Parametric Optimization of Solar Parabolic Collectors Using AHP-TOPSIS

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Abstract - *In the present work the behavior of linear solar parabolic Collector is studied. An experimental design is prepared based on the considered parabolic collector parameters such as Temperature, Discharge and Period of Sun Incidence (POI). The copper alloy c101 tube and aluminum alloy 1199 are used in experimental setup as absorbers. Copper alloy c101 tube has composition of Copper(99.998%), Antimony (0.1ppm), Arsenic(0.1ppm), Bisumasu (0.1ppm), Cadmium (<0.1ppm), Iron (1ppm), Lead (1ppm), Manganese (<=0.1ppm), Nickel (0.5ppm) and Aluminium alloy1199 has aluminium (99.98%), copper (0.006%), gallium (0.005%), iron (0.005%), titanium(0.002%), magnesium (0.006%) and the reflective surfaces are considered at two levels, one is Glass mirror and other is polished aluminum. Present work is focused on improvement of temperature of working fluid (water) and discharge of fluid, which influenced by parameters such as absorber tube materials, reflective sheet materials, time duration. The experiments are conducted according to the Taguchi design on the solar parabolic collector. This data is analyzed using AHP-TOPSIS and optimal parameter combination has been identified.*

Key Words: 1)Parabolic Shaped Structure, 2) Supporting legs, 3) Reflective Surfaces, 4) Heat collecting element(Absorber), 5) Auto Tracking System, 6) Piping system and Storage tank.

1. INTRODUCTION

The powerful presence of the sun is hard to ignore in one's everyday life: indeed, the majority of life on Earth could not exist without its vast output of radiant energy. At any given moment, the Earth's upper atmosphere receives solar radiation amounting to 174 PW (Peta Watts) of power. As shown in Figure 1.2, about 55% of this reaches the Earth's surface and is either absorbed or reflected by land and oceans. With such a vast amount of solar energy available, humanity could meet its demands by harnessing just a small fraction of this. Indeed, the total annual solar radiation falling on the Earth is more than 7500 times greater than the world's total annual primary energy consumption (WEC 2007). Furthermore, unlike fossil fuels, solar energy will continue to be available for billions of years.

1.1 Introduction of Solar Thermal systems

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.

1.2 Experimental Setup

(a) The experimental setup consists of the following components:

1)Parabolic Shaped Structure, 2) Supporting legs, 3) Reflective Surfaces, 4) Heat collecting element(Absorber), 5) Auto Tracking System, 6) Piping system and Storage tank.

The whole experimental setup is placed on the top of the buildings. 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.

(b) Plan of investigation: It is planned that the experiments are conducted according to the L_{36} array with respect of factors and levels of problem.

Table2.: Process parameters and their levels

S. No	Process Parameters	Level 1	Level 1	Level 1
1	Reflectivity	Polished Aluminum (AP)	Glass Mirror (GM)	-
2	Absorptivity	Copper Alloy C101 tube	Aluminum Alloy 1199 tube	-
3	Period of sun incidence (POI)	10.00AM-12.00PM	12.00PM-2.00PM	2.00PM-4.00PM

Fig-1. Experimental Setup

2. EXPERIMENTAL WORK

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 storage tank is heated by the natural convection.

