

Report on Collector Performance Theoretical Prediction Experimental Verification and Analysis

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ABSTRACT: In this report, the accuracy of a theoretical prediction method is established by comparing with experimental results. This analysis is used to show the importance of considering mass flow rate as an independent parameter in performance evaluation. The critical variation in performance with large flow rates has led to the optimization of number of collector modules in series operation by considering the gain in output over the extra frictional power required. The effects of other parameters are also studied with a view to improve the performance at high temperatures in the present collectors. Selective coating on the present configuration with single glass cover is found to remarkably improve the performance at high temperatures.

I. INTRODUCTION

The performance of a solar collector varies from place to place depending upon the climatic conditions, flow rate and temperature requirement. It is both expensive as well as time consuming to obtain experimental curves for all these cases. We are presently using an experimental characteristic curve (η vs $\Delta TF/IR$) for designing the solar systems. Since preheating facility was not present, the characteristic curves were obtained by varying the flow rates to cover wide range of ($\Delta TF/IR$). It was thought necessary to study the accuracy of the present prediction method. We have and therefore decided to make use of presently available theoretical method (Appendix -1) after establishing its accuracy by comparing with experimental results.

Different Configurations Tested:

Particulars		
Configuration	Fig.1	Fig.2
Collector Size in sq.m.	1.7	5.4
Flow area in sq.m	0.0176	0.027
Flow passage	Gap between inner glass and plain MS absorber sheet	Rectangular G I duct black painted outside
Insulation thickness in mm	50	25

II. EXPERIMENTAL PROCEDURE

Experiments were started daily from 10 AM in the morning. Flow rate was adjusted to obtain a particular average outlet temperature and kept constant for the whole day. The insolation level, ambient, inlet and outlet temperatures were noted at regular intervals. The average values were

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noted at regular intervals. The average values over a period of 6 hours of operation are used to calculate the efficiency and $\Delta TF/IR$.

III. THEORETICAL ACCURACY

To evaluate the accuracy in theoretical method the average values of the above noted variables are used and the flow rate adjusted to match the governing equations (Ref.Appendix-1 for details).The experimental and theoretical efficiencies for various $\Delta TF/IR$ are shown in Table -1. It is observed that the maximum variation between the experimental and theoretical results for case 1 and case 2 configurations are 12% and 7% respectively. The cause of larger variation in case 1 are found to be due to unreasonable leakages from the glass edges.

IV. EFFECTS OF PARAMETERS

However to investigate the consistently poor performance of the second configuration, it was decided to study the effects of various parameters on its theoretical performance (Refer Table-1). The influencing factors considered are (a) Cross sectional area, (b) Insulation thickness, (c) Collector size, (d) Surface emissivity, (e) Flow passage, and (f) Insolation level.

V. RESULTS

Cross Sectional Area: A decrease of 35% in cross section area increases the performance by 27% at 70 deg C outlet temperature. (Refer case D)

Insulation Thickness: For a given operating temperature difference and insolation, a reduction of 50% in insulation thickness decreases the performance by 16% at 70 deg C outlet temperature. (Refer case C)

Heat Transfer Surface Emissivity: An increase in emissivity from 0.22 to 0.95 increases the efficiency by 23% at 70 deg C outlet temperature. (Refer case G)

Collector Size: By decreasing the area from 5.4 sq.m. to 1.7 sq.m. the performance decreases by 63% at 70 deg C outlet temperature. (Refer case F)

Flow Passage: Change in flow passage from type 2 to type 1 increases the emissivity and hence efficiency. Also direct absorption of energy by inner glass cover increases the available energy and hence efficiency. Neglecting the effect of emissivity, the resulting increase in efficiency because of change in flow passage is 38% at 70 deg C outlet temperature. (Refer case E).

Insolation Level: The effect of insolation level for the same operating temperature difference to insolation ratio ($\Delta TF/IR$) is to decrease the efficiency by 6% at $\Delta TF/IR$. (Refer case H).

Accuracy of the Present Design:

The configuration that was commercialized has a larger surface area 9sq.m. and insulation thickness of 50 mm. The effects of these are found to increase the performance by about 15 to 18% at 70 deg C outlet temperature (Refer Graph 2 – Curves 3 and 4). The improved performance

curves lie within 10% accuracy to the experimental characteristic curve and hence recommended for design.

Effect of Selective Coating: Double glass covers in the commercial collectors were used in order to achieve high temperatures. Since high temperatures can be achieved even with selective coating on the absorber, its effect on a single configuration is studied. (Refer Graph 2 –Curve 5). It shows upto 30% improvement in performance at high temperatures.

