Effect of using Water and Ethanol on Thermal Performance of a Heat Pipe Heat Exchanger Insulated with Vacuum Chamber under Natural Convection: An Experimental Study

[1]Sumit Kumar Rai, [2]Anjaney Pandey, [3]Alok Chaube

Department of Mechanical Engineering, Mahatma Gandhi Chitrakoot Gramoday Vishwavidyalaya, Satna (M.P.), India. [1]sumit.rai87@gmail.com, [2]anjaneypandey_mgcgv@rediffmail.com, [3]alokchaube@rediffmail.com

Abstract - An experimental replica has been evolutes to resolve heat execution of HPHEVC under free convection cooling conditions by acquiring heat protection commence. The replica estimates the CCHT and RHT of the HPHEVC under free convection. Inventive outcomes existed at 0^0, 15^0, 30^0, 45^0 and 60^0 tilt angles from vertical axis of HPHEVC when water and ethanol is utilized as functioning fluids. The test setup has been invented in a manner such that the execution of the HPHEVC can be estimated at separate tilt angles under free convection conditions. The inventive outcomes of setup when water is utilize as functioning fluid has been compared from inventive outcomes of setup when ethanol is utilize as functioning fluid for the same conditions of HP form the vertical axis, i.e., 0^0, 15^0, 30^0, 45^0 & 60^0 and various temperatures of the heating fluid, i.e., 40, 43, 46, 49, 52, 55, 58 & 61^0C at in the HPHEVC at climate temperature. The innovative opinions disclose that slope of HP & inlet temperature of evaporator influence the CCHT and RHT of the HPHEVC under natural convection. Ethanol gives the better outcomes to be utilized in low heat input while water in high heat input.

Keywords: Heat pipe heat exchanger, Rate of heat transfer (RHT), Coefficient of convective heat transfer (CCHT),

I. INTRODUCTION

Energy systems manufacturers normally offer the base systems, which are utilized in a diversity of heating implementations. For conversion of these base arrangements into a complete one, the manufacturers normally depend upon the local vendors for procurement of accessories including heat exchangers, which may not be optimally designed. Since these heat exchangers are to be adopted in a new configuration and layout, therefore, even well designed heat exchangers in a particular configuration are subject to change in usefulness. To magnify the usefulness of realistic heat exchangers, one may look for a variety of solutions in the given situation. One of the solutions may be increasing exterior region of heat transfer, which increases the dimensions of the setup, whereas, the other solution may be increasing the flow rates of the fluids involved, which results in more pressure drops of the fluids. The first option needs more space, whereas, the second may not be permitted by virtue of design implications. In the recent past, HPHE is utilized in many heating process for enhancing their usefulness. Most of the studies on these exchangers are limited to forced convection but a little effort is being reordered in free convection conditions. Therefore, contemporary task aims at conducting research on HPHE under natural convection conditions.

There are definite situation in which liquefied gesture is caused due to fluctuation in solidity developing from temperature drops, which is thermal transmit technique termed as free convective condition. The concept of free thermal transmit from warmth to chilled grains is due to the liquefied atoms in the instant place of warmth entity become hotter than circumferential liquefied evolving in adjustment of solidity. The hot grains will be reinstate by the cold grains creates convection flow. These particles should be replaced without help of any superficial power under free convection. The thermal transmitting technique through the free convection plays important role for thermal execution of a HPHE. The dimensionless numbers also plays the very important roles in free convective conditions, Aim of the present investigation is to emerge a model for predicting heating execution of a HPHEVC with evap. reveal to force convective & condenser to free convective conditions. The complete composition of a HPHE includes heat aspects & mechanical design .The

 DOI : 10.35291/2454-9150.2020.0500

present work has considered only thermal aspects. The HPHE heat composition problems are further categorized as grading & scaling problems. The grading or execution problem involves analysis for anticipating the heat execution of a known configuration, while the scaling problem involves the design of a new configuration for a specified heat execution. The objectives set forth in the present investigation have been achieved by considering rating problem only.

