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Experimental Analysis of Power Generation by Solar Energy for Automotive Vehicle

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Abstract - Renewable energy sources in general, and Solar Energy source in particular, has the potential to provide energy services with zero or almost zero emission. The solar energy is abundant and no other source in renewable energy is like solar energy.Sun provides huge amount of energy in the form of solar radiation. The energy that reaches on the earth surface in the form of solar radiation is extremly more than that needed to fulfill our day to day energy requirements. To get rid of increasing energy crisis and increasing level of pollution we need to develop a system that uses solar radiation to harness energy in an efficient and pollution free manner.
Researcher tried to develop a system by using parabolic collector and receiver to collect and trap solar energy to run the vehicle or other mechanical systems in an efficient and economical way.The solar energy traped by the receiver is converted into electrical energy by using a turbine and generator. The electrical energy is stored in a battery. To run the vehicle, use the electrical energy stored in the battery with the help of traction motor.
Key words: solar energy, concentrating collector, receiver, traction motor, battery

1. INTRODUCTION

Solar energy is radiant light and heat from the sun harnessed using a range of ever-evolving technologies such as solar heating, solar photovoltaic, solar thermal electricity, solar architecture and artificial photosynthesis. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating climate change, and keep fossil fuel prices lower than otherwise. The Earth receives 174 peta watts (PW) of incoming solar radiation (insolation) at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet.

Solar energy is available in abundance in most parts of the world. The amount of solar energy incident on the earth's surface is approximately 1.5×10^{18} kWh/year, which is about 10,000 times the current annual energy consumption of the entire world. The density of power radiated from the sun (referred to as solar energy constant) is 1.373 kW/m^2.

Solar powered electrical generation relies on heat engines and photovoltaics. Solar energy's uses are limited only by human ingenuity. A partial list of solar applications includes space heating and cooling through solar architecture, potable water via distillation and disinfection, day lighting, solar hot water, solar cooking, and high temperature process heat for industrial purposes.

1.1 Solar Energy Potential in India

India is located in the equatorial sun belt of the earth, thereby receiving abundant radiant energy from the sun. The Indian Meteorological Department maintains a nationwide network of radiation stations, which measure solar radiation, and also the daily duration of sunshine. According to data it has been observed that Rajasthan, Gujarat, west Madhya Pradesh and north Maharashtra receive more than 3000 to 3200 hours of bright sunshine in a year. Over 2600 to 2800 hours of bright sunshine are available over the rest of the country, except Kerala, the north-eastern states, and Jammu and Kashmir where they are appreciably lower.

The annual global radiation varies from 1600 to 2200 kWh/m^2, which is comparable with radiation received in the tropical and sub-tropical regions. The equivalent energy potential is about 6,000 million GWh of energy per year. It can also be observed that although the highest annual global radiation is received in Rajasthan, northern Gujarat and parts of Ladakh region, the parts of Andhra Pradesh, Maharashtra, Madhya Pradesh also receive fairly large amount of radiation as compared to many parts of the world especially Japan, Europe and the US where development and deployment of solar technologies is maximum.

1.3 Concentrating Solar Collector

Flat plate collectors generally cannot provide carrier fluids at temperatures sufficiently elevated to be effective in case of air conditioning, central power generation, and numerous industrial heat requirements. In such cases, they may be used as first-stage heat input devices; the temperature of the carrier fluid is then boosted by other conventional heating means. Alternatively, more complex and expensive concentrating solar collectors can be used. These are devices that optically reflect and focus incident solar energy onto a small receiving area. Due to this concentration, the intensity of the solar energy is magnified, and the temperatures that can be achieved at the receiver can approach several hundred or even several thousand degrees Celsius. The concentrators must be movable to track the sun to perform effectively [1].

Concentrating solar collectors intercept direct radiation over a large area and focus it onto a small absorber area. Since the absorption surface area is much smaller, concentrating solar collectors can provide high temperatures more efficiently than flat-plate collectors. However, diffused sky radiation cannot be focused onto the absorber. Mechanical equipment is required to constantly orient the collectors toward the sun and keeps the absorber at the point of focus for most concentrating collectors [2].

