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Performance Evaluation of Parabolic Trough Collector with Different Polymers as Reflector by Taguchi method

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Abstract-**The objective of the study is to optimize various parameters for performance evaluation of solar parabolic trough collector by using Taguchi method. An experimental study is carried out with operating parameters like mass flow rate, period of incidence and Types of reflectors. Three polymers like Adhesive vinyl, Aluminium polymer, and Silvered polymer are used for testing purpose. These variables have a major impact on the performance of a solar parabolic trough collector. An experimental study is carried out to find out the effect of these parameters on performance. The different combination of experiments, the L9 orthogonal array-based design of experiments and the result of mass flow rate, period of incidence and reflector for each run have been optimized using the Taguchi method in MINITAB 17 software. The optimum combination of parameters for each response has been predicted with respect to signal to noise ratio(S/N). The results show that parameters have a significant impact on performance. Thermal efficiency increases with an increase in mass flow rate. Three mass flow rate and period of incidence are considered for experimentation purpose. Maximum instantaneous efficiency obtained for a period of incidence 12-2 pm, mass flow rate 34.2 lph and Silvered polymer. Overall instantaneous efficiency for the silvered polymer is 65.35% more than Aluminium polymer (50.79%) and Adhesive vinyl (47%).**

Keywords* —Parabolic trough collector, *Mass flow rate, Period of incidence, Types of reflectors, Taguchi method.

I. INTRODUCTION

Renewable energy sources are a non-depleting source of energy. Solar energy is one of the prominent sources of energy. There are issues like climate change, global warming is emerging. Use of a commercial source of energy hazardous to the environment, so as to prevent environmental damages and for sustainable use of energy renewable source is a favorable source of energy. Solar energy is a prime renewable energy source. The target set by the government of India for renewable energy is about 175GW.Out of which 100 GW for solar energy. The government started implementing and supporting various schemes to achieve the target. [3]

Energy radiated by the sun is about $3.8*10^{23}$KW out of which only small fraction i.e. $1.8*10^{14}$ reach to the earth surface which is enough to fulfill energy needs. The solar concentrating device is one of the applications of solar energy. In this device energy incident on the reflector is reflected towards a focal point or focal line. Fluid is flowing though focal tube absorbs solar energy. Hot water stored in a tank for domestic use. Recent many application devices for heating and electricity generation receive an attention. [4]

There are various forms of solar energy technology consist of solar photovoltaic cells, solar flat plate collectors, solar towers etc. out of which concentrating device like solar parabolic trough collector(PTC)are capable of producing hot water, the steam can be further used for industrial process heat and power production. These applications can be used in industrial as well as in domestic application which is economically feasible to use. [10] Prakash and Rai (2018) carried out an experimental investigation by Taguchi method for performance optimization. Mass flow rate, Diameter of the receiver and material of receiver tube are design and operating parameters. The result shows that the parameters chosen in this study have a significant influence on the response and validation of result shown significant improvement in performance characteristics. [1] Patil and Joshi (2018) took few parameters on which performance of parabolic trough collector depends. The result obtained shows that by increasing mass flow rate the value of outlet temperature decreases, at the same time value of useful heat gain increases and as the cross-section area of absorber tube increases, both outlet temperature and useful heat gain decreases. [2] Now it's time to use a parabolic trough collector for domestic application and manufactured from the locally available material. A

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problem associated with manufacturing for domestic application is not economically feasible and losses are more because of lack of streamline of solar radiation towards the focal line. A polymer material low-cost material as compared to glass and easily available. The polymer has low weight and has curability, so it is easy to use on the reflector. The polymer has specular reflectivity is about 0.88 is the same as a glass mirror. The polymer reduces the diverging of solar radiation this enhances the performance of the parabolic trough collector.

The main objective of the study is to optimize the performance of parabolic trough collector using the Taguchi method. Taguchi method reduces the number of runs of experiments. It also reduces the time and cost.

