Proceedings of the 18th UK Heat Transfer Conference
9-11 September 2024, Birmingham
UKHTC2024-142

# TEMPERATURE PREDICTION OF HEAT SINK BASE INTEGRATED WITH COPPER FOAM/PHASE CHANGE MATERIAL USING MACHINE LEARNING FOR THERMAL MANAGEMENT APPLICATIONS

Ahmad Al Miaari[1*], Hafiz Muhammad Ali[1]

[1]Mechanical Engineering Department, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

## 1. ABSTRACT

To minimize the need for experimental and numerical work, an artificial neural network is proposed to predict the temperature of a heat sink base at a new unexplored Phase change material (PCM) volume fractions of 0.5 and 0.9 integrated with copper foam of 0.95 porosity subjected to 8 W heating load respectively. The neural network was trained based on data from a prior experimental study. These training data involved subjecting a heat sink to varying heating loads of 8, 16, and 24 Watts cooled with two variations of copper foam with porosities of 0.95 and 0.97, combined with different PCM volume fractions of 0.6, 0.7, and 0.8. Results showed that the model was successfully trained with low mean squared error values of 0.003, 0.0025, and 0.0038 on the training, validation, and testing sets respectively. The trained model is then used to predict the temperature of the heat sink at new PCM volume fractions of 0.5 and 0.9 that was not experimentally explored. Results showed increasing the volume fraction to 0.9 can further reduce the temperature of the heat sink to 33.5 °C.

## 2. INTRODUCTION

Technologies are evolving, and electronic circuits and chips are becoming more complex and compact. With these advancements, technologies are generating more heat, which can decrease the overall performance or cause system failure[1]. Nowadays, researchers are using PCM as a passive cooling method in electronics, where they can successfully manage cooling without the need for power consumption. Al Miaari et al. experimentally explored the cooling effect PCM on the photovoltaic panels [2]. Experimental and numerical work has shown an effective outcome in exploring different cooling approaches, however exploring all possible cooling technologies, parameters, and configurations to reach the most optimized cooling solution can be resource-intensive and time-consuming. To overcome this problem and reduce the amount of experimental and numerical work, researchers are utilizing neural networks. By training neural networks on existing data, it can predict and estimate the system temperature and help in the thermal management process [3]. This study will focus on training ANN to predict the temperature of a heat sink integrated with PCM and copper foam at different heating loads. The trained ANN will be then used to predict the temperature of the heat sink at new PCM volume fractions.

## 3. METHODOLOGY

The effect of paraffin wax integrated with different types of copper foam on cooling a heat sink exposed to different heat loads was experimentally investigated in previous study [4]. Figure 1 shows the schematic of the experimental setup. The investigated paraffin wax has a melting temperature range of 47-57 °C and a latent heat of 167 J/g. While the two investigated copper foam materials have porosities of 0.95(15 PPI) and 0.97(35 PPI) respectively. For this investigation, a 100 x 100 x 25 mm aluminium heat sink shown in figure 1 is utilized. The heat sink can be used in different electronics cooling applications.

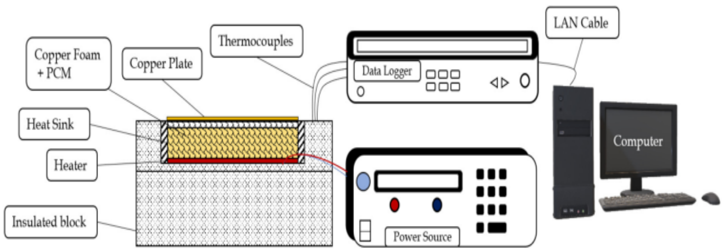


**Fig. 1** Schematic of the experimental setup [4]

In the experimental work, the authors recorded the temperature of the fin base with time and a total number of samples collected with time was 19234 [4]. The optimized proposed neural network for this study is shown in Figure 2 with 10, 5, and 10 neurons in the three hidden layers, respectively.

