

# Development of Solar Coffee Dryer using Forced Convection

Madhu R<sup>1</sup>, Ravishankar M D<sup>2</sup>,

<sup>1,2</sup>Assistant Professor, Department of Mechanical Engineering, NIE Institute of Technology, Mysuru, India.  
Corresponding Author: Madhu R

Submitted: 01-03-2022

Revised: 13-03-2022

Accepted: 16-03-2022

**ABSTRACT:** Indirect type solar dryer with forced convection was constructed and fabricated. Solar drying has proved to be technically and economically valuable. The thermal performance of the drying chamber was studied by passing hot air through the connecting pipes from the solar collector. It is observed that the dried product is free from undesired contaminant. Small quantity of coffee beans are dried quickly. They are also more efficient than patio drying technique because their hotter drying temperature dry coffee beans at a faster rate. Drying the coffee beans at a faster rate was one of the main objective which was validated with experimental results. The product is designed to its maximum optimal functioning at a very low cost. Our machine is capable of drying coffee beans in small quantity quickly. It is capable of drying at a faster rate than other means of drying process.

**Keywords:** irradiation; chamber and cabinet difference

## I. INTRODUCTION

Coffee has been for decades the most commercialized food product and most widely consumed beverage in the world. Since the opening of the first coffee house in Mecca at the end of the fifteenth century, coffee consumption has greatly increased all around the world. In 2010, coffee production reached 8.1 million tons worldwide. This represents more than 500 billion cups, with the United States, Brazil, Germany, Japan, and Italy being the major consumer countries. However, per capita consumption in North European countries such as Finland, Norway, Denmark, and Sweden may reach 8 kg/year, more than two times that of the United States or Brazil.

Coffee contains a number of compounds that contribute to the flavor and bioactivity of the brew. Complex reactions take place during roasting at high temperatures and modify considerably coffee's chemical composition, with some beneficial

compounds degraded and some created. A small amount of harmful compounds is also created during roasting; however, the beneficial compounds appear to predominate. To obtain a functional, healthy coffee, it is important to consider every aspect of coffee production, starting with high-quality seeds roasted to light-medium to dark-medium color degree, preferably at low to medium temperatures. Medium-roast coffees contain relatively high amounts of antioxidant compounds compared with other food products, a considerable amount of niacin, low acrylamide content, and typically no PAHs. Decaffeinated coffee is indicated for individual's sensitive to caffeine's effects and those who wish to use coffee as an additional tool to reduce the risk of type 2 diabetes.

### 1.1. Solar dryer

Preservation of fruits, vegetables, and food are essential for keeping them for a long time without further deterioration in the quality of the product. Several process technologies have been employed on an industrial scale to preserve food products; the major ones are canning, freezing, and dehydration. Among these, drying is especially suited for developing countries with poorly established low-temperature and thermal processing facilities. It offers a highly effective and practical means of preservation to reduce post-harvest losses and offset the shortages in supply.

Drying is a simple process of moisture removal from a product in order to reach the desired moisture content and is an energy intensive operation. The prime objective of drying apart from extended storage life can also be quality enhancement, ease of handling, further processing and sanitation and is probably the oldest method of food preservation practiced by humankind. Drying involves the application of heat to vaporize moisture and some means of removing water vapor after its

separation from the food products. It is thus a combined and simultaneous heat and mass transfer operation for which energy must be supplied. The removal of moisture prevents the growth and reproduction of microorganisms like bacteria, yeasts and molds causing decay and minimizes many of the moisture-mediated deteriorative reactions. It brings about substantial reduction in weight and volume, minimizing packing, storage, and transportation costs and enables storability of the product under ambient temperatures. These features are especially important for developing countries, in military feeding and space food formulations.

Drying in earlier times was done primarily in the sun, now many types of sophisticated equipment and methods are used to dehydrate foods. During the past few decades, considerable efforts have been made to understand some of the chemical and biochemical changes that occur during dehydration and to develop methods for preventing undesirable quality losses. The widest among drying methods is convective drying, i.e. drying by blowing heated air circulating either over the upper side, bottom side or both, or across the products. Hot air heats up the product and conveys released moisture to atmosphere. In direct solar drying called "sun drying" the product is heated directly by the sun's rays and moisture is removed by natural circulation of air due to density differences.

