N Santhi Sree, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 12, Issue 11, November 2022, pp. 213-220

RESEARCH ARTICLE OPEN ACCESS

Performance Analysis of CLPHP Using L9 Orthogonal Array

N Santhi Sree [1] * N V V S Sudheer [2] P.Bhramara [3] A.Kalyan Charan[4]
[1]* *Associate Professor, Department of Mechanical Engineering, Matrusri Engineering College ,Hyderabad.*
[2] *Professor, Departments of Mechanical Engineering, RVRJC College of Engineering, Andhra Pradesh, India-522019*
[3] *Professor, Department of Mechanical Engineering, JNTUH Hyderabad, India-500085*
[4].*Assistant Professor, Department of Mechanical Engineering, Matrusri Engineering College* ,Hyderabad

ABSTRACT
Closed loop Pulsating heat pipes (CLPHP) are emerged as heat transfer devices which are an alternative to conventional heat transfer technologies. The present paper a statistical approach-Taguchi method is adopted to optimize the parameters in order to improve the quality. To study the performance parameters an orthogonal array, analysis of variance and ANOVA are employed. By varying input parameters and by considering L9 orthogonal array analysis is made. Analysis of variance (ANOVA) is performed to determine the optimum levels for minimizing the thermal resistance of the working fluids. By plotting graphs the optimum parameters values are obtained. From the results the most significant parameter that influences performance of CLPHP is heat input. As Heat input increases thermal resistance decreases. The results are verified with experimental work carried out on an 8-turn pulsating heat pipe.

KEYWORDS: Closed loop pulsating heat pipe (CLPHP),Heat Input, Orthogonal array, Taguchi method, Working fluid.

Date of Submission: 15-11-2022 Date of Acceptance: 30-11-2022

I. INTRODUCTION

Akachi proposed pulsating heat pipe in 1990[1].It's two phase heat transfer device with evaporation and condensation phenomena .At Evaporator heat input is given and it condenses in the condenser by the liquid –vapour pulsation action. Due to the pressure pulsations the transfer of liquid and vapour bubbles takes place from one end to other[2]. Khandhekhar and Groll [3] demonstrated a CLPHP operating with 2mm inner diameter tube, the flow pattern inside the tube strongly effects the overall performance. Also inclination angle does affect its performance, for systems with less number of turns. Uneven heating and cooling causes pressure fluctuations and causes temperature difference in the evaporator and condenser. Zhang and Faghri [4] found that latent heat is required to drive the oscillatory motion in the tube whereas in the overall heat transfer (greater than 90%) sensible heat plays important role.They also found the optimum charging ratio will be between 20-80%..Chroneswran et al. [5] indicated that CLPHP performance with respect to orientation would be affected by two physical phenomena –one is the inclination angle at which PHP was operated and the other was number of parallel tubes that PHP setup consists of. Along with these two parameters heat input is also one of the important parameter that affects the thermal performance with respect to orientation. Yang et al [6] found that for decreased inner tube diameter the operational orientation effect will be insignificant or relatively small and also concluded that when PHP operated in vertical bottom heat mode best thermal and maximum performance limitation was obtained. Taguchi and Konishi [7] developed a statistical method named as Taguchi method for improving the quality and careful selection of performance parameters. Jokaret. al. [8] presented a novel approach for simulating and optimized the heat pipe using artificial neural network and Genetic algorithm. The setup is fabricated and the experiment had been carried out[9]. Experiment was carried on with working fluids namely Water, Ethanol, at three different inclinations and at three different fill ratios of heat pipe. [10]

II. RESULTS AND DISCUSSIONS

The temperatures of different sections of CLPHP were recorded by using data logger system.

The procedure is repeated for all the considered fill ratios by changing the positions. For the fluids considered the above procedure was carried out systematically. With the average evaporator and condenser values thermal resistance of the CLPHP had been found out at all operating conditions.