II. THERMAL DESIGN OF PARABOLIC TROUGH COLLECTOR

Reflector and Receiver-

The equation of the parabola is $y^2=4ax$ because of which focal line should be located at a distance of 1/4a. This is basic design consideration of parabolic trough collector.

Aperture of the concentrator (W)	1.10 m
Inner diameter of absorber tube ($D_{r,i}$)	0.011 m (for single circular tube)
Outer diameter of absorber tube ($D_{r,o}$)	0.0125 m (for single circular tube)
Inner diameter of glass tube	0.050 m
Outer diameter of glass tube	0.056 m
Length of parabolic trough	1.21 m
Concentration ratio	13.69
Collector aperture area	1.33 m^2
Specular reflectivity of concentrator (ρ)	0.85
Glass cover transitivity for solar radiation(τ)	0.85
Absorber tube emissivity/emissivity (α)	0.82
Intercept factor (γ)	0.95
Emissivity of absorber tube surface (ε_a)	0.08
Emissivity of glass (ε_g)	0.82

Table 2.1 Details about Reflector and Receiver

III. PERFORMANCE OF SOLAR PARABOLIC TROUGH COLLECTOR-

Collector efficiency (ηcollector) = Qu /AI =m C_p (T_{fo}-T_{fi})

Where,

Qu = Useful heat gain (KJ/hr.)

A = Aperture area (m2)

I = Solar Radiation Intensity (W/m^2)

m = Mass flow rate (Kg/hr.)

C_p = Specific heat capacity of water (J/Kg-K)

T_{fo}, T_{fi} = Outlet and inlet temperature of water (^{0}C)

IV. DESIGN AND EXPERIMENT

A. Design of Experiment-

Optimum input parameter combination was found out by Taguchi method. Taguchi method reduces the number of combination of experiments. It also reduces the time and cost. To achieve a high signal to noise ratio it's necessary to reduce noise factor and increase signal value. The goal of experiments was to find out the parameters which have major influence and potential to enhance the performance. Taguchi Design of Experiment (DOE) was carried out in 9 different combinations for optimization of parabolic trough collector.

B. Parameter selection-

Three key parameters have a significant impact on the performance of the parabolic trough collector. Parameters are mass flow rate, Period of incidence and Types of the reflector.

Reflector material	Adhesive vinyl	Aluminized mylar	Silvered polymer
Period of incidence	9:30-11:30 am	12-2pm	3-5 pm
Mass flow rate	0.006	0.0095	0.007

Table 2.1 Orthogonal matrix

C. Selection of orthogonal array-

An orthogonal matrix is a fractional factorial matrix, which assures a balanced comparison of levels of any factor or interaction of factors. It's matrix of numbers arranged in rows and columns where each row represents the level of the factors in each run and each column represents a specific factor that can be changed from each run. This array is called orthogonal because all columns can be evaluated independently of one another. Orthogonal array accommodates many design parameters simultaneously. In this experimental work, 3 parameters containing three levels. The orthogonal array of L9 is found out using the software Minitab 17 for 3 independent variables and 3 levels.

Experiment number	Parameters		
	Mass flow rate(lph)	Reflectors	Period of incidence
1	21.6	Adhesive Vinyl	9:30-11:30
2	34.2	Adhesive Vinyl	12-2
3	25.2	Adhesive Vinyl	3-5

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4	34.2	Aluminized Mylar	9:30-11:30
5	25.2	Aluminized Mylar	12-2
6	21.6	Aluminized Mylar	3-5
7	25.2	Silver polymer	9:30-11:30
8	21.6	Silver polymer	12-2
9	34.2	Silver polymer	3-5

Table 2.2 Taguchi Orthogonal L9 array for the experiment

D. Experimental procedure-

Testing of the performance of parabolic trough collector on the set up available at Department of technology, Shivaji University, Kolhapur. Experiments are performed according to ASHRAE standard to determine the performance of parabolic trough collector with water as working fluid. An experiment performed under the assumption that collector is thermally in steady state and flow inside receiver is uniform.

