Optimization of process parameters of a solar parabolic trough in winter using Grey-Taguchi approach

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ABSTRACT

Among the renewable sources of energy, solar energy offers a practical solution for the energy problem which is clouding the prospects of mankind. The present paper deals with the experimental investigation of parameters of a solar parabolic trough in winter conditions and to obtain optimum process parameters by Grey Relational Analysis. The experiments were planned using Taguchi's L_9 orthogonal array. In this study, parabolic collector parameters namely reflector materials, Absorber materials, Positions of the Absorber tube and Angles of the absorber tube are optimized with the consideration of multi responses such as Temperature, Enthalpy, Optical efficiency and Thermal efficiency. A grey relational grade is obtained from the grey analysis. Based on the grey relational grade, optimum levels of parameters have been identified. Finally Conformation test is conducted to validate the test result. The experimental results have shown that, the use of Vacuum glass tube as a absorber gives best result.

KEY WORDS
Grey relational analysis, Grey relational grade, orthogonal arrays, Reflector materials and solar parabolic collectors

1. INTRODUCTION

Energy is the key input to drive and improve the life cycle. Primarily, it is the gift of the nature to the mankind in various forms. With ever growing population, improvement in the living standard of the humanity, industrialization of the developing countries, the global demand for energy is expected to increase rather significantly in the near future [9]. The primary source of energy is fossil fuel, however the finiteness of fossil fuel reserves and large scale environmental degradation caused by their widespread use, particularly global warming, urban air pollution and acid rain, strongly suggests that harnessing of non-conventional, renewable and environment friendly energy resources is vital for steering the global energy supplies towards a sustainable path.

2. Solar Thermal systems

Solar thermal systems play an important role in providing non-polluting energy for domestic and industrial applications. Concentrating solar technologies, such as the parabolic dish, compound parabolic collector and parabolic trough can operate at high temperatures and are used to supply industrial process heat, off-grid electricity and bulk electrical power. In a parabolic trough solar collector, or PTSC, the reflective profile focuses sunlight on a linear heat collecting element (HCE) through which a heat transfer fluid is pumped. The fluid captures solar energy in the form of heat that can then be used in a variety of applications. Key components of a PTSC include the collector structure, the receiver or HCE, the drive system and the fluid circulation system, which delivers thermal energy to its point of use [6].

3. Experimental Works

3.1 Description experimental setup

From the previous literature review, a solar parabolic trough has been fabricated as show in Fig 1

Figure 1 Experimental set of solar parabolic collector

Experimental setup consists of

- Parabolic Shaped Structure (made of MS Flat)
- Two legs to support the structure
- Reflective Surface
- Absorber
- Auto Tracking System
- Storage tank
- Data acquisition and Instrumentation
- Piping system

The whole experimental setup is placed on the top of the building. All the components are assembled to form the entire setup. The entire set is placed in the N-S direction to face the axis of the parabolic trough towards east. The parabolic structure has a flexibility to change the reflective and Absorber materials. A provision has been made to change the position of absorber tube away from the focal point. A mechanism is provided to change the angle of the absorber. A hydraulic actuator coupled with Light sensor is attached to the system. It looks after the Auto-tracking. Light sensor senses the intensity of light and give signal to servo switch intern the signal is given to the hydraulic actuator.

3.2 Plan of investigation

The Factors and their levels Considered in this study are shown in Table 1. Experiments are conducted with three factors each at three levels and hence a three level orthogonal array (OA) is chosen. It is planned to conduct the experiments according to the L_9 array [2].