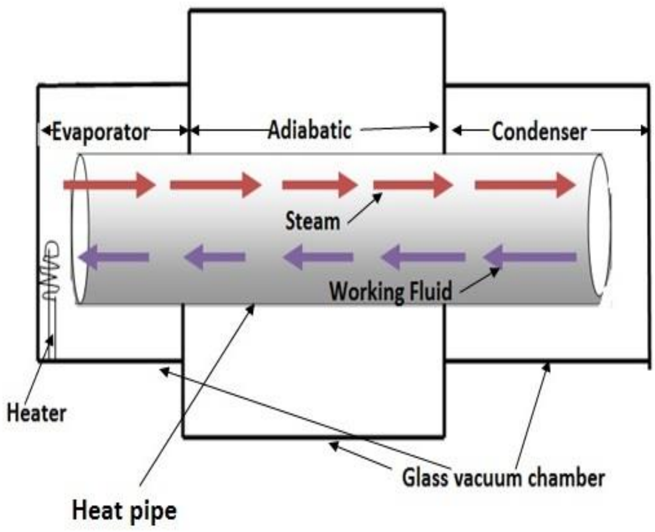

Fig.1. HP Insulated with Glass Vacuum Chamber

The literature review indicates that a good quantity of work has been accomplished on fundamental studies of HPs, which includes different types of transport limitations, choice of functioning fluid & matter of construction of panel of HP & heat resistances. These are critical parameters, which determine the execution of HP. For low temperature applications differ from 30 ^{0}C to 200 ^{0}C, Cu water HP & steel water HP has been extensively utilized, which may be because of its better thermal execution and cost effectiveness. The RHT of grooved HP is more towards Cu water wicked HP, which may be due to less resistance in condensate return and uniform distribution of functioning fluid in grooves, but its manufacturing procedure is relatively more complicated.

II. PROBLEM FORMULATION

To make an experimental setup of HPHEVC who is functioning under the natural convection condition.

Arrange a single HP made by stainless steel with a setup in which we can rotate HP in different- different angles and also use a glass made vacuum chamber as an insulating material: shaped like a cuboids and fixing the HP inside it.

1. In this experiment,**" Water and Ethanol"** utilize as functioning fluids**.**
2. In this experiment RHT and CCHT are to be calculated with the help of experimental setup in different tilting positions (like 0^0, 15^0, 30^0, 45^0 and 60^0 from vertical axis) of HP.
3. The value of Grashoff number, Prandtl number, Nusselt number, RHT and CCHT is to be determined by the correlations of natural convection.
4. The typical experimental values carried out on HPHEVC when water utilize as functioning fluid is to be compared with the experimental values carried out when ethanol utilize as functioning fluid.

III. SELECTION OF FUNCTIONING FLUID

The functioning fluid chose on the basis of price, accessibility, agreement with container materials, and using vapour temperature variety. The other reflection for selection of functioning fluid are best heating strength, quickly converts liquid into vapour, viscosities must be low and vapour pressure according to the working temperature variety. Based on all above parameters Water and Ethanol is utilizing as functioning fluids. If variety of temperature from 40 ^{0}C to 61 ^{0}C, water gives best result of RHT & CCHT as differentiate to other functioning fluids and is easily accessible. The pipe should neither be under filled nor over filled. Humiliation of execution of HP when pipe not so much fill and over fill may result in occlusion of pipe.

The functioning fluids that are utilized in this investigation having physical and thermal properties and details are as follows:

3.1 Properties of Water

Physical effects are as follows.

- Molecular Formula - H_2O
- Molecular Weight - 18.02 g/mol
- Gas Number - 7732-18-5
- Boiling point - 100^0C
- Melting point - 0^0C
- Refractive Index - 1.340 at 20^0C
- Viscosity - 1.000 at 20^0C

3.2 Properties of Ethanol

Ethanol or simply alcohol is explosive, flammable and colorless liquid. It made by the fermentation of sugar. Ethanol has a medical application as an antiseptic. Chemical reaction is given in below;

$$C_2H_4 + H_2O \rightarrow CH_3CH_2OH$$

Physical properties of ethanol are as follows.

