DESIGN, FABRICATION AND TESTING OF TWO IN ONE SOLAR COOKER ALONG WITH INTERNAL FINNED RECEIVER

PROJECT REPORT

Submitted by

S V AADHALARASEN (715515114301)

K S AJAYKUMAR (715515114302)

V HARIHARAN (715515114308)

S VINOTHKUMAR (715515114313)

In partial fulfilment for the award of the degree

Of

BACHELOR OF ENGINEERING

in

MECHANICAL ENGINEERING

PSG INSTITUTE OF TECHNOLOGY AND APPLIED RESEARCH, COIMBATORE

ANNA UNIVERSITY: CHENNAI 600 025

APRIL 2019

ANNA UNIVERSITY: CHENNAI 600 025

BONAFIDE CERTIFICATE

Certified that this project report "DESIGN, FABRICATION AND TESTING OF TWO IN ONE SOLAR COOKER ALONG WITH INTERNAL FINNED RECEIVER" is the bonafide work of "S V AADHALARASEN, K S AJAYKUMAR, V HARIHARAN, S. VINOTH KUMAR" who carried out the project work under my guidance.

Submitted for the Anna University Semester examination conducted on 03.04.2019

SIGNATURE	**SIGNATURE**
(Dr.N. Saravanakumar)	**(Mr. T. Premkumar)**
PROFESSOR &HEAD	**ASSISTANTPROFESSOR**
Department of mechanical engineering	**Department of mechanical engineering**
PSG institute of technology & applied research	**PSG institute of technology & applied research**

INTERNAL EXAMINER	**EXTERNAL EXAMINER**

ABSTRACT

Generally in box type solar cooker, food or water is heated through the radiation from the solar energy using reflectors. It consists of adjustable reflecting mirror to track sun’s position and glass sheet top cover to induce greenhouse effect. It is also available with reflecting inner glass surface to induce multiple reflections along with the single compartment where receiver will be kept. In the newly designed hybrid box type solar cooker, the frustum of dodecagon shape of reflectors (12 slanting mirrors with angle of 45^o) is placed around the receiver for focusing more radiation towards the receiver in order to increase the efficiency. In the inner compartment of the cooker, receiver is kept where the main course (water/food) is heated whereas in the artificially created outer compartment, atmospheric air is induced by Induced Draft fan in order to retrieve the heat and hot air is obtained. Hence in a single hybrid solar cooker, it is designed to get both cooked food and hot air & hence the savings in space is obtained.

The material of the receiver of hybrid solar cooker is studied with mild steel and aluminium. Although mild steel outweighed aluminium receiver with respect to easiness in machining and cost, the efficiency of cooker with mild steel is 3% lesser than the aluminium receiver. The introduction of internal fins increases the heat transfer area and hence the effect of internal fins in the receiver of aluminium pan is studied. It is observed that solar cooker with internal finned aluminium receiver is around 7 % more efficient with respect to Mild steel pan and 2.78 % more efficient than the un finned Aluminium pan. The cost and the performance of the designed hybrid solar cooker with internal finned aluminium pan are compared with conventional LPG (Liquefied Petroleum Gas) Stove and electric air heaters. From the analysis the simple payback period to obtain the investment for the solar cooker is 8 months and around 0.216 ton of CO_2 emission can be saved.

Key words: Hybrid Box type Solar Cooker, Dodecagon shape reflectors, materials of receivers, internal finned aluminium receiver, efficiency, payback, emission

LIST OF TABLES

LIST OF FIGURES:

CONTENTS **Page**

1. INTRODUCTION:

1.1 GENERAL STUDY:

Every physical activity in this world, are carried out by nature or by human beings. It is caused due to flow of energy from one form to other. Energy is one of the most important inputs for the economic development of any country. Energy can be classified into several types. From the all source of energy renewable energy takes a major part in the development of the country. As this renewable source of energy are repeatedly available in nature and this makes the output cost cheat hence for every activity renewable resources are preferred. For example wind power, solar power, geothermal energy, tidal power, hydroelectric power these are some renewable resources. The important feature of renewable energy is that the energy can be used without emitting any pollutants which are harmful to human beings and other living organisms.

The increase in the price of fuels has led to the search of alternative source of energy, so that we can utilize the solar energy for different applications. One of the most important applications of solar energy is solar cooking. This energy is clean, environment friendly which is becoming more extensive and is used in various applications such as thermal utilization (solar water and air heating, cooking, drying, distillation) and photovoltaic utilization. To cook food we need some heat energy and solar energy presents in feasible alternative over the usage of wood and fuels (kerosene, LPG and other fuels).Among these thermal applications solar cooking can be one of the simple, viable option for utilization of solar energy.

1.2 SOLAR COOKER

Most of the solar cookers are working on the basic principle of "Solar energy is converted into heat energy", that is retained for cooking. A Solar cooker needs an outdoor spot where a direct sunlight is available for several hours and it should be protected from strong to ensure that the food will be safe. The solar cookers don't work at night or on cloudy days. Dark surfaces equipments are mostly used in solar cooker to have an maximum heat gaining capacity at which the required temperature can be achieved to fulfil the requirements (cooking, boiling etc).And an tight lid are used to hold the temperature and pressure.

The basic purpose of a solar box cooker is to heat things up - cook food, purify water, and sterilize instruments. A solar box cooks because the interior of the box is heated by the energy of the sun. Sunlight, both direct and reflected, enters the solar box through the glass or plastic top. It turns to heat energy when it is absorbed by the dark absorber plate and cooking pots. This heat input causes the temperature inside of the solar box cooker to rise until the heat loss of the cooker is equal to the solar heat gain. Temperatures sufficient for cooking food and pasteurizing water are easily achieved.

1.3 TYPES OF SOLAR COOKERS

There are many types of solar cookers are developed. But, mostly all of the solar cookers fall within the following three categories

1. Solar box cooker
2. Solar panel cooker
3. Solar parabolic cooker

1.4 HEATING PRINCIPLES

The following heating principles will be considered initially,

1. Heat gain
2. Heat loss
3. Heat storage

1.4.1 HEAT GAIN

The Green house effect takes place in the heat gaining process. This effect results in the heating of enclosed spaces into which the sun shines through a transparent material such as glass or plastic. Here the usage of glass has an advantage of allowing the radiation to enter into the solar cooker and at the same time it will not allow the radiation from the solar cooker. Visible light easily passes through the glass and is absorbed and reflected by materials within the enclosed space.

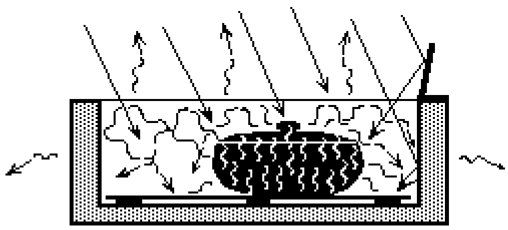

FIG 1.1Greenhouse effect

The light energy that is absorbed by dark pots and the dark absorber plate underneath the pots is converted into longer wavelength heat energy and radiates from the interior materials. Most of this radiant energy, because it is of a longer wavelength, cannot pass back out through the glass and is therefore trapped within the enclosed space. The reflected light is either absorbed by other materials within the space or, because it doesn't change wavelength, passes back out through the glass.

Reflectors and orientation of glasses are also used to additional input of heat energy. This energy results in higher cooker temperature.

1.4.2 HEAT LOSS

The Second Law of Thermodynamics states that heat always travels from high to low energy. Heat within a solar box cooker is lost in three fundamental ways,

- Conduction
- Convection
- Radiation

In Solar cooker conduction takes place in the pan(receiver) which conducts the heat from the one end of the pan to other end.

The convection takes place in the cooker in two ways, one is the convection of heat from the pan to the surrounding another one is the air move in and out of the box through gaps.

After getting certain temperature at pan they radiate heat to their surroundings. Most of the radiation is given off by the hot pan and some of the radiation escapes directly through the glazing.

1.4.3 HEAT STORAGE

The interior of a box including heavy materials such as woods, heavy pans, water, or heavy foods will take longer to heat up because of this additional heat storage capacity. The incoming energy is stored as heat in these heavy materials, slowing down the heating of the air in the box.

These dense materials, charged with heat and as it does not allow the heat flow from the solar cooker which will radiate that heat within the box, keeping it warm for a longer period at the day's end.

2. LITERATURE SURVEY

Heat from sun's rays can be harnessed to provide heat to a variety of applications such as cooking, air conditioning and generating electricity. But in general, Sun's rays are too diffuse to be of direct use in these applications. So solar concentrators are used to collect and concentrate sun's rays to heat up a working fluid to the required temperature.

2.1BOX SOLAR COOKER

Box type solar cooker is the main type of solar cooker and it is easy to handling because the construction of the cooker is simple and portable. The inner walls of the box and the bottom face have to be painted black colour to increase absorption of heat. A plain mirror is also attached on the top of the box. It is used to increase the efficiency of the cooker by reflecting more and more energy inside the box.

The author N M Nahar(6) has designed, constructed, developed and tested a double reflector hot box solar cooker with a transparent insulation material. Here the author used double reflector, the use of double reflectors resulted in avoidance of tracking towards the sun for long hours. So the cooking operations should be performed well as compared single reflector. Two experiments has done in this double reflector hot box solar cooker. The experiments are efficiency of the solar cooker with and without transparent insulation material, and the efficiencies where 30% and 24% for the cookers with and without transparent insulation material respectively. The energy saving by use of a solar cooker with TIM has been estimated to be1485.0 MJ of fuel equivalent per year. The payback period varies between 1.66 and 4.23 years depending upon the type of transparent insulation material used.

2.2HYBRID SOLAR COOKING

The Hybrid cooker is combining the use of solar energy with either electricity or LPG to cook the food or boil the water.

Shyam S. Nandwani[(10)] has designed, constructed, studied and promoted Hybrid solar food processor. It has been used for cooking, heating/pasteurizing water and distillation of small quantity of water and drying domestic products. Here Shyam suggested some reflecting materials for increase the efficiency of the cooker. The construction of this food processor is similar to a conventional solar oven is made of inclined stainless steel box and it has an electric black plate as an absorbing surface. It also has one reflector made of bright stainless sheet, to increase the solar radiation on metallic plate. This device is a hybrid device so we can use electrical energy to complete the desired process. This device can be used at any time and for different uses but with the reduced consumption of conventional fuel. The limitation of this food processor is it consumes more electrical energy as compared other solar cookers

U.R.Prasanna and Umanand[(9)] has designed and developed a hybrid cooking system with the combination of solar thermal energy and LPG energy sources. This paper proposes a hybrid solar cooking system where the solar energy is brought to the kitchen. The energy source is a combination of the solar thermal energy and the Liquefied Petroleum Gas (LPG) that is in common use in kitchens. The solar thermal energy is transferred to the kitchen by means of a circulating fluid. The working of this hybrid cooker is heat from the solar energy is stored in the heat storage tank by using pump (with the help of battery on grid), now the stored energy can be used at any time when needed, so cooking could be carried out any time of the day.

