the performance of the condensing process and eventually the evaporation process in CAHP. For achieving high heat transfer coefficient fins can be attached on the condenser area, surface area of the condenser can be increased or water cooling can be used which will eventually improve the efficiency of operation of concentric annular heat pipe.

References

- [1] P.K.Nag, 2007, "Heat and Mass transfer", 2nd edition, McGraw Hill Education(India) Private Limited
- [2] P.D. Dunn and D.A.Reay,1982, "Heat Pipes", 3rd edition, Pergamon, New York
- [3] A.Faghri, 1995, "Heat Pipe Science and Technology", Taylor & Francis, Washington D. C.
- [4] A. Nouri-Borujerdi and M. Layeghi, 2005, "A Review of Concentric Annular Heat Pipes", Heat Transfer Engineering, 26(6):45–58
- [5] L.L. Vasiliev, 1973, "Heat and Mass Transfer in Low Temperature Heat Pipes", Proceedings of The 1st Heat Pipe Conference, Stuttgart, Germany
- [6] A. Faghri,1986, "Vapor Flow Analysis in a Double-Walled Concentric Heat Pipe", Numerical Heat Transfer, vol. 10, no. 6, pp. 583–595.
- [7] A. Faghri and S. Parvani, 1988, "Numerical Analysis of Laminar Flow in a Double- Walled Annular Heat Pipe", Journal of Thermophysics and Heat Transfer, vol. 2, no. 2
- [8] A. Faghri & S.Thomas, 1989, "Performance Characteristics of a Concentric Annular Heat Pipe: Part I—Experimental Prediction and Analysis of the Capillary Limit" J. Heat Transfer, Volume 111, Issue 4, 844-851
- [9] M. Layeghi & A.N. Borujerdi, 2004, "Vapor Flow Analysis In Partially Heated Concentric Annular Heat Pipes" International Journal of Computational Engineering Science, Vol.5, No. 1, 235 – 244
- [10] A.N. Borujerdi and M. Layeghi, 2004, "A Numerical Analysis of Vapor Flow in Concentric Annular Heat Pipes", ASME Journal of Fluids Engineering, vol. 126, pp. 442–448.
- [11] J.H. Boo, S.Y. Park and D.Y Kim, 2005, "An experimental study on the thermal performance of a concentric annular heat pipe" Journal of Mechanical Science and Technology, Volume 19, Number 4, 1036-1043
- [12] A. Jalilvand, 2008, "The Study On The Thermal Performance Of Concentric Annular Heat Pipe With The Application In The Heat Roll Of Fusing Unit Of Copy Machine" International Heat Transfer Conference 13 ISBN: 1-56700-225-0 / CD 1-56700-226-9