Performance analysis of solar concentrator dish by various reflector and absorbent

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Abstract. Recent days the availability of a conventional source of energies are limited due to overexploitation of resources. This can be prevented by replacing the conventional source of energy to renewable energy which is believed to be the future. In renewable energy, there are many types among which solar energy is the best and most effective as it is abundant, freely available, and it has a lot of versatile applications. The main objective of the research is to study the suitability of antenna dish for thermal application by optimizing the various parameters to achieve maximum thermal collector efficiency. Considerable enhancement in the performance of the solar dish collector was observed by altering various absorbents on the receiver.

1. Introduction
The world is facing triple crisis problem number 1. Increase in demand and pricing 2. Increase in pollution leading to acid rain, ozone layer depletion and global warming 3. Depletion of fossil fuel reserve. This crisis is due to rapid growth in automobile population and industrialization. Hence scientist and researchers are intimidated to find renewable and sustainable energy sources for meeting the energy demand at lower cost. There are different alternative sources of energy such as solar energy, wind energy, tidal energy, Ocean energy, geothermal energy etc. Decision to select type of alternative energy to be opted must be made on the basis of economical, environment friendly and safety consideration. Among the available energy solar energy finds source of alternative energy with respect to environmental and safety though the initial cost involved is higher.

Kalogirou et al.[1] explained solar collectors are classified based on the motion such as stationery, single axis tracking, two axis tracking and operating temperature. The stationery collectors are flat plate collectors, activated evacuated tube collectors whose Concentration ratio various from 1 to 5 and operating temperature ranges from 30 to 240°C. Concentration ratio is a term which signifies collector area to the receiver observed area. The single Axis tracking types of dishes are linear fresnel lens reflector, parabolic trough collector and cylindrical trough collector. The concentration ratio various from 5 to 50 and operating temperature various from 60 to 300°C. The two-
axistracking typeof collector are parabolic dish reflector and heliostat field collector, concentration ratio various from 100 to 2500 and the operating temperature ranges from 100 to 2000°C.

Vanita et al. [11] proposed solar concentrated power shows greater promise to resolve energy crisis problem across the globe. Parabolic solar dish concentrator has higher conversion efficiency. Ibrahim et al. developed a parabolic dish solar water for household application at capacity of 40 litres a day for a family of 4 members. To get effective results experiments are conducted with sun tracking mechanism and obtained thermal efficiency of 52% - 56% which are higher than designed value of 50%

Senthil et al. [5] studied the effect of phase change material magnesium chloride hexahydrate outside the receiver of Scheffler type solar parabolic dish concentrator for enhancing the thermal performance. Solar radiation intensity, receiver temperature, ambient temperature, wind velocity are the parameters considered to analyses the energy and exergy efficiency of the system. The results yielded that a 5.6 improvement in the efficiency was achieved due the addition of PCM outside the receiver. Gustavo et al. [6] studied the solar dish concentrator by building, characterizing and analyzing the performance by simulation and experiments for desalination application. To characterize the setup dynamic heating was simulated and was validated experimentally. The yield of distilled water varied from 4.11 kg/m² to 4.95 kg/m² per day as a consequence of colligative effect of salt water. The authors concluded that the dish has a promising potential for producing potable water for a community application.

Wang et al. [9] simulated the three-dimensional model of Parabolic dish receiver with working fluid as argon gas to study the impact of aperture size, inlet outlet configuration of the receiver and the rim angle of the parabolic dish on the thermal performance. The researchers projected that aperture size and different inlet and outlet configuration has a considerable impact on the performance and rim angle of the dish had a negligible impact. After reviewing the literature, the main observation was made that most of the work carried out was simulation modeling and very few of the researchers have done experimental work. Major problem is economic viability and high initial cost lack of generalized parameters due to various parameters affecting the performance which various geometrical location to location. Hence the present research work focuses on studying the suitability analysis of dish antenna receiver for solar thermal power generation as solar concentrator dish and optimizing the thermal performance.

2. Experimentation
2.1 Experimental Set up
The experiments were carried out in SRM Institute of Science and Technology, Kattankulatur, Chennai, India which lies at 13.5°N altitude and 80.16°E longitude during the period of January to March 2020. Solar Dish Concentrator (SDC) and receiver were designed and fabricated to compare the performance of different colours coating on the receiver.

