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HIGH RATED INTEGRATED SOLAR DRYER AND COOKER

Kirankumar Rathod[1], H.S.Ashoka[2], S.S.Inamdar[3]
[1 ,2,3] Assistant Professors, Department of Chemical Engineering SDM College of Engineering and Technology, Dharwad- 580 002. Karnataka, INDIA.

***Abstract**: Energy being a necessary element in the fields of industry, agriculture, communication, transport and other sectors, the demand for it is growing manifold and the energy sources are becoming scarce and costlier. Solar energy is one of the most ancient sources which is easily available and the root for almost all fossil and renewable types. Special devices have been used for benefiting from the solar and other renewable energy types. In this paper, an effort is made to design a high rated integrated solar drying and cooking system. This system is composed of solar Flat Plate Collector (FPC), and chamber housing both drying and cooking facility, and positive displacement blower. The air present in the collector is subjected to forced circulation with the help of positive displacement blower and sent to the chamber having solar dryer and cooker. The forced air helps in increasing the cooking rates during the solar cooking process. Simple passive and active designs were followed to enable to save energy requirement for fast operation. Potato moisture reduction rate, drying system efficiency and time taken for cooking were determined. Thus proving solar energy is one of the best remedies for fuel crisis.*

***Keywords:** Flat Plate collector (FPC), High rated solar cooker and dryer, Integrated solar cooking and drying*

1. INTRODUCTION

Sufficient, reliable sources of energy are the essential commodities for industrialized nations. Energy can be generally classified as renewable (can be regenerated) and non-renewable (cannot be regenerated quickly enough to keep pace with their use). According to a new report from the United States Energy Information Agency, world marketed energy consumption is projected to increase by 50 percent from 2005 to 2030 [1] and around 85% of energy used in the world is from non-renewable supplies [2]. But since the non-renewable energy sources are depleting quickly and getting exhausted eventually, this worldwide increase in energy demand has put ever-increasing pressure on identifying and implementing new and noble ways to save energy.

The first best way to save non renewable energy sources is to use the alternative forms of energy that is Renewable sources of energy. The decision as to which type of renewable energy source suits best for utilization has to be made on the basis of economic, environmental and safety considerations. In this context, solar energy has a greater relevance. Solar energy is utilized instead of any other forms of alternative energies because the desirable environmental and safety aspects are satisfied by it even though the costs involved are slightly higher. It is estimated that the solar energy equivalent to over 15,000 times the world's annual commercial energy consumption reaches the earth every year. It is the most ancient source and available in abundance. The greatest advantage of solar energy as compared to other forms of energy is that it is clean and can be supplied without any environmental pollution. The other benefits arising from the installation and operation of the solar energy systems are energy saving and generation of new working posts.

The sun is a continuous fusion reactor in which hydrogen is turned into helium. The sun's total energy output, 3.8×10^{20} MW (which is equal to 63 MW/m^2) is produced by nuclear fusion reaction. Only a small fraction, 1.7×10^{14} kW, of the total radiation emitted is intercepted by the earth. However, even with this small fraction it is estimated that 30 min of solar radiation falling on earth is equal to the world energy demand for one year.

In this project, emphasis is given to a solar thermal system. Solar thermal system is non-polluting and ensures significant protection of the environment and public health. Reduction of greenhouse gases is the main advantage of utilizing solar energy. Therefore, solar thermal system should be employed whenever possible in order to achieve a sustainable future. The objective of this project is to present a solar thermal system in which drying and cooking can be done at a faster rate. The high rated integrated solar dryer and cooker consists of a chamber which is facilitated with cooking and drying and a blower to provide forced convection. The undertaken study evaluates the performance of high rated integrated solar dryer and cooker by designing and fabricating the same. It is tested for the solar drying and cooking.

II. INTEGRATED SOLAR DRYER AND COOKER

Integrated solar dryer and cooker is an indirect solar system in which solar cooking and drying takes place in a single chamber with the help of a flat plate collector (FPC) which is used to harness the solar energy. The modes by which the heat transferred are Conduction and convection.

A. Components of Integrated Solar Dryer and Cooker

The main components of Integrated solar cooker or solar dryer are: 1. Solar cooker, 2. Solar dryer and, 3. Solar collector.

A1. Solar Cooker or Solar Oven

Solar cooker (Fig. 1) is a device which has an insulated box with a glazed cover that cooks food through the "greenhouse effect." The main principle used in solar cooker is conversion of sunlight into heat energy which is retained for cooking.

