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“EXPERIMENTAL STUDY ON A NOVAL PELTIER HYBRID VEHICLE COOLING SYSTEM”

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ABSTRACT

This research paper investigates the heat transfer performance of an electric vehicle (EV) cooling system utilizing a hybrid Peltier 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. The research focuses on the application of ethylene glycol as a coolant, exploring the thermal parameters, temperature drop, and heat transfer rates of the hybrid cooling system. The research methodology involves experimental work, the design of the experiment using Taguchi, and the confirmation tests to evaluate thermal-output parameters. The preparation of base fluids has two levels of input control parameters, such as flow rate and coolant ratios. The experiment is run for the optimal solution using Taguchi analysis using an L16 orthogonal array. The influential parameters that are significant in contributing to the performance of ethylene glycol and water were studied using a Taguchi table. After parametric optimization, the control parameter optimization level is obtained at 13 l/hr flow rate a coolant ratio at 100% ethylene glycol. the control parameter optimization level is obtained at 19 l/hr flow rate a coolant ratio at 70% ethylene glycol.

Key Words: *Taguchi, Hybrid Cooling, Heat Transfer, Percentage of concentration, Thermal Parameters.*

I. INTRODUCTION

Ethylene glycol has been widely used as antifreeze in automobile radiators for many years because of its compatibility with metals and better heat transfer characteristics. Mixtures of ethylene glycol (EG) and water (W) are used in cooling the engines in automotive applications. 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. 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.

II. LITERATURE REVIEW

Anand Baghel et al. (2023) [1] [2] [3] examined the impact of process parameters on the characteristics of austenitic stainless steel SS304 bead-on plate welds. Experiments were conducted using a Taguchi L9 orthogonal array, analysing weld bead profile, penetration depth, bead width, microstructure, and hardness.

B. Nagaraja et.al (2023) [4] optimized heat transmission rate of a Casson-Carreau nanofluid flow over a curved surface using ANOVA and Taguchi. Factors like heat generation, thermal radiation, Joule heating, chemical reaction, velocity slip, and Stefan blowing are considered. The Taguchi method achieves the highest signal-to-noise ratio.

Selvalakshmi.et.al (2021) [5] explored the performance of bio fluids for solar thermal applications using the Taguchi method and Taguchi Grey Relational Analysis. The optimal solution was found to be sunflower oil with 15% concentration at 15000 RPM stirrer speed.

Rohinee Barai. **et. al (2023)** [6] investigated on convective heat transfer in an Al2O3/water Nano fluid and compares it with pure water in an automobile radiator. Results show that increasing fluid circulating rate improves heat transfer performance, and low concentration Nano fluids can enhance efficiency up to 40-45% compared to pure water.

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. A fully turbulent regime was achieved by varying the test fluid flow rate between 3 and 8 LPM. The obtained results show that heat transfer performance can be enhanced by increasing the fluid circulating rate. Applying a low-concentration nanofluid can increase heat transfer efficiency by 40–45% as compared to pure water.

III. EXPERIMENTAL SETUP AND METHODOLOGY

As shown in schematic layout presented in **Fig-1** the experimental setup consists of a thermocouple-based hybrid automotive cooling system along with heat source and instrumentation for measurement. For the experimental, two input variables (flowrate and coolant ratio) and their four levels are considered. And their respect for the L-16 orthogonal array matrix is mentioned in Table 1. Here radiator used is a compact heat exchanger with 36 tubes and aluminium's 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 90:10. 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 digital 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, temperature sensor, and flow sensor. Table 2 contains the technical specifications of the components used in the experiment.