In the experiment, there are three different experimental setups using three different reflector material like Adhesive vinyl, Aluminium polymer and silvered polymer with copper receiver tube. Experimental set up performed with three different reflector material and three mass flow rate. Hence there will be nine combinations of parameters were tested which will be analyzed with the help of the Taguchi Method using Minitab software. The Taguchi method was used in determining the optimum useful heat gain and Efficiency according to the S/N ratios and means computed by Minitab software.

V. THEORETICAL PERFORMANCE ANALYSIS-

The meteorological data will be obtained from the sites as NASA Surface Meteorology and RET Screen Data for the site i.e. Kolhapur.

	Unit	Climate data location
Latitude	°N	16.42
Longitude	°E	74
Elevation	m	458
Heating design temperature	°C	18.17
Cooling design temperature	°C	34.74
Earth temperature amplitude	°C	16.48
Frost days at the site	day	0

Table 4.1 NASA surface metrology and RET screen data for Kolhapur

Data required for theoretical performance calculation is obtained from NASA surface metrology and RET screen. Following results are obtained from the above data. The results are obtained by using the Taguchi method for three period of incidence and three reflectors shown below,

Instantaneous thermal efficiency %				
Sr.No	Period of Incidence	Adhesive vinyl	Aluminized mylar	Silvered polymer
1	12:00 pm	33.23	53.60	47.22
2	12:30 pm	47.85	53.65	48.57
3	1:00 pm	47.85	59.76	55.33
4	1:30 pm	48.50	49.58	51.10
5	2:00 pm	57.58	40.95	60.86
6	3:00 pm	37.56	55.81	84.74
7	3:30pm	31.86	30.22	59.81
8	4:00pm	33.06	35.42	53.17
9	4:30 pm	34.14	30.91	52.34
10	5:00 pm	37.99	23.61	76.68
11	9:30 am	44.07	51.84	36.13
12	10:00 am	56.67	70.15	55.83
13	10:30 am	48.97	37.38	48.37
14	11:00am	43.12	57.21	55.09
15	11:30 am	37.78	37.38	59.68

Table 4.2 Instantaneous thermal efficiency for a period of Incidence

The result obtained for three mass flow rate obtained by using Taguchi method shown below,

Sr.No	Instantaneous thermal efficiency %		
	Mass flow rate		
	34.2 lph	25.2 lph	21.6 lph
1	33.23	37.56	44.07
2	47.85	31.86	56.67
3	47.85	33.06	48.97
4	48.50	34.14	43.12
5	57.58	37.99	37.78
6	51.84	53.60	55.81
7	70.15	53.65	30.22
8	37.38	59.76	35.42
9	57.21	49.58	30.91
10	37.38	40.95	23.61
11	59.81	36.13	47.22
12	53.17	55.83	48.57
13	52.34	48.37	55.33
14	76.68	55.09	51.10
15	36.13	59.68	60.86

Table 4.3 Instantaneous thermal efficiency for mass flow rate

Case no.	Reflector	Overall instantaneous efficiency (%)
		Mass flow rate(lph)

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		34.2	25.2	21.6
1	Adhesive vinyl	47.00	34.92	46.12
2	Aluminized mylar	50.79	51.51	35.19
3	Silvered polymer	65.35	51.02	52.62

Table 4.4 Overall Experimental efficiency for all cases

From the table shown above overall experimental efficiency for the silver polymer is maximum for mass flow rate of 34.2 lph and 21.6 lph. The overall experimental efficiency of Adhesive vinyl is maximum in case of mass flow rate of 25.2 lph.

