CASE STUDY OF SOLAR THERMAL PLANT

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ABSTRACT

Conventional Sources of energy are depleting year by year. Fuels are getting costlier resulting in costly transportation and electricity generation. Renewable sources of energy are emerging as promising solution to such energy needs. Government in various countries is encouraging the use of such non-conventional sources of energy. Sun is never exhausting and ultimate source of energy. The energy from the sun can be harvested in two ways; it can be converted directly to electricity by photovoltaic cells or its rays can be concentrated to raise the temperature at particular point. A solar thermal plant at Bergen group, Gurugram (India) was studied and some key results are discussed in this paper. It was a Demo plant that utilizes the solar thermal energy to convert water into steam which was used to pump the water at certain height. There can be other application like energy generation, chemical processing, food processing, textile and other industries requiring process heat. Total solar radiation at location, heat loses, final output power and efficiency of the system is calculated theoretically based on real time data.

Keywords: Solar energy, Solar thermal, Heat loses, solar radiation calculation

Introduction:

Technology: It is based on non-imaging technology in which the solar radiation is concentrated after multiple reflections on the tube placed at the center. It gives wide acceptance angle, maximum concentration through sunshine hours and it also eliminates the use of solar tracker. [1]

The non-imaging reflector consists of a series of stationary evacuated borosilicate glass tubes with solar thermal absorbers. The design consists of a set of parallel cylindrical absorbers, each of them placed in the center of an evacuated glass tube. Each absorber is thermally connected to a manifold using a U tube. Each Glass tube is placed in center of a non-imaging reflector. It is a fully integrated system with no moving parts, comprised mostly of aluminum and glass, insures the easy maintenance and long life of the system. NICC provides remarkable 50-55 % of efficiency and the temperature of the fluid in the tube can reach at maximum 200 Deg C. [4,7]

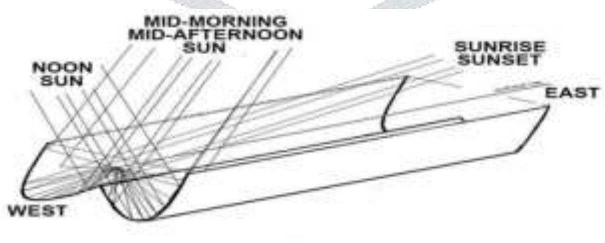

Figure 1 NICC Collector

Plant Layout:

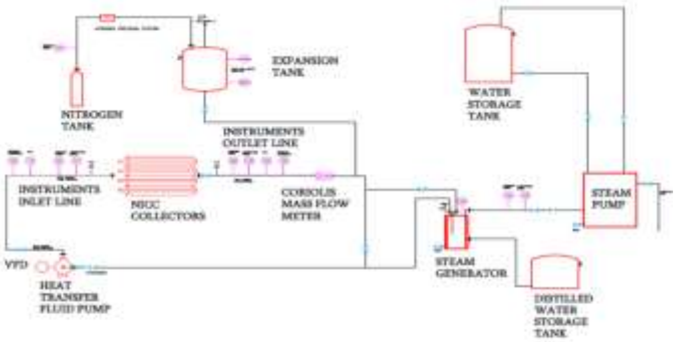

Figure 2 Plant Layout

The NICC collector collects the heat from the sun and transfers to the oil running in the pipes. The oil is circulated through the system using a pump. The heated oil is then directed to the steam generator, where the water is converted to the steam. Hot oil tubes runs through the distilled water converting the water to steam. The steam is collected in a chamber maintaining the pressure. When the desired pressure is reached the steam is then supplied to the half horse power steam pump which pumps the water to a height of 8 meters. [2-3]

The oil pressure in the system is maintained by expansion tank which is backed by nitrogen tank. It plays two important roles, it maintains the pressure of the oil which is flowing in the system and the oil is charged in the system through expansion tank.