Table 1: Design Summary for the L-16 Orthogonal Array Matrix

Experiment No.	Flow Rate	Coolant Ratio
1	13	100
2	13	90
3	13	80
4	13	70
5	15	100
6	15	90
7	15	80
8	15	70
9	17	100
10	17	90
11	17	80
12	17	70
13	19	100
14	19	90
15	19	80
16	19	70

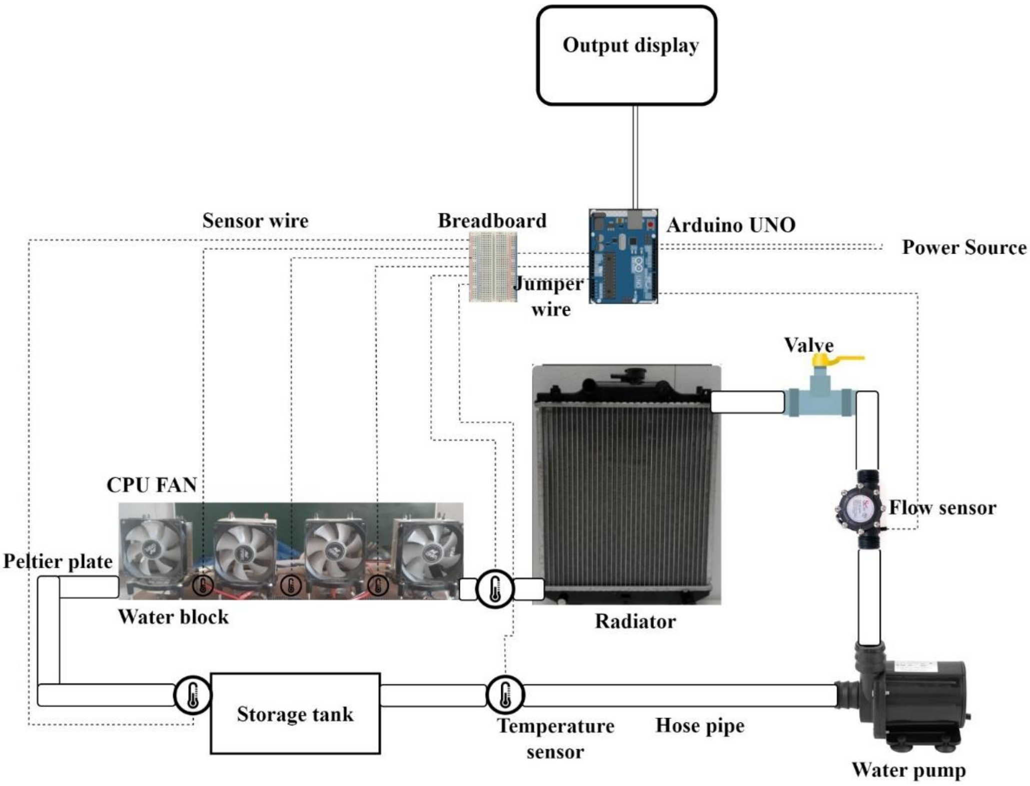

Fig. 1: Schematic Diagram of Experimental Setup

Table 2: The Technical Specifications of the Components Used in the Experiment

S. No.	Component	Specification	Quantity
1	Radiator	Denso (315*315) mm	1
		Aluminium Tubes (36)	
2	Water block	Aluminium (40*40*10) cm	4
3	Peltier plate	Tecl-12706 (40*40*3.6) mm	4
4	Water pump	Arise (240 v)	1
		flow rate 10-20 l/min	
5	Dc fan	Dc-tech (600-3000) rpm	4
6	Flow sensor	FS-300A flow rate (10-20) l/hr	1
7	Temperature sensor	DS-18B20	5

Experimental work is performed with following considerations:

a) Ethylene glycol and water mixtures were taken as primary heat exchanger fluid in the system.
b) Inlet temperature of the hot fluid was kept at 60°C in the storage tank.
c) 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.
d) While keeping the inlet temperature and flow rate of hot fluid constant, readings for temperature were taken at various locations of the heat exchanger.
e) Steps c) and d) were repeated for 5 numbers of samples constituting 20 experiments.
f) To record reading steady was maintained, all readings were recorded at a 15-minute time interval to achieve steady state.

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IV. TAGUCHI OPTIMIZATION ANALYSIS

The design of the experiment using the Taguchi orthogonal array approach is the most sought-after and economical one. It is a type of general fractional factorial design that is based on a design matrix proposed by Dr. Genichi Taguchi and considers a selected subset of combinations of multiple factors at multiple levels. and satisfies the needs for solving problems and product design optimization projects. By applying Taguchi's method, one can reduce the time, resources, and money required for a small experimental investigation. The DOE provides the relationship existing between the input and output variables. In order to determine the factors that influence the performance criteria, Taguchi's array L16 (4^2) is used. Also, it is possible to determine the factors that are more important than others using this array. The Taguchi technique uses an array to deliver the core of input factors with the least number of experiments using larger is better, smaller is better and nominal is better as mentioned below.