1.4 Types of Concentrating Solar Collector

(i) Parabolic trough system: It is a device having letter “u” like shape. The troughs concentrate sunlight onto a receiver tube that is positioned along the focal line of the trough. To reduce heat loss, sometimes a transparent glass tube envelops the receiver tube. Temperature of the receiver can reach 400 °C and produce steam for generating electricity. In California, multi-megawatt power plants were built using parabolic troughs combined with gas turbines [3].

(ii) Parabolic dish systems: It is similar in appearance to a large satellite dish, but it has mirror-like reflectors and an absorber at the focal point. It has dual axis sun tracker.To track the sun and concentrate the sun's rays onto a receiver located at the focal point in front of the dish, a computer is used in this systems. In some systems, a heat engine, such as a Stirling engine, is linked to the receiver to generate electricity. This systems can reach 1000 °C at the receiver, and achieve the highest efficiencies for converting solar energy to electricity in the small-power capacity range[3] .

(iii) Power tower system:A heliostat uses a field of dual axis sun trackers that direct solar energy to a large absorber located on a tower. To date the only application for the heliostat collector is power generation in a system called the power tower.A power tower has a field of large mirrors that follow the sun's path across the sky. The mirrors concentrate sunlight onto a receiver on top of a high tower. A computer keeps the mirrors aligned so the reflected rays of the sun are always aimed at the receiver, where temperatures well above 1000°C can be reached. High-pressure steam is generated to produce electricity [3].

2. PROBLEM FORMULATION

Idea generated by researcher is generally a person who uses a car to go to his office has to drive his car for 1 hour to 2 hour .For rest of the time the car is left idle in the garage / parking. Researcher need an efficient and economical system that can collect and store power from solar light during the time the car is in garage or parking. The purpose of this research paper is to store solar power and to convert it into mechanical work in an effective, efficient and economical way to run vehicles and other machines so that the solar power can be used widely to fulfill our requirements of energy. Researcher wants to reduce dependency on fossil fuel that causes pollution.

2.1 Working Principle of Concentrating Solar Collectors

Concentrating solar power systems generate electricity with heat whereas solar photovoltaic cells use light to produce electricity. Similar to a boiler tube, concentrating solar collectors use mirrors and lenses to concentrate and focus sunlight onto a thermal receiver. The receiver absorbs and converts sunlight into heat. The heat is then transported to a steam generator or engine where it is converted into electricity. These technologies can be used to generate electricity for a variety of applications, ranging from remote power systems as small as a few kilowatts (kW) up to grid connected applications of 200-350 megawatts (MW) or more [5].

2.2 Design of Solar Light Concentrator

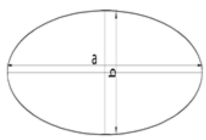
Researcher has used a parabolic disc to concentrate the solar radiation. About 750 square shaped mirror pieces having 20 mm x 20 mm dimensions are pasted on the disc. The mirror focuses radiation onto the receiver thereby increasing the density of solar radiation. Dense solar radiation generates high temperature in the receiver.

Calculation for total power generated by using disc

Here a= 700 mm and b=580 mm

$$Area\ of\ plate = \pi \frac{a \times b}{4} = 3.14 \frac{700 \times 580}{4} = 0.3188\ m^2$$

Average solar flux E= 1000 w/m^2
Maximum power available
P = E x A
= 1000 x 0.3188
P =318.8 watt



The mirrors made of low iron float glass have transmitivity around 98%. The high quality of mirror allows 97% of the reflected rays to be incident on the receiver. Therefore we can develop a very high efficient system to collect solar energy by using parabolic disc collector.
Electric Power generated by a photovoltaic cell having same area (assuming 10% efficiency) = 0.3188x1000x0.1 = 31.88 watt.

3. STEPS INVOLVED IN THE DEVELOPMENT OF THE DISC

(a) Size of the mirrors to be pasted on the disc: To concentrate solar light onto a small area and to increase sunlight for the disc, needed small mirror as much as possible. But the decrease in the size of mirror was likely to produce the following problems:

- When no. of mirror increased then no. of joint between two mirrors increased which was lead towards the loss of effective area of the disc due to small gap between tow mirrors.
- The reflection of light at the sides of the mirror was expended to be irregular therefore it was required to reduce the total perimeter of all mirrors.
- As the size of the mirror was decreasing the cost of the cutting of mirror was increasing exponentially.