2.3 BOX SOLAR COOKER WITH AND WITHOUT INTERNAL REFLECTOR

Solar cookers use reflectors which reflects maximum solar radiation on the cooker thus it is very important to choose the correct reflectors for cooker design. There are various types of reflectors that can be employed in the solar cookers they are flat Plate, compound concentrating collectors, cylindrical parabolic collectors.

Negi and Purohit[5] designed, fabricated and experimentally evaluated the thermal performance of the solar cooker with two planar reflectors. Here the author Purohit suggested the direction of arrangement of the reflectors which is placed on the box of the cookers. The temperature of concentrator cooker was increased around 15-22 $^{\circ}$C. Also, the cooker reached the boiling point by 50-55 mins.

John[13] has designed constructed and tested a simple box type solar cooker. In this box type solar cooker the temperature of around 100 $^{\circ}$ C is achieved and it is suitable for cooking food and boiling water. This temperature is achieved by means of concentrator inside the box, such cooker may either fail to cook or take a longer time to cook full load of food. The author is report the comparisons made between the box type solar cooker with and without internal reflector. Also, the author analyze the thermal performance of this solar cooker, it has been made by considering the radiation, convection and conduction heat transfer methods. Experimental comparisons were also made on the same cooker. Here the stagnation test and boiling test and dry test also made to compare the theoretical and experimental analysis. Finally the result of the theoretical analysis predicts that the performance will be higher in the cooker with and without internal reflectors. The cumulative efficiency of some tests is calculated. The efficiency in experimental analysis is low as compared theoretical analysis.

2.4 A COMPREHENSIVE REVIEW ON SOLAR COOKERS

Erdem Cuce[1] explained some literature on solar cookers. This paper covers with comparison, types, design, performance analysis, thermal assessment of solar cookers. The theoretical and experimental performance of the solarcooker is analysed in this paper. Some experimental performance of the different types of solar cooker is explained below.

2.4.1 FIGURE OF MERIT OF SOLARCOOKER

The author Purohit[2]carried out a large number of experiments on solar cookers. He determined the efficiency of the solar cooker and figure of merit using initial and final water temperature, ambient temperature, and illumination intensity etc, the energy efficiency of the solar box cooker is varied from 4.7% to 29.1%.

2.4.2 HEMISPHERICAL SOLAR HEATER

Yadav and Tiwari[3] from Indian institute of technology carried out a simple transient analysis to get the performance of the solar cooker using hemispherical solar heater. Here the author used analytical model (mathematical and numerical) to analyse the solar radiation and heat transfer in a solar heater. The experiment's typical efficiency and overall heat transfer coefficient of the cooker are between 45 to 50% and 0.6 to 1.6 w/m^2.

2.4.3 SOLAR COOKER WITH INNER AND OUTER REFLECTORS

El-sebaii[7] analysed the box solar cooker by numerical method for inner and outer reflectors. The calculations based on the tilt angle of the reflectors. The comparisons were made on the case of cooker without the outer reflectors.

Finally the overall efficiency of the solar cooker was determined to be 31% with outer reflectors and the efficiency of the cooker without outer reflectors is less than the cooker with outer reflectors.

2.4.4 SOLAR COOKER WITH BOOSTER MIRROR

Ibrahim and Elreidy[4] investigated the performance of the solar cooker with a plane booster mirror reflector. The mirror is placed at tilt position with respect to the cooker position. Here the position of the cooker and the booster mirror angle is adjusted in order to maximize the solar concentration. It was found that better heat transfer occurred when the cooking pot covered with a transparent cover. And the average efficiency of this booster mirror solar cooker was determined to be around 14%.

2.4.5 BOX SOLAR COOKER WITH LATENT HEAT

Buddhi and Sahoo[6] designed a box type solar cooker with latent heat for the climatic conditions in India. In this design the cooking is possible even the sun goes away. The experiments are made by using a phase change material as a heat storage medium. The results were also compared with simple box solar cookers. The absorber plate temperature is remained constant at about 70°C for a long period of time.

2.5 THERMAL PERFORMANCE OF BOX-TYPE SOLAR COOKER

Thermal performance is also known as efficiency of the device that uses thermal energy. In solar cooker thermal performance is nothing but it is the ratio of net energy output to the heat input.

Subodh kumar[11] designed and tested the box type solar cooker with double glazed material. The experiments were performed for the determination of efficiency of the cooker for outdoor conditions. The efficiency of the cooker is calculated for plus or minus 2 hours of outdoor solar condition. Here the booster mirror also used to increase the efficiency of the cooker by means of placed the booster mirror at some inclined angle and obtained high concentration. Finally the theoretical and experimental performances were compared. Here also the efficiency of the theoretical performance is high as compared experimental tests.

2.6 EFFECTIVE CONCENTRATION RATIO OF SOLAR COOKER

Atul A. Sagade(12) determined the effective concentration ratio (ECR) experimentally by means of thermal tests. The ECR is determined with and without booster reflector. In first test the booster reflector is covered with black cloth. In second test the booster reflector is directly concentrate to the required area. For both tests the normal water is used as a standard load. The optical efficiency factor for both cases is calculated. The efficiency factor for covered booster reflector is 0.264 and for booster reflector is 0.177, so it is clear that the value of efficiency factor is decreases when the booster reflector is used. Here the boiling time for both cases also noted, the time is decreased (from 117 minutes to 82 minutes) for the booster reflector.

2.7 DOUBLE EXPOSURE SOLAR COOKER WITH FINNED COOKING VESSEL

Author ArezkiHarmim(17)has designed and investigated the double exposure solar cooker experiment where conducted in two phases. The first phase includes the simple type of box solar cooker.The second phase includes with some changes in volume and lateral surface of the solar cooker, here lateral surface where provided with external fins. These fins are provided to increase the heat transfer into solar cooker which in turn reduces the time consumption and increase the efficiency (from the first phase 29.8% to second phase 32.4%) of the double exposure solar cooker. The tests were conducted in Research unit in Renewable energies in Saharan Medium of Adrar.

2.8 NEW HYBRID SOLAR COOKER WITH AIR DUCT

Abhishek Saxena[18] and Nitin Agarwal has designed a new hybrid solar box cooker in order to test the thermal performance in different climatic conditions of western Uttar Pradesh, India. This hybrid solar cooker is integrated with the trapezoidal duct. The objective of this study is to reduce the time consumption with usage of minimum heat source. Here the external heat source 200W halogen lamps are used to enhance the heat transfer and with this external source 450 small hollow balls of copper are added in solar cooker this helps in improve the thermal performance of solar box cooker in forced convection. After the completion of study the thermal efficiency 45.75% have been observed. And overall heat loss coefficient is around 6.2w/m2C.The use of halogen lamp and hollow copper balls has enhanced the overall efficiency of the solar box cooker.

2.9 EXPERIMENTAL DETERMINATION OF ENERGY AND EXERGY EFFICIENCY OF THE SOLAR PARABOLIC-COOKER

Hassan k[16] has designed the low cost parabolic type solar cooker. From this experiments the energy and exergy efficiency are calculated. The experiment is performed in period from 10.00 to 14.00 solar time. During this time it has been observed that the temperature of water and the temperature of water and ambient air are 330 K and 31 K respectively, The energy output varied from 20 and 78.And the exergy efficiency varies from 3-6.5 W.The energy and exergy efficiency varies between 2.5-15% and 0.3-1.2% respectively.

2.10 EXPERIMENTAL INVESTIGATION OF A BOX-TYPE SOLAR COOKER WITH A FINNED ABSORBER PLATE

Author A.Harmim[15] and M.Belhamel designed and investigated the box type solar cooker. The experiments have been carried out to compare the performance of a box type solar cooker equipped with finned absorber plate to a cooker without a finned plate. Fins are used to enhance the heat transfer of the absorber plate to the cooker. The results of the experiments have been analyzed for both conditions. The efficiency of the box type solar cooker with a finned absorber was about 7% more than the box type solar cooker without fins. Similarly, the time required for heating water up to boiling temperature in both box-type solar cookers was reduced with about 12% when a finned absorber plate was used.

2.11 EFFECT OF FIN CONFIGURATION PARAMETERS ON SINGLE BASIN SOLAR STILL PERFORMANCE

Author A.A El-Sebaii [14] and M.R.I Ramadan designed and investigated the effect of fin configuration parameters on single basin solar still performance both experimentally and theoretically. The performance of the finned basin linear still was compared with that of conventional still. The results are analyzed for both experiments. The efficiency of the solar still increases with respect to the finned configuration. The effect of configuration parameters are investigated, the effects on solar still increases with increasing the fin height,however, it decreases with increasing the thickness of the fins and number of fins. The amount of solar radiation available was majorly effect the efficiency and performance of the finned basin linear still.

TABLE 2.1 LITERATURE SURVEY

SL.NO	AUTHOR	JOURNAL NAME & YEAR	REMARKS
1	N M Nahar	Performance and testing of a hot box storage solar cooker. Energy conversion and management Volume 44, May 2003, Pages 1323-1331	• Double reflector with transparent insulation material used to improve the efficiency of the cooker • The efficiency of the cooker with and without reflective mirror4 and transparent insulation material is 30% and 24% respectively.
2	Shyam.S Nandwan	Design, Construction and study of a hybrid solar food processor in the climate of cost Rica. Renewable energy, Volume 32, March 2007, Pages 427-441	• Reflecting materials are used to improve the performance of the solar food processor by 4 -9 % • Reflectors are made up of stainless steel sheet to increase the solar radiation on metallic plate
3	UR Prasanna, Umanand	Medeling and design of a hybrid solar cooker. Solar energy, Volume 159, 2018, Pages 984-991	• Combination of solar and LPG energy sources have been more effective • Cook the food with less time using the heat storage tank (solar and LPG)
4	Negi, Purohit	Experimental investigation of a box type solar cooker	• Experimentally evaluated the thermal performance of

		employing a non tracking concentrator. Energy conversion and Management, Volume 46, March 2005, Pages 577-604	the solar cooker with two planar reflectors. • The temperature of concentrator cooker was increased around 15-22^{o} C. Also, the cooker reached the boiling point by 50-55 minutes.
5	John	Theoretical and experimental comparison of solar box cooker with and without internal fins. Energy, Volume 57, 2014, Pages 1613-1622	• Comparisons made between the box type solar cooker with and without internal reflector. • Adding fins improve the performance of the cooker by 9-10 %
6	Erdem Cuce	Comprehensive review on solar cookers. Applied Energy, Volume 102, (2013), Pages 1399-1421	• Analysed the box solar cooker by numerical method for inner and outer reflectors. • The experiments are made by using a phase change material as a heat storage medium. PCM leads the absorber plate temperature to remain constant at about 70°C for a long period of time. • The performance of the

			solar cooker investigated and determined with booster mirror, the implementation of booster mirror improved the efficiency of the cooker to 14%. • Analysed the solar radiation and heat transfer in a solar heater. The experiment's typical efficiency and overall heat transfer coefficient of the cooker are between 45 to 50% and 0.6 to 1.6 w/m^2. • Determined the efficiency of the solar cooker and figure of merit using initial and final water temperature, ambient temperature, and illumination intensity etc, the energy efficiency of the solar box cooker is varied from 4.7% to 29.1%.
7	Atul A. Sagade	Effective concentration of solar cooker, Solar energy, Volume 159, 2018,Pages 984-991	• Determined the effective concentration ratio (ECR) experimentally by means of thermal tests i.e. with ad without booster mirror

			• . The efficiency factor for covered booster reflector is 0.264 and for booster reflector is 0.177.
8	Nitin Agarwal	Performance characteristics of a new hybrid solar cooker with air duct. Solar energy, Volume 159, 1 Jan 2018, Pages 628-637	• To reduce the time consumption with usage of minimum heat source i.e. 200W halogen lamps to enhance the heat transfer. • Small copper balls are used to improve the thermal performance of the solar cooker. After the completion of study the thermal efficiency 45.75% have been observed.
8	Hassan K	Experimental determination of energy and exergy efficiency of the solar parabolic cooker. Solar energy, Volume 77, 2004, Pages 67-71	• Low cost parabolic cooker • Energy and exergy efficiency are calculated. • The energy output varied from 20 and 78.And the exergy efficiency varies from 3-6.5 W. The energy and exergy efficiency varies between 2.5-15% and 0.3-1.2% respectively.

