Artificial Neural Network Analysis of the Grooved Heat Pipe

[1]S.Gajalakshmi, [2]R.Senthilkumar, [3]G.Sasikumar
[1]Associate Professor, Department of Mechanical Engineering, CK College of Engineering & Technology, Cuddalore-607003, India
[2]Assistant Professor, Department of Mechanical Engineering, Annamalai University, Chidambaram – 608002, India
[3]Professor Department of Mechanical Engineering, CK College of Engineering & Technology, Cuddalore-607003, India

Abstract - In this study, a feed-forward back propogation artificial neural network (ANN) algorithm is proposed for the thermal performance of grooved heat pipe .Thermal performance of grooved heat pipe is experimentally studied using DI water and various nanofluids as working fluids. The average size of the nano particles is 50nm. The experiment has been conducted with varying heat inputs from 30 to 70 W with 10 W intervals, inclination angle varies from 0° to 90 ° with 15° interval, filling ratio is 75 % with constant flow rate of coolant in the condenser section as 0.08 kg/min. In this, the back-propagation learning algorithm with Levenberg–Marguardt (LM) is used in the network so that the best approach could be found.

Keywords: Grooved heat pipe, Nano fluids, Thermal efficiency, Thermal resistance

I. Introduction

Heat pipes are high-efficient heat transfer devices and have been widely applied in various thermal systems. The heat pipe is a heat transfer device, which has three regions likely evaporator, adiabatic and condenser. Adiabatic region is also called as transport region. The evaporator section is attached to the heat source and the heat pipe filled with small quantity of working fluid. The working fluid evaporated to vapour in the evaporator region by using the heat availability and that vapour condensed in the condenser region. The condensed fluid return backs to the evaporator region with the help of capillary pressure created by the groove which is provided in the heat pipe. The process proceeds until there is a sufficient pressure, drives the condensate back to the evaporator region.

Balram Suman *et a*l [2005] developed a transient model of triangular shape micro-grooved heat pipe. The combined equations of heat, mass and momentum transfer are determined to obtain the transient as well as steady state profiles of various parameters like substrate temperature, liquid pressure and liquid velocity. It was found that the time required 20 s to attain the steady state for the substrate temperature. Kyu Hyung Doa *et.al* [2008] developed a mathematical model for predicting the thermal performance of a flat micro heat pipe with a rectangular grooved wick structure. The results obtained from the proposed model are in close agreement with several existing experimental data in terms of the wall temperatures and the maximum heat transport rate. The maximum heat transport rate of a micro heat pipe with a grooved wick structure is optimized with respect to the width and the height of the groove by using the proposed model.

Reay *et al* [2006] The radial thermal resistance of grooves will be radically different in the evaporator and condenser sections. This occurs because of the differences in the mechanisms of heat transfer. In the evaporator the land or fin tip plays no active part in the heat transfer process. The probable heat flow path is conduction via the fin, conduction, across a liquid film at the meniscus and evaporation at the liquid–vapour interface. In the condenser section, grooves will be flooded and the fin tip plays an active role in the heat transfer process. The buildup of a liquid film at the fin tip will provide the major resistance to heat flow. The thickness of the liquid film is a function of the condensation rate and the wetting characteristics of the working fluid.Naphon *et al* [2008] studied experimentally the thermal efficiency of the heat pipe using titanium nano fluids of diameter 21 nm. The heat pipe container is copper which has dimensions of 15 mm OD and length 600 mm. The experimental result shows that the thermal efficiency was improved greatly by use of nanofluids.

Klasing *et al* [1999] developed a mathematical model to determine the operating limits of a revolving helically grooved straight heat pipe. The capillary limit calculation required an analysis of the total body force imposed by rotation and gravity on the liquid along the length of the helical grooves. Sugumar and Tio [2006] investigated the inclined micro-heat pipes showed that the maximum allowable heat transport rate of a cusped-diamond-shaped micro-heat pipe outperforms the equilateral-triangle-shaped counterpart with the effect of gravity taken into consideration. It was concluded that for a fixed angle of inclination, the performance of a cusped-diamond-shaped micro-heat pipe is superior to that of an equilateral-triangle micro-heat pipe, based on the heat transport capacity and the position where flooding first occurs at the condenser section.

In the present study, grooved heat pipes are fabricated with copper as a container material. The working fluids used in this analysis are DI water and nanofluids. The experiments are conducted for various heat inputs (60 and 70 W) and inclinations (45° and 60°to horizontal). The filling ratio of the working fluid is 75%. The performances of the heat pipes are analyzed based on the thermal efficiency and thermal resistance.