Solar radiation in the form of solar thermal energy, is an alternative source of energy for drying especially to dry fruits, vegetables, agricultural grains and other kinds of material, such as wood. This procedure is especially applicable in the so-called "sunny belt" world-wide, i.e. in the regions where the intensity of solar radiation is high and sunshine duration is long. It is estimated that in developing countries there exist significant post-harvest losses of agricultural products, due to lack of other preservation means. Drying by solar energy is a rather economical procedure for agricultural products, especially for medium to small amounts of products. It is still used from domestic up-to small commercial size drying of crops, agricultural products and foodstuff, such as fruits, vegetables, aromatic herbs, wood, etc. contributing thus significantly to the economy of small agricultural communities and farms.

### 1.1.1 Drying principles

Drying is basically a phenomenon of removal of liquid by evaporation from a solid. Mechanical methods for separating a liquid from a solid are not generally considered drying. In the

following section an attempt is made to provide a concise overview of the fundamental principles of drying process for agricultural products. These principles are applied, in general, to mechanical conventional drying and here concerned mainly with solar drying. However, in general, must be noted that conventional drying principles and phenomena are independent of the type of energy used. Ekechukwu and Norton (1999) and Mujumdar, 2007 gives a comprehensive review of fundamental principles and theories governing the drying process. A major part of energy consumption during drying is for the evaporation of liquid water in to its vapour (2258 kJ/kg at 101.3 kPa). The water may be contained in the solid in various forms like free moisture or bound form which directly affects the drying rate.

Moisture content is expressed either on dry or wet basis, e.g. moisture content in wet ( $\square$ ) basis is the weight of moisture per unit of wet material.

$m^w$

$$X_w = \frac{m}{m+d} \text{ kg per kg of mixture}$$

and on dry basis ( $X_d$ ), is expressed as the ratio of water content to the weight of dry material:  $m^d$

$$X_d = \frac{m}{d}$$

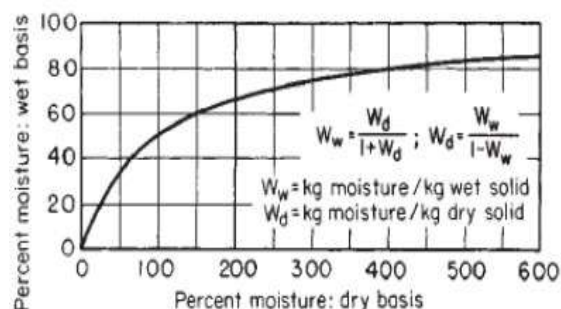


Figure 1.1: Relationship between wet-weight and dry-weight basis (Perry 2007).

Although the most convenient way to express moisture for mathematical calculations is on dry basis but for agricultural products moisture content normally is expressed in wet basis. Figure 1.1 shows the plot of relationship between the dry and wet weight basis.

### 1.1.2 Solar drying technology

Solar drying has been used since time immemorial to dry plants, seeds, fruits, meat, fish, wood, and other agricultural, forest products. In order to benefit from the free and renewable energy source provided by the sun several attempts have been made in recent years to develop solar drying mainly for preserving agricultural and forest products. However,

for large-scale production the limitations of open-air drying are well known. Among these are high labour costs, large area requirement, lack of ability to control the drying process, possible degradation due to biochemical or microbiological reactions, insect infestation, and so on. The drying time required for a given commodity can be quite long and result in post-harvest losses (more than 30%). Solar drying of agricultural products in enclosed structures by forced convection is an attractive way of reducing post-harvest losses and low quality of dried products associated with traditional open sun-drying methods (Jain and Tiwari, 2003). In many rural locations in most developing countries, grid-connected electricity and supplies of other non-renewable sources of energy are either unavailable, unreliable or, too expensive. In such conditions, solar dryers appear increasingly to be attractive as commercial propositions (Mekhilefa et al., 2011; Xingxing et al., 2012).

During the last decades, several developing countries have started to change their energy policies toward further reduction of petroleum import and to alter their energy use toward the utilization of renewable energies. With very few exceptions, the developing countries are situated in climatic zones of the world where the insolation is considerably higher than the world average of 3.82 kWh/m<sup>2</sup> day. In Figure daily average horizontal insolation data and sunshine hours of some developing countries are given. An alternative to traditional drying techniques and a contribution toward the solution of the open-air drying problems is the use of solar dryers. Accordingly, the availability of solar energy and the operational marketing and economy reasons offer a good opportunity for using solar drying all over the world.