Larger is better

The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for the larger-is-better S/N ratio using base 10 log is: $S/N = -10*\log(\Sigma (1/Y^2)/n)$

Smaller is better

The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for the smaller-is-better S/N ratio using base 10 log is: $S/N = -10*\log(\Sigma (Y^2)/n)$

Where Y = responses for the given factor level combination and n = number of responses in the factor level combination.

Nominal is better

The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for nominal-is-better S/N ratio using base 10 log is: $S/N = -10*\log(1/n *\Sigma (1/Y\text{-}N)^2)$

In the Taguchi technique, individual responses are optimized only in the experimental domain. In the preparation of the fluid process, using two input variables with four levels: (i) flow rate and (ii) coolant ratio. On the basis of table 1, identify its effect on temperature drop and heat transfer rate as mentioned response table 3.

Table 3: Response Table

Experiment no.	Hybrid TD	Heat transfer rate
1	30.00	301.63
2	28.70	312.00
3	27.80	322.76
4	27.10	332.70
5	28.90	335.27
6	27.90	349.97
7	27.10	363.04
8	25.90	366.89
9	27.80	365.51
10	26.80	380.99
11	26.00	394.75
12	24.80	398.15
13	27.10	398.22
14	26.00	413.10
15	25.18	427.27
16	24.00	430.63

V. THERMAL PERFORMANCE AND OPTIMIZATION

The research methodology involves a comprehensive approach to conducting experiments, designing experiments using Taguchi, performing confirmation tests, 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.

1.1 THERMAL PARAMETERS

The thermal parameters evaluated during experimentation work are discussed below:

a. Empirical Relations for Heat Transfer Modeling

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

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

b. Empirical Relations for Mean Temperature Difference

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

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

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

VI. RESULT

4.1 HYBRID TEMPERATURE DROPS

Hybrid temperature drop had to be maximized, so larger the better criterion is used for analysis. The response table for signal-to-noise ratios of hybrid temperature drops is presented in Table 4. The coolant ratio had much higher delta values than the flow rate. It can be concluded from the response table that the coolant ratio has the largest effect on hybrid temperature drop. The variation of the main effects plot for SN ratios for hybrid temperature drops with various input factors is shown by the main effect plots for hybrid temperature drops, as shown in **Fig. 2**. The optimum maximum hybrid temperature drop recommended by main effect plots for the SN ratio is obtained at 100% ethylene glycol and a flow rate of 13 l/hr. Coolant ratio had the highest (51.04%) contribution percentage, followed by flow rate (48.47%); therefore, both were statistically significant.

4.1.1 Analysis of Variance for SN Ratios for Hybrid Temperature Drop

Statistical analysis was carried out to assess the impact of process input variables (flow rate, coolant ratio) on responses. Table 4 summarizes the variance of the analysis for means of hybrid temperature drop. The significance of the parameters was determined with the help of the P-value. If the P-value is less than 0.05, the input parameter is statistically significant at a 95% confidence level. Otherwise, the term is insignificant and may be removed from the analysis. The predicted R^2 of (99.52%) is in reasonable agreement with the adjusted R^2 of (99.19 %.)

Table 4: Analysis of Variance for SN Ratios for Hybrid Temperature Drop

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of Contribution
Flow Rate	3	1.92534	1.92534	0.641779	300.69	0	48.47%
Coolant Ratio	3	2.02749	2.02749	0.675829	316.64	0	51.04%
Residual Error	9	0.01921	0.01921	0.002134			
Total	15	3.97203					
S	R-Sq			R-Sq(adj)			
0.0462	99.52%			99.19%			

4.1.2 Response Table for Signal to Noise Ratios for Hybrid Temperature Drop

The response table for means of temperature drop is presented in Table 5. Coolant ratio had much higher delta values than flow rate, with the lowest delta values varying in rank.

