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# Design and Construction of Indirect Solar Coffee Dryer

**Abeba Gachen, Zewude Hirpesa, Lemi Negera Woyessa**

***Abstract*****:** ***Drying is the process of removing moisture contents from solid. Solar drying refers to a technique that utilizes incident solar radiation to convert it into thermal energy required for drying purposes. This project presents the design, construction and performance of an indirect type solar dryer for coffee product. In the dryer the air inters into the solar collector from the atmosphere through air inlet hole. This air will be heated in the collector and then pass to the drying chamber through the hole. Then the air exhausts through the outlet hole at the top of the drying chamber. The system designed can handle a capacity of up to 50kg of wet coffee per m$^2$at a depth of 100 mm. The average sunshine at Bale Robe was found to be 12 hours per day. The daily solar insolation at the site was found to be 5.86kW/m$^2$ of surface per day. By utilizing the solar collector in question and assuming a collector efficiency of 20 %, the total solar energy received is 5.86 kW-hrs/m$^2$/day or 46.88 kW-hours per day (assuming the sunshine hours per day to be 8 hours). This solar dryer has a collector efficiency of 39.1%, a pick-up efficiency of 49.3%, and a system efficiency of 32.2%. the collector area of the system is calculated to be 1.11m$^2$ and the total length of 1000mm by 300mm. The drying chamber is essentially a cabinetry dryer and measures 1020mm × 800mm × 30mm. It accommodates a drying bin which acts as the holding compartment for the wet coffee to be dried. The base of the drying chamber is made of a block of wood material 50mm deep, since wood is a good thermal insulator. The wood must be well seasoned and pre-treated to ensure it is protected from the humid environment. The air outlet is fitted at the top of the drying chamber which serves as the exit for the moisture ridden air. It is important since it ensures that moisture does not condense at the top of the drying chamber and speeds up the rate of drying through creating the suction effect. The drying bin measures 800mm × 800mm × 20mm***.

***Keywords*** **:** ***Coffee, Collector ,Drying Chamber, Solar energy***

## I. INTRODUCTION

Drying is a process that removes unwanted liquids (e.g., water or oils) from a solid to reach specified wanted moisture content. It is one of the methods used to preserve food products for longer periods.

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Coffee drying entails moisture reduction from about 60% to about 11% wet basis (w.b) to achieve a stable product.

For coffee producers, the drying process of coffee grain is critical for obtaining a good quality and a good price for their product. The drying process is very important for keeping the quality of the coffee, because it reduces the humidity content of the grain in order to store and impedes the microbial action that is responsible for spoilage. The conventional way of drying coffee is open beds at 25mm depth, and the mandatory requirement of exposing coffee to sunshine in Ethiopia, demands high labor input, vast drying space, and longer drying periods. Sun drying is still widely practiced in many tropical and subtropical countries. It is the cheapest method of drying coffee but the quality of the dried products is far below the international standards. In recent years, solar drying technologies have become a preferred option for drying majority of agricultural-based products. 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 [1]. In many rural locations in most developing countries, grid-connected electricity and supplies of other nonrenewable sources of energy are non-existent, unreliable or, too expensive. In such conditions, solar dryers appear increasingly to be attractive as commercial propositions [1].[11] The hot air that flows into the chamber heats up the solid and then the moisture conveys to the atmosphere, the warm air rises and brings the moisture out of the drying chamber. An outlet is often provided at the top, and the inflow can be placed into the chamber sideways or underneath Figure.1. The technique is very simple, forcing hot air into the drying chamber to make the air inside the dryer move while the solids release liquid into the air in the area.