II. Experimental Setup and Experimental Procedure

The grooved heat pipe is made up of copper material with evaporator length of 150 mm, condenser length 150 mm and adiabatic length 300 mm. The outer diameter of the heat pipe 9.5 mm and inner diameter of heat pipe 8.75 mm. Heat is supplied to the evaporator with the help of external heat source of capacity 250 W. The heat pipe is fully insulated using glass wool to reduce the heat loss from the surface of the heat pipe. The concentric tube condenser is used to remove the heat from the working fluid in condenser section. K-Type thermocouples are used to measure the surface temperature of the heat pipes as well as inlet and outlet temperature of cooling water which is used in the condenser with accuracy of temperature measurement is ± 0.1 °C. Nanofluid concentration of 100 mg/lit was used in this study. Experiments were conducted DI water and nanofluids as working fluids for different orientation with different heat inputs.

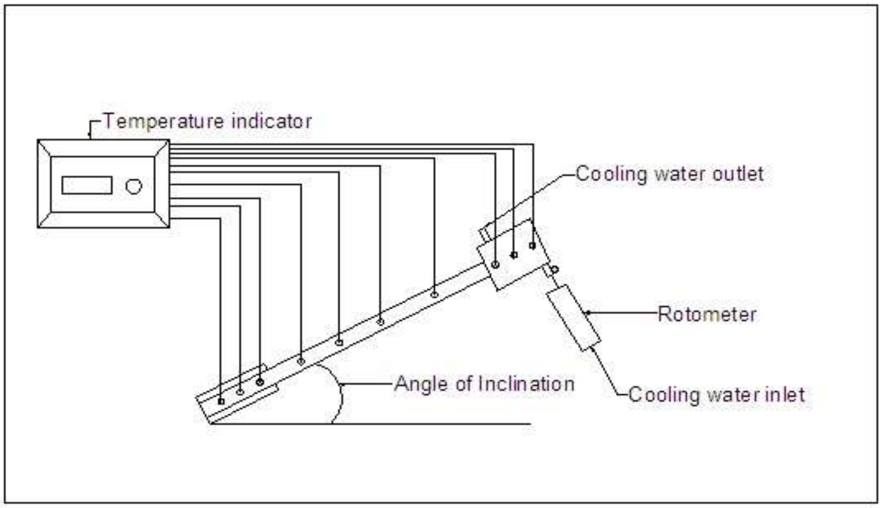


Fig.1 Experimental setup

The schematic diagram of the experimental setup is shown in the fig. 1. In this experiment, small amount of five different working fluids such as iron oxide, copper oxide, titanium oxide, graphene oxide and DI water was used in five different grooved heat pipes of same dimensions. After filling the working fluid in the heat pipe, the input power is given to the evaporator section by using variac and the temperature distribution along the heat pipe was observed at regular interval of five minutes until steady state prevails. The heat pipe takes nearly 45 to 50 minutes to attain steady state. The input power is measured by wattmeter. After attain the steady-state condition had been reached, the temperature distribution was measured and recorded. The process was repeated for 60 W and 70 W heat inputs of 10 W . The fill ratios used in this experiment was 75% of the evaporator volume for all two different working fluids. The experiments were repeated for various tilt angles (45° and 60°).

III. Artificial Neural Network

Artificial Neural Network have been widely used in a broad range of applications. These applications include pattern recognition, function approximation optimization, simulation, estimation, automatic, among many other application areas. Furthermore, research has produced a large number of network paradigms. Nowadays, ANNs have been trained to solve complex problems that are difficult by conventional approaches. ANNs overcome the limitations of the conventional approaches by extracting the desired information by using the input data. An ANN does not need such a specific equation form. Instead, it needs sufficient input–output data. Also, it can continuously be re-trained, so that it can conveniently adapt to new data (Kalogirou, 2005).

An ANN has been investigated to deal with the problems involving incomplete or imprecise input information. An ANN is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information (Ermis, 2007). The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. A schematic diagram of typical three-layer feed-forward neural network architecture is shown in Fig.2.

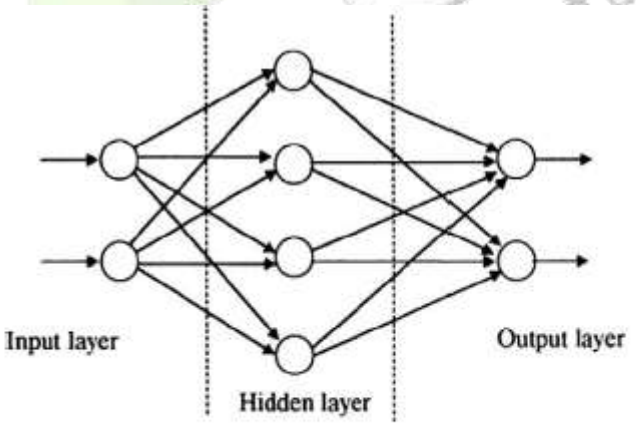


Fig .2 Three-Layer Feed-Forward Neural Network Architecture

The network usually consists of an input layer, one hidden layer and an output layer. Learning in biological systems involves adjustments to the synaptic connections that exist between the neurons. An artificial neuron is a device with many inputs and one output. There are numerous algorithms available for training neural network models; most of them can be viewed as a straightforward application of optimization theory and statistical estimation (Ertunc, 2006). Most of the algorithms used in training artificial neural networks are employing some form of gradient descent. This is done by simply taking the derivative of the cost function with respect to the network parameters and then changing those parameters in a gradient- related direction. The most popular of them is the back propagation algorithm, which has different variants. Standard back-propagation is a gradient descent algorithm. It is very difficult to know which training algorithm will be the fastest for a given problem, and the best one is usually chosen by trial and error. An ANN with a back-propagation algorithm learns by changing the connection weights, and these changes are stored as knowledge.

