International Journal of Early Childhood Special Education (INT-JECSE)
DOI:10.9756/INTJECSE/V14I5.356 ISSN: 1308-5581 Vol 14, Issue 05 2022

Experimental and Numerical Investigation on Thermal Performance of Pulsating Heat Pipe by Using Ethylene Glycol

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ABSTRACT
Experimental Investigation on two phase system of a pulsating heat pipe takes into account useful heat transfer. In the field of thermal management, many new prospective concepts and technique have been developed, one of which is the Pulsating Heat pipe a classic heat transfer technique. The PHP made up 8 turns of copper, having inner dimeter of 2mm, wall width of thickness of 1mm and total length 5324mm. The CLPHP uses Ethylene Glycol as the functioning liquid at different filling proportions of 45%, 55%, 65%, 75%, and 85% of its amount. The evaporator section is heated electrically by a Plate Heater of 120Watts to 600Watts, the condenser part is cooled through on stop circulation of cooling water. The results show that The investigation requires accepted resistance decreases rapidly. Apparent that lesser rate of thermal resistance is achieved by filling ratio of 55%. It is found that for Ethylene glycol measured for calculating heat transfer performance at 600W, evaporator temperature is 181.5778°C and condenser temperature is 41.062°C, thermal resistance is 0.136°C/W, heat transfer coefficient is 526.45W/m^2-°C and hence exhibits good improvement at a filling percentage of 55% .

Keywords: Pulsating Heat Pipe, Filling Ratio, Heat input, Ethylene Glycol.

1. INTRODUCTION

Filling ratio also depends on how much charging working fluids as the proportions of the quantity of operational liquid present in PHP. its complete quantity (stream phase) at a specific temperature for the most part in room temperature. Filling ratio can from 0 to 100%. it apply with next to number of functioning liquid and heat will be moved from evaporator to condenser simply through the mode of conduction. Filling ratio100% addresses a device having a stream channel completely filled up with working liquid. The filling ratio extensively affects Pulsating heat pipe in transfer heat. Different experiments conducted have shown in reduce thermal resistance of PHP. It is used transport small temperature a heat flux across[1,2]. N. santhisre et al 2020 Experiment performing 8 turn Pulsating Heat pipe using variety of low temperature operational liquids DI water, methanol, Acetone & Ethanol. Analysis of variance and Annova techniques were employed by applying the optimization Parameter. Heat Input is the main effective factor that influence the experimentation of PHP [3]. The ideal filling proportion changes depending on the functioning liquid properties are utilized for a given PHP [4, 5]. It was seen that for a similar FR, the PHP with working fluid limit and latent heat of vaporizations both generally lower value, effectively dry out even at low temperatures[6]. It is seen that various FRs prompt different heat input needed for setting off the oscillatory stream in PHP. For starting the stream motions, the PHP with moderately FRs of more modest quality requires more heat inputs [7]. Nandan S. et al. observed that the ideal FR was dependent upon direction on fluid flowing in clock wise directions and antilock wise directions [8]. Mauro M. et al. concentrated to joined effect filling ratio and the tendency point on execution of CLPHP with FC-72 as the turning out liquid for various heat input levels. The base heated PHP with Filling ratio 50% the best result , with heat opposition multiple times lower than the vacant device [9]. [10].Jian Q et al 2013 Simulations and flow behaviour of micro –PHP by using working fluids FC-72 and R-113.at a moderate rise in the evaporators wall temperature a maximum power heat input of roughly 9.5W was achieved, with a heat flux of up to 10.7W/cm^2 .Micro device maximum Power Heat input of about 9.5W associated with a heat flux up to 10.7W/cm^2 was reached at a moderate rise in wall tem of the evaporator[13]. Dong Xu et al. optimum Filling ratio for the largest heat motion different from the heat input for the cryogenic PHP using Helium is the operating liquid. Various FR impacts the flow motion. In the case of PHP with a lower filling, it was simple to understand influential movement of the liquid in any event, for a low heat input .If an occurrence of the PHP with higher filling ratios occurred, the low information power was insufficient to move extra fluid in bearing of

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the condenser segment .In 1990, the akachi PHP was made in two phase heat move apparatus. The PHP is Comprised of three zones of narrow cylinders, specially evaporator region, condenser region, and adiabatic region, all turns coordinated as displayed in Fig.1.taking re classified Two types of PHP open loop and closed loop. PHP was utilized for this examination since it into account the preferred working liquid flow over open circle PHP. Moreover, PHP with an open circle is quicker. The heat move in PHP is developed by the utilization of exude air pockets and fluid slugs, i.e., through the transmission of Latent and Sensible heat through heating development, hence the term pulsating heat pipe. few scientists have announced their test heating development, hence the term pulsating heat pipe. few scientists have announced their test discoveries work regards to the best filling proportion, tube width, direction and greatest heat transfer of PHP, in addition to other things. Sarangi [14].

