RESEARCH ARTICLE OPEN ACCESS

Optimization of Thermal Performance on Evacuated Tube Solar Collector Water Heating System

I.George *, R.Kalaivanan **
**(Assistant Professor, Department of Mechanical Engineering, Annamalai University, Annamalai Nagar,*
*** (Associate Professor, Department of Mechanical Engineering, Annamalai University, Annamalai Nagar,*
Corresponding Author: I.George

ABSTRACT
Solar energy is considered one of the main alternative sources of energy to replace the dependency on other fossil resources. Solar water heating are very common systems, extensively used in many countries with high solar radiation potential. In this work, an experimental setup of evacuated tube solar collectors with U pipe is constructed to study the thermal performance and optimizes the working parameters using the Response Surface Methodology (RSM). The performance evaluation are carried based on heat extraction of U-pipe evacuated-tube solar collectors with three different arrangement of glass tubes with heat shields and various flow rate. A test system to evaluate the thermal performance of medium-temperature solar collectors is developed. The values of the daily useful energy gain, efficiency and solar fraction are obtained. Also values of the outlet water temperature from each evacuated tube, ambient temperature and solar radiation are extracted for the three different model. In order to improve the performance of the evacuated tube solar water heater, optimization of the efficiency and water temperature in this system is expressed by genetic algorithm Toolbox in RSM.

Keywords: Center distance, Evacuated tube solar water heater, Efficiency, RSM.

Date of Submission: 23-10-2017 Date of acceptance: 04-11-2017

I. INTRODUCTION

Solar water heaters are powerful and popular techniques to make use of solar energy, which typically use solar collectors and concentrators to gather, store, and use solar radiation to heat air or water in domestic, commercial, or industrial plants. As one of the most important types of stationary collector like evacuated tube solar collectors have substantially lower heat loss coefficient and cost than standard flat plate collectors. In Chinese area, all-glass evacuated tubular solar water heaters are widely used due to their excellent thermal performance, convenient installation, and easy transportability. In recent years, there are many research groups that focus on the theoretical and experimental studies of the thermal performance of water-in-glass evacuated tube solar water heaters.

Jeongbae Kim and HeeYoulKwak [1] analyzed testing results for flat-plate and evacuated solar collectors to determine the effects of the collector area and mass flow rate, which were not necessarily consistent across all tests. They highlighted differences in the standards used in performance tests of solar collectors. This analysis showed that the factor, $F'(\tau\alpha)$, including collector efficiency factor, could be correlated with the flow rate or area regardless of the collector type.

R.K.Mishra and Vihang Garg [2] deals in this paper with the detailed analysis of evacuated tubular collector connected in series in the terms of thermal energy and exergy gain. The study has been done by considering four type of weather conditions for the climatic condition of New Delhi, India. The maximum outlet temperature increases from 53.91^{o}C to 129.23^{o}C and the useful daily thermal gain increases.

Pierre-Luc Paradis and Daniel R. Rousse [3] presented in the paper a one dimensional thermal model of a solar evacuated tube open at both ends under transient conditions for variations of fluid mass flow rate, ambient temperature, solar radiation, and wind speed. The semi-analytical model relies on the energy conservation equation for small control volumes along the longitudinal axis of the tube. The first order differential equations obtained for each control volume are solved by use of a fully explicit scheme using a fourth order Runge–Kutta algorithm. The comparison between simulated and experimentally measured outlet air temperatures.

A.E.Kabeel and A.Khalil [4] introduced a simulation of mathematical model for evaluating the performance of water-in-glass evacuated tube solar collector considering tube shading effect. The procedure is developed to calculate the daily utilized solar energy and outlet collector temperature for different tilt angles, collector azimuth angles and geometric parameters without requirement for any experimental factor determination. The simulation results also show that solar collector with wide tube spacing reduce the shading effect and hence increase the absorbed radiation.

Dilip Mishra [5] carried experimental analysis on evacuated collector with U-Tube at different operating conditions. The analysis of thermal performance carried at different temperature due to variation of solar intensity. In this study it is found that the concept of inserting copper fin in to it, has increased the thermal performance of evacuated tube collector by 10%-15% from water-in-glass evacuated collector.

Liangdong Ma and Zhen Lu [6] discussed in this paper, based on the energy balance for the glass evacuated tube solar collector with U-tube, the thermal performance of the individual glass evacuated tube solar collector is investigated by analytical method. The heat loss coefficient and heat efficiency factor are analyzed using one-dimensional analytical solution. The results show that the function relation of the heat loss coefficient of the glass evacuated tube solar collector with temperature difference between the absorbing coating surface and the ambient air is nonlinear. In the different ambient temperatures, the heat loss coefficient of the solar collector should be calculated by different expressions. The heat efficiency factor will be subject to influence of air layer between absorber tube and the copper fin. Specially, the influence is remarkable when the heat loss coefficient of the collector is large.

Yan Gao and Qunli Zhang [7] analysed the effects of thermal mass and flow rate on forced circulation solar hot-water system of water-in-glass and U-pipe evacuated tube solar collectors. A comparison of the thermal performance of systems installed with collectors having the same efficiency curve was made.

