ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 5, Special Issue 3, January 2018

OPTIMIZATION OF PULSATING HEAT PIPE PARAMETERS BY TAGUCHI METHOD

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ABSTRACT

Pulsating heat pipe is an effective method of heat transfer through passive two phase mechanism. In the present research work, experimental studies were performed on working parameters of pulsating heat pipe such as heat input, filling ratio, working fluid etc. on thermal resistance and heat transfer co-efficient. In this paper, the PHP working parameters are analyzed by using taguchi method. The taguchi method is used to analyze the effect of working parameters of the pulsating heat pipe and predict the optimum design parameters such as heat input, filling ratio and working fluid etc. In taguchi method, three parameters and five levels were considered. The L25 orthogonal array was selected and the best optimum parameters were identified based on main effect plot for means and signal to noise ratio plot under the characteristic of smaller and larger is the better respectively. The results showed that heat input plays a significant role in performance of PHP on thermal resistance and heat transfer coefficient followed by working fluid and filling ratio. Further randomly selected combination of parameters was compared with actual results of experiment.

Key words: Pulsating heat pipe, Heat input, Filling ratio, Taguchi method etc.

I. INTRODUCTION

Pulsating heat pipe (PHP) is a two phase heat transfer device, which is developed by akachi [1] in 1990. The PHP consists of capillary tubes having three zones i.e. evaporator zone, condenser zone and adiabatic zone, which is arranged in a serpentine manner as shown in Fig.1.

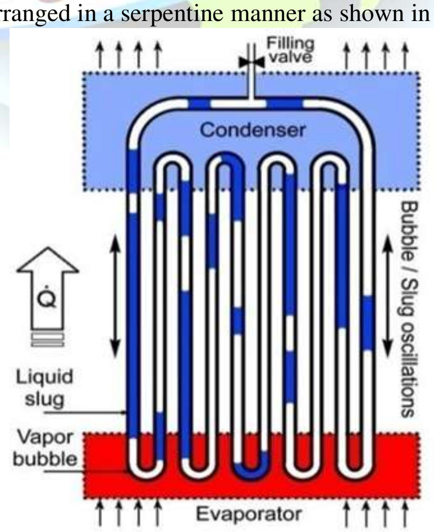

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Fig.1. Schematic representation of pulsating heat pipe

The PHP is classified into two types i.e. open loop and closed loop PHP. In the present investigation closed loop PHP is used because it has better circulation of working fluid than open loop PHP also it gives better performance [2]. In PHP, the heat transfer takes place by means of vapor bubbles and liquid slugs i.e. by Latent heat and Sensible heat by means of pulsating movement, hence the name pulsating heat pipe (PHP). Number of research persons has presented their experimental results for optimum filling ratio, tube diameters, orientation and maximum heat load of PHP etc. Taguchi techniques are experimental design optimization techniques [3, 4] which use standard orthogonal arrays for forming a matrix of experiments in such a way to extract the maximum important information with minimum number of experiments Senthil kumar [5] reported the effect working parameters on performance of PHP using taguchi method. It was reported that the heat input, flow rate and inclination angle plays an important role in functioning of PHP. Bhosale chandrakant analyzed the heat transfer enhancement using Al_2O_3 nano fluid and numerically investigated and predicted by using taguchi method. From the investigation, orthogonal array showed considerable parameters have a significant influence on thermal resistance and heat transfer coefficient. Frank pai [7] conducted finite element analysis on PHP and stated that heat transfer coefficient increases with increase in amplitudes of oscillation when the difference in temperature between evaporator and condenser increases.

II. EXPERIMENTAL SET UP

The closed loop pulsating heat pipe is fabricated with four turns, consists of evaporator, condenser and adiabatic zones. The evaporator and condenser zone is made up of copper material and adiabatic zone is made up of borosilicate glass tube for flow visualization. The inside diameter of copper and borosilicate glass tube was 2 mm with a thickness of 0.5mm. The lengths of evaporator, condenser and adiabatic zones were chosen as 640, 512 and 800 mm respectively. The evaporator zone is subjected to a heat input which varied from 20 watt to 60 watt with an increment of 10 watt. To measure the evaporator and condenser temperatures, eight K-type thermocouples were used. Out of eight thermocouples, four were employed at evaporator zone and rest was connected to condenser zone with alternative copper tubes respectively. The condenser zone is cooled by cooling water with a constant flow rate of 1.25 ml/sec.