Calculation of Total Solar Radiation:

The solar radiation data for any location is freely available. We can find the solar radiation falling in Gurugram in months of May and June by taking the average of previous years data. The solar radiation increases and reaches its peak at 12 NOON, after which it decreases gradually. Hence we can select 11:00 AM, 15^{th} of April for calculations.[6]

I_D (Direct Radiation), $G_{DHI} = 259$ W/m^2

I_B (Beam Radiation), $G_{DNI} = 417$ W/m^2

I_T (Total Radiation), $G_{GHI} = 648$ W/m^2

Hence, n=166 as on 15^{TH} day of 6^{TH} month JUNE.

Latitude for Gurgaon $\varphi = 28.47$

Declination angle :

$$\delta = 23.45 \sin\left[\frac{2\pi}{365}(284+n)\right]$$

$\delta = 23.312$

Hour angle : $\omega = -15^{O}$ as on 11 am

Slope : $\beta = 25^{O}$

Surface azimuth angle $\Upsilon = 0^{O}$ as system is facing south

Angle of incidence θ:

$$\cos\theta = (\cos\phi\cos\beta + \sin\phi\sin\beta\cos\Upsilon)\cos\delta\cos\omega + \cos\delta\sin\omega\sin\beta\sin\Upsilon + \sin\delta(\sin\phi\cos\beta - \sin\beta\cos\Upsilon)$$

Cos $\theta = 0.9267$ or $\theta = 22.07$

Now, $G_{i,total} = G_i + G_{i,DHI}$

$G_i = G_{DNI}$ X Cos θ

=417 X 0.9267

=386.43 W/m^2

$G_{i,DHI} = G_{DHI}$ X Cos β

=259 X 0.9063

=234.73 W/m^2

$G_{i,total}$ =386.43 + 234.73

=621.16 W/m^2

Energy Calculation:

Energy falling on collectors can be calculated by multiplying the total surface of the collectors to the total radiation incident on the surface. Total area of collector was 20 m^2.

$Q_{solar} = A_{net} X G_{i,total}$

= 20 X 621.16

= 12423.2 W

Hence the total solar energy incident on the reflectors was Q_{solar} = 12.42 KW. We can say that this is the maximum energy which is received by the system. We can now calculate the energy converted by the NICC collectors by simply multiplying by its efficiency.

(I) Heat transfer from solar radiation to oil:

Taking 55% of Q_{solar} which will be transferred to the oil

Therefore, Q_{oil} = 6832.76 W

= 6.83 KW

(II) Heat loss through Manifold:

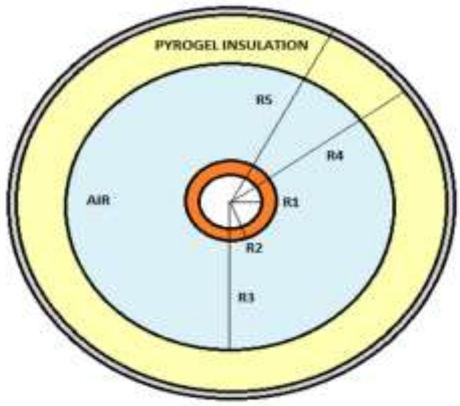

Figure 3 Manifold Cross Section

In the manifold the MS pipe is passing through the air cavity, which is surrounded by the pyrogel insulation and steel sheet casing. Taking the radius and thermal conductivity of different medium the heat loss through manifold can be calculated by using the formula.

$$Q_{manifold\ loss} = \frac{2\pi L\ (\ t1 - t5)}{\frac{\ln(R2/R1)}{K_P} + \frac{\ln(R3/R2)}{K_A} + \frac{\ln(R4/R3)}{K_I} + \frac{\ln(R5/R4)}{K_B}}$$