For any instance to the input heat the ratio of difference in average temperature of evaporator and condenser at that particular time is defined as thermal resistance. Mathematically can be expressed as

$$Rth = \frac{(Te-Tc)}{Q} \quad \text{-------------------------------- (i)}$$

Where, Q = heat input in Watts,
$(Te - Tc)$ = Average evaporator and condenser temperature difference in ^{o}C
Rth = Thermal resistance in ^{o}C/W

In the present study by using Taguchi technique the experimental values are analyzed .L9 orthogonal array is considered.
Based on the Taguchi L9 Orthogonal array experiments are conducted and are tabulated in the table for the fluids considered [11].

Water: As a Working fluid

Table: Input parameters, symbols and their levels

	Symbol	**Level 1**	**Level 2**	**Level 3**
Fill Ratio	FR	50	60	75
Heat Input	Q	20	40	60
Inclination Angle	ϕ	0	45	90

1.1 Analysis of Signal-to-noise ratio

The mean signal-to-noise (S/N) ratio for each level of the heat pipe calculated in a similar manner and the results tabulated in Table 0. Additionally, the total mean S/N ratio computed by averaging the overall S/N ratios. Based on data presented in table 1, for thermal resistance was obtained at 75 fill ratio (level 3), 20 heat input (level 1) and 90^0 inclination angle (level 3). The criteria smaller-the-better considered for selection of S/N ratio for the thermal resistance. The mean effect and S/N ratio for the thermal resistance of water as working fluid calculated by using a statistical software and are shown in fig.1 and fig. 2 respectively.

Table 1: Response table mean signal-to-noise ratio for thermal resistance

Symbol	Process Parameters	Mean S/N ratio			
		Level 1	Level 2	Level 3	Max-min
FR	Fill Ratio	3.863	3.876	3.351*	0.526
Q	Heat Input	1.459*	3.249	6.382	4.924
ϕ	Inclination Angle	4.118	3.622	3.352*	0.767
* Optimum level					

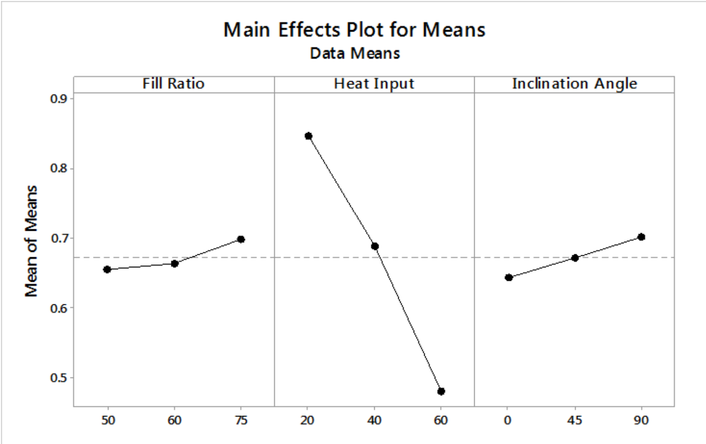

Figure 1: Mean effects plot for the thermal resistance for water as working fluid

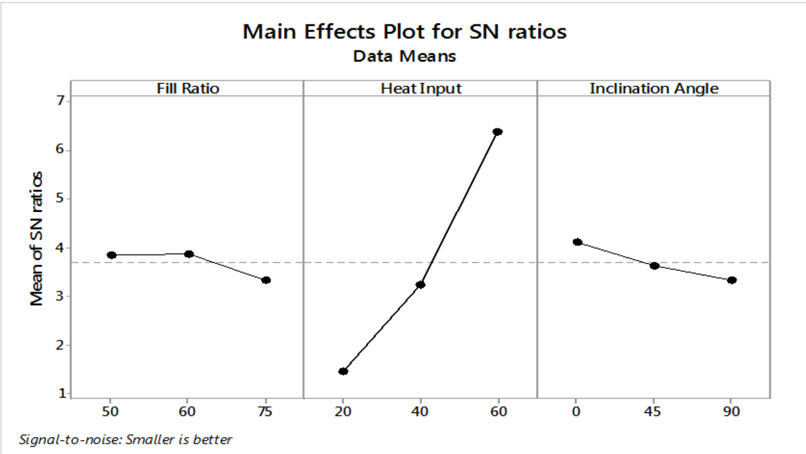

Figure 2: Mean effects plot for S/N ratio the thermal resistance for water as working fluid

1.2 ANOVA (Analysis of Variance)

Analysis of variance (ANOVA) is used to check the influence of given input conditions from a series of experimental values by using the design of experiments for optimize the pulsating heat pipe, and it also supplies an interpretation output data.