- Molecular Formula - C_2H_6O
- Molecular Weight - 46.07 g/mol
- Boiling point - 78.37^0C
- Melting point - --114.1^0C
- Refractive Index - 1.36 at 20^0C

 DOI : 10.35291/2454-9150.2020.0500

Table 1. Properties of Water and Ethanol in S.I. Units

S. No.	Temperature (^0C)	Density ρ (kg/m^3)		Specific heat Cp (J/kgk)		Dynamic viscosity μ (Pa.sec.)		Thermal conductivity K (W/mk)		Kinematic viscosity υ (M^2/sec)	
		Water	Ethanol	Water	Ethanol	Water	Ethanol	Water	Ethanol	Water	Ethanol
1	40	992	772	4178.5	2574	0.000653	0.000818	0.630	0.164	6.58E-07	1.05E-06
2	43	991	770	4179.2	2599	0.000630	0.000784	0.633	0.162	6.31E-07	1.01E-06
3	46	990	765	4180.6	2648	0.000577	0.000719	0.639	0.163	5.79E-07	9.39E-07
4	49	988	763	4181.4	2674	0.000547	0.000688	0.642	0.162	5.53E-07	9.01E-07
5	52	987	760	4182.1	2700.5	0.000527	0.000661	0.645	0.162	5.33E-07	8.68E-07
6	55	986	758	4182.8	2727	0.000507	0.000633	0.648	0.160	5.14E-07	8.35E-07
7	58	984	756	4183.1	2755	0.000487	0.000609	0.651	0.160	4.94E-07	8.05E-07
8	61	985	753	4184.3	2782	0.000467	0.000584	0.654	0.159	4.75E-07	7.75E-07

IV. FLOW CHART

The flowchart of the program for computation of operating limits of HPHEVC shown in Fig.-2. All the inserted facts associated to evap. inlet temperature, dimensions of HPHEVC, e.g., tube outer & inner diameter, evaporator, adiabatic & condenser length, and thermal properties of the functioning fluids like thermal conductivity, viscosities, etc.

The flowchart of the program for heat execution judgments of HPHEVC is shown in Fig.-2. All the inserted facts associated to fluid heating variables e.g., properties, temperature of the heating fluid at HPHEVC, CCHT, value of voltmeter and ammeter.