VI. EXPERIMENTAL SETUP

a - Flow control valve
b - Inlet temperature sensor
c - Outlet temperature sensor
d - Solar radiation meter
e - Digital Differential Manometer
f – Anemometer
g - Storage tank

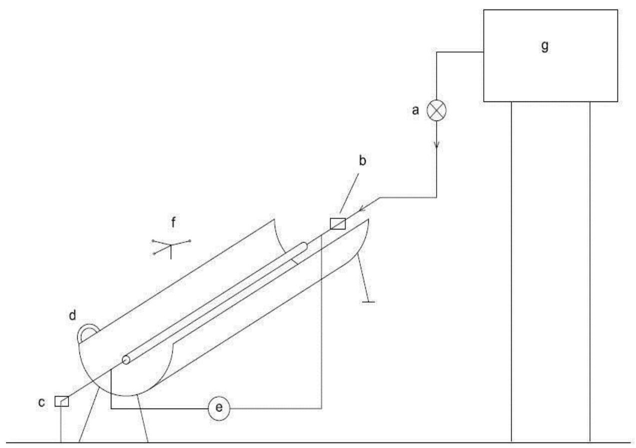

Figure 5.1 Test set up with a different instrument

VII. ANALYSIS OF EXPERIMENTS

Instantaneous Thermal Efficiency (%)				
Sr. No.	Period of Incidence	Adhesive vinyl	Aluminized mylar	Silvered polymer
1	12:00	41.81	52.74	47.68
2	12:30	58.75	52.82	43.85
3	1:00	59.81	58.36	47.22
4	1:30	60.09	39.64	54.23
5	2:00	58.02	44.93	60.61
6	3:00	35.93	54.27	82.82
7	3:30	25.48	32.31	59.81
8	4:00	29.85	34.34	47.85
9	4:30	32.41	31.81	65.65
10	5:00	29.11	30.47	79.75
11	9:30	46.50	59.03	38.48
12	10:00	50.04	68.46	50.85
13	10:30	45.86	41.16	45.59
14	11:00	38.95	56.08	55.09
15	11:30	38.47	34.80	59.50

Table 6.1 Instantaneous thermal efficiency for a period of incidence.

Instantaneous Thermal Efficiency (%)			
Sr.No.	Mass flow rate		
	34.2 lph	25.2 lph	21.6 lph
1	41.81	35.93	46.50
2	58.75	25.48	50.04
3	59.81	29.85	45.86
4	60.09	32.41	38.95
5	58.02	29.11	38.47
6	59.03	52.74	54.27
7	68.46	52.82	32.31
8	41.16	58.36	34.34
9	56.08	39.64	31.81
10	34.80	44.93	30.47
11	82.82	38.48	47.68
12	59.81	50.85	43.85
13	47.85	45.59	47.22
14	65.65	55.09	54.23
15	79.75	59.50	60.61

Table 6.2 Instantaneous thermal efficiency for mass flow rate.

Case no.	Reflector	Overall instantaneous efficiency (%)		
		Mass flow rate(lph)		
		34.2	25.2	21.6
1	Adhesive vinyl	55.69	30.55	43.96
2	Aluminized mylar	51.90	49.69	36.63
3	Silvered polymer	67.17	49.90	50.71

Table 6.3 Overall Experimental efficiency for all cases.

Case no.	Reflector	Overall heat gain		
		Mass flow rate(lph)		
		34.2	25.2	21.6
1	Adhesive vinyl	811.44	310.675	492.391
2	Aluminized mylar	708.02	791.34	321.56
3	Silvered polymer	437.54	574.45	683.31

Table 6.4 Overall Useful Heat Gain for all cases

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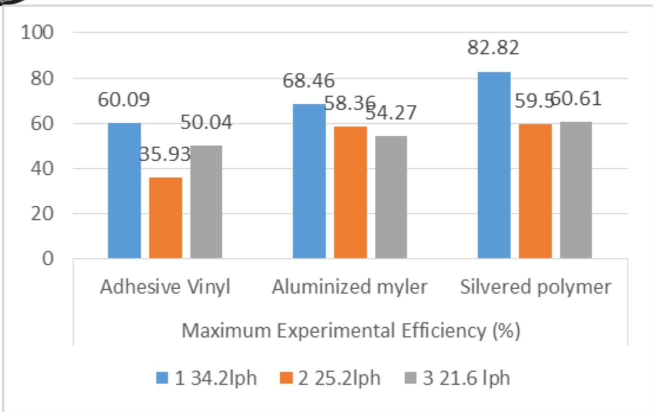

