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Exergy Analysis of Steam Generating Solar Concentrators

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Abstract

Generation of the steam using solar power is not a new concept. However, to study the properties of steam harnessed via the solar concentrator in a hilly region (in this case Chandwad) is undertaken in this project. The aim of this research is to find out a growth and actual exergy analysis of solar collector to appraise the actual exergy attainable from the setup. By performing energetic analysis, we can draw a graph of how the exergy destruction and loss are distributed along the surface of the collector. The main purpose of using exergy analysis is to find out the exergy available of energy losses at the various components in the test setup. With the help of this, we are able to do the correct analysis of the system to find out its effectiveness and can be used more effectively in another application in future. Here we are considering the movement of the collector as the sun rotates with the help of sun-tracking mechanism. By performing the exergy analysis we determined the actual values of the exergy available. This kind of information is used in case of the thermodynamic system to work with solar power systems very effectively to gain the efficiency of the available ones.

Keywords: Solar Energy. Exergy Analysis, Availability, Scheffler concentrator

1. Introduction

In modern times we are becoming purely dependent on the use of fossil fuels and the burning of more and more fossil fuels leads to the formation of greenhouse gases. Therefore the greenhouse gases are totally responsible for the unexpected changes in the climate. Solar energy is the biggest source of energy in the world and the part of that can be used with available technology greatly fulfill the need of primary energy requirement. More than that, solar energy is free, clean, and renewable. Solar collectors are used to converting the solar energy radiation into power. The solar concentrator used in this research with the reorganized cavity receiver is operating in tracking mode. The receiver is part of the system which is used to absorb the solar radiation and convert it into some other useful form of energy form; it consists of the absorbers with insulation and its associated covers insulation. The concentrating collectors are used to direct the solar radiation on the surface of the plain receiver. Solar radiation enters the collector through the opening area called as an aperture of the collector. Firstly in the 1980'sWolfgang Scheffler has been designed the Scheffler concentrator of parabolic type. From that period many improvements in solar concentrator are done. The new solar parabolic dish having area 16m2 is partially based on the previously used solar collector having area of 12 m^2.The parabolic dish has the large area which creates trouble to handling, it divides into two parts and joint with the use of flanges whenever required and supports the forceful tracking mechanism. This designed odd collector is done by much more meeting and discussion of the thermal department. Because of that easy transportation and handling is possible at the site and unnecessary efforts are avoided. After taking some tests on the concentrator we found that the considerable amount of heat loss is taking place at the receiver. The receiver plays an important role in radiation absorption, It is expected that the cone type receiver will absorb more radiations and increase the efficiency of the system. As we compare the plate and cone type of receiver, cone type is more effective as it absorbs a lot of radiations. Scheffler is a type of fixed focus solar concentrator. As it uses the tracking mechanism to maintain the fixed focus it is termed as rotating concentrators with the constant focus point.The small lateral section of the paraboloid is termed as a reflector.Due to the inclined cut, it produces the armed appearance of the collector. The sunlight falls on the collector is directed to the focus which is at some distance from the reflector point indirectly. For the project purpose, the area under consideration for the test is 16m^2.The opening area of the concentrator is near about 11.5 m^2. This approves to collect more energy at one point and therefore we don't need to use the double dish arrangement which reduces the cost requirement for the principle and construction of the receiver. The primarily designed parabolic collector has totally made over and made more powerful. For easy handling and transportation, the parabolic dish collector is divided into two parts and connected with the help of flanges whenever required. The material used for the construction is mild steel. The collector is fitted on the powerful tracking mechanism which helps to collect the more and more solar rays at one point. The parabolic dish collector is made up of several numbers of mirror glass pieces which help to reflect the sun rays near about 93%.the sunlight is collected on the round receiver having 40 cm diameter with reference to the end of the revolving support at a distance of 5.2m.collector dish gives 8KW at 1000W/m^2 solar radiation as a maximum output. The maximum temperature of the focus is 350°C.

Literature has been studied and some of the findings are highlighted below;