2.12 OBJECTIVES

Based on the literature survey the following objectives are formulated.

1. To design a solar box cooker with booster mirror (reflecting mirror) that is adjustable and easy to reflect the radiations from the sun towards the pan (i.e. cooking pan).This reflecting mirror is used to focus all the radiations to the cooker even when the sun is not perpendicular to the cooker surface.
2. To design a concentrator with dodecagon shape of frustum of mirror with an angle of 45˚, so that all the 12 sides of it concentrates the solar radiation towards the receiver. It will increase the efficiency of the solar cooker.
3. In order to save the space apart from heating the water/ cooking the food, the provisions can be made to heat the air induced inside the box by fans for the effective usage of cooker space as well as increase the efficiency of the efficiency.
4. Two receiver pans of different materials i.e. Mild steel and Aluminium have to be checked to analyze the contrast between them including efficiency.
5. The effect of internal fins in receiver has to be compared to the best heat effective material (i.e. Al) by analyzing the efficiency of solar cookers having finned and unfinned receiver.

3 DESIGN AND FABRICATION

3.1 DESIGN PARAMETERS AND IT SYMBOLS

Table 3.1

PARAMETERS	UNITS	SYMBOLS
Height of the cooker	m	H
Diameter of the cooker	m	D
Mass of thecooker	kg	m_c
Mass of the water	kg	m_w
Volume of the cooker	m^3	v
Time	s	t_w
Initial temperature	^oC	T_1
Final temperature	^oC	T_2
Heat absorbed	kJ/s	Q
Heat input	kJ/s	Q_{in}
Area of the solar box	m^2	A
Specific heat capacity at constant pressure	kJ/kg K	Cp
Efficiency	%	Ƞ
Area of the ID fan	m^2	A_F
Length of the fin	m	L
Height of the fin	m	H
Thickness of the fin	m	t

Volume of the fin	m^3	V
Efficiency of the fin	%	η_f
Effectiveness	-	∑
Heat transfer coefficient of the fin	W/m^2K	h_f

3.2 DESIGN OF COOKER

Dimensions of cooker

Height of the cooker (h) = 100mm (Assumption)

Radius of the cooker(r) = 100mm (Assumption)

Mass calculation (for simplicity purpose heating the water task at cooker is considered)

Volume of the cooker $V = \pi r^2 h$

$V = \pi \times (0.100)^2 \times (0.100)$

$\mathbf{V = 3.14 \times 10^{-3}\ m^3}$

Density of the water **(ρ_w) = 1000 kg/m³**

Therefore,

The maximum mass of the water in cooker **(m_w) = density** × **Volume**

The maximum mass of the water in cooker **(m_w) = 1000** × **3.14 × 10^{-3}**

The maximum mass of the water in cooker **(m_w) = 3.14 Kg**

For analysis approximate mass of water considered **(m_w) = 2 Kg**

3.2.1 HEAT REQUIRED

Specific heat capacity

Specific heat capacity of water at constant pressure = **4.18 kJ/Kg K**

Time

Time taken to heat up the water (t_w) = 2100 seconds

(Assumed as constant time)

Temperature

Initial temperature of the water (T_1) = 27 °C

Final temperature of the water (T_2) = 100 °C

Heat requiredto heatup the water (Q)

$Q = \dot{m} \times Cp \times (T_2 - T_1)$

$Q = (2/2100) \times 4.18 \times (100-27)$

Q = 0.290 kJ/s

3.2.2 HEAT INPUT (Q_{in})

Efficiency of the cooker Ƞ = 35% (Assumed)

Heat input (Q_{in}) = $\frac{\text{heat required or heat absorbed}}{\text{efficiency}}$

Heat input (Q_{in}) = $\frac{0.290}{0.35}$

Heat input (Q_{in}) = 0.828 kJ/s

3.2.3 AREA OF THE BOX (A)

Average solar radiation of Coimbatore = 0.95 KW/m^2

(Taken from the Pyranometer)

Area needed to heat up the water (A) = $\frac{\text{heat input}}{\text{solar radiation}}$

Area needed to cook the water (A) = $\frac{0.828}{0.95}$

Area required to cook the food (A) = 0.871m^2

3.3 DESIGN OF FINS

Dimensions of fins

Height of the fins (H) = 65mm (based on the required water volume)

Length of the fins (L) =100mm (based on the maximum possibility)

Length of the fin respect to temperature

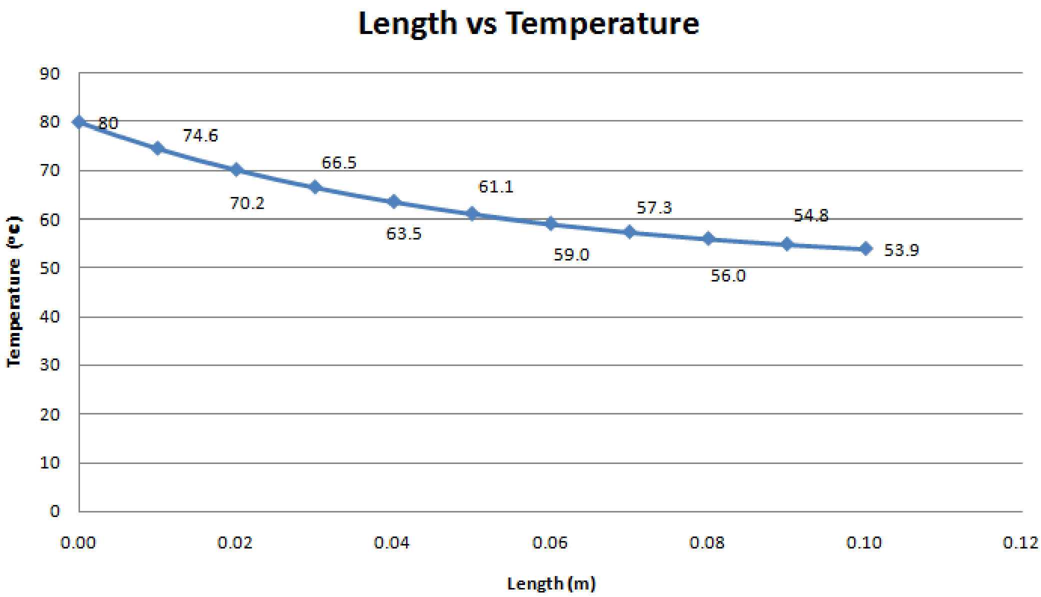

Figure 3.1 Length vs Temperature

As per the designed length the characteristic of temperature do not harm the heat transfer regardless the change in the length of the fin within the pan.

Thickness of the fins (T) = 2mm (Assumption)

Heat transfer without fins

Heat required ($Q_{withoutfins}$) = ṁ × Cp × (T_2-T_1)

Mass per time (ṁ) = $\frac{2}{2100}$

ṁ = 0.952× 10^{-3} kg/s

Specific heat of water at constant pressure (Cp) = 4.18 kJ/kg K

Final temperature (T_2) = 56.4 °C

Initial temperature (T_1) = 24 °C

Heat required ($Q_{withoutfins}$) =0.952× 10^{-3}× 4.18 × (56.4-24)

Heat required ($Q_{withoutfins}$) = 0.1289 kJ/s

Heat transfer with fins

Effectiveness of the fin (∑) = 1.5 (assumed)

Effectiveness of the fin (∑) = $\frac{\text{Q fins}}{\text{Q withoutfins}}$

Therefore, heat transfer with fins = Effectiveness × $Q_{withoutfins}$

Heat transfer with fins (Q_{fins}) = 1.5 × 0.128

Heat transfer with fins (Q_{fins}) = 0.192 kJ/s

Number of fins

Efficiency of the fin (η_f) = 70% (From HMT data book [19], for rectangular fins)

Convection heat transfer coefficient (water to aluminum) h_f = 30 W/ m²K

Efficiency of the fin $\eta_f = \frac{\text{heat transfer with fins}}{\text{heat transfer withoutfins}}$

$$\eta_f = \frac{0.192}{\text{h x At x dT}}$$

$$0.7 = \frac{0.192}{0.03 \text{ x At x } (75-35)}$$

Where,

A_t– total area of the fins

dT – temperature difference between base and the water i.e. the stuff inside the cooker (T_b - $T\infty$)

T_b= 75 °C (measured base temperature of the receiver)

T_∞ = 35 °C (average water temperature from initial to final)

Therefore, Total area of the fins (A_t) = 0.228 m²

Total area of the fins (A_t) = Number of fins × Surface area for 1 fin

Surface area of one fin (A_{1s}) = 0.1 × 0.065 × 2 (2 contact surfaces)

(A_{1s}) = 0.013 m²

Total number of fins = $\frac{\text{Total area of the fins (At)}}{\text{Surface area of the fin(A1s)}}$

Now, the number of Fins (N) = $\frac{0.22}{0.013}$

N = 16.5

Approximately,

N = 16 fins

Effect of volume occupied by fins

Volume of the single fin (V) = Length x Height x Thickness

Volume of the single fin (V) = 100 x 65 x 2

Volume of the single fin (V) = 1.3×10^{-5} m^3

Volume of the fins (including all fins) (B) = 1.82×10^{-4} m^3 (x 16)

Total volume of the pan = 3.14×10^{-3} m^3

Volume of the pan after fabrication of fins= total volume – volume of fins

Volume of the pan after fabrication of fins =$3.14 \times 10^{-3} - 1.82 \times 10^{-4}$

Volume of the pan after fabrication of fins =2.958×10^{-3} m^3

Actual volume of the food or water taken = 2×10^{-3} m^3

Available volume of the pan with

Fabricated fins and food = $2.958 \times 10^{-3} - 2 \times 10^{-3}$

Available volume of the pan with

Fabricated fins and food = $0.958 \times 10^{-3} m^3$

So, the total volume of the pan after fabrication of fins does not affect the required volume of the food or water.

3.4 COMPONENTS OF SOLAR COOKER

The main components of solar cooker are

3.4.1Wooden box: It is the square shape box which supports the cooker, concentrator and to attain green house effect by means of box covered with reflector sheets.

