iJRASET
International Journal For Research in
Applied Science and Engineering Technology

# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

**Volume:** 12 **Issue:** III **Month of publication:** March 2024

**DOI:** https://doi.org/10.22214/ijraset.2024.58768

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
*ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538*
*Volume 12 Issue III Mar 2024- Available at www.ijraset.com*

# Heat Transfer Performance Analysis of an E-Vehicle Cooling System Using a Hybrid Peltier System

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***Abstract: This research investigates the heat transfer performance of an electric vehicle (EV) cooling system utilising a hybrid Peltier as integrated system with advancements in EV battery technology, the demand for efficient cooling systems has become crucial for ensuring battery safety, longevity, and overall performance. Present research focus on the application of ethylene glycol as a coolant, exploring the thermal parameters, heat transfer rates, and overall effectiveness of the hybrid cooling system. A literature review highlights the significance of heat transfer enhancement techniques, emphasising the need for energy-efficient methods in the automotive industry. The research methodology involves experimental work, analytical calculations, and the preparation of coolant samples to evaluate thermo-physical parameters. The results demonstrate the temperature drop, Overall heat transfer for different flow rates, Logarithmic Mean Temperature difference, and Comparative Power Consumption of different setup. The result showed that presence of ethylene glycol in water enhances the desirable temperature drop of the heat transfer fluid. The Overall heat transfer rate is increased by 58% for EG-100 sample as compared to pure water. Further an ANN model is also developed for prediction of temperature drop, the result showed 2 layer model with 8, 8 neurons as optimum model for prediction.***
***Keywords: Electric Vehicle, Hybrid Cooling, Heat Transfer, Thermoelectric Effect, Ethylene Glycol, Thermal Parameters, and ANN modelling.***

## I. INTRODUCTION

Advancements in electric vehicle (EV) battery technology have led to improved power delivery and reduced charging frequency. However, effective cooling remains a significant challenge for ensuring battery safety and performance. This study explores the heat transfer performance of an EV cooling system using a hybrid Peltier approach, with a focus on the application of ethylene glycol as a coolant. However, one of the biggest challenges that remain for battery safety is the ability to design an effective cooling system. Heat transfer has been involved in almost every sector of the engineering field. Heat transfer is classified into three categories: conduction, convection, and radiation. Peltier modules operate on the principle of the Peltier effect. This effect brings up a temperature difference by transferring heat through two junctions.

Heris S. Zeinali et. al. [1] performed experimentation work using mixture of water/EG as a base fluid for different volumetric concentrations (0.05– 0.8 vol. %) of based fluid of different flow rates (4–8 LPM) and inlet temperatures (35, 44, 54°C). The heat transfer coefficient enhancement of about 55% compared to the base fluid was recorded. Peyghambarzadeh S.M. et. al. [2] compared the heat transfer performance of pure water and pure EG with their binary mixtures its effects on the heat transfer performance of the car radiator were determined experimentally. Liquid flow rate was changed in the range of 2-6 LPM with the fluid inlet temperature changed for all the experiments. In the best conditions, the heat transfer enhancement of about 40% compared to the base fluids has been recorded. NS Vele, RK Patil [3] concluded hybrid Nano fluids are potential fluids that offer better heat transfer performance and thermo-physical properties than conventional heat transfer fluids. Their research on recent progress related to preparation methods of hybrid Nano fluids. However, they used the excess amount of surfactant which affects the viscosity, thermal conductivity and stability of hybrid Nano fluid. Junkui Huang et. Al. [4] experimented on innovative cooling system utilizing heat pipes and circulating liquid was designed and simulated for electric motors. The system offers significant benefits, including multiple heat rejection pathways for power minimization and compact design. It incorporates a reduced order thermal model to predict internal hot spots and a nonlinear controller to maintain temperature within prescribed limits while minimizing energy consumption. Simulation results showcased its effectiveness under varying conditions. The hybrid cooling system showed significant energy savings compared to conventional methods during the 1500s simulation time.

Huminic et al. [5] conducted experiments with FeC / water Nano fluid at three weight concentrations of 0.1 to 1wt.% between the temperatures ranging from 10 °C to 70 °C. The thermal conductivity enhancement is 24.1% for 1.0 wt. % of FeC / water at the temperature of 70 °C. Keblinski et al. [6] conducted experiments and concluded that the thermal conductivity increases by the decrease of grain size. The heat transfer properties and clustering were reported by the molecular layering of the liquid and the Brownian motion. JS lee et al. [7] studied on CuO, Al2O3 (18.6 nm, 23.6 nm, 24.4 nm, and 38.4 nm) in water or ethylene glycol and obtained four combinations of nanofluids. It is declared that the CuO/Ethylene Glycol mixture has shown more than 20% enhancement of thermal conductivity at 4 vol% of nanoparticle addition.