Table 1 Input Parameters and Levels

Symbol	System Parameters	Level 1	Level 2	Level 3
A	Reflector Material	Polished Aluminum	Silvered Mirror	Stainless steel
B	Absorber Material	Vacuum glass tube	Bare Copper tube	Bare Aluminum
C	Position of Absorber tube	Position 1	Focal point	Position 2
D	Angle of Absorber	vertical	Angle 1	Angle 2

The experiments were conducted for several days on the solar parabolic trough by changing the reflective and Absorber materials. After absorbing sufficient radiation, the water in the absorber tube gets heated and its density decreases. Due to the differential, and the end of the absorber tube is closed the natural convection in counter flow direction has occurred. At each Experiment the temperature is noted at the surface of the absorber and bottom of the water tank, The water in the Storage tank is heated by the natural convection.

Table 2 Experimental design using L_9 orthogonal array

Exp No	Combinations				Temperature °C	Liquid Enthalpy (KJ/Kg)	Optical Efficiency (%)	Thermal Efficiency (%)
1	AP	VG	P1	VR	77°C	322.426	79.147	54.44
2	AP	BC	FP	A1	69°C	288.88	76.17	55.49
3	AP	BA	P2	A2	70°C	293.07	69.99	48.88
4	SM	VG	FP	VR	85°C	356.02	80.79	52.04
5	SM	BC	P2	A2	78.5°C	324.525	77.75	52.28
6	SM	BA	P1	A1	68°C	284.69	71.35	47.14
7	SS	VG	P2	A1	74°C	309.838	66.82	43.62
8	SS	BC	P1	A2	73°C	305.646	64.20	41.50
9	SS	BA	FP	VR	65°C	272.12	60.23	41.57

4. Grey Relational Analysis

In grey relational analysis, experimental data i.e. measured features of quality characteristics of the product are first normalized ranging from zero to one. This process is known as grey relational generation. Next, based on normalized experimental data, grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall grey relational grade is determined by averaging the grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade [8]. This approach converts a multiple- response-process optimization problem into a single response optimization situation, with the objective function is overall grey relational grade. The optimal parametric combination is then evaluated by maximizing the overall grey relational grade.

4.1 Data pre-processing

Depending on the characteristics of a data sequence, there are various methodologies of data pre-processing available for the grey relational analysis [1]. If the target value of original sequence is infinite, then it has a characteristic of the "**higher is better**". The original sequence can be normalized as follows:

$$x^{*}_{i}(k) = \frac{x^{o}_{i}(k) - \min\, x^{o}_{i}(k)}{\max\, x^{o}_{i}(k) - \min\, x^{o}_{i}(k)} \quad (1)$$

When the "**lower is better**" is a characteristic of the original sequence, then the original sequence should be normalized as follows:

$$x^{*}_{i}(k) = \frac{\max\, x^{o}_{i}(k) - x^{o}_{i}(k)}{\max\, x^{o}_{i}(k) - \min\, x^{o}_{i}(k)} \quad (2)$$

However, if there is a definite target value (desired value) to be achieved, the original sequence will be normalized in form:

$$x^{*}_{i}(k) = 1 - \frac{|\, x^{o}_{i}(k) - x^{o} \,|}{\max\, x^{o}_{i}(k) - x^{o}} \quad (3)$$

4.2 Grey relational coefficient and grey relational grade

In grey relational analysis, the measure of the relevancy between two systems or two sequences is defined as the grey relational grade. When only one sequence, $x_o(k)$, is available as the reference sequence, and all other sequences serve as comparison sequences, it is called a local grey relation measurement [4]. After data pre-processing is carried out, the grey relation coefficient $\xi_i(k)$ for the k th performance characteristics in the i th experiment can be expressed as

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta\,\Delta_{\max}}{\Delta_{oi}(k) + \zeta\,\Delta_{\max}} \quad (4)$$

Table 3 Comparability Sequence table for Responses

Experiment No.	Comparability sequence			
	Temperature	Enthalpy	Optical efficiency	Thermal efficiency
1	0.6	0.599	0.92	0.9249
2	0.2	0.199	0.775	1
3	0.25	0.249	0.474	0.52751
4	1	1	1	0.7533
5	0.675	0.6246	0.8521	0.770
6	0.15	0.1498	0.5405	0.4031
7	0.45	0.449	0.3205	0.1504
8	0.4	0.3999	0.19309	0
9	0	0	0	0.00535