Table2.1: Experimental results and response data

POI	Absorber Tube	Reflector	Output Temp (°C)	Discharge (lit/hr)	Thermal efficiency (%)
10 a.m-12p.m	Cu alloy	GM	60.6	19	89.37
12a.m-2p.m	Cu alloy	GM	75.3	16	135
2p.m-4p.m	Cu alloy	GM	68.1	18.5	112.5
10a.m-12p.m	Cu alloy	GM	61.3	18.3	91.6
12p.m-2p.m	Cu alloy	GM	78.5	15	145
2p.m-4p.m	Cu alloy	GM	65.5	17	104.68
10a.m-12p.m	Cu alloy	GM	59	19.1	84.37
12p.m-2p.m	Cu alloy	GM	77	15.5	140.6
2p.m-4p.m	Cu alloy	GM	65.2	18	103.7
10a.m-12p.m	Cu alloy	Al Sheet	51	19.4	59.37
12p.m-2p.m	Cu alloy	Al Sheet	65.3	18.7	104.06
2p.m-4p.m	Cu alloy	Al Sheet	58.1	19.1	81.56
10a.m-12p.m	Cu alloy	Al Sheet	50.4	19	57.5
12p.m-2p.m	Cu alloy	Al Sheet	62.2	18.8	94.37
2p.m-4p.m	Cu alloy	Al Sheet	56.1	17.2	75.31
10a.m-12p.m	Cu alloy	Al Sheet	49.3	19.2	54.06
12p.m-2p.m	Cu alloy	Al Sheet	66	18.4	106.25
2p.m-4p.m	Cu alloy	Al Sheet	59.2	18.6	85
10a.m-12p.m	Al alloy	GM	50	19.3	56.25
12p.m-2p.m	Al alloy	GM	68.2	18.5	113.12
2p.m-4p.m	Al alloy	GM	59.2	19	85
10a.m-12p.m	Al alloy	GM	49.2	19.1	54.06
12p.m-2p.m	Al alloy	GM	67.5	18.7	110.09
2p.m-4p.m	Al alloy	GM	58.2	19	81.8
10a.m-12p.m	Al alloy	GM	51.2	19.2	60
12p.m-2p.m	Al alloy	GM	69.3	18	116.56
2p.m-4p.m	Al alloy	GM	59.4	18.7	85
10a.m-12p.m	Al alloy	Al Sheet	46.2	19.6	44.37
12p.m-2p.m	Al alloy	Al Sheet	58.1	19.1	81.56
2p.m-4p.m	Al alloy	Al Sheet	49.2	19.4	53.7
10a.m-12p.m	Al alloy	Al Sheet	45.4	19.7	41.87
12p.m-2p.m	Al alloy	Al Sheet	57.6	19	80
2p.m-4p.m	Al alloy	Al Sheet	48.2	19.6	56
10a.m-12p.m	Al alloy	Al Sheet	43.3	19.8	35.31
12p.m-2p.m	Al alloy	Al Sheet	55.2	19.2	72.5
2p.m-4p.m	Al alloy	Al Sheet	46.5	19.4	45.31

3. EVALUATION OF WEIGHTAGE FOR RESPONSES USING IN AHP

AHP method is used to evaluate the weightages for responses using the procedure given in section

Step I

Specify the set of criteria for evaluating the weights and tabulated in **Table3.1**

	Temperature	**Efficiency**	**Discharge**
Temperature	EP	Not BEtMP	Not MP
Efficiency	BEtMP	EP	Not BEtMP
Discharge	MP	BEtMP	EP

Step II

The criterion is compared with each other in order to determine the relative importance of each factor to accomplish the overall objective. The importance of each factor is represented on the left (row) relative to the importance of the factor on top (column) of the matrix. Thereby, consider the higher value which means the factors on the left is relatively more important than the factor on the top and compute the priorities or weights of the criteria based on this information and is tabulated as in Table

Table3.2: Pair wise comparison matrix

	Temp	**Thermal Efficiency**	**Discharge**	**Eigen Values (EV)**	**Weightages (EV/3.367)**
Temp	1	1/2	1/3	0.5502	**0.1633**
Efficiency	2	1	1/2	1	**0.2969**
Discharge	3	2	1	1.8171	**0.5396**
Total	6	3.5	1.83	**3.3673**	
λ_{max}	**3.007**				

Step III

Compute Eigen vectors for each matrix by approximation of priorities using geometric mean method. This is done by multiplying the elements in each row and taking their *n*th root and these values are shown below. Where n is number of criteria.

- Eigen vector or value for Temperature

$$EV_{temp} = \sqrt[3]{1 \times \frac{1}{2} \times \frac{1}{3}} = 0.5502$$

- For Efficiency

$$EV\ Effi = \sqrt[3]{2 \times 1 \times \frac{1}{2}} = 1$$

- For Discharge

$$EV\ Dis = \sqrt[3]{3 \times 2 \times 1} = 1.8171$$

Step IV

Sum of each column is then multiplied with corresponding Priority vector. Sum of column one with Priority vector of component one and so on and sum of product is called Principal Eigen vector.

$$\lambda_{max} = \sum_{i=1}^{n} T_i * Pv_i$$

$$\lambda_{max} = \mathbf{3.006}$$

Step V

Consistency index is calculated using the equation C. I = $(\lambda_{max} - n)/n - 1$

C.I= $(\lambda_{max}-n)/(n-1)$ = (3.006-3)/3-1 = 0.0032

Then calculation of consistency ratio (CR)

In this case R.I is 0.58 as the size of matrix is three (Table 4.2). The value of CR should be around 10% to be acceptable.