Fig. 1: Different Types of Solar Cooker (Box Type, Parabolic Cooker)

Sunlight enters the oven through the glazing and heats the dark inside walls and cooking vessels. Since the heat cannot escape through the glass, the oven gets very hot. Mirrors around the window send even more sunlight into the oven [3]. This increases the intensity of sun light falling on the cooker and helps in increasing the rate of cooking.

It is a form of outdoor cooking, and is often used in the situations where minimum fuel consumption or fire risks are considered highly important

- Concentrators: some device, usually mirror or some type of reflective metal, is used to concentrate light and heat from the sun into a small cooking area, making the energy more concentrated and therefore more potent.
- Absorbers (Converting light to heat): Any black on the inside of the solar cooker, as well as certain materials for pot, will improve the effectiveness of turning light into heat. A black pan will absorb almost all of the sun’s light and turn it into heat, substantially improving the effectiveness of the cooker. Also, the better the pan conduct heat, the better the oven will work.
- Glazing material (Trapping heat): Isolating the air inside the cooker from the air outside the cooker makes an important difference. Using a clear solid, like a plastic bag or a glass cover, allow light to enter, but once the light is absorbed and converted to heat, a plastic bag or a glass cover trap the heat inside. This makes it possible to reach similar temperatures on cold and windy days as on hot days.
- Plastic sheet: Uses plastic sheet to assure that the liquids do not seep through the oven. Also to prevent staining of the underlying sheet in the oven.

There are many different types of Solar cooker, however they all will follow three basic designs namely Box Solar cooker, Panel solar cooker and Parabolic solar cooker [4]. The type of cookers used in the Integrated solar dryer and cooker is Box type solar cooker. Despite the name “box cooker”, they are made in both circular and rectangular shapes. They consist of an enclosed inner box covered with clear glass or plastic, a reflector, and insulation. There is a wide variety of patterns and plans for the box cooker. While they do not heat quickly, they do provide slow, even cooking and are extremely cheap to make. Box cookers are very easy and safe to use, and fairly easy to construct [4].

A2. Solar dryer

Solar dryers (Fig. 2) are the specialized devices that control the drying process and protect produce from damage by insects, dust and rain. The basic principle of a solar dryer is that air is heated by the sun in the collector by green house effect and then, passed over the produce. The hot air then dries the produce in the drying chamber. Depending on the construction, both collector and drying chamber can be combined or separated [5].

Solar dryer use sun's heat to evaporate the moisture. Water content of properly dried food varies from 5 to 25% depending on the food. Successful drying depends on:

- Enough heat to draw out moisture, without the cooking food.
- Dry sir to absorb released moisture
- Adequate air circulation to carry off the moisture. [6]

There are mainly three types of solar dryers: traditional open air dryer, Direct solar dryer (Cabinet dryer), Indirect solar dryer (thermosyphon dryer). The dryer which is used in Integrated solar dryer and cooker is Thermosyphon dryer type [5]. Thermosyphon dryer have a collector and a separate drying chamber. They operate more efficiently and allow more control over the drying. The collector heats up air, which then rises up by natural convection, forcing its way through the racks of drying produce in the drying chamber. These dryers may be with or without flow enhancement. Such dryers are best suited for high value commercial scale drying [5].

Fig. 2: Solar Dryer

A3. Solar Collectors

It is a device that transforms solar radiation into heat and transfers that heat to a medium (air, water or any fluid). Solar collectors are of two types namely: Non-concentrating collectors (Flat plate collectors) and Concentrating collectors (Focussing collectors). The Flat plate collector (FPC) is used in the Integrated solar dryer and cooker. Flat plate collector is basically a flat box and is composed of three main parts, a transparent cover (glazing), tubes which carry a coolant and an insulated back plate (absorber). The solar collector works on the green house effect principle; solar radiation incident upon the transparent surface of the solar collector is transmitted through the surface. The inside of the solar collector is usually evacuated, the energy contained within the solar collect is basically trapped and thus heats the coolant contained within the tubes. The tubes are usually made from copper, and the back plate is painted black to help absorb solar radiation. The solar collector is usually insulated to avoid heat losses.

These collectors heat liquid or air at temperatures less than 180°F [7]. Flat-plate collectors (Fig. 3) are used for residential water heating and hydronic space-heating installations.