IV. Modelling of Artificial Neural Network

There are many types of ANN architectures in the literature; however, multi-layer feed-forward neural network is the most widely used for estimation. A multi-layer feed-forward neural network typically has an input layer, an output layer, and one or more hidden layers. In multi-layer feed-forward networks, neurons are arranged in layers and there is a connection among the neurons of other layers (Esen, 2009). The input signals are applied to the input layer, the output layer contributes to the output signal directly. Other layers between input and output layers are called hidden layers. Input signals are propagated in gradually modified form in the forward direction, finally reaching the output layer (Salehi, 2011).

In this study, the input layer has four inputs (neurons) are heat input, inclination angle, mass flow rate and filling ratio. The thermal efficiency, thermal resistance and overall heat transfer coefficient are three outputs (neurons) present in the output layer. The hidden layer has 15 neurons. Fig.3 & 4 shows the Custom neural network and ANN architecture.

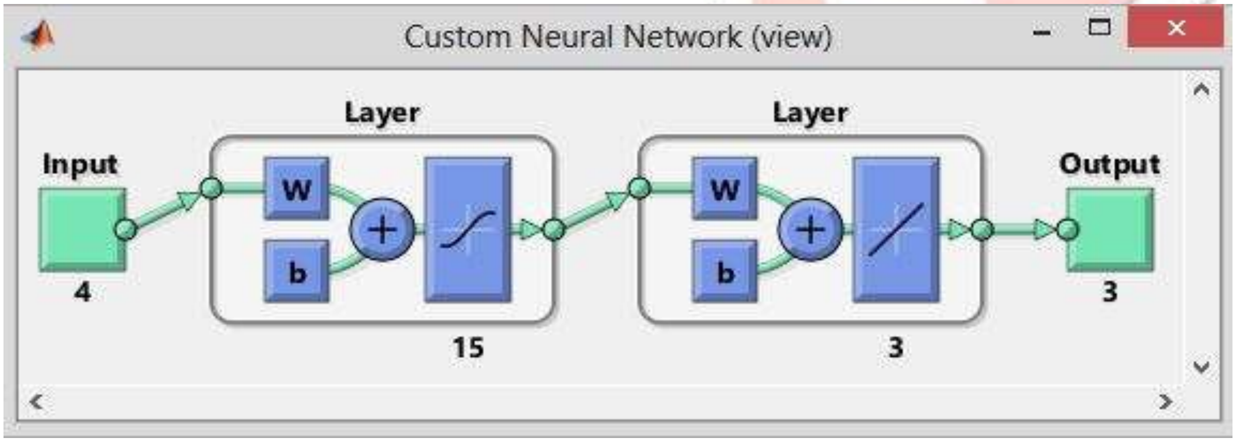


Fig.3 Custom Neural Network

The back-propagation learning algorithm has been used in a feed-forward, single hidden layer neural network. The variants of the algorithm used in the study is the Levenberg–Marquardt (LM)algorithms. A tangent sigmoid transfer function has been used for both the hidden layer and the output layer. The computer program was performed by using MATLAB using the neural network toolbox.

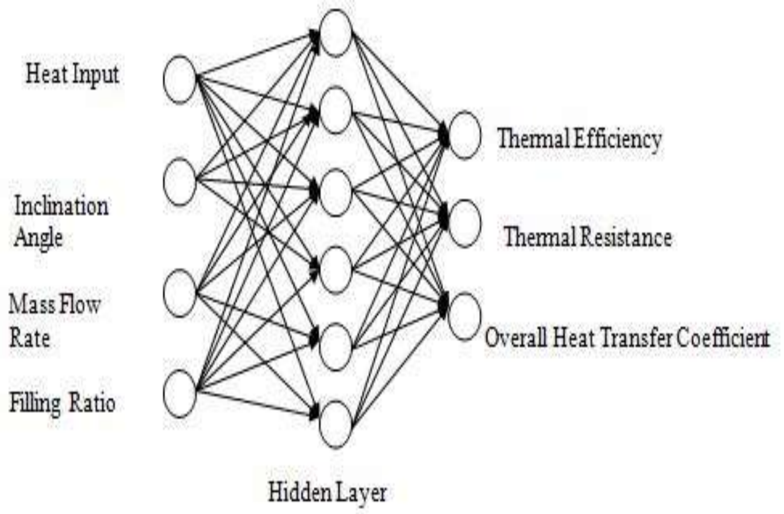


Fig.4 ANN architecture

V. Results and Discussions

5.1 Effect of Tilt Angle on Thermal Efficiency

The thermal efficiency of the heat pipe is defined as the ratio of heat carrying capacity of the cooling medium in the condenser section to the to the heat supplied in the evaporator section [Naphon, 2008].