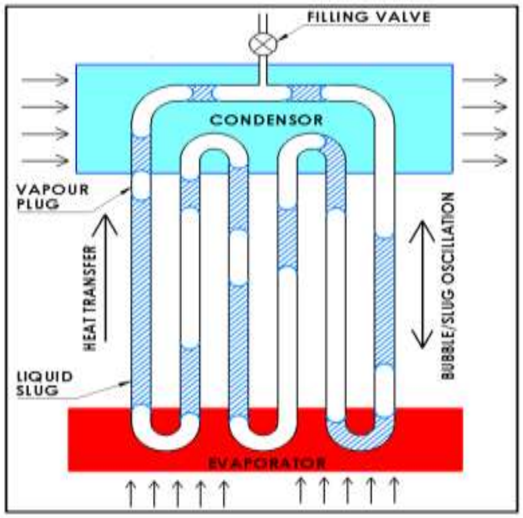

Fig 1. Closed Loop Pulling Heat Pipe.

the ideal filling proportion is directed by the qualities of the functioning liquid and its working temperatures. Himel Barunal showed the impact of substantial proportion happening PHP execution, revealing PHP works at various substantial proportions for various operational liquids, for example, half for ethanol and 70% for DI water, the various of Evaporator and condenser temperatures for the effect of Nano fluids SiO_2 –H_2O with different mass concentrations. Increasing the instantaneous velocity and driving force of the working fluid, on the other hand. on the other hand increases the instantaneously velocity and the driving force of working fluid [15]. At the point when heat at different mass constrictions between evaporator with condenser rises, Honest pai did a limited component concentrate on PHP and track down that the heat transport coefficient increments with the expansion in amplitudes of wavering[16]. About alebi directed a trial examination concerning the exhibition of pivoted shut circle PHP and reached the resolution that the turning velocity of shut circle PHP made, radiating power that guide in the easing back of the drying system and improved warm proficiency[17].It was like wise shown that the ideal filling proportion for all rotational velocities is 50% filling ratio. Tsai et al examined the heat move abilities of PHP utilizing gold nanofluid, exhibiting that presentation further develops when nanofluid is utilized, just as the variety in warm difficulty when the breadth of the nano particles is changed[18]. M. Aboutalebi et al directed an examination with jewel nanofluid and noticed an expansion in heat opposition with the utilization of nanofluid[19]. They like wise expressed that the exhibition is reliant upon the functioning temperature of PHP, with the least worth of heat opposition being 0.03ºC/W at a heat contribution of 336W. Since end focuses on open circle confine and possibly avoid fume/fluid stream inside the circle, a shut circle development was demonstrated to be more effective [20].

2.Numerical Investigation

2.1Physical model

FIG. 1 depicts the structure of PHP in the model. PHP may be seen of as a straight tube with an alternately appearing evaporating and condensing portion if the bend loss is neglected.

The following presumptions are made in order to solve the issue:

1. Slug flow is the flow pattern.
2. The vapour has optimal gas behaviour, while the liquid is incompressible.
3. ignoring the shear tension between the liquid sheet and vapour plug.

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4. Considering simply heat transmission due to phase transition between vapour plug and liquid film.
5. Neglect is shown to the effect of the liquid film on the change in momentum of liquid slugs.