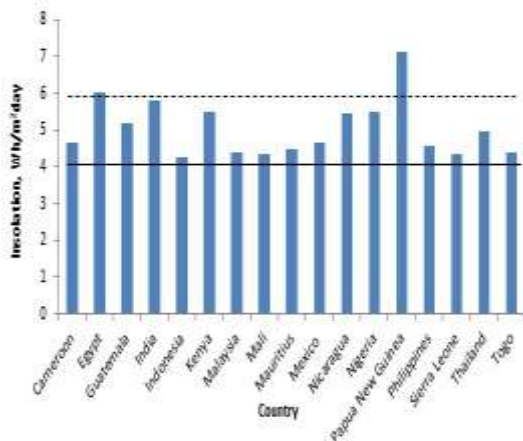


Figure 1.2: Total horizontal solar insolation for some developing countries

### 1.1.3 Classification of solar dryers:

Drying equipment may be classified in several ways. The two most useful classifications are based on (1) the method of transferring heat to the wet solids or (2) the handling characteristics and physical properties of the wet material. The first method of classification reveals differences in dryer design and operation, while the second method is most useful in the selection of a group of dryers for preliminary consideration in a given drying problem. A classification chart of drying equipment on the basis of heat transfer is shown in Figure below (Ekechukwu,1999; Sharma et al., 2009). This chart classifies dryers as direct or indirect, with sub classes of continuous or batch wise operation. Solar energy drying systems are classified primarily according to their heating modes and the manner in which the solar heat is utilized. In broad terms, they can be classified into two major groups, namely:passive solar-energy drying systems (conventionally termed natural-circulation solar drying systems) and, active solar-energy drying systems (most types of which are often termed hybrid solar dryers).

Three distinct sub-classes of either the active or passive solar drying systems can be identified namely:

- Direct-type solar dryers;
- Indirect-type solar dryers; and
- Hybrid solar dryers.

The main features of typical designs of the various classes of solar-energy dryers are illustrated in fig -1.7, showing three main groups for solar dryers on the basis of the energy sources used. The design of solar dryers is adjusted to the quantity, character, and designation of the material to be dried as well as to the energy sources used and accordingly, various types of solar dryers have been developed and are in use to date.

## II. LITERATURE SURVEY

### 2.1 Cunha M. et. al. (2003)

Cunha M. summarized that when compared to conventional drying processes the development process of microwaves to pulped coffee cherries production, to reduce the drying time and to increase the industrial yield and product quality was better. Two drying cycles were tested.

a) hot air drying conventional batch process using a rotary dryer from 45-50 to 11-13% (wb) moisture product

b) a two stage process, whereby the product was pre dried with hot air from 45-50 to 30% (wb), followed by the final microwave and hot air drying stage, to reduce product moisture from 30 to 11-13% (wb). The overall drying time was reduced from 15 to 37.5 hours to about 10 hours, respectively. The sensory quality of the product was evaluated by the "cup

test", complemented by scanning electronic microscope analyses (SEM) and showed satisfactory results. A preliminary study of the economic aspects involved in up-grading an industrial scale coffee processing line.

### 2.2 Abdullah et al. (2001)

Abdullah develop prototype of a greenhouse effect (GHE) solar dryer and tested it performances for various crops including coffee. The GHE unit consisted of several important components such as the radiation absorber, heat ex-changer (two units with 100 W blower attached), the auxiliary heating using hot water, air blowers (0.5 HP) and chimneys. To enhance thermal performance, a blackened steel plate was installed inside the structure either on the upper section or at both sides of the wall. Studies on coffee drying were carried out using UV stabilized plastic sheet (1.5 mm thick, 70% transmissivity) to form the GHE enclosure. The floor size was 6 m x 2.2 m with height 2.8 m. A wooden bin (3 m x 2 m x 1 m) was placed at the middle of the drying floor and loaded with 1.1 ton of wet coffee berries at 0.3 m depth. Results were obtained for the drying of Robusta coffee in this dryer. Drying efficiency was recorded at 57.4% as compared to conventional drying at 21.1% while specific energy was recorded at 5.5 and 11.6 MJ/kg water, respectively, in each method. Drying time was recorded at 58 hours in the GHE unit as compared to 70 hours in conventional drying.