Figure 6.1 Comparison of Maximum Experimental Thermal Efficiency for all cases

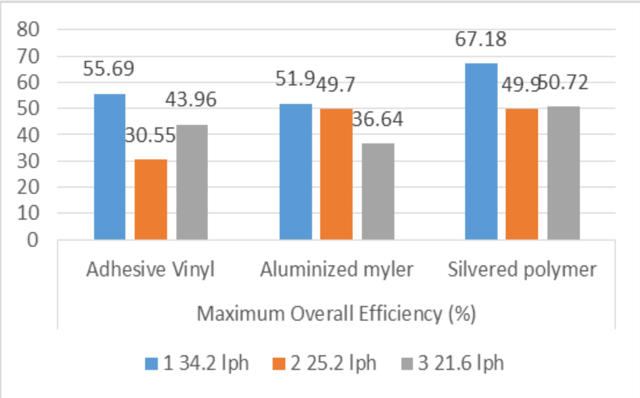

Figure 6.2 Comparison of Maximum Overall Thermal Efficiency for all cases

From graph 6.1 and 6.2, it shows that comparative maximum thermal efficiency and overall thermal efficiency for all three parameters (Mass flow rate, a period of incidence and types of polymers). Silver polymer shows better performance in all cases. Aluminium polymer shows highest performance in case of mass flow rate of 25.2 lph.

VIII. THEORETICAL TAGUCHI OPTIMIZATION

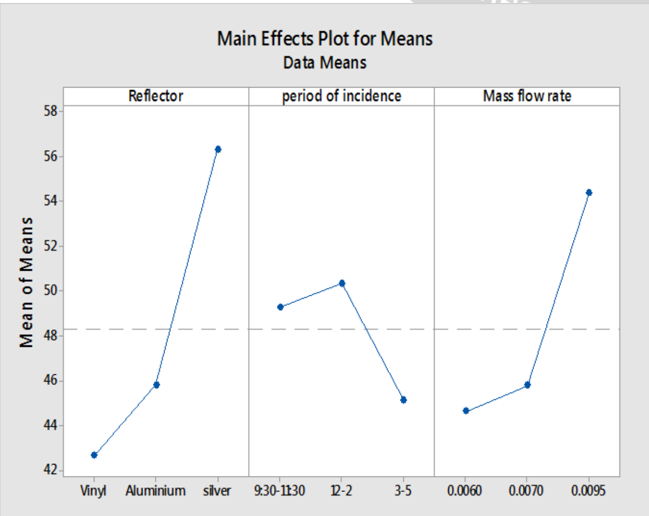

Figure 5.1 Optimization of parameters by the Taguchi method for Overall Thermal Efficiency

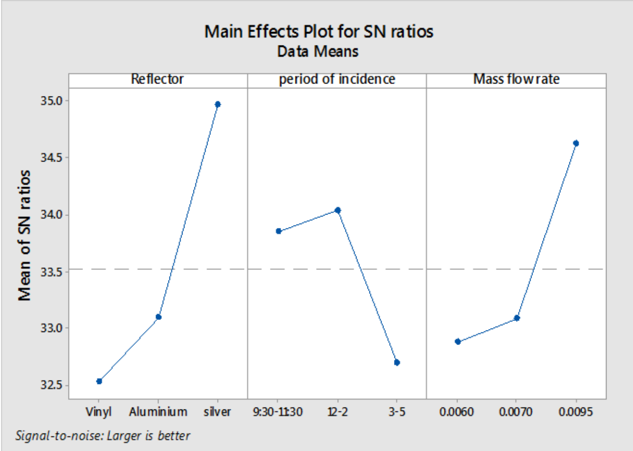

Figure 5.2 Optimization of parameters by the Taguchi method for Overall Thermal Efficiency