3. Experimental Investigation.

3.1 Experimental Set up.

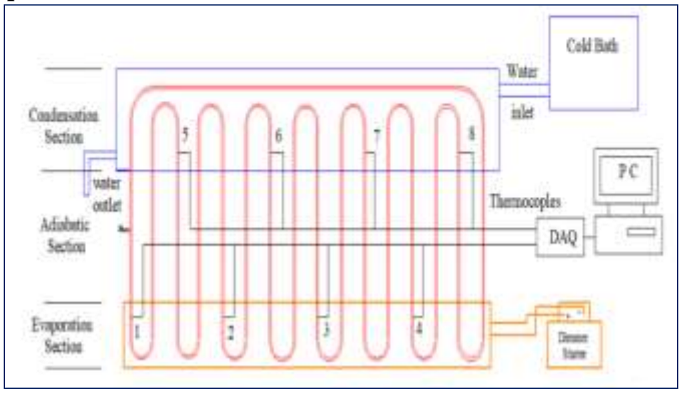

Fig 2. PHP Diagram of the test setup system.

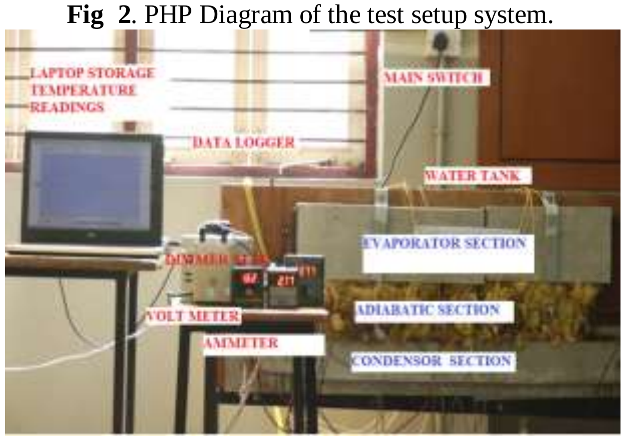

Fig 3. PHP test setup.

Test ring design as shown in Fig.3 includes a power supply framework and a CLPHP temperature measurement framework made of copper tubes appropriate to its high thermal conductivity. The copper pipe is of 2 mm diameter and the thickness of each pipe is 1 mm. When the built-in Evaporator zone U curves and condenser zone rearranged using U twist with a 25mm radius shaped design of eight turns. When the steam area is compressed the temperature changes with a radiator plate mica heater with a limit of 1000Watt. Input temperature varies from 120Watt to 600Watt by including step size 120Watt step.

Condenser section has constant flow rate of water 0.85m/sec. The whole set is collected in copper tubes and operates at the same temperature. Distance of end to end of the evaporator stage, the adiabatic area and the condenser area in the test set are1040mm, 1920mm, and 2364mm, respectively. Eight k-Type thermocouples are used to calculate the temperature, four of which have been used with in the Evaporator stage and other four are connected to the condenser place. When the frame reaches focus on stage, data acquisition is used to determine the temperature.

The condenser zone is under a stable flow of cooling water. condenser single flow of active fluid at 0.85m/sec each, in the test board above the vapor part of the vapor. At a time when the texture is concentrated in the region, the temperature is measured by construction using successively. With a relative conduit rate of 0.85 mlt/sec, the condenser belt is exposed to cooling water.

3.3 Experimental data calculations were done by the following formulas

3.3.1 Selection of working fluid in Pulsating Heat Pipe.

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Fig 4. Ethylene Glycol fluid

Another key aspect that influences PHP performance is the choice of operating fluid in Ethylene Glycol. Fluids basic thermodynamics consider surface tension, Thermal conductivity, Latent Heat are used to describe the properties of a substance. The vapour pressure of a fluid and merit number (Additionally recognized the liquid delivery element)M, are two quantitative parameters used to assess its appropriateness for heat pipe applications.

$$M = \frac{\rho_l \times \sigma \times \lambda}{\mu_l} \quad (1)$$

The merit number is calculated by grouping the fluid's favourable qualities in the numerator and less desired properties in the denominator. As a result, the higher the value of M, the better the fluid is for pulsating heat pipes. Each of these qualities will be examined individually and in combination in the evaluation of heat pipe fluids. Melting and critical points of prospective heat pipe fluids are first determined. Stull (1947) provided vapour pressure data for a wide range of elements, organic, and inorganic fluids. The vapour pressure and merit number data are used in the first screening and assessment of a heat pipe fluid.