Table 5: Response Table for Signal to Noise Ratios for Hybrid Temperature Drop

Level	Flow Rate	Coolant Ratio
1	29.06	28.10
2	28.76	28.47
3	28.41	28.73
4	28.15	29.08
Delta	0.91	0.97
Rank	2	1

The optimum maximum hybrid temperature drop recommended by main effect plots for SN ratios is obtained at a coolant ratio of 100 and a flow rate of 13. This is shown in **Fig. 2**.

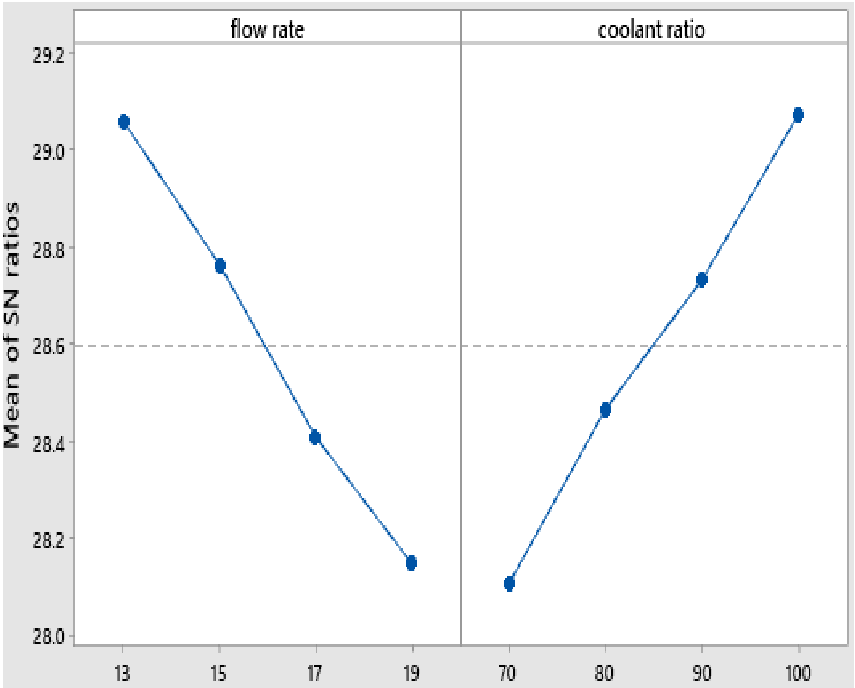

Fig. 2: Main Effect Plot for SN Ratios for Temperature Drop

4.1.3 Analysis of Variance for Means for Hybrid Temperature Drop

Statistical analysis was carried out to assess the impact of process input variables (flow rate, coolant ratio) on responses. The significance of the parameters was determined with the help of the P-value. If the P-value is less than 0.05, the input parameter is statistically significant at a 95% confidence level. Otherwise, the term is insignificant and may be removed from the analysis. The R2 score indicates how much of the variability in the data is explained by the model. The analysis of variance for SN ratios for temperature drops of hybrid temperature drops is presented in Table 6. Coolant ratio had the highest (51.03%) contribution percentage, followed by flow rate (48.63%); therefore, both were statistically significant. The predicted R2 of (99.67%) is in reasonable agreement with the adjusted R2 of (99.46%).

Table 6: Analysis of Variance for Means Ratios for Hybrid Temperature Drop

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of contribution
flow rate	3	18.4667	18.4667	6.15557	446.41	0	48.63%
coolant ratio	3	19.3787	19.3787	6.45957	468.46	0	51.03%
Residual Error	9	0.1241	0.1241	0.01379			
Total	15	37.9695					
S	R-Sq			R-Sq(adj)			
0.1174	99.67%			99.46%			

4.1.4 Response Table for Means for Hybrid Temperature Drop

The response table for means of temperature drop is presented in Table 7. The coolant ratio had much higher delta values than the flow rate. With the lowest delta values varying in rank.

Table 7: Response Table for Means for Hybrid Temperature Drop

Level	flow rate	Coolant ratio
1	28.4	25.45
2	27.45	26.52
3	26.35	27.35
4	25.57	28.45
Delta	2.83	3
Rank	2	1

The optimum maximum hybrid temperature drop recommended by main effect plots for S/N ratios is obtained at a coolant ratio of 100 and a flow rate of 13. This is shown in **Fig. 3**.

