Performance Analysis of Methanol in Heat Pipe Heat Exchanger – An Experimentation and Numerical study using ANFIS

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Abstract. In electronic cooling systems and utilization of waste heat to safeguard the electronic components from overheating the heat pipe are used. This study focuses on the experimentation and numerical comparison of an Heat Pipe Heat Exchanger (HPHE) using methanol. The investigation focuses on various orientation angles (0º and 90º) and extended with (10º to 80º) angles. The maximum Reynolds number obtained as 1.33% for 0º than 90º, similarly 8.56% for 60º comparing with 10º. The minimum thermal resistance obtained as 2.65% for 0º than 90º, similarly 3.81% for 60º while related with 10º. The observed average minimum thermal resistance for experimental value as 3.29% and predicted value as 3.46%. From the investigation it’s evident that experimental results are closes to the numerical values using ANFIS - Neuro fuzzy system. In the utilization of waste heat recovery system the HPHE shows better performance and this can scaled and utilized for electronic component cooling applications.

1. Introduction
The heat exchangers are widely used in industries by utilizing the waste heat and increasing the performance, to minimize the operation & capital cost the heat pipes are implemented and also to obtain maximum heat transfer with minimum components. The heat pipe with 50% fill ratio of De-ionised water shows lower thermal resistance [1]. The pulsating HP with DI water at inclination angle shows lowest heat resistance [2]. In automobiles for exhaust gas recovery the heat pipe heat exchanger [3]. The performance of concentric tube heat pipe heat exchanger were investigated using various parameters like working fluids, heat transport fluids, geometry and angles [4-5]. Heat pipe with numerical study using different models and has good agreement in results [6-7].The eco-friendly refrigerants are used in analysing the heat pipe heat exchanger [8]. In spacecraft applications the loop heat pipe were used to increase the heat transmits ability [9]. The methane cryogenic LHP analysed
with different heat loads possess the maximum performance [10]. The heat pipe using Insulated Gate Bipolar Transistor modules had maximum efficiency at the flow of air at 450 m$^3$ h$^{-1}$ [11]. The CLPHP with 50% fill ratio has supreme performance in the system using different fill ratio, angles and heat input [12-13]. The heat pipe concepts were implemented in solar plants, industries, thermal plants, processing units, research laboratories and domestic equipment’s [14-15]. The satellite ammonia heat pipe experimentation shows minimum thermal resistance [16]. The Studies were carried out on helicoidal double pipe heat exchanger by Adaptive Neuro-Fuzzy inference system reveals adequate and compelling results on comparing with the experimental result [17]. Thermal performance was analysed using heat pipe with R134a and maximum performance obtained at 22º [18]. In high power electronic cooling system the LHPs were tested for various conditions and loads [19]. In the exhaustive literatures shows that the previous studies possess with minimum geometrical and working constraints of the heat pipe heat exchanger. In the present analysis, the heat pipe is fabricated and introduced in a concentric tube heat exchanger.

2. Experimental Design
The HPHE are designed and fabricated using copper and introduced in the heat exchanger (galvanized iron material) shown in Figure 1. The red and blue line specifies the hot and cold fluid flow path given in Figure 2. The experimental fabrication has geometry of the HPHE as 1000 mm, including 700 and 300 mm as evaporator and condenser regions. The heat pipe has 19 and 17 mm as outer and inner diameter. The evaporator and condenser shell diameters of 50 and 35 mm. HP has stainless steel wick with mesh size of 50 holes/inch and 2000 m$^{-1}$ number of wires/unit length. Methanol as Working Fluid (WF), Water as a Heat Transport Fluid (HTF). The hot and cold fluid tank capacity of 5 litres with 3 LPM rotameters each, an immersion heater has 2000 W with 10 W capacity to regulate the temperature of hot fluid. A Monoblock 0.5 HP pump used to circulate the hot water to the evaporator portion of the heat exchanger where the flow rates are controlled using rotameter. The temperatures are measured using K-type thermocouples at all nodes.