Importance of Flow rate in Hot Air Collectors:

In the governing equation of the performance of solar hot air collector, the efficiency factor F' is given by

$$F' = (, ,)$$

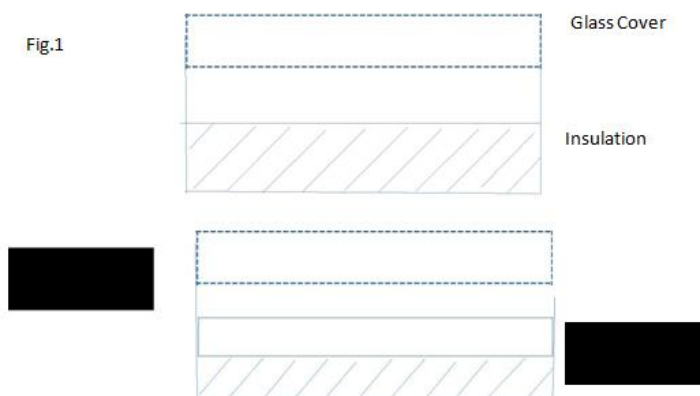
Since values of UL and HR are usually low compared to H, the efficiency factor becomes a strong function of heat transfer coefficient H. Therefore any change in flow rate significantly changes the heat transfer coefficient and hence the efficiency. It can be recalled from the earlier results that any change in parameter influences the efficiency mainly through the change in flow. Therefore it is important to consider flow rate as an independent parameter in determining the performance characteristics. This can be verified from the fact that previous characteristic curves drawn for various configurations do not match for any other operating temperature difference on insolation for a given ($\Delta T_F/IR$) value. Thus the characteristic curves are to be obtained for constant flow rates by varying the ($\Delta T_F/IR$). Such curves for various flow rates in the commercialized configurations are given in Graph 3.

It can be observed that by increasing the flow rate to twice the value, the efficiency is improved by about 13% at 300 kg/hr flow rate. Thus it seems desirable to operate two collectors in series with twice the flow rate. However any number of collector modules cannot be connected in series for two reasons.(a) With increasing flow rates, the rate of improvement decreases; (b) Power consumption to overcome friction increases with increasing flow rates. Therefore it is desirable to operate only that many modules in series for which gain in output is more than the corresponding increase in input. Optimum Number of Modules in Series: Electrical energy being a high grade energy, its actual thermal value considering plant factors, production and transmission efficiency is about 4 times as much. The gain in output and increase in input are compared in Table – 2. It can be seen from the table that a maximum of 3 modules can be efficiently operated in series for optimum utilization.

VI. CONCLUSIONS

The theoretical prediction can be confidently followed for future systems.

Performance of the module can be improved up to 20% by black coating the inside surface of the GI sheet.



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Annexure – 1

The governing equation that determines the efficiency of a solar collector is

$$\eta = \left[1 - \frac{U_L (T_m - T_a)}{G} \right]$$

Where for Type 1 configuration,

$$\eta = \left[1 - \frac{U_L (T_m - T_a)}{G} \right] ; \quad \eta = \frac{1 - (1 - \tau)0.24}{1 + \frac{U_L (T_m - T_a)}{G}} = \frac{1 - (1 - \tau)0.24}{1 + \frac{U_L (T_m - T_a)}{G}}$$

For Type 2 configuration,

$$\eta = \left[1 - \frac{U_L (T_m - T_a)}{G} \right] = \frac{1 - (1 - \tau)0.24}{1 + \frac{U_L (T_m - T_a)}{G}}$$

$$= \left[1 - \frac{U_L (T_m - T_a)}{G} \right] = \frac{1 - (1 - \tau)0.24}{1 + \frac{U_L (T_m - T_a)}{G}}$$

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$$= \frac{1}{(1 - 0.04 + 0.0005 + 0.0005^2)(1 + 0.058)}$$

$$= 5.7 + 3.8 ;$$

Heat Transfer coefficients H and HR are given by

$$= 0.0158 \cdot 0.8^{\frac{2}{3}}$$

$$= \frac{3.6}{0}$$

$$= \frac{(+) (\frac{1}{1} \frac{2}{2} \frac{1}{1} \frac{2}{2} +)}{\frac{1}{1} + \frac{1}{2} - 1}$$

Following heat balance equations are used for solving T1 and T2 involved in the above governing equation.

$$= (1 -) + (2 -)$$

$$\begin{aligned} (1 -) - (2 -) &= (2 -) & 1 \\ (1 -) - (2 -) &= (2 -) & 1 \end{aligned}$$

Efficiency is obtained by solving the above equations by iteration.

