Parametric optimization of Solar Parabolic Collector using metaheuristic Optimization

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Abstract

Estimation of an exceptionally exact model for solar parabolic collector from the experimental data is an important task for the researchers for the recreation, assessment, control and plan. Efficient optimization techniques are fundamental to accomplish this undertaking. In this paper a modified optimization technique is proposed for productive and precise estimation of the parameters of solar parabolic collector. The proposed algorithm is concentrated on the modification of Elephant Swarm Water Search Algorithm. This algorithm tested on parabolic collector parameters, namely reflectivity, Absorptivity & period of sun incidence. Response surface methodology has been used to implement the non linear model between the input & output parameters of the process. In addition, the proposed ESWSA optimization technique has been tested against the manufacture datasheet of solar parabolic reflector. Results show the effectiveness of ESWSA algorithm for modeling of the solar parabolic systems.

Keywords

ESWSA, Optimization, Parameters, Solar parabolic Collector.

INTRODUCTION

Sun based vitality as of now speaks to the most copious, boundless, non-contaminating, compelling, and free vitality asset accessible in practically all pieces of the world ([1], 2007),([20], 2009) , ([25], 2011) & ([6], 2011). In the event that the accessible sun powered vitality on the earth is appropriately tackled the world might not have a requirement for non-renewable energy source any more ([11], 2012) & ([15], 2009). As of late, impressive consideration has been paid to sunlight based warm focusing frameworks which are viewed as ecologically neighborly options in contrast to regular warm power frameworks. In sunlight based warm thinking frameworks, occurrence sun oriented radiation is changed over into warm vitality at the center ([15], 2009). These frameworks are named either point center concentrators (explanatory dishes and focal recipient frameworks) or line center concentrators (allegorical trough authorities and direct Fresnel gatherers).

Displaying and recreation are fundamental devices for the joining of sunlight based warm frameworks into mechanical procedures since they permit anticipating the presentation of each coordinated framework ([22], 2017). Besides, the measuring of parts inside a framework dependent on sustainable power sources is an unpredictable issue. Also, overseeing various designs is expected to choose the most proper one for every specific application, without the need to contribute numerous assets, both monetary and time. Thus, computational demonstrating presents a few points of interest, including the avoidance of models costs, the investigation in the association of complex frameworks, the likelihood of enhancing the parts, the chance of assessing the vitality streams of the framework, among others ([24], 2016).

A solar based electric force model has been proposed for applying at a higher temperature applications by ([23], 2008). ([19], 2014) has been performed the simulation to indentify the effective input parameters for designing a solar parabolic collector & determined the optimum input parameters corresponding to response variables by applying the ANOVA & desirability analysis approach. ([19], 2014) proposed Fuzzy logic based intelligent system for identifying the best material in a solar based parabolic collector for reflective surface & absorber tube. A multiobjective optimization technique is used to minimized the fuel consumption, effective area of the solar system & production of electricity in a solar assist gas turbine([4], 2017). Three different optimization technique utilized in a solar thermal system where solar storage volume & collector area are the primary process variable to obtain the maximum energy & optimum economical cost ([3], 2018). A mathematical model has been proposed to stimulate the energetic & exergetic performance of the solar- thermal collector system on the basis of solar parameters basis ([27], 2019). Optimization of solar thermoelectric energy corresponding to hot side temperature , thermoelectric leg length & thermal concentration ratio([12], 2020). Single & multi effect absorption was conduct in a solar heating & cooling system using Multiobjective optimization([21], 2017).

Elephant Swarm Water Search Algorithm (ESWSA) is a one of the modern metaheuristic optimization technique which was motivated by the water asset search technique of astute and social elephant swarm during dry season ([17], 2017), ([9], 2018) & ([13], 2018). This optimization technique effectively applied in different process system for the parameters tuning due to presence of a least number of parameters setting are required. Till now ESWSA was applied to numerous domain, for example, displaying the fluid stream process, parametric enhancement of the photovoltaic cell, and demonstrating of the welding process ([13], 2018).

The primary target of this work is to propose or build up some proficient advancement procedure with the end goal that we can demonstrate the biodiesel creation all the more precisely and dependably. In this journal we applied ESWSA metaheuristic by presenting the Lévy based global search & fluctuating Switching Probability. RSM is utilized as the non linear numerical models (which are advanced utilizing improved renditions of ESWSA) for the solar parabolic reflector.

The remainder of this paper is sorted out as follows. Section 2 demonstrating of solar parabolic reflector process. In this segment the test data sets along with their experimental level described. In section 3 RSM based nonlinear numerical models for the process are explained here. Philosophy of ESWSA metaheuristic also explained. In area 4, reenacted results, conversations and examinations are given. The points of interest and disservices of these improved forms of ESWSA are additionally examined. At long last, segment 5 finishes up this paper followed by the references.