Figure 3.2 Wooden box

3.4.2 Receiver pan: It is a container or receiver which contains a water or food. The outer surface of the receiver pan is coated with black paint for increasing the absorptivity of the pan.

Figure 3.3 Mild steel Pan

Figure 3.4Mild steel Pan

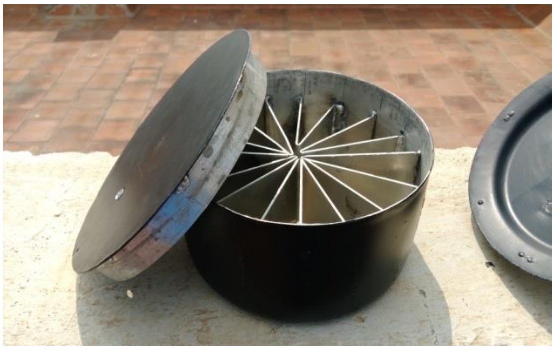

Figure 3.5 Aluminium Pan

Figure 3.6 Aluminium pan with Internal fins

3.4.3 Reflecting mirror: It is a mirror of glass material (4mm thickness) which is used to reflect the solar radiation to the receiver.

Figure 3.7 Reflecting mirror

Figure 3.8 Reflecting mirror

3.4.4 Concentrator: It is in the shape of frustum having 12 sides which is placed at the centre of box. The angle of the frustum with respect to the bottom surface is 45^{o}.

Figure 3.9 Concentrator

3.4.5 Top cover: This cover is a glass material which is placed at the top of the box. This glass cover is used to provide green house effect to the box.

Figure 3.10 Top cover

3.4.6 Induced draft fan (ID fan): This fan is used to induce the air from the atmosphere into the solar cooker in order to retrieve the heat at outer compartment i.e. outside the central dodecagon concentrator and hence the hot air can be obtained.