C.R = (C.I/R.I) = (0.0032 /0.58) = 0.055

Hence the C.R is less than 10%; therefore the pair wise comparison matrix is acceptable and the weightage obtained for output responses as follows.

Weightages:

Temperature	=0.1633
Thermal Efficiency	=0.2969
Discharge	=0.5396

4. SELECTION OF OPTIMAL PROCESS PARAMETERS COMBINATION USING TOPSIS METHOD

TOPSIS method is used to determine the optimum parameter combination by analyzing the experimental data.

Step1: The first step is to formulate decision matrix with 'm' alternatives and 'n' attributes are shown in table 3.1.

Step 2: Take weightages for each response, after normalization of experimental data, the weighted normalized decision matrix is obtained by using equation (2). This weighted normalized matrix is formed by integrating the AHP weightage calculated in table 4.2 with TOPSIS normalization matrix

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$V_{ij} = W_i \times r_{ij} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$S_i^+ = \sqrt{\sum_{j=1}^{m} \left(V_{ij} - V_j^+\right)^2} \quad \ldots\ldots\ldots\ldots\ldots\ (3)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} \left(V_{ij} - V_j^-\right)^2} \quad \ldots\ldots\ldots\ldots\ldots\ (4)$$

Table4.1: Normalization Matrix

NORMALISATION MATRIX			
s.no	**Output Temp**	**Discharge**	**Efficiency**
1	0.1702	0.1701	0.1695
2	0.2116	0.1432	0.2561
3	0.1913	0.1655	0.2134
4	0.1722	0.1638	0.1738
5	0.2205	0.1342	0.2751
6	0.1840	0.1521	0.1986
7	0.1658	0.1709	0.1601
8	0.2163	0.1387	0.2657
9	0.1832	0.1611	0.1967
10	0.1433	0.1736	0.1126
11	0.1835	0.1673	0.1974
12	0.1632	0.1709	0.1547
13	0.1416	0.17007	0.1091
14	0.1747	0.1682	0.1791
15	0.1576	0.1539	0.1429
16	0.1385	0.1718	0.1025
17	0.1854	0.1647	0.2016
18	0.1663	0.1664	0.1612
19	0.1405	0.1727	0.1067
20	0.1916	0.1655	0.2146
21	0.1663	0.17007	0.1612
22	0.1382	0.1709	0.1025
23	0.1896	0.1673	0.2088
24	0.1635	0.17007	0.1552
25	0.1438	0.1718	0.1138
26	0.1947	0.1611	0.2211
27	0.1669	0.1673	0.1612
28	0.1298	0.1754	0.0841
29	0.1632	0.1709	0.1547
30	0.1382	0.1736	0.1018
31	0.1275	0.1763	0.0794
32	0.1618	0.17007	0.1518
33	0.1354	0.1754	0.1062
34	0.1216	0.1772	0.0670
35	0.1551	0.1718	0.1375
36	0.1306	0.1736	0.0859

WEIGHTED NORMALSED MATRIX			
s.no	**Output Temp**	**Discharge**	**Efficiency**
1	0.027	0.051	0.091
2	0.034	0.042	0.138
3	0.031	0.049	0.115
4	0.028	0.048	0.093
5	0.036	0.039	0.148
6	0.031	0.045	0.107
7	0.027	0.051	0.086
8	0.035	0.041	0.143
9	0.029	0.047	0.106
10	0.023	0.051	0.061
11	0.029	0.049	0.106
12	0.026	0.051	0.083
13	0.023	0.051	0.058
14	0.028	0.049	0.096
15	0.025	0.045	0.077
16	0.022	0.051	0.055
17	0.031	0.048	0.108
18	0.027	0.049	0.087
19	0.022	0.051	0.057
20	0.031	0.049	0.115
21	0.027	0.051	0.087
22	0.022	0.051	0.055
23	0.030	0.049	0.112
24	0.026	0.051	0.083
25	0.023	0.051	0.061
26	0.031	0.047	0.119
27	0.027	0.049	0.087
28	0.021	0.052	0.045
29	0.026	0.050	0.083
30	0.022	0.051	0.054
31	0.020	0.052	0.042
32	0.026	0.050	0.081
33	0.022	0.052	0.057
34	0.019	0.052	0.036
35	0.025	0.051	0.074
36	0.021	0.051	0.046