The literature review emphasizes the growing importance of heat transfer enhancement in the automotive industry. Studies suggest that ethylene glycol, in conjunction with Peltier plates, can provide superior heat absorption compared to traditional coolants. Addressing these gaps and challenges through advanced thermal analysis, impact studies of different cooling systems, and the development of energy-efficient and environmentally friendly cooling technologies is essential for ensuring the reliable operation of electronic devices in the future. This study aims to investigate a real-size car radiator and conditions close to reality. Therefore, ethanol and glycol have been added to the engine coolant (including 50% EG and 50% water), and a hybrid radiator set-up was designed for this purpose. The coolant, which consists of EG and water, is tested at an air velocity between 1.7 and 4.3 m/s and at cooling fluid flow rates between 13 and 19 lpm. The review sets the stage for the research, indicating the potential of Peltier-based cooling systems.

## II. EXPERIMENTAL SETUP

The experimental setup consists of a cross-flow compact heat exchanger with a single pass of 36 tubes with aluminium fins. To study the effect of replacing the conventional heat transfer fluid with ethylene base fluid, firstly, the experiments were performed using EG and water at a ratio of 70:30. Heat transfer fluid experiments were performed by varying the inlet temperature of the hot fluid, the flow rate of the hot fluid, and the velocity of air passing over the heat exchanger. The flow rate of hot fluid was fixed at different values with the help of a valve provided at the bottom of the rotameter. Temperature sensors were placed at different locations of the heat exchanger to measure the temperature of hot and cold fluids. In this setup, the main components include a water block, peltier, radiator, water pump, inlet and outlet fan, Arduino UNO, rotameter, temperature sensor, and flow sensor.