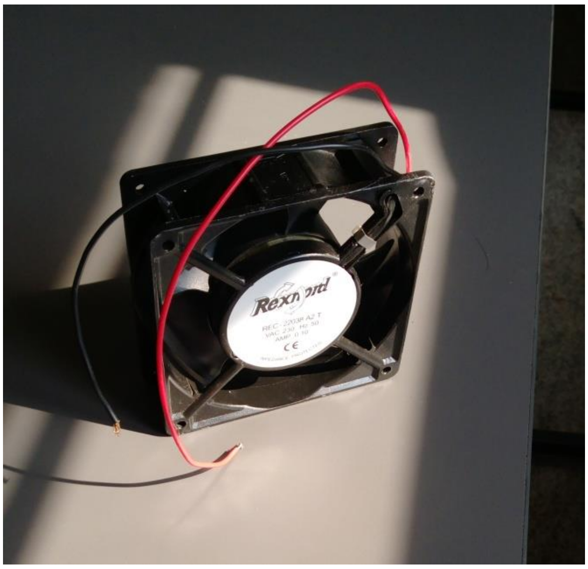

Figure3.11 ID Fan

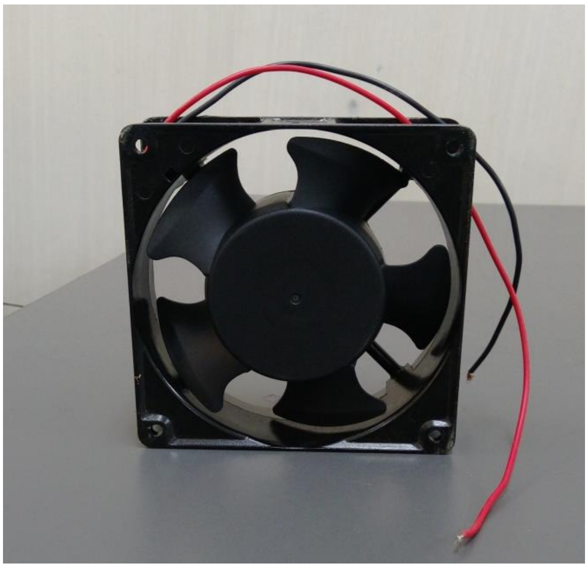

Figure 3.12 ID Fan

3.4.7 Duct: It acts as a passage for air from atmosphere to come inside the solar box by means of induced draft fan.

Figure 3.13Duct

Figure 3.14 Duct

3.5 SOLID WORKS MODEL OF THE SOLAR COOKER

3.5.1 MODEL OF COMPONENTS

Bottom box

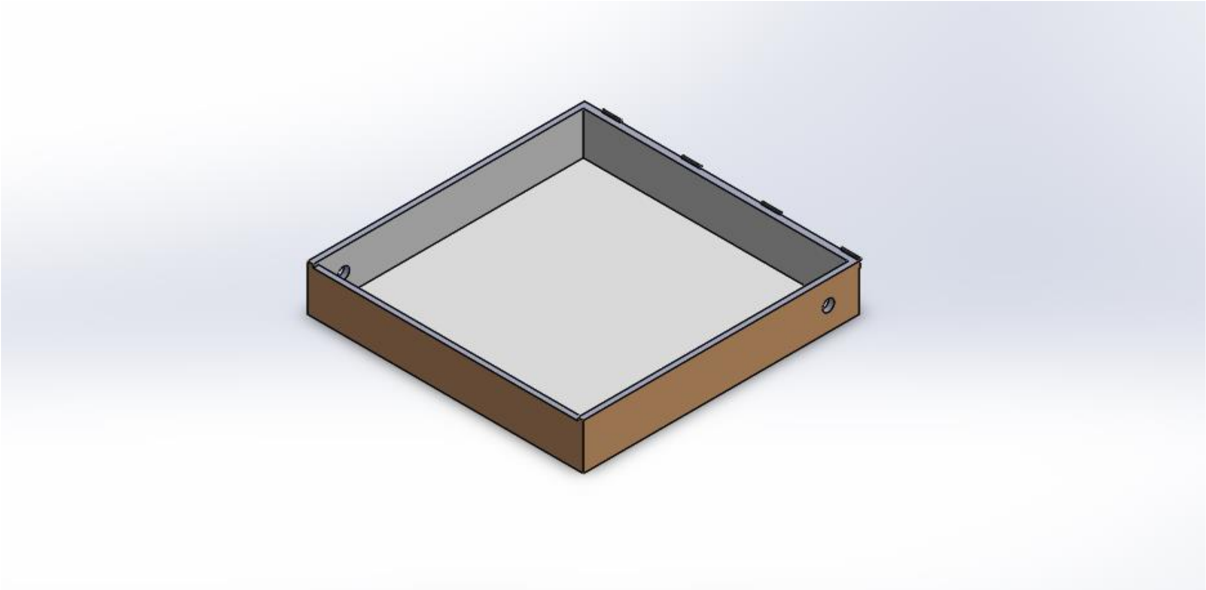

Figure 3.15 Bottom box

Reflecting mirror

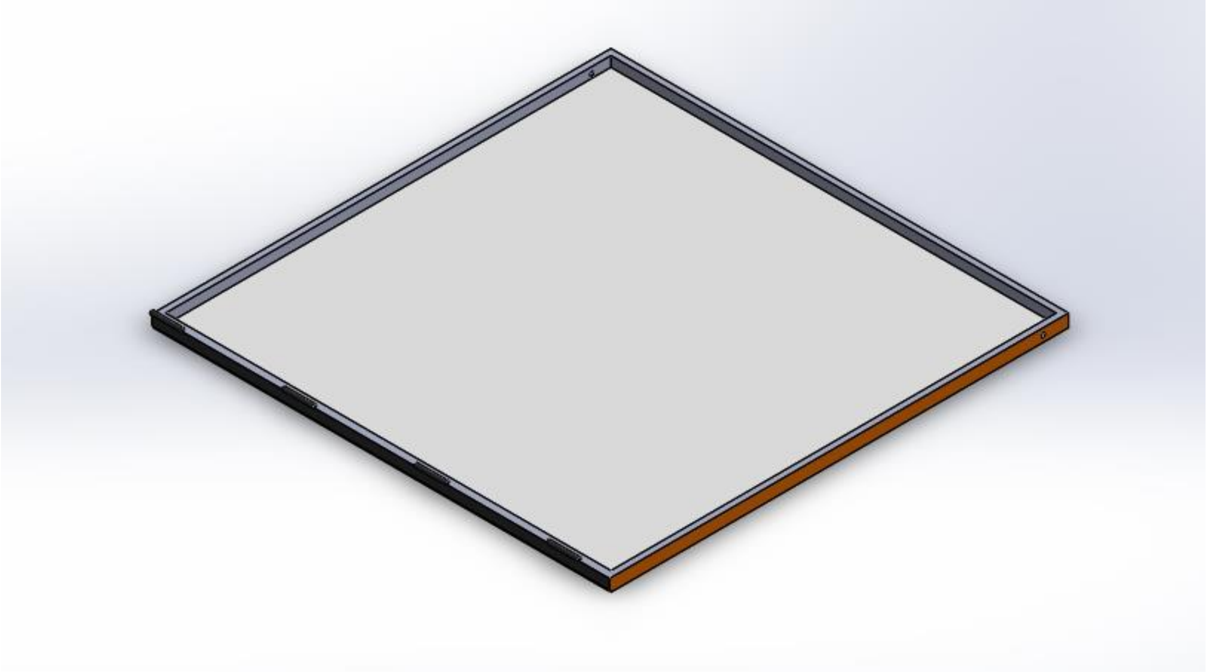

Figure 3.16 Reflecting mirror

Receiver Pan

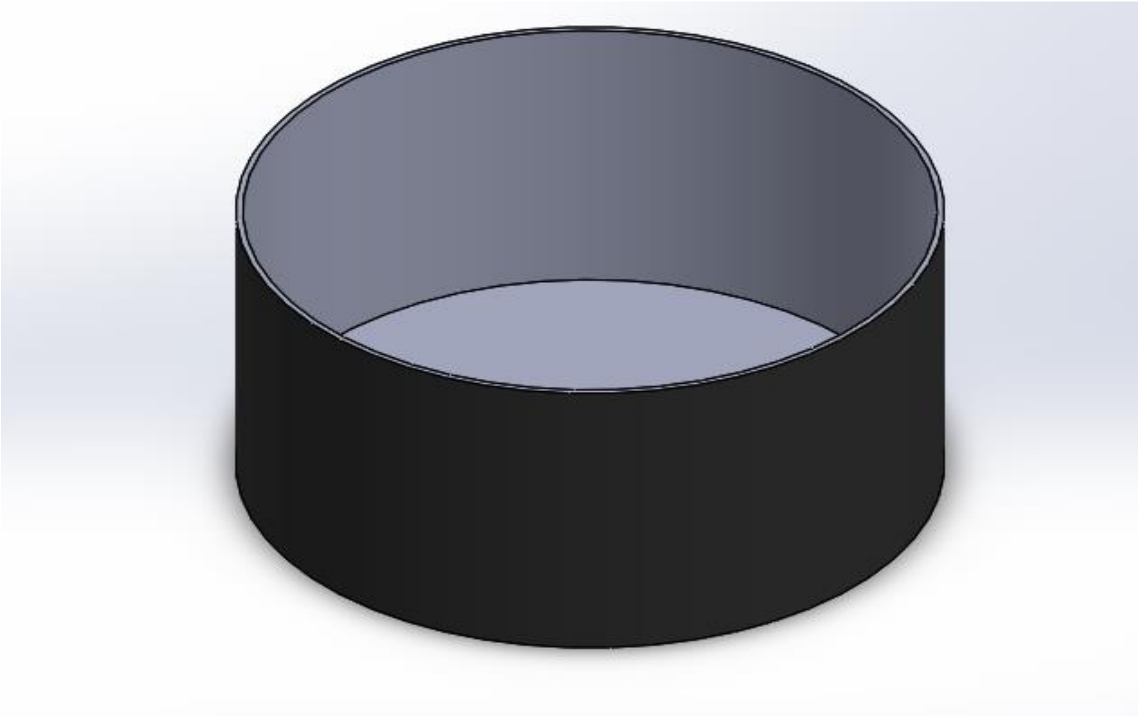

Figure 3.17 Receiver Pan

Aluminium receiver pan with internal fins

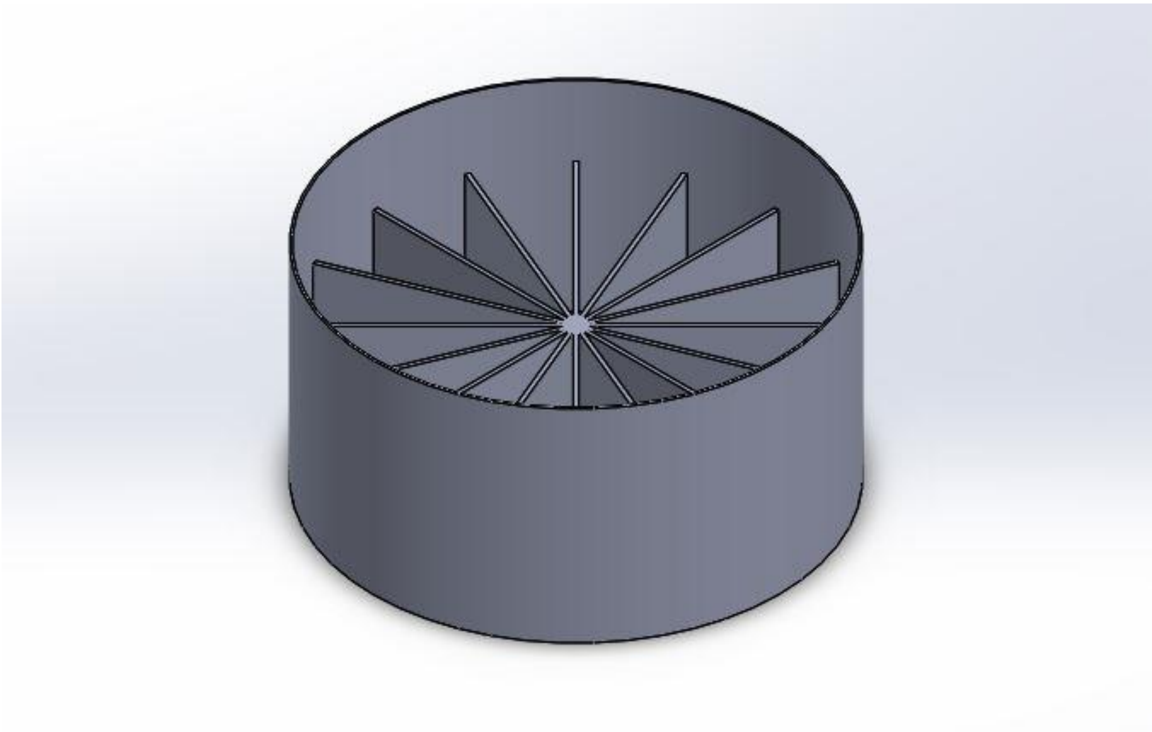

Figure 3.17 Aluminium Pan with fins

Receiver pan lid

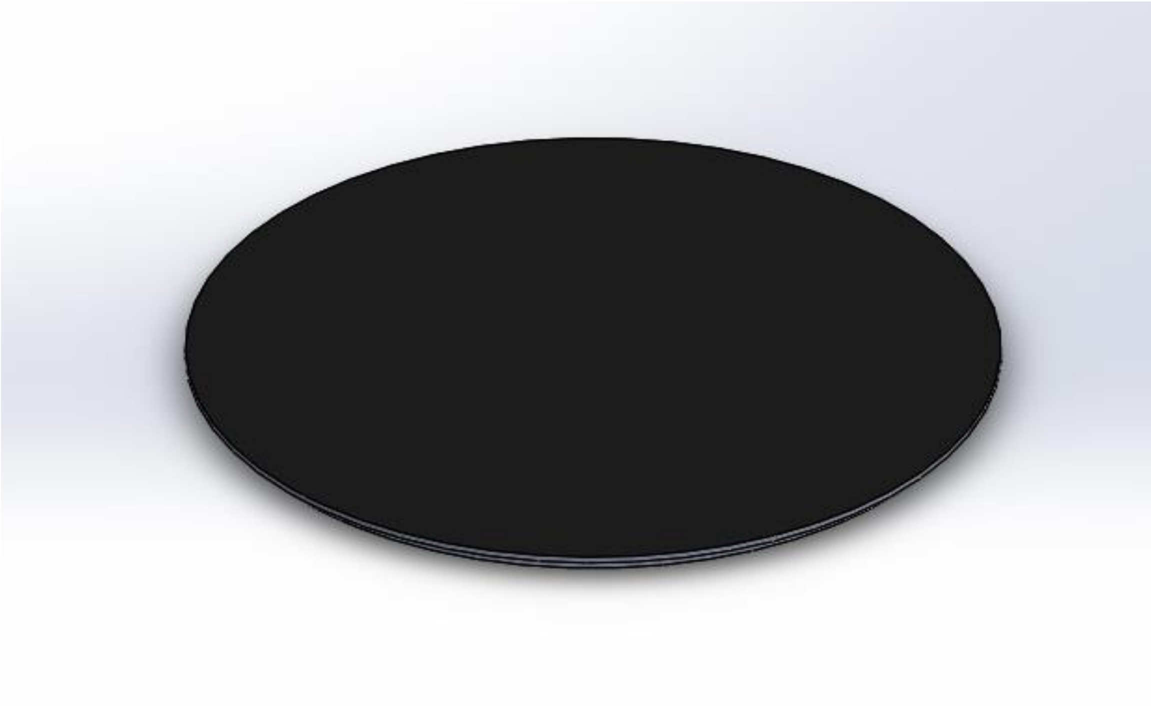

Figure 3.18 Pan Lid

Duct

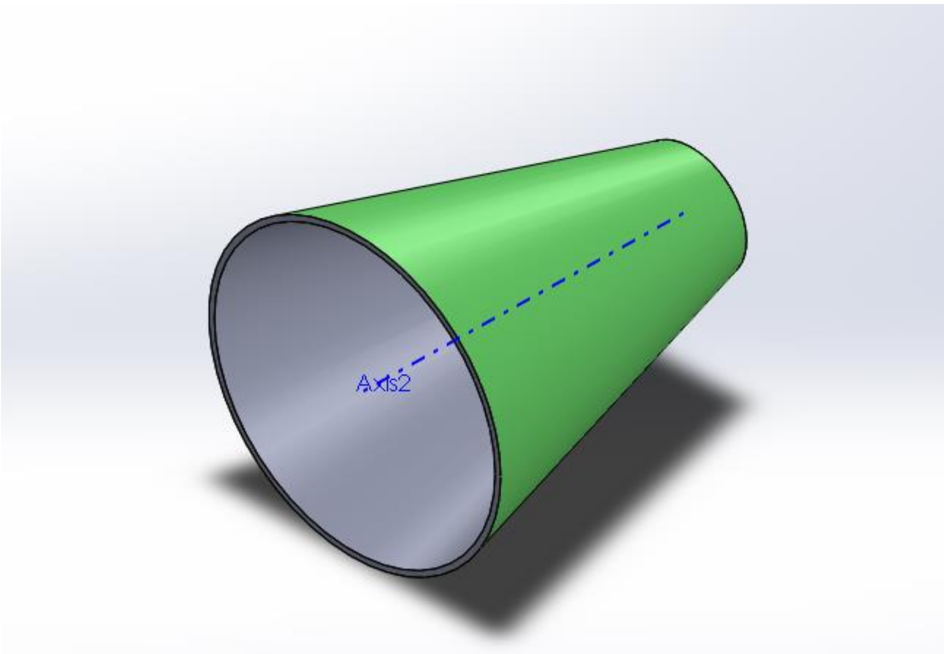

Figure 3.19 Duct

Dodecagon shape concentrator

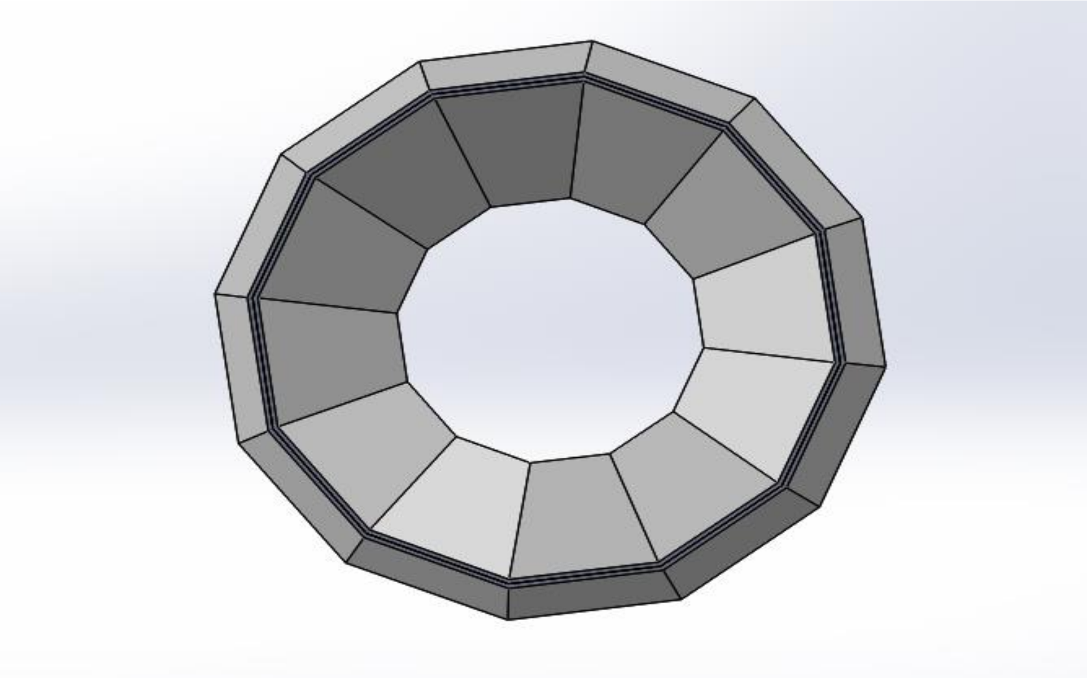

Figure 3.20 concentrator

3.5.2 OVERALL SETUP OF THE COOKER

Solar cooker model

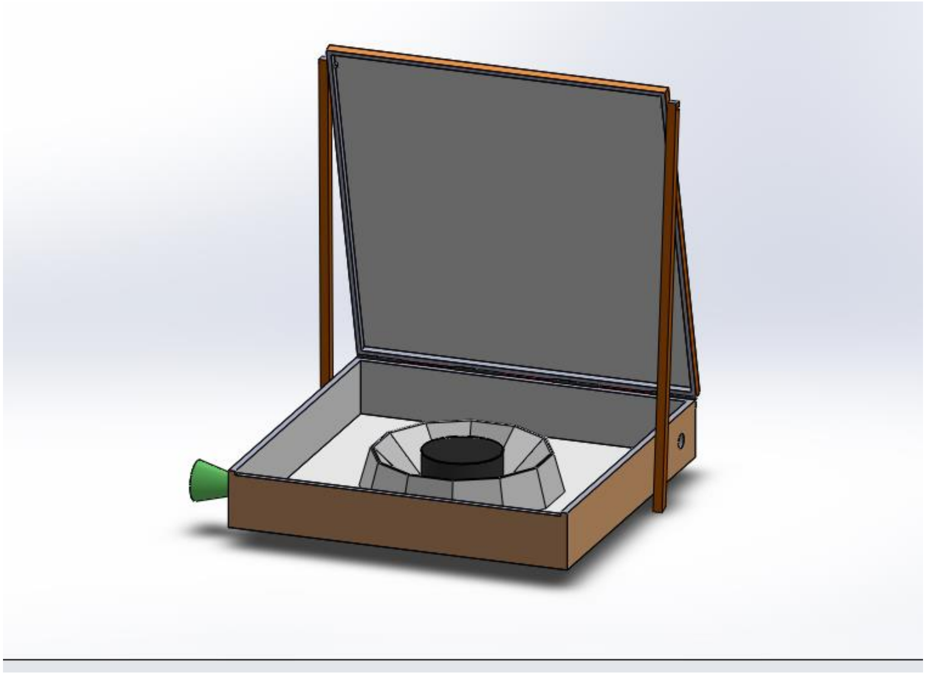

Figure 3.21 Modelling of cooker

3.5.3 DRAFTING OF COOKER

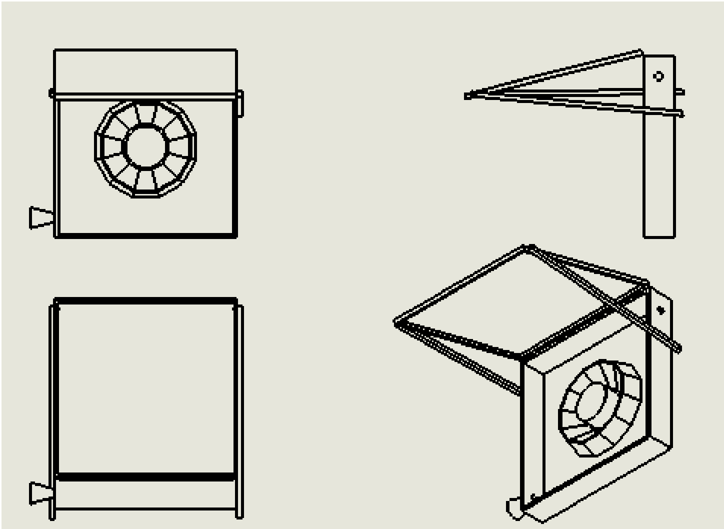

Figure3.22 drafting of cooker

3.5.4 MATERIALS USED FOR FABRICATION

1. Aluminium reflective sheets
2. Plastic duct
3. Reflective mirror of glass material (4mm thickness)
4. Plywood for outer box of the cooker
5. Top cover of glass material (4mm thickness)
6. Mild steel pan coated with black paint
7. Aluminium pan coated with black paint
8. Aluminium fins (No's 16)
9. Thermal paste

4. EXPERIMENTATION, RESULTS AND DISCUSSION

4.1 INSRTUMENTS USED FOR MEASUREMENTS

4.1.1Digital thermometer: It is used to measure the temperature of water (initial and final), outlet air temperature from theID fan and the atmospheric air temperature.

Figure 4.1 Digital Thermometer

4.1.2Digital Anemometer: Digital anemometer is used to measure the velocity of air induced by ID fan and hence to find mass flow rate of the air.

Figure 4.2 Anemometer

4.1.3 Measuring jar: It is used to measure the volume of water poured in the cooker.

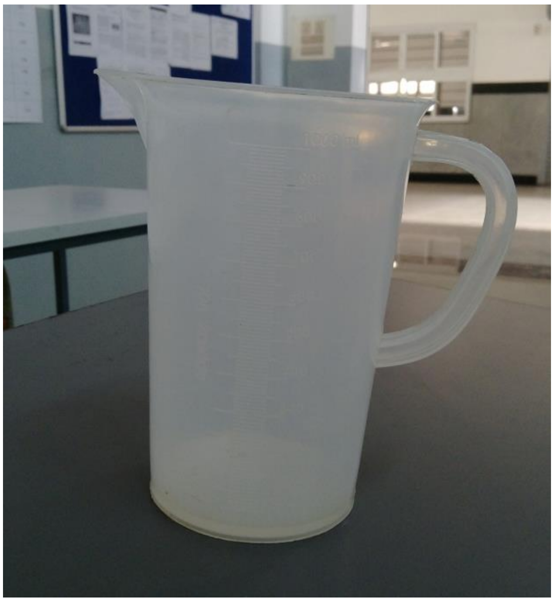

Figure 4.3 Measuring jar

4.1.4 Pyranometer: It is used to measure the total solar radiation of the area where the cooker has kept.

Figure 4.4 Pyranometer

4.2EXPERIMENTS ON SOLAR COOKER

4.2.1EXPERIMENT PARAMETERS AND IT SYMBOLS

Table 4.1

PARAMETERS	**UNITS**	**SYMBOLS**
Height of the cooker	m	h
Diameter of the cooker	m	d
Mass of the cooker	kg	m
Volume of the cooker	m^3	V
Density of the food	kg/m^3	Ƥ
Time	s	T
Initial temperature	^oC	T_1
Final temperature	^oC	T_2
Heat required	kJ/s	Q
Heat input	kJ/s	Q_{in}
Area of the solar box	m^2	A
Specific heat capacity	kJ/kg K	Cp
Efficiency (water contribution)	%	η_w
Efficiency (air contribution)	%	η_a
Total efficiency	%	η
Area of the fan	m^2	A_F
Mass of water	kg	m_w
Mass flow rate of the air	kg/s	m_a

Specific heat capacity of the air at constant pressure	kJ/kg K	Cp_{air}
Density of the air	kg/m^3	$ϐ_{air}$
Outer diameter of the fan	m	d_o
Inner diameter of the fan	m	d_i