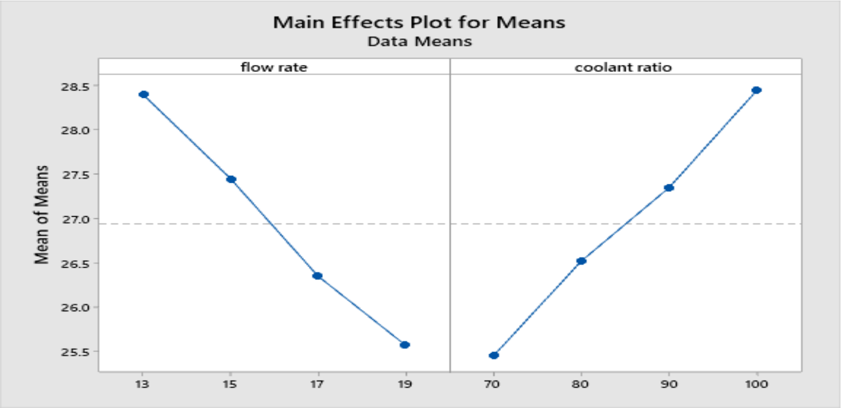

Fig. 3: Main Effect Plot of Means for Temperature Drop

4.1.5 Confirmation Test Result Mean for Hybrid Temperature Drop

The confirmation test was run on the parametric combination chosen from the best set of parameters. The regression models were used to predict the value of the response parameters for optimal set of input parameters and experimental trials were also conducted for each set of optimal input parameters. The predicted and experimental values thus obtained are presented in Table 07. It is evident that predicted values were very close to experimental ones i.e., lies within ± 10% of actual ones. The error percentage represents the discrepancy between the experimental mean and the expected result. Table 8 clarifies that the projected values closely match the experimental findings because the error percentage is so small. It is evident that the Taguchi technique has provided optimal results with the minimum number of experiments. The results were far better than the results in numerical trials.

Table 8: Confirmation Test Result Mean for Hybrid Temperature Drop

<table>
<tr><th rowspan="2"></th><th rowspan="2">Initial process parameter</th><th colspan="2">Optimum process parameter</th><th rowspan="4">Percentage error in prediction and experiment</th></tr>
<tr><th>Prediction</th><th>Experimental</th></tr>
<tr><td>Level</td><td>Eg 80. Fr 15</td><td>Eg 100, Fr 13</td><td>Eg 100, Fr 13</td></tr>
<tr><td>Temperature drop (°c)</td><td>27.02</td><td>29.90</td><td>30</td></tr>
<tr><td>Percentage increment in temperature drop from initial and experiment</td><td colspan="3">9.6</td><td>0.3</td></tr>
</table>

4.2 HEAT TRANSFER RATE

Heat Transfer Rate had to be maximized, so larger the better criterion is used for analysis. The response table for signal-to-noise ratios of heat transfer rate is presented in Table 9. The flow rate had much higher delta values than the coolant ratio. It can be concluded from the response table for S/N. The coolant ratio has the largest effect on heat transfer rate. The variation of the main effects plot for SN ratios heat transfer rate with various input factors is shown by the main effect plots for SN ratios, as shown in **Fig. 4**. The heat transfer rate varies differently with each input parameter. The optimum maximum heat transfer rate recommended by main effect plots for SN ratios is obtained at a coolant ratio of 70% ethylene glycol and a flow rate of 19 l/hr.

4.2.1 Analysis of Variance for SN Ratios of Heat Transfer Rate

A statistical analysis was carried out to assess the impact of process input variables (flow rate, coolant ratio) on responses. Table 9 summarizes the variance of the analysis for SN ratios of heat transfer rate of heat transfer rate. P-values less than 0.05 indicate model terms are significant. In this case, coolant ratio and flow rate were significant model terms. Coolant ratio had the highest (89.80%) contribution percentage, followed by flow rate (10.05%); therefore, both were statistically significant. The predicted R2 of (99.86%) is in reasonable agreement with the adjusted R2 of (99.77%).