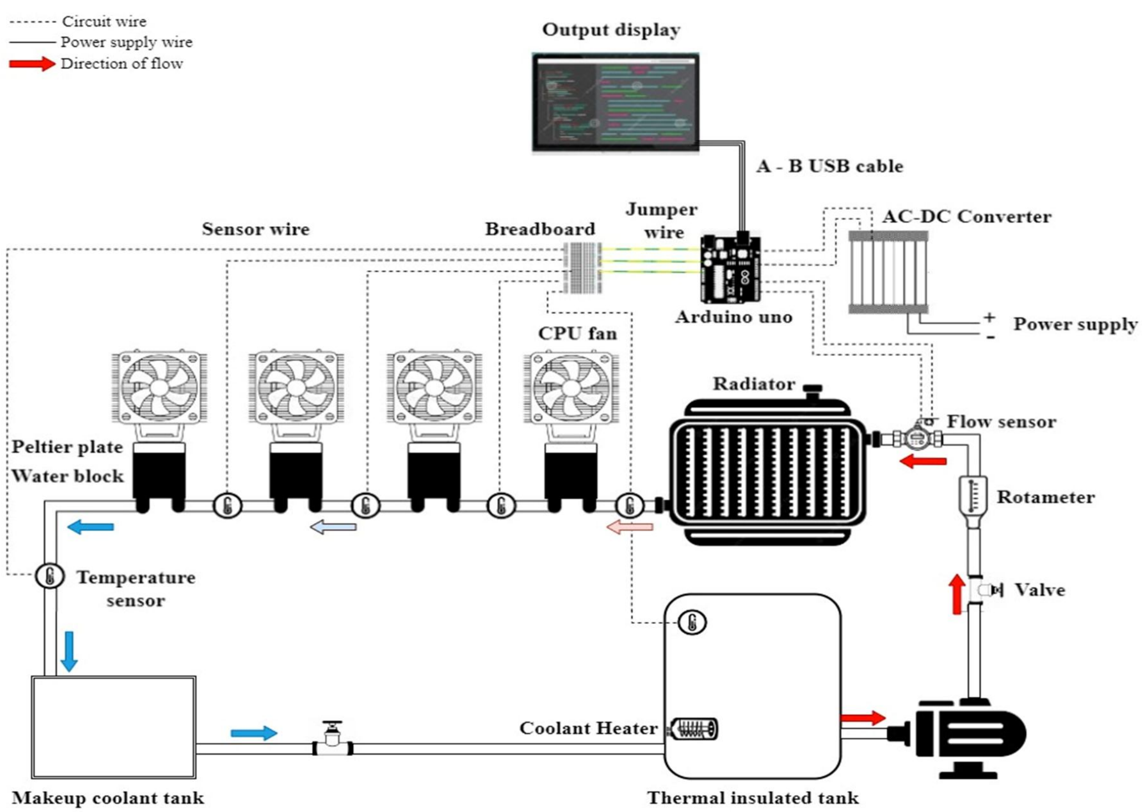


Fig. 2: Schematic Diagram of Experimental Setup

Experimental work is performed with following considerations:
1) Ethylene glycol and water mixtures were taken as primary heat exchanger fluid in the system.
2) Inlet temperature of the hot fluid was kept at 50°C in the storage tank.
3) Flow rate of the hot fluid is varied from 13 to 19 LPH with the help of a valve provided at its bottom and flow rate is measured with a digital rotameter.
4) While keeping the inlet temperature and flow rate of hot fluid constant, readings for temperature were taken at various locations of the heat exchanger.
5) Steps c) and d) were repeated for 5 numbers of samples constituting 20 experiments.
6) To record reading steady was maintained, all readings were recorded at a 15-minute time interval to achieve steady state.

## III. EXPERIMENTAL METHODOLOGY

The research methodology involves a comprehensive approach of conducting experiments, collecting data, and performing analytical calculations for thermal parameters. The study employs a hybrid cooling system with ethylene glycol as the coolant, and the experimental setup involves the preparation of coolant samples through direct mixing using a magnetic stirrer.

### A. Thermal Parameters

The thermal parameters evaluated during experimentation work are discussed below:

#### 1) Empirical Relations for Heat Transfer Modeling

The heat transfer rate of overall section at hot fluid side is

$$\dot{Q} = \dot{m}C_p\,(T_0 - T_i) \qquad 1$$

#### 2) Empirical Relations for Mean Temperature Difference,

As flow in radiator is counter flow thus by hot side and air side temperature difference is written

$$\Delta T_1 = (T_{fi} - T_{a0}) \qquad 2$$

$$\Delta T_2 = (T_{f0} - T_{ai}) \qquad 3$$

Arithmetic Mean Temperature shows error, which is less than 1% when $\Delta T$ 1 and $\Delta T$ 2 differ by less than 40%, but error increase with increase in temperature difference thus LMTD should be preferred while calculating rate of heat transfer for automobile cooling system.

$$LMTD = \frac{(T_{fi} - T_{a0}) - (T_{f0} - T_{ai})}{\ln\frac{(T_{fi} - T_{a0})}{(T_{f0} - T_{ai})}} \qquad 4$$

#### 3) Empirical Relations for Overall Heat Transfer Coefficient

The overall heat transfer coefficient is a sum of a series of conductive and convective resistance. There are different ways to calculate the heat transfer coefficient; here we have adopted experimental one with LMTD as shown in Eq. 5 and a theoretical one with effectiveness and NTU relation to validate the experimental result. The higher the coefficient, the easier is to transfer heat.

$$\dot{Q} = UA_0\theta_m \qquad 5$$

### B. Miscellaneous Analysis

#### 1) ANN Modelling

The flow rate along with inlet temperatures and sample proportions are used as input in ANN to develop a static prediction model for determination of temperature drop. In this way configuration with 03 inputs and 01 target parameters are used in this study. The input, hidden and output layers are expressed in the index of neurons. The input neurons receive the data and pass the output to the next hidden layer as shown in Fig 1.

The performance of predicted ANN models is measured using mean square error (MSE) and correlation coefficient (R) between the predicted values of the network and the target or experimental values, as given by the Eqs. 6 And 7:

$$MSE = \frac{\sum_{i=1}^{N}(MR_{pre.o,i} - MR_{exp.o,i})^2}{N} \qquad 6$$

$$R = \sqrt{1 - \frac{\sum_{i=1}^{N}(MR_{pre.o,i} - MR_{exp.o,i})^2}{\sum_{i=1}^{N}(MR_{pre.o,i} - \overline{MR_{exp.o}})^2}} \qquad 7$$

Where MRpre.o,i is the predicted output from observation i, MRexp.o,i is the experimental (target) output from observation i, MRexp.o is the average value of experimental output, and total number of data observations is N.