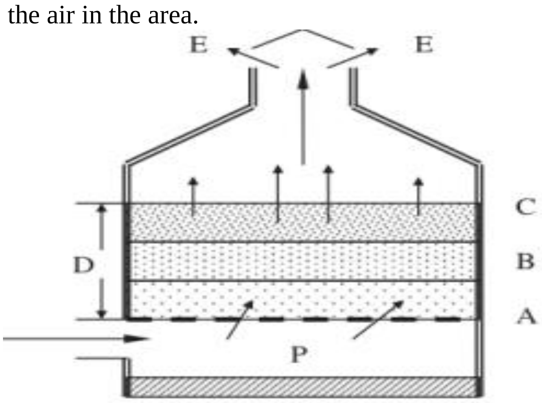


**Figure 1 Convection dryer Deep bed drying zones of grains. D, bed height; P, plenum chamber; A, Outflow locations;[2].**

After oil, coffee is the second largest volume commodity sold in the world. Ethiopia is the primary center of origin and genetic diversity of the Arabica coffee plant. The agriculture-based Ethiopian economy is highly dependent on coffee Arabica as it contributes more than 60 percent of the country's foreign exchange earnings. No other product or service in Ethiopia has earned as much. The labor-intensive tree crop also provides much employment in rural areas and is the means of livelihood for over 15 million people in Ethiopia. The quality of Coffee is depends on the way it's processed and Coffee processing is generally divided into two, which is named as dry and wet processes. Ethiopia exports 80-85 percent natural or sun-dried coffee and 15-20 percent wet-processed coffee. Coffee goes through a series of processing stages before it reaches the cup. Each of these processing stages contributes significantly to the final quality of coffee and hence there is need for careful and skillful handling. The drying of coffee is a step in coffee processing that is required, as for many other food crops, to stabilize an otherwise unstable product. Depending on the processing method employed, the whole fruit, the crushed fruit, parchments (bean enclosed by the inner integument), or naked beans may be dried. It is very important to note that, the processes of drying and fermentation are the key stages that influence coffee quality.

The moisture content of a fresh coffee bean is between 50 and 75 percent of its total weight, depending on the variety and condition of the bean. Dry coffee beans usually contain between 15 and 25 percent moisture, but the recommended moisture content for storage and sale is 12 percent. A low moisture content is the most important factor in maintaining the quality of the beans during storage, as moist beans provide an ideal environment for insects and for the development of micro- organisms. High moisture content during storage is therefore certain to ruin the taste and appearance of the coffee.

Coffee drying entails moisture reduction from about 55% to about 11% wet basis (w.b) to achieve a stable product. For coffee producers, the drying process of coffee grain is critical for obtaining a good quality and a good price for their product. The drying process is very important for keeping the quality of the coffee, because it reduces the humidity content of the grain in order to store and impedes the microbial action that is responsible for spoilage.

The use of solar energy in drying applications is becoming an important and feasible alternative since it decreases consumption of conventional energy by 27-80%at an average solar collector system efficiency of 40% [1].

Generally, as our work is focused on the indirect solar coffee dryer design and manufacturing the prototype it is important to know the types of dryer, solar dryer and mechanism of operation. This will be done in the literature review part.

## II. PROBLEM STATEMENT

Drying is one of the methods used to preserve coffee products for longer periods. The traditional method, still widely used throughout the world, is open sun drying where wet coffee beans are spread on the ground and turned regularly until sufficiently dried so that it can be stored safely. However, there exist many problems associated with open sun drying. It has been seen that open sun drying has the following disadvantages.

- ✓ It requires both large amount of space and long drying time
- ✓ The coffee is damaged because of the hostile weather conditions; contamination from the foreign materials, degradation by overheating.
- ✓ Product may loss quantity wise on attack of birds, animals and rodents**.**
- ✓ There is no control on the drying process.
- ✓ slow drying rate, contamination and poor quality of dried products

Major disadvantage of this method is contamination of the products by dust, birds and insects some percentage will usually be lost or damaged, it is labor intensive, nutrients loss, and the method totally depends on good weather conditions. Therefore, indirect solar coffee dryer is the best system to dry coffee products rapidly, uniformly and hygienically, the prerequisites for industrial coffee drying processes.

### *2.1. General Objective*

The overall objective is to design, construct a model and analysis an affordable indirect solar coffee dryer system for drying parchment coffee to replace or reduce dependence on fuel fired mechanical dryers.

This project is very important for farmers who cultivate coffee beans in tropical and subtropical country especially those who live in rural area where there is no electrical power is reached. It is also important for those who want to replace fuel energy by solar energy in order to dry coffee beans locally. The system is operating manually and simply.