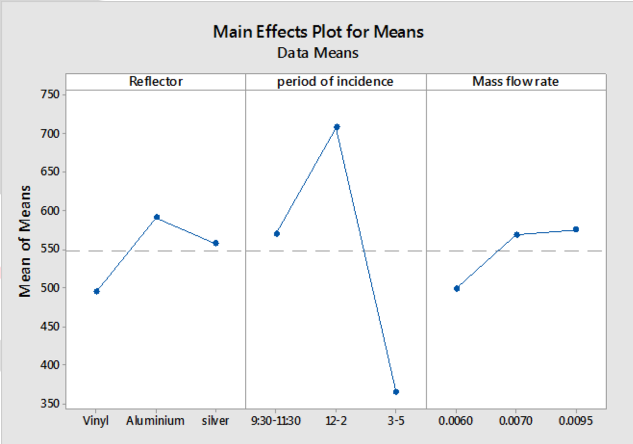

Figure 5.3 Optimization of parameters by Taguchi method for Overall heat gain

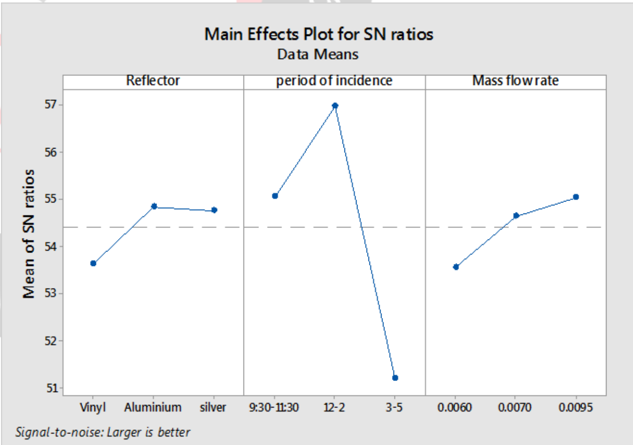

Figure 5.4 Optimization of parameters by Taguchi method for Overall heat gain

IX. EXPERIMENTAL TAGUCHI OPTIMIZATION

A. Taguchi analysis Efficiency Vs Reflector, Period of incidence and Mass flow rate-

Level values of the factors obtained for Efficiency according to Taguchi design are given in Table 8.1 Larger is the better characteristic was selected and figure 8.2

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shows the effect of input parameters on Efficiency. Hence interpretations can be made based on the level values of Reflector, Period of incidence and Mass flow rate factors given in table 8.1 and figure 8.2. The different values of S/N ratio between maximum and minimum are (the main effect also) shown in Table 8.2.

Table 6.1 Response Table for Means

Level	Reflector	Period of incidence	Mass flow rate
1	32.49	33.71	32.75
2	33.17	34.32	32.53
3	34.87	32.51	35.25
Delta	2.38	1.81	2.72
Rank	2	3	1