$$\text{Thermal efficiency} = \frac{\mathrm{mC_p(T_{co}-T_{ci})}}{\mathrm{Q_{in}}} \qquad (1)$$

Where m is the flow rate of cooling water in the condenser in kg/s, C_p is the specific heat of water in J/kg K, Q_{in} is the heat supplied at the evaporator in W, T_{ci} and T_{co} are the temperature of the cooling water in the condenser jacket at inlet and exit respectively in K.

Figure 5 & 6 shows the variation of heat pipe thermal efficiency with heat pipe tilt angle for nanofluids and DI water. It can be seen from the all figures that the heat pipe efficiency increases with increasing tilt angle up to 45° and then decreases for further increase in tilt angle. This is due to the gravitational force acting on the working fluid in the heat pipe has a significant effect when the fluid moving between the evaporator section and the condenser section. The thermal efficiency of the grooved heat pipe increases with increase in the heat input at the evaporator section. It is owing to the increase in the evaporation of working fluid at the higher heat inputs. Therefore, the grooved heat pipe thermal efficiency tends to increase as the heat flux increases. At lower heat inputs the thermal efficiency is low because of poor evaporation of working fluid. The thermal efficiency of the grooved heat pipe filled with graphene oxide is higher for all heat inputs and inclinations. The graphene oxide has the good heat transport properties than the other nanofluids and the base fluid (DI water).

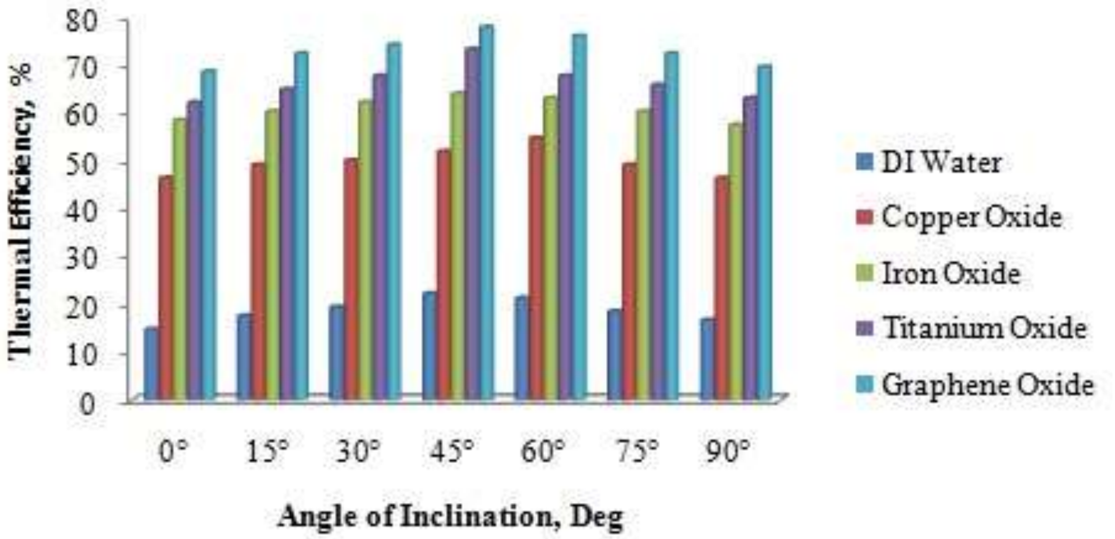
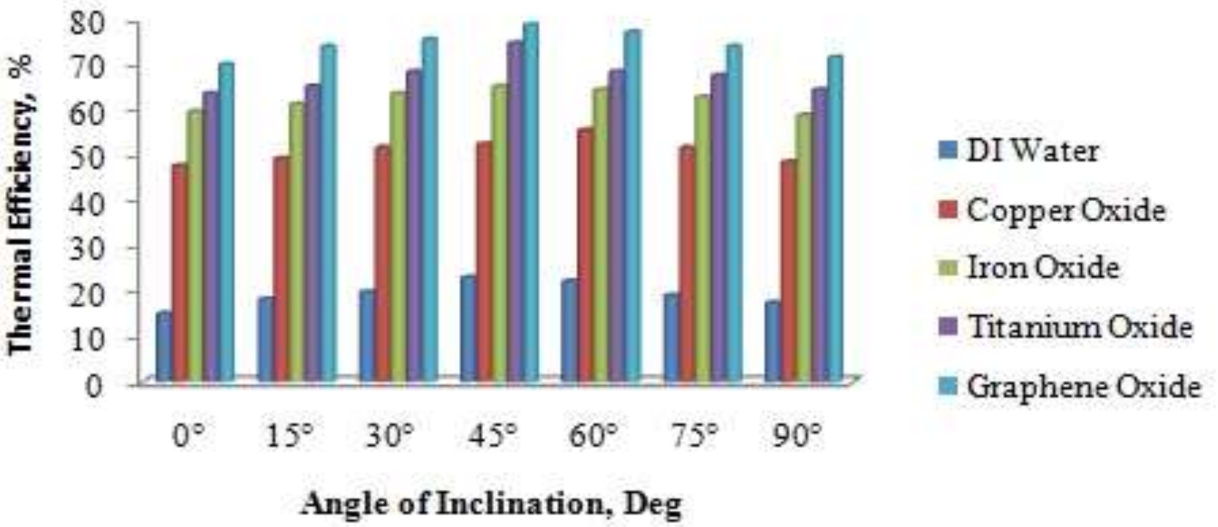