Pin-Yang Wang and Hong-Yang Guan [8] are conducted experiment and simulation work on all-glass evacuated tubular solar air heater with simplified compound parabolic concentrator (CPC) and U-shaped copper tube. The heat transfer model of the solar air heater is established and the outlet air temperature, the heat power and heat efficiency are calculated. Calculated and experimental results show that the present experimental system can provide the heated air exceeding $200^{o}C$. The whole system has an outstanding high-temperature collecting performance and the present heat transfer model can meet the general requirements of engineering calculations.

Xinyu Zhang, Shijun You and Hongchuan Ge [9] evaluate experimental performance and comparative analyses based on heat extraction of direct-flow coaxial evacuated-tube solar collectors with and without heat shields. A test system to evaluate the heat flow rate and collector efficiency of solar collectors. Test results showed that the ETC with a heat shield had higher optical efficiency, lower heat loss, and better thermal performance when compared with the ETC without a heat shield because of the covering effect of the heat shield.

Evacuated tube solar collectors are used in many different form applications such as water heating, drying agricultural materials, green house pre-heating, etc. As part of the design and control operation of such equipment, it may be necessary to compare the performance of several types of solar collector taking thermal performance and economics into account. Therefore, it is important to develop an appropriate model and determine its parameter identification, while considering the control aspects of the collectors at the same time. In the literature, several aspects of such modelling techniques can be found. One of the techniques is connected with physically based approaches.

Other modelling approaches are closely linked to the use of artificial intelligence techniques such as neural networks. Kalogirou [10] developed a model for solar domestic water heating systems using artificial neural networks (ANN`s). The model estimated the useful energy extracted from a solar water heating system and the temperature rise in the stored water under the stated physical parameters of the system and the weather conditions. The accuracy of the predictions was within 7.9%.

Kalogirou and Panteliou [11] predicted the long-term system performance of a domestic thermosiphon type solar water heating system using an ANN model. The system performance was quantified in terms of solar energy input to the system and the average amount of hot water generated per month. This approach was able to estimate the suitability of a system for a specific application quickly and easily.

Lalot and Lecoeuche [12] employed an ANN model for the system identification of solar collectors during service. The applied feedback type of network included solar irradiation as initial input and fluid temperature as output. The authors intend to increase the accuracy of the model by extending the input parameters to include ambient temperature, wind speed and the mass flow rate of collector medium. Modelling methods are commonly used to describe the dynamic behavior of a system.

Vajk [13] has suggested the consideration of model sensitivity with respect to discretisation and structural realisation and has introduced a tool for reducing the modelling error.

Response surface methodology is a collection of mathematical and statistical techniques widely used to determine the effect of several variables and to optimize different processes. The RSM has been successfully applied for optimizing conditions of various fields like aerodynamic noise, heat transfer, in solar research. Many research have also been done to analyse thermal performance on various types of solar collectors.

Mangesh R.Phate and Rupesh [14] carried a work consists of 2.7 m^2 scheffler reflector used for water heating. The position of the reflector surface with respect to the sun i.e. tilting angle, the processing timing measured and the water quantity are considered as an independent parameters. The parameter related with the reflector performance is the efficiency of the reflector. The response surface methodology was used to predict and analyze the performance of reflector.

G Sudhakar and P Lakshmi Reddy [15] studied the thermal performance of cylindrical screen mesh wick heat pipe using Cu nano fluid as the working medium and optimize the working parameters using the Response Surface Methodology. The working parameters considered are heat input, angle of inclination and concentration of the copper nano particles in the copper nano fluid. In this study, the thermal efficiency, H.T coefficient and thermal resistance of the heat pipe are optimized by Response Surface Methodology.

In this paper a mathematical model utilising the response surface methodology has been developed for predicting the optimum center distance between the glass tubes with heat shield. This study mainly focuses on few variables, which are arrangement of collector tubes, water flow rate, and intensity of solar radiation. In this model a historical data design is used to study the combined effect of water temperature and efficiency of the system.

II. EXPERIMENTAL TESTING

The Evacuated Tube Solar Water Heater (ETSWH) system consists of square header insulated with 50mm PU connected to an array of evacuated glass tubes. The array consist of 15 numbers of 47 mm outer diameter, 34 mm inner diameter and 1500 mm long double wall evacuated glass tubes with 14 mm outer diameter and 12.5mm inner diameter copper tubes bent into a U-shape as shown in fig.1. The ends of the evacuated glass tubes were sealed and as selective surface coating applied to the outside walls of the inner glass tubes. A copper U-tube with fin contacted each of the inner glass tube. The ends of the copper U-tubes were inserted into a common flow manifold at the top of the array that allowed water to flow along the copper tubes. Three different setup was developed by changing the center distance of ETSWH system (65mm, 90mm and 115mm respectively). Fig.2. shows the photographic view of the ETSWH system located on the solar lab, department of Mechanical Engineering, Annamalai University, Chidambaram. The collectors are positioned facing south and were supported on a steel structure with an inclination of 12^o to the horizontal since the latitude of Chidambaram is equal to 11° 23' 57.1056" N.