Larger is better

Table 6.2 Response Table for Signal to Noise Ratios

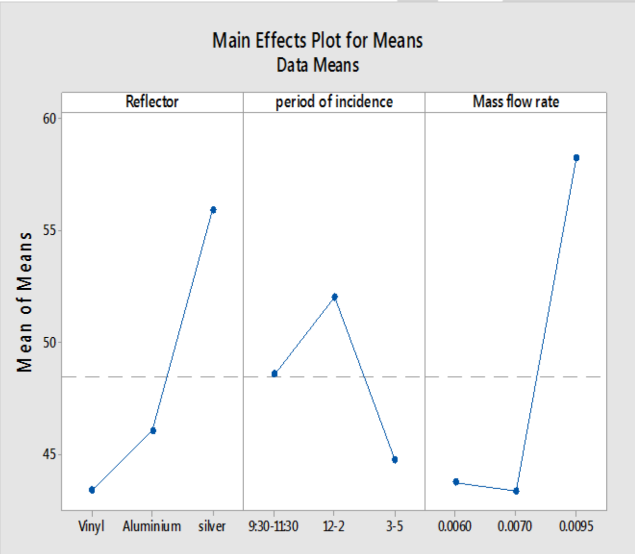

Figure 6.1 Main plot effects for means

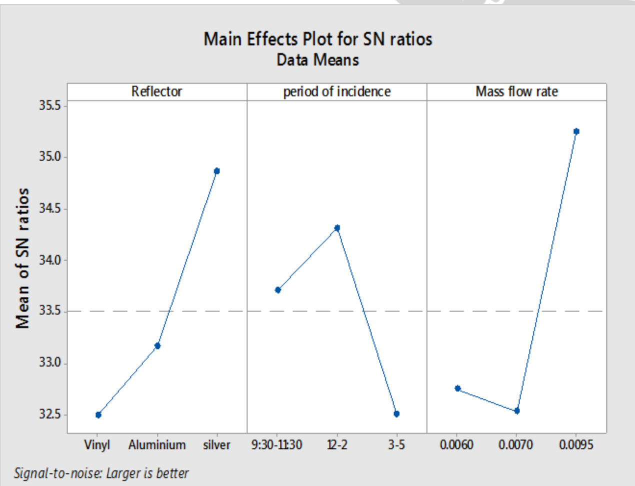

Figure 6.2 Main plot effect for S/N ratio

B. Taguchi analysis Heat gain vs Reflector, Period of incidence and Mass flow rate-

Level values of the factors obtained for Heat gain according to Taguchi design are given in Table 8.3 Larger is the better characteristic was selected and figure 8.4 shows the effect of input parameters on Heat gain. Hence interpretations can be made based on the level values of Reflector, Period of incidence and Mass flow rate factors given in Table 8.3 and figure8.3.The different values of S/N ratio between maximum and minimum are (the main effect also) shown in Table 8.4

Table 6.3 Response Table for Means

Level	Reflector	Period of incidence	Mass flow rate
1	53.96	55.34	53.96
2	55.04	57.61	54.33
3	54.90	50.94	56.00
Delta	1.08	6.68	2.44
Rank	3	1	2

Larger is better

Table 6.4 Response Table for S/N ratio.

Level	Reflector	Period of incidence	Mass flow rate
1	43.40	48.59	43.77
2	46.08	52.04	43.39
3	55.93	44.79	58.26
Delta	12.53	7.25	14.87
Rank	2	3	1