### 2.3 Amir et al. (1991)

Application of a solar tunnel dryer for coffee drying was reported by Amir that consist of a centrifugal blower, solar air heater and a tunnel drying chamber. The tunnel (width 2 m) and solar collector (width 1 m) were attached side by side and measured 20 m in length. The air was initially heated in the collector and the flow was channeled back into the tunnel through a U-shaped duct at the end of the drying unit. Drying temperatures of 40 – 60°C can be achieved by adjusting the air flow rate from 400 – 900 m<sup>3</sup>/hr. Fermented coffee beans of 500 – 600 kg were loaded into the dryer and it took 50 hours to reach the final moisture content below 125 while sun drying required 75 hours. Consumption of electrical energy was 41.7 Wh/kg dry material or 5.0 kWh/drying batch.

### 2.4 Martin S. et. Al. (2009)

In a study assessing intermittent drying of parchment coffee, Martin S. combined 12 hours of drying with 50° C heated air and 12 hours of rest and observed a 24.56% reduction in effective drying time relative to continuous drying. Generally mechanical

dryers are used in the coffee industry in the second stage of drying. According to ICO in case of mechanical dryers for 1kg of sample vertical and horizontal dryers were taking 21.5 h to 10.2 h to reduce the moisture content from 30% (w.b) to 12% (w.b). Concurrent flow dryers were taking 7-5h to reduce the moisture content from 25% (w.b) to 12% (w.b) and combination of concurrent and counter current dryer took 22.5 h to 12.5 h to reduce the moisture content from 35% (w.b) to 12% (w.b).

### 2.5 T. B. Shaikh et. al. [2003]

The solar-biomass drying system has able to dry fresh maize within 15 hours. Maximum drying temperature of 47oC was obtained with solar and biomass heating source even though ambient temperature for the test period was between 24oC to 30oC. Their studies prove that effectiveness of agricultural dryers be able to increase through the use of a grouping of solar biomass heating method. It implies that improvements in design and construction of various components of system would lead to more efficient drying system for sustainable development of developing countries. Via combined solar biomass drying structure has the possible to diminish wastage of grains and increases the efficiency of drying system.

## III. METHODOLOGY

The methodology consists of PDCA Cycle that mainly works on following four phases. Such as,

### 3.1 Planning Phase

The planning phase begins with corporate strategy and includes assessment of technology development and market objectives. The output of planning phase is project mission statement, which specifies the target market for the product, business goals, key assumptions and constraints. It also includes the concept development phase, where the needs of target market is identified, alternative product concepts are generated and evaluated, and one or more concepts are selected for further development and testing. A concept is a description of the form, function and features of a product and is usually accompanied by a set of specifications, an analysis of competitive products and an economic justification of the project.

### 3.2 DO (design) Phase

This phase includes the definition of the product architecture and the decomposition of the product into subsystems and components. The final assembly scheme for the production system is usually defined during this phase as well. The output of this phase usually includes a geometric layout of



the product, a functional specification of each of the products subsystems, and a preliminary process flow diagram for the final assembly process.

### 3.2.1 Detailed design

This phase includes the complete specification of the geometry, materials and tolerances of all of the unique parts in the product and the identification of all of the standard parts to be purchased from suppliers. A process plan is established and tooling designed is designed for each part to be fabricated within the production system. The output of this phase is the control documentation of the product – Drawings or computer files describing the geometry of each part and its production tooling, the specifications of the purchased parts, and the process plans for the fabrication and assembly of the product. Two critical issues addressed in the detail design phase are production cost and robust performance

### 3.3 Check (Testing and refinement) Phase

This phase involves the construction and evaluation of multiple preproduction versions of the product. At this stage, the equipment is tested in the fields by working for 10 hrs. and to determine the performance and other factors. The feedback from the formers is collected later, by testing it in different crop cultivation. The work performances, reliability, load bearing capacity after working through the different crop forming.

### 3.4 Act Phase

In this phase, the feedback on the developed product is analyzed using the results from testing and any small modification of the product is done if necessary. The purpose of the act phase is to train the work force and to work out any remaining problems in the production processes. Products produced during this phase are sometimes supplied to preferred customers and are carefully evaluated to identify any remaining flaws.