## III. LITERATURE REVIEW

Solar drying refers to a technique that utilizes incident solar radiation to convert it into thermal energy required for drying purposes. Most solar dryers use solar air heaters and the heated air is then passed through the drying chamber (containing material) to be dried. The air transfers its energy to the material causing evaporation of moisture of the material [1].

### *3.1 Drying Mechanism*

Drying basically comprises of two fundamental and simultaneous processes:

i) Heat is transferred to evaporate liquid, and
ii) Mass is transferred as a liquid or vapour within the solid and as a vapour from the surface.

The factors governing the rates of these processes determine the drying rate. The different[3] [13] dryers may utilize heat transfer by convection, conduction, radiation, or a combination of these. However, in almost all solar dryers and other conventional dryers heat must flow to the outer surface first and then into the interior of the solid, with exception for dielectric and microwave drying [6].

The drying phenomenon follows the psychometric principles since drying rate is governed by air water vapour relationship. Several factors affect the drying process such as; the drying method adopted the drying air temperature, the relative humidity, the drying air velocity, and the drying time. The removal of water from foods provides microbiological stability and reduces deteriorative chemical reactions.

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Also, the process allows a substantial reduction in terms of mass, volume, packaging requirement, storage and transportation costs with more convenience [6][15].

In the process of drying, heat is necessary to evaporate moisture from the material and a flow of air helps in carrying away the evaporated moisture. There are two basic mechanisms involved in the drying process: the migration of moisture from the interior of an individual material to the surface, and the evaporation of moisture from the surface to the surrounding air[4].

The drying of a product is a complex heat and mass transfer process which depends on external variables such as temperature, humidity and velocity of the air stream and internal variables which depend on parameters like surface characteristics (rough or smooth surface), chemical composition (sugars, starches, etc.), physical structure (porosity, density, etc.), and size and shape of products. The rate of moisture movement from the product inside to the air outside differs from one product to another and depends very much on whether the material is hygroscopic or non-hygroscopic. Non-hygroscopic materials can be dried to zero moisture level while the hygroscopic materials like most of the food products will always have residual moisture content. This moisture, in hygroscopic material, may be bound moisture which remained in the material due to closed capillaries or due to surface forces and unbound moisture which remained in the material due to the surface tension of water as shown in fig 2 bellow

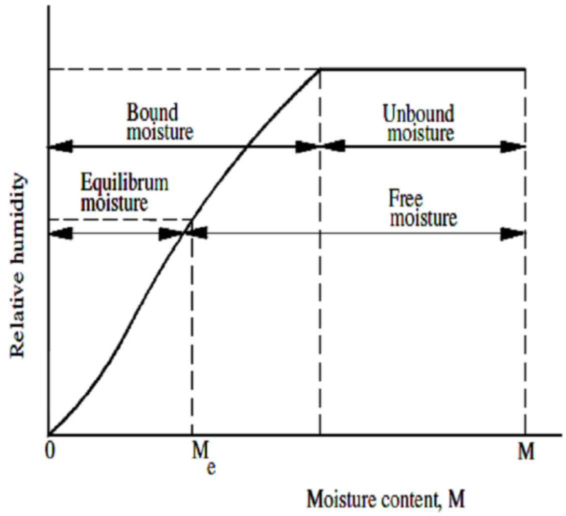


**Figure 2 Moisture in the drying materials [2]**

When the hygroscopic material is exposed to air, it will absorb either moisture or desorbs moisture depending on the relative humidity of the air. The equilibrium moisture content (EMC = Me) will soon reach when the vapour pressure of water in the material becomes equal to the partial pressure of water in the surrounding air [14].

The equilibrium moisture content in drying is therefore important since this is the minimum moisture to which the material can be dried under a given set of drying conditions. A series of drying characteristic curves can be plotted. The best is if the average moisture content M of the material is plotted versus time as shown in Figure 3.