Due to all the above factors and the size of the disc into account researcher decided to use mirror having dimension 20 mm x 20 mm and approximately 750 mirrors was used on the disc.

(b)Pasting of mirror: The pasting of mirror was performed in the following three steps.

(i) Initially researcher put the mirror on the disc which was kept on a movable base (fig.-1).
A laser torch was fixed vertically at the ceiling of a room. A beam of light from laser torch was allowed to incident at different mirrors placed at different location. The direction of laser beam after reflection was observed and the area at which the laser beams coming from different mirror met was identified.

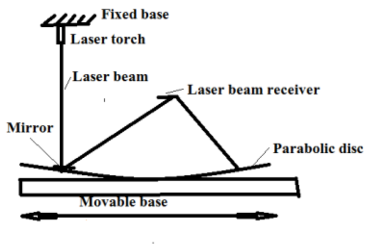


Figure: 1

(ii) Secondly the mirror was pasted onto the disc by using glue. It was a temporary pasting of mirror to check that whether all was going to happen well after permanent pasting of mirror or not. The disc was again checked by the same procedure as in case (i).
(iii) Finally mirror was pasted on the disc permanently by using arardite adhesive.

Finally after passing all the above steps, the disc was ready to collect solar light. To estimate the performance of the disc researcher lighted up sheets of paper of different thickness. It was a sign of success in this estimation. Researcher was also experiencing high temperature at the area where light was concentrated.

4. RECEIVER

To receive the solar energy concentrated by the disc an insulated black body is required researcher developed the receiver by taking the heat transfer mechanism and greenhouse effect in to account as shown in fig.2. Researcher developed an insulated cylindrical cavity made of borosil glass by arranging a small beaker (500 ml) inside a large beaker (1000 ml). The upper end of the beakers was closed by clay. The most of the part of the solar energy available at earth's surface was in the form of visible light. The heat waves generated in the receiver comes in the infrared region. Glasses were transparent for visible light but opaque for infrared light. Thus the glass beakers were not allowing the solar radiation to come out once entered into the receiver. A copper tube bent in helical form placed inside the small beaker. The copper tube was painted black to receive the maximum amount of the solar energy. The copper tube was act as a heat exchanger and was heating up the fluid inside it. In a rough testing of the receiver, researcher was able to boil water as it boils on a gas stove.


Figure: 2

Maximum Temperature Attainable by the Receiver

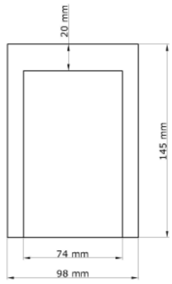
Dimensions of the Beakers Used

Large Beaker	Small Beaker
Outside diameter = 98 mm	Outside diameter = 74 mm
Height = 145 mm	Height = 115 mm
Thickness = 2 mm	Thickness = 2 mm

Thermal conductivity of glass 'Kg' =1.0 w/mK

Thermal conductivity of air 'Ka'=0.05 w/mK

Area of curved Section,



A_1 = 3.14x0.074x0.115 = 0.0267 m^2

A_2 = 3.14x0.098x0.115 = 0.0358 m^2

For cylindrical surface, the thermal resistances

$$R_1 = \frac{1}{(h \times A)} = \frac{1}{(20 \times A_1)} = 1.873\ K/w$$

$$R_2 = \frac{1}{(2 \times 3.14 \times K \times L)} \ln\left(\frac{r_1}{r_2}\right) = \frac{1}{(2 \times 3.14 \times 1 \times 0.115)} ln\left(\frac{3.9}{3.7}\right) = 0.073\ K/w$$