## IV. MATERIALS AND METHODS

### 4.1 COMPONENTS USED

#### 4.1.1 Solar collector

A solar collector is basically a flat box and are composed of three main parts, a transparent cover, tubes which carry a coolant and an insulated back plate. The solar collector works on the greenhouse effect principle; solar radiation incident upon the transparent surface of the solar collector is transmitted through though this surface.

The basic principle of solar thermal heating is to utilize the sun's energy and convert it into heat which is then transferred into your home or business

heating system in the form of hot water and space heating.

The collector is the main component of a solar thermal system and would in most cases be installed on the roof of the property. The collector contains specially coated reinforced glass pipes to capture the radiation emitted from the sun, which can then be transferred into heat.

#### 4.1.2 Control valve:

Both ball and gate valves control the flow of liquid in pipes, but gate valves should never be used in solar thermal systems because they create resistance when they are closed. You can recognize a traditional gate valve by the external spin handle that lifts or lowers a gate inside the pipe.

Ball valves have a lever on the outside of the pipe and a ball inside. The ball has a hole drilled through the middle. Ball valves offer some flow control: by turning the external lever, the ball is slowly rotated so the hole is perpendicular to the pipe walls, shutting off more and more of the flow. It's not very precise, but it's workable.

It is very important to always choose "full port" or "full flow" ball valves: these have a ball that is bigger than the pipe, through which a hole of the pipe's internal diameter is drilled – when they are in the full "on" position, there is no impediment to the flow in the system. Never use reduced port valves.

#### 4.1.3 Blower:

An air blower is a machine used for generating flow of air at substantial pressure. The air flow generated is used for different purposes such as small car cleaning blowers, vacuum cleaners, air conditions etc. Centrifugal Blower - Air enters axially and leaves the blade radial direction.

#### ➤ Working principle:

Air enters the center of a spinning impeller and is divided between the impeller's vanes. As the impeller turns, it accelerates the air outwards using centrifugal force. This high-velocity air is then diffused and slowed down in the surrounding blower housing to create pressure

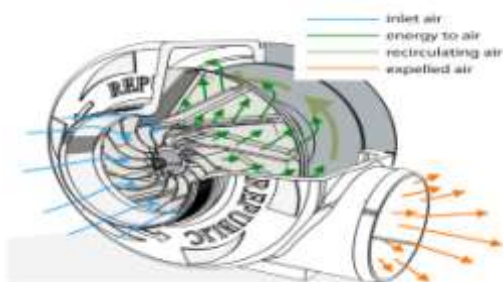


Figure 4.1: Air blower

#### 4.1.4 Connecting pipe:

Connecting pipes are those which are connected from one part to another and helps in fluid movement between the two parts.

Hot air from the solar collector circulates through this pipe which is connected to the drying cabinet.

#### 4.1.5 Auxiliary heaters:

Auxiliary heaters provide supplementary heating for cabinet without having to rely on the heat given off by the solar collector.

#### 4.1.6 Solar panel:

Solar cell, also called photovoltaic cell, any device that directly converts the energy of light into electrical energy through the photovoltaic effect. The overwhelming majority of solar cells are fabricated from silicon—with increasing efficiency and lowering cost as the materials range from amorphous (non-crystalline) to polycrystalline to crystalline (single crystal) silicon forms. Unlike batteries or fuel cells, solar cells do not utilize chemical reactions or require fuel to produce electric power, and, unlike electric generators, they do not have any moving parts.

### 4.2 CHARACTERISTICS OF THE SOLAR COFFEE DRYER:

The dryer is built like a greenhouse, consisting mainly of a wooden frame covered by durable greenhouse plastic, developed to withstand the weather and also deterioration caused by the sun. The roof can be either flat or sloping. It is advisable to leave a space of 40 - 70 cm just above the ground uncovered and to have some openings near the roof so that the air can circulate. Platforms made of wood and steel mesh are placed inside the dryer for spreading out the beans. It is possible to have one, two or three levels, depending on requirements. A space of at least 50 cm between each level is

recommended for easy access and to allow air circulation. The air inside the dryer is heated by the sun, reducing its relative humidity. The hot dry air circulates around the damp coffee beans, absorbs the water and gradually dries the beans. The air keeps circulating because of the difference in temperature between the inside and outside of the dryer – the hot air rises out of the openings near the roof and is replaced by cold air entering via the openings near the ground.