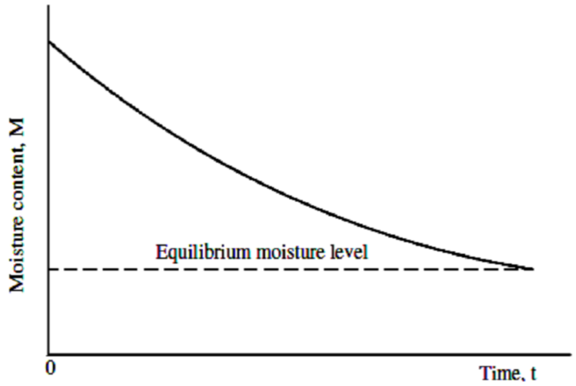


**Figure 3 Rate of moisture loss [2]**

Another curve can be plotted between drying rate i.e. dM/dt versus time t as shown in Figure.3. But more information can be obtained if a curve is plotted between drying rate dM/dt versus moisture content M as shown in Figure 4.

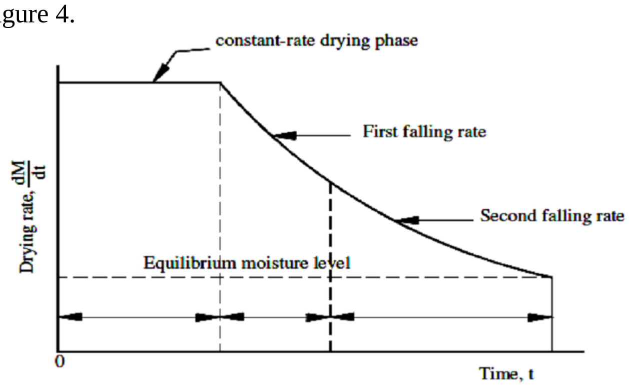


**Figure 4 draying rate with time curve [2]**

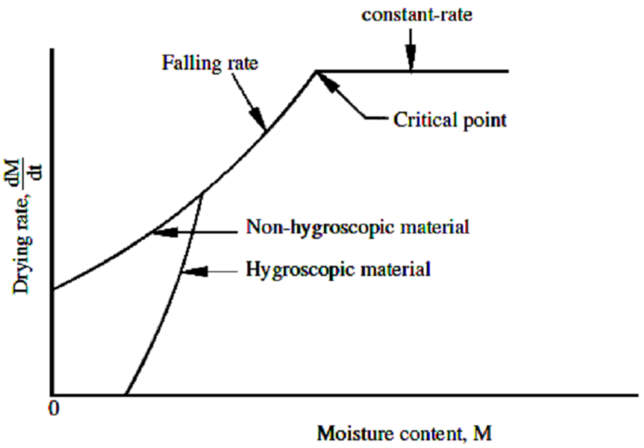


**Figure 5 Typical draying rate curve [2].**

As seen from Figure 4 for both non-hygroscopic and hygroscopic materials, there is a constant drying rate terminating at the critical moisture content followed by falling drying rate. The constant drying rate for both non-hygroscopic and hygroscopic materials is the same while the period of falling rate is little different. For non-hygroscopic materials, in the period of falling rate, the drying rate goes on decreasing till the moisture content become zero. While in the hygroscopic materials, the period of falling rate is similar until the unbound moisture content is completely removed,

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then the drying rate further decreases and some bound moisture is removed and continues till the vapour pressure of the material becomes equal to the vapour pressure of the drying air. When this equilibrium reaches then the drying rate becomes zero [4].

The indirect applications of heat offer better control over the drying process than can be achieved with direct headings. The following can be controlled.

→ Temperature of the air
→ Velocity of air
→ Direction of air
→ Humidity of air etc.

**Methods of operations**

Another method of classifying dryers is by the manner in which they function:

- **Batch dryer**: are used to process individual batches of material which are placed in the dryer and stay there until this reach the desired final moisture and are removed
- **Continuous dryer:** works with raw materials being fed into one end of the dryer on a continuous basis. Dried products come out the other end on a continuous basis. This requires the use of some means of conveying the material through the dryer. Continuous dryers are used in large scale drying operations. They are generally costly and require a large facility to house them plus a crew of operators to run them.
- **Tunnel dryers:** these are really a semi- continuous type of dryer. The product to be dried is placed on trays, screws or necks which are slid into carts. The carts are pulled through a long drying tunnel when heated air blows across the product.
- **Cabinet Dryers: -** The essential design [12] involves placing the material to be dried inside a closed chamber and blowing heated air across it.