$R_3 = R_1$ = 1.873 K/w

$$R_4 = \frac{1}{(2 \times 3.14 \times 0.05 \times 0.115)} ln\left(\frac{4.9}{3.9}\right) = 6.32\ K/w$$

$$R_5 = \frac{1}{(20 \times A_1)} = 1.873\ K/w$$

$$R_6 = \frac{1}{(2 \times 3.14 \times 1 \times 0.115)} ln\left(\frac{5.1}{4.9}\right) = 0.055\ K/w$$

$R_7 = R_5$ = 1.873 K/w

R = $R_1+R_2+R_3+R_4+R_5+R_6+R_7$ = 13.94 K/w

Area of circular section

$$A = \pi \frac{d^2}{4} = 7.54 \times 10^{-2}\ m^2$$

For lower circular portion, the thermal resistance

$$R_1 = \frac{1}{(h \times A)} = \frac{1}{(20 \times A)} = 6.63\ K/w$$

$$R_2 = \frac{1}{(Kg \times A)} = 0.26\ K/w$$

$R_3 = R_1$ = 6.63 K/w

R' = $R_1+R_2+R_3$ = 13.52 K/w

For upper circular portion, the thermal resistance

$$R'' = \frac{0.02}{(1 \times A)} = 2.65\ K/w$$

$$Q_1 = \frac{T}{R} = \frac{T}{13.94}$$

$$Q_2 = \frac{T}{R'} = \frac{T}{13.52}$$

$$Q_3 = \frac{T}{R''} = \frac{T}{2.65}$$

$$Q = Q_1 + Q_2 + Q_3$$

318 = T x 0.623

$$T = \frac{318}{0.623} = 510^{\circ}C$$

Maximum temperature available (assuming surrounding temperature = 25 ^{0}C)

T= 535^{0}C

5. EXPERIMENTAL SETUP

To check the performance of the disc and receiver system and to know the total power output from the system researcher perform the experiment as shown in figure-3.In this experiment, researcher allowed water to enter in the receiver with a constant flow rate through the inlet pipe of the receiver. The water coming out of the receiver through outlet pipe was collected in a beaker. The quantity of water stored in the receiver during a known period of time was measured. The whole experiment was repeated three times and the following table was constructed:

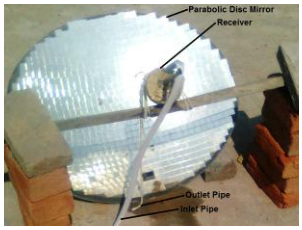


Fig.3: Parabolic Disc Mirror

S. No.	Time Duration (Sec)	Amount of water collected in (Kg)	Water flow rate m(Kg/s)	Inlet water temp T_1(°C)	Outlet water temp T_2(°C)	ΔT = (T_2-T_1)	Heat Collected per sec P = msΔT (watt)
1	311	0.2	6.4x10^{-4}	32	52	20	53.75
2	306	0.2	6.5x10^{-4}	32	54	22	60.14
3	301	0.2	6.6x10^{-4}	32	54	22	61.06

Average Power Received =(53.75+60.14+61.06)/3 = 58.32 watts

Result: We used a parabolic disc having outer contour elliptical the major and minor diameter of disc we used are 70 cm and 58 cm respectively. By experiments we found out that the average power output by our disc and receiver system in a sunny day was 58.32 watt.

6. CONCLUSION

For Tata Nano

Length =3.1 m and Width =1.5 m

Floor area =3.1 x1.5=4.65 m^2

Energy received on the floor =4.65kw

Assuming availability of sun light for 8 hours

the total energy received = 4.65 x 1 x 60 x 8 x 60 =133920 kj

Mileage for Tata nano= 22km/litre

Calorific value of petrol = 48000 kj/kg = 35376KJ/litre.

If 35376 KJ energy can run the car = 22 km then 133920 KJ energy can run the car = 83 km

Thus we have high hope for the system developed by us to be used in future vehicles. The power generate by our system is about 2 times that we can generate by using a photovoltaic cell having the same dimension as the parabolic collector has. We can attain still higher efficiency by using mirrors of good quality (like low iron float mirrors which has transmitivity around 98%).We can also employ anti reflective coating onto the mirrors to reduce reflactive losses of light. In future modification we can employ reversible chemical reactions to store heat energy into chemical energy which can increase the overall effeciency of the system.

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