In the case of Scheffler solar concentrator, the heat losses at receiver are taking into consideration. The convection and radiation loss are taking place at the receive. Therefore to reduce this kind of heat losses we use the insulation to the receiver and try to improve the efficiency of the Scheffler solar concentrator. Also, we are finding exergy losses and exergy efficiency. Wolfgang Scheffler [1] describes the idea about how to design the Scheffler reflectors and how it wad done.the analysis is done by considering the various parameters like by stopping the sun, by moving the sun, bending and flexing etc.Golopilz[2]developed and test 16m^2 parabolic dish with cavity receiver for a solar steam system considering increased Dish size, flange system, improved receiver design and concluded that as the area of Scheffler dish increases efficiency isalsoincreses.P.Rajamohan,R.V.Jebarajsekhar,N.SankaraSubramanian and K.Ramanathan[3]observed that lower temperature ranges can be achieved by parabolic dish i.e. below 180°C but for higher temperature ranges we could switch over for Scheffler concentrator which gives comparatively good output than that of the parabolic one. Methodology for performance evaluation of fixed focus moving solar concentrators. and R. Pillai, Ajay G. Chandak[4]These concentrators are also now being used for other thermal applications up to 150°C.A new methodologies has been developed for testing of concentrators taking into account latent heat required for phase change at constant pressure steam generation. A Scheffler concentrator is evaluated using this test procedure. For particular test conditions, it is observed that the efficiency of a 16 m^2Scheffler concentrator reduced from 41 ±3.5% to 19 ±1.6% when the steam generation pressure increased from 2 bars(g) to 10.5 bars(g). This methodology of performance evaluation can be used for characterizing the Scheffler concentrator. S. J. Bhosale, S.B. Cedar and J.K. Nayak [5]Testing of different types of solar concentrating collectors of various sizes has been carried out at various places around the world but a generalized standard testing procedure is not available. Besides different test procedures are followed for testing of concentrating collectors generally the linearised efficiency characterizes the performance of a solar flat plate collector in terms of two parameters, m F η0 and m F U. But for high temperature concentrating collectors, U value is not constant but depends upon receiver temperature, air temperature, and receiver inclination. It is a Fresnel paraboloid reflector with 160 m^2 aperture area having cavity receiver at its focus. It has differentially unclened reflector facets, which concentrate the incoming beam radiation on to a small area at 8 m focal length. The radiation is absorbed by downward facing cavity receiver designed for minimum thermal loss. An insulated pipeline delivers this heat energy to the user. The dish has an electronically controlled mechanism for continuously tracking the Sun from east to west during the day around a polar axis as well as for north to south seasonal tracking. The unit is named as ARUN™ and is installed at Latur (18°23'N, 76°36'E) in a dairy for pasteurization of about 25000 liters of milk per day at the annual solar fraction of about 0.7 to 0.8.The thermal output of dish to is around 50 to 80 kWth. To determine the thermal performance of a paraboloid concentrating solar collector, a test procedure is proposed and the field test was conducted.

2. Problem Definition, Objective

Problem Definition:

Exergy analysis is one of the best analysis methods to find out the working efficiency of the system. With the help of exergy analysis, we are able to find out the exergy destruction and loss is spread over the Scheffler concentrators, all these things are carried out by considering the solar radiations incident on the Scheffler.by performing the exergy analysis we are able to draw the result graphs and from that, we can conclude the results. Also, the amount of heat loss to find out

Objective:

The objectives of this research are:

1. Todo the exergy analysis and accumulation of steam generating solar concentrator.
2. To calculate the actual exergy available from the system.

Scope:

Scheffler concentrators were initially designed and developed for the sole purpose of cooking wherein the testing was only limited to boiling water and its capacity to be utilized for cooking purposes. Recently they have found their use in thermal applications with temperatures up to 1500°C. The concentrator under testing will be evaluated taking into consideration the latent heat required at constant pressure for steam generation. This evaluation will be further assisted by superheating of steam in an electric calorimeter. For particular test conditions, it is observed that the efficiency of a 16 m^{2}Scheffler concentrator reduced from 4l±3.5% to 19± 1.6% when the steam generation pressure increased from 2 kg/cm^2(g) to 10.5 kg/cm^2(g). This criterion will be compared with the incorporation of the electrical calorimeter to a condition which is different from the one being previously tested which in this case is hilly terrain, known as Chandwad with steam generation up to a pressure range of 2-14 kg/cm^2. Thus the above-mentioned methodology of performance evaluation can be used for characterizing the Schefflerconcentrator.A procedure for testing of solar concentrators at different temperatures even higher than the boiling temperature of water.

Analysis:

Thermal Performance Test;

To calculate the sensible heat during solar heating as

Qsensible = mwCpΔT……… (1)

and latent heating as

Qlatent = mv (x hfg)………… (2)

Where,

mw =mass of water heated in kg,

mv = mass of water evaporated during test in kg,

Cp = specific heat of water as 4.186 kJ/kg.°C,

ΔT = temperature rise of water in °C,

x = dryness fraction of steam generated and

hf_g = latent heat of water as 2269 kJ/kg.