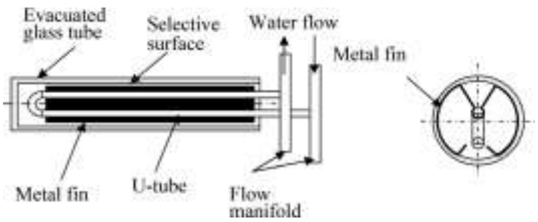


Fig.1. U-tube solar collector.

All temperatures are measured using Cu-con (Type T) thermocouples with an accuracy of ±0.1^{o}C. It is connected with a digital temperature indicator (model: TPLR-96-16U) supplied by Tempsen devices, India. Thermocouples are inserted inlet and outlet pipes to determine the temperature in the collector. Ambient temperature is measured with a Cu-con thermocouple located nearby in the shade. Solar radiation is measured with an Eppley radiometer (model PSP), supplied by The Eppley laboratory, USA with an accuracy of ±2%. All temperatures and radiometer outputs are connected to a data logger and continuously. The mass flow rate of water is measured at the beginning of experimental work. A rotameter is attached to the inlet pipe to measure the mass flow rate with an accuracy of 1 lit/sec.


Fig.2. Experimental setup

Three series of tests are performed in order to determine and to compare the performances of the ETSWH's conducted at different mass flow rate. Test is conducted daily from 10.00am to 4.00pm at a flow rate of 15, 30 and 45kg/hr.m^2. One set of reading repeated over a three days. The cycle of draining and refilling the tank is repeated over a period of the days. For all tests, the temperature of the water in the collector, ambient temperature and instantaneous solar radiation intensity are recorded every 15min. Experimental measurements are conducted from March to May 2016.

III. PERFORMANCE ANALYSIS

Three experimental setup of various center distance are arranged with measuring instruments. The effect of center distance are analysed with reflected heat shield. Thermal performance of the model according to the collector center distance, if it is increased the utilization of solar energy increases due to reflected heat shield. By the change of center distance the shadow pattern also changes when the collector tubes are close to each other. The performance of the collector becomes better because the increase of center distance. At higher center distance the manifold size also increased to lead the heat loss and the performance of the collector decreased. So, we need optimum center distance for best performance of the collector. The analysis is carried by RSM Methodology.

3.1 Response Surface Methodology

The response surface is a collection of statistical and mathematical method used for analysing complex engineering problems. Response surface methodology is used for optimising the process parameters. Further, it establishes a mathematical regression model which could predict the relationship between response and independent variables (process parameters). This mathematical model is used to predict the response when, we changes the process parameters within the range. Geometrically, regression model represent a surface and can be plotted as response versus any of the two parameter. Such plots help in visualising the effect of process parameters on response. Response plot and contour plot helps in visualising the optimum process parameter for the response.

Table 1: Process parameters

Numeric Factors: 4 (1 to 30)

Categoric Factors: 0 (0 to 10)

	Name	Units	Min	Max
A:	Center Distance	mm	65	115
B:	Time	Hrs	10	16
C:	Solar Internsity	W/Sq.m	700	1150
D:	Flow Rate	kg/hr Sq.m	15	45

The response properties of the evacuated tube solar collector efficiency and temperature difference of water are a function of A - Center Distance, B -Time, C - Solar Internsity and D - Flow Rate. Table.1 shows the process parameters and their minimum and maximum values.

Design expert software is used for estimating the all the coefficient and tested using f-test at 95% confidence. Adequacy of the developed model is checked using ANOVA technique. Table.2 and Table.3 shows the result of anova for the models (temperature difference and Efficiency). It can be seen that calculated f ratio is less than the standard f ratio (from f table) at 95% deserved level of confidence. Which indicate that the models are adequate. The coefficient of determination (r^2) shows the goodness of fit for the developed model. Higher the value of r^2 better the model in predicting the response. The difference between r^2 and adjusted r^2 is less than 2% which indicate that the model is not over fitted. The adjusted r^2 value is high, which points out high significance of the model. Value of adequate precision was found to be good which gives a justifiable performance in prediction. Usually, a value greater than 4 is suitable.

Table.2. The Anova analysis of temperature difference (dt)

Response (2) : dt						
ANOVA for Response Surface Quadratic Model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob>F	
Model	49733.19	14	3552.37	1744.79	<0.0001	significant
A-Center Distance	2541.98	1	2541.98	1248.52	<0.0001	
B-Time	527.00	1	527.00	258.84	<0.0001	
C-Solar Intensity	522.92	1	522.92	256.84	<0.0001	
D-Flow Rate	11324.04	1	11324.04	5561.93	<0.0001	
AB	20.17	1	20.17	9.91	0.0017	
AC	53.10	1	53.10	26.08	<0.0001	
AD	50.09	1	50.09	24.60	<0.0001	
BC	0.07	1	0.07	0.03	0.8529	
BD	91.19	1	91.19	44.79	<0.0001	
CD	454.15	1	454.15	223.06	<0.0001	
A^2	6271.23	1	6271.23	3080.19	<0.0001	
B^2	3039.49	1	3039.49	1492.88	<0.0001	
C^2	1.13	1	1.13	0.55	0.4571	
D^2	82.83	1	82.83	40.68	<0.0001	
Residual	1343.75	660	2.04			
Lack of Fit	1326.60	651	2.04	1.07	0.5063	not significant
Pure Error	17.15	9	1.91			
Cor Total	51076.95	674				
Std. Dev.	1.43		R-Squared	0.97		
Mean	35.81		Adj R-Squared	0.97		
C.V. %	3.98		Pred R-Squared	0.97		
PRESS	1408.22		Adeq Precision	190.81		

It is also desirable to have relatively low value for coefficient of variation, as lower coefficient of variation signifies a good reliability of conducted experiment and high degree of precision. It is suitable to have a lower value for PRESS as it indicates how well the model is likely to predict the response in a new experiment.

