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Performance Evaluation of Parabolic Dish Collector with Different Reflecting Polymeric Materials

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Abstract

The parabolic dish solar collector is very useful for all solar energy applications such as heating purpose, cooking purpose, power generations, etc. The experimental investigations were carried out to determine the performance of concentrating parabolic dish collector with different polymeric reflecting films as a reflector. There are three polymeric films use such as an aluminum polymer, silver polymer, and gold chrome polymer film. A parabolic collector having aperture diameter, depth, focal height and point for fabrication. The pot was filled with a suitable quantity of rice. The solar radiation, pot temperature, ambient temperature, cooking time and temperature were recorded. The thermal efficiency, useful energy and cooking power are calculated.

Keywords: Solar energy; Reflecting material; Cooking power; Thermal energy.

I. INTRODUCTION

Solar energy is one of the best renewable energy sources which is easily and freely available all over the world. In a world population, solar energy is contributing to major energy requirements. If the majority of the populace use cleaner and environmentally friendly sources of energy like solar and wind, the use and its effects of fossil fuels and firewood can only be minimized. However, gas can be costly and difficult to obtain, so people widely uses trees and shrubs as an alternative fuel for heating, [1] boiling water and cooking [2] This contributes to deforestation. To tackle these issues and utilize the high levels of available sunlight, a parabolic dish collector are used for cooking and preparing food has been developed. The parabolic concentrator is also less cost and meets the cooking energy needs as well as environmental protection. [3]

In recent years, parabolic solar collectors have taken the lead upon a large range of other existing solar collectors and became the subject of many studies because they offer the possibility to control the produced thermal energy. [4]

Cooking is major and necessary household chores in every society of the world. In the rural areas most of developing countries cooking is usually done by firewood. In the cities, stoves are more common, fuelled by wood, charcoal and fuel gas. Solar cooking saves not only fossil fuels but also keeps the environment free from pollution without hampering the nutritional value of the food. [5]

Parabolic dish cookers efficiency is best in terms of the utilization of the reflector area because in fully steerable dish system there are no losses due to aperture projection effects. Also, radiation losses are decreases due to small area of the absorber at the focus. [6] The parabolic solar cooker is based on the principle of the concentration of the rays. The solar energy is concentrated on a point of a pot surface hence it's attaining a high temperature and giving a good efficiency.

II. THEORY

Concentrator defined by following methods [7]:

The parabolic collector uses solar radiation directly and heating at its focus which placed a pot.

2.1 Optical concentration (C_0):

- It is the ratio of solar intensity of the absorber to solar intensity of the collector.

$$C_0 = I_r/I_0 \quad \text{eq. (1)}$$

Where,
I_r = Solar intensity of absorber, in W/m^2
I_0 = Solar intensity of collector, in W/m^2

2.2 Geometric concentration (C):

- It is the ratio of aperture areal dimension of parabolic collector to absorber surface area.

$$C = A_a/A_{ab} \quad \text{eq. (2)}$$

Where,
A_a = Aperture area, in m^2
A_{ab} = Absorber area, in m^2

2.3 Focal point (F):

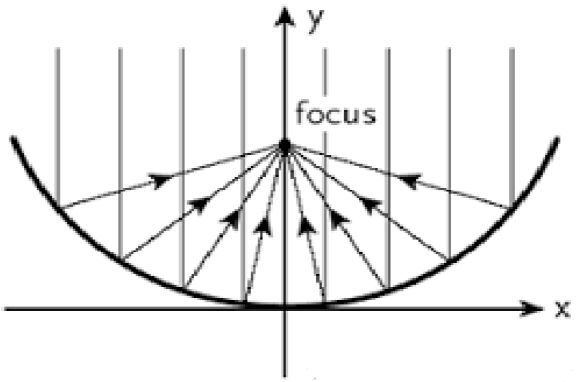

Figure 1. Focal point

- The focal point is the point at which light waves travelling parallel to axis of the parabola meet after reflecting off its surface.