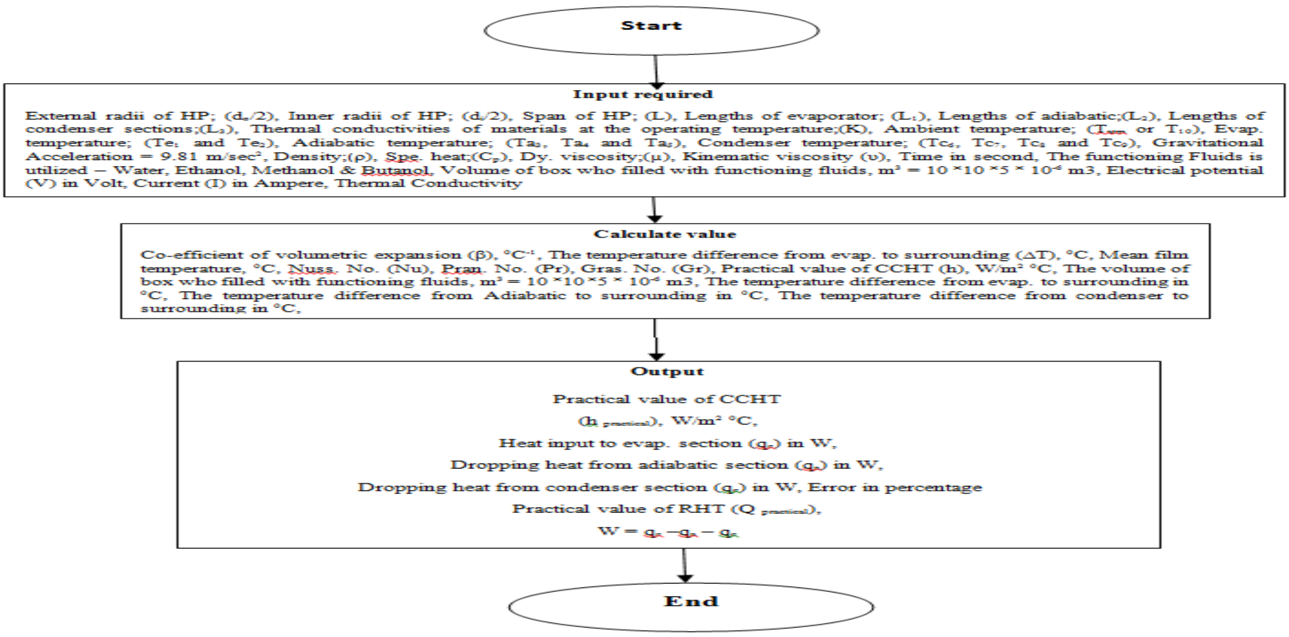

Fig.2. Problem Formulation for CCHT

V. TEST RIG FOR HPHEVC

The test rig has been invented in a manner such that the execution of the HPHEVC can be evaluated under free convection conditions. Elementary diagram of test rig is showing by Fig.-4. Span of HP, Inner radii of HP and External radii of HP are 50 cm, 1 cm and 1.4 cm respectively. The HP divided into three parts. First part having 10 cm length represents evaporator section, middle parts having length 30 cm represents adiabatic section and third part having 10 cm length represents condenser section of HP. The HPHE enclosed by cuboids chamber made of glass. This chamber is used as insulated wall of the when the internal pressure of glass chamber is less than vacuum pressure. The condenser removes the heat by natural convection. The functioning fluid heated through an Electrical heater. The power supply to heater is commanding by load manager & estimated by power analyzer. The thermocouples are mounted with the external surface of evaporator, adiabatic and condenser

 DOI : 10.35291/2454-9150.2020.0500

ISSN : 2454-9150 Vol-06, Issue-04, July 2020

section of HP. One thermocouple has been left open in atmosphere.

These characteristic are utilized to compute the practical estimate of CCHT and RHT. The variable parameters for evaluations are Inlet temperature of evap. (like 40, 43, 46, 49, 52, 55, 58 and 61^{0}C), Tilt angle of HP from vertical position (like 0^0, 15^0, 30^0, 45^0 and 60^0), and Water and Ethanol is utilized as functioning Fluids. The thermal properties of all the fluids plays very important role for natural convection conditions. The thermal properties are also varies at variable input temperature range of evaporator.

Fig.3. Test Rig of HPHEVC

VI. Results & Deliberations

1.1 CCHT

The CCHT has been computed at the internal surface of HP. The CCHT on internal surface of HP determines the rate at which heat is transported from heating fluid to the evap. side of HP. The experimental value of CCHT has been determined based upon the difference between average heating fluid temperature of HP and ambient temperature. The CCHT at individual inlet temperatures & inclination of HP has been presented by Tables and the same has been shown by Figures. The practical values of CCHT has been calculated when water and ethanol is utilized as functioning fluids.

The table 2 and table 3 are showing the experimentally measured and calculated values of CCHT of HPHEVC under natural convection. The tables show the results at verities of input temperature of evaporator, tilting angles of HP from vertical axis and water and ethanol utilized as functioning fluids.

Table 2. The Value of CCHT when Water is utilize as Functioning Fluid

S. No.	Angle of inclination	0	15	30	45	60
	Temperature	$h_{PRACTICAL}$	$h_{PRACTICAL}$	$h_{PRACTICAL}$	$h_{PRACTICAL}$	$h_{PRACTICAL}$
1	40	1254.53	1201.09	1201.09	1115.23	973.85
2	43	1334.54	1334.97	1279.70	1177.20	1046.39
3	46	1433.12	1453.80	1388.63	1303.32	1137.87
4	49	1568.00	1550.37	1473.68	1368.20	1207.53
5	52	1601.34	1581.72	1555.95	1434.19	1280.43
6	55	1705.23	1646.66	1659.28	1532.38	1350.29
7	58	1799.89	1766.17	1692.44	1584.41	1428.76
8	61	1839.22	1829.98	1769.12	1644.45	1494.67

 DOI : 10.35291/2454-9150.2020.0500

ISSN : 2454-9150 Vol-06, Issue-04, July 2020

Table 3. The value of CCHT when Ethanol is Utilize as Functioning Fluid

S. No.	Angle of inclination	0	15	30	45	60
	Temperature	h PRACTICAL	h PRACTICAL	h PRACTICAL	h PRACTICAL	h PRACTICAL
1	40	336.83	333.12	323.64	310.62	264.94
2	43	365.19	365.19	337.20	322.60	291.13
3	46	386.70	381.99	373.24	344.54	310.62
4	49	409.46	413.68	387.44	376.06	325.89
5	52	434.82	434.82	418.76	386.71	349.89
6	55	458.20	453.55	432.39	406.09	363.27
7	58	480.97	474.40	450.97	421.16	378.22
8	61	486.39	494.43	476.84	435.36	396.58

Fig.-4 to Fig.-8 reveals the Practical outcomes of CCHT decreases as rising of tilting position of HPHEVC from vertical axis at different inlet temperature of evaporator for water and ethanol is utilized as functioning fluids.