Table 9: Analysis of Variance for SN Ratios of Heat Transfer Rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of contribution
flow rate	3	12.478	12.478	4.15932	1948.74	0	89.80
coolant ratio	3	1.3974	1.3974	0.46581	218.24	0	10.05
Residual Error	9	0.0192	0.0192	0.00213			
Total	15	13.8946					
S	R-Sq			R-Sq(adj)			
0.0462	99.86%			99.77%			

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4.2.2 Response Table for Signal to Noise Ratio of Heat Transfer Rate

The response table for signal-to-noise ratios of heat transfer rate is presented in Table 10. Flow rate had much higher delta values than coolant ratios, with the lowest delta values varying in rank.

Table 10: Response Table for Signal to Noise Ratio of Heat Transfer Rate

Level	flow rate	coolant ratio
1	50.02	51.6
2	50.97	51.48
3	51.7	51.18
4	52.41	50.84
Delta	2.38	0.76
Rank	1	2

The optimum maximum heat transfer rate recommended by main effect plots for SN ratios is obtained at a coolant ratio of 70 and a flow rate of 19. This is shown in **Fig. 4**.

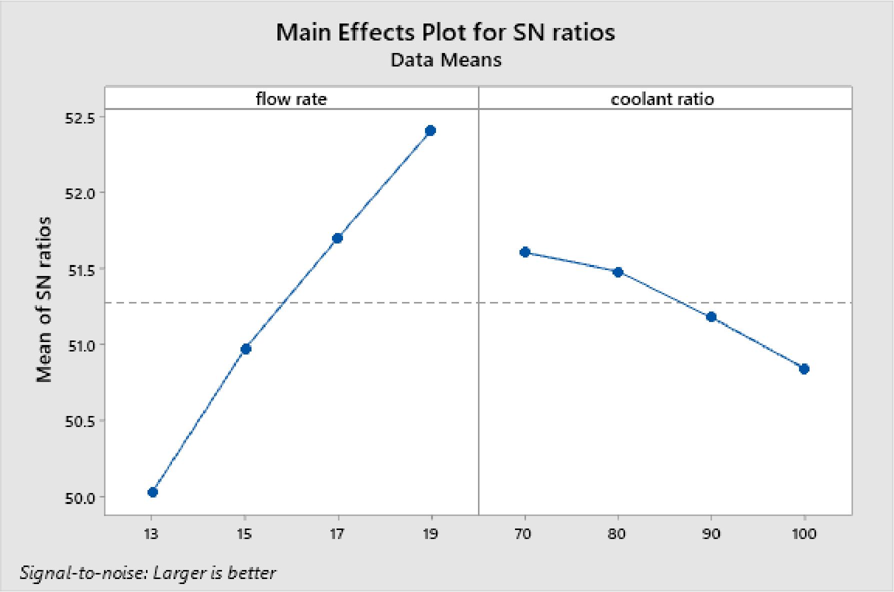

Fig. 4: Main Effect Plot for SN Ratios for Heat Transfer Rate

4.2.3 Analysis Of Variance for Mean of Heat Transfer Rate

Statistical analysis was carried out to assess the impact of process input variables (flow rate, coolant ratio) on responses. The significance of the parameters was determined with the help of the P-value. If the P-value is less than 0.05, the input parameter is statistically significant at a 95% confidence level. Otherwise, the term is insignificant and may be removed from the analysis. The R2 score indicates how much of the variability in the data is explained by the model. The analysis of variance for SN ratios for temperature drops of hybrid temperature drops is presented in Table 11. Coolant ratio had the highest (89.06%) contribution percentage, followed by flow rate (10.02 %); therefore, both were statistically significant. The predicted R2 of (99.89%) is in reasonable agreement with the adjusted R2 of (99.81%).

Table 11: Analysis of Variance for Mean of Heat Transfer Rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Of contribution
flow rate	3	21959.6	21959.6	7319.87	2411.22	0	89.06
coolant ratio	3	2450.8	2450.8	816.95	269.11	0	10.02
Residual Error	9	27.3	27.3	3.04			
Total	15	24437.8					
S	R-Sq			R-Sq(adj)			
1.7423	99.89%			99.81%			

4.2.4 Response Table for Means of Heat Transfer Rate

The response table for means of heat transfer rate is presented in Table 12. Flow rate had much higher delta values than coolant ratios, with the lowest delta values varying in rank.