The empirical equation for temperature difference (dt) is given as,

$$dt = -359.92634 + 1.85704 * A + 42.04564 * B + 0.045898 * C + 0.68607 * D + 5.27042E\text{-}003 * AB + 1.68856E\text{-}004 * AC - 1.08819E\text{-}003 * AD + 1.03895E\text{-}004 * BC - 0.021285 * BD - 9.45485E\text{-}004 * CD - 0.010848 * A^2 - 1.56951 * B^2 - 6.36116E\text{-}006 * C^2 + 3.45862E\text{-}003 * D^2$$

Table 3. The Anova analysis for Efficiency

ANOVA for Response Surface Quadratic Model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob>F	
Model	220940.31	14	15781.45	2353.64	<0.0001	significant
A-Center Distance	5439.42	1	5439.42	811.23	<0.0001	
B-Time	2237.85	1	2237.85	333.75	<0.0001	
C-Solar Intensity	421.09	1	421.09	62.80	<0.0001	
D-Flow Rate	147915.81	1	147915.81	22060.11	<0.0001	
AB	127.93	1	127.93	19.08	<0.0001	
AC	86.96	1	86.96	12.97	0.0003	
AD	802.54	1	802.54	119.69	<0.0001	
BC	2.84	1	2.84	0.42	0.5158	
BD	2437.72	1	2437.72	363.56	<0.0001	
CD	523.19	1	523.19	78.03	<0.0001	
A^2	11345.10	1	11345.10	1692.00	<0.0001	
B^2	5271.95	1	5271.95	786.26	<0.0001	
C^2	193.78	1	193.78	28.90	<0.0001	
D^2	1549.11	1	1549.11	231.03	<0.0001	
Residual	4425.38	660	6.71			
Lack of Fit	4411.31	651	6.78	4.33	0.0099	significant
Pure Error	14.07	9	1.56			
Cor Total	225365.69	674				
Std. Dev.	2.59		R-Squared	0.98		
Mean	49.80		Adj R-Squared	0.98		
C.V. %	5.20		Pred R-Squared	0.98		
PRESS	4641.22		Adeq Precision	178.53		

The empirical equation for efficiency is given as,

$$\text{Efficiency} = -426.53792 + 2.26434 * A + 51.04747 * B + 0.075782 * C - 0.57868 * D + 0.013272 * AB + 2.16089E\text{-}004 * AC + 4.35591E\text{-}003 * AD + 6.60839E\text{-}004 * BC + 0.11005 * BD + 1.01482E\text{-}003 * CD - 0.014591 * A^2 - 2.06704 * B^2 - 8.33993E\text{-}005 * C^2 - 0.014957 * D^2$$

3.2 Analysis of the experimental data

Experiments are conducted by varying the flow rate (15, 30 and 45kg/hr.m^2). The temperature of water at inlet and outlet and atmospheric are recorded. The variables flow rate, heat input, center distance are chosen as three independent variables in the experiment design. From the experimental data the models are developed.

The value of "r^2" for the developed models above is found to be 92% and 58°C for efficiency and temperature difference, respectively, which indicates high correlation between experimental values and predicted values and this is further supported by correlation graphs shown in below fig.3a and 3b.

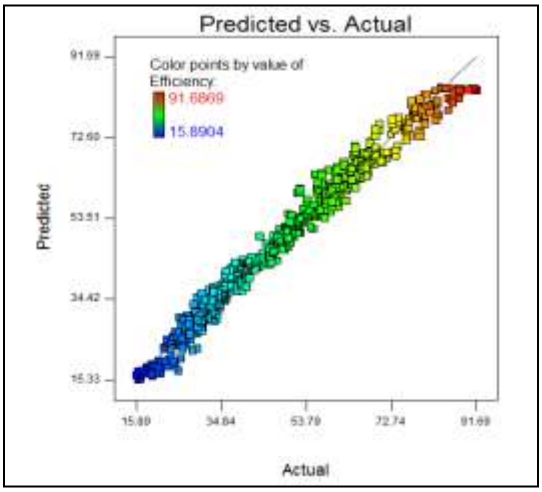


Fig.3a. Plot of predicted response with actual value for Efficiency

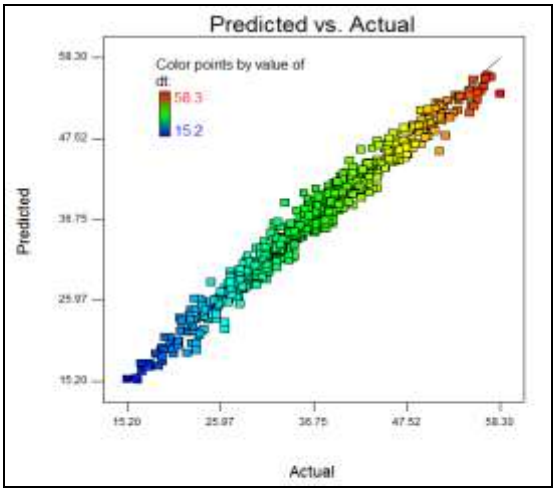


Fig.3b. Plot of predicted response with actual value for temperature difference (dt)