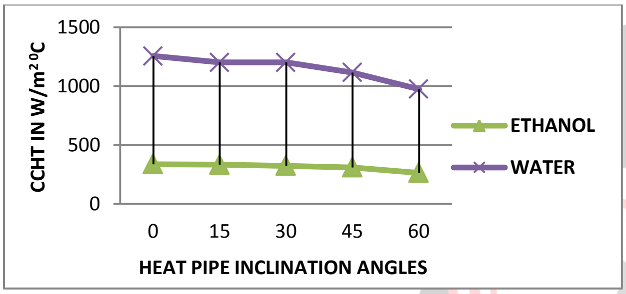

Fig. 4. Co-efficient of Heat Transfer when 40^0 Inlet Temperature

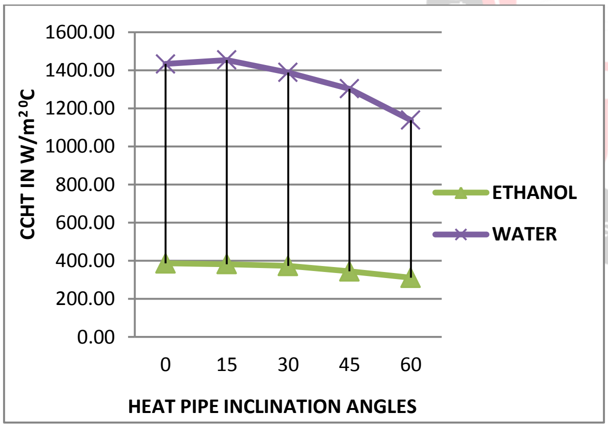

Fig. 5. Co-efficient of Heat Transfer when 46^0 Inlet Temperature

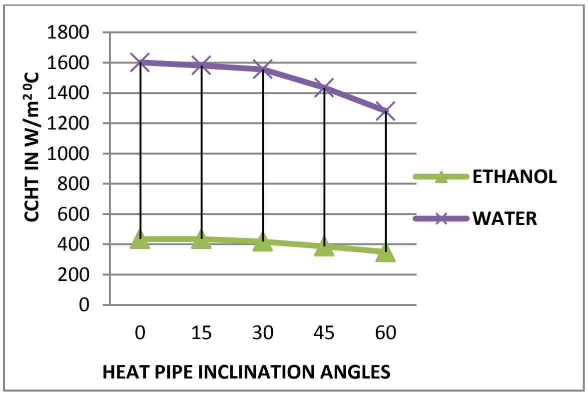

Fig. 6. Co-efficient of Heat Transfer when 52^0 Inlet Temperature

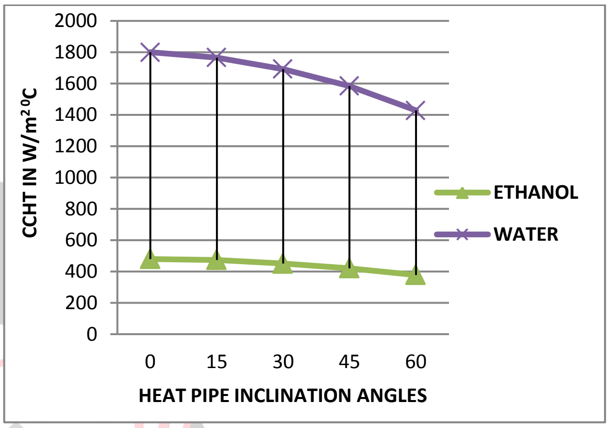

Fig. 7. Co-efficient of Heat Transfer when 58^0 Inlet Temperature

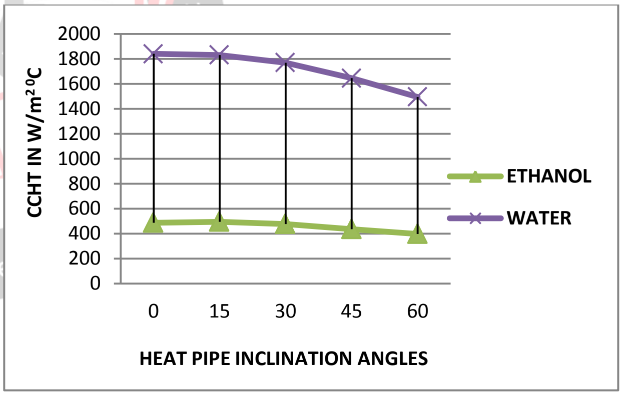

Fig. 8. Co-efficient of Heat Transfer when 61^0 Inlet Temperature

DOI : 10.35291/2454-9150.2020.0500

1.2 RHT

The thermal execution of the HPHEVC has been evaluated based on the amount of heat transported by the HPHEVC under various operating conditions, viz., separate functioning fluids e.g. water and ethanol as heating fluid, inlet temperatures of HP varies from 40 – 61 ^{0}C with equal interval of 3 ^{0}C and inclination of HPHEVC (like 0^0, 15^0, 30^0, 45^0, and 60^0 from vertical axis of HPHEVC).

