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Long Term Performance of Large Scale Solar Water Heating System

D. Bharath, G. Satyanarayana
Mechanical Engineering Department, K L University, Vaddeswaram, Guntur 522502

Abstract*-The manufacturers of large scale solar water heating systems (SWHS), for commercial and industrial usage, guarantee for minimum average performance of the supplied system. The design and performance simulation requires sophisticated software tools like TRANSYS with large weather data. The medium and small scale industries are dominated in Solar Thermal Applications in India. These industries lack expertise to use sophisticate software packages and also uneconomical for their range of operations. This paper reviews design and performance simulation methods of SWHS and discusses a simple method to find long term performance of such systems. The test results of a SWHS are presented and compared with the predicted performance.

***Key Words:* Solar Thermal Energy, Solar Water Heating Systems, Utilizability Factor, Design of Solar Thermal Systems**

I. INTRODUCTION

The demand for Solar Heating systems in India is increasing in domestic and Industrial sectors. It is estimated that the demand will increase in double figures in the near future. In industrial and commercial sectors, it is necessary to estimate long term performance of the system and the fraction of energy demand supplied by solar system. This helps to design the auxiliary system working on other sources of energy. The computer simulation technique, like TRNSYS [1], is accurate and gives additional information such as range of system temperature and control strategy. Most of the Solar Equipment Manufactures come under medium and small scale sector, lack expertise, infrastructure and uneconomical to use computerized design methods. Also, these methods requires detail solar irradiation data and load shape & size pattern that are not easily available at many places. These methods are restricted to research labs and to validate the simplified methods. The popular f-chart Method [2], developed for a particular configuration of system, with detailed simulation on TRNSYS, is well suited for sizing domestic water heating systems. The method is developed for set temperature between 50° and 70° C and make-up water enters the system between 5° and 20° C. This not applicable where ambient temperature is above 20° C and to industrial systems where make-up water temperature is generally above 30° C. Table 1 [3] shows the performance deviation of results for an Industrial system calculated with TRNSYS and f-chart method. The concept of utilizability was introduced for long term performance of solar thermal collectors by Whillier [4] and latter generalised for time and geographic location by Liu and Jordan [5]. The method requires tedious calculation involving input data as monthly average hourly irradiation and the results are not completely independent of location. It cannot be completely automated as many graphs are needed for which analytical data is not available. The method is simplified by S. A. Klein [6] using daily average utilizability charts rather than hourly utilizability charts. D. L. Evans, T. T. Rule and B. D. Wood [7] greatly simplified the utilizability method to estimate long term performance of solar collectors. The method is independent of location and suitable for any given inlet temperature. The effect of change in collector design, location and fluid inlet temperature can be easily evaluated. It is suitable for industrial and commercial solar heating systems. The method is used to design with a commercially available solar collector for an industrial water heating system and long term performance is compared with test results.

Table 1 Comparison of Trnsys and F-Chart Results [3]

Domestic Hot Water Heating System Heating (40° C set and 11° C make-up)			Industrial Process (65° C set and 50° C make-up)		
	TRNSYS	f- chart		TRNSYS	f-chart
Jan	0.45	0.47	Jan	0.56	0.55
Feb	0.61	0.64	Feb	0.77	0.68
Mar	0.81	0.81	mar	0.83	0.75
Apr	0.83	0.81	Apr	0.98	0.84
May	0.84	0.90	may	0.99	0.85
Jun	0.93	0.95	Jun	0.98	0.85
Jul	0.96	0.99	Jul	0.99	0.83
Aug	0.97	0.99	Aug	0.98	0.84
Sep	0.93	0.91	Sep	0.98	0.82
Oct	0.76	0.71	Oct	0.94	0.80
Nov	0.51	0.45	Nov	0.76	0.68
Dec	0.36	0.30	Dec	0.60	0.57
Year	0.75	0.74	Year	0.86	0.75

II. THE DESIGN APPROACH

The design approach is to find monthly average performance of the system in terms of the hot water delivery at the set temperature for each month of the year. The monthly average efficiency will be calculated for a selected commercial solar collector with the given monthly average solar radiation. The useful energy gain is [8]

$$q_U = \eta \int H_T \, dt \qquad (1)$$

Using Hottel-whillier expression

$$q_u = \int F_R[(\tau\alpha)H_T - U_L(T_{in}-T_o)]^+ \, dt \qquad (2)$$

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The plus (+) superscript in equation (2) denotes that only positive values of the integrand are considered. The $F_R(\tau\alpha)$ and $F_R U_L$ are characteristics of collector and can be determined from standard collector test methods. The equations (1, 2) relate monthly average efficiency with the solar weather data, from which efficiency can be determined easily. The monthly utilizability for $\bar{\phi}$ is defined as

$$\bar{\phi} = \eta / [F_R(\tau\alpha)] \qquad (3)$$

Using the equations (1, 2, 3) the $\bar{\phi}$ can be expressed explicitly l7]

$$\bar{\phi} = \frac{\eta}{F_R\,(\tau\alpha)} = \int \left[1 - \frac{F_R U_L}{F_R\,(\tau\alpha)} . \frac{(T_{in} - T_a)}{H_T}\right]^{+} dt \Big/ \int H_T dt$$

D.L Evans [7] carried out extensive simulation studies for various locations, tilt factor, characteristic parameters of collector and solar radiation data.