### *3.3. Drying of Wet Processed Coffee*

The drying and fermentation operations are the two main stages which significantly influence the flavor and final quality of the coffee. Unlike grain, coffee has a high moisture content of about 60% w.b at the start of drying (i.e. immediately after fermentation or soaking). There is therefore, more water to be removed during the drying operation; this makes the process slower and more difficult to mechanize. The solution to complete mechanization is further complicated due to the requirement of sunlight exposure at the soft black stage, when the bean moisture content is between 32% and 22% [6].

**Figure 6 collection of fresh coffee at the site**

3.3.1. Drying stages

There are six stages that coffee goes through during drying:

a) Skin drying stage
b) White stage
c) Soft black stage drying
d) Medium black stage drying
e) Hard black stage drying
f) Fully dry and conditioning stage

### *3.4. Drying Method*

There are two broad methods of drying coffee, that is, natural sun-drying and forced air drying. Sometimes a combination of both methods may be used. However, each method has its limitations depending on the location and effects on the coffee quality

### *3.4.1 Natural sun drying*

This is the oldest method of drying and is used to dry a wide variety of agricultural products. In this method,[15] immediately after the coffee is removed from the soak tanks, the wet coffee is spread out on wet parchment drying tables where most of the water can drip off. This is the skin drying stage and may last up to two days in the sun. Drying will continue until moisture content of about 11% is achieved. However, this method suffers the key draw-backs mentioned earlier hence yielding low quality coffee.

### *3.5 Solar Dryer*

In developing countries, majority of population is engaged in farming activities. Almost 80% of the total food products are cultivated by small farmers. These farmers use conventional means of drying (open sun drying) for their products. Open sun drying is still the most common and the oldest method to preserve agricultural products. But, this type[14] of drying has many drawbacks like contamination problems, uneven type of drying, and uncontrolled moisture content in end products, causing degradation in the quality of the products. Solar dryers have thus been developed to overcome these problems of open sun drying [www.arpnjournals.com]. 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 active and passive mode [5]:.

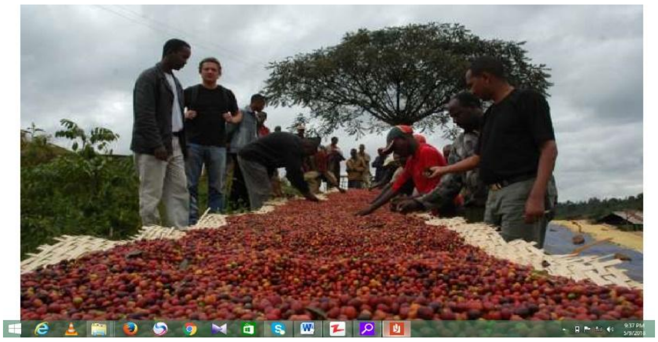

**Figure 7 Drying parchment coffee using sun light**

I n indirect dryers, solar energy is collected in a separate solar collector (air heater) and the heated air then passes through the grain bed, while in the mixed-mode type of dryer, the heated air from a separate solar collector is passed through a grain bed, and at the same time, the drying cabinet absorbs solar energy directly through the transparent walls or the roof.

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Solar dryer is the simple devices used to collect the solar radiations and transfer that radiation in the form of heat energy and this heat energy then transfer to product for drying[7].

A coffee solar dryer transforms solar energy into heat that helps diminish the humidity of the coffee grains; the quantity of water that can be reduced by evaporation from the coffee grains depends mainly on the air temperature and velocity of air circulation [8][17].

The most important advantage of the solar dryers is that they work on renewable energy and are pollution free. Also, solar dryers can be easily constructed from local materials. It is successfully proved how solar dryer technology is key element to climatic and environmental protection as well as sustainable development [9.][16].

### *3.5.1 Main Types of Solar dryers*

According to Baker& Christopher G.J, 1997there are three types of solar dryers and they are classified according to the type of energy used.