$$F=x^2/4a \qquad \text{eq. (3)}$$

Where,

x= Radius of the collector, in mm

a = Depth of parabola, in mm

III. SELECTION OF MATERIALS FOR CONSTRUCTION OF THE PARABOLIC DISH COLLECTOR

3.1 Material for body of the dish:

Steel was used because its strength and durability are better than aluminum. The energy required to produce steel is calculated that 16,500 kJ/kg as compared to aluminum required 141000 kJ/kg. [8]

3.2 Material for a reflective surface:

There are three polymer film was used as a reflective material. The aluminized, golden and silver polymer film was used for carrying out the efficiency of the collector. The reflectivity of the films are also good as well as the main aim to using the polymer was to reducing the weight of the collector. The aluminum sheet cost is 100 rupees. Per square feet and polymer film rate is 30 rupees. Per square feet, so the as per cost is also effective to using polymer films.

3.3 Material for absorber and surface coating:

Pot is used which made by steel. It is low cost and lightweight. Black paint is use as an absorber coating. It was selected over other coating because of its high absorptivity when exposed to sunlight.

3.4 Food material:

Rice was selected as a representative food to be cooked because it is a staple food for about two-third population of the world**.** [9] Water was used as heat transfer fluid because it is most commonly used for domestic heating applications.

3.5 Material for vertical support and base of the collector:

A rectangular, hollow, steel bar was selected for the support of dish. A combination of angles and channel section steel bar were selected for base support the whole solar collector structure. Steel is select for supporting structure of the collector because of its strength, rigidity, resistance to deflection by commonly encountered winds and its ability to withstand cross-sectional loads of entire heating portion of the parabolic collector.

IV. DESIGN SPECIFICATION OF PARABOLIC DISH COLLECTOR

Table 1. Design specification of PDC

Diameter of reflector/concentrator, D_a	1.34m
Diameter of absorber, D_{ab}	0.17m
Focal height, f	0.23m
Aperture area of the reflector, A_a	1.4m^2
Absorber area, A_{ab}	0.017m^2
Concentration ratio, C	82.35m

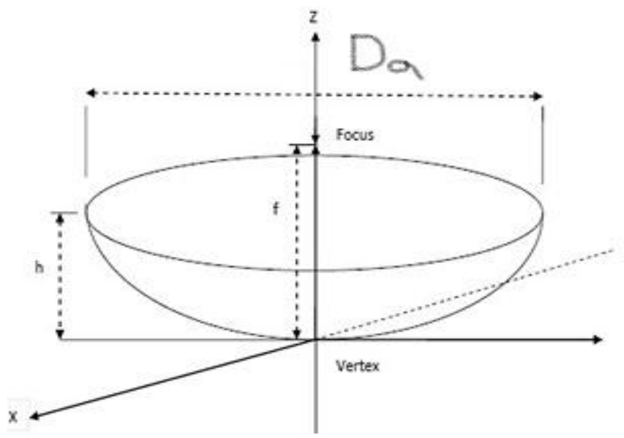

Figure 2. Schematic view of PDC

V. PARAMETER CHARACTERIZING THERMAL PERFORMANCE OF PARABOLIC DISH COLLECTOR

The optical efficiency, η_0 is defined as the ratio of the energy absorbed by the absorber to the energy incident on the concentrator aperture. It includes the effect of mirror surface, shape and reflection losses, tracking accuracy, shading, absorber cover transmittance, absorptance of the of the absorber, and solar beam incidence effects. The optical efficiency is given as-

$$\eta_0 = P_{abs}/A_a I_b \quad \text{eq. (4)}$$

Where,

P_{abs} = Rate of energy absorb by absorber, in W

A_a = Aperture area, in m^2

I_b = Standard average solar radiation, in W/m^2

The optical efficiency of most solar concentrators lies between 60% and 70%. In a solar thermal cooker [10], a combination of a working fluid and food substance is used to extract energy from the absorber. The thermal efficiency (η th) is defined as the ratio of the useful energy delivered to the energy incident at the aperture of a concentrator.