The fig.4a. and 4b. show the normal plot of residuals, which indicates that Normal plots for residuals for both for efficiency and temperature difference (dt) fall along a straight line which says that the errors are normally distributed.

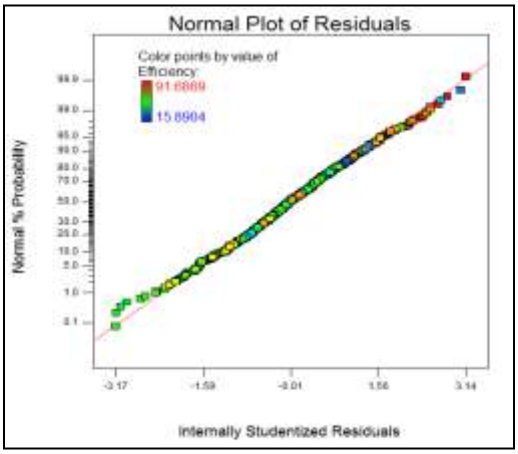


Fig.4a. Normal plot for residuals for Efficiency

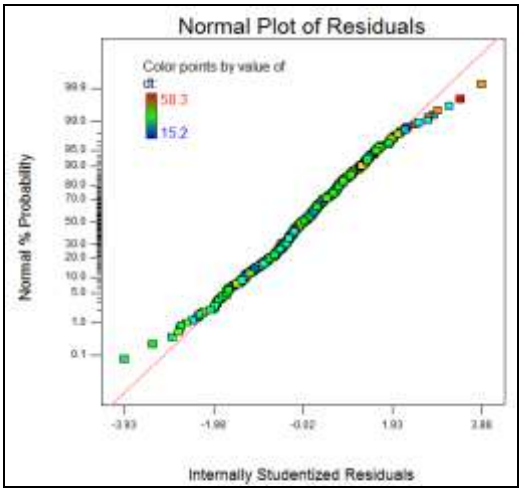


Fig.4b. Normal plot for residuals for temperature difference (dt)

IV. RESULTS AND DISCUSSION

The response result is plotted in Perturbation plot as shown in fig.5. The perturbation plot helps compare the effect of all the factors at a particular point in the design space. The response is plotted by changing only one factor over its range while holding of the other factors constant. By default, Design-Expert sets the reference point at the midpoint (coded 0) of all the factors.

A steep slope or curvature in a factor shows that the response is sensitive to that factor. A relatively flat line shows insensitivity to change in that particular factor. If there are more than two factors, the perturbation plot could be used to find those factors that most affect the response. These influential factors are good choices for the axes on the contour plots.

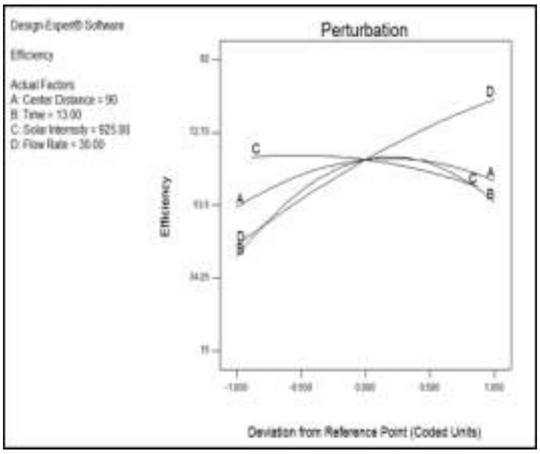


Fig.5. Perturbation plot

In order to determine optimum process parameter contour plot and response plot were used. Counter plot and response plot are plotted for each response vs. any two process parameter, while keeping the other parameter at middle level. Counter plot and response plot gives a visual region of optimum settings. Counter and response plot play an important role in identifying optimum factor settings. Design expert software is used for identifying the optimum factor settings for maximum mechanical properties.