![Figure 1. Schematic configuration of a HPHE](image)

3. Experimental Procedure
The experimentation is done using fabricated HPHE setup shown in Figure 3. Inside the HP the gases are removed using the vacuum pump this is ensured with the coupled 30 inches of Hg vacuum gauge. The methanol with fifty percent fill ratio is used as a WF for experimentation [4]. The heat transport fluid for the test chosen as water for the investigation. In the preliminary test, HPHE is kept at 0º and 90º tilt angles (horizontal and vertical orientation) and further experimentation with other angles as 10º to 80º. Initial experiment, the hot and cold fluid mass flow rate as 40 and 20 LPH and inlet temperature as 50 and 30.5ºC, respectively. Similarly for other angles (10 to 80º) and mass flow rates (60 to 120 LPH). The heat exchanger outer shell is fully insulated with the Styrofoam (20 mm) to reduce the heat interface with the environment.
4. Uncertainty Calculation
Uncertainties are considered for the experiment using Kline and McClintock’s method [20]. To reduce the uncertainty of the instruments systematic calibration with national standards. The uncertainty for Thermal resistance is 2.8%. The uncertainties are obtained with the sensitivities of thermocouples, rotameters and heaters at the heat exchanger.

5. Result and Discussion
The above parameters are consider for this experiment and the results are given below. In Figure 4, the maximum Reynolds number (Re) obtained at 60ºC, 100 LPH for 0º is 914 and 90º it’s 902, there is an increment of 1.33%. Investigation shows (Re) increases from 40 to 100 LPH and similarly at 120 LPH, this reduced at other inlet hot fluid temperatures. In case of 120 LPH it’s 771 to 768 for 0º and 90º.

In Figure 5, the maximum (Re) obtained for 60ºC, 100 LPH for 60º. The observed values are 797.84 to 866.14 for 10º to 60º and 836.66 and 846.96 for 70º and 80º, respectively. There is 9.66% increment in result for 60º than 10º. This is observed as 692.17 to 748.27 for 10º to 60º, 725.52 and 736.72 for θ as 70º and 80º, respectively for 120 LPH. Figure 6, shows that minimum thermal resistance (Rth) obtained for 60ºC, 100 LPH for 0º. The inferred values of 0º and 90º are 0.00664 and 0.00681 °C/W are 2.65 % decrement than 90º. Rth reduces from 40 to 100 LPH, similarly for 120 LPH Rth increases as 0.00687 and 0.00685 °C/W for 0º and 90º at 120 LPH. Hence, there is reduction in thermal resistance leads to increase the performance of HPHE. Figure 7, the minimum (Rth) values observed at 60ºC, 100 LPH for 60º, the obtained results are 0.00716 to 0.006897 °C/W for 10º to 60º, respectively 0.00755 and 0.00733 °C/W for 70º and 80º, respectively. Similarly, 3.81% reduction for 60º than 10º. At 120 LPH
starts increasing from as 0.00721 to 0.006924 °C/W for 10° to 60°, 0.00762 and 0.00737 °C/W for 70° and 80° for 120 LPH. Due to the faster flow of liquid working fluid to evaporator causes friction leads to increase in thermal resistance at higher angles.

6. Neuro Fuzzy Prediction Model

An adaptive neuro fuzzy inference system is developed to create a prediction model from the experimental data. Neuro fuzzy inference tool from the MATLAB 2020 is used for the development of the prediction model. The experimental data associated with the process is input into the module and the plot of the data is shown in the Figure 8. The entire experimental data is divided into three categories. 70%, 20% and 10% data’s for the training, testing and checking process, respectively.

During the training process the model runs the experimental data and creates a neuro fuzzy network which satisfies the relationship between input and the output factors. The testing and checking data are just data which are used to test the efficiency of the developed prediction model.

The network developed for the neuro fuzzy system is given in the Figure 9. The three input factors are Angle, Mass flow rate and Temperature and the output response as Thermal resistance. A sugeno based neuro fuzzy model is developed here and three membership functions for every input parameter has been described here namely low, medium and high.
The membership function used here is the bell MF at Figure 10. The analysis is conducted with other membership functions also such as triangular, gauss, trapezoidal but bell function as considered appropriate as it provided better results in minimum amount of processing time.

The Figure 11, shows the attributes from each and every input is compared and based on that a relationship with the output. The checking error also is shown in the form of the solid blue line in the graph and it indicates the checking error to be close to the testing error (0.375) at Figure 12. For a better representation the testing data and checking data are plotted against the experimental data given in Figure 13. It’s concluded from both the plots that the developed prediction model is robust as the experimental and predicted values are very closer. Once the training is completed, we obtain a rule viewer which enables us to understand the variation of output when any of the input is varied.