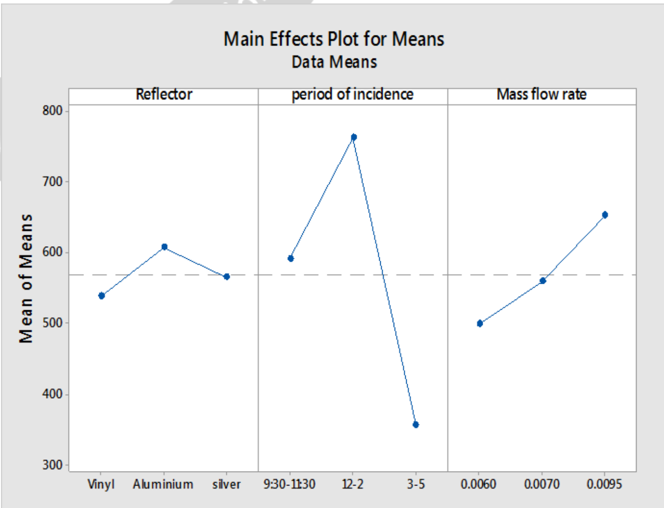

Figure 6.3 Main effect plot for Means

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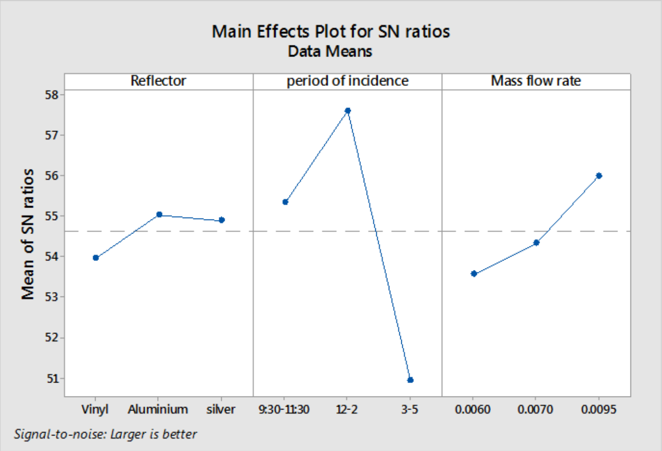

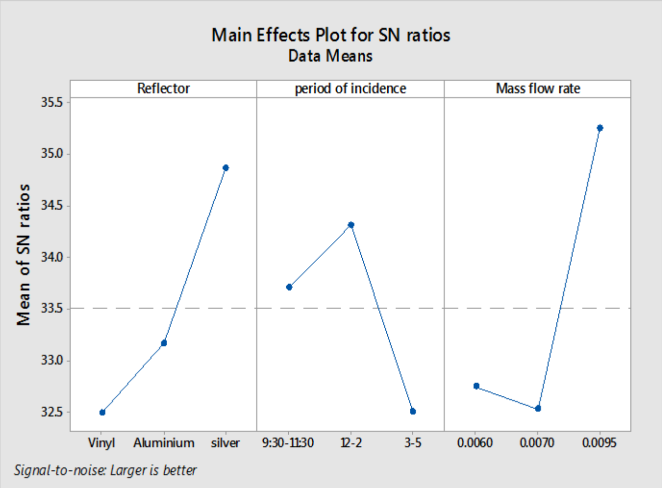

Figure 6.4 Main effect plot for S/N ratio

X. DISCUSSION

From theoretical and experimental comparative analysis, it shows that silvered polymer gives a better performance in term of useful heat gain and instantaneous efficiency than other two polymers. Silver polymer shows better performance in all three parameters. After that Aluminium polymer shows better performance. In some cases like mass flow rate of 25.2 lph maximum overall efficiency of Aluminium polymer is more than silver polymer. There are many factors which affect the performance of polymers like specular reflectivity of polymer, solar intensity etc. Optimum factor level in case of efficiency for a period of incidence 12-2 pm, for a mass flow rate of 34.2 lph and for the polymer is a silver polymer. The similar optimum condition is obtained for heat gain shown below,

Factors	Parameters	
	Efficiency	Heat gain
Reflectors	Silver	Silver
Period of Incidence	12-2 pm	12-2 pm
Mass flow rate	0.0095	0.0095

Table 7.1 Factors and their optimum levels

VIII. CONCLUSION

From the result, we conclude that Silver polymer shows better performance with all mass flow rate and period of incidence than aluminized mylar and Adhesive vinyl. Maximum Overall efficiency Adhesive vinyl is more than Aluminized mylar only in case of the mass flow rate of 34.2 lph. In other case performance of Aluminized mylar is better than Adhesive vinyl. Efficiency increased when mass flow rate increased for all polymers.

Taguchi experimental design was used to obtain optimum performance characteristics of parabolic trough collector. Experiments were conducted using water as the heat transfer medium.L9 orthogonal array was selected by using the Taguchi Method. S/N ratio was found to find the major influence factors. Larger is the better characteristic was selected. Efficiency was found to be maximum for silver material, mass flow rate 0.0095 and Period of incidence 12-2 PM. Heat gain was found to be maximum for Silver material, mass flow rate 0.0095 and Period of incidence 12-2 PM.

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