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Performance Characterisation of Scheffler Solar Concentrator and Primary Feasibility Assessment of Performance Improvement Using Combination System of Scheffler With Flat Plate Concentrator

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Abstract

Scheffler fixed focus concentrators are used for medium temperature applications. These concentrators are lateral sections of paraboloids and provide fixed focus away from the path of incident beam radiations throughout the year. In this paper design of a Scheffler Solar Concentrator system and it's thermal characterisation is presented.

In the second part of the papar thermal characterization of a flat plate collector is presented which was done under identical conditions as the scheffler concentrator. In case of flat plate collector efficiency is high in the low temperature region (50^0C to 80^0C) while that of point focus concentrator was found to be low and in subsequent temperature range (80^0C to 150^0C) it increases and remains stable almost throughout the range.

By super imposition of two performance curves, system of flat plate with scheffler may give a stable higher efficiency throughout the range of low to medium temperature range (50^0C to 150^0C)

Keywords: Solar, thermal, concentrators, characterization, performance, scheffler.

Introduction

A scheffler concentrator can be used for medium temperature industrial process heat applications. Hence it's thermal characterization is an essential requirement.

Generalised standard test procedure is not currently available for such concentrators and hence an attempt is made to evolve such standard procedure for characterization. In this paper, performance of a scheffler solar concentrator was evaluated under different operating and natural conditions. Performance curve has been constructed by calculation of efficiency for temperature ranging from 50^0C to 150^0C at an interval of 10^0C.[1]

Performance curve for flat plate collector was constructed by passing water and outlet temperature fixed between 40^0C to 70^0C at an interval of 10^0C. The experimentation work was done on a scheffler and flat concentrator constructed specially for the purpose and organizing an experimentation setup well calibrated.

Design of Scheffler Concentrator For Reflector Area

The area of the reflector is obtained from all the quantity of heat to boil water to steam in relation to the design insulation.[2]

Suppose 8 kg of water is present in scheffler receiver.

Heat required to boil 8 kg of water.

$$Q_1 = M \times C \times \Delta T$$

$$C = Sp.Heat\,capacity\ of\ water\ (J/kg^{-1}K^{-1})$$

= 8 x 4200 (100-32)

= 2284800 Joules.

Heat required vaporizing 4 kg of steam.

$$Q_2 = 4 \times 2.2 \times 10^6$$
$$= 9040000\ \ Joules$$

Losses of receiver [4]

$$\frac{Q_{loss}}{A_r} = h_w (T_r - T_a) + \varepsilon 6 (T_r^4 - T_{sky}) + U_{cond} (T_r - T_a)$$
$$= (h_w + h_r + U_{cond})(T_r - T_a)$$
$$= 495.6\,watts.$$

Total heat required per hour

= 2284800+9040000/3600

= 3145.7 watts

Power needed for boiling 3145.7+495.6 = 3641.3 watts

Applying solar isolation and reflectance of the mirror for the design, the effective solar beam,

I_t = 0.85 x 740 = 629 watts / sq.m.

Using a design factor 1.5 to calculate area of reflector (Duffie, 1990) [4]

$A = (3641.3 / 629)^{1.50}$

= 8.7 sq.m.

Characterisation of Scheffler Concentrator

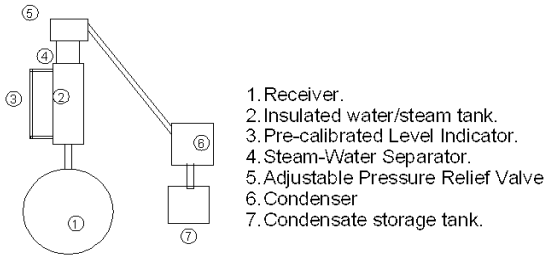

Figure 1: Experimental Set-up for Scheffler

Test Procedure For Scheffler Concentrator

1) Working fluid water is poured into receiver. Water level indicator mounted on steam water tank indicates water level in the tank. Steam water tank was full of water.
2) For every ten minutes global, indirect and direct radiations were measured.
3) Pressure gauge which was mounted below the receiver indicates pressure of steam produced.
4) When pressure gauge indicates 1, 2, 3, 4 and 5 bar, how much steam was developed was indicated on glass tube of water level indicator for these pressures. Rates of steam formation are measured.
5) Total time period for testing 9.30 to 4.30 p.m.
6) Pressure relif valve was mounted on the steam water tank. Temperature above 100^0C needs a pressure, relief valve so that steam of 100, 120, 140, 160 degree C can be generated.