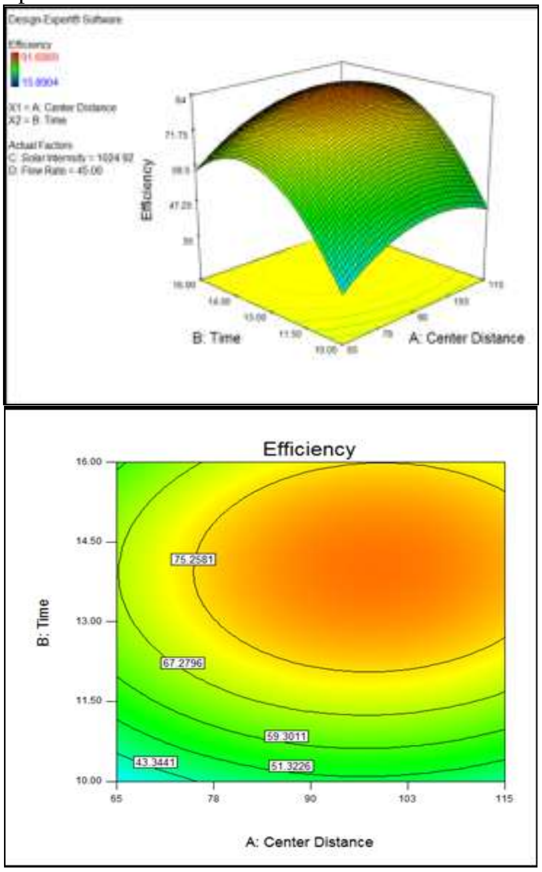
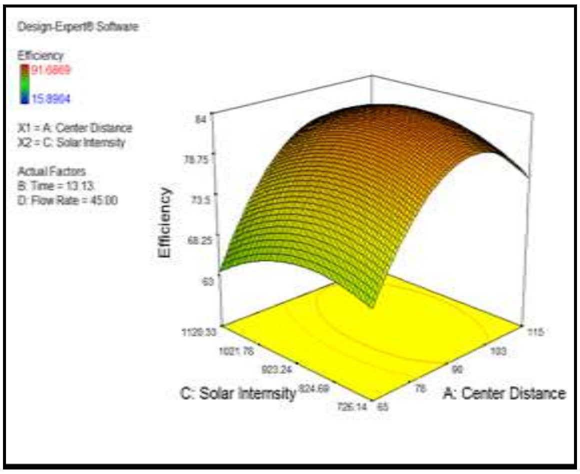


Fig.6. 3D surface and contour plot for efficiency

The 3D surface and contour plot fig.6 shows the effect of the center distance and time on the efficiency at a solar intensity of 1025 W/m^2 and flow rate of 45kg/hr.m^2. The results indicated that at noon and the center distance in-between 90 to 100 mm the efficiency is at its maximum.



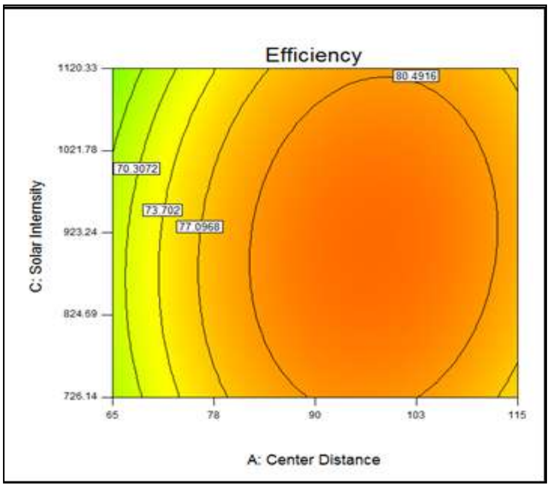


Fig.7. 3D surface and contour plot for efficiency

The 3D surface and contour plot fig.7 shows the effect of the center distance and solar intensity on the efficiency at noon (i.e. Time = 13.13 hr.) and flow rate of 45kg/hr.m^2. It is observed from fig. 7 that the thermal efficiency of solar collector increases with solar intensity, the heat input in to the collector. The results indicated that at noon and the center distance in between 90 to 100 mm the efficiency is at its maximum.

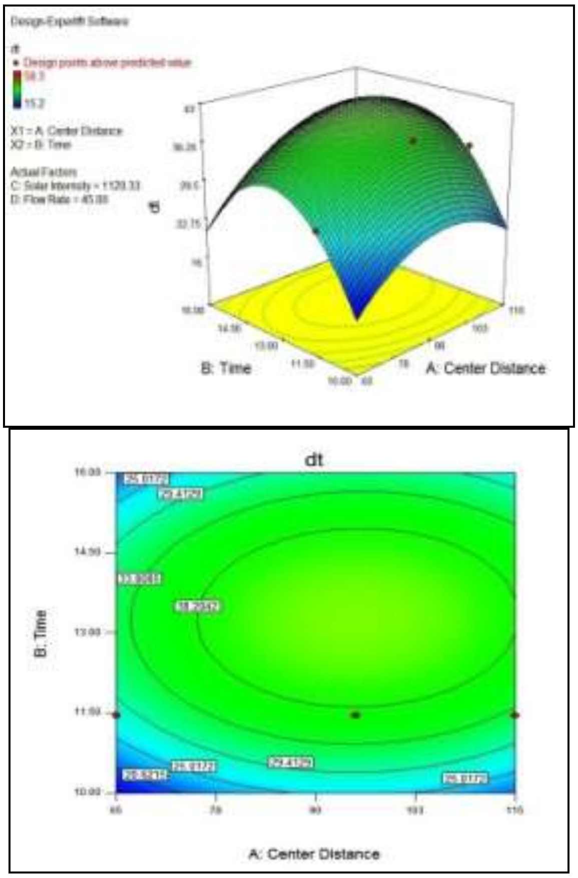


Fig.8. 3D surface and contour plot for temperature difference

The 3D surface and contour plot fig.8 shows the effect of the center distance and time on the temperature difference at a solar intensity 1120W/m^2 and flow rate of 45kg/hr.m^2. The results indicated that at noon and the center distance in-between 90 to 100mm the temperature difference is at its maximum.