Khalifa et al. used to evaluate solar cooker performance by calculating the overall thermal efficiency ηu as well as the specific time ts and characteristic boiling time tc. The ts (min m^2/kg) represents the time required to boil 1 kg of water using a solar cooker of 1 m^2 aperture area. The tc (min m^2/kg) may be used as a constitution tocomparedifferent solar cooker designs under various solar power levels. Mathematical expressions for ts, tc and tu are given as below

$$ts = \frac{\Delta t A_c}{m_w} \quad ...(3)$$

$$tc = \frac{t_s I_{av}}{\dot{I}_{av}} \quad ...(4)$$

$$\eta u = \frac{m_w C_p \Delta T_f}{I_{av} A_c \Delta t} \quad ...(5)$$

where

mw= mass (kg) of the Woking fluid,

Cp = specific heat (J/kg-K) of the working fluid,

Δt = time required to achieve the highest temperature of the working fluid,

Iav = average solar intensity (W/m^2) during the time interval Δt,

$\dot{I}_{av}$ = reference average solar intensity equals 900 W/m^2,

ΔTf = temperature difference between the maximum temperature of the cooking fluid and the ambient air temperature and

Ac is the aperture area (m^2) of the cooker.

3. Experimental Setup

Figure frame structure, the material used for the frame is mild steel. All the other components like the water tank, receiver, steam separator, electric calorimeter, and condenser with safety valve are mounted on this frame. The system is insulated with glass wool and asbestos rope wherever necessary and mica sleeves are placed over the heater connection wire for heat protectin.

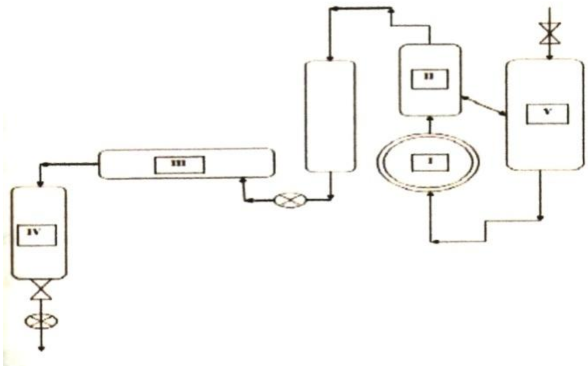

Fig.1 Schematic of Experimental Setup

Setup:

Fig 2. Actual Scheffler Solar Concentrator Setup

3.1 Development of New Tracking Mechanism:

Scheffler solar concentrators are polar mounted. Rotating axis is mounted in a North-South direction at an angle equal to latitude angle of the place.This rotating pipe is driven by tracking mechanism and it keeps the focus on to the receiver throughout the day. Optical leverage of the concentrator is very large and distance from the reflector to the focus is 4 meters and hence any small change at reflector end results in large movement of focus. It is noticed from the field installation that any error in locating exact south direction or any error in setting the stand at latitude angles results in unwanted movement of focus.

Schefflerconcentrators when launched were provided with the clock mechanism. A dead weight used to be placed at the higher elevation and potential energy of this weight used to drive a clock mechanism which used to turn the rotating arm at speed of 15° per hour. Clock mechanism has too many moving parts and friction of the system can change during half rotation, the speed of the clock mechanism can change. There were lots of field complaints. Many manufacturers use timer based D.C. motor along with large mechanical reduction. A wiper motor of a car is used as a D.C. motor and a battery is charged with a 5 Watt solar PV panel. This system is more reliable. However change in friction, over or under voltage from battery due to over or under charging changes motor speed. In such cases the system malfunctions. An active tracking method can calculate the altitude angle and azimuth of the sun. A simple innovation was added to take care of this problem in this system. A control circuit of the wiper D.C. motor was added after the timer. The timer triggers the control circuit at a predefined time interval. One trigger to the control circuit rotates the D.C. motor by one rotation before it stops. Effectively the D.C. motor turns through one rotation in the time interval between two triggers. The time interval between two triggers can be very precisely set using On-Off Timer. This innovation ensures that the final effective speed of the rotating arm is 15° per hour.

Fig.3 Sun Tracking arrangement Assembly

3.2 Receiver:

The receiver is made of mild steel plates 0.5 m internal diameter and 50 mm deep. The mild steel plates are given the desired shape on fixtures and then welded. After welding, and finishing by the grinder. These receivers are tested under water pressure up to 16 kg/m2. For testing of the receiver, the inlet pipe is welded to a hand pump and equipped with two pressure gauges. The exit valve is closed. As water is pumped in the receiver, and the pressure starts building up and shape of receiver becomes more curved under the pressure. The pressure is increased to 16 kg/m^2 gradually. Any leaks of water are checked during the pressure rise

Fig.4 Receiver

The specifications of test setup:

1)Area of Scheffler concentrator: 16 m^2.

2)Aperture area = 11.5m^2 and

3) Tracking mechanism is PLC based which rotates 150°/hr in clockwise direction

4) Test setup layout:

i. Water storage tank having the capacity of 35lit.
ii. Heat receiver (d= 0.5m)
iii. Electrical calorimeter
iv. Condenser (cross flow type)

The testing equipment:

1) Anemometer: 0.4-30 m/s capacity
2) Infrared Thermometer: 0-650 °C, €=0.95
3) Solar meter (W/m^2)
4)RTD's (Temperature sensor) : 0650°C(platinum)
5) Electrical energy meter
6) Pressure gauge: 0-25 bar

IV. RESULTS AND DISCUSSIONS

Following are the figures which give the result for different receiver temperature and for different mass flow rate.Exergy destruction due to absorption increases with increase in mass flow rate. Theexergydestruction is very small by pressure drop and can be neglected. Since its contribution is much smaller than other exergy rate destruction.

