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Performance Analysis of Solar Water Heater Through Computational Techniques

G. Senthil Kumaran, S. Jaisankar

***Abstract:** By implementing the computational techniques, the solar water performance was analysed. Employing the orthogonal design, experiments were accompanied with the input variables L/D ratio, condition of twist and time. Using the recorded measurements nusselt number and efficiency were calculated and further it was optimized in a combined objectively manner. The optimal input variables to accomplish the higher performance of solar water heater is identified. Also, the dominance of input variables was identified with the statistical analysis for the combined objective.*

***Keywords:** Solar Water Heater, Efficiency, Nusselt number, Optimization.*

I. INTRODUCTION

Energy crisis the most significant tailback facing by many countries due to the scarcity of fossil fuels and the environmental impacts. To prevail over the scenario, sustainable developments in the renewable energy sources is needed. Solar energy, one among the renewable energy source has plenty of opportunities for the development and its utilization in all over the sectors. Solar water heater, a device which supports the effective usage of solar energy source by acting as a heat exchanger [1]. There are two different modes of collectors one is flat plate collector and other is concentrating collectors [2]. Several innovative attempts were made on the solar water heater made of flat plate type to improve the performance either through the modifications in design or variations in the working fluid. The modifications in the working fluid was nano powder addition which improves the thermal conductivity and thereby increased the efficiency. Next is the variations in design with the inserts of twist to vary the fluid flow dynamics and flow rate and thereby increases the efficiency of system. The performance of the solar collector was explored by measuring the collector efficiency [3]. The identification of optimal parameter and significant parameter can be effectively propose through the computational techniques in various domain [4–6].

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***** Correspondence Author
G. Senthil Kumaran, Research Scholar, Department of Computer Science Engineering, PRIST University, Thanjavur, Tamil Nadu, India. Email: senthil.mrec@gmail.com
S. Jaisankar*, Professor, Department of Mechanical Engineering, Star Lion College of Engineering & Technology, Thanjavur, Tamil Nadu, India. Email: jaisankar1312@gmail.com

The angle of incidence of solar rays have a great impact on the energy production and the optimum tilt angle and orientation of collector improved the system performance by 15 % [7]. The efficiency of the flat plate collector was improved by employing comprehensive model and found the energy of maximum 80% and exergy efficiency of 8% [8]. The process parameters of solar collector was optimized using the Taguchi analysis and grey relational analysis and found the optimal parameter [9]. The parameters which influence the exergy and energy efficiency of solar collector was optimized through the grey relational analysis and attained the optimal parameter to higher energy efficiencies [10]. The process parameters of solar drying was optimized through the grey relational analysis and found the effective improvement in the performance [11]. The outcome of the literature expresses the developments in the solar water heater performance. Also, it was found that the computational technique was used in the optimization of energy sources in an efficient way. Hence the present work focus in the effectiveness improvement of solar water heater through computational technique namely Grey-Taguchi analysis.

II. EXPERIMENTAL DETAILS

An indigenous solar water heater setup was made to experiment and investigate the effectiveness of solar water heater [12]. The setup has the built in measurement systems namely, pyranometer, thermometer, pressure and flow measuring device. The setup was erected in the location of specified latitude and longitude of 10°51'25.7"N and 79°09'39.0"E respectively. The major constituents of solar collector was riser tube, collector and storage tank. To investigate the performance of solar water heater the riser was modified with the different twist conditions i.e., tube inserted with the helical twist, tube inserted with the left right twist and tube inserted with the screw twist (Table I). Also, the twist dimensions was varied in three aspects and it was mentioned as L/D ratio (Table I). With the above modifications, the experiment was conducted with the combinations of design as mentioned in Table II throughout the day i.e., from 9:00 am to 04:00 pm. The working fluid considered for the present work is water and parameters like temperature, pressure and flow rate of the working fluid entry and exit condition was observed and recorded. Using the measurements, the value of nusselt number and efficiency was calculated with the standard mathematical relations [12].

Table- I: Parameter and range

Parameters	Low	Medium	High
L/D ratio	0	3	6
Time, hours	9	13	16
Twist condition	(1) Helix	(2) HLR	(3) Screw