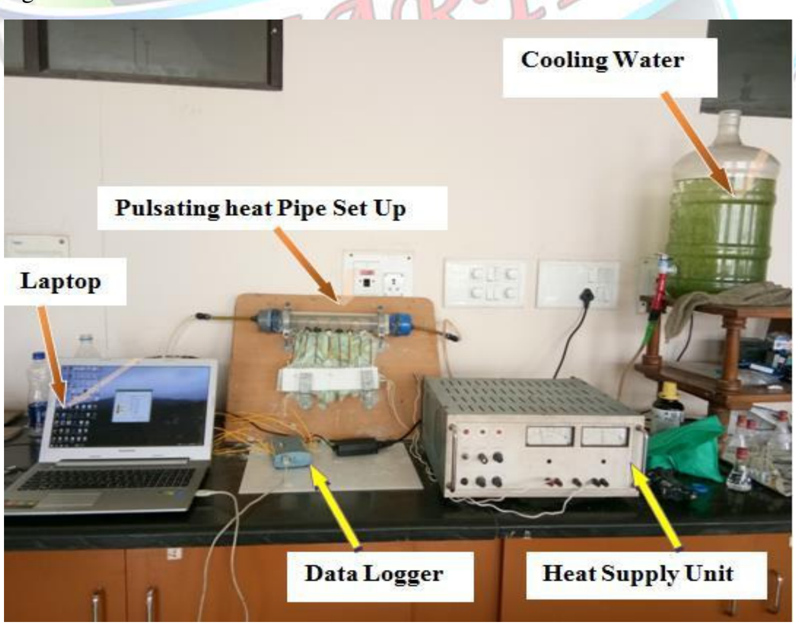

Fig.2. Experimental setup

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III. DESIGN OF EXPERIMENTS

In the present investigation, three parameters and five levels are used for taguchi method. The factors to be studied are presented in table 3.1.According to taguchi design concept L25 orthogonal array is chosen for the experiments as shown in table 3.2. Each experimental trail is performed as per L25 table and the optimization of the observed values is determined by comparing the standard method and analysis of variance (ANNOVA) which is based on the taguchi method. In taguchi method all the observed values are calculated based on the concept higher the better and smaller the better. In this analysis, the values of thermal resistance and heat transfer coefficient are smaller and larger the better respectively.

Table.3.1. Control Parameters and Levels

Factors/Parameters	Level 1	Level 2	Level 3	Level 4	Level 5
Filling Ratio	50%	60%	70%	80%	90%
Heat Input	20	30	40	50	60
Working Fluid	Acetone	Methanol	Ethanol	Benzene	Water

Table 3.2. L25 Orthogonal array for design of experiments with three parameters at five levels.

SL.NO	Filling Ratio	Heat Input	Working Fluid	Thermal Resistance (°K/W)	Heat Transfer Co-efficient (W/m² °K)
1	50%	20	ACETONE	1.25	199
2	50%	30	METHANOL	1.02	245
3	50%	40	ETHANOL	0.94	264
4	50%	50	BENZENE	0.77	324
5	50%	60	WATER	0.92	271
6	60%	20	METHANOL	1.18	211
7	60%	30	ETHANOL	0.89	280
8	60%	40	BENZENE	0.92	272
9	60%	50	WATER	1.00	249
10	60%	60	ACETONE	0.36	695
11	70%	20	ETHANOL	1.53	162
12	70%	30	BENZENE	0.98	253
13	70%	40	WATER	1.11	224
14	70%	50	ACETONE	0.6	414
15	70%	60	METHANOL	0.54	462
16	80%	20	BENZENE	2.08	119
17	80%	30	WATER	1.45	172
18	80%	40	ACETONE	0.98	253

