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Design and Characterizations of Solar Steam Engine

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***Abstract*- In this paper a conceptual design of solar steam dish concentrated (2 m^2) area was used .With cylindrical receiver as a solar boiler and two axis tracking system .the experimental were conductance from 80-150 °C under a mean solar flux of (250 -780 W/m^2) concentration product analysis of this innovative solar boiler applied drive to steam engine. We have found that overall efficiency of the conversion from direct solar irradiation energy to above 20%.**

***Keywords*- Solar energy, solar dish, electrical generation, steam engine, solar steam generator, Characteristic curve**

I. INTRODUCTION

The rapid growth and change in the energy utilization sector with its related impact on environmental awareness have lead to more interest in the utilization of renewable energies cooling techniques in the last years with a focus on solar energy. In 2006 presented the most recent over view of possible technologies for solar powered refrigeration and air–conditioning systems [1]. Throughout the literature, studies with water as working refrigerant in solar driven were reported [2-3]. In 2008, optical and thermal losses occurring in collector affect the performance of focusing type collector [4]. Today, several companies work on parabolic trough systems such as Solel [5], Schott [6], Acciona [7] Euro Trough [8] and Archimed Solar Energy [9]. Just to mention some of them, manufacturers offers various kinds of collectors, with different performances and temperature operation ranges. Thermal power plan costs are still high and mainly related to the solar field. In recent years, the idea of analyzing a fuel cell –based energy conversion system by mean of an energy analysis has become popular[10-12].In particular when dealing with solar – powered fuel cell system ,an energetic analysis simply based on the first law of thermodynamics neglects a major point :a fair comparison and evaluation is needed for different qualities of energy namely solar irradiance ,chemical energy stored in fuels ,heat and finally electrical energy[13-15]. These different forms of energy provide different availabilities to be converted to useful work. The solar driven steam jet ejector chiller (SJEC) is a new device for solar air-conditioning [16]. The purpose of this work is to analyze and optimize a small, portable solar steam engine as well as the influence of the intensity of solar radiation.

A. Theory concepts

The basic principle adopted in the construction of the parabolic dish solar steam is that when parallel rays of light from the sun close to and parallel to the principal axis are incident on a concave or parabolic shaped mirror, they converge or come together after reflection to a point (F) on the principal axis called the principal focus as shown in Figure 1.

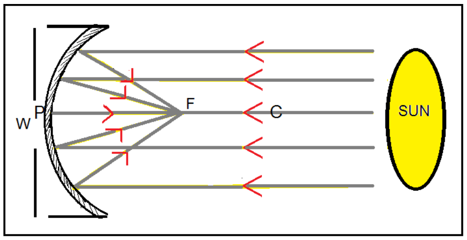

Fig. 1 Parabolic Dish, where F represents Principal Focus, C is Centre of Curvature, and w is Aperture is the width of the pole (p).

B. *Collector Efficiency*

The solar energy collection efficiency (η_{col}) of both thermal collectors and photovoltaic collectors is defined as the ratio of the rate of useful thermal energy leaving the collector, to the useable solar irradiance falling on the aperture area. Simply stated, collector efficiency is:

$$\eta_{col} = \frac{\dot{Q}_{useful}}{A_a I_a} \quad (1)$$

where $\dot{Q}_{useful}$ is the rate of (useful) energy output (W)

A_a = aperture area of the collector (m^2)

I_a = solar irradiance falling on collector aperture (W/m^2)

This general definition of collector efficiency differs depending on the type of collector. The rate of useful energy output from thermal collectors is the heat addition to a heat transfer fluid as defined by equation (3) whereas the useful energy output of a photovoltaic collector is electrical power defined in equation (5). The incoming solar irradiance falling on the collector aperture I_a multiplied by the collector aperture area represents the maximum amount of solar energy that could be captured by that collector to a heat transfer fluid passing through the receiver or absorber [17].

$$\dot{Q}_{useful} = \dot{m} c_p (T_{out} - T_{in}) \quad (2)$$

Where, $\dot{m}$ is mass flow rate of heat transfer fluid (kg/s)

c_p - specific heat of heat transfer fluid (J/kg K)

T_{out} - temperature of heat transfer fluid leaving the absorber (K)

T_{in} - temperature of heat transfer fluid entering the absorber (K)

These losses are shown schematically in Figure 2.