Fig 5.Variations of heat pipe efficiency with nano fluids for 60 W heat input



3

Fig. 6.Variations of heat pipe efficiency with nano fluids for 70 W heat input

5.2 Effect of Tilt Angle on Thermal Resistance

The figures 7 & 8 shows the thermal resistance of grooved heat pipe filled with various nano fluids and DI water. The thermal resistance of grooved heat pipe is defined as the ratio of the temperature difference between the evaporator section and condenser section to the heat input at the evaporator region. The value of thermal resistance decreases with increase in value of heat input at the evaporator section. When the heat load is high, the vapour formation is higher than the lower heat inputs. So the thermal resistance is low at the higher heat loads. Similarly when the heat load is low thermal resistance is high owing to presence of liquid film in the condenser side inner wall gives the resistance to flow of heat between the liquid and the vapour of the working fluid. The thermal resistance of the nanofluid filled heat pipes are lower than the DI water because of the suspended nanoparticles tend to breaks the vapour bubble during the time of vapour bubble formation. Therefore, it is expected that the size of vapour bubbles are much smaller for fluid with suspended nanoparticles than that without nanoparticles. The thermal resistance of the graphene filled heat pipe is lower than the other nanofluid and the DI water at all heat loads and inclinations of the grooved heat pipe. The value is nearly half of the DI water filled grooved heat pipes.