4.2.2 EXPERIMENT ON WATER ALONE (MILD STEEL)

TABULATION

Table 4.2 experiment on water

EXP	m (kg)	Cp (kJ/kgk)	T_1 (°C)	T_2 (°C)	t (sec)	Q (kJ/s)	Q_{in} (kJ/s)	Ƞ (%)	Solar radiation (KW/m^2)	Area (A) (m^2)
Water	2	4.186	24	56.7	2100	0.130	0.752	17.3	0.929	0.81

Observation: (for water alone)

Mass of the water =**2 kg**

Density of the water **= 1000kg/m^3**

Specific heat capacity = **4.18 kJ/ kg k**

Initial temperature of the water = **24**℃

Final temperature of the water =**56.7**℃

Time taken =**2100 seconds**

Solar radiation = **0.929 kW/m²**

Area of the Box = **0.8 m²**

CALCULATIONS FOR HEATNG WATER

Heat absorbed by water:

Heat absorbed by water (Q) = $\dot{m} \times Cp \times (T2\text{-}T1)$

Heat absorbed by water (Q) = (2/2100) × (4.18) × (56.7-24)

Heat absorbed by water (Q) = 0.130 kJ/s

Heat input:

Heat input (Q_{in}) = solar radiation × Area of the box

(Q_{in})= 0.929 ×0.8

Heat input (Q_{in}) = 0.756kJ/s

Efficiency on water considering total aperture area of cooker

Efficiency (η_w) = $\frac{\text{Heat absorbed by water (Q)}}{\text{Heat input (Qin)}}$

Efficiency (η_w) = $\frac{0.130}{0.756}$

Efficiency (η_w) = 17.3%

4.2.3 EXPERIMENT ON MILD STEEL:

(WATER HEATING+HOT AIR GENERATION)

TABULATION

Table 4.3 experiment on Mild steel

EXP	Ratio between mass to time (or) Mass flow rate ṁ (kg/s)	Cp (kJ/ KgK)	T_1 (°C)	T_2 (°C)	t (sec)	Q (kJ/s)	Q_{in} (kJ/s)	Ƞ (%)	Solar radiation (kW/m²)	Total Area (A) (m²)
Water	2	4.186	22.5	47.7	2100	0.100	0.686	14.7	0.848	0.81
Air	0.0298	1.005	38.2	46.5	2100	0.248		36.5		

Observation: (for water)

Mass of the water =**2 kg**

Density of the water **= 1000kg/m^3**

Specific heat capacity of water at constant pressure = **4.18 kJ/ kg K**

Initial temperature of the water =**22.5**℃

Final temperature of the water =**47.7**℃

Time taken =**2100 s**

Solar radiation = **0.848 kW/m^2**

Area of the Box = **0.81 m^2**

CALCULATIONS FOR WATER HEATING

Heat absorbed by the water:

Heat absorbed by the water (Q) = $m_w \times Cp \times (T_2 - T_1)$

Heat absorbed by the water (Q) = (2/2100) ×(4.18)×(47.7-22.5)

Heat absorbed by the water (Q)= 0.100 kJ/s

Total Heat input :(for water and air)

Heat input (Q_{in}) = solar radiation × Area of the cooker

(Q_{in})= 0.848 × 0.81

Heat input (Q_{in}) = 0.686 kJ/s

CALCULATIONS FOR AIR

Observation: (for air)

Inlet temperature of the air (T_1) =**38.2**℃

Outlet temperature of the air (T_2) =**46.5**℃

Time taken (t) = **2100 s**

Average velocity of the air (v) =**3.4 m/s**

Outer diameter of the fan (D) =**120 mm**

Hub diameter / Inner diameter of the fan (d) =**65 mm**

Specific heat capacity of the air at constant pressure(Cp_{air})=**1.005 kJ/kgK**

Density of the air (β) = **1.11 kg/m^3 (from psychometric chart)**

Mass flow rate of air (m_a)

(m_a) = Density of the air ($β_{air}$) × velocity of the air × area of the fan

(m_a) = 1.11× 3.4× 0.0079

(m_a) = 0.0298 kg/s

Heat absorbed by the air

Heat absorbed by the air (Q) = $\dot{m} \times Cp_{air} \times (T_2 - T_1)$

Heat absorbed by the air (Q) = 0.0298 × 1.005 × (46.5-38.2)