EXPERIMENTAL WORK

Figure1. Experimental setup of solar parabolic collector ([19], 2014)

Glass reflect for intelligent surface and Aluminum for safeguard tube is chosen dependent on picked for a part of SPC to meet all exhibition prerequisites like guarantee no necessary upkeep, and most economical and also of materials: thickness, warm conductivity, cost, coefficient of warm extension, temperature and erosion obstruction ([26], 2014).

In view of the reference ([26], 2014) test arrangement has been set up for leading investigations, utilizing the best materials acquired fluffy rationale. The entire exploratory arrangement is set in the N-S direction so that the essence of explanatory reflector ought to be towards the east. The physical structure of the parabolic reflector designed in such a manner that absorbing materials & reflective surface can be changed manually. Position & angle of the absorber tube can be adjustable. For the auto tracking an actuator is mechanically coupled with the light sensor. The optical sensors identify the intensity of light & offer a hint to the servo switch to control the direction of a actuator.

Process Parameters and Their Levels

In this research reflectivity, Absorptivity & period of sun incidence these three dominant input parameters has been considered. The Absorptivity is considered at three levels by covering with three coats; blending silicon, dark nickel and chromium with dark finish paint each in turn individually and utilized for covering of best safeguard tube which is chosen through fuzzy logic controller ([26], 2014). Two types of reflective surface have been considered: glass reflects and silver mirror film.

Design of Experiment and Experimental Data

In this section we describe the name & levels of powerful input parameter in solar parabolic collector set up in Table1 where Table 2 describe the details of the input & response variables in tabular form. For this experiment we consider the period of sun incidence from 9.00 am to 4pm Table 2 consists of 18 experimental datasets contained the objective process variables: Temperature & discharge rate.

Table 1. Process input parameters and their ranges

Process Parameters	Level 1	Level 2	Level 3
Reflectivity (A)	0.95	0.97	-------------
Absorptive (B)	0.83	0.93	0.97
Period of Sun Incidence (PSI)(C)	9.00 AM -11.00 Am	11.00 AM - 01.00 PM	01.00 PM - 04.00 PM

Table 2. Experimental results.

	Input Experimental Parameters			Output	
Exp. run	**Refectivity**	**Absorptive**	**Period of Sun Incidence (PSI)**	**Temperature (˚C)**	**Discharge (lit/hr)**
	A	B	C	T	Q
1	0.95	0.83	1	60	10
2	0.95	0.83	2	70	7
3	0.95	0.83	3	45	22
4	0.95	0.93	1	60	12
5	0.95	0.93	2	55	14
6	0.95	0.93	3	45	20
7	0.95	0.97	1	50	16
8	0.95	0.97	2	60	12
9	0.95	0.97	3	45	20
10	0.97	0.83	1	50	18
11	0.97	0.83	2	70	9
12	0.97	0.83	3	55	15
13	0.97	0.93	1	60	13
14	0.97	0.93	2	65	10
15	0.97	0.93	3	63	11
16	0.97	0.97	1	62	10
17	0.97	0.97	2	50	14
18	0.97	0.97	3	45	18

MATHEMATICAL MODEL OF SOLAR PARABOLIC COLLECTOR

Due to nonlinear characteristics of the solar parabolic collector, variation of temperature & discharge has been observed with the change in period of sun incidence (PSI). Moreover, temperature & discharge both are depends upon the Absorptivity & reflectivity. It is very tedious & hard to recalibrate the analysis each time if any change of the predominant input parameter is changed.

To improve the calibration a mathematical model is implemented by using an empirical tool: RSM or ANOVA & find the optimal values of prevailing input parameters by using computational intelligence .These numerical models are based on nonlinear connections between input process parameters: period of sun incidence, reflectivity & Absorptivity with output process parameters temperature & discharge rate. These models will assist with discovering the ideal working condition and to foresee the temperature and release rate under specific condition (for example for various estimations of time of sun frequency, reflectivity and Absorptivity) without recalibration. There various non straight scientific model to depict a procedure however the most well known nonlinear models are RSM ([2], 2007), ([5], 2008) and ANOVA ([14], 2016).