Table: 2 Analysis of variance for thermal resistance of water as a working fluid

Source	DF	SS	MS	F value	P-value	% Contribution	Remarks
Model	3	0.208374	0.069458	199.76	0.0000		
FR	1	0.002927	0.002927	8.42	0.0340	1.393067	Significant
Q	1	0.200356	0.200356	576.21	0.0000	95.35676	Significant
ϕ	1	0.005091	0.005091	14.64	0.0120	2.422993	Significant
Error	5	0.001739	0.000348			0.827654	
Total	8	0.210112				100	

Observed that thermal resistance significantly influenced by heat input followed by the inclination angle and fill ratio, respectively. The percentage contribution of process parameters on thermal resistance for water was heat input (95.35%), inclination angle (2.42%) and fill ration (1.39%) respectively, which tabulated in table 2.

1.3 Regression analysis

Linear regression study was used by using the Minitab 17.0 statistical software, predictive models were developed for dependent variable thermal resistance as a function of fill ratio, heat input and inclination angle for varying working fluids.

The linear regression equation for thermal resistance for water shown in eq. 1.

Thermal Resistance $_{Water}$ = 0.8998 + 0.001755*FR – 0.009137*Q + 0.000647*ϕ (1)

(R^2 = 99.17%) (R^2 – adj = 98.68%)

The coefficient of determination value is from zero to one range. If it is close to one, it means that there is a good fit between the dependent and independent variables. Here the developed regression model for thermal resistance (water) has high R^2 value as 99.17%. The residual plot is used to check the significance of the coefficients in the predicted model. If the residual plot is a straight line means that the residual errors in the model normally distributed and coefficients in the model are significant and from the plot in fig. 3. It recognized that the residuals fall near the straight line for thermal resistance (water) which implies that the developed model is significant.

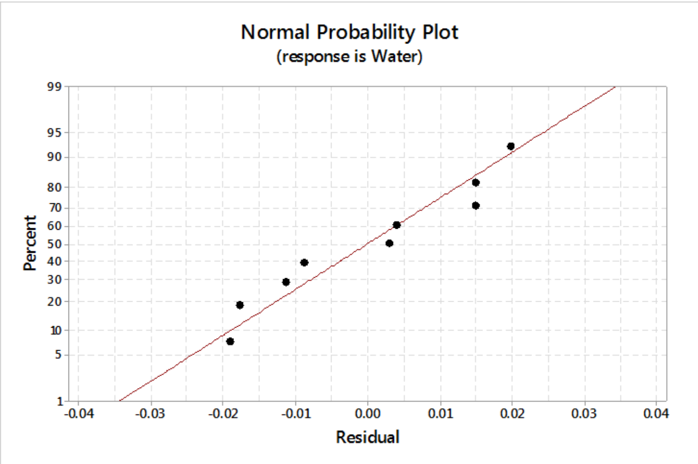

Figure 3: Normal probability plot of the residuals for thermal resistance (water as working fluid)

Confirmation tests were conducted to validate the developed model, and the results tabulated in Table 3. Some of the test results randomly chosen from the L_9 orthogonal array design of experiments. It noticed that models and experimental results were followed good agreement within the given range of parameters.