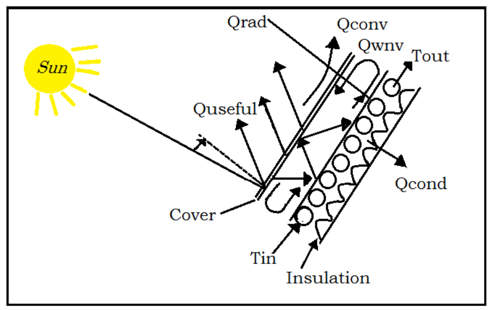

Fig. 2 Energy balance on a solar collector absorber / receiver

An energy balance of a photovoltaic cell incorporated within a panel can be written as:

$$P_{elect} = i.v = \dot{E}_{opt} - \dot{Q}_{loss} \text{ (w)} \quad (3)$$

where i - electrical current through the cell (amps)

v - voltage across the cell (volts)

C. *Convection*

Convection transfers energy from the absorber surface directly to the air in contact with it. When the air is stationary it is referred to as natural convection and when it is in motion it is referred to as forced convection. Equation (4) gives the heat loss due to natural convection for a cavity [18]

$$Q_{cond} = h_{A_{cav}} \_ (T_s - T_{amb}) \quad (4)$$

$$\bar{h} = \frac{\bar{N}_{uf}.k_{amb}}{L} \quad (5)$$

$$N_u = 0.088 \,.\, Gr^{\frac{1}{3}} \,.\, (T_s/T_{amb})^{0.18} . (cos\theta)^{2.47} . (L/D_{cav})^{s} \quad (6)$$

In this equation:

$$s = 1.12 - 0.98 . (L/D_{cav}) \quad (7)$$

$$Gr = \frac{g.\beta.(T_s/\bar{T}_f).L^3}{v^2} \quad (8)$$

$\bar{h}$ = Average heat transfer coefficient

A_{cav} = Cavity area

T_s = temprature of reciever surface

T_{amb} = Ambient fluid temprature

T_f = Average fluid temperature

Nu = Nusselt number

Gr = Grashoff number

kf = Thermal conductivity of ambient fluid

L= Characteristic length of aperture opening (diameter)

D_{cav} = Diameter of cavity

v − Kinematic visocity

θ = Angle reciever makes with zenith (at $\theta = \theta^{\circ}$ the reciever is horizintal)

g= Gravity

β = Volumetric thermal expansion coefficinent

At a tilt angle of □ = 90° (vertical), the air inside a cavity becomes trapped. The hot buoyant air inside the cavity cannot escape and convection losses are nearly eliminated. As the tilt angle decreases (□ < 90°) a dramatic increase in heat loss occurs as the lighter air begins escaping from the cavity. In this case buoyancy works to aid in heat loss. To reduce convective losses a translucent cover can be placed over the aperture. A cover allows the insulation to transmit through the material while trapping gas inside. Convection would still occur at the surface of the cover, but it would be reduced due to the reduction in exposed surface area. Convective loss can be calculated in this case by modeling the cover as a Inclined at plate. Using equation(9) gives the Nusselt number for an inclined at plate, which can be used with equation(4) to calculate convective losses compares the energy loss for an open and covered cavity.