Here the parabolic solar dish is a C-Band Satellite dish whose diameter is 1.8 meters. The dish is fabricated with Aluminium foil tape with a thickness of 0.1 mm. Smooth polished aluminium surface has a reflectivity of about 88 percent. The strips of aluminium foil tape were placed carefully to get higher optical efficiency.
Figure 1. A schematic diagram of the experimental setup.

Figure 2. Photographic view of experimental setup.

Figure 3. The parabolic dish dimensions.
The receiver consists of a pressure vessel of a capacity of 5 litres and it has a diameter of 21.5 cm. The bottom of the pressure vessels has been coated with different colours in order to understand how absorptivity coefficient effects the performance of the experiment. Total three pressure cookers were taken. The first vessel was coated black having an absorptivity coefficient of 0.97, second was coated green having an absorptivity coefficient of 0.95 and the last one was not coated (original material i.e. Aluminium) having an absorptivity coefficient of 0.40.

Firstly, 3 litres of brackish water were fed into the pressure vessel. After filling the pressure vessel with brackish water, it is mounted on the 2-axis adjustable receiver stand where the pressure vessel is placed above the solar dish and adjust it in such a way that the focal point at which all the rays converge fall on the base of the pressure vessel. The pressure vessel is connected to the heat exchanger through copper tube which has a length of 1.5 m and has an inner diameter of 1 cm. There is some height difference between pressure vessel and condenser to produce gravity fall of steam from pressure vessel to condenser. A gate valve is attached to the copper rod which is connected between to pressure vessel and condenser to control the flow of the steam and pressure of the pressure vessel. The condenser has a capacity of 2.72 litres and has a diameter of 14.5 cm. Here cross flow type condenser by using copper coil which is having length of 1 m and diameter of 1 cm. In it flow of vapour takes place where phase changes from vapour to water when condenser is filled with 2 litres of coolant (cold tap water) and potable water was obtained as a product.

2.2 Experimental procedure
The SDC reflects and converges all the incoming direct normal radiation to the focal point where receiver is placed. Vaporization of brackish water takes place due to intense heat supplied by the dish to the bottom surface of the receiver. The generated vapour flows from vessel to condenser through copper tube and in condenser it changes its phase from vapour to water as latent heat of the vapour is absorbed by the coolant in the condenser. The final product obtained from the condenser is potable water.

The performance analysis of solar dish and various coating of the receiver were investigated. The experimental setup was evaluated by measuring the wind speed, surface temperature, brackish water temperature and amount of fresh water productivity. The surface temperature of the receiver was measured using IR thermometer. The brackish water temperature and condenser inlet temperature were measured using thermocouple (range of -20°C to 140°C and accuracy of 1.5°C) which was connected to a 12-point display temperature indicator (accuracy of +/- 0.5°C). Wind speed was measured by using van type anemometer (range of 1-25 m/s). The potable water was measured using 2 litres Borosilicate glass beaker. TDS meter is used to measure the PPM level of brackish water and potable water. From the above experiment performance analysis was carried on the two different coated vessels and one non coated vessel during daytime and the respective temperature values were noted and energy gain and losses were calculated.

2.3 Thermal Analysis
The energy balance of the solar collector and receiver helps us develop the thermal analysis model.

Solar Radiation utilization (Q_s): The solar energy absorbed by the collector is calculated as the product of collector area (A_c) and incident solar energy (I_0).

\[ Q_s = A_c \cdot I_0 \]  \hspace{1cm} (1)

Concentration ratio (C): It is defined as the ratio of collector area (A_c) to the receiver area (A_r).

\[ C = \frac{A_c}{A_r} \]  \hspace{1cm} (2)
Optical Efficiency ($\eta_{opt}$): It is defined as the product of absorption coefficient of receiver ($\varepsilon_a$), reflection coefficient ($\varepsilon_r$) and intercept factor ($\Upsilon$).

$$\eta_{opt} = \varepsilon_r \times \varepsilon_a \times \Upsilon$$  \hspace{1cm} (3)