3.3.2 The diameter in Closed loop Pulsating Heat Pipe is used to outline it

Characteristics that essentially define a PHP is the internal tube diameter. Only below a specific range of diameters does the physical behavior remain in the 'pulsating' state. Akachi and Polasek calculated the theoretical highest acceptable inner diameter, Dmax, of PHP capillary is based on the following equilibrium equations between capillary and gravity forces:

$$D_{\max} = \sqrt{\frac{\sigma}{g(\rho_l - \rho_v)}} \quad (2)$$

PHP is directly affected by the interior diameter. A wider hydraulic diameter lowers wall thermal resistance and enhances effective heat conductivity, but it also limits capillary action, preventing the development of a liquidvapor slug train.Surface tension forces dominate when Dmax, and stable liquid plugs develop.

Where If D > Dmax, water pressure decreases, active fluid disperses due to gravity, and rotation.

Heat Resistance and Transmission Heat together are calculated using the formulas as shown in Eq.3. and Eq.7.

$$R_{th} = \frac{T_e - T_c}{Q} \quad (3)$$

Evaporator temperature and Condenser temperatures of PHP are calculated by using the formula as shown in Eq.4 and Eq.5.

$$T_e = \frac{T1+T2+T3+T4}{4} \quad (4)$$

$$T_c = \frac{T5+T6+T7+T8}{4} \quad (5)$$

Heat input Q of PHP is calculated by using the formula as shown in Eq.6.

$$Q = V*I \quad (6)$$

$$h = \frac{Q}{As(T_E - T_C)} \quad (7)$$

4.2 Experimental results.

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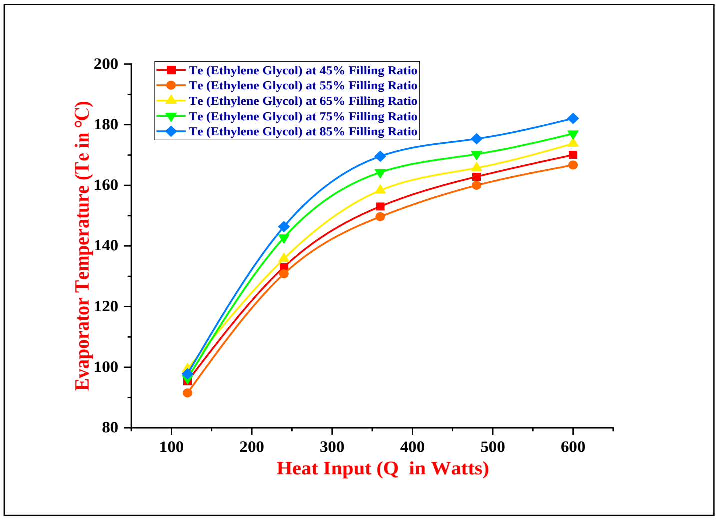

Fig 5. Evaporator Temperature v/s Heat Input

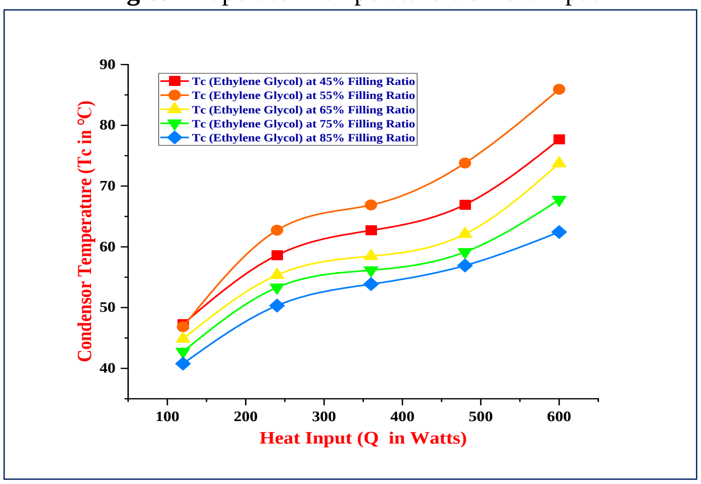

Fig.6 Condenser Temperature v/s Heat Input

Fig.5 and Fig.6 show effect of thermal efficiency on the link between the temperature differential between the evaporator and the condenser temperature. The temperature differential between the evaporator and the PHP Condenser, in which heat is transferred in the shape of vapor to the condenser .Appearing from a low temperature input, the evaporator temperature is relatively low and rises with an increase in the temperature of all filling concentrations considered as the evaporator temperature raises rising Vapour bubbles and liquid plugs fluid pipes in the suction pipe accelerating. this enhances heat transfer, as in the condenser phase for additional thermal inputs, If there are too many liquid oscillations within PHP, the heat transfer rate goes up.