Table- II: Design for experimental study

S.No	L/D ratio	Time, Hrs	Twist	Efficiency	Nusselt No
1	0	9	1	28.91	4.06
2	0	9	2	28.91	4.06
3	0	9	3	28.91	4.06
4	0	13	1	66.65	5.39
5	0	13	2	66.65	5.39
6	0	13	3	66.65	5.39
7	0	16	1	30.49	4.26
8	0	16	2	30.49	4.26
9	0	16	3	30.49	4.26
10	3	9	1	36.17	11.17
11	3	9	2	43.19	15.41
12	3	9	3	41.05	12.39
13	3	13	1	76.67	14.40
14	3	13	2	83.73	21.03
15	3	13	3	84.30	16.04
16	3	16	1	49.72	11.35
17	3	16	2	54.87	16.53
18	3	16	3	54.49	12.62
19	6	9	1	31.81	8.53
20	6	9	2	39.79	13.43
21	6	9	3	34.94	8.16
22	6	13	1	69.20	11.07
23	6	13	2	78.21	18.90
24	6	13	3	71.75	10.68
25	6	16	1	33.80	9.04
26	6	16	2	50.29	14.20
27	6	16	3	46.90	7.39

III. RESULTS AND DISCUSSION

The process of obtaining an optimal parameter is most needed one and particularly in the energy conservation it has a greater significance. Even a smaller amount of increase in the performance will greatly influence the energy conservation and environment. The objective is to strengthen the solar water heater performance by optimizing the Nusselt number and efficiency. As it is a combined objective to optimize the Nusselt number and efficiency, grey relational technique is adopted.

A. Grey Relational Analysis

Initially, the objectives in individual form is transmuted to combined objective through the grey relational technique, by following the sequence mathematical formulations and calculations. The general process of grey analysis sequence are normalizing the objective variables, finding deviations, identifying the coefficients, grade and ranking of them using the empirical relations (equation (1-3)) [13–15]. During the normalization process, the selection of characteristics is most important one and based on the objective it will be selected. In this case, larger the better is used for the normalization process as the Nusselt number and efficiency need to be maximized.

Normalization,

$$z_i^*(k) = \frac{maximum\ z_i^0(k) - z_i^0(k)}{maximum\ z_i^0(k) - minimum\ z_i^0(k)} \quad (1)$$

Grey relational coefficient,

$$\xi_i(p) = \frac{\Delta_{minimum} + \psi\ \Delta_{maximum}}{\Delta_{0i}\ (k) + \psi\ \Delta_{maximum}} \quad (2)$$

Grey grade,

$$\gamma_i = \frac{1}{n}\sum_{p=1}^{n} \xi_i(p) \quad (3)$$

By following the grey sequence, the analysis was carried out and the grey results were shown in Table III. To obtain the maximum effectiveness of solar water heater of combined objective was the parameters of 3 of L/D ratio, 13 hours of time and left right helix twist.

Table- III: Grey relational analysis for solar water heater

S. No	Normalization		Deviation sequence		Gray Relational Coefficient		Grey grade	Rank
	Max.	Max.	Max.	Max.	Max.	Max.		
1	0.0000	0.0000	1.0000	1.0000	0.3333	0.3333	0.3333	25
2	0.0000	0.0000	1.0000	1.0000	0.3333	0.3333	0.3333	25
3	0.0000	0.0000	1.0000	1.0000	0.3333	0.3333	0.3333	25
4	0.6813	0.0788	0.3187	0.9212	0.6107	0.3518	0.4813	11
5	0.6813	0.0788	0.3187	0.9212	0.6107	0.3518	0.4813	11
6	0.6813	0.0788	0.3187	0.9212	0.6107	0.3518	0.4813	11
7	0.0284	0.0120	0.9716	0.9880	0.3398	0.3360	0.3379	22
8	0.0284	0.0120	0.9716	0.9880	0.3398	0.3360	0.3379	22
9	0.0284	0.0120	0.9716	0.9880	0.3398	0.3360	0.3379	22
10	0.1310	0.4189	0.8690	0.5811	0.3652	0.4625	0.4139	17
11	0.2577	0.6687	0.7423	0.3313	0.4025	0.6015	0.5020	8
12	0.2191	0.4910	0.7809	0.5090	0.3904	0.4955	0.4429	16
13	0.8623	0.6094	0.1377	0.3906	0.7841	0.5614	0.6728	4
14	0.9897	1.0000	0.0103	0.0000	0.9799	1.0000	0.9900	1
15	1.0000	0.7060	0.0000	0.2940	1.0000	0.6297	0.8149	2
16	0.3756	0.4299	0.6244	0.5701	0.4447	0.4672	0.4560	14
17	0.4685	0.7352	0.5315	0.2648	0.4848	0.6537	0.5692	6
18	0.4618	0.5044	0.5382	0.4956	0.4816	0.5022	0.4919	10
19	0.0523	0.2634	0.9477	0.7366	0.3454	0.4043	0.3749	21
20	0.1964	0.5524	0.8036	0.4476	0.3836	0.5276	0.4556	15
21	0.1088	0.2415	0.8912	0.7585	0.3594	0.3973	0.3784	20
22	0.7273	0.4133	0.2727	0.5867	0.6471	0.4601	0.5536	7
23	0.8901	0.8743	0.1099	0.1257	0.8197	0.7992	0.8095	3
24	0.7734	0.3900	0.2266	0.6100	0.6881	0.4504	0.5693	5
25	0.0882	0.2939	0.9118	0.7061	0.3542	0.4146	0.3844	19
26	0.3859	0.5974	0.6141	0.4026	0.4488	0.5539	0.5014	9
27	0.3247	0.1965	0.6753	0.8035	0.4254	0.3836	0.4045	18