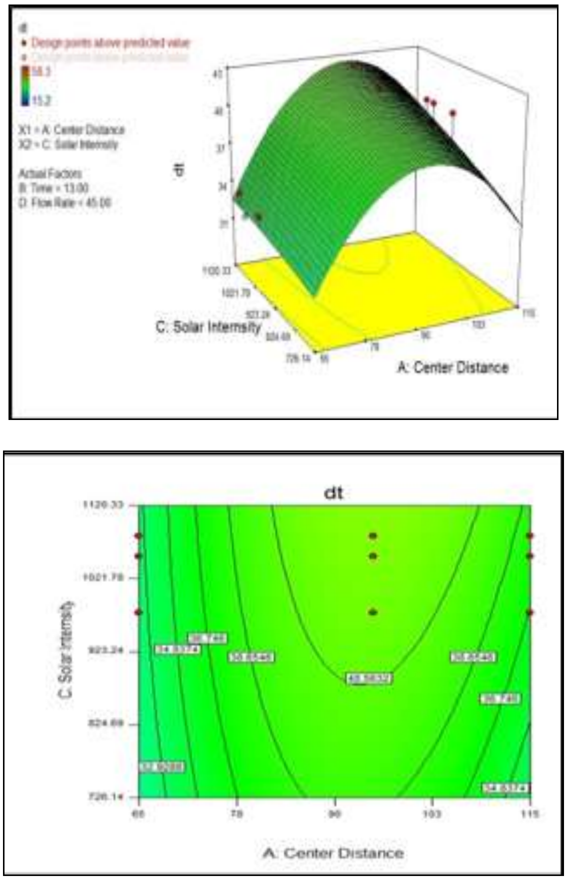


Fig.9. 3D surface and contour plot for temperature difference

The 3D surface and contour plot fig.9 shows the effect of the center distance and solar intensity on the temperature difference at noon (i.e. Time = 13.00 hr.) and flow rate of 45kg/hr.m^2 The results indicated that at noon and the center distance in-between 90 to 100mm the temperature difference is at its maximum.

4.1 Optimizing the Process Parameters

The optimization plot generated by the RSM with a desirability of 0.737. In fig.10 shows that the optimum process parameters for efficiency (82.67%) and temperature difference (dt = 41.81^{o}C) are found out to be center distance 96mm, Time 13.13 hr. solar intensity 1024.92 W/m^2 and flow rate 45 kg/hr.m^2.

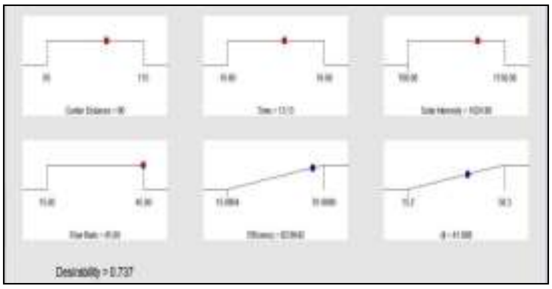


Fig.10. Numerical Optimization Ramps

The Fig.11 shows the contour plot for optimized values of efficiency and temperature difference with respect to center distance and time at a solar intensity of 1025 W/m^2 and flow rate of 45kg/hr.m^2

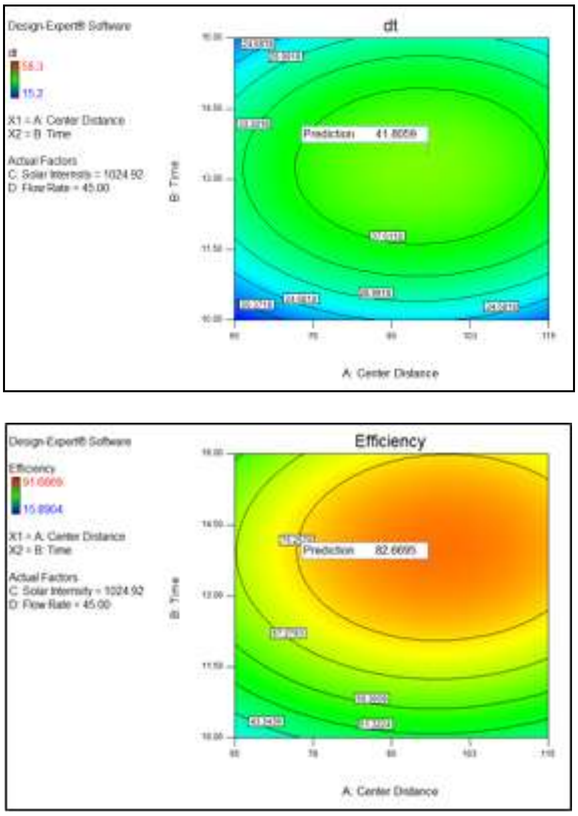


Fig.11. Contour plot showing optimum factor setting for Efficiency and temperature difference (dt)

4.2 Validation

In order to confirm the optimization results, the experiment is conducted with center distance 95mm, Time 13.15hr., solar intensity 999.6 W/m^2 and flow rate 45kg/hr.m^2. The efficiency of the system is found as 80.82% which is nearer to the optimum value. Similarly, temperature difference (dt = 40.70^{o}C) also found out to be within the confidence interval.