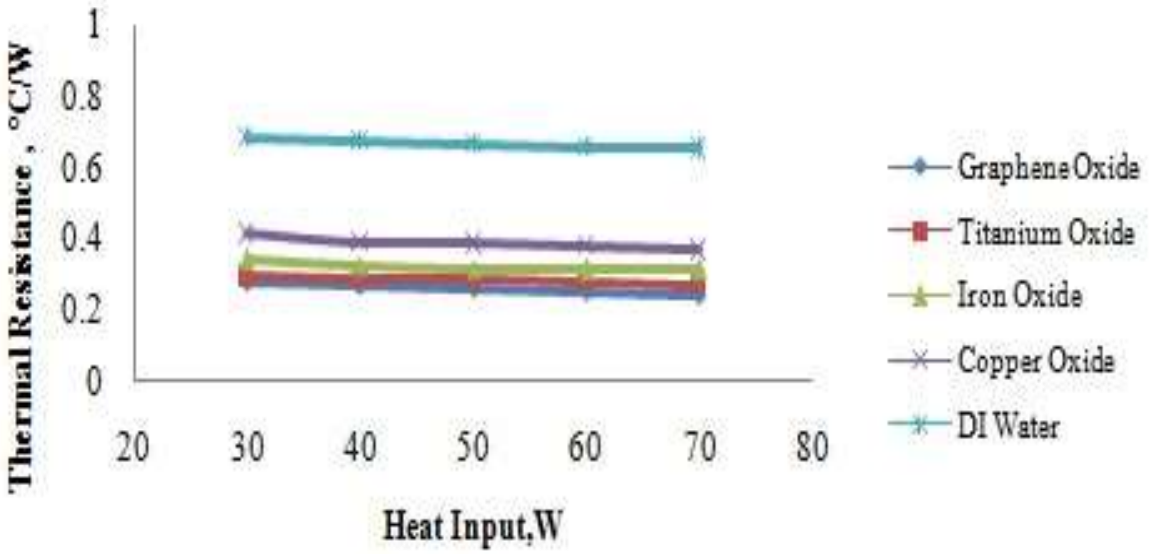


Fig. 7. Effect of 45° Tilt angle on Thermal Resistance

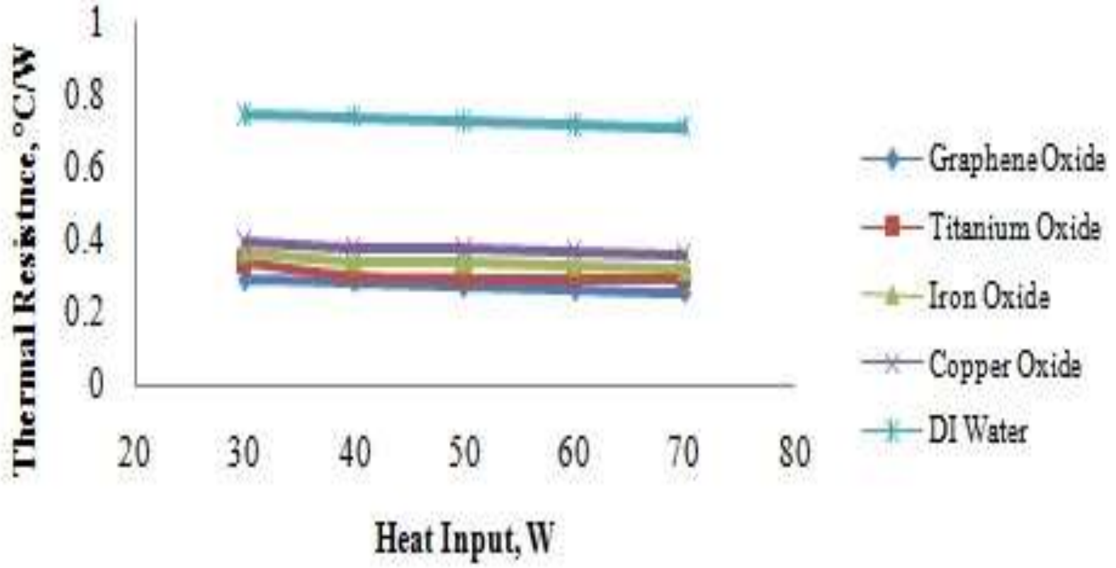


Fig. 8. Effect of 60° Tilt angle on Thermal Resistance

5.3 Artificial Neural Network simulation results

The thermal efficiency of Simulated results of ANN were compared with experimental data. It has been observed that ANN were found very close to experimental values. Variation of experimental and simulated values has been found within 5% on either side.