4.3. Effect of Thermal Resistance on Thermal Performance of PHP.

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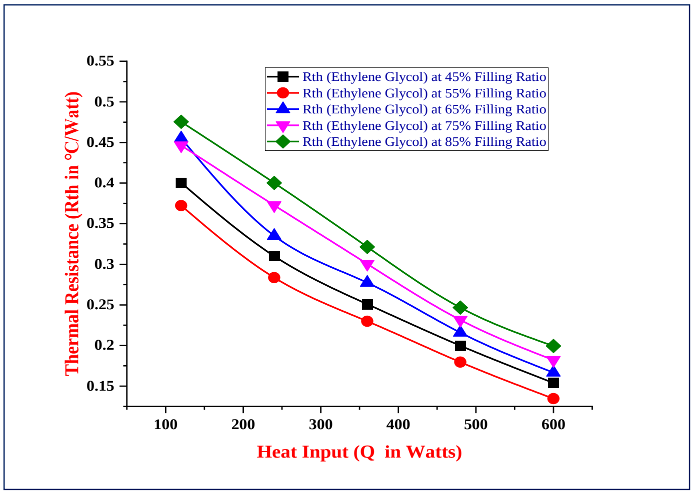

Fig 7. Thermal Resistance versus Heat Input.

Fig.7 shows that The cost of thermal resistance decreases with the boom in increment of warmth enter for the Ethylene glycol. Until approximately 240W input of heat there's a drastic development in thermal performance whilst thereafter it's mild. In general as the heat input increases, the pumping of working fluid increases. Further it is observed that as the filling ratio increases the performance of pulsating heat pipe diminishes with on increasing in heat input. the working fluids are considered at a filling ratios 85% and 75%.it was observed that the performance was poor due to surface tension and insufficient pulsations. Ethylene glycol 55% filling ratios indicates lower value of thermal resistance with growth in heat input. It was observed that formation of bubbles is more with increses in heat input which causes extra perturbations. The pulsating heat pipe operated in Pulsating mode. Effective thermal resistance, which is defined as the relationship between the temperature distinction among the evaporator and the condenser and the net warmth enter of the machine. Thermal resistance decreased as heat of input increased, and it is worth noting that the 55% filling ratio generated the bottom thermal resistance of all of the filling ratios tested... Thermal resistance clearly decreased as heat input increases, and it is worth noting that the 55% filling ratio generates the lowest thermal resistance of all the fill ratios examined, about 0.36 °K / W at 600 watts. As a consequence, PHP out performed other fill rates when the fill rate was 55%.

4.4. Effect of Heat Transfer Co-efficient on Thermal Performance of PHP.

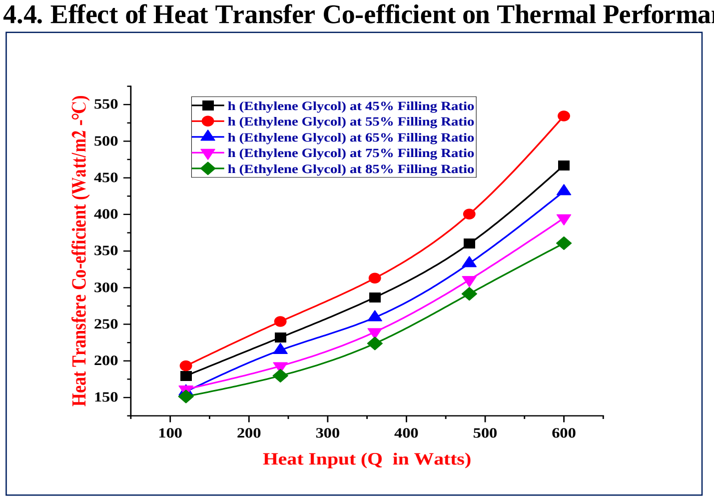

Fig 8. Heat Transfer Co-efficient versus Heat input.