The table 4 and table 5 are showing the experimentally measured and calculated values of RHT of HPHEVC under natural convection. The tables show the results at verities of input temperature of evaporator, tilting angles of HP from vertical axis and water and ethanol utilized as functioning fluids.

Table 4. The value of RHT when Water is Utilize as Functioning Fluid

S. No.	Angle of inclination	0	15	30	45	60
	Temperature	Q PRACTICAL	Q PRACTICAL	Q PRACTICAL	Q PRACTICAL	Q PRACTICAL
1	40	234.88	217.61	218.43	202.07	173.54
2	43	258.84	264.55	253.97	229.40	204.70
3	46	324.59	335.26	300.76	302.13	254.97
4	49	378.70	409.77	385.85	359.56	311.26
5	52	456.35	457.08	445.96	431.78	369.28
6	55	570.51	519.47	503.38	490.51	432.82
7	58	684.44	589.409	562.97	544.43	486.42
8	61	775.90	688.72	668.03	623.14	563.20

Table 5. The value of RHT when Ethanol is Utilize as Functioning Fluid

S. No.	Angle of inclination	0	15	30	45	60
	Temperature	Q PRACTICAL	Q PRACTICAL	Q PRACTICAL	Q PRACTICAL	Q PRACTICAL
1	40	50.35	47.27	48.92	43.69	43.80
2	43	64.51	64.51	56.25	51.29	46.24
3	46	75.27	74.11	70.52	68.03	65.38
4	49	98.04	95.77	85.86	86.94	77.75
5	52	118.05	118.65	110.86	99.79	92.10
6	55	139.59	140.99	128.34	119.09	109.04
7	58	167.75	165.81	154.79	141.86	127.32
8	61	194.34	189.23	184.33	165.00	150.88

This study reveals the graph of practical values of RHT of HPHEVC with respect to the inlet temperature of evaporator & inclination of HP from vertical axis for water, and ethanol is utilized as functioning fluids. In this reveals the results of RHT of HPHEVC for different - different functioning fluids is utilized in a same tilt angle of HPHEVC from vertical.