In present research we utilized RSM ([10], 2019), ([7], 2017), ([18], 2019), ([9], 2018) & ([8], 2020) is a factual model, by and large utilized for experimental model structure and breaking down an issue. The most broad utilizations of RSM are in the specific circumstances where a few information factors conceivably impact execution or reaction of the procedure. In RSM, higher request polynomial condition is utilized to depict the connections among factors. The ensuing solicitation models are versatile and can take on wide grouping of utilitarian structures. Therefore, in this present research of RSM demonstrating, temperature (T) & Discharge (Q) in solar parabolic collector can be expressed in term of period of sun incidence, reflectivity & absorptivity using RSM based model as follows:

Mathematical model was formulated from each response which correlates the response (Yield) to the process variables through first and second order as well as interactive terms according to equation 1

$$Y= \beta_0 + \sum_{j=1}^{k} \beta_j X_j + \sum_{j=1}^{k} \beta_j X_j^2 + \sum_{j=1}^{k} \sum_{i=1}^{k} \beta_{ij} X_i X_i \quad (1)$$

Where, Y=Response (solar parabolic collector Yield)

β_0, β_j and β_{ij} are the regression coefficients with i, j = 1,2,…, k and X_i are the k input variables

Optimization of the mathematical model

Discovering the exact estimations of the coefficients of a solar parabolic collector need an efficient optimization technique. Ordinarily, metaheuristics can be utilized for this sort of improvement to such an extent that determined attribute of sun oriented explanatory collector fit with the trial one. Hence the temperature & liquid discharged should satisfy the three variable RSM mathematical equations.

$$f(A,B,C) = \beta_0 + \beta_1.A + \beta_2.B + \beta_3.C + \beta_{11}.A^2 + \beta_{22}.B^2 + \beta_{33}.C^2 + \beta_{12}.A.B + \beta_{23}.B.C + \beta_{13}.A.C \quad (2)$$

$$X = \{\beta_0, \beta_1, \beta_2, \beta_2, \beta_{11}, \beta_{22}, \beta_{33}, \beta_{12}, \beta_{23}, \beta_{13}\} \quad (3)$$

From the equation 2 & 3 it is seen that RSM mathematical equation of temperature & liquid discharge contain a multiple number of coefficients which can be obtained from it. In next stage our objective is to apply a proficient metaheuristic technique to obtain the optimum value of input process parameter corresponding to a given target output flow rate(by evaluating the ideal or best arrangement of qualities for the model parameters). In this exploration work, we have utilized fundamental ESWSA advancement strategy ([13], 2018) and for streamlining or demonstrating of sun oriented allegorical gatherer control issue.

Proposed Methodology

Basic Elephant Swarm Water Search Algorithm (ESWSA)

Elephant Swarm Water Search Algorithm was proposed by ([16], 2018). This optimization was for the most part dependent on the water search methodology of elephant swarm during dry spell with the assistance of various correspondence procedures.

Let the optimization problem is *d*-dimensional & the elephant group are randomly placed.

Now the position of *i*-th elephant group of a swarm after *t*-th iteration is given as $\boldsymbol{X^t_{i,d}} = (\boldsymbol{x_{i1}}, \boldsymbol{x_{i2}}, \ldots, \boldsymbol{x_{id}})$ &

velocity is by $\boldsymbol{V^t_{i,d}} = (\boldsymbol{v_{i1}}, \boldsymbol{v_{i2}}, \ldots, \boldsymbol{v_{id}})$.

Locally best solution by *i*-th elephant group at current iteration $\boldsymbol{P^t_{best,i,d}} = (\boldsymbol{P}_{i1}, P_{i2}, \ldots, P_{id})$ and

Global best solution is denoted by $G^t_{best,d} = (G_1, G_2, \ldots, G_d)$.

These values are updated according to following equations depending on the switching probability (p) ([10]. 2019b)

$$V^{t+1}_{i,d} = V^t_{i,d} * \omega^t + \epsilon \odot (G^t_{best,d} - X^t_{i,d}) \quad \text{if } rand > p$$
[for global search] (4)

$$V^{t+1}_{i,d} = V^t_{i,d} * \omega^t + \epsilon \odot (P^t_{best,i,d} - X^t_{i,d}) \quad \text{if } rand \le p$$
[for local search] (5)

Where the range of ϵ within [0,1]. $\odot$ & ω^t are denotes element wise multiplication & inertia weight to balance between exploration and exploitation. It changes according to the following equation:

$$\omega^t = \omega_{max} - \left\{\frac{\omega_{max} - \omega_{min}}{t_{max}}\right\} \times t \quad (6)$$

Where, t_{max}, ω_{max}, *and* ω_{min} are the values of maximum iteration number, upper boundary (0.6) and lower boundary (0.4) of the inertia weight respectively ([18], 2019). The updated position of an elephant group is expressed by following equation:

$$X^{t+1}_{i,d} = V^{t+1}_{i,d} + X^t_{i,d} \quad (7)$$

Optimum output obtained from the best position value of the algorithm. It has been found from the writing ([16], 2018) that p=0.6 gives unrivalled execution for ESWSA. In this way, we have additionally utilized this incentive for our current issue.