Fig 8.shows The impact of heat input on heat transfer co-efficient of PHP for Ethylene glycol respectively with filling ratios of 45%,55%,65%,75%,85% .It is observed that the heat transfer co-efficient of PHP increases with increasing in heat input. The heat input is the 'Pump' for the thermo-fluidic movement, hence, growing Pumping Power increases the performance. Further it is seen that Ethylene glycol with 55% filling ratios reveals higher value of heat switch heat transfer coefficient compared to other filling ratios, this is due to the extra pulsation of vapor plugs and liquid plugs . The filling ratios will increase to the extent of the fluid in the PHP tube. Which could

DOI:10.9756/INTJECSE/V14I5.356 ISSN: 1308-5581 Vol 14, Issue 05 2022

be very difficult to form bubbles or vapor plugs and it was observed that no oscillations have been located in PHP. higher value of heat transfer co-efficient 562W/m2-℃ was obtained filling ratios of 55%.Hence for higher value of heat transfer co-efficient corresponding to filling ratios, the PHP have better heat transport capability compared to other filling ratios.

5. Conclusion

The temperature of evaporation and condensing is determined in the experimental test of a sharp heat pipe driven by a working Ethylene glycol liquid. Water with a filling ratio 45%,55%,65% ,75% and 85% by varying the heat input From 120Watt to 600Watt in step size 120W. the heat transfer coefficient and thermal resistance are computed using these data to compare the performance of the pulsating heat pipe under various situations. The following results made from the investigations. .

1. It appears that the active fluid inside the tube is abrupt and there is no active circulation of the liquid at the beginning of the low temperature heat input in 120W. The oscillations of the active fluid will have continuous oscillations the input temperature raises. such as temperature conditions, which lead to an increase in heat transfer rate When the input temperature is low, the number and size of bubbles created by all the active fluids tested is smaller and fewer, but as the heat input increases, it increases and larger bubbles are needed to transfer heat from the evaporator to the condenser Sections.

2. Fluid the heat input increases in 120W, 240W,360W,480Wand 600W , Ethylene glycol, like all other working fluid investigated, has a higher thermal resistance. Ethylene glycol reduces when the heat input is increased .the temperature of the working fluid in the evaporator charged as well as liquids As with all working fluids studied, Ethylene glycol has better thermal resistance 0.136℃ /W when the heat input increases 600W. When the heat input is increased, the thermal resistance of the Ethylene glycol decreases. A change in the evaporator temperature of the working fluid was also observed.

3. The heat transfer coefficient of Pulsating Heat Pipe is could be enhanced in 526.45W/m^2-℃ case of 55% filling ratio of Ethylene glycol at 90° inclination at 600 W with respect to flow of fluid PHP operation.

6. Nomenclature

Bo Boit Number
h Heat transfer co-efficient w/m^2-℃
C Specific heat capacity, J/kg-°C
As surface area heat transfer in m^2
L length of PHP in m
A_{CS} area of cross area of pipe in m
D Outer diameter of the tube, mm
d Inner diameter of the tube, mm
h Heat Transfer Coefficient W/m2-℃.
K Thermal Conductivity of heat Pipe w/m-k.
Q Heat input in W.
ρ_l Density of Liquid in Kg/m^3.
ρ_g Density of Liquid in Kg/m^3.
L Characteristic length in mm.
q Heat flux, W/m2.
L Length of the section, mm
m Number of trials
Mo Morton number
P Pressure in baa
Q Heat load, W ˙
r Resistance, °C/W
R Radius of the bend, mm
Re Reynolds number
V Volume, ml
T Temperature
htc Heat transfer portion of condenser
T absolute Temperature in ℃
Q heat power input W
D_{cr} diameter of pipe in mm.
g acceleration due to gravity in m^2/sec.

T_E Evaporator Temperature in ℃
T_c Condenser Temperature in ℃
h Enthalpy, J/kg
R_{th} Thermal Resistance in ℃/W
T_4,T_3,T_2, T_1 Evaporator Temperatures in ℃
T_8,T_7,T_6, T_5 Condenser Temperature in ℃

Acknowledgments

The authors would like to thanks the management JSS Mahavidya Peetha, Mysuru, India and the Department of Mechanical Engineering, JSS Academy of Technical Education Noida, India for expanding the research resources and kindly supporting the Department of Mechanical Engineering, Bangalore Institute of Technology, Bangaluru, India.

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