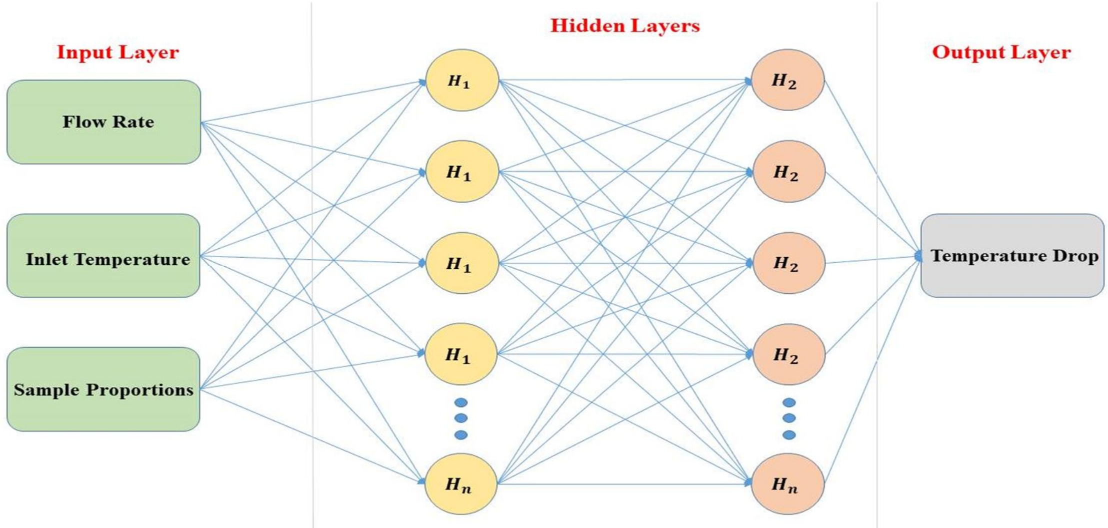


Fig. 1: Configuration of neural network for predicting temperature drop with hidden layer

*2) Comparative Power Consumption*

The power consumptions for Peltier cooling, radiator cooling, and combined Peltier and radiator cooling are evaluated. The voltage drops (V) and current consumed (I) is determined for the three setup and power consumption (V*I) is determined.

$$P = VI \qquad 8$$

## IV. RESULTS

### *A. Temperature Drops*

The temperature drops with respect to flow rate for ethylene glycol and water-based coolant at different proportions is shown in Fig 3. The trend of the graph shows negative slope due to constant specific heat of the sample. For fixed inlet temp 55 ˚C the maximum temp drop is obtained for the sample EG100. The temperature drop remains equivalent to coolant EG-100 up to 90:1 (EG- 90) proportional. The average variation in temperature drops for the flow rate range of 13-19 L/hr. increase 41 % in temperature drop for sample (EG-100).

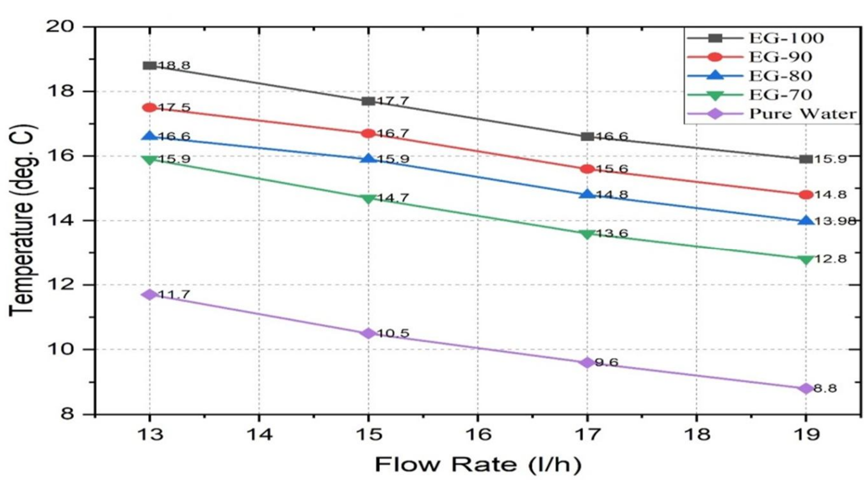


Fig. 3: Comparison of Temperature Drop with respect to flow rate

*B. Logarithmic Mean Temperature Difference (LMTD)*

The fig 4 shows the logarithmic mean temperature difference with respect to flow rate for the test run conducted on 05 sample of coolant, The logarithmic mean temperature difference (LMTD) of the coolant and water shows almost similar trend and the percentage of LMTD for coolant is 21% increase with flow rate for pure water.