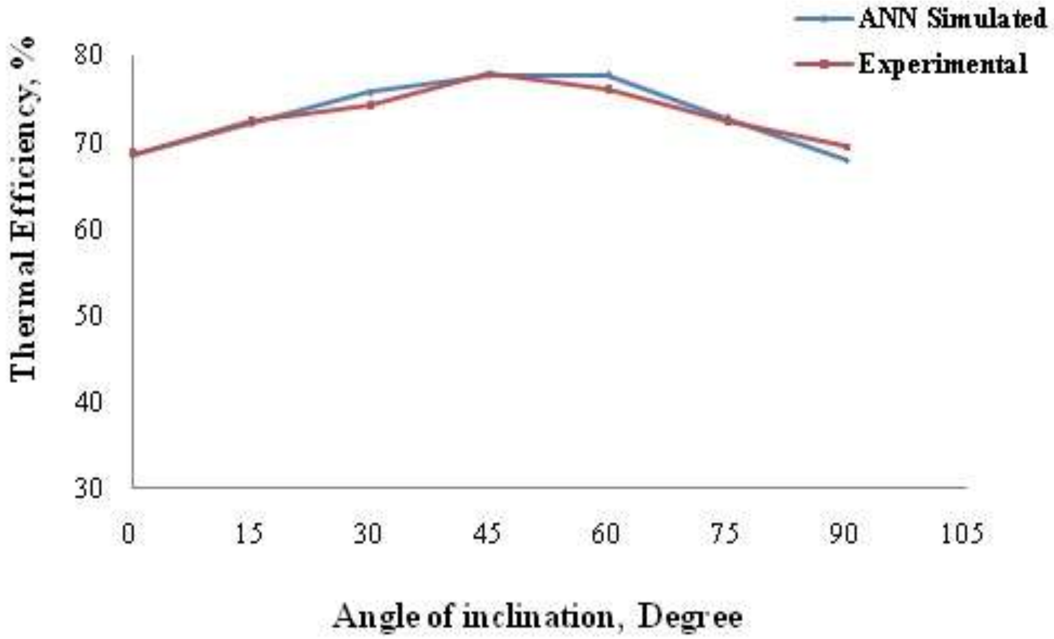


Fig.9 Comparison of experimental and ANN simulated value for efficiency for 60 W

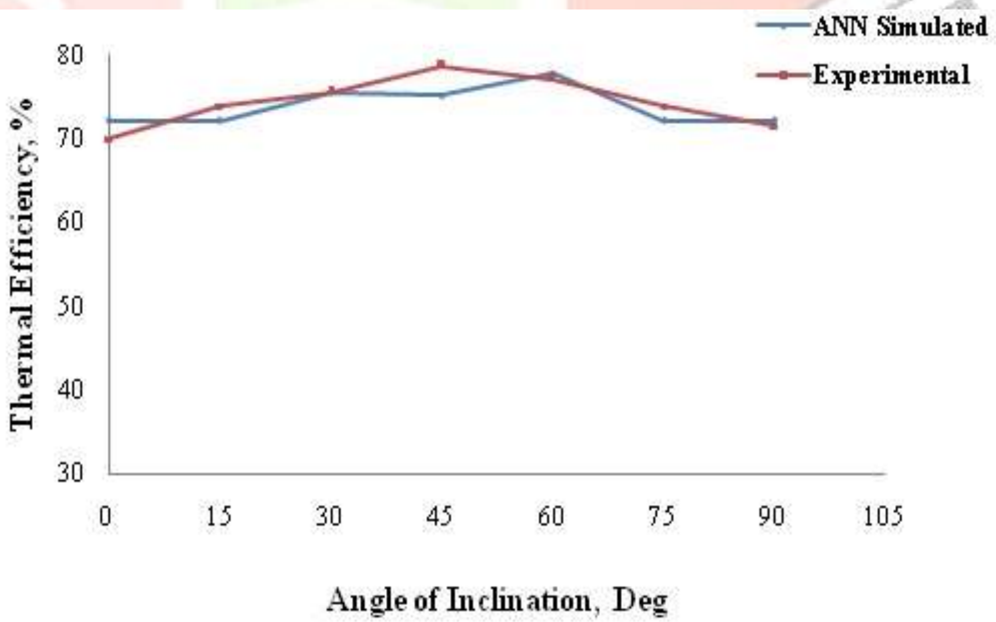


Fig.10 Comparison of experimental and ANN simulated value for efficiency for 70 W

The thermal resistance of Simulated results of ANN were compared with experimental data. It has been observed that ANN were found very close to experimental values. Variation of experimental and simulated values has been found within 6.5% on either side.

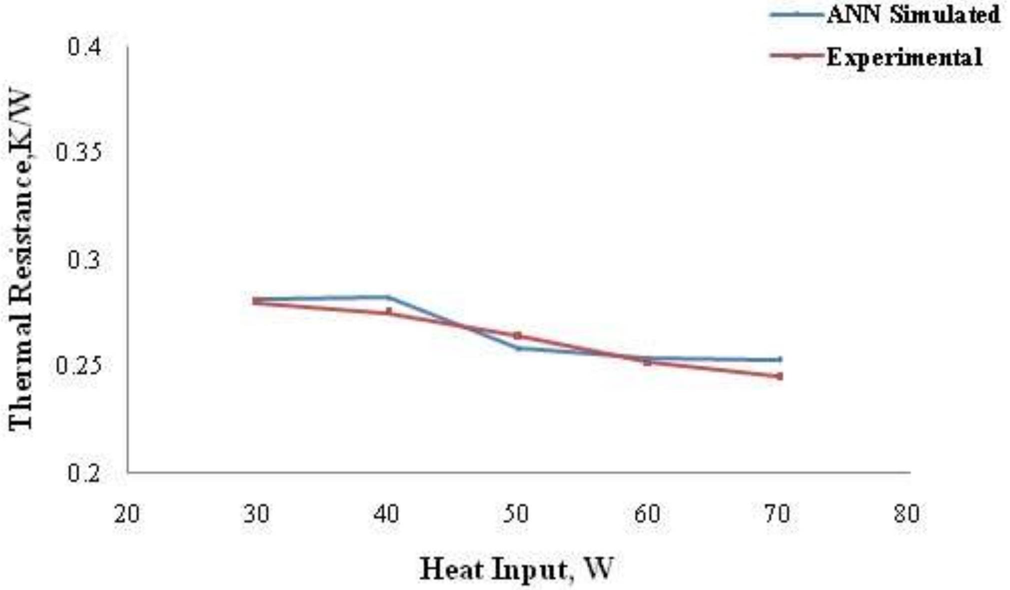


Fig.11 Comparison of experimental and ANN simulated value for thermal resistance for 45° inclination angle