→ Solar natural dryers
→ Semi-artificial dryers
→ Solar-assisted dryers

There are two main characters of drying using the sun radiation, depending how the source is used [9]

→ The direct exposure of the sun or open-air sun drying, Direct solar drying (DSD)
→ Indirect solar drying or convective solar drying, (ISD)

## IV. METHODOLOGY

If Firstly the principle of the solar dryer is explained so that further expanse in the project can be followed. In the process of drying relative and absolute humidity are of great importance. Air can take up moisture, but only up to a limit. This limit is the absolute humidity, the maximum, is also dependent on temperature. When air passes over the wet coffe it will take up the moisture until it is fully saturated. Because the humidity is dependent on the temperature, the capacity of the air for taking up this moisture will grow with the rising temperature. If air is warmed, the amount of moisture in it remains the same, but the relative humidity falls. Thus the air is therefore enabled to take up the moisture from the wet coffee.

### *4.1. Design Methods*

For the design of the solar dryer we will concentrate on a low-cost solar dryer that can be built in rural area from almost any kind of available building materials and by locally available power source. First a literary research on the available solar dryers on the market was done. Different solar dryers were found. They can be organized in direct and indirect solar dryers. The direct solar dryers will make use of the sun to heat the drying chamber directly, whereas an indirect solar dryer will have collector that will be heated by the sun. The hot air from the collector will be transferred to the drying chamber. Then there are also passive and active solar dryers. Active dryers mean that hot air gets transferred using a fan, whereas passive dryers depend on wind speed in the air vents. Then there are mixed mode dryers with combine the direct and indirect methods. All of these different dryers have their own advantages and disadvantages. After these we investigated the specifications and advantages of all the solar dryers and analyzed what the best options for the solar dryer would be. The results and the design for the solar dryer can be seen and read below. The calculations can be found at the end of the project.

In order to reach the project’s objective, the following procedure is followed:

- ✓ Literature review on coffee draying system,
- ✓ Weather condition data collection
- ✓ Specification of indirect solar dryer system.
- ✓ Conceptual and theoretical design.
- ✓ Detail design for selected conceptual design
- ✓ Acquire materials needed is suitable for model fabrication.
- ✓ Component design and analysis
- ✓ Performance of solar dryer for collector efficiency, drying air temperature and weight loss will be compared with different types of drying method.
- ✓ Detail drawing and assembly drawing.

### *4.2. Factors Affecting the Rate Of Drying*

**a)** Drying Temperature
**b)** Air Drying Potential
**c)** Relative Humidity
**d)** Velocity of Drying Air

### *4.3. Design Consideration*

With the design of the indirect solar coffee dryer there are some considerations that need to keep in mind to make a working design.

These considerations are listed below.

- ✓ The amount of moisture that needs to be removed, approximately 44%

The material to be dried is the wet coffee beans with moisture content of 50%-75 %.) The required moisture content needs to be below 11%. This means that roughly 44% of moisture needs to be removed from the product.

- ✓ The harvesting period, thus temperature and humidity

The harvesting period for the coffee is from months of October to January in which summer rain fall is experienced with low sun radiation. In this season the average temperature of four months is calculated from NASA world Weather and Climate condition data at the site altitude.

- ✓ The quantity of air needed

The quantity of air needed to dry the coffee will determine the size of the drying chamber. The quantity of air needed can be calculated by taking the moisture content of the coffee and the temperature inside the drying chamber.

- ✓ Daily solar radiation and daily sun hours. Bale Robe is found in the southeast region of Ethiopia at latitude of 7° 00′ North and longitude of, 40° 0′ East.
- ✓ Solar radiation over the year on horizontal surface in Bale Robe is found to be 5. 86 kW/m2 by the National Solar Radiation Database. So the total radiation on a 7° tilted surface is calculated as 507.152 Wh/m2. It will have a daily sun hour rate of 8 hours per day all year round.
- ✓ The weight of the coffee beans.

The maximum weight of the coffee beans has been chosen as 50 kg.

### *4.4 Material Selection*

The following materials were used for the construction of the domestic indirect type solar dryer.