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19	80%	50	METHANOL	0.85	294
20	80%	60	ETHANOL	0.76	327
21	90%	20	WATER	2.33	107
22	90%	30	ACETONE	1.32	188
23	90%	40	METHANOL	1.1	225
24	90%	50	ETHANOL	0.95	261
25	90%	60	BENZENE	0.87	286

3.1 Analysis of Variance (ANNOVA)

The adequacy and significance of the developed regression model was tested using ANOVA method. In ANOVA factors with 95% or P-value of 0.005 is considered as significant. Significance of the factors can be confirmed by main plot and normal probability plot. Table 3.3 shows analysis of variance for thermal resistance, in which all the factors considered is significant as its value is less than 0.005. Hence the heat input is the most influencing factor, followed by working fluid and filling ratio.

Table.3.2. Analysis of variance for Thermal resistance

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Remarks
Filling Ratio	4	0.72628	0.72628	0.18157	10.22	0.001	Significant
Heat Input	4	2.86168	2.86168	0.71542	40.28	0	Significant
Working Fluid	4	0.68472	0.68472	0.17118	9.64	0.001	Significant
Error	12	0.21312	0.21312	0.01776			
Total	24	4.4858					

S = 0.2133267 R-Sq = 95.25% R-Sq (adj) = 90.50%

Table 3.4 shows analysis of variance for heat transfer co-efficient, in which the heat input factor is significant followed by working fluid; however the filling ratio is insignificant as its value is more than 0.005. Hence the heat input is the most influencing factor, followed by working fluid and filling ratio

Table.3.4. Analysis of variance for heat transfer co-efficient

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Remarks
Filling Ratio	4	54190	54190	13548	3.23	0.051	Insignificant
Heat Input	4	175417	175417	43854	10.46	0.001	Significant

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Working Fluid	4	57394	57394	14348	3.42	0.044	Significant
Error	12	50315	50315	4193			
Total	24	337317					

S = 64.7529 R-Sq = 85.08% R-Sq(adj) = 70.17%

IV. RESULTS AND DISCUSSIONS

Figure 4.1 shows the variation of thermal resistance of pulsating heat pipe with all the parameters considered. From the figure it is observed that among all the parameters considered the thermal resistance is lower at an heat input of 60watt. When compared with filling ratio the optimum filling ratio is 60% and the better working fluid is ammonia. Fig.4.2 and Fig.4.3 shows 3D-surface plots for variation thermal resistance for three parameters. It is observed that the thermal resistance decreases with the increase in heat input as well as the filling ratio. Furthermore, it could be observed from the surface plots that the thermal resistance at a filling ratio of 60% is minimum at 60 watt heat input. Also among all the fluids considered, the acetone working fluid shows lower value of thermal resistance as compared to other working fluids.