Table 12: Response Table for Means of Heat Transfer Rate

Level	flow rate	coolant ratio
1	317.3	382.1
2	353.8	377
3	384.8	364
4	417.3	350.2
Delta	100	31.9
Rank	1	2

The optimum maximum heat transfer rate recommended by main effect plots for means ratios is obtained at a coolant ratio of 70 and a flow rate of 19. This is shown in **Fig. 5.**

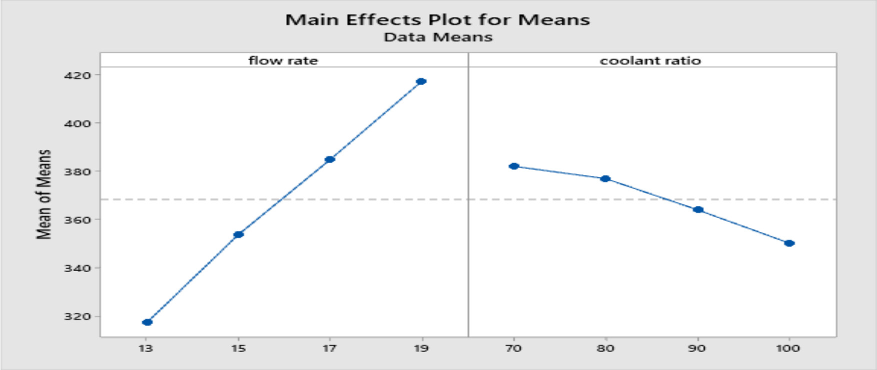

Fig. 5: Main Effect Plot of Means for Heat Transfer Rate

4.2.5 Confirmation Test Result Mean for Heat Transfer Rate

The confirmation test was run on the parametric combination chosen from the best set of parameters. The regression models were used to predict the value of the response parameters for optimal set of input parameters and experimental trials were also conducted for each set of optimal input parameters. The predicted and experimental values thus obtained are presented in Table 13. It is evident that predicted values were very close to experimental ones i.e., lies within ± 10% of actual ones. The error percentage represents the discrepancy between the experimental mean and the expected result. Table 13 clarifies that the projected values closely match the experimental findings because the error percentage is so small. It is evident that the Taguchi technique has provided optimal results with the minimum number of experiments. The results were far better than the results in numerical trials.

Table 13: Confirmation Test Result Mean for Heat Transfer Rate

	Initial process parameter	**Optimum process parameter**		Percentage error in prediction and experiment
		Prediction	**Experimental**	
Level	Eg 80. Fr 15	Eg 100, Fr 19	Eg 100, Fr 19	
Convective heat transfer($w/m^{2\circ}c$)	362.44	399.16	398.22	
Percentage increment in Convective heat transfer from initial and experiment	9.1			0.23

VII. CONCLUSION

A statistical approach to the design of experiments using Taguchi techniques was used to minimize the number of experiments to get optimal results. The influence of process parameters on the thermal property's location was analyzed. The optimum parameters were obtained from the design of experiments using L16 arrays. The results showed two parameters using the Taguchi method. Temperature drops, heat transfer rate of various proportions of liquids were observed. Analysis of variance has helped in studying the influence of responses. The summary of significant results is discussed as follows:

- Hybrid temperature drops are recommended to obtained for the maximum hybrid temperature drop at a coolant ratio of 100% and a flow rate of 13 l/hr. The hybrid temperature drops the percentage error in the prediction and experiment by 0.3%.
- Heat transfer coefficient is recommended to obtained for the maximum bulk mean temperature at a coolant ratio of 70% and a flow rate of 19 l/hr. hybrid temperature drops the percentage The error in the prediction and experiment is 0.23%.

To expend the research use, Comparative analysis using different designs of heat exchangers can be done.