$$Q_{manifold\ loss} = 106.45\ W$$

(III) Calculation for heat losses through the insulated pipe

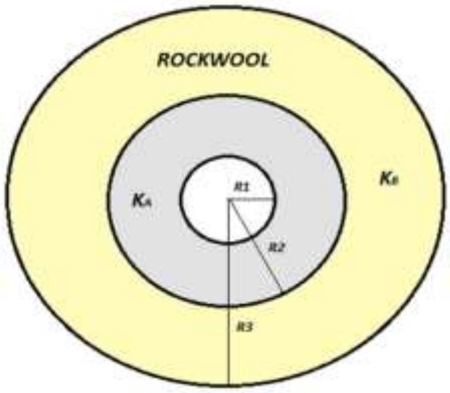

Figure 4 Insulated Pipe Cross Section

The pipe which is running through the system is insulated with Rockwool to minimize the heat losses. Now there are two pipelines running in the system. One is Hot Pipe which is collecting the heat from the concentrated heat collectors and delivering it to steam generator and the other is cold pipe which collecting the cooled oil from steam generator and circulating it to the heat collectors. The heat loss from these pipe lines can be calculated by using formula. [10-11]

$$Q = \frac{2\pi L\,(t1 - t3)}{\frac{\ln(R2/R1)}{K_A} + \frac{\ln(R3/R2)}{K_B}}$$

Where, t1 = temperature of the oil flowing in the pipe

t3= outside temperature of insulation used

K_A= thermal conductivity of MS schedule 40 pipe

K_B= thermal conductivity of insulating material

Total Heat Loss through Pipe = Heat loss through Hot Pipe + Heat Loss through Cold Pipe

$Q_p = Q_h + Q_c$

$Q_p = 0.251 + 0.209$

$Q_p = 0.46$ KW

(IV) Heat transfer to steam through boiler:

It is assumed that the efficiency of the steam generator is 90 %. Hence we can calculate the final power which is received at the application end by considering all the losses in the system and the efficiency of the components.[9]

Q steam = 90% of Q′ oil

Since, Q′ oil = Q oil - Qp - Q manifold loss

Q′ oil = 6.832 - 0.460 – 0.106 KW

Q′ oil = 6.266 KW

Q steam = 5.63 KW

Conclusion:

From the above data we can calculate the efficiency of the system by taking the radiation falling on panel as input and energy at application point as output.

$\eta = \frac{Qsteam}{Qsolar}$ X 100 = 45.32 %

Now we can compare this theoretical efficiency with the actual efficiency by the actual data collected from the system.

Table 1 Actual Data Analysis

Time (Hrs)	Solar Power Incident on Pannel (KW)	Power Output (KW)	Efficiency
9:18	8.96	2.676	29.87
9:26	9.62	3.076	31.98
9:46	10.3	4.676	45.40
10:03	10.96	4.896	44.67
10:23	12.12	5.44	44.88
10:40	12.44	5.516	44.34
10:58	12.96	5.384	41.54
10:59	12.96	5.384	41.54
11:14	12.96	5.404	41.70
11:25	13.82	5.544	40.12
11:31	13.82	5.544	40.12
11:38	13.8	5.444	39.45
11:45	13.8	5.444	39.45
12:00	14.24	5.524	38.79
12:11	14.32	5.476	38.24
12:23	14.46	5.496	38.01
12:27	14.46	5.496	38.01
12:38	4.54	1.808	39.82
13:04	12.4	4.796	38.68
13:10	9.78	3.904	39.92
13:17	9.78	3.904	39.92
13:45	13.82	5.604	40.55
14:56	11.3	4.94	43.72
15:05	9.72	4.34	44.65

The average efficiency was found to be 40.22%. Which is little less than the theoretical efficiency. It is clear from the data that there are other losses which are involved in the system. A graph can be plotted between the solar power available to the system and the power generated at the point of application to get some clear image between the variations of power. The dip in graph shows the overcast condition. [5]

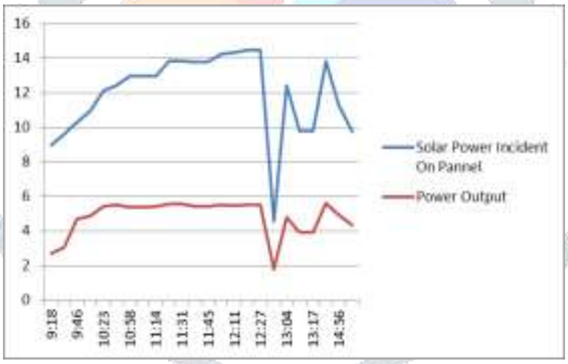

Figure 1 Time VS Power Graph

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