From this prediction of input data can be given in Figure 14. The variation of the thermal resistance is plotted for different m, T, at the various angles are shown in Figure 15, 16, and 17. From the rule viewer the prediction model is analysed by obtaining the predicted values for the corresponding test data. Error percentage is calculated using the given equation 1,
Error $\% = \frac{(\text{Predicted value}) - (\text{Experimented value})}{(\text{Experimented value})} \times 100$  

\begin{align*}
\text{Mean Average Deviation} &= \frac{\sum_{i=1}^{n}(\text{Experimental value} - \text{Predicted value})}{n} \\
\text{Root Mean Square Error} &= \sqrt{\frac{\sum_{i=1}^{n}(\text{Predicted value} - \text{Experimented value})^2}{n}}
\end{align*}

The predicted and experimental value for the testing data is plotted in the Figure 18. The graph represents that there is very little inconsistency between the experimental and the predicted values.

7. Analysis of Variance

Analysis of variance of the data conducted to study the behaviour of thermal resistance towards the three input parameters. The normal probability plot depicts the values are aligned across the mean line, thus indicating the robustness of the conducted experiments. The histogram also reveals a bell shaped curve hence validating the fact that the experimental readings are reliable and there is no discrepancy in the robustness of the data are shown in Figure 19. From the analysis of variance, the results are given in Table 1. From the F-value it’s clear that the most influencing factor affecting thermal resistance is Temperature. The analysis of variance model is obtained with a $R^2$ value of 97%. The main effects plot of the experimental data in Figure 20. The $0^\circ$ and $90^\circ$ angles minimum thermal resistance are observed. Similarly, the $R_{th}$ decreases for $m_{th}$ of 100 LPH shows the downward trend.
In the case of temperature, the $R_\theta$ peaks at 60 °C and then steeply begins to decline with the increase in temperature.

### Table 1. Analysis of variance for F-value.

| Parameters             | Degrees of Freedom | Sum of Squares | Mean of Squares | F-Value |
|------------------------|--------------------|----------------|-----------------|---------|
| Angle (º)              | 9                  | 125.90         | 13.989          | 44.13   |
| Mass flow rate (LPH)   | 4                  | 2904.71        | 726.178         | 2290.88 |
| Temperature (ºC)       | 4                  | 112.42         | 28.106          | 88.67   |

At 70º, for 40 LPH and 50ºC the thermal resistance obtained is maximum at 18.24, for this parameter setting the predicted value obtained is 17.8. The above readings are fed into the neuro fuzzy model and the predicted values are obtained. The experimental and the predicted values given in the Table 2.

### Table 2. Comparison of Experimental and Predicted value

| S.No. | Angle (º) | Mass flow rate (LPH) | Temperature (ºC) | Experimental value (%) | Predicted value (%) | Error (%) |
|-------|-----------|----------------------|------------------|------------------------|---------------------|-----------|
|       |           |                      |                  | MAXIMUM THERMAL RESISTANCE |                     |           |
| 1.    | 70        | 40                   | 50               | 18.2426                | 17.8                | 2.42      |
|       |           |                      |                  | MINIMUM THERMAL RESISTANCE |                     |           |
| 1.    | 0         | 100                  | 60               | 3.1852                 | 3.20                | 0.46      |

The lowest thermal resistance of 3.18 is observed at 0º, 100 LPH and 60ºC, the predicted value as 3.20. Thus the neuro fuzzy model are able to successfully predict the values with an acceptable error of margin.

### 8. Conclusion

The analysis states the effect of methanol, water and inclination angles are experimented and compared numerically using Neuro fuzzy interpolation. Thermal performance observed maximum for 0º than 90º angle. Similarly, for 10º to 80º the maximum results are observed for 60º angle. In this analysis, for optimum situations, increase in Reynolds number obtained are 1.33% for 0º than 90º, similarly 8.56% for 60º than 10º. Thermal resistance the minimum values are 2.65% for 0º than 90º, at inclination angles 3.91% for 60º than 10º. The experimental results are closely similar to the predicted value, hence Neuro fuzzy interpolation makes good results for this experimentation.
9. References

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