$$N_u = 0.56(Gr.Pr.cos\theta)^{\frac{1}{4}} \quad (9)$$

where

$$\theta < 88^{\circ}, 10^5 < Gr.Pr.cos\theta < 10^{11} \quad (10)$$

All properties are evaluated at a reference temperature Te, except for which is evaluated at T

$$T_e = T_w - 0.25(T_s - T_\infty) \quad (11)$$

$$T_\beta = T_\infty + 0.50(T_s - T_\infty) \quad (12)$$

II. EXPERIMENTAL WORK

A. Solar Collector

The primary power source for the acquisition system is a solar collector subsystem that converts directive irradiation from the sun into steam. This subsystem is presented in Figure 1. The subsystem consists of one solar concentrator units mounted on a concrete base [19], with associated feed water. Water from the high pressure feed water tank is forced by pump into carbon steel steam pipes on the solar concentrator units via steam hoses. As the solar collector units track the sun via a two degree-of-freedom (DOF) azimuth and zenith hinge system,-sunlight striking the parabolic mirrors dish with solar boilers at the focal length, which have a black coating. Much of the reflected irradiation incident on the focus is conducted through the surface of the pipes it connect with storage tanked. This steam bubbles back through the insulated steam hoses and through the high pressure feedwater tank to the steam engine, bypassing the biomass boiler in the process.

B. Boiler

The boiler subsystem is used to convert the chemical energy of a burning by solar radiation into heat energy that can be utilized to transform water into steam. Figure 2 illustrates the chosen cylindrical -type boiler design. Water is injected into the boiler by removing the safety valve and pouring the water in manually, until approximately half of the cylinder tank is full. This removes any requirement for a water injector, and simplifies the overall design. The brick housing supports the cylindrical boiler and can easily be built on site. Combustion of biomass occurs inside the furnace, which heats up the bottom surface of the cylinder causing the water inside to boil. Finally, a sight glass will be included to observe the water level inside the cylinder. The high temperature/high pressure steam produced inside the boiler will then be carried from the outlet to the steam engine via steam pipes with a black surface coating. The boiler will only be used at night, or on cloudy days when there is not enough solar energy available to run the steam engine.

C. Steam engine

The mini steam engine shown in Figure 3 will be used to convert the energy in the steam to mechanical motion that is required to run the pump. A detailed explanation of engine cycles can be found in reference [2]. The steam enters the cylinder at a high temperature and pressure and causes the internal piston to reciprocate back and forth, which drives the connecting rod. The connecting rod connects the piston to the crankshaft. The crankshaft transfers its rotational energy to the flywheel, which is essentially a rotating mass with a large moment of inertia. The flywheel stores energy and provides the angular momentum that is required to alternate between expansion and compression cycles in the cylinder. The camshaft is a rotating shaft that controls when valves open and close, through mechanical linkage that is driven off the crankshaft. Accurate valve timing is essential for controlling the length of engine cycles and ensuring proper operation of the steam engine. A gear coupling and universal joint will be used to transmit the torque off the crankshaft, to the drive shaft connected to the water pump; the two shafts will be perpendicular to one another. The rotating drive shaft will in turn cause the impellers of the pump to rotate and drive water up the well to the required head.

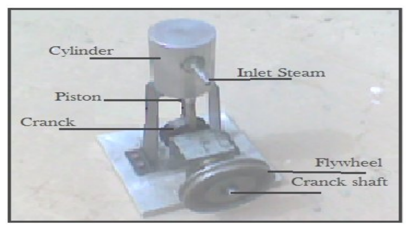

Fig.3 Steam Engine

D. Storage tank

Choosing the metal of inner and outer storage tank is made of 2.5mm thickness of carbon steel. This material offers enough toughness and resists corrosion and intense light. This tank shape is made of stainless steel cylinder with dimension of 50cm*30cm*30cm. In order to transfer the heat fluid from /or to storage tank by tubes, two input valves was chosen and also two output valves the first (input/output valves) are connected between receiver and storage tank ,the second (input/output valves) are connect between storage tank and load by flexible hose.

E. System Connected Method

The parabolic dish solar steam generator considered in this paper is connected with another part as shown in Figure 4.

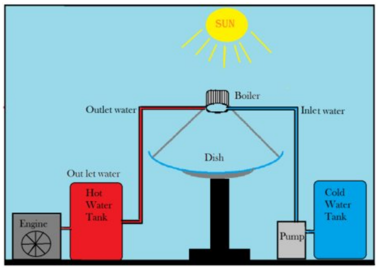

Fig. 4 Components of Solar Steam System

III. RESULTS AND DISCUSSIONS

As any solar driven system, the system performance is mainly a function of solar energy collector subsystem efficiency, and the system coefficient of performance. For the solar energy subsystem, shown in Figure 4, which consists of the solar collector, the steam drum and pump, the solar radiation energy is absorbed and converted into heat that is transferred to the water which flows into the steam drum which is serving as heat energy buffer plus motive steam engine.