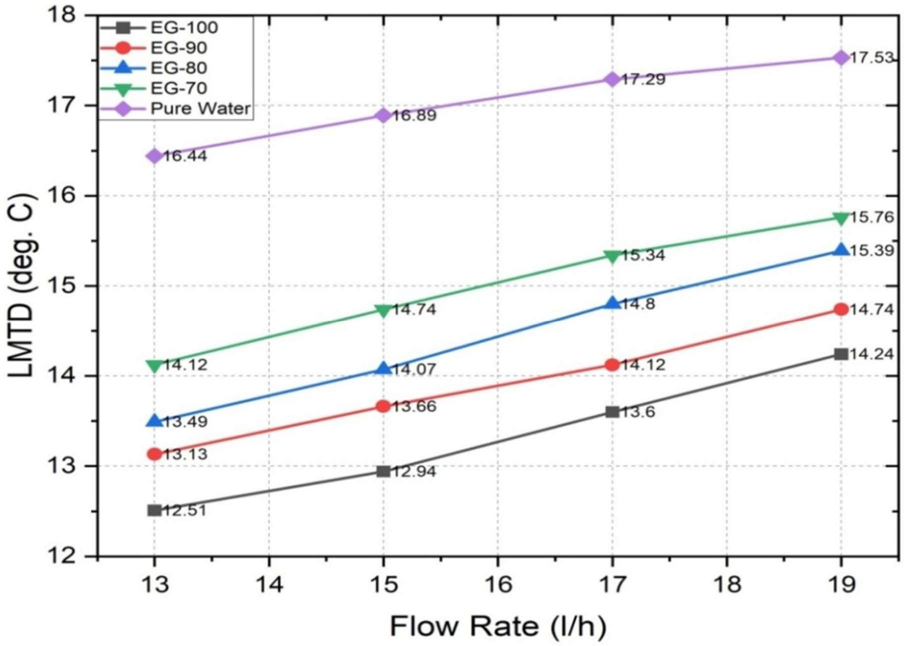


Fig. 4: Comparison of logarithmic mean temperature difference with respect to flow rate

*C. Overall Heat Transfer*

The Overall heat transfer with respect to flow rate for ethylene glycol and water-based coolant at different proportions is shown in Fig 5. The trend of the graph shows positive slope due to constant specific heat of the sample. For fixed inlet temp 55 ˚C the maximum Overall heat transfer rate is obtained for the sample EG100. The Overall heat transfer rate is increased by 58% for sample EG-100 as compared to pure water.

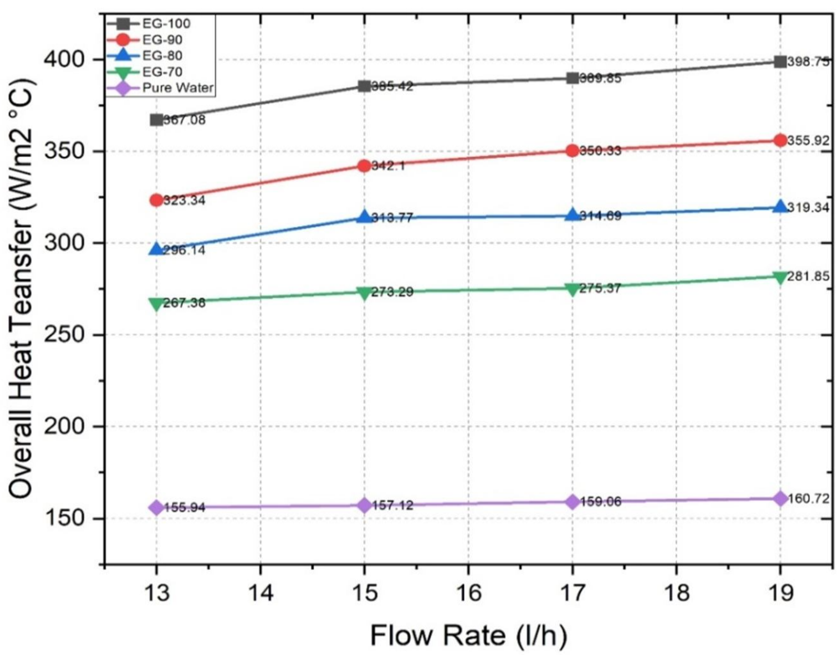


Fig. 5: Comparison of Overall heat transfer difference with respect to flow rate

*D. ANN Model*

The training results of the static model to predict the temperature content are shown in Table 1. This summarised table shows that the neural network with 8 and 8 neurons in the first and second hidden layers, respectively, provided best results for kinetic modelling of coolant sample. This model had lowest values of RMSE and highest values of R for train, validation and test.