Heat absorbed by the air (Q) = 0.248kJ/s

EFFICIENCY CONTRIBUTION

Water contribution (considering total aperture area of the cooker)

Efficiency (η_w) = $\frac{\text{Heat absorbed by the water}}{\text{Heat input}}$

Efficiency (η_w) = $\frac{0.100}{0.686}$

Efficiency (η_w) = 14.74%

Air contribution (considering total aperture area of the cooker)

Efficiency (η_a) = $\frac{\text{Heat absorbed by the air}}{\text{Heat input}}$

Efficiency (η_a) = $\frac{0.248}{0.686}$

Efficiency (η_a) = 36.57%

Total efficiency

$$\text{Efficiency } (\eta_T) = \frac{\text{Total heat absorbed by the water and air}}{\text{Heat input}}$$

$$\text{Efficiency } (\eta_T) = \frac{(0.100+0.248)}{0.686}$$

Efficiency (η_T) = 50.72 %

4.2.4 EXPERIMENT ON ALUMINIUM:

(WATER HEATING+HOT AIR GENERATION)

TABULATION

Table 4.4 experiment on Aluminium

EXP	Ratio between mass to time (or) Mass flow rate $\dot{m}$ (kg/s)	Cp (kJ/ Kg K)	T_1 (°C)	T_2 (°C)	t (sec)	Q (kJ/s)	Q_{in} (kJ/s)	η (%)	Solar radiation (kW/m^2)	Total Area (A) (m^2)
Water	2	4.186	22.4	50.2	2100	0.110	0.651	17.4	0.804	0.81
Air	0.0298	1.005	38.2	46.5	2100	0.248		38.0		

CALCULATIONS FOR WATER HEATING

Observation: (for water)

Mass of the water =**2 kg**

Density of the water **= 1000kg/m^3**

Specific heat capacity of water at constant pressure = **4.18 kJ/ kg K**

Initial temperature of the water =**22.4**℃

Final temperature of the water =**50.2**℃

Time taken =**2100 s**

Solar radiation = **0.804 kW/m^2**

Area of the Box = **0.81 m^2**

Heat absorbed by the water:

Heat absorbed by the water (Q) = $m_w \times Cp \times (T_2 - T_1)$

Heat absorbed by the water (Q) = (2/2100)×(4.18)×(50.2-22.4)

Heat absorbed by the water (Q)= 0.110 kJ/s

Total Heat input :(for water and air)

Heat input (Q_{in}) = solar radiation × Area of the cooker

(Q_{in})= 0.804 × 0.81

Heat input (Q_{in}) = 0.651 kJ/s

CALCULATIONS FOR AIR

Observation: (for air)

Inlet temperature of the air (T_1) =**38.2**℃

Outlet temperature of the air (T_2) =**46.5**℃

Time taken (t) = **2100 s**

Average velocity of the air (v) =**3.4 m/s**

Outer diameter of the fan (D) =**120 mm**

Hub diameter / Inner diameter of the fan (d) =**65 mm**

Specific heat capacity of the air at constant pressure(Cp_{air})=**1.005 kJ/kgK**

Density of the air (ꞵ) = **1.11 kg/m^3 (from psychometric chart)**

Mass flow rate of air (m_a)

(m_a) = Density of the air ($ꞵ_{air}$) × velocity of the air × area of the fan

(m_a) = 1.11× 3.4 × 0.0079

(m_a) = 0.0298 kg/s

Heat absorbed by the air

Heat absorbed by the air (Q) = $\dot{m} \times Cp_{air} \times (T_2\text{-}T_1)$

Heat absorbed by the air (Q) = 0.0298 × 1.005 × (46.5-38.2)

Heat absorbed by the air (Q) = 0.248kJ/s

EFFICIENCY CONTRIBUTION

Water contribution (considering total aperture area of the cooker)

$$\text{Efficiency } (\eta_w) = \frac{\text{Heat absorbed by the water}}{\text{Heat input}}$$

$$\text{Efficiency } (\eta_w) = \frac{0.110}{0.651}$$

Efficiency (η_w) = 17.10%

Air contribution (considering total aperture area of the cooker)

$$\text{Efficiency } (\eta_a) = \frac{\text{Heat absorbed by the air}}{\text{Heat input}}$$

$$\text{Efficiency } (\eta_a) = \frac{0.248}{0.651}$$

Efficiency (η_a) = 38.09%

Total efficiency

$$\text{Efficiency } (\eta_T) = \frac{\text{Total heat absorbed by the water and air}}{\text{Heat input}}$$

$$\text{Efficiency } (\eta_T) = \frac{(0.110+0.248)}{0.651}$$

Efficiency (η_T) = 54.99 %

4.2.4 EXPERIMENT ON ALUMINIUM RECEIVER PAN WITH INTERNAL FINS:

(WATER HEATING+HOT AIR GENERATION)

TABULATION

Table 4.4 experiment on Aluminium with internal fins

EXP	Ratio between mass to time (or) mass flow rate ṁ (kg/s)	Cp (kJ/kg K)	T_1 (°C)	T_2 (°C)	t (sec)	Q (kJ/s)	Q_{in} (kJ/s)	η (%)	Solar radiation (kW/m²)	Area (A) (m²)
Water	2	4.186	18.5	55.1	2100	0.145	0.732	0.200	0.904	0.81
Air	0.0298	1.005	38.2	47.5	2100	0.278		0.385		

CALCULATIONS FOR WATER HEATING

Observation: (for water)

Mass of the water =**2 kg**

Density of the water **= 1000kg/m³**

Specific heat capacity of water at constant pressure = **4.18 kJ/ kg K**

Initial temperature of the water = **18.5℃**

Final temperature of the water =**55.1℃**

Time taken =**2100 s**

Solar radiation = **0.904 kW/m²**

Area of the Box = **0.81 m²**

Heat absorbed by the water:

Heat absorbed by the water (Q) = m_w × Cp × (T_2-T_1)

Heat absorbed by the water (Q) = (2/2100)×(4.18)×(55.1-18.5)

Heat absorbed by the water (Q)= 0.145 kJ/s

Total Heat input :(for water and air)

Heat input (Q_{in}) = solar radiation × Area of the cooker

(Q_{in})= 0.904 × 0.81

Heat input (Q_{in}) = 0.732 kJ/s

CALCULATIONS FOR AIR HEATING

Observation: (for air)

Inlet temperature of the air (T_1) =**38.2℃**

Outlet temperature of the air (T_2) =**47.5℃**

Time taken (t) = **2100 s**

Average velocity of the air (v) =**3.4 m/s**

Outer diameter of the fan (D) =**120 mm**

Hub diameter / Inner diameter of the fan (d) =**65 mm**

Specific heat capacity of the airat constant pressure(Cp_{air})= **1.005 kJ/kgK**

Density of the air (β) = **1.11 kg/m^3 (from psychometric chart)**

Mass flow rate of air (m_a)

(m_a) = Density of the air ($β_{air}$) × velocity of the air × area of the fan

(m_a) = 1.11× 3.4 × 0.0079

(m_a) = 0.0298 kg/s

Heat absorbed by the air

Heat absorbed by the air (Q) = $\dot{m} \times Cp_{air} \times (T_2\text{-}T_1)$

Heat absorbed by the air (Q) = 0.0298 × 1.005 × (47.5-38.2)

Heat absorbed by the air (Q) = 0.278kJ/s

EFFICIENCY CONTRIBUTION

Water contribution (considering total aperture area of the cooker)

$$\text{Efficiency } (\eta_w) = \frac{\text{Heat absorbed by the water}}{\text{Heat input}}$$

$$\text{Efficiency } (\eta_w) = \frac{0.145}{0.732}$$

Efficiency (η_w) = 20.08%

Air contribution (considering total aperture area of the cooker)

$$\text{Efficiency } (\eta_a) = \frac{\text{Heat absorbed by the air}}{\text{Heat input}}$$

$$\text{Efficiency } (\eta_a) = \frac{0.278}{0.732}$$

Efficiency (η_a) = 38.50%

Total efficiency

$$\text{Efficiency } (\eta_T) = \frac{\text{Total heat absorbed by the water and air}}{\text{Heat input}}$$

$$\text{Efficiency } (\eta_T) = \frac{(0.145+0.278)}{0.732}$$

Efficiency (η_T) = 58.58%

4.3 SIMPLE PAYBACK PERIOD CALCULATIONS

4.3.1 LPG CALCULATION

Efficiency of the LPG gas (for cooking) = 55% [20e]

Heat input for LPG

$$\text{Heat input } (Q_{in}\,\text{LPG}) = \frac{\text{heat required for cooking}}{\text{Efficinecy of LPG}}$$

$$\text{Heat input } (Q_{in}\,\text{LPG}) = \frac{0.290}{0.55}$$

Heat input (Q_{in} LPG) = 0.527kJ/s

CO_2 emission

Calorific value of the LPG = 43000 kJ/kg [20f]

Mass flow rate of the LPG ($\dot{m}$) = $\frac{\text{Heat input (Qin LPG)}}{\text{Calorific value of the LPG}}$

Mass flow rate of the LPG ($\dot{m}$) = $\frac{0.527}{43000}$

Mass flow rate of the LPG ($\dot{m}$) = 1.225×10^{-5} kg/s

Density of the LPG [20g] = 495 kg/m^3

Density of LPG in kg / litre = $\frac{495}{1000}$ (1000 Litre = 1m^3)

Density of LPG in kg / litre = 0.495 kg / litre

1 liter of LPG weighs **0.51 kg** [20d]. LPG consists of 82.5%of carbon (0.454 kg of carbon). In order to combust this carbon to CO_2 **1.211 kg** of oxygen is needed.