For solar thermal cookers, the thermal efficiency is given as-

$$\eta_{th} = m_f \times C_{pw} (T_c - T_a)] / tc\ A_a\ I_b \quad \text{eq. (5)}$$

Where,

m_f = Mass of food, in kg

T_a = Ambient Temperature, in ℃

T_c = Cooking Temperature, in ℃

A_a = Aperture area, in m^2

I_b = Standard average solar radiation, in w/m^2

tc = Cooking time, in min

C_{pw} = Standard value = 4186 KJ/ Kg K = Specific heat capacity of constant pressure of water, in kJ/kg K

The incident solar radiation consists of beam and diffuse radiation. Consider average solar radiation is 700 W/ m^2. However, the majority of concentrating collectors can utilize only beam radiation. [11]

VI. COOKING TEST:

This was done to evaluate the time taken to cook a certain quantity of food like rice. For cooking process rice to water ratio by volume is 1:2.5. Ambient temperature, cooking temperature, and time is taken to cook the food are recorded during the testing.

6.1 Reading of parabolic dish collector using silver polymer film:

Figure 3. Parabolic Dish Collector with Silver Polymer Film

- Date of reading: 17/05/2019

Table 2. Reading for 100gm Rice + 250ml Water

Time AM/PM	Cooking Time (t_c) (min)	Ambient Temperature (T_a) (℃)	Cooking Temperature (Tc) (℃)	Solar Radiation (I_r) (W/m^2)	Wind Speed (m/s)	Pot Temperature (T_{pot})(℃)
12pm-1pm	42	37	81	849	1.2	110
2pm-3pm	44	39	79	938	2.26	105

- Date of reading: 18/05/2019

Table 3. Reading for 150gm Rice + 375ml Water

Time AM/PM	Cooking Time (t_c) (min)	Ambient Temperature (T_a) (℃)	Cooking Temperature (T_c) (℃)	Solar radiation (I_r) (W/m^2)	Wind Speed (m/s)	Pot Temperature (T_{pot})(℃)
12pm-1pm	46	38	78	902	0.8	106
2pm-3pm	50	40	74	850	2.2	102

6.2 Reading of parabolic dish collector using aluminium polymer film:

Figure 4. Parabolic Dish Collector with Aluminum Polymer Fil

- Date of reading: 20/05/2019

Table 4. Reading for 100gm Rice + 250ml Water

Time AM/PM	Cooking Time (t_c) (min)	Ambient Temperature (T_a) (℃)	Cooking Temperature (T_c) (℃)	Solar radiation (I_r) (W/m^2)	Wind Speed (m/s)	Pot Temperature (T_{pot})(℃)
12pm-1pm	30	40	87	875	1.51	125
2pm-3pm	34	42	85	797	1.81	120

- Date of reading: 21/05/2019

Table 5. Reading for 150gm Rice + 375ml Water

Time AM/PM	Cooking Time (t_c) (min)	Ambient Temperature (T_a) (℃)	Cooking Temperature (T_c) (℃)	Solar radiation (I_r) (W/m^2)	Wind Speed (m/s)	Pot Temperature (T_{pot})(℃)
12pm-1pm	40	41	85	910	0.92	118
2pm-3pm	42	43	83	895	1.56	114

6.3 Reading of parabolic dish collector using golden polymer film:

Figure 5. Parabolic Dish Collector with Gold Chrome Polymer Film

- Date of reading: 22/05/2019

Table 6. Reading for 100gm Rice + 250ml Water

Time AM/PM	Cooking Time (t_c) (min)	Ambient Temperature (T_a) (°C)	Cooking Temperature (T_c) (°C)	Solar radiation (I_r) (W/m^2)	Wind Speed (m/s)	Pot Temperature (T_{pot})(°C)
12pm-1pm	35	40	86	921	2.1	119
2pm-3pm	38	41	84	869	2.4	115

- Date of reading: 23/05/2019

Table 7. Reading for 150gm Rice + 375ml Water

Time AM/PM	Cooking Time (t_c) (min)	Ambient Temperature (T_a) (°C)	Cooking Temperature (T_c) (°C)	Solar radiation (I_r) (W/m^2)	Wind Speed (m/s)	Pot Temperature (T_{pot})(°C)
12pm-1pm	41	41	82	939	1.86	112
2pm-3pm	45	42	80	902	2.2	111

VII. THERMAL PERFORMANCE OF PARABOLIC DISH COLLECTOR

Thermal performance of parabolic dish collector are calculated by using following equations. [10]:

Sample equations:-

Consider the reading recorded on 17/05/2019 at 12.00 pm – 1.00 pm. by using aluminum polymer as a reflector.