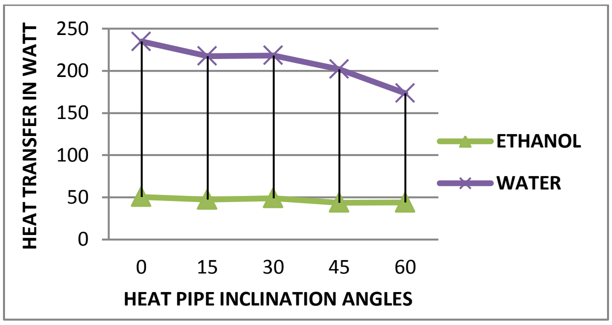

Fig. 9. Heat Transfer when 40^0 Inlet Temperature

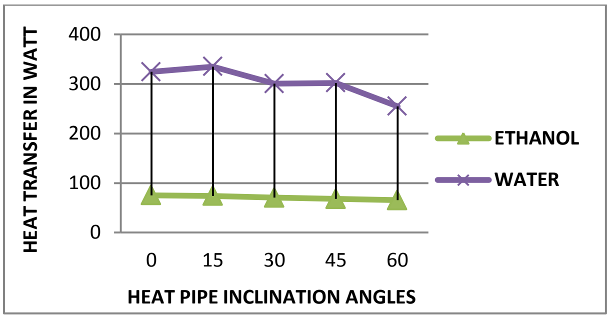

Fig. 10. Heat Transfer when 46^0 Inlet Temperature

 DOI : 10.35291/2454-9150.2020.0500

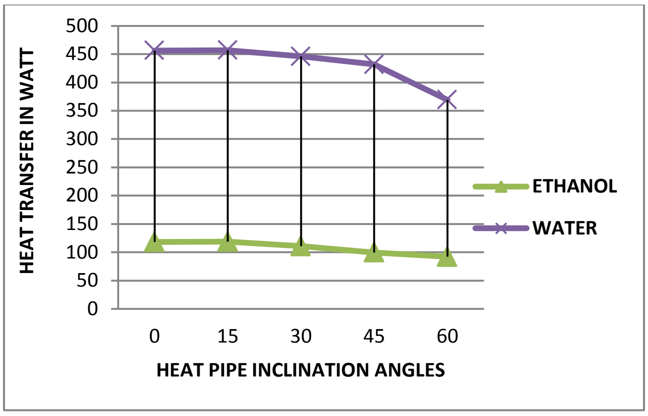

Fig. 11. Heat Transfer when 52^0 Inlet Temperature

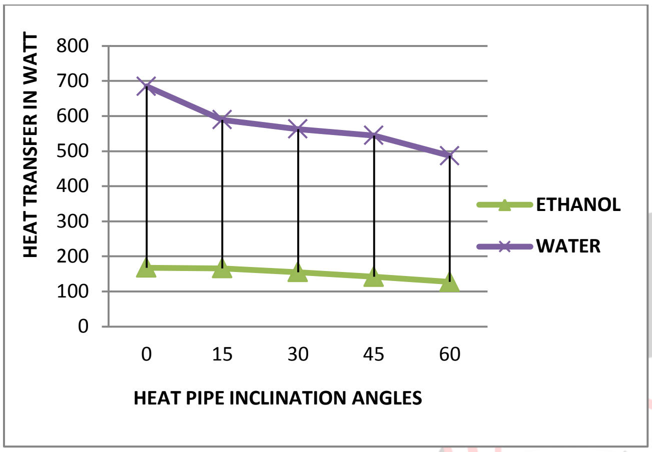

Fig. 12. Heat Transfer when 58^0 Inlet Temperature

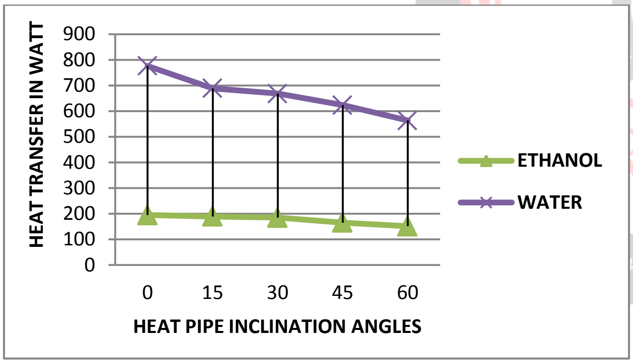

Fig. 13. Heat Transfer when 61^0 Inlet Temperature

The extreme Practical value of RHT of HPHEVC is 775.90 W for water is utilized as functioning fluid & the minimal Practical value of RHT of HPHEVC is 43.80 W for ethanol is utilized as functioning fluid.

VII. CONCLUSIONS

1.3 The Co-efficient of Heat Transfer for a Heat Pipe Heat Exchanger it is found that:

1. The value of CCHT rises as the inlet temperature of evaporator gradually enhances.
2. The value of CCHT decreases as the tilting angle of heat pipe increases from vertical axis.
3. The lower experimental value of internal heat transfer coefficient may be due to higher thermal resistances of cylindrical structure of the heat pipe which has resulted in more temperature drop across evaporator & condenser end.
4. It has been observed that as the tilt angle of heat pipe increases from vertical axis 0^0 to 15^0 the coefficient of convective heat transfer increases, and it starts decreasing beyond 15^0 tilt angle for inlet evaporator temperature 61 ^{0}C and ethanol used as working fluids.

1.4 The Heat Transport Rate for a Heat Pipe Heat Exchanger it is found that:

1. It has been observed that as the tilt angle of heat pipe increases from vertical axis the heat transport rate decreases.
2. For maximum RHT in the range of 200 to 800 W, water gives the best outcomes under natural convection condition.
3. For minimum RHT in the range of 40 to 180 W, ethanol gives the best outcomes under natural convection condition.
4. It has been observed that as the tilt angle increases from vertical axis 0^0 to 15^0 the heat transport rate increases, and it starts decreasing beyond 15^0 tilt angle for the inlet temperature of evaporator is 43 ^{0}C, 46 ^{0}C, 49 ^{0}C and 52 ^{0}C for water used as working fluid.
5. It has been observed that as the tilt increases from 0^0 to 15^0 the heat transport rate increases, and it starts decreasing beyond 15^0 tilt angle for the inlet temperature of evaporator is 43 ^{0}C, 46 ^{0}C, 49 ^{0}C, 52 ^{0}C and 55 ^{0}C for ethanol used as working fluid.
6. Ethanol gives the better outcomes to be utilized in low heat input while water in high heat input.