Table 3: Conformation results for the developed model water as working fluid

Run	Experimental	Predicted	Residuals	Error %
	Thermal Resistance (^{0}C/W)	Thermal Resistance (^{0}C/W)	Thermal Resistance (^{0}C/W)	Thermal Resistance (^{0}C/W)
2	0.6661	0.6512	0.0149	2.2348
5	0.7178	0.6979	0.0199	2.7731
8	0.6809	0.6660	0.0149	2.1904

The predicted values obtained from the linear regression model compared with experimental results and the relationship between these values plotted, as shown in Fig. 4. It received from the fig.4 that the variations between experimental and predicted values were minimal.

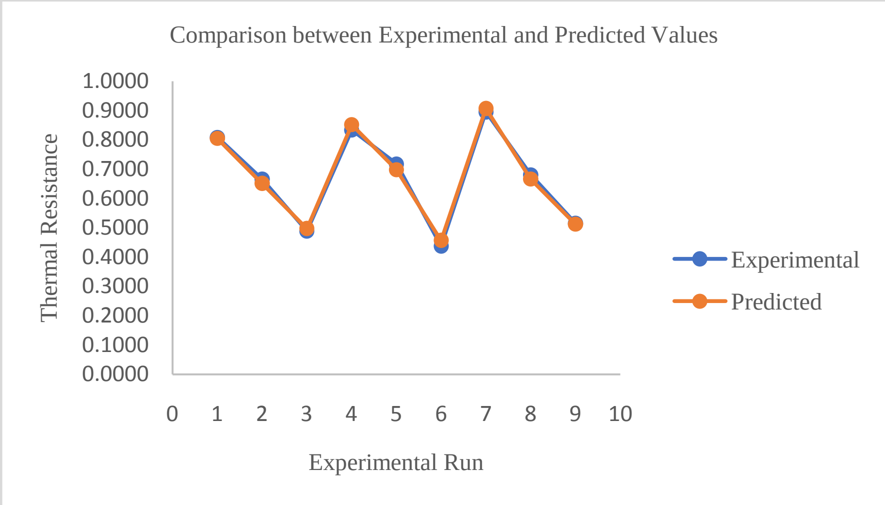

Figure 4: Comparison between experimental and predicted values of thermal resistance

Ethanol as working fluid

2.1 Analysis of Signal-to-noise ratio

The mean signal-to-noise (S/N) ratio for each level of the heat pipe calculated in a similar manner and the results tabulated in Table 0. Additionally, the total mean S/N ratio computed by averaging the overall S/N ratios. Based on data presented in table 4, for thermal resistance was obtained at 75 fill ratio (level 3), 20 heat input (level 1) and 90^0 inclination angle (level 3). The criteria smaller-the-better considered for selection of S/N ratio for the thermal resistance. The mean effect and S/N ratio for the thermal resistance of ethanol as working fluid calculated by using a statistical software and are shown in fig.5 and fig. 6 respectively.

Table 4: Response table mean signal-to-noise ratio for thermal resistance for ethanol as working fluid

Symbol	Process Parameters	Mean S/N ratio			
		Level 1	Level 2	Level 3	Max-min
FR	Fill Ratio	6.667	5.895	5.715*	0.953
Q	Heat Input	2.574*	6.589	9.114	6.541
ϕ	Inclination Angle	6.531	5.953	5.793*	0.739
* Optimum level					

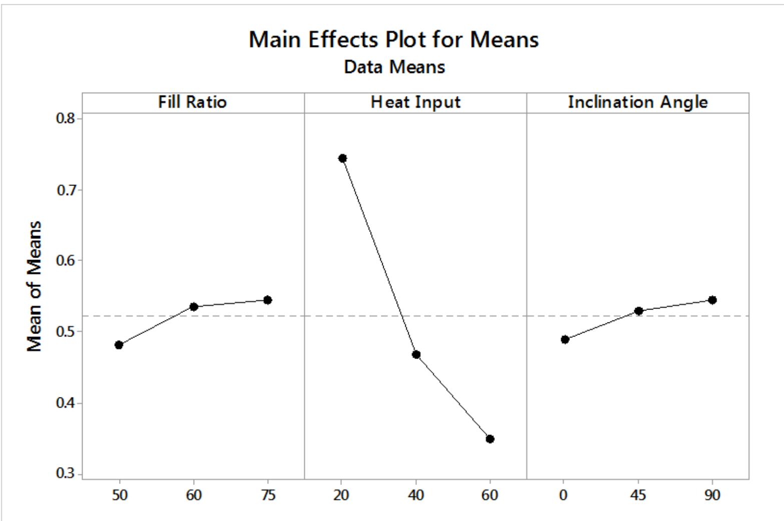

Figure 5: Mean effects plot for the thermal resistance for ethanol as working fluid