Fig.5 show that as the receiver temperature increases the exergy efficiency increases.

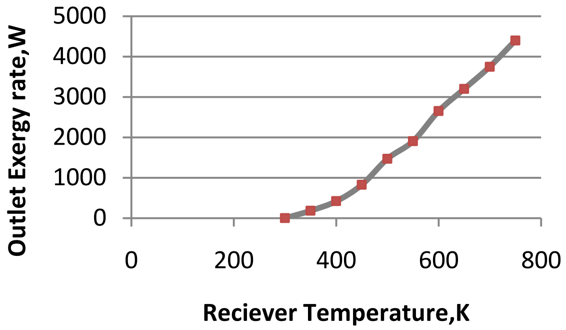

Fig.5 Outlet exergyrate,W versus Receivertemperature, K

Fig. 6 show that as the mass flow rate increases the exergy efficiency increases up to the optimum is reached.

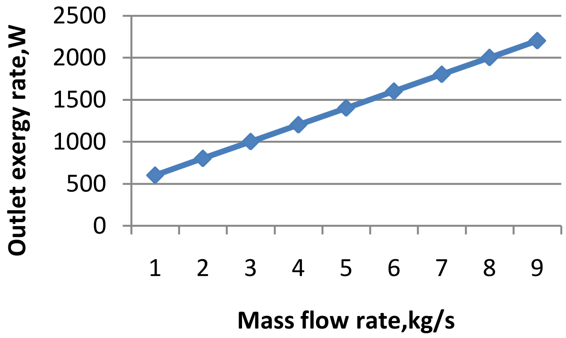

Fig.6 Outlet exergyrate,W verses Mass flow rate, Kg/s

V. Conclusion

-The efficiency of the Scheffler concentrator is increased by using insulation to the cavity receiver.

Cavity receiver gives better efficiency than that of the plain cylindrical receiver.

-Exergy efficiency increases as the receiver temperature increase till the optimum temperature.

-As the mass flow rate increases the exergy efficiency increases.

-By using exergy analysis we able to use solar energy more effectively.

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VII.References

1. Wolfgang Scheffler "Introduction to the revolutionary design of Scheffler reflectors", International Conference on Solar Cookers, Spain, 15-16 July 2006, Germany, e-mail: Info@Solare-Bruecke.org.
2. Khalifa AMA, Taha MMA, Akyurt M. Solar cookers for outdoors and indoors. Energy 1985;10(7):819–29.
3. Khalifa AMA, Taha MM, Akyurt M. On the prediction of solar cooker performance and cooking in Pyrex pots. Solar Wind Technol 1986;3(1):13–19.
4. Suharto H, SayighAM, Abdullah K, Mathew K. The comparison of three types of Indonesian solar box cookers. Renew Energy 2001; 22(1-3):379–87.
5. Nahar NM. Design, development, and testing of a double reflector hot box solar cooker with a transparent insulation material. Renew Energy 2001;23(2):167–79.
6. Dr. Kundapur Ashok, Dr. Sudhir C.V., Proposal for new world standard for testing solar cookers, International solar cooker Conference, at Granada, Spain in June 2007.
7. Varghese, J., Batch Type Solar Water Heater, Thesis submitted to S. G. Amravati University,
8. India, 2000, pp. 28-32.
9. Patel NV, Philip SK. Performance evaluation of three solar concentrating cookers. Renew Energy 2000; 20(3):347–55.
10. Sharma SD, Buddhi D, Sawhney RL, Sharma A. Design, development and performance evaluation of a latent heat storage unit for evening cooking in a solar cooker. Energy Convers Manage 2000;41(14): 1497–508.
11. SolarCookerInternational., http://www.solarcooking.org.
12. Olwi I, Khalifa AMA. Numerical modeling and experimental testing of a solar grill. J Solar Energy Eng1993;(115):5–10.
13. Dr. Kundapur Ashok, Dr. Sudhir C.V., Proposal for new world standard for testing solar cookers, International solar cooker Conference, at Granada, Spain in June 2007.
14. Solar Cooker International., http://www.solarcooking.org.
15. Shaw, S. Development of a comparative framework for evaluating the performance of solar cooking devices. Thesis submitted at Rensselaer Polytechnic Institute, USA, 2002.
16. Varghese, J., Batch Type Solar Water Heater, Thesis submitted to S. G. Amravati University, India, 2000.