VIII. ACKNOWLEDGEMENT

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REFERENCES

[1] A. Baghel, C. Sharma, V. Upadhyay, and R. singh, “Investigating the influence of single and multicomponent activated fluxes on macrostructure, microstructure, and hardness of ATIG welded SS304,” *International Journal on Interactive Design and Manufacturing*, 2023, doi: 10.1007/s12008-023-01620-1.

[2] A. Baghel, C. Sharma, M. K. Singh, and V. Upadhyay, “Modeling and optimization of bead geometry and hardness of bead on plate TIG welds of Stainless Steel SS202,” *International Journal on Interactive Design and Manufacturing*, 2023, doi: 10.1007/s12008-023-01439-w.

[3] B. Nagaraja, F. Almeida, Y. Ali, P. Kumar, A. R. Ajaykumar, and Q. Al-Mdallal, “Empirical study for Nusselt number optimization for the flow using ANOVA and Taguchi method,” Case Studies in Thermal Engineering, vol. 50, Oct. 2023, doi: 10.1016/j.csite.2023.103505.

[4] A. Baghel, C. Sharma, S. Rathee, and M. Srivastava, “Influence of activated flux on micro-structural and mechanical properties of AISI 1018 during MIG welding,” in Materials Today: Proceedings, Elsevier Ltd, 2020, pp. 6947–6952. doi: 10.1016/j.matpr.2021.05.210.

[5] A. Baghel, C. Sharma, V. Upadhyay, and R. singh, “Optimization of process parameters for autogenous TIG welding of austenitic stainless-steel SS-304,” International Journal on Interactive Design and Manufacturing, 2023, doi: 10.1007/s12008-023-01455-w.

[6] Selvalakshmi, I. Karthikeyan, R. Immanual, A. Paul Vinofer, E. Varadha, and B. Chokkalingam, “Multi-response optimization of the Thermal properties of Bio fluids using Taguchi-Grey Analysis,” in IOP Conference Series: Materials Science and Engineering, IOP Publishing Ltd, Feb. 2021. doi: 10.1088/1757-899X/1059/1/012051.

[7] R. Barai, D. Kumar, A. Wankhade, and M. Kilic, “Heat transfer performance of nanofluids in heat exchanger: a review ARTICLE INFO,” vol. 9, no. 1, pp. 86–106, 2023, doi: 10.14744/jten.2023.xxxx.

[8] K. Goudarzi and H. Jamali, “Heat transfer enhancement of AL 2 O 3-EG nanofluid in a car radiator with wire coil inserts,” 2017. [Online]. Available: https://www.elsevier.com/open-access/userlicense/1.0/

[9] P. C. M. Kumar, J. Kumar, R. Tamilarasan, S. Sendhil Nathan, and S. Suresh, “Heat transfer enhancement and pressure drop analysis in a helically coiled tube using Al2O3 / water nanofluid,” Journal of Mechanical Science and Technology, vol. 28, no. 5, pp. 1841–1847, 2014, doi: 10.1007/s12206-014-0331-z.

[10] N. Sadashiv Vele and R. K. Patil, “Review on Heat Transfer Enhancement in Car Radiator Using Nano Fluids.”

[11] M. Ali, A. M. El-Leathy, and Z. Al-Sofyany, “The effect of nanofluid concentration on the cooling system of vehicles radiator,” Advances in Mechanical Engineering, vol. 2014, 2014, doi: 10.1155/2014/962510.

[12] M. Naraki, S. M. Peyghambarzadeh, S. H. Hashemabadi, and Y. Vermahmoudi, “Parametric study of overall heat transfer coefficient of CuO/water nanofluids in a car radiator,” International Journal of Thermal Sciences, vol. 66, pp. 82–90, Apr. 2013, doi: 10.1016/j.ijthermalsci.2012.11.013.

[13] M. M. Elias et al., “Experimental investigation on the thermo-physical properties of Al2O3 nanoparticles suspended in car radiator coolant,” International Communications in Heat and Mass Transfer, vol. 54, pp. 48–53, 2014, doi: 10.1016/j.icheatmasstransfer.2014.03.005.

[14] S. M. Peyghambarzadeh, S. H. Hashemabadi, M. S. Jamnani, and S. M. Hoseini, “Improving the cooling performance of automobile radiator with Al 2O3/water nanofluid,”