Let,

1. The estimated rate of useful energy (Q_u) absorbed by the food is given by –

$$Q_u = \eta_{th} I_b A_a \quad \text{eq. (6)}$$

Where,

I_b = Standard average solar radiation in, w/m^2 = 700 W/m^2 [10]

A_a = Aperture area = 1.4 m^2

Q_u = Useful energy

Calculations:-

7.1 Cooking power (P_{abs}):

$$P_{abs} = [m_w \times C_{pw} \times (T_c - T_a)] / t_c \quad \text{eq. (7)}$$

Where,

m_w = mass of water (kg)

C_{pw} = Specific heat capacity of constant pressure of water, in kJ/kg K

T_a = Ambient Temperature, in ℃

T_c = Cooking Temperature, in ℃

tc = Cooking time, in min

$$P_{abs} = [m_w \times C_{pw} \times (T_c - T_a)] / t_c \quad \text{eq. (8)}$$

P_{abs} = [(250/ 1000) x 4186 x (81 – 37)] / [42]

P_{abs} = 1096 W

7.2 Thermal efficiency (η_{th}):

$$\eta_{th} = m_f \times C_{pw} (T_c - T_a)] / tc\ A_a I_b \quad \text{eq. (9)}$$

Where,

m_f = Mass of food, in kg

η_{th} = m_f x C_{pw} (T_c – T_a)] / tc A_a I_b

η_{th} = 0.1 x 4186 (81 – 37) / 42 x 1.4 x 700

η_{th} = 0.44 = 44%

7.3 Useful energy (Q_u):

$$Q_u = \eta_{th} I_b A_a \quad \text{eq. (10)}$$

Where,

A_a = Aperture area, in m^2

I_b = Standard average solar radiation, in W/m^2

Q_u = η_{th} I_b A_a

Q_u = 0.44 x 700 x 1.4

Q_u = 438 W

Also follow the above same procedure to calculating the thermal performance value for different time and dates these values are arranged in following tables.

7.4 Thermal performance of parabolic dish collector:

- Using silver polymer film as a reflector:

Table 8. Thermal Performance of Parabolic Dish Collector using Silver Polymer Film as Reflector

Time	Cooking power (W)	Efficiency (%)	Useful energy (W)
Date: 17/05/2019 & Food - 100gm rice + 250ml water			
12pm-1pm	1096	44	438
2pm-3pm	951	38	382
Date: 18/05/2019& Food - 150gm rice + 375ml water			
12pm-1pm	1365	55	549
2pm-3pm	1067	43	426

- Using aluminium polymer film as a reflector:

Table 9. Thermal Performance of Parabolic Dish Collector using Aluminum Polymer Film as Reflector

Time	Cooking power (W)	Efficiency (%)	Useful energy (W)
Date: 20/05/2019 & Food - 100gm rice+ 250ml water			
12pm-1pm	1639	66	655
2pm-3pm	1323	54	529
Date: 21/05/2019& Food - 150gm rice+ 375ml water			
12pm-1pm	1726	70	690
2pm-3pm	1495	61	597

- Using gold chrome polymer film as a reflector:

Table 10. Thermal Performance of Parabolic Dish Collector using Gold Chrome Polymer Film as Reflector

Time	Cooking power (W)	Efficiency (%)	Useful energy (W)
Date: 22/05/2019& Food - 100gm rice + 250ml water			
12pm-1pm	1375	56	550
2pm-3pm	1184	48	473
Date: 23/05/2019& Food - 150gm rice+ 375ml water			
12pm-1pm	1569	64	627
2pm-3pm	1325	54	530

VIII. RESULT AND DISCUSSION:

- The graph shows diurnal variation in hourly cooking power of silver, aluminum and gold chrome polymer reflector with time. From the above plot, it is also that the cooking power increases 12 pm -1 pm and it decreases 2 pm-3 pm. The highest cooking power is 1726W and lowest is 951W. The highest power is reaching while using an aluminum film and lower power is get while using a silver film as a reflector on a parabolic dish.