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Details of Collector Configurations

Case	Configuration	Collector Area Sq.m	Flow Cross Section mm x mm	Insulation Thickness	Inside Surface emissivity
A	1	1.7	20 x 880	50	0.95,0.85
B	2	5.4	30 x 900	25	0.23
C	2	5.4	30 x 900	50	0.23
D	2	5.4	30 x 900	25	0.23
E	1	5.4	30 x 900	25	0.95,0.85
F	2	1.7	30 x 900	25	0.23
G	2	5.4	30 x 900	25	0.95
H	2	5.4	30 x 900	25	0.23

Insolation values: A to G Experimental insolation; H 950 W/m² insolation

Performance Comparison for different configurations

Configuration 1 Case A		
($\bar{\eta}$)	Theoretical Efficiency	Experimental Efficiency
0.0239	46.7	52.7
0.0245	46.2	52.7
0.0258	42.0	45.7
0.0274	42.0	47.4
0.0323	32.7	36.0

Performance Comparison for configuration

($\bar{\eta}$)	Experimental Efficiency	Theoretical Efficiency Cases B to H						
		B	C	D	E	F	G	H
0.0250	35.1	36.8	41.7	43.1	53.7	18.4	41.3	35.0
0.0275	32.7	33.8	39.0	40.5	51.5	15.7	35.9	31.8
0.0261	31.1	32.2	37.5	39.4	51.5	13.8	37.9	29.2
0.0301	28.2	30.3	35.7	37.3	48.5	12.6	36.0	28.1
0.0293	27.5	28.1	33.6	35.7	47.6	10.5	34.5	26.3
0.0323	27.5	26.3	32.0	33.8	45.5	9.3	32.8	24.8
0.0241	35.6	39.0	43.6	44.9	54.8	21.0	43.0	37.2

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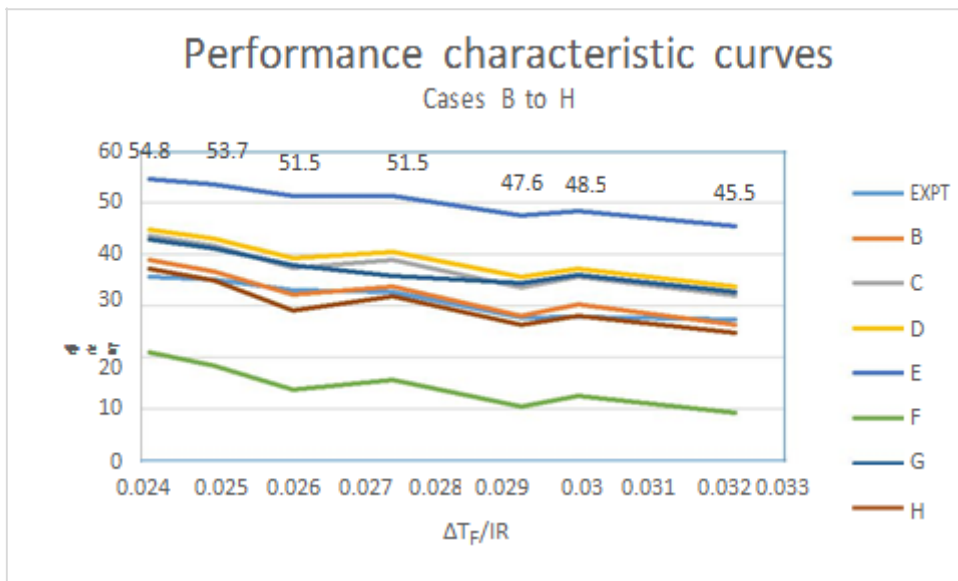
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Comparison of incremental output to incremental input

Length m	Flow	η series	Output kW		ΔkW output	Input kW		100% Blower ΔkW input	δkW input	Normal Blower 40% δkW	
			Series	Parallel		Series	Parallel			δkW o/p	
10	300	0.308	2.736			0.00198					
20	600	0.430	6.192	5.472	0.720	0.0266	0.00396	0.023	0.023	0.720	0.057
30	500	0.455	9.828	8.208	1.620	0.122	0.0059	0.116	0.093	0.90	0.24
40	1200	0.4675	13.464	10.944	2.520	0.358	0.0079	0.350	0.234	0.900	0.59
50	1500	0.4738	17.057	13.680	3.377	0.828	0.0099	0.818	0.468	0.851	1.170
60	1800	0.4769	20.602	16.416	4.186	1.640	0.0119	1.628	0.810	0.809	2.025
70	2100	0.4784	24.111	19.152	4.959	2.923	0.0139	2.909	1.281	0.773	3.200



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