Table 4 Deviation Sequence table for Responses

Experiment No.	Deviation sequence			
	Temperature	Enthalpy	Optical efficiency	Thermal efficiency
1	0.4	0.4001	0.08	0.007
2	0.8	0.801	0.225	0
3	0.75	0.751	0.526	0.477
4	0	0	0	0.2467
5	0.325	0.3754	0.1479	0.23
6	0.85	0.8502	0.45915	0.5969
7	0.55	0.551	0.6795	0.8499
8	0.6	0.6001	0.80691	1
9	1	1	1	0.99465

Where, Δ_{oi} is the deviation sequence of the reference sequence and the comparability sequence.

$$\Delta_{oi} = \| x^*_o(k) - x^*_i(k) \| \quad (5)$$

$$\Delta_{\min} = \min_{\forall j \epsilon i} \min_{\forall k} \| x^*_o(k) - x^*_j(k) \| \quad (6)$$

$$\Delta_{\max} = \max_{\forall j \epsilon i} \max_{\forall k} \| x^*_o(k) - x^*_j(k) \|$$

$x^*_o(k)$ denotes the reference sequence and $x^*_i(k)$ denotes the comparability sequence. ζ is distinguishing or identification coefficient: ζ [0, 1] (the value may be adjusted based on the actual system requirements). A value of ζ *is* the smaller and the distinguished ability is the larger. $\zeta = 0.5$ is generally used.

Table 5 Grey coefficients and Grey grades

Experiment No.	Grey coefficients				Grey Relational Grade
	Temperature	Enthalpy	Optical efficiency	Thermal efficiency	
1	0.555	0.555	0.8620	0.9861	0.7395
2	0.3846	0.3843	0.6896	1	0.6146
3	0.4	0.3999	0.4873	0.51177	0.4497
4	1	1	1	0.6693	0.9173
5	0.606	0.5711	0.77172	0.6849	0.6584
6	0.370	0.370	0.521376	0.45578	0.4292
7	0.4761	0.4757	0.4239	0.3703	0.4365
8	0.454	0.454	0.3825	0.333	0.5411
9	0.333	0.3333	0.3333	0.3344	0.333

After the grey relational coefficient is derived, it is usual to take the average value of the grey relational coefficients as the grey relational grade. The grey relational grade is defined as follows:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \quad (7)$$

5. Results and Discussions

In the present study the responses taken as Temperature, Enthalpy, Optical efficiency and Thermal efficiency. These responses should be maximized. For data processing in the grey relational analysis process, all the four responses were taken as "Higher-the-better". All the sequences, after data preprocessing using Eqs. 1 and 2 are listed in Table 3 and 4. And denoted as $x_o{}^*(k)$ and $x_i{}^*(k)$ for reference sequence and comparability sequence, respectively.
The distinguishing coefficient ξ can be substituted into Eq. 4 to produce the grey relational coefficients and grade values for each experiment of L_9 orthogonal array were calculated by applying the Eqs. 4 to 7 (Table 5). According to the performed experimental design, it is clearly observed from table 5 that the solar parabolic trough parameters setting of run 4 has the highest grey relational grade. Therefore run 4 (A2B1C2D3) is the optimal parameters setting for maximum Responses.

In addition to the determination of optimum solar parabolic trough parameters for Temperature, Enthalpy, Optical efficiency and Thermal efficiency, the response table of Taguchi method was to calculate the average grey relational grade for each level of the parameters. The greater value of the grey relational grade means that the comparability sequence has a strong correlation to the reference sequence. Therefore, the optimal level of parameters is the level with the greatest grey relational grade value. The optimal parabolic trough performance for maximizing all responses was obtained for Silvered mirror, vacuum glass tube, Focal point and Angle 2 of absorber tube. Figure3 indicates the effect of parabolic trough parameters on the multiperformence characteristic and the response graph of each level of the parabolic trough parameters for the performance.