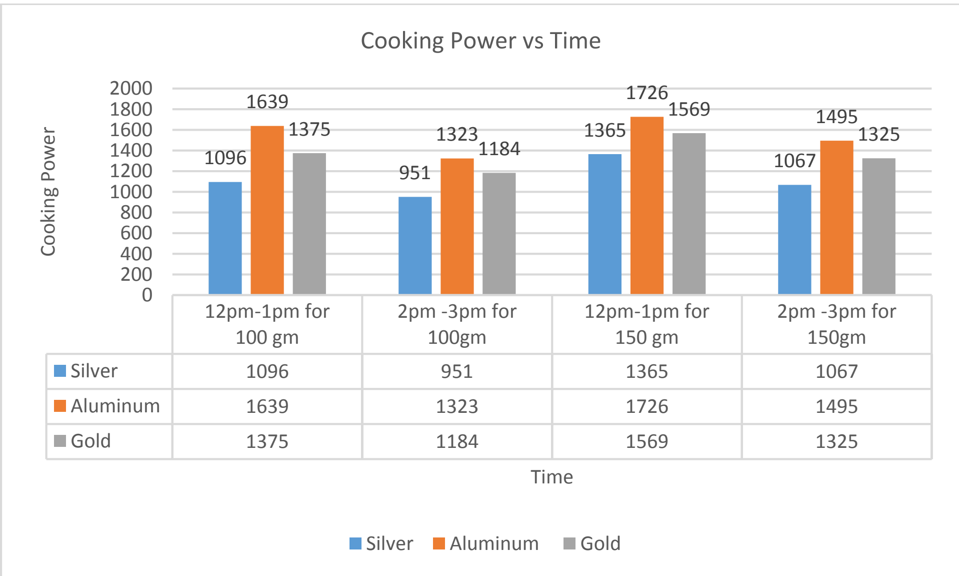

Figure 6. Cooking Power vs Time

- The graph shows that the variation in hourly efficiency of silver, aluminum and gold chrome polymer reflector with time.