## V. GENERATE PRODUCT CONCEPTS

### 1.2. Decomposition of problem:

As discussed in previous sections, if mechanical dryers are used for drying process the essence of the coffee beans may get affected. This is due to high temperature drying technique use in these dryers.

Open sun drying is old process used for drying technique. But the moisture content of coffee beans may not be removed at a higher level. In all aspects indirect coffee drying process where solar collectors are used for drying coffee beans gives better results.

We also modified by connecting a air blower where hot air trapped by the collector moves to the blower through connecting pipes and finally moves into the drying cabinet to reduce the moisture content of the coffee beans.

## VI. DETAIL DESIGN AND FABRICATION

### 6.1 DETAIL DESIGN:

#### ● SOLAR COLLECTOR

Designing of the SOLAR AIR COLLECTOR includes its dimensions of the collector and the material used for its construction.

Collector dimensions {L\*W\*H} in mm – 1500\*1000\*130

Overall area – 2 m<sup>2</sup>

Fluid capacity- 1.2 L

Recommended flow rate (L/h) – 0.023 kgs/m<sup>2</sup>

#### ● SOLAR PANEL:

SPECIFICATIONS – 20W 12V

MATERIAL – Silicon

TYPE – Poly-crystalline

SOLAR POWER – 20W

OUTPUT VOLTAGE – 12V

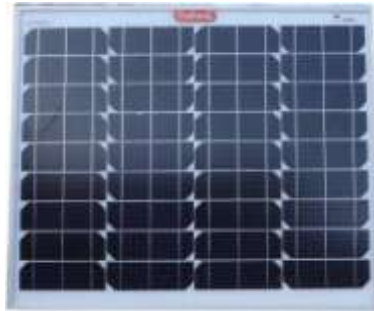


Figure 6.1: solar panel

- **AIR BLOWER:**  
12V 4.5Ah



Figure 6.2: Air blower

- **AUXILIARY HEATER:**  
Auxiliary heaters provide supplementary heating for cabinet without having to rely on the heat given off by the solar collector.

- **CABINET:**  
CABINET DIMENSIONS in mm  
DIAMETER- 400mm  
LENGTH – 500mm

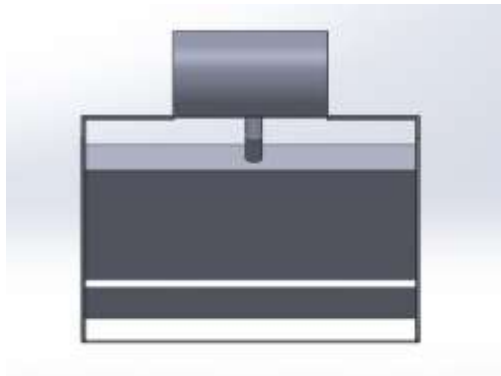
## 6.2 3D MODEL



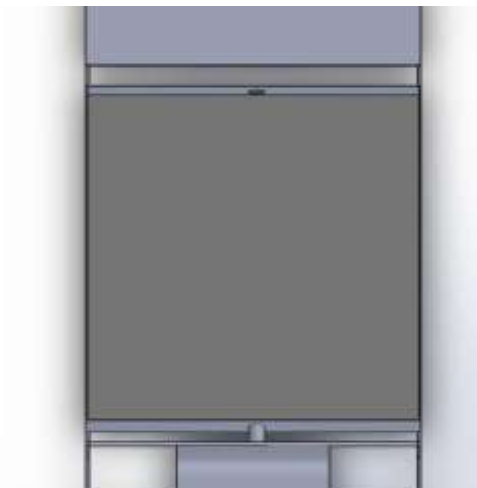
Figure 6.3: design 1 (side view)



**Figure 6.4:** design 2



**Figure 6.5:** design 3 (back view)



**Figure 6.6:** Design 4 (Top view)

➤ **Working model:**





Figure 6.7 working model

➤ **BILL OF MATERIAL**

Sl.	Part/material description	Quantity
1	Collector	1
2	Air blower	1
3	Drying cabinet	1
4	Solar panel	1
5	Connecting pipes	1m (length)
6	Foam	1m wide, 1.5m long, 5cm thickness
7	Battery	1
8	MS sheet	1 (roll)

Table 6.1: Bill of Materials

**VII. TESTING AND RESULTS**

The amount of water is determined by subtracting the dry weight from the initial weight, and the moisture content is then calculated as the amount of water divided by the dry weight or total weight, depending on the reporting method.