Table I

Characteristics of the Solar Dish Concentrator

Diameter of the parabola	1.6 m
Surface collecting of the parabola	2.0 m^2
Focal distance f	0.84 m
Depth of the parabola	0.18

A. Efficiency of collector

Figures (5) show the variation of instantaneous efficiency with operating temperature (Tmr-T_a) for a receiver [20]. It is clear that the system efficiency is decreased with receiver temperature because that the radiated losing energy is proportional to fourth Power of receiver temperature as mentioned before. Also, the results indicate that the cylindrical receiver is more efficient.

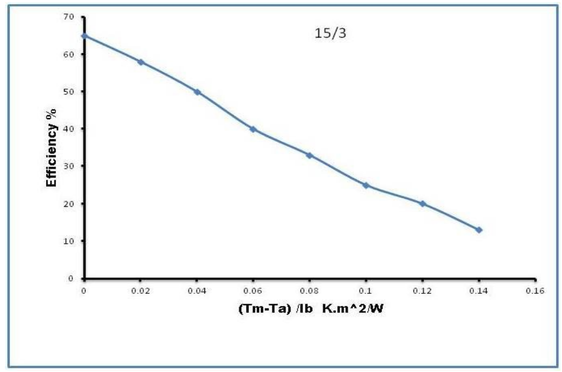

Fig. 5 Variation of instantaneous efficiency with temp for collector

Figure 6 shows the instantaneous ratio of Q_{loss} with respect to the Q_{useful}. It is about 10%. This refers to weakness in insulator technique. By measuring the degradation in temperature of storage tank for 24 hours as follow ,water is pre-heated to average temperature of 80 °C by using solar heating system, and this water moved from solar heating system to the storage tank at temperature 80°C the start of the test.

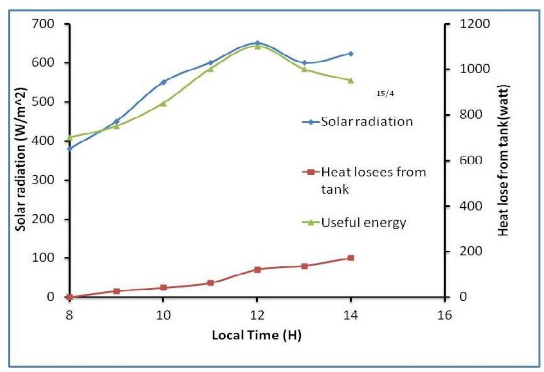

Fig. 6 Relation between solar radiation and heat loss from tank with time

B. Steady State Thermal Testing

Test were performed to determined total conversion efficiency .In these test, water inlet, the water at (20º C) was heated by the receiver to temperature under (145ºC). The working inlet flow was not flashing [21] that allowed accurate collected energy measurement. Results from steady state thermal conversion test are shown in Figure 7 outlet water temperature and insulation during each test. It is observed the increasing of the outlet temperature with increasing of solar radiation between 11:00 am to 12:15 pm otherwise increasing the pressure in final tank to work the steam engine. Figures (8,9) shows increased (rpm) with increasing temperature and pressure.

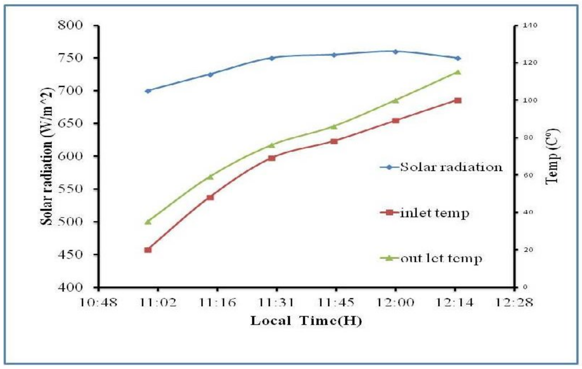

Fig.7 Relation between solar radiation and temperature with time for solar system