Therefore 1 Litre of LPG liberates of 1.665 (1.211 Kg of oxygen+0.454 kg of carbon) kilogram of CO_2.

$$\frac{\text{kg of CO2}}{\text{kg of LPG}} = \frac{\text{kg of CO2/litre of LPG}}{\text{Density of LPG in kg/litre}}$$

$$\frac{\text{kg of CO2}}{\text{kg of LPG}} = \frac{1.665}{0.495}$$

$$\frac{\text{kg of CO2}}{\text{kg of LPG}} = \mathbf{3.363}\ \frac{\text{kg of CO2}}{\text{kg of LPG}}$$

Amount of CO_2 emitted with respect to time

kg of CO_2 emission per time = $\frac{\text{kg of CO2}}{\text{kg of LPG}}$ x mass flow rate of LPG

kg of CO_2 emission per time = ($3.363 \times 1.225\times10^{-5}$)

kg of CO_2 emission per time **= 4.119×10^{-5} kg/s**

Amount of co_2 emission per day

Total working hours per day = 4hours

$$\frac{\text{kg of CO2 Emission}}{\text{day}} = (CO_2 \text{ emission per time}) \times (\text{working hours})$$

$$\frac{\text{kg of CO2 Emission}}{\text{day}} = 4.119\times10^{-5} \times (4\times60\times60)$$

$$\frac{\text{kg of CO2 Emission}}{\text{day}} = 0.593 \text{ kg of } CO_2 \text{ per day}$$

Amount of co_2 emission per year

$$\frac{\text{kg of CO2 Emission}}{\text{year}} = \frac{\text{kg of CO2 Emission}}{\text{day}} \times 365$$

$$\frac{\text{kg of CO2 Emission}}{\text{year}} = 0.593\times365$$

$$\frac{\text{kg of CO2 Emission}}{\text{year}} = 216.530 \text{ kg of } CO_2 \text{ per year}$$

$$\frac{\text{Ton of CO2 Emission}}{\text{year}} = 0.216 \text{ Ton of } CO_2 \text{ per year}$$

4.3.2 COST OF THE COOKER

MATERIALS	QUANTITY	COST(Rs)
Reflecting mirror (4mm thickness) (900mm×900mm)	1	900
Top glass cover (4mm thickness) (900mm×900mm)	1	520
Concentrating mirror (4mm thickness)	12	480
Aluminium Reflecting sheet (0.2mm thickness)	1	944
Fan (230 V, AC supply)	1	383
Aluminium pan	1	500
Welding for pan (fins)	1	800
Plywood (12 & 8 mm thickness)	-	1500
Thermal paste	1	100
	Total	**Rs 6127**

TABLE 4.5 COST ESTIMATION

4.3.3 SIMPLE PAYBACK PERIOD

$\frac{\text{cost of LPG}}{\text{kg of LPG}}$= 61.971 Rupees per kg of LPG [20h]

(Cost of domestic LPG cylinder = Rs 880 for 14.2 kg of LPG)[20h]

Cost of the LPG stove is approximately = Rs 2000

Cost of LPG per day

Cost per day = mass flow rate of LPG× working hours (sec) × cost per kg

Cost per day =$1.225\times10^{-5} \times (4\times60\times60) \times 61.971$

Cost of LPG per day = Rs 10.93 per day

Cost of LPG per year (Running cost)

Cost of LPG per year = Cost of LPG per day × 365

Cost of LPG per year = 10.93× 365

Cost of LPG per year = Rs 3990.11 per year

Cost of air dryer

The fixed cost of simple air dryer is approximately [20i] = **Rs 1550**

Total cost

Total cost = Actual cooker cost-Fixed cost of LPG stove and air dryer

Total cost = 6127-(2000+1550)

Total cost =Rs 2577

Simple payback period

Running cost of the LPG is = Rs 3990.1 per year

Simple payback period in months = $\frac{2577}{3990.1/12}$

Simple payback period in months = 7.75 months

Simple payback period in months approximately = 8 months

4.4 RESULT

The experiments were done on solar cooker having different receivers i.e. Mild steel receiver pan, Aluminium receiver pan and Aluminium receiver pan with internal fins. Here the observed readings are noted and tabulated. Initial temperature of water is noted, after the time interval of 2100 seconds the final temperature of the water is noted. Inlet temperature i.e. temperature of atmospheric air is noted. The outlet air temperature is noted at every 10 minutes interval in the total time span of 2100 seconds i.e. 35 minutes. The velocity of the air is measured using anemometer. The temperature of the water and air was measured by using thermometer. Total solar radiation of the area where the cooker kept was measured using Pyranometer.

The efficiency of the solar cooker while heating the water alone on the mild steel receiver pan is 17.3% the improved efficiency of the cooker on mild steel receiver pan while heating water and air is 50.72 % whereas the water heating is 14.74% and the efficiency of air heating is 36.57 % There is drop of efficiency in water heating is 3% but there is improvement of efficiency 36.5 % in air heating on mild steel receiver pan. So the combined usage i.e. water and air heating is benefitted and more effective.

The Mild steel receiver pan is replaced with aluminium receiver pan to improve the efficiency of the cooker. The improved efficiency of the cooker on Aluminium receiver pan is 54.99 % whereas the water heating is 17.10% and the efficiency of air heating is 38.56 % .there is an improvement of efficiency in water heating is 3% when compared to Mild steel receiver pan. The efficiency of air heating is more or less same. So the usage of aluminium receiver pan is more effective.

The aluminium receiver pan is replaced with aluminium receiver pan with internal fins to improve the efficiency of the cooker again. The improve efficiency of the cooker on aluminium pan with internal fins is 58.58% whereas the water heating is 20.08% and the efficiency on air heating is 38.50 % . There is an improvement of efficiency in water heating is 3% when compared to aluminium receiver pan without fins. Hence the usage of fins in pan is contemporarily high in advantage and effective.

5 SUMMARY AND CONCLUSION

5.1 SUMMARY OF CALCULATION

TABLE 5.1 EFFICIENCY COMPARISONS

Experiments	**Heat absorbed by the water and air** (Q) (kJ/s)	**Total Heat input** (Q_{in}) (kJ/s)	**Efficiency on water heating** (η_w) %	**Efficiency on air heating** (η_a) %	**Total efficiency (water +air)** (η_t) %
Mild steel	0.348	0.686	14.74	36.57	50.72
Aluminium	0.358	0.651	17.10	38.56	54.99
Aluminium with internal fins	0.423	0.732	20.08	38.50	58.58

5.2ADVANTAGES AND DISADVANTAGES

Advantages:

1. The main advantage of this cooker is obtaining the required temperature of the water or food with less time as compared with other simple box type solar cookers. Because the shape of dodecagon concentrator frustum with an angle of 45^{o} leads to focus all the rays to the cooker, and the reflecting mirror used to keep the radiations perpendicular to the dodecagon shape of concentrator

2. The bottom and four sides of the box are covered with aluminium reflector sheets and the top of the box also covered with glass (top cover). This enclosed space results green house effect and also the rate of convection inside the surfaces increased
3. This cooker is not only for cooking the food or boils the water; it is also used to heat the air by convection heat transfer from cooker surfaces to air.
4. Solar cooker is environment friendly. When in use, it does not release CO_2 and other gases which pollute the air. Hence, it is very suitable for India.
5. The combination of water heating and hot air generation is increasing the efficiency of the cooker by means of inducing atmospheric air to flow through the solar cooker by induced draft fan except inner area of the concentrator.
6. The introduction of internal fins on the aluminium pan is increase the heat transfer rate and enables to attain the designed temperature with less time.

Disadvantages

1. The main disadvantage of this cooker is little more weight as compared simple box type solar cooker. It can be reduced by changing the material of the box or using the other grade ply woods that is suitable for our benefit
2. Handling the cooker while cooking is little difficult because of high temperature.
3. It is not suitable for rainy and winter seasons.

4. The adjusting mirror (Reflecting mirror) has to be adjusted with respect to the position of the sun at every time manually. It can be automated in future.
5. It is only suitable for a family with 4 members, because the capacity of cooker is less.
6. Due to limitation of solar energy collection, the solar cooking process is slow in comparison with cooking that use conventional fuels.

5.3 FUTURE SCOPE

a. If the outer box of the cooker tend to fabricate in less weight material, it will more comfortable to handle.
b. Automation of the adjustment of reflecting mirror is also benefitted, which will reduce the manual work.

5.4 CONCLUSION

Thus the box type solar cooker is benefitted for both water heating and hot air generation. The efficiency of the cooker is also increased when the aluminium pan with internal fins is used. Apart from water heating the heated air is used for hand drying and fruit drying process. There are no emissions that pollute the environment in this solar cooker. The induced green house effect leads to increase the rate of convection and also increase the temperature of the cooker. Hence the combined usage is more benefitted and effective.

REFERENCES

1. E. Cuce, P.M. Cuce, A comprehensive review on solar cookers, Applied Energy 102 (2013)1399–1421
2. Purohit I. Testing of solar cookers and evaluation of instrumentation error. Renewable Energy (2010) 2053-2064
3. Yadav YP, Tiwari GN. Transient analytical study of box-type solar cooker. Energy Conversion Management(1987) 121-125
4. Ibrahim SMA, Elreidy MK. The performance of a solar cooker in Egypt. Renewable Energy (1995) 1041-1050
5. Negi BS, Purohit I. Experimental investigation of a box type solar cooker employing a non-tracking concentrator. Energy Conversion Management(2005) 577-604
6. Buddhi D, Sahoo LK. Solar cooker with latent heat storage: design and experimental testing. Energy Conversion Management(1997) 493-498
7. El-Sebaii AA. Thermal performance of a box-type solar cooker with outer-inner reflectors. Energy (1997)1011-1021
8. Nahar NM. Design, development and testing of a double reflector hot box solar cooker with a transparent insulation material. Renew Energy (2001) 167-179
9. Prasanna UR, Umanand L. Modeling and design of a solar thermal system for hybrid cooking application. Applied Energy(2011) 1740-1755
10. Nandwani SS. Design, construction and study of a hybrid solar food processor in the climate of Costa Rica. Renewable Energy (2007) 427-441
11. S. Kumar, Thermal performance of box type solar cooker, Renewable Energy 30 (2005) 1117-1126

12. Atul A. Sagade, Effective concentration ratio of solar cooker, Solar energy, volume 159, (2018) 984-991
13. MuluBayray and John Paintin, “Box Solar Cooker User Manual,” EiTM, Mekelle University, (2012) 1613-1622
14. A.A El-Sebaii and M.R.I Ramadan, Effect of fin configuration parameters on single basin solar still performance “Desalination”, Volume 365, 1 June 2015, Pages 15-24
15. A.Harmim and M.Belhamel, experimental investigation of a box-type solar cooker with a finned absorber plate, “Energy”, Volume 35, Issue 9, September 2010, Pages 3799-3802
16. Hassan K , Experimental determination of energy and exergy efficiency of the solar parabolic-cooker “Solar Energy”, Volume 77, Issue 1, 2004, Pages 67-71
17. Arezki Harmim, Double exposure solar cooker with finned vessel, “Solar Energy”, Volume 82, Issue 4, April 2008, Pages 287-289
18. Abhishek Saxena and Nitin Agarwal , New hybrid solar cooker with air duct, “Solar Energy”, Volume 159, 1 January 2018, Pages 628-637.
19. Heat and mass transfer data book, C P Kothandaraman , New age international publishers, Ninth edition.
20. Wikipedia

    a) *http://solarcooking.wikia.com/wiki/Principles_of_Solar_Box_Cooker_Design*
    b) *https://people.exeter.ac.uk/TWDavies/energy_conversion/Calculation%20of%20CO2%20emissions%20from%20fuels.htm*

c) *https://www.google.co.in/search?q=cost+of+hot+air+from+dryer&ie=utf-8&oe=utf-8&client=firefox-b&gfe_rd=cr&dcr=0&ei=kuPKWreECNOvX9z2qMAL*
d) *https://www.elgas.com.au/blog/389-lpg-conversions-kg-litres-mj-kwh-and-m3*
e) *https://energypedia.info/wiki/LPG_Stoves*
f) *https://en.wikipedia.org/wiki/Liquefied_petroleum_gas*
g) *https://www.google.com/search?client=firefox-b&q=density+of+domestic+lpg*
h) *https://www.indiatoday.in/india/story/lpg-cylinder-price-rises-again-here-s-how-much-you-have-to-pay-1379937-2018-11-01*
i) *https://www.shoppersstop.com/philips-travel-dryer-bhd006-00-/p-9826011*