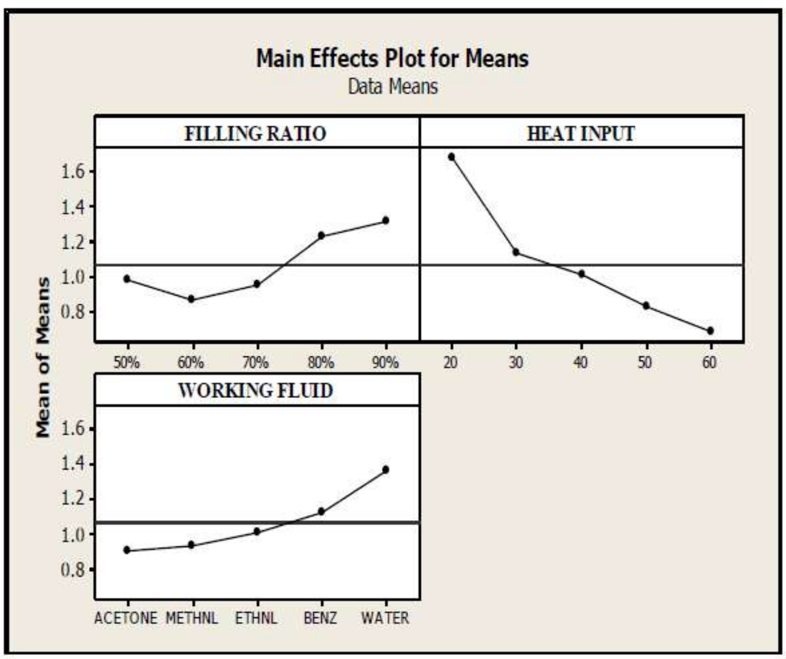

Fig.4.1. Main plot for effect of each parameter at different levels

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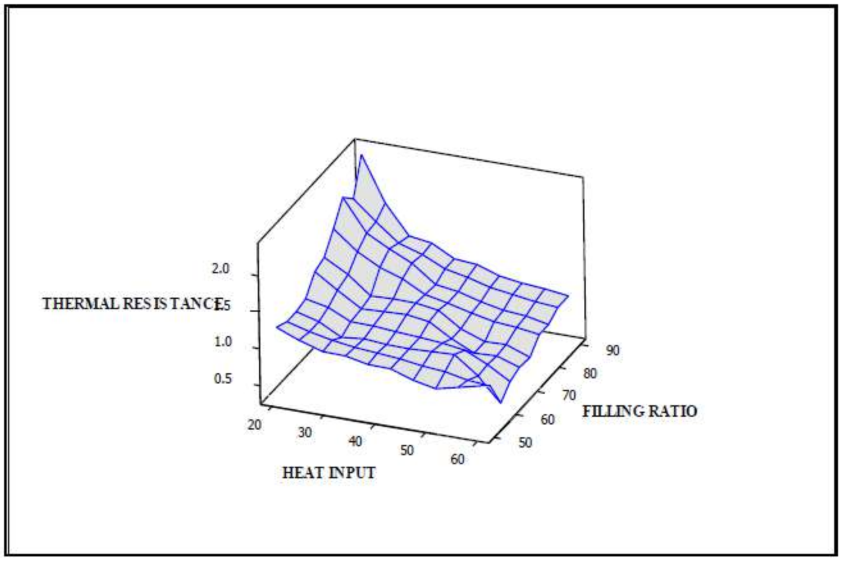

Fig.4.2. 3D Surface plot for variation of thermal resistance for heat input and filling ratio

