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STUDY ON SOLAR PARABOLIC TROUGH COLLECTOR WITH DIFFERENT COPPER ABSORBER TUBES

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Abstract

In this work different absorber tubes like polished copper tube, unpolished copper tube, Ni-Al coated copper tube, Ni-Cr coated copper tube are used separately in solar parabolic trough collector for conducting performance study with heat transfer fluids of water and salt water. The tracking system is used for the solar rays tracking to get a better performance of the solar parabolic trough collector. The four absorber tubes and two heat transfer fluids are used as factors to design of experiment of solar parabolic trough collector. Ni-Al and Ni-Cr coatings are done on copper tube by using thermal spray coating technique. The experiments are conducted according to DOE on the solar parabolic trough collector. The temperature and discharge of working fluid are measured. These measured values are analysed and the optimum value of factors are identified using the WASPAS method.

Keywords: Absorber tubes, Heat transfer fluids, Thermal spray coating, Mini tab software, Optimization.

1. Introduction

Solar energy is an essentially inexhaustible source of energy potentially capable of meeting a significant portion of the all nation’s future energy needs with a minimum of adverse environmental consequences. The current industrial growth and environmental impacts show that solar energy for solar thermal power plants is the most promising of the unconventional energy sources. The future of solar power plant development depends on how a number of serious constraints, including scientific and technological problems are dealt with. The most common commercially available solar power plants are using parabolic trough concentrators. The Parabolic Trough Solar Collector is one of the most proven technologies among the various concentrating type solar collectors for electricity generation and production of steam for Industrial Process Heating. PTSC consists of a metallic absorber tube which is coaxial with the focal line of the parabolic reflector. Absorber tube receives concentrated solar rays reflected from a parabolic trough. A Heat Transfer Fluid flows within the absorber tube, to which heat is transferred from the heated tube wall.

2. Experimental setup

The experimental setup consists of the following components.

- Parabolic Shaped Structure
- Supporting frame
- Reflective Surfaces
- Heat Receiving elements (Absorber tubes)
- Auto Tracking System with ARDUINO Technology
- Measuring Instruments
- Pumping motor for working fluid recycling process
- Piping system and Storage tank

Fig 1: Experimental setup

Table 1: Solar parabolic collector key parameter and material properties

Feature/Parameters	Value
Length of the trough (L)	2m
Width of the trough (W)	1.5m
Depth of the trough	0.5m
Aperture area	$4m^2$
Absorber tube copper diameter (D)	19.05mm
Focal length (f)	28.125cm from vertex
Structure	Ms Flat bent structure
Concentration ratio (C)	33.416
Reflectivity of Mirror Film (ρ)	0.96
Absorbance of copper (α)	0.85
Absorbance of polished copper (α)	0.87
Absorbance of Ni-al coated copper tube (α)	0.93
Absorbance of Ni-Cr coated copper tube (α)	0.89
Specific heat capacity, C_p of water	4189 j/kg k
Specific heat capacity, C_p of salt water	3985 j/kg k
Auto tracking	Chain mechanism with the help of ARDUINO Technology
Battery	12V DC
Capacity Pumping motor	0.85m/s

Absorber tubes

Copper tubes with 1 mm thickness and 19.05 mm outer diameter were used to fabricate the absorber tubes. The specifications of cylindrical axis trough collector, absorber tubes and the apparatus are given in Table 1. All the tubes were made of 2 m long copper tubes. Parabolic trough with rim angle of 120° and focal length 28.125 cm, was used which has reflective surface of mirror film and reflectivity of about 96%. Details for fabrication processes of the tubes have been included.

With the thermal spray coating technique Ni-Al metal powder mixture is coated on copper tube at high temperature and Ni-Cr metal powder mixture is coated on another copper tube with same thermal spray coating technique at high temperature.

FIG 2: POLISHED COPPER TUBE

FIG 3: UNPOLISHED COPPER TUBE

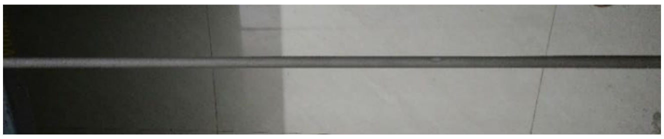

FIG 4: Ni-Al COATED TUBE

FIG 5: Ni-Cr COATED TUBE

Thermal spraying is a technology which improves or restores the surface of a solid material. The process can be used to apply coatings to a wide range of materials and components, to provide resistance to: Wear, erosion, cavitation, corrosion, abrasion or heat. Thermal spraying is also used to provide electrical conductivity or insulation, lubricity, high or low friction, sacrificial wear, chemical resistance and many other desirable surface properties.

3. Conducting of experiments

Taguchi employs design experiments using specially constructed table, known as "Orthogonal Arrays (OA)" to treat the design process, such that the quality is build into the product during the product design stage. Orthogonal Arrays (OA) are a special set of Latin squares, constructed by Taguchi to lay out the product design experiments. An orthogonal array is a type of experiment where the columns for the independent variables are “orthogonal” to one another. Orthogonal arrays are employed to study the effect of several control factors. Orthogonal arrays are used to investigate quality. Taguchi has simplified their use by providing tabulated sets of standard orthogonal arrays and corresponding linear graphs to fit specific projects.