B. Grey Taguchi Analysis

The outcome of grey relation analysis is the grey grade and it is considered as input variable for Taguchi analysis. Here the objective is maximization, as high grey grade is required, therefore the larger the better is considered as the quality characteristics. The analysis produces the response table (Table IV) and main effect plot (Fig. 1). Higher the ranking shows the higher significance and therefore time has more effect over the grey grade with 0.254 delta value followed by 0.2107 for L/D ratio and 0.108 for Twist condition from Table IV. Fig. 1 displays the main effect plot of ideal value of 3 for L/D ratio, 13 hours of time and left right helix twist.
Statistical analysis on the grey grade through analysis of variance (Table V) exhibits the significance.

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The significance is observed for all the three input variables with the less than 0.05 probability. This proves that the performance of solar water heater is influenced by all the three input variables. Though all the three input variables are found significance, the dominance is with time as it holds higher percentage of 49.46 and followed by L/D ratio 28.31.

Table- IV: Response table

Level	L/D ratio	Time, hours	Twist condition
1	0.3842	0.3964	0.4453
2	0.5948	0.6504	0.5533
3	0.4924	0.4246	0.4727
Delta	0.2107	0.254	0.108
Rank	2	1	3

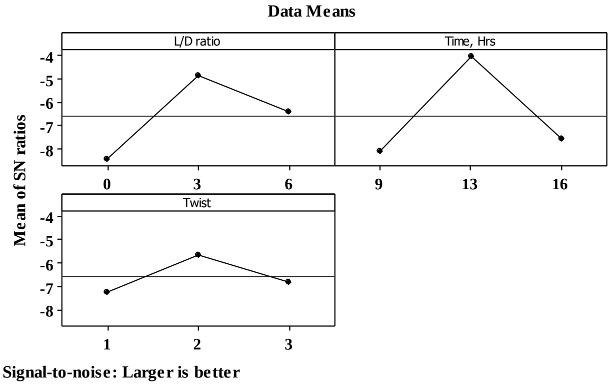


Fig. 1.Grey grade main effect plot

Table- V: ANOVA for grey results

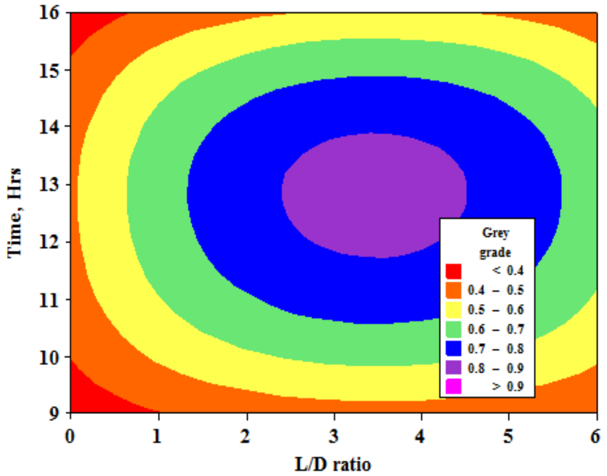
Source	DF	Seq SS	Adj SS	Adj MS	F	P	P%
L/D ratio	2	0.19976	0.19976	0.09988	78.36	0.000	28.31
Time, Hrs	2	0.34899	0.34899	0.1745	136.89	0.000	49.46
Twist	2	0.05676	0.05676	0.02838	22.26	0.001	8.04
L/D ratio* Time, Hrs	4	0.04255	0.04255	0.01064	8.35	0.006	6.03
L/D ratio* Twist	4	0.03077	0.03077	0.00769	6.03	0.015	4.36
Time, Hrs * Twist	4	0.01661	0.01661	0.00415	3.26	0.073	2.35
Error	8	0.0102	0.0102	0.00128			1.45
Total	26	0.70564					100.00