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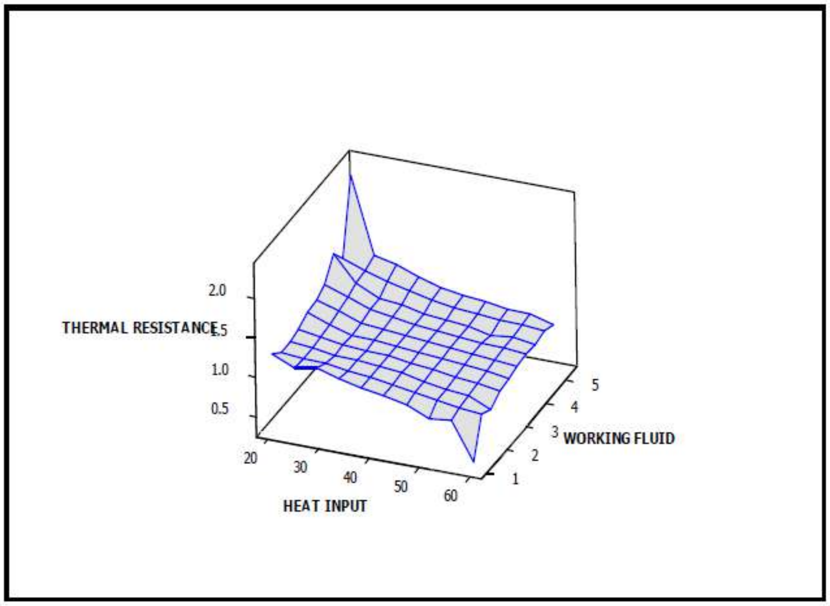
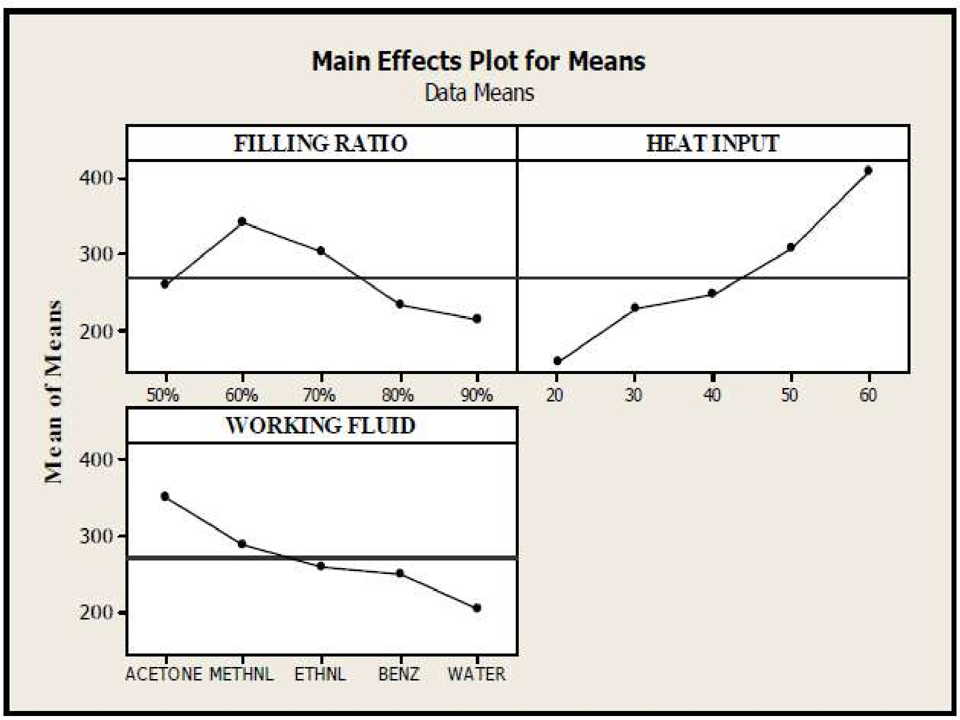


Fig.4.3. 3D Surface plot for variation of thermal resistance for heat input and working fluid



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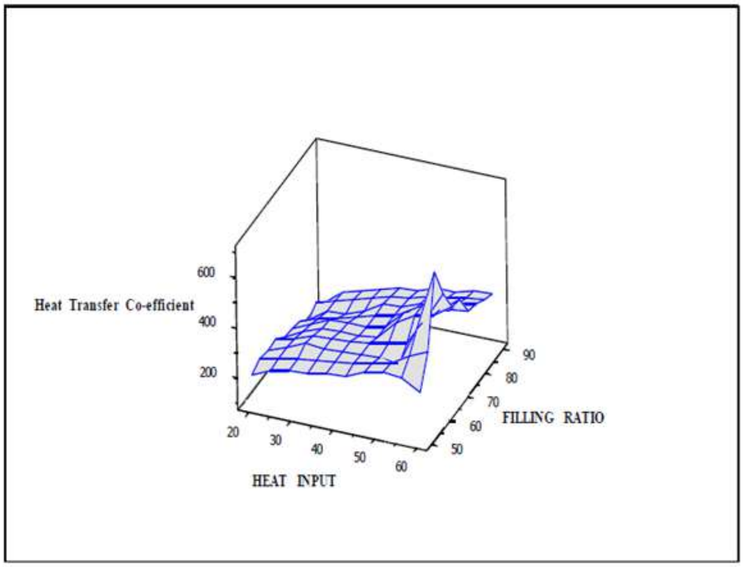

Fig.4.5. 3D Surface plot for variation of heat transfer co-efficient for heat input and filling ratio