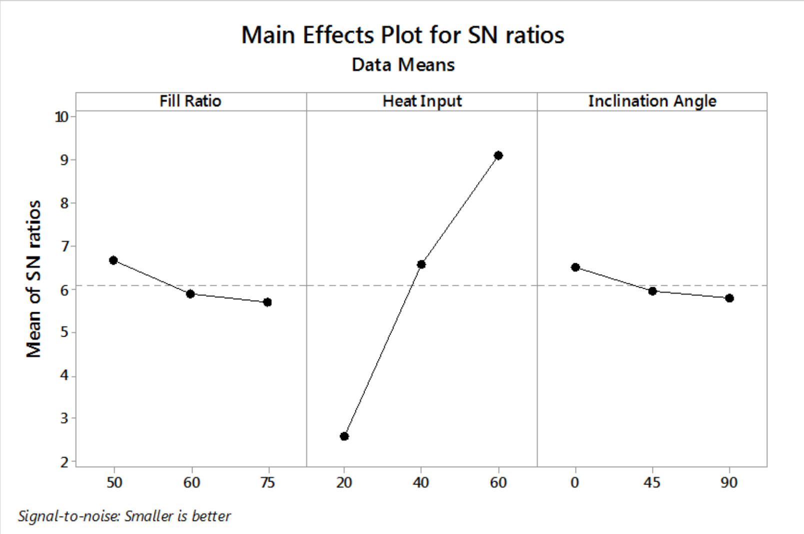

Figure 6: Main effects plots for S/N ratio for Ethanol as working fluid

2.2 ANOVA Analysis

Analysis of variance (ANOVA) is used to check the influence of given input conditions from a series of experimental values by using the design of experiments for optimize the pulsating heat pipe, and it also supplies an interpretation output data.

Table: 5 Analysis of variance for thermal resistance ethanol as a working fluid

Source	DF	SS	MS	F value	P-value	% Contribution	Remarks
Model	3	0.244559	0.08152	27.45	0.002		
FR	1	0.005422	0.005422	1.83	0.235	2.09	InSignificant
Q	1	0.234398	0.234398	78.92	0	90.35	Significant
ϕ	1	0.004738	0.004738	1.6	0.262	1.82	Insignificant
Error	5	0.01485	0.00297			5.72	
Total	8	0.259408				100	

Observed that thermal resistance significantly influenced by heat input followed by the fill ratio and, inclination angle respectively. The percentage contribution of process parameters on thermal resistance for ethanol was heat input (90.35%), fill ration (2.09%) and inclination angle (1.82%) respectively, which tabulated in table 5. Based on the ANOVA analysis, in the case of thermal resistance for ethanol inclination angle and fill ration are not significant due to its p-value (greater than 0.05), further it does not contribute to the evaluation of the response.

2.3 Regression analysis

The linear regression equation for thermal resistance for water shown in eq. 2.

$$\text{Thermal Resistance}_{\text{Ethanol}} = 0.742 + 0.00239*FR - 0.00988*Q + 0.000624*\phi \quad (2)$$

(R^2 = 94.28%) (R^2 – adj = 90.84%)

The coefficient of determination value is from zero to one range. If it is close to one, it means that there is a good fit between the dependent and independent variables. Here the developed regression model for thermal resistance (ethanol) has high R^2 value as 94.28%. The residual plot is used to check the significance of the coefficients in the predicted model. If the residual plot is a straight line means that the residual errors in the model normally distributed and coefficients in the model are significant and from the plot in fig. 7. It recognized that the residuals fall near the straight line for thermal resistance (ethanol) which implies that the developed model is significant.