Atmospheric temperature-28 c  
 Total drying time-5 hrs.  
 Initial weight-100g (approx. 50% moisture)

Final weight or dry weight-64g

$$\% \text{ of moisture reduced} = \left( \frac{100-64}{100} \right) \times 100 = 36\%$$

Therefore % of moisture in the sample - (50-36)  
 = 14% (10 to 15 %)

Initial weight	Final weight	% of moisture reduced	% of moisture in sample
100	65	35	15
100	64	36	14
100	62	38	12
100	67	33	17
100	66	34	16
Average % of moisture in sample			14.8

Table 7.1: Results

## VIII. CONCLUSION & SCOPE FOR IMPROVEMENTS

### 8.1 Conclusion:

Indirect type solar dryer with forced convection was constructed and fabricated. Solar drying has proved to be technically and economically valuable. The thermal performance of the drying chamber was studied by passing hot air through the connecting pipes from the solar collector. It is observed that the dried product is free from undesired contaminant. Small quantity of coffee beans are dried quickly.

They are also more efficient than patio drying technique because their hotter drying temperature dry coffee beans at a faster rate.

Drying the coffee beans at a faster rate was one of the main objective which was validated with experimental results. The product is designed to its maximum optimal functioning at a very low cost.

The developed model is capable of performing well at extreme working condition. The intention and outcome of this project is practically achieved without any failure in any structural member.

### 8.2 Scope of future improvement:

- This model can be improved for drying other products such as green chillies, peas etc.
- Use of long-lasting batteries to increase the capacity of the solar dryer.

## REFERENCE

- [1]. S. Deeto, S. Thepa, V. Monyakul and R. Songprakorp, "The experimental new hybrid solar dryer and hot water storage system of thin layer coffee bean dehumidification", *Renewable Energy*, Vol. 115, pp. 954968, 2018.
- [2]. Mohajer, O. Nematollahi, M. M. Joybari, S. A. Hashemi, and M. R. Assari, "Experimental investigation of a Hybrid Solar Drier and Water Heater System", *Energy Conversion and Management: Elsevier*, Vol. 76, pp. 935–944, 2013.
- [3]. M. A. Amer, M. A. Hossain, K. Gottschalk, "Design and performance evaluation of a new hybrid solar dryer for banana", *Energy Conversion and Management: Elsevier*, Vol. 51, pp.813–820, 2010.
- [4]. S. Nabnean, S. Janjai, S. Thepa, K. Sudaprasert, R. Songprakorp and B. K. Bala, "Experimental performance of a new design of solar dryer for drying osmotically dehydrated cherry tomatoes", *Renewable Energy*, Vol. 94, pp.147-156, 2016.
- [5]. Mohamed A. Eltawil, Mostafa M. Azam and Abdulrahman O. Alghannam, "Solar PV powered mixed-mode tunnel dryer for drying potato chips", *Renewable Energy*, Vol. 116, pp.594-605, 2018.
- [6]. Alejandro Reyes, Andrea Mahn, Francisco Cubillos and Pedro Huenulaf, "Mushroom dehydration in a hybridsolar dryer", *Energy Conversion and Management*, Vol. 70, pp. 31–39, 2013.
- [7]. S. Dhanushkodi, Vincent H. Wilson and K. Sudhakar, "Mathematical modelling of drying behavior of cashew in a solar biomass hybrid dryer", *Resource-Efficient Technologies*, pp. 1–6, 2017.
- [8]. Prashant Singh Chauhan, Anil Kumar and Bhupendra Gupta, "A review on thermal models for greenhouse dryers", *Renewable and Sustainable Energy Reviews*, Vol.75, pp. 548–558, 2017.
- [9]. D. Kamthania, S. Nayak, G. N. Tiwari, "Performance evaluation of a hybrid photovoltaic thermal double pass facade for space heating", *Energy and Buildings: Elsevier*, Vol. 43, pp. 2274–2281, 2011.