S = 0.0357031 R-Sq = 98.55% R-Sq(adj) = 95.30%

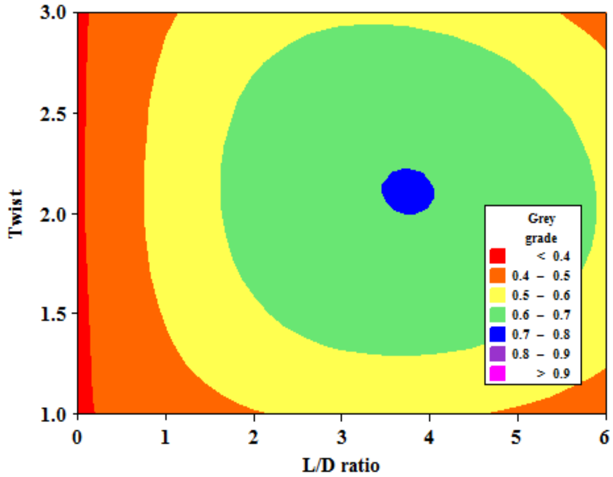
The contour plot expresses the grey grade with the predictor variable L/D ratio, time and twist condition (Fig. 2). Fig. 2(a) shows the grey grade for the predictor variable L/D ratio with time. The maximum grey grade of greater than 0.9 is obtained with medium L/D ratio and medium time interval, whereas minimum grey grade of less than 0.4 is obtained with lower L/D ratio and lower time. Fig. 2(b) shows the grey grade for the predictor variable L/D ratio with twist. The maximum grey grade of greater than 0.7 is obtained with medium L/D ratio and medium twist, whereas minimum grey grade of less than 0.4 is obtained with lower L/D ratio and with all intervals of time. Fig. 2(c) shows the grey grade for the predictor variable L/D ratio with twist. The maximum grey grade of greater than 0.7 is obtained with medium time and medium twist condition, whereas minimum grey grade of less than 0.4 is obtained with lower time and at lower twist.

IV. CONCLUSION

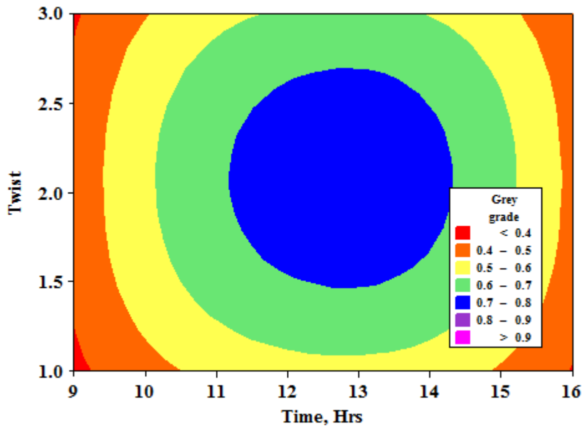
With the designed experimentation, solar water heater performance was experimented considering response nusselt number and efficiency was calculated. The response variables were optimized in a combined objectively manner using the grey relational analysis. With the combined objective, the maximum solar water heater effectiveness was obtained at the parameters of 3 for L/D ratio, 13 hours of time and left right helix twist. Further the Taguchi's approach was linked with the grey analysis to accomplish the optimal and significant parameters. Though all the three input variables are found significance, the dominance is with the time as it holds higher percentage of 49.46.



(a) L/D ratio Vs time



(b) L/D ratio Vs twist



(c) Time Vs twist

Fig. 2.Contour plot for grey grade

APPENDIX

$z_i^*(k)$ - normalized value

$\xi_i(p)$ - grey relational coefficient,

ψ - distinguishing coefficient (0.5 taken)

n - No. of response

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AUTHORS PROFILE

Mr. G. Senthil Kumaran, is working as Assistant Professor in Department of Computer Science Engineering at Meenakshi Ramaswamy Engineering College. He is a Research Scholar in PRIST University, Thanjavur. He received the B.Tech. Degree in Information Technology at Anna University Chennai in 2009, and M.Tech degree in Computer Science Engineering at PRIST University in 2012. He has 8 years of teaching experience in Computer Science Engineering. He is a Life Member of the Indian Society for Technical Education (ISTE). He has attended many conferences and has presented papers. He is specialized in the networking field and optimization techniques.

Dr. S. Jaisankar, working as a Principal & Professor in the Department of Mechanical Engineering at Star Lion college of Engineering and Technology, Thanjavur, Tamil Nadu. He has more than two decades experience in engineering field. He has published more than 45 International journals in SCI. He is working more than 15years in the field of Renewable energy engineering. He design and fabricated Renewable energy products such as Solar water Heater, Solar Distillation, Solar Cooker, Solar Dryer and Biomass gasification. He is reviewer and Editorial board member for many SCI journals. He is published more than 5 books. He presented more than 40 research papers in international conference. He registered more than 10 patents in IPR Govt. of India.