Table 1: Summary of ANN models

| Activation/transfer function | Neurons (First hidden layer) | Neurons (Second hidden layer) | Coefficient of correlation (R) | | | Mean square E | | |
|---|---|---|---|---|---|---|---|---|
| | | | Training | Validation | Test | Training | Validation | Test |
| Log/Tan-Sigmoid | 2 | - | 0.99045 | 0.99961 | 0.99784 | 0.003264 | 0.000265 | 0.0001641 |
| Log/Tan-Sigmoid | 4 | - | 0.99958 | 0.99996 | 0.99791 | 0.00008339 | 0.00000274 | 0.0001331 |
| Log/Tan-Sigmoid | 6 | - | 0.99964 | 0.99844 | 0.99986 | 0.0000477 | 0.0001317 | 0.001785 |
| Log/Tan-Sigmoid | 8 | - | 0.99998 | 0.99996 | 0.99999 | 0.000003223 | 0.000002251 | 0.00152 |
| Log/Tan-Sigmoid | 10 | - | 0.99991 | 0.99999 | 0.9994 | 0.000009939 | 0.0001929 | 0.001373 |
| Log/Tan/Tan-Sigmoid | 5 | 5 | 0.9987 | 0.99998 | 0.9998 | 0.0002968 | 0.000009773 | 0.00007247 |
| Log/Tan/Tan-Sigmoid | 5 | 6 | 0.9987 | 0.99972 | 0.98372 | 0.0006694 | 0.00004731 | 0.02708 |
| Log/Tan/Tan-Sigmoid | 6 | 5 | 0.99085 | 0.99837 | 0.99278 | 0.00179 | 0.00119 | 0.003138 |
| Log/Tan/Tan-Sigmoid | 6 | 7 | 0.93811 | 0.9999 | 0.99974 | 0.01408 | 0.00007968 | 0.00004632 |
| Log/Tan/Tan-Sigmoid | 7 | 8 | 0.91805 | 0.93067 | 0.99731 | 0.01455 | 0.000395 | 0.0006878 |
| Log/Tan/Tan-Sigmoid | 8 | 8 | 0.99993 | 1 | 0.99976 | 0.00001523 | 0.000002 | 0.000009801 |
| Log/Tan/Tan-Sigmoid | 8 | 10 | 0.9974 | 0.99986 | 0.99567 | 0.0006838 | 0.00004066 | 0.0003673 |

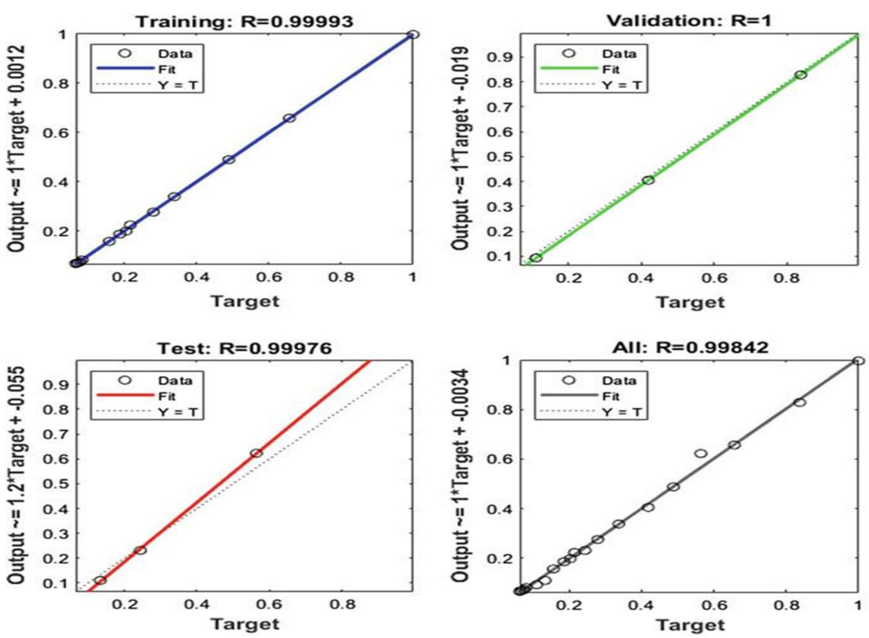


Fig. 6: Correlation between experimental and predicated values of temperature drop for optimum topologies