Table 2: Factors and Responses

Levels → / Factors ↓	Level 1	Level 2	Level 3	Level 4
Absorber tube	Copper tube	Polished copper tube	Ni-Al coated copper tube	Ni-Cr coated copper tube
Heat transfer fluid	Water	Salt water	————	————
Days	Day 1	Day 2	————	————

Table 3: Design of experiments and experimental data

E.NO	Absorber Tube	HT fluid	Day	Temperature(°C)	Discharge (lit/min)	Heat loss (watts)
1	C0PPER	Water	1	71.2	33	867.386
2	COPPER	Salt-water	2	70.0	30	248.160
3	POLISHED C0PPER	Water	1	71.0	34	301.441
4	POLISHED C0PPER	Salt-water	2	72.0	31	484.244
5	Ni-Al COATED COPPER	Water	2	73.6	36	578.820
6	Ni-Al COATED COPPER	Salt-water	1	74	33	126.130
7	Ni-Cr COATED COPPER	Water	2	71.3	34	752.698
8	Ni-Cr COATED COPPER	Salt-water	1	72.0	32	484.040

An experimental design L8 is developed based on the factors and their levels. The experiments are conducted according to DOE (Table 3) and temperature and discharge are recorded.

4. WASPAS method

WASPAS method is applied on experimental values to get optimal solution. The following steps are used to for identification of optimum parameters combination.

Step 1: Data normalization

$$\bar{x} = \frac{x_{\mathrm{ij}}}{max_{\mathrm{i}}\, x_{\mathrm{ij}}} \quad for\ beneficial\ criteria \tag{1}$$

i.e if $\max_i x_{ij}$ value is preferable and

$$\bar{x} = min_{\mathrm{i}} \frac{x_{\mathrm{ij}}}{x_{\mathrm{ij}}} \quad for\ non-beneficial\ criteria \tag{2}$$

i.e. if $\min_i x_{ij}$ value is preferable

Table 4: Normalized values of responses x_{ij}

Exp no	Temperature(xij)	Discharge(xij)	Heat loss(xij)
1	0.962162	0.916667	0.145379
2	0.945946	0.833333	0.50814
3	0.959459	0.944444	0.418324
4	0.972973	0.861111	0.260406
5	0.994595	1	0.217857
6	1	0.916667	0.999762
7	0.963514	0.944444	0.167531
8	0.972973	0.888889	0.260516
Total	7.771622	7.305556	2.977915

Step 2: Entropy Approach For Weights Determination:

$$p_{\mathrm{ij}} = \frac{x_{\mathrm{ij}}}{\sum_{i=1}^{m} x_{\mathrm{ij}}} \quad ; \qquad x_{\mathrm{ij}} = is\ normalized\ matrix$$

Entropy value e_j; $\quad e_{\mathrm{j}} = -k \sum_{i=1}^{m} p_{\mathrm{ij}} \ln(p_{\mathrm{ij}})$

$$k = \frac{1}{\ln(m)} \quad ; \qquad m = 8\ (number\ of\ experiments).$$

$$W_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)} \quad ; \qquad W_j = W_1, W_2, \ldots W_j$$

Table 5: Weights (W_j) of responses

	W_j		
S.no	**Temperature(°C)**	**Discharge(Lt/min)**	**Heat loss(watts)**
1	0.000689	0.006808	0.992504

The total relative importance of the i^{th} alternative, based on weighted sum method (WSM), is calculated as follows

$$Q_i^1 = \sum_{j=1}^{n} x_{ij}.W_j \; ; \tag{3}$$

The total relative importance of the i^{th} alternative, based on weighted product method (WPM), is calculated as follows

$$Q_i^2 = \prod_{j=1}^{n} x_{ij}^{W_j} \quad ; \tag{4}$$

In order to have increased ranking accuracy and effectiveness of the decision making process, in the WASPAS method, a more generalized equation for determining the total relative importance of alternatives is developed as below

$$Q_i = \lambda.Q_I^1 + (1-\lambda).Q_I^2 \quad ; \quad \lambda = 0, 0.1, \ldots 1. \tag{5}$$

Table 6**:** Total relative importance and ranks

S.NO	**Q_i^1**	**Q_i^2**	**Q_i**	**RANK**
1	0.151193	0.147405	0.149299	8
2	0.510656	0.510072	0.510364	2
3	0.422279	0.420890	0.421584	3
4	0.264987	0.262773	0.263880	5
5	0.223717	0.220359	0.222038	6
6	0.999198	0.999172	0.999185	1
7	0.173368	0.169719	0.171544	7
8	0.265285	0.262940	0.264112	4

Table 7: Response table for WASPAS index

PROCESS PARAMETER	**AVERAGE WASPAS INDEX**					**RANK**
	LEVEL 1	**LEVEL 2**	**LEVEL 3**	**LEVEL 4**	**MAX-MIN**	
HEAT TRANSFER FLUID	0.24111625	0.**509385**	------------	------------	0.2678217	**2**
DAY	**0.458545**	0.2919565	------------	------------	0.1665885	**3**
ABSORBER TUBE	0.3298315	0.342732	**0.6106115**	0.217828	0.2678795	**1**

The optimal level of factors are

- Heat transfer fluid level 2 (salt water),
- Day level 1 (Day 1),
- Absorber tube level 3 (Ni-Al coated copper tube).

5. Conclusion

Tirupati is 156 m above sea level and receives two periods of monsoons mostly during June - August and October – December. As the experiments were conducted during the second phase of monsoon, intensified solar flux was not available compared to that obtained in summer season, slightly affecting the performance of the absorber tube. In the present work the controllable parameters such as heat transfer fluids, absorber tube materials which influence the responses (temperature, discharge and heat loss) and the experiment are conducted according to Taguchi experimental design. Finally experimental response data is analysed using WASPAS method and optimum parameter levels identified. It is observed that among the absorber tubes Ni-Al coated copper tube is best absorber tube and salt water is best heat transfer fluid.

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