- *Liquid flat-plate collectors* heat liquid as it flows through tubes in or adjacent to the absorber plate. The simplest liquid systems use potable household water, which is heated as it passes directly through the collector and then flows to the house. Solar pool heating also uses liquid flat-plate collector technology, but the collectors are typically unglazed.
- *Air flat-plate collectors* are used primarily for solar space heating. The absorber plates in air collectors can be metal sheets, layers of screen, or non-metallic materials. The air flows past the absorber by using natural convection or a fan. Because air conducts heat much less readily than liquid does, less heat is transferred from an air collector's absorber than from a liquid collector's absorber, and air collectors are typically less efficient than liquid collectors. Air flat-plate collectors are used for space heating.

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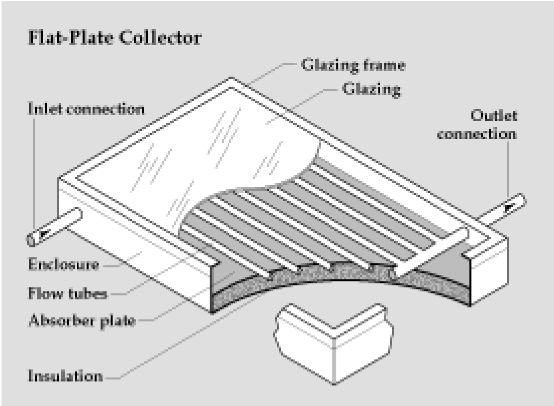

Fig. 3: Flat Plate Collector

B. Mechanism of Integrated solar dryer and cooker

Integrated solar dryer and cooker is a single chambered solar system. In this system, the chamber is sub divided into the upper part, solar cooker and lower part, solar dryer. The air inlet is provided at the lower part whereas outlet is at the upper part of the chamber. The system contains Flat Plate Collector as well, which is also having inlet and outlet. The inlets and outlets are produced for the air circulation. In this system, the air is circulated naturally. The atmospheric air enters the tubes of Flat plate collector and start flowing through it. The solar radiations received by the absorber of FPC are transferred into heat form. The converted form of solar energy heats up the air which is present in the tubes of FPC. The hot air is sent to the chamber's lower part by connecting the outlet of FPC to inlet of chamber. The hot air is circulated over the produce which needs to be dried and it takes out the moisture content. Later the hot air moves to cooking chamber. The left out heat of air helps in cooking process. The solar cooker gets the heat from diffused solar radiations as well. Solar radiations fall directly on the glazing material and enter the cooking chamber. A mirror is attached to the chamber such that the angle of it with the glazing material of the cooker can be varied. The mirror reflects the solar radiations which fall on it there by increasing the intensity of radiation. Therefore, cooking is done with the help of direct solar radiation and also with the heat rejected by the air after drying. The cooled air moves out from the outlet of the chamber by natural convection.

III. BLOWER

Blowers are the equipments used for ventilation and for industrial processes that need an air flow. These systems are essential to keep manufacturing processes working and consist of a fan, an electric motor, a drive system, ducts or piping, flow control devices and air conditioning equipment (filters, cooling coils, heat exchangers, etc.). Blowers can achieve higher pressures of 1.20 kg/cm2. They are also used to produce negative pressures for industrial vacuum systems.

A. Variations in Blower

There are mainly two types of blowers: The centrifugal blower and the positive displacement blower.

1. Centrifugal blower:
   Centrifugal blowers look more like centrifugal pumps than fans. The impeller is typically gear-driven and rotates as fast as 15,000 rpm. In multi-stage blowers, air is accelerated as it passes through each impeller. In single-stage blower, air does not take many turns, and hence it is more efficient. Centrifugal blowers typically operate against pressures of 0.35 to 0.70 kg/cm2, but can achieve higher pressures. One characteristic is that airflow tends to drop drastically as system pressure increases, which can be a disadvantage in material conveying systems that depend on a steady air volume. Because of this, they are most often used in applications that are not prone to clogging.
2. Positive displacement Blowers:
   Positive displacement blowers have rotors, which "trap" air and push it through housing. These blowers provide a constant volume of air even if the system pressure varies. They are especially suitable for applications prone to clogging, since they can produce enough pressure (typically up to 1.25 kg/cm2) to blow clogged materials free. They turn much slower than centrifugal blowers (e.g. 3,600 rpm) and are often belt driven to facilitate speed changes.