It established that $\bar{\phi}$ is a strong function of parameter $(T_{in}-T_M)/K'_T$

Where T_M is monthly average day time temperature and

$$K'_T = K_T \cos[0.8)]$$

The $\bar{\phi}$ is expressed as quadratic equation in terms of X

$$\bar{\phi} = 1 + AX + BX^2$$

Where $X = (T_{in}-T_M)/K'_T(\beta_M-\beta$

The values of A and B are expressed in terms of collector parameters

$$Y = (F_R U_L)/[F_R(\tau\alpha)]$$
$$A = A_1 + A_2 Y + A_3 Y^2$$
$$B = B_1 + B_2 Y + B_3 Y^2$$

Table 2 gives the values of A_i & B_i for $F_R U_L/[F_R(\tau\alpha)]$ in w/m^2 C and $(T_{in}-T_a)$ in ^0C

Table 2: Values Of Constants A_i & B_i [7]

CONSTANT	VALUES ($W/m^2/sec$)
A_1	$-3.26*10^{-4}$
A_2	$-1.08*10^{-3}$
A_3	$6.49*10^{-6}$
B_1	$3.35*10^{-8}$
B_2	$6.77*10^{-7}$
B_3	$2.12*10^{-7}$

The monthly average utilizability $\bar{\phi}$ can be calculated by knowing the performance characteristics $F_R U_L$ & $F_R(\tau\alpha)$ of a signal collector. The monthly average η and output of the system can be estimated for each month for a given area of collector system. The method allows finding out easily the effect of collector area and inlet temperature to suggest the optimum system for the given specifications, accordingly, the auxiliary energy unit can be specified to meet the year round demand.

III. DESIGN AND TEST RESULTS OF INDUSTRIAL SOLAR WATER HEATING SYSTEM

An industrial solar water heating system is designed using monthly average utilizability method. The year round performance of the system is predicted and compared with the experimental values. Table 3 gives the specification of the system. A commercial solar flat plat collector with selective coating is used and the specifications are given in Table 4. The fig 1 shows the layout of the system.

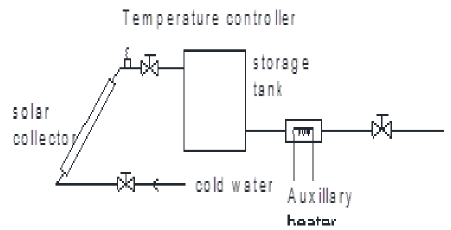

Fig. 1 Layout of Solar Water Heating System

Table 3: Solar Water Heating System Specifications

Place	Mumbai
Number of Solar Collectors	20
Latitude	19.12^o N
Slope of the collector	35^o
Temperature set point	60^o C
Storage capacity	2500 LPD

Table 4: Solar Collector Parameter

Collector absorber area	$1.85\ m^2$
$F_R(\tau\alpha)$	0.69
$F_R U_L$	$4.05\ W/m^2$ C
Selective coating	Black Chrome
Overall Dimensions	2 x 1 x 0.08 m

Fig 2. Gives characteristics of the solar flat plate collector used in the design of heating system.

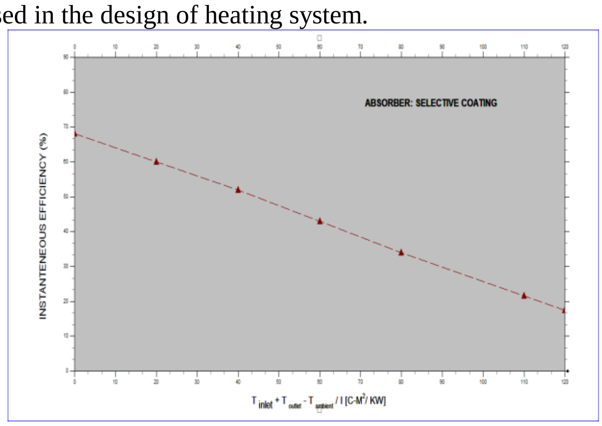

Fig 2 Performance characteristic of solar flat plate collector

For the solar collector used in the system fig 3 gives the relation between $\bar{\phi}$ and the factor $(T_{in}-T_M)/K'_T$.