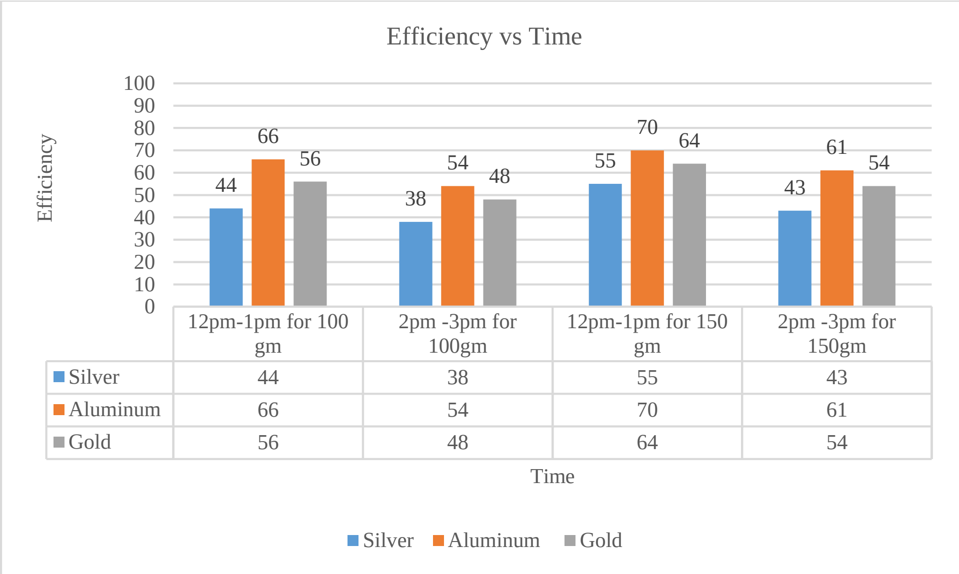

Figure 7. Thermal efficiency vs Time

From the above plot, it is also shown that the efficiency initially increases 12 pm -1 pm and it decreases 2 pm-3 pm. It is because of solar intensity slowly decreases after 2 pm. The graph also shows that the efficiency is high using aluminum polymer as a reflector. The highest efficiency 70% reaches from 12 pm to 1 pm. while using aluminum polymer.

We also saw that the lowest efficiency is 38% at 2 pm to 3 pm while using a silver polymer as a reflector.

- The graph shows diurnal variation in hourly useful energy of all polymer film with time.

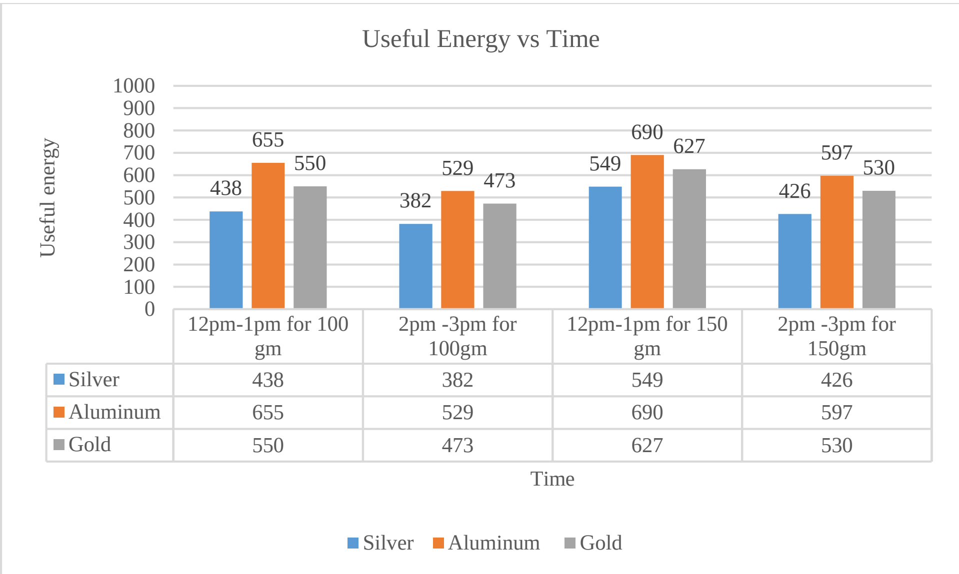

Figure 8. Useful energy vs Time

From the above plot, it is also that the useful energy increases from 12 pm -1 pm and it decreases 2 pm-3 pm. The highest useful energy is 690W and it can be decreased 382W. The highest energy reaches while using aluminum film and lower power is get while using a silver film as a reflector on a parabolic dish.

IX. CONCLUSION

In this work, the parabolic dish collector was tested for cooking test purpose. The experimental and performance analysis of parabolic dish carried out with aluminum, gold chrome and silver polymer film as a reflecting material. Here we studied the useful heat gain, cooking power and thermal efficiency of all above three different reflecting materials.

The results show that the overall thermal efficiency, useful heat, and cooking power is highest while using aluminum film as a reflector, and having a very good response to solar intensity as a reflecting material. The reason behind this result is that aluminum film has good reflectance as compared to other polymer films. We can also see that the thermal performance of the dish also better while using a gold chrome polymer as compared to silver polymer film as a reflector. The analysis also indicates that thermal efficiency, cooking power, useful heat increases initially and then decreases gradually along time. Another advantage of using a polymer film as a reflector is its weight less and also the films are cost effective. It is also shown that thermal efficiency is also better than all other types of solar cookers.

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