IV. HIGH RATED INTEGRATED SOLAR DRYER AND COOKER:

As seen above, positive displacement blower provides constant air from the atmosphere to the tubes of FPC which is a favourable condition for the solar drying and cooking. Hence, the positive displacement blower is connected to the inlet of FPC.

A. Proposed system

The High rated integrated solar dryer and cooker provides higher rate of drying and cooking than the solar cooking and solar drying which is conducted in separate chambers. But to further increase the rate of solar cooking and drying, positive displacement blower is used. This creates the forced circulation of air throughout the system.

The main parts of proposed system are: Chamber (Solar cooking and drying), FPC and blower.

1. Chamber: A space where solar drying and cooking takes place.
2. Solar collector: Solar collectors are the key component of active solar-heating systems [7]. It harness the solar radiations
3. Blower: Increases the flow rate of air by forced convection.

Fig. 4: Experimental Setup of Integrated Solar Dryer and Cooker

B. Material used

- Aluminium vessels with lid :2
- Weighing machine
- Rice :100 gm , water :200 ml
- Dhal: 100gm , water :200 ml
- Potato slices: 200gm
- Hygrometer
- Fan

C. Methodology

- The food of required quantity is taken in the vessel with proper closing and placed in solar cooking chamber. The produce is placed on the trays of drying chamber.
- The air is heated due to the solar heat and stored in the collector. The blower is put on for forced circulation of air.
- The heated air is passed to the chamber and evaporates the moisture from products.
- The constant circulation of heated air accelerates the drying of the product.
- The solar radiations fall on the mirror and get reflected to the transparent glass of cooking chamber.
- Due to the black body of the cooking chamber, heat will be absorbed quickly and heats up the chamber and the vessel.
- The food items kept in the vessels will be cooked.

D. Experimental Procedure

- For cooking: At first, about 100 gram of rice was taken in an aluminium box with black coating and about 200 ml of water was added. Then the initial temperature of the vessel and the cooking chamber was noted down. Soon after which box was kept inside the cooking chamber and top cover of glass was closed. Then the mirror was adjusted such that maximum reflection falls on the cooking box. Initial time was noted down and system was allowed to cook. Then final temperature was noted. The above procedure is carried for other products.
- For drying of Potato: First the potato was weighed by removing its peel. It was sliced into round pieces of equal size (about 3mm), and it was placed uniformly in the trays. Air flow rate and temperature inside the chamber was taken down. Then sliced potato was kept in the drying chamber. Forced circulation was provided at the inlet of the collector and hot air was blown to the drying chamber through the outlet of the flat plate collector. During the drying experiments, air temperature was recorded at inlet and outlet of drying cabinet. Dry bulb temperature was measured using thermometer

and wet bulb temperature was measured using hygrometer. Temperature measurements were performed at the regular intervals of 1 hour. Air temperature was recorded continuously at ambient, air inlet and outlet of collector and the weight was noted till the product was dried. After that, final weight and time was noted down.

V. RESULTS AND DISCUSSIONS

A. Temperature plot

Table 1. Flat Plate Collector vs Time

Time (Hrs)	Ti(°C)	To(°C)	Ta (°C)
9.30	66	68	30
10.00	77	80	32
10.30	87	90	33
11.00	93	96	34
11.30	98	101	35
12.00	97	103	36
13.00	98	103	35
14.00	97	97	34
15.00	78	78	31
16.00	62	62	30

As the time was increased from 9.30 AM to 12 PM the ambient temperature of the flat plate collector was increased from 30°C to 36°C, after 12 PM, the temperature decreased due to tilt angle of sun. The inlet temperature of flat plate collector increased from 66°C to 97°C from 9.30 AM to 12.00 PM then decreased from 97°C to 62°C so as the outlet temperature from 68°C to 103°C and decreased from 103°C to 62°C. The maximum temperature of the model was about 376 K. The absorber plate had the maximum temperature. It was obvious from the fact that the thermal conductivity of the absorber (aluminum surface) plate is very large compared to the other materials.