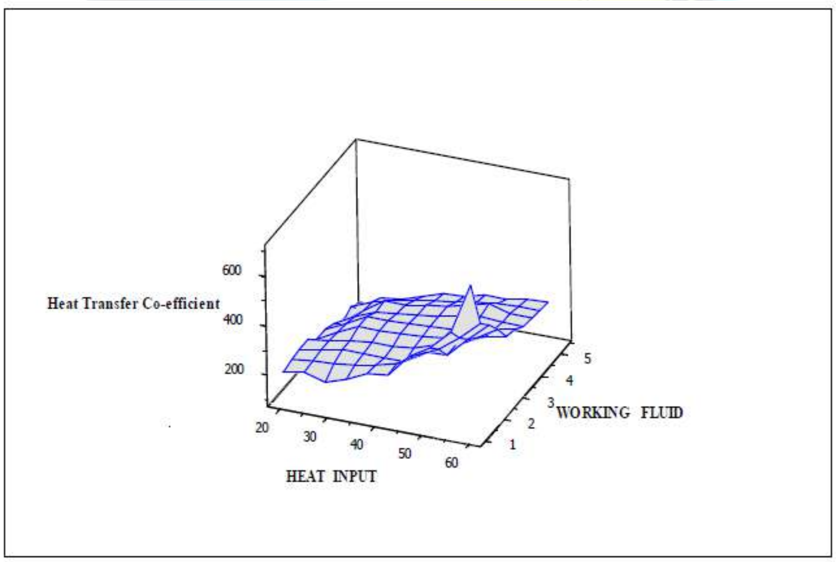

Fig.4.6. 3D Surface plot for variation of heat transfer co-efficient for heat input and working fluid

Fig.4.4 shows the effect of each parameter at different levels for heat transfer co-efficient. The higher value in each graph specifies the optimum level of that particular parameter. Therefore, the optimum level of each parameter for the better operation of PHP was 60% filling ratio at 60watt heat input with acetone as a working fluid. Fig.4.5 and 4.6 shows 3D-surface plots for variation heat transfer co-efficient for three parameters. It is observed that the heat transfer co-efficient increases with the increase in heat input as well as the filling ratio. From the surface plots, the heat transfer co-efficient is maximum at a filling ratio of 60% at 60 watt heat input. [6] proposed a principle in which another NN yield input control

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law was created for an under incited quad rotor UAV which uses the regular limitations of the under incited framework to create virtual control contributions to ensure the UAV tracks a craved direction. Utilizing the versatile back venturing method, every one of the six DOF are effectively followed utilizing just four control inputs while within the sight of un demonstrated flow and limited unsettling influences. Elements and speed vectors were thought to be inaccessible, along these lines a NN eyewitness was intended to recoup the limitless states. At that point, a novel NN virtual control structure which permitted the craved translational speeds to be controlled utilizing the pitch and the move of the UAV. At long last, a NN was used in the figuring of the real control inputs for the UAV dynamic framework. Utilizing Lyapunov systems, it was demonstrated that the estimation blunders of each NN, the spectator, Virtual controller, and the position, introduction, and speed following mistakes were all SGUUB while unwinding the partition Principle.

ACKNOWLEDGMENT

The authors are grateful to the Management and Department of Mechanical Engineering, Bangalore Institute of Technology, Bangalore, India, for extending the facilities to carry out this investigation.

V. CONCLUSION

An experimental investigation on thermal analysis of a closed loop pulsating heat pipe was conducted for different filling ratios with different heat inputs for acetone, methanol, ethanol, benzene and Di-water. The conclusions that could be drawn from this investigation are as follows:

1. Among all working parameters such as working fluid, filling ratio and heat input, heat input plays a significant role in performance of PHP, followed by working fluid and filling ratio in taguchi method.
2. The thermal resistance and heat transfer coefficient in pulsating heat pipe could be predicted successfully with acceptable error by Taguchi method.
3. The optimum level gives the better result for working fluid and filling ratio by Taguchi method and also reduces number of experiments that are required for finding its performance.
4. The optimum level of 60% filling ratio at 60watt heat input with acetone as working fluid gives the maximum heat transfer coefficient compared to other working fluids and filling ratios.

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