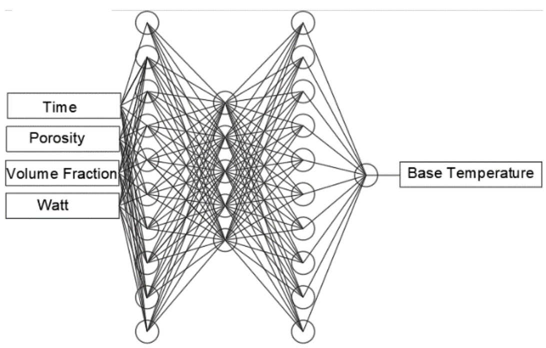


**Fig. 2** Proposed NN structure

## 4. RESULTS

The data is divided into final four sets. Training, validation, testing, and simulation sets. The total number of training samples are 12121, validation samples of 2598, number of testing samples are 2598, and the total number for simulation samples are 1925. Training was accomplished using MATLAB R2018a with the help of NN train toolbox. The best MSE score on the validation data is 0.00254 at epoch 370. The iteration stopped at 376 epochs after 6 validation checks. It is also noted that the MSE of the training, and testing are almost the same as the validation with MSE values of 0.003 and 0.0038 respectively. The simulation set of 1925 samples are used to evaluate the network. The majority samples show errors fluctuating below 2.5 °C. and -2.5 °C. The MSE value of the error is 0.8031 and the R2 score is 0.9956. The trained neural network is used to further investigate the cooling effect of PCM combined with copper foam at a new uninvestigated PCM volume fractions. Figure 3 shows the temperature of the heat sink integrated with copper metal foam of 0.95 porosity mixed with PCM at different volume fractions of 0.5, 0.6, 0.7, 0.8, and 0.9 subjected to heating load of 8 Watt. Higher PCM volume fractions (VF) enhance the cooling ability, leading to lower temperatures at the heat sink, while lower volume fractions result in higher temperatures at the heat sink. The variation in temperature of the heat sink at volume fractions of 0.6, 0.7, and 0.8 are experimentally investigated and plotted in figure 3 with the red, green, and blue lines respectively. The trained NN is then used to predict the temperature of the heat sink at those given volume fractions. A complete fit is shown between the temperatures collected experimentally and the temperatures predicted by the trained NN which are presented by the red, green, and blue triangles respectively.

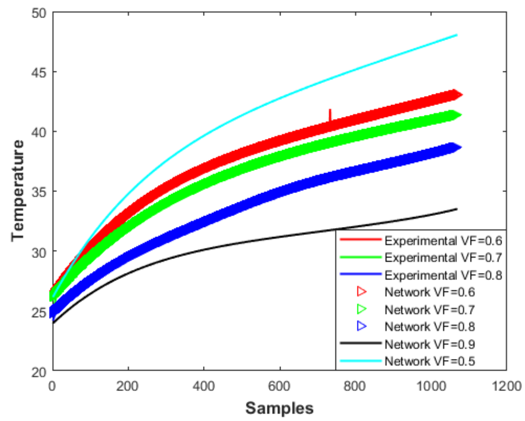


**Fig. 3** The temperature of the heat base sink integrated with metal foam of 0.95 porosity mixed with PCM at different volume fractions subjected to 8-watt heating load.

The lines presented in cyan, and black colors are the temperature of the heat sink at unexplored PCM volume fractions of 0.5, and 0.9 respectively. These lines are predicted by the trained NN. When the PCM volume fraction decreases to 0.6, the heat sink temperature rises to a higher level, reaching a maximum of 48°C. whereas, increasing the PCM volume fraction to 0.9 can further reduce the temperature of the heat sink to 33.5°C as predicted from the trained NN. The trained NN shows the ability to predict the temperature of the heat sink at different volume fractions with small error in the temperatures that may reach a maximum of 3 °C.

## 7. CONCLUSION

In this work, artificial neural network is proposed to predict the temperature of a heat sink base at new PCM volume fractions that was not experimentally explored previously, aiming to reduce the need for experiment work. The artificial neural network was trained using previous experimental data. The experimental data is divided into training, validation, testing, and simulation sets. The training, validation, and testing sets are utilized for training purposes, while the simulation set is used to assess the performance of the neural network after training. The trained model is then used to predict the temperature of the heat sink at new PCM volume fractions of 0.5 and 0.9. Results showed that increasing the volume fraction can decrease the heat base temperature to 33.5 °C while decreasing the PCM volume fraction to 0.5 can result in increasing the heat sink temperature to 48 °C.

## REFERENCES

[1] X. Long, Y. Guo, Y. Su, K. S. Siow, and C. Chen, “Unveiling the damage evolution of SAC305 during fatigue by entropy generation,” *Int. J. Mech. Sci.*, vol. 244, p. 108087, Apr. 2023, doi: 10.1016/j.ijmecsci.2022.108087.

[2] A. Al Miaari and H. M. Ali, “Technical method in passive cooling for photovoltaic panels using phase change material,” *Case Stud. Therm. Eng.*, vol. 49, p. 103283, Sep. 2023, doi: 10.1016/j.csite.2023.103283.

[3] A. Al Miaari and H. M. Ali, “Batteries temperature prediction and thermal management using machine learning: An overview,” *Energy Reports*, vol. 10, pp. 2277–2305, Nov. 2023, doi: 10.1016/j.egyr.2023.08.043.

[4] T.- Rehman and H. M. Ali, “Experimental investigation on paraffin wax integrated with copper foam based heat sinks for electronic components thermal cooling,” *Int. Commun. Heat Mass Transf.*, vol. 98, pp. 155–162, Nov. 2018, doi: 10.1016/j.icheatmasstransfer.2018.08.003.