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue III Mar 2024- Available at www.ijraset.com

### E. Comparative Power Consumption

The power consumptions for Peltier cooling, radiator cooling, and combined Peltier and radiator cooling are evaluated. The voltage drops (V) and current consumed (I) is determined for the three setup and power consumption (V*I) is determined. The power consumptions of the three setups are Peltier 16.22, Radiator 69.03, and hybrid 86.03 W respectively.

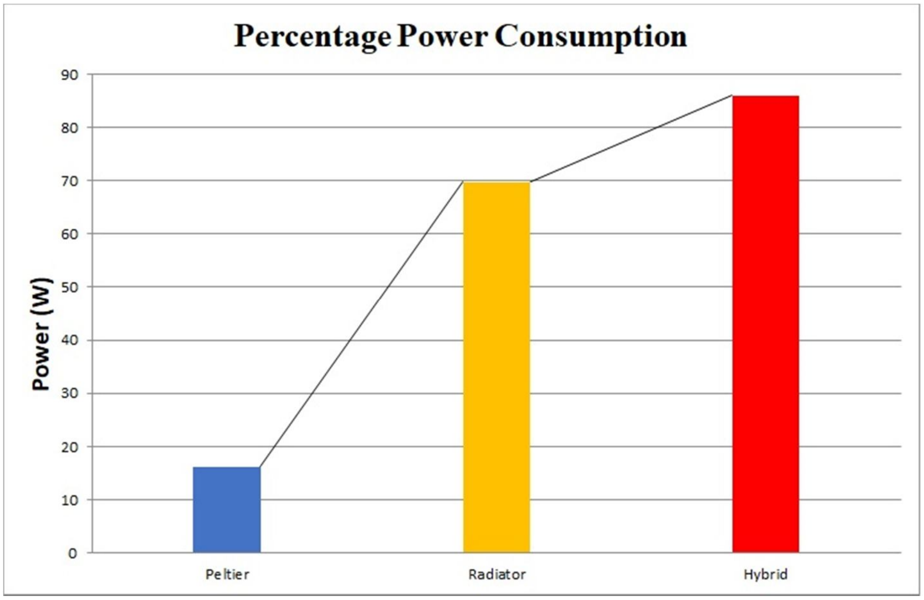


Fig. 7: Comparative Power Consumption of different setup

## V. CONCLUSION

An innovative hybrid cooling system using thermoelectric systems in conjunction with conventional radiator-based cooling is designed and installed. Considerable augmentation in output factors against input variables was documented for processing the thermal parameters using mathematical relations.

1) The presence of ethylene glycol in water enhances the desirable temperature drop of the heat transfer fluid (coolant). The increase in temperature drop depends on the amount of water added to ethanol glycol. The temperature drops for pure ethanol glycol get increased by 3.1 ºC by considering the 6 lpm variation in flow rate, which is higher than other samples.
2) LMTD varies inversely to the convective heat transfer rate hence, pure water has a higher LMTD of 1.49 °C, but convective heat transfer is less than 16.65 w/m2 °C. While ethanol glycol has a 1.73 °C LMTD, the heat transfer rate is 70.95 w/m2 °C.
3) Results of experimental study showed, overall heat transfer gets increased in comparison with the base fluid. Overall heat transfer for ethanol glycol and water is 31.67 $w/m^2$ °C and 4.78 $w/m^2$ °C respectively.
4) The best prediction of temperature drop with ANN is obtained from a two-layer hidden neural network having 8 neurons in each layer.
5) The cooling system with ascending order of power consumption is peltier, radiator, and hybrid with 16.22, 69.80, and 86.03 W respectively.

## VI. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the automobile engineering department of Rustamji Institute of Technology, BSF Academy, Tekanpur for providing support for the present research work. Author also gratefully acknowledges innovation team of SAE-BAJA electric design team of the institute.

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