The rate of absorbed energy from the receiver ($Q_{abs}$): It is the product of optical efficiency ($\eta_{opt}$) and solar radiation energy ($Q_s$).

$$Q_{abs} = Q_s \times \eta_{opt}$$  \hspace{1cm} (4)

Thermal losses due to radiation:

$$Q_{rad} = A_r \times \varepsilon_a \times \sigma \times (T_r^4 - T_{am}^4)$$  \hspace{1cm} (5)

Thermal losses due to convection:

$$Q_{conv} = A_r \times h_{air} \times (T_r - T_{am})$$  \hspace{1cm} (6)

Heat convection coefficient between receiver and ambience: [13]

$$h_{air} = 2.8 + 3 \times V_{air}$$  \hspace{1cm} (7)

Thermal losses to the environment due to radiation and convection

$$Q_{loss} = Q_{rad} + Q_{conv}$$  \hspace{1cm} (8)

Useful Energy ($Q_u$): The useful heat energy is the difference between the rate of absorbed solar ($Q_{abs}$) and thermal losses ($Q_{loss}$)

$$Q_u = Q_{abs} - Q_{loss}$$  \hspace{1cm} (9)

Thermal Efficiency ($\eta_{th}$): It is defined as the ratio of useful heat energy output ($Q_u$) to the available solar radiation energy input ($Q_s$)

$$\eta_{th} = \frac{Q_u}{Q_s}$$  \hspace{1cm} (10)

3. Results obtained and Discussion

On clean sunny days, experiments were conducted with three different receivers. The incident solar radiation ($I_s$), ambient temperature ($T_{am}$), receiver surface temperature ($T_r$), wind speed, storage tank temperature is noted during the experiment. Black colour receiver, green colour receiver and non-coated aluminum receiver are used to conduct the experiments. The experiments are conducted during the month of March, the experiments are repeated for three different days to ensure the repeatability of the readings. The convection and radiation heat losses mainly affect the thermal efficiency of the system. The losses are mainly depending on inclination angle of receiver, wind speed, receiver surface temperature and emissivity of receiver surface area.
Figure 4 shows the receiver surface temperature with respect to time. The experiments are conducted at afternoon session between 1.00 p.m. – 2.30 p.m. The receiver coated with black colour shows higher surface temperature with respect to time. The average surface temperature of black colour receiver is 5 -10 °C higher than green colour receiver and 25- 35 °C higher than non-coated aluminium receiver.

Figure 5 shows the radiation heat loss on various time interval. The incident solar radiation $I_b$ observed during the testing period was 950 W/m$^2$ and lowest was 600 W/m$^2$. The wind speed varies between 0.6 m/s and 0.8 m/s. The ambient temperature during testing period varies between 308 K and 311 K. The radiation heat loss is maximum for the receiver coated with black colour.
Figure 6. Plot for Total heat loss Vs Time.

Figure 6 shows the variation of radiation and convection heat loss with time. The black colour receiver has more heat losses compare of green colour and non-coated aluminum receiver. Radiation losses are high as compare with convection losses. The radiation heat transfer is explained by Boltzmann law in which the radiation emission from the hot source (receiver) is proportional with fourth power of source temperature.

Figure 7. Plot for Thermal efficiency Vs Receiver coating material.

Figure 7 describes the relation of thermal efficiency with receiver coating material. The receivers coated with black and green colour shows increasing in efficiency 48 and 46 percentage respectively compare with non-coated aluminum receiver. In order to increase the efficiency further have to reduce the radiation losses. The heat produced in receiver can utilize for various application namely solar desalination. The heat energy produced in receiver will used to heat the brackish water. The vapours formed during heating are condensed in condenser, after condensation portable drinking water are produced.

4. Conclusion
In this work a dish satellite antenna dish receiver is selected for the experiment as the cost is minimum and can used in small scale application. The rural household where commercial water purification is not possible can utilize solar desalination. By varying the various absorbents on the
receiver, black colour absorbent shows higher thermal efficiency as compare with other absorbents. In future work, studies will conduct by altering various reflecting material and conduct experiments to convert brackish water to drinking water.

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