B. Drying unit observation

Table 2

Product	Potato
Weight of trays	Tray 1 = 740 g Tray 2 = 785 g
Weight of product	200 g
Initial temperature of potato slice	30 ^{0}C
Initial temperature of drying cabinet	32 ^{0}C
Air flow rate entering heat unit	1 m^3/min
Air temperature before passing through heating unit	30 ^{0}C
Air temperature before passing through drying cabinet	65 ^{0}C
Air vent temperature	36 ^{0}C
Time required to dry 200 g of potato slices	Mw*hfg= 500.4 kJ Ma* $(W_2\text{-}W_1)$ =33 min
Hear required to dry 200 g of potato chips	Q = Mw*hfg/ Ma*$(W_2\text{-}W_1)$= 421.2 W

Table 3: Drying Unit Observation

Time	**Outlet of collector**		**Outlet of dryer**		**Total weight of potato chips**
(hrs)	DBT(°C)	WBT(°C)	DBT(°C)	WBT(°C)	(g)
9.00	32	24.4	31	24.6	200
10.00	34	28.6	34	26.2	150
11.00	36.1	31.1	35	28.4	90
12.00	38	34	36	34.5	35

Time taken for drying potato is 3 hrs by forced convection only on clear sunny days.

Fig. 6: Dried Potato Chips

C. Drying rate calculations

Quantity of potato: 200g
Time taken for drying:
Moisture percentage on wet basis:
M% = {(Mi-Mf)/Mi} × 100
M% = {(200-150)/200} × 100
M = 25%

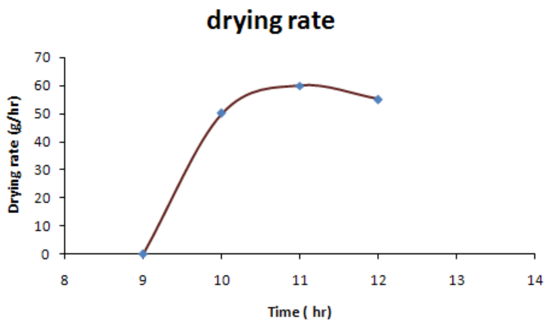

Fig. 7: Graph of Drying Rate vs Time

Raw potato slices with initial moisture contents in the range of 445.41–599.3% (DBT) or 81.67– 85.7% (WBT) were dried until reaching their equilibrium moisture contents to 25 %. Fig 7 shows the drying curve of potato chips undergoing hot air drying. The drying rate increases from 9.00 AM to 11.00 AM and then decreases due to solar insolation. It was found that drying at higher temperature took shorter time to reach the desired moisture content because of a larger driving force for heat transfer.

Table 4

Product	Rice	Dhal
Weight	100	100
Water quantity	200	200
Initial temperature	36	34
Final temperature	86	84
Start time	10.00	10.00
End time	12.00	12.00

Test showed that the total time taken for cooking rice and thur dhal (Fig. 8) was exactly 2 hours on clear sunny days.

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Fig. 8: Cooked Rice and Dhal

VI. BENEFITS OF HIGH RATED INTEGRATED SOLAR DRYING AND COOKING SYSTEM

- The positive displacement blower helps in providing constant air flow causing uniform drying of the produce.
- Low cost system.
- Low maintenance cost and easy in operation.
- Doesn't demand frequent attention.
- Fast drying takes place by adopting forced convection method. The higher temperature, movement of the air and lower humidity increases the rate of drying.
- Food to be cooked or to be dried was enclosed in the chamber and therefore protected from dust, insects, birds and animals.
- The higher temperature deters insects and the faster drying rate reduces the risk of spoilage by micro-organisms.
- Saving the fuel cost as no fuel is required.
- Hygiene and quality of the food is maintained.
- There are neither fire hazards nor damage to the vessel.

VII. CONCLUSION

Since day-by-day the demand for energy is increasing and there is exhausting of non-renewable sources like coal and other fuels, renewable sources preferably solar energy need to be utilized. Non-renewable energies also contribute to the warming of the planet, Global warming. It causes pollution resulting in acid rain, which harms the flora and fauna on the earth [8]. To overcome all the disadvantages of non-renewable resources, renewable resources are necessary.

- Low cost system can be designed for integrated solar cooking and drying.
- Flat plate collectors can be constructed from locally available materials and are relatively low cost.
- The application areas described show that solar energy collectors can be used in a wide variety of systems, which include water heating, space heating and cooling, refrigeration, industrial process heat, desalination, thermal power systems, solar furnaces which could provide significant environmental and financial benefits, and should be used whenever possible.

VIII. NOMENCLATURE

- Ta = Ambient temperature of FPC
- Ti = Inlet temperature of FPC
- To = Outlet temperature
- DBT = Dry Bulb temperature
- WBT = Wet Bulb temperature
- Mi = Initial weight of potato slices
- Mf = Weight of potato slices after drying

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