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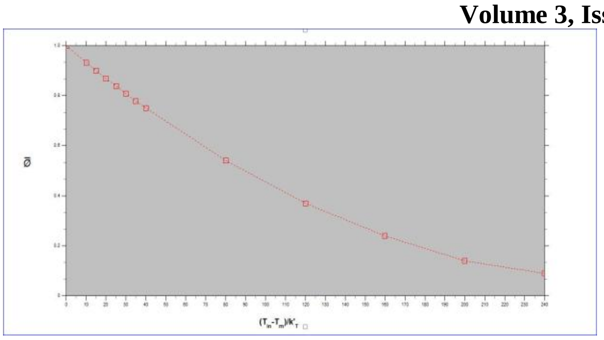

Fig 3. Relation Between $\bar{\varnothing}$ and $(T_{in}-T_M)/K_T'$ for Solar Collector

The curve is represented by the following equation.

$$\bar{\phi} = 1 - 6.753 * 10^{-3}\left(\frac{T_{in} - T_M}{K_T'}\right) + 1.231 * 10^{-5}\left(\frac{T_{in} - T_M}{K_T'}\right)^2$$

The collector array is designed with 5 collectors in row and two collector arrays in series. The correlation factor for parallel series combination of collector is taken into account using the following relation

$$CFN = \frac{1}{N\varphi}[1 - (1 + \varphi)^N]$$

$$\varphi = {(F_R U_L A_{CM})}/{(m\acute{c}p)}$$

Where A_{cm} = signal array area
N= number of collectors in series
m = mass flow rate of water
Table 5 gives the values of calculated output of the system as per the above procedure. The solar radiation data of monthly average solar radiation on horizontal surface H, the factor K_T ,Tilt Factor and day time average temperature were taken from ref [9].

Table 5: Monthly Average Performance Of Heating System

Month	K_T	H KWH /m^2.	T_M ^{0}C	Tilt Factor	T_i ^{0}C	$\bar{\varnothing}$	H	Q_P LPD
Jan.	0.676	5.121	27	1.391	25	0.852	0.533	2613
Feb.	0.675	5.833	29	1.234	27	0.876	0.548	2857
Mar.	0.650	6.310	31	1.050	29	0.893	0.558	2820
Apr.	0.649	6.810	33	0.898	31	0.911	0.570	2822
May.	0.638	6.905	35	0.801	33	0.929	0.582	2720
June.	0.505	5.485	34	0.807	32	0.892	0.558	2020
July.	0.407	4.399	31	0.855	29	0.809	0.504	1450
Aug.	0.420	4.445	32	0.889	30	0.847	0.509	1662
Sept.	0.505	5.054	31	0.967	29	0.861	0.539	2012
Oct.	0.627	5.660	30	1.143	28	0.876	0.548	2638
Nov.	0.694	5.329	28	1.338	26	0.864	0.541	2721
Dec.	0.680	4.948	26	1.441	24	0.842	0.527	2521

The solar water heating system installed is tested for one year. The outlet temperature is set at 60^o C. Every month for fifteen days the output of the system is monitored and averaged for monthly performance Q_t. Table 6 gives the average monthly system output Q_t and the solar fraction f, of heat load met by solar system. For easy of comparison predicted output of the system Q_c from Table 5 is also shown along with Q_t.

Table 6: Solar Fraction of Heat Load

Month	Q_c LPD	Q_t LPD	f
Jan.	2613	2402	0.96
Feb.	2857	2621	1.00
Mar.	2820	2692	1.00
Apr.	2822	2790	1.00
May.	2720	2695	1.00
June.	2020	1820	0.73
July.	1450	1620	0.65
Aug.	1662	1705	0.68
Sept.	2012	1850	0.74
Oct.	2638	2501	1.00
Nov.	2721	2520	1.00
Dec.	2521	2350	0.94

The results are within the limits for industrial and commercial applications using a simple method. The output of the system in rainy season is low due to long rainy period. There are some days in these months where the system delivered the designed output. The required auxiliary heating system can be sized depending upon the lowest output of the month. Also, the optimum area of the collector array and size of the auxiliary heating unit can be arrived after a few numbers of iterations.

IV. CONCLUSION

The method to size the commercial/industrial solar water heating system is simple and suitable for medium/small enterprises using a hand calculator. It also helps finding the effect of inlet temperature and the area of collector array. It allows sizing the auxiliary energy unit. By fixing the solar fraction of the load, optimum size of the system can be arrived with a few calculations.

NOMENCLATURE

A Collector area
A_{cm} Signal array collector's area
f Fraction of the heat load met by solar
$F_R(\tau\alpha)$ Intercept of the collector efficiency curve
F_R Overall heat removable factor of the collector
F_RU_L Negative slope of the collector efficiency curve
H Monthly average daily horizontal radiation
H_T Hourly total radiation incident on collector surface
K_T Ratio of monthly average of daily sum of Global radiation and extra-terrestrial solar radiation on Horizontal surface
T_i Monthly average of inlet water temperature
T_M Monthly average day time temperature

Q_P Predicted monthly average daily system capacity in liters per day
Q_t Measured monthly average daily system capacity in Liters per day
q_u Useful energy collection
U_L Collector thermal loss coefficient
β Tilt of the collector
β_M Monthly collector tilt for optimum incident energy
$\underline{\eta}$ Monthly average system efficiency
$\overline{\varnothing}$ Monthly utilizability factor

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