Performance of Scheffler

Time 12 to 1 (afternoon)

Pressure built-up in the receiver

Pg = 3 bar

P = 3 + 1 (atm) = 4 bar

Solar radiation

I = 663 w/m^2

m_s = Mass of steam produced

= 4.2 lit

= 4.2 * 0.91 = 3.833 kg/hr

h_{fg} = 2132.9 kJ / kg (heat of steam)

Heat output = m_s* h_{fg}

= 3.833 x 2132.9

= 8151.94 kJ

η = Heat output / Heat input

= 8151.94 / 15514.2 = 53%

Heat input = A_p = Aperture area of collector, m^2

= 6.5 m^2

I = Solar radiation

= A_p x I

= 6.5 x 663 watts

$$= \frac{6.5 \times 663 \times 3000}{1000} kJ$$

= 15514.2 Kj

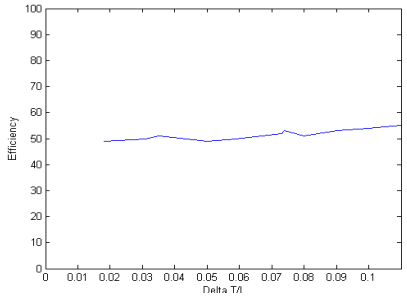

Figure 2: Performance Curve for Scheffler

Results

Performance curve of scheffler concentrator indicates that efficiency for temperature range 80 to 150 is maximum and low in lower temperature region due to high concentration ratio (75)

Characterisation of Flat Plate Collector

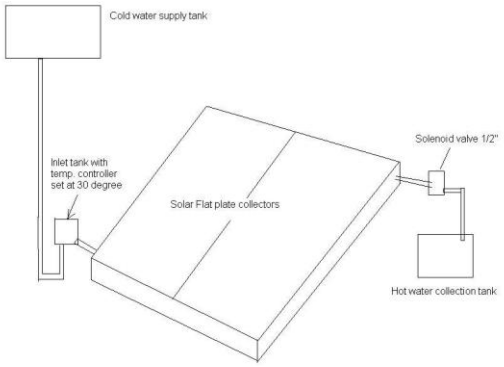

Figure 3: Experimental Set-up for Flat Plate

Test Procedure For Flat Plate Collector

1) Inlet temperature of water is kept constant as 32^0C.
2) Solenoid valve is mounted at outlet of flat plate collector.
3) Reading were taken by passing water at 32^0C and taking it out at fixed temperatures 40, 50, 60, 70 degree C.
4) When specific outlet temperature was reached solenoid valve opens and flow rate was measured in a pot for every thirty mins.
5) Four days trials were taken for four different outlet temperatures (40, 50, 60, 70 ^{0}C)

Performance For Flat Plate Collector

Time = 12 to 12.30

It = 983 w/m^2, Collector area A = 2 m^2 = Latitude – 18.31^0, declination angle – 4.413^6 hour angle – 7.5^0, incident angle – 4.413^0.

m_w – mass flow rate of water

= 32 lit/30 min, $\Delta T = (50 - 32)$

$$\text{Efficiency} = \frac{m_w C_{pw} \Delta T}{I A} = 62.13\%$$

Performance curve for flat plate collector as well as scheffler concentrator.for comparision

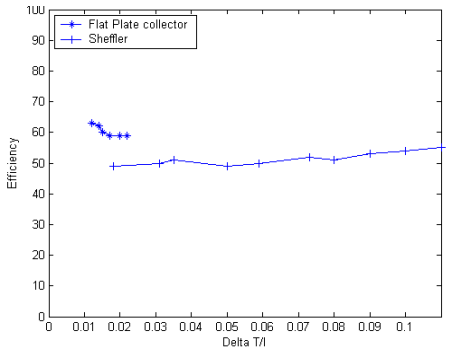

Figure 4: Performance curve for Flat Plate and Scheffler

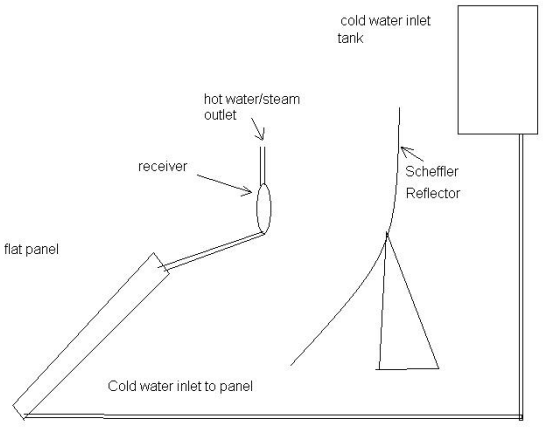

Figure 5: Experimental Set-up Combined unit

Result & Discussions

From the two graphs of two concentrators it is cleared that initial heating of water is in flat plate collector (up to 50^0C) and then that water is supplied to scheffler for steam generation.

Considering maximum efficiency points of flat plate in lower temperature region and maximum efficiency points of scheffler in higher temperatures region, then the efficiency of Solar System is maximum in lower as well as higher temperature range (from 32 to 150^0C)

Due to initial heating in flat plate collector scheffler concentrator area for 4 kg steam generation reduces from 8.7 sq.m to 7.10 sq.m.

Capacity of flat plate collector is 120 lits of 60^0C water, within six hours (standard size of $2m^2$ area)

Tests were conducted on same days in the month of April for flat plate and scheffler concentrator.

Due to initial heating in flat plate collector steam generation rate increases as compaired with only scheffler concentrator.

Conclusion

To determine the thermal performance of a scheffler concentrator, a test procedure is proposed and tests were conducted. Scheffler reflector area was designed for medium temperature range (32 to 150^0C). It is proposed a combined Solar System of flat plate and scheffler concentrator for better efficiency throughout the temperature range.

Acknowledgment

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Nomenclature

It	:	Global radiation.
I	:	Direct Radiation
Tr	:	Receiver temperature.
Ta	:	Ambient temperature.

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