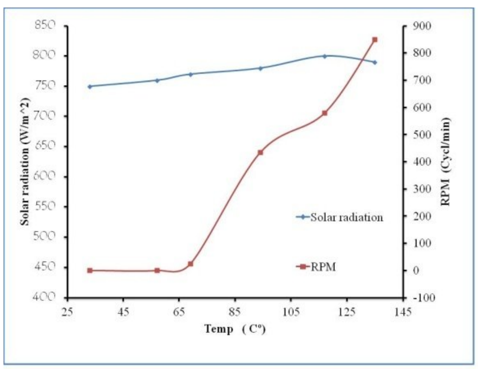

Fig. 8 Relation between solar radiation and rpm with temperature for solar system

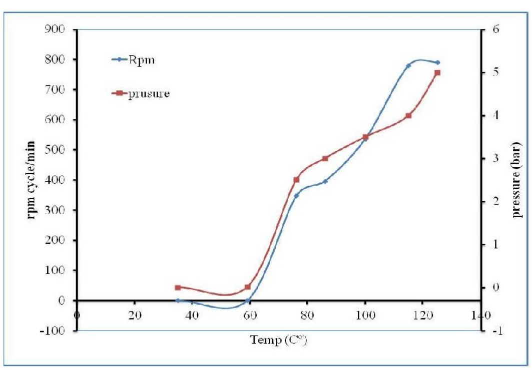

Fig.9 Relation of rpm and pressure with temperature for solar system

C. Thermodynamic analysis and efficiency calculations

It was determined that the boiler would operate at a pressure of (2.7 bar) to (15 bar). Referring to steam tables, it is found that the boiling point of water at such a pressure is approximate (80Cº-130), with an enthalpy of evaporation of 2720.8(kJ/kg). Assuming negligible heat loss inside the steam pipes between the boiler and steam engine (by minimizing pipe length and convective losses), this value also represents the steam temperature at the engine inlet. As the steam expands inside the cylinder, which results in a temperature drop at the outlet that is proportional to the efficiency of the engine. To avoid further system complexity and unnecessary capital costs for a simple water pumping system, a condenser was not included in the design. Accordingly, a value of (55 Cº) is chosen as a reasonable approximation for the outlet steam temperature of the engine. Knowing that a steam engine operates on a Rankine cycle, the expected Carnot efficiency of the engine is calculated from Equation (13)

$$\eta\ carnot = \frac{Tin - Tout}{Tin}\ x100\% \qquad (13)$$

η_{carnot}=(403K−323K)/401K×100%=19.8519%

where T_{in} is the inlet temperature and T_{out} is the outlet temperature. A value of (19.85 %) is obtained, which is to be expected from a small steam engine that lacks a condenser. Moreover, small scale steam engines of this type typically lack extensive regenerators and re-heaters, and as a result, typically have low isentropic efficiencies of approximately (50%). The isentropic efficiency involves a comparison between actual performance of a device, and the performance that would be achieved under ideal circumstances, for the same inlet state and exit pressure [22]. The overall engine efficiency is then,

$$\eta_{engine} = \eta_{carnot} \cdot \eta_{isen} = 0.189 \cdot 0.5 \times 100\ \% = 9.5\ \%$$

IV. CONCLUSIONS

The design of a mini solar steam engine has been proposed in this paper. The work of the system as a conventional thermal power, the heat comes from dish concentrate focused on solar receiver up to (200°C) heating the water pumped to receiver with low flow rate. The temperature of out let receiver or heat tank up to (140°C) saturated steam sufficient to work steam engine The results of our conceptual design show that performance of 20%, the two axis tracking system is very important to increasing power because the engine is small the dish Area small, but when increasing the engine will be will be increasing dish area to increasing income power of solar radiation and temperature to increasing pressure in the hot tank and work the engine. The analysis points out that the overall efficiency, for a given radiation field, is higher than the calculated values of other types of solar system.

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