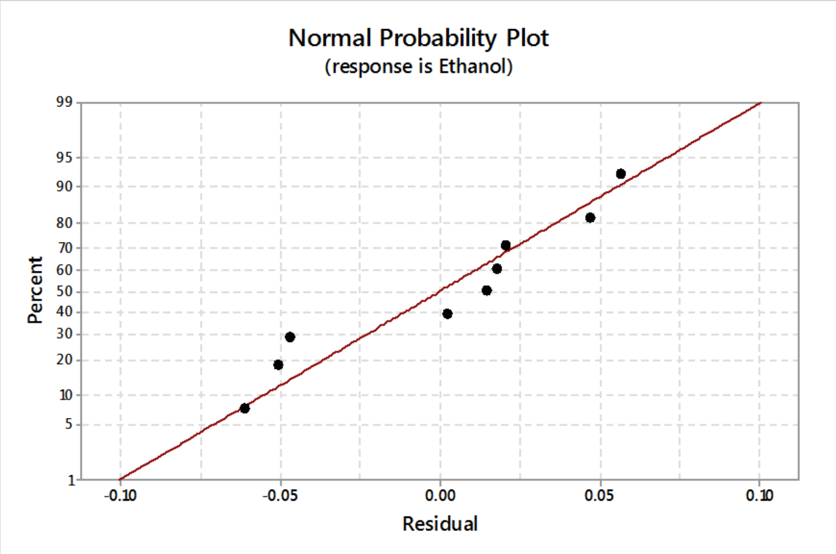

Figure 7: Normal probability plot of the residuals for thermal resistance (Ethanol as working fluid)

Confirmation tests were conducted to validate the developed model, and the results tabulated in Table 6. Some of the test results randomly chosen from the L_9 orthogonal array design of experiments. It noticed that models and experimental results were followed good agreement within the given range of parameters.

Table 6: Conformation results for the developed model water as working fluid

Run	Experimental	Predicted	Residuals	Error %
	Thermal Resistance (^{0}C/W)	Thermal Resistance (^{0}C/W)	Thermal Resistance (^{0}C/W)	Thermal Resistance (^{0}C/W)
2	0.6657	0.6634	0.0022	0.3356
7	0.7998	0.7794	0.0204	2.5539
9	0.3739	0.3560	0.0180	4.8007

The predicted values obtained from the linear regression model compared with experimental results and the relationship between these values plotted, as shown in Fig. 8. It received from the fig.8 that the variations between experimental and predicted values were minimal for ethanol as working fluid.

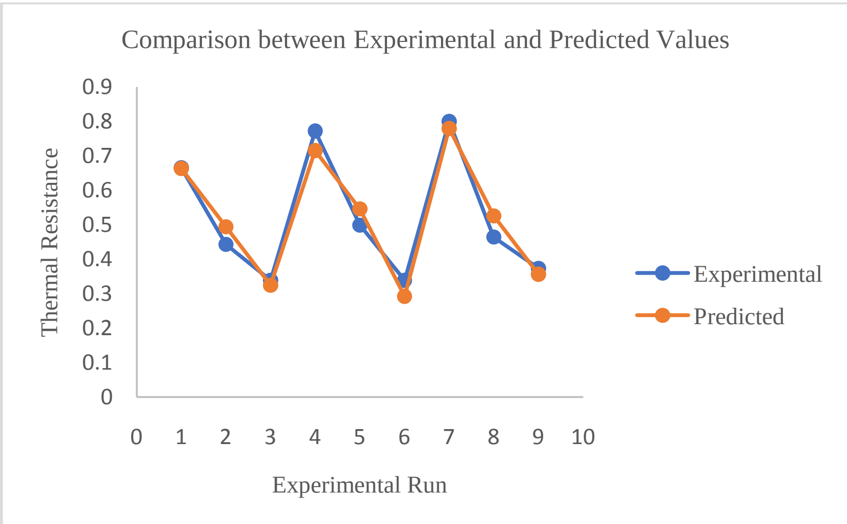

Figure 8: Comparison between experimental and predicted values of thermal resistance for Ethanol as working fluid

III. CONCLUSIONS

Taguchi philosophy employed to optimize the parameters in pulsating heat pipe on thermal resistance for working fluids such as water and ethanol. Optimum values are identified in order to minimize the thermal resistance of all working fluids.