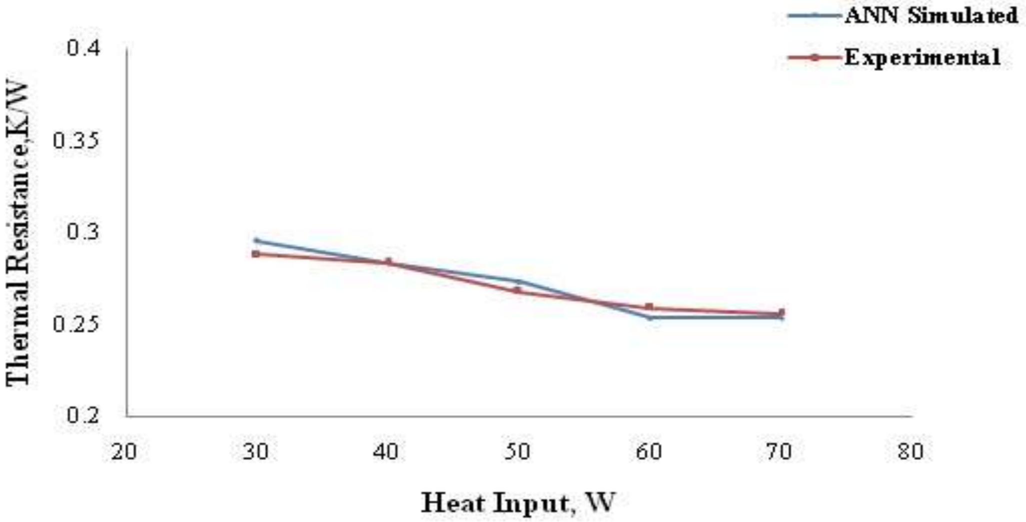


Fig.12 Comparison of experimental and ANN simulated value for thermal resistance for 60° inclination angle

VI. Conclusion

It has been concluded that the experimental analysis of the thermal performances of the heat pipe filled with nanofluids gives the better performance than the base working fluids. The nanofluids have the superior potential for heat transfer than the base fluids. And also the results has been concluded that the value predicted with the ANN with the back propogation algorithm along with feed - forward can be used to predict the performance of grooved heat pipe. Therefore, the faster and simpler solutions are obtained using ANN.

Acknowledgements

The authors thank the authorities of Annamalai University and CK College of Engineering & Technology, Cuddalore-Dt for providing the support and necessary facilities in order to carry out the work.

References

[1] Woo –Sung HAN ,Seok –Ho RHI,(2011), “Thermal characteristics of grooved heat pipe with hybrid nano fluids”,*Thermal Science*,Vol.15(1),pp 195-206.

[2] Horng-Jou Wang, Hsin-Chang Tsai, Hwang-Kuen Chen, (2005),“Capillarity of Rectangular Micro grooves and their Application to Heat Pipes”, Tamkang Journal of Science and Engineering,Vol(3),pp 249-255.

[3] C.Y. Tsai, H.T. Chien, P.P. Ding, B. Chan, T.Y. Luh, P.H. Chen,(2004), “Effect of structural character of gold nanoparticles in nanofluid on heat pipe thermal performance”, *Materials Letters*,Vol.581,pp 461– 1465.

[4] Zhen – Hua Liu ,Yuan –Yang Li,Ran Bao, (2015),“Thermal performance of inclined grooved heat pipes using nano fluids”, *International Journal of Thermal Sciences*,Vol.49 , pp.1680-1687.

[5] Y.H. Peng, Y.H. Su, H.J. Ken,(2004), “Experimental study on thermo syphon by adding nanoparticles to working fluid”,*Journal of Chemical Industry and Engineering*, Vol.11pp.1768–1772.

[6] Z.H. Liu, L. Lu, (2009) “Thermal performance of axially micro grooved heat pipe using carbon nanotube suspensions”, *Journal of Thermophysics and Heat Transfer*, Vol. 23, pp.170–175.

[7] Guo-Shan Wang, Bin Song, Zhen-Hua Liu,(2010), “Operation characteristics of cylindrical miniature grooved heat pipe using aqueous CuO nanofluids, *Experimental Thermal and Fluid Science*, Vol. 34, pp.1415–1421.

[8] Lips, S., Lefevre, F., and Bonjour, J., (2011), Physical mechanisms involved in grooved flat heat pipes, Experimental and numerical analyses, *International Journal of Thermal Sciences*, Vol.50, pp.1243-1252.

[9] Littwin, D,A.and Mccurley, J (1981), Heat pipe waste recovery boilers, *Heat Recover Systems*, Vol.1, pp.339-348.

[10] Xuan, Y. and Li, Q (2000), Heat transfer enhancement of nanofluids, *Journal of Heat and Fluid Flow*, Vol. 21(1), pp.58 - 64.

[11] Xuan, Y. and Li, Q (2003), Investigation on convective heat transfer and flow features of nanofluids, *Journal of Heat Transfer*, Vol. 125, pp.151 - 155.

[12] Yan, S., Hong, Z., Hui, X., Ping, Y., and Tong , B., (2015), Maximum heat transfer capacity of high temperature heat pipe with triangular grooved wick, *Journal of Central South University*, Vol.22, pp.386-391.

[13] Yong, L., Hui, X., Bin, L., Yong, T., and Zeng, Z,X., (2008), Forming method of axial micro grooves inside copper heat pipe, *Transactions of Nonferrous Metals Society of China*, Vol.18, pp.1229-1233.