V. CONCLUSION

It has been shown the determination of the thermal behavior of evacuated tube solar collector solar collector at various center distance can be optimized through RSM. Based on the measurements the evacuated tube solar collectors can be trained to evaluate the process variables like Solar Intensity with respect to time and the flow rate are found to be statistically significant. In order to confirm the optimization results, the experiment is conducted with center distance 95mm, Time 13.15hr., solar intensity 999.69 W/m^2 and flow rate of 45 kg/hr.m^2. The efficiency of the system is found as 80.82% which is nearer to the optimum value. Similarly, temperature difference of also found 40.70^{o}C, it is within the confidence interval.

REFERENCES

[1] Jeongbae Kim, HeeYoulKwak and Dong Won Lee. An analytical study on the thermal characteristics of flat-plate and evacuated solar collectors. Journal of Mechanical Science and Technology 21, 2007, 2159-2167.
[2] R.K. Mishra, Vihang Garg and G.N. Tiwari. Thermal modeling and development of characteristic equations of evacuated tubular collector. Solar Energy, 116, 2015, 165–176.
[3] Pierre-Luc Paradis, Daniel R. Rousse, Ste´phane Halle, Louis Lamarche, Guillermo Quesada. Thermal modeling of evacuated tube solar air collectors. Solar Energy, 115, 2015 708–721.
[4] A.E. Kabeel, A. Khalil, S.S. Elsayed and A.M. Alatyar. Modified mathematical model for evaluating the performance of water-in-glass evacuated tube solar collector considering tube shading effect. Energy, 89, 2015, 24 – 34
[5] Dilip Mishra. Experimental Analysis of Thermal Performance of Evacuated U-Tube Solar Collector. Advance Physics Letter, 2(3), 2015, 2349-1108.
[6] Liangdong Ma, Zhen Lu, Jili Zhang, Ruobing Liang. Thermal performance analysis of the glass evacuated tube solar collector with U-tube. Building and Environment 45, 2010, 1959-1967.
[7] Yan Gao, Qunli Zhang, Rui Fan, Xinxing Lin, Yong Yu. Effects of thermal mass and flow rate on forced-circulation solar hot-water system: Comparison of water-in-glass and U-pipe evacuated-tube solar collectors. Solar Energy, 98, 2013, 290–301.
[8] Pin-Yang Wang, Hong-Yang Guan and Zhen-Hua Liu. High temperature collecting performance of a new all-glass evacuated tubular solar air heater with U-shaped tube

heat exchanger. Energy Conversion and Management, 77, 2014, 315–323
[9] .Xinyu Zhang, Shijun You and Hongchuan Ge. Thermal performance of direct-flow coaxial evacuated-tube solar collectors with and without a heat shield. Energy Conversion and Management, 84, 2014, 80–87
[10] Kalogirou, S.A., Panteliou, S., Dentsoras, A., Modelling of solar domestic water heating system using artificial neural networks. Solar Energy, 65(6), 1999, 335-342.
[11] Kalogirou, S.A., Panteliou, S., Thermosiphon solar domestic water heating system: long-term performance prediction using artificial neural networks. Solar Energy, 69(2), 2000, 163-174.
[12] Lalot, S., Lecoeuche S., 2001. Identification of solar collectors during service using artificial neural networks. In: Proceedings of the ISES 2001 Solar World Congress, p. 128.
[13] Vajk, I., 1999. Sensitivity of non-linear dynamic modelling. Proceedings of the 14th World Congress of IFAC, Beijing, China, pp. 19-24.
[14] Mangesh R.Phate and Rupesh V. Bhortake “Predicting and Analyzing the Efficiency of Portable Scheffler Reflector by Using Response Surface Method”, International Journal of Mechanical Engineering (IJME) Volume 4 Issue 2, 2014, 34-50.
[15] G Sudhakar and P Lakshmi Reddy, An experimental analysis on thermal performance of cylindrical screen mesh wick heat pipe with CUO Nano fluid using Response Surface Methodology, Int. J. Engg. Res. & Sci. & Tech. Vol. 4, No. 3, 2015, 240-251.

International Journal of Engineering Research and Applications (IJERA) is **UGC approved** Journal with Sl. No. 4525, Journal no. 47088. Indexed in Cross Ref, Index Copernicus (ICV 80.82), NASA, **Ads**, Researcher Id Thomson Reuters, DOAJ.

I.George . “Optimization of Thermal Performance on Evacuated Tube Solar Collector Water Heating System.” International Journal of Engineering Research and Applications (IJERA) , vol. 7, no. 10, 2017, pp. 47-55.