- The heat input (95.25%) is the most significant factor, followed by least contributions to fill ratio and inclination angle for minimum thermal resistance for water as working fluid.
- The heat input (90.35%) is the most significant factor, followed by least contribution to fill ratio whereas inclination angle has no effect for minimum thermal resistance for ethanol as working fluid.
- The total error obtained by considering all the input parameters from the analysis is 0.827 for Water fluid and for Ethanol fluid it is 5.72.
- The experimental results are validated with the confirmation tests used by the Taguchi method for optimizing the pulsating heat pipe.
- The predicted values obtained from analysis deviates a maximum of 4.8 percentage from experimental values in random comparison of ethanol fluid whereas for water it is 2.79% only.
- For parameter optimisation Taguchi method provides a systematic, simple and efficient methodology.

REFERENCES

[1]. Akachi, H., 1990, “Structure of A Heat Pipe,” U.S. Patent.

[2]. Nagvase S.Y. and Pachghare P.R., 2013, “Parameters Affecting the Functioning of Close Loop Pulsating Heat Pipe: A Review,” Engineering Science, 2(1), pp. 35-39

[3]. Khandekar, S., Groll, M., 2004, “An Insight into Thermo-Hydrodynamic Coupling in Closed Loop Pulsating Heat Pipes”, International Journal of Thermal Sciences, 43(1), pp.13-20

[4]. Zhang, Y. W. and Faghri, A., 2008, “Advances and Unsolved Issues in Pulsating Heat Pipes,” Heat Transfer Engineering, 29(1), pp. 20-44

[5]. Charoensawan, P., Khandekar, S., Groll, M., Terdtoon, P., 2003, “Closed Loop Pulsating Heat Pipes Part A: Parametric Experimental Investigations,” Applied Thermal Engineering, 23(16), pp. 2009-2020

[6]. Yang, H., Khandekar, S. and Groll, M., 2008, “Operational Limit of Closed Loop Pulsating Heat Pipes,” Applied Thermal Engineering, 28(1), pp. 49-59

[7]. Taguchi Konishi S, Taguchi Methods,orthogonal arrays and linear graphs,for quality American supplier Institute,American Supplier Institute;1987.

[8]. Jokar, A., Godarzi, A.Saber, M., & Shafii, M. B. (2016). Simulation and optimization of a pulsating heat pipe using artificial neural network and genetic algorithm. Heat and Mass Transfer, 52(11), 2437-2445.

[9]. N. Santhi Sree, N. V. V. S. Sudheer & P. Bhramara., Experimental Analysis of Closed Loop Pulsating Heat pipe with Different Working fluids at Different inclinations, Jour of Adv. Research in Dynamics and Control systems Vol 11, No 8,pp.13-19, (ISSN: 1943-023X). 2019

[10]. N. Santhi Sree, N. V. V. S. Sudheer & P. Bhramara., Experimental Analysis Of Multi Turn Closed Loop Pulsating Heat Pipe– Impact Of Fill Ratio, Journal Of Mechanics Of Continua And Mathematical Sciences, ISSN (Online) : 2454 -7190 Vol.-15, No.-6, pp 69-81,Web of Science Journal .https://doi.org/10.26782/jmcms.2020.06.00006.

[11]. N. Santhi Sree, N. V. V. S. Sudheer; P. Bhramara., Analysis of CLPHP Using Optimization Techniques., International Journal of Ambient Energy, Taylor &Francis https://doi.org/10.1080/01430750.2020.1778525 .