METHODOLOGY

To confirm the exhibitions of the proposed Elephant Swarm Water Search Algorithm the calculations are tried against parameters or coefficients estimation issues for displaying the sun-powered allegorical gatherer. Here, these calculations are tried against RSM based model as depicted before the area. The trial dataset has been acquired from the examination as referenced in the prior segment. The dataset comprises of 18 information purposes of temperature, release rate, a time of sun frequency, reflectivity and Absorptivity. This exploratory dataset has been utilized to design the RSM based nonlinear model of the solar parabolic collector. Target capacities for these cases are RMSE which is as of now examined in the previous segment. After advancement, the best arrangement of coefficients can be acquired so that RMSE is limited.

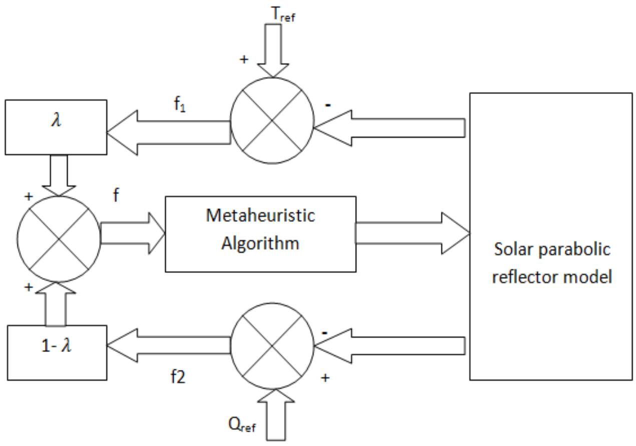

Figure 3. Flow chart of the present optimization technique

Table 4. Different Co-efficient of a RSM model from Minitab

Regression equation for Temperature		**Regression equation for Discharge**	
Terms	**Co efficient**	**Terms**	**Co efficient**
Constant	406.78	Constant	-1162.72
Reflectivity	-1258.33	Reflectivity	1491.67
Absorptivity	830.861	Absorptivity	740.110
PSI	-161.708	PSI	149.95
Absorptivity*Absorptivity	-1047.62	Absorptivity*Absorptivity	309.524
PSI*PSI	-8.3333	PSI*PSI	4.41667
Reflectivity *Absorptivity	1089.74	Reflectivity *Absorptivity	-1364.15
Refectivity*PSI	216.667	Refectivity*PSI	-175.00
Absorptivity*PSI	-18.2692	Absorptivity*PSI	2.88462

In this study, the optimization problem model of the solar parabolic reflector shown in figure 3 given by [15]. Table 4 represent the regression co efficient of temperature (T) & discharge (Q) by using RSM model with the help of MINITAB 17. Equation 9 & Equation 10 are representing non linear regression equation for temperature (T) & discharge (Q). Finally Equation 11 is optimized by the novel elephant swarm water search algorithm.

$$f_1 = 407 - 1258 *A + 831*B -162*C -1048 *B^2 - 8.33 *C^2 +1090 *A*B + 217*A*C - 18.3 *B*C \quad (9)$$

$$f_2 = -1163+1492 *A+ 740 *B+150.0 *C+310*B^2+4.42*C^2- 1346*A*B -175.0 *A*C +2.9*B*C \quad (10)$$

$$f = \lambda * f_1 + (1-\lambda) * f_2$$

$$f = \lambda *(65 - 407 + 1258 *A - 831*B + 162*C + 1048 *B^2 + 8.33 *C^2 - 1090 *A*B - 217*A*C + 18.3 *B*C)+(1-\lambda)(14 +1163 - 1492 *A - 740 *B - 150.0 *C - 310*B^2 - 4.42*C^2 + 1346*A*B + 175.0 *A*C - 2.9*B*C) \quad (11)$$

From Minitab for Temperature T ref =65 & Q ref = 14
Multiple Response Prediction
Variable Setting
λ 0.9976
A 0.95
B 0.97
C 2

CONCLUSION

The performance of solar parabolic reflector is depends upon the properties of mirror & reflecting materials. According to review of literatures it found that in respect to price, operating temperature, corrosions, thermal conductivity & density for experimental purpose best reflecting material & absorbing materials considered as a Glass mirror & Aluminum. In this research Author used three influential input parameters: periods of sun incidence (POS), reflectivity & Absorptivity to get the desired output parameter: temperature & discharge of water (lit/hr).

To indentify the optimum influential input parameters experimental response data are analyzed using Elephant swarm water search algorithm for optimized the mathematical model of RSM (response surface methodology).It is also found that the identified optimum parameters levels also experimentally confirmed.

Conflict of interest:

The authors declare the nonexistence of competing or other interests

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