As listed in table 6, the difference between the maximum value and the minimum value of the gray relational grade of parabolic trough were as follows: 0.231433 for Reflector Material, 0.293800 for Absorber Material, 0.106767 for Position of Absorber and 0.142600 for Angle of Absorber. The most effective factor on performance characteristics was determined by comparing these values.. This level of comparison presents the level of significance of the controllable factors over the multiperformance characteristics. The most effective controllable factor was the maximum of these values. Here, the maximum value among the max-min values is 0.293800. The value demonstrated that the absorber material has the strongest effect on the multiperformance characteristic among the other parabolic trough parameters.

Table 6 Average Grey grades

Factor	**Average Grey grade**			**Delta**	**Rank**
	Level 1	**Level 2**	**Level 3**		
Reflector Material	0.601267	0.668300[a]	0.436867	0.231433	2
Absorber Material	0.697767[a]	0.604700	0.403967	0.293800	1
Position of Absorber	0.569933	0.621633[a]	0.514867	0.106767	4
Angle of Absorber	0.576967	0.493433	0.636033[a]	0.142600	3

a Optimum level

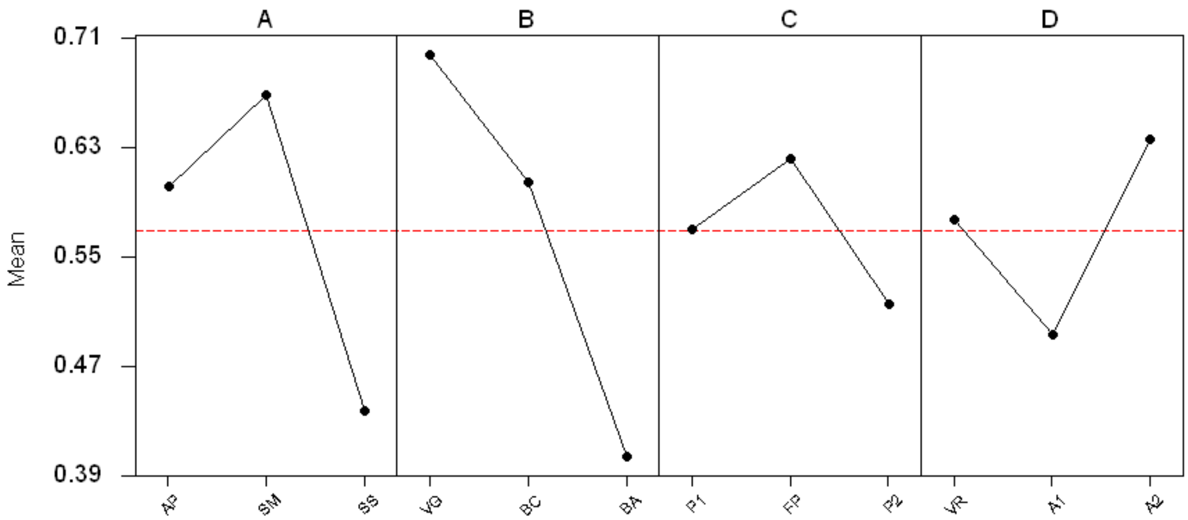

Figure 2 Average grey grade graph

6. Conclusion

The grey relational analysis based on Taguchi method's response table was conducted as a way of studying the optimization of process parameters level of a solar parabolic collector. The maximum Temperature, Enthalpy, Optical efficiency and Thermal efficiency were selected to be the quality targets. From the response table of the average grey grade, the largest value of grey relational grade for the parabolic trough parameters was found. The absorber material was the strongest factor among the other parameters used on the multiperformance characteristics. Finally we found out optimal setting (A2B1C2D3) in winter conditions. The study indicated that clearly that the gray relational analysis accomplished effectively the optimization of responses in solar parabolic trough.

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