REFERENCES

[1] Silva, et al., Longitudinal vortex generator applied to heat transfer enhancement of a flat plate solar water heater, Applied Thermal Engineering 158 (2019) 113790 www.elsevier.com/locate/apthermeng

[2] Afroza Nahar, et al., Numerical investigation on the effect of different parameters in enhancing heat transfer performance of photovoltaic thermal systems, Renewable Energy 132(2019) 284e295 www.elsevier.com/locate/renene

[3] Zhang, et al., A review of heat transfer enhancement techniques in plate heat exchangers Renewable and Sustainable Energy Reviews 101 (2019) 305–328 www.elsevier.com/locate/rser

[4] Ivošević, et al., Thermal performances and their impact on design of bayonet-tube heat exchangers – single phase plug flow. Springer-Verlag GmbH Germany, 2019 https://doi.org/10.1007/s00231-019-02568-3

 DOI : 10.35291/2454-9150.2020.0500

[5] Afzal , et al., Steady and Transient State Analyses on Conjugate Laminar Forced Convection Heat Transfer, © CIMNE, Spain 2019 https://doi.org/10.1007/s11831-018-09303-x

[6] Keerti Sharma, et al., Natural convection heat transfers modelling by the cascaded thermal lattice Boltzmann method, IJTS 134 (2018) 552–564 www.elsevier.com/locate/ijts

[7] Acharya & Sukanta K. Dash, Natural convection heat transfer from a hollow horizontal cylinder with external longitudinal fins: (2018) ISSN: 1040-7782 (Print) 1521-0634 http://www.tandfonline.com/loi/unht20

[8] Obeidat, et al., Effect of cutoff radius, long range interaction and temperature controller on thermodynamic properties of fluids: PII:-S0378-4371(18)30001-3, https://doi.org/10.1016/j.physa.2018.01.001

[9] E. Nee1, Numerical analysis of three dimensional natural convection in a closed rectangular cavity under conditions of radiant heating and conjugate heat exchange, 01027 (2017) Smart Grids, DOI: 10 .1051/matecconf/20179101027

[10] Liu, et al., Heat Transfer Analysis of Passive Residual Heat Removal Heat Exchanger under Tube outside Boiling Condition Hindawi Volume 2017, Article ID 3497103, 10 pages https://doi.org/10.1155/2017/3497103

[11] Turgut, et al., Thermal design of spiral heat exchangers and heat pipes through global best algorithm, © Springer-Verlag Berlin Heidelberg 2016

[12] Zhang, et al., Effects of the arrangement of triangle-winglet-pair vortex generators on heat transfer performance of the shell side of a double-pipe heat exchanger enhanced by helical fins, © Springer-Verlag Berlin Heidelberg 2016 DOI 10.1007/s00231-016-1804-7

[13] Hazbehian, et al., Experimental investigation of heat transfer augmentation inside double pipe heat exchanger equipped with reduced width twisted tapes inserts using polymeric nanofluid. Springer-Verlag Berlin Heidelberg 2016 DOI 10.1007/s00231-016-1764-y

NOMENCLATURE

Symbol	Description	Unit
A	Surface area of HP	m^2
C_p	Specific heat	J/(kg-K)
$h_{practical}$	Practical value of CCHT	$W/(m^2\text{-}K)$
$h_{theoretical}$	Theoretical value of CCHT	$W/(m^2\text{-}K)$
k	Thermal conductivity	W/(m-k)
$Q_{practical}$	Practical value of RHT	W
$Q_{theoretical}$	Theoretical value of RHT	W

SUBSCRIPT

CCHT	Coefficient of convective heat transfer
HP	Heat pipe
HPHE	Heat pipe heat exchanger
HPHEVC	Heat pipe heat exchanger insulated with vacuum chamber
RHT	Rate of heat transport

 DOI : 10.35291/2454-9150.2020.0500