Step 4: After obtaining weighted normalized matrix, Positive separation ideal solution (PIS) and negative separation ideal solution (NIS) are determined. Using Equations 3 and 4. These ideal solutions are as follows.
From weighted normalized decision-making matrix, the positive separation ideal solution V^+ obtained as

$$V^+ = \{0.036, 0.052, 0.143\}$$

From weighted normalized decision-making matrix, the negative separation ideal solution V^- obtained as

$$V^- = \{0.019, 0.039, 0.036\}$$

Step 5: The separation of each alternative from positives separation ideal solution (PSIS) and negative separation ideal solution (NSIS) are calculated using the equation as in the Table 4.3

Table 4.3: Positive and Negative Separation ideal solution

s.no	S_i^+	S_i^-
1	0.052	0.056
2	0.011	0.103
3	0.028	0.081
4	0.051	0.058
5	0.013	0.113
6	0.037	0.072
7	0.057	0.051
8	0.011	0.108
9	0.038	0.07
10	0.083	0.027
11	0.037	0.071
12	0.061	0.049
13	0.085	0.025
14	0.047	0.061
15	0.067	0.041
16	0.089	0.022
17	0.035	0.074
18	0.057	0.052
19	0.086	0.024
20	0.028	0.081
21	0.057	0.052
22	0.089	0.022
23	0.031	0.078
24	0.061	0.049
25	0.082	0.027
26	0.024	0.084
27	0.057	0.052
28	0.099	0.015
29	0.061	0.049
30	0.089	0.022
31	0.102	0.014
32	0.062	0.047
33	0.087	0.024
34	0.108	0.012
35	0.071	0.041
36	0.098	0.015

Step 6: The closeness co-efficient (Table 4.4) of each alternative is $CC_i = \frac{S_i^-}{S_i^+ + S_i^-}$

Table 4.4: Closeness coefficient

s.no	CCI	RANK
1	0.521	14
2	0.901	2
3	0.736	6
4	0.539	13
5	0.892	3
6	0.657	9
7	0.473	18
8	0.904	1
9	0.652	11
10	0.248	26
11	0.657	10
12	0.447	20
13	0.228	27
14	0.566	12
15	0.382	23
16	0.201	30
17	0.677	8
18	0.478	17
19	0.221	28
20	0.742	5
21	0.479	15
22	0.201	31
23	0.714	7
24	0.449	19
25	0.252	25
26	0.772	4
27	0.478	16
28	0.135	34
29	0.447	21
30	0.201	32
31	0.123	35
32	0.432	22
33	0.221	29
34	0.105	36
35	0.364	24
36	0.137	32

Step 7: Rank the preference order based on their largest relative closeness co-efficient. It is observed from the Table 4.4, for the higher closeness coefficient is obtained for 8th experimental run. Hence the best parameter combinations of experimental 8th run are in the following.

Best combination of parameter

- Period of incidence : **12.00 p.m. – 2.00 p.m.**
- Absorber Tube : **Copper alloy c101**
- Reflector : **Glass Mirror**

Best Output Responses for best combination of reflector and absorber tube

- Temperature : **77°C**
- Discharge : **15.5 lit/hr.**
- Thermal Efficiency : **140.6%**

Conclusions

The following conclusions are drawn from the results.

- In the present work, the behaviour of linear solar parabolic Collector for cooking system is studied and analysed using Mathematical models.
- Finally experimental response data is analysed using AHP-TOPSIS and optimum parameters levels have been identified.
- Among the combination of different reflector and absorber, glass mirror and copper alloy c101 tube combination is given best results for obtaining maximum temperature and discharge, thermal efficiency.

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