- **Wood: -** as the casing (housing) of the entire system; wood was selected being a good insulator and relative.
- **Glass**:-as the solar collector cover and the cover for the drying chamber. It permits the solar radiation into the system but resists the flow of heat energy out of the systems.
- **Mild steel sheet** of 1mm thickness (dimension 115cm × 65cm) painted black with tar for absorption of solar radiation ( for solar collector)
- **Net cloth** (cheesecloth) and wooden frames for constructing the trays.
- **Nails and glue** as fasteners and adhesives.
- **Glass wool insulation**.
- **Paint** (black and gray)

The Equipment that are used to make the solar dryer are used in our ever day life. And they are found easily near our locality. Such as: Plywood, Hammer, Nail and Glue, Thermometer, Glass, Black Paint and so on.

## V. DESIGN OF INDIRECT SOLAR DRYER SYSTEM

### *5.1. Design Consideration*

The considerations for the draying of indirect type solar coffee dryer are listed below.

- ✓ The amount of moisture that needs to be removed, approximately 44%

The material to be dried is the wet coffee beans with moisture content of 50%-75 %.) The required moisture content needs to be below 11%. This means that roughly 44% of moisture needs to be removed from the product.

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- ✓ The weight of the coffee beans.

The maximum weight of the coffee beans has been chosen as 50 kg

Two important factors were covered during the design:

a) Design Calculations [10]
b) Design system components

### *5.2. Collected Data*

**The collected wind speed data above 50m from the earth surface**

**Table 1 wind speed data at given latitude of Bale Robe ($7^o$North,$40^o$East)**

| Month | October | November | December | January | Average |
|---|---|---|---|---|---|
| Average wind speed , m/s | 3.7 | 4.31 | 4.67 | 4.73 | 4.3525 |

**Average temperature ($C^o$) at Bale Robe**

**Table 2 average temperature for four months**

| Month | October | November | December | January | Average |
|---|---|---|---|---|---|
| Avg. Temp ($C^o$) | 13.6 | 12.8 | 13.1 | 13.6 | 13.54 |

**Table:3. Average solar radiation in kwh/$m^2$/day**

| Month | October | November | December | January | Average |
|---|---|---|---|---|---|
| Solar radiation (Kwh/$m^2$/day) | 5.48 | 5.82 | 5.95 | 6.19 | 5.86 |

### *5.3. Determination Of The Various Drying Parameters*

**a) Available solar energy approximation**

This is estimated by employing the Angstrom's expression

$$Q = Q_o(a + b\frac{s}{s_o}) \qquad (1)$$

Where;

Q is average daily radiation received on horizontal surface, KW/$m^2$

$Q_o$ is solar radiation constant per day, KW/$m^2$

*S* is hours of sunshine recorded at the site per day

$S_o$ is maximum possible number of hours of sunshine at the site per day

a, b is constants which depend on location, a being relatively constant and b is dependent on latitude.

Now from the NASA wind and solar radiation constant per day

i.e. $Q_o$=$Q_{verage}$=5.86 w/$m^2$/day

a=0.25 and b=0.24 which are angstrom's constants

Let we take hours of sunshine recorded at Robe bale is eight hours and maximum possible number of hours of sunshine is twelve hours.

i.e. s=8hours/day and $s_o$=12hours

Therefore average daily radiation received on horizontal surface at Bale Robe in which the location is found at latitude of seven degree north and longitude of forty-four degree south can be calculated as follows.

$$Q = 5.86 * (0.25 * 0.24 * \frac{8}{12})$$

KW/$m^2$/hours

$Q = 2.38$Kw/$m^2$/hours

Q= 2.38 *8hours kw/$m^2$/day

**Q=19.06 KW/$m^2$/day**

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**b) Energy requirement**

The following two equations will be applied: The quantity of heat required to evaporate the water would be:

$$1)\ Q = m_w * h_{fg} \ldots\ldots\ldots\ldots(2)$$

Where;

Q=the amount of energy required for the drying process, kJ

$m_w$=mass of water, kg

$hfg$=latent heat of evaporation, kJ/kg

$$2)\ m_w = m_p \frac{mi-mf}{100-mf} \ldots\ldots\ldots\ldots (3)$$

Where,

$m_i$ =initial moisture content, % wet basis;

$m_f$ =final moisture content, % wet basis;

$m_w$=Amount of water to be removed of water, kg;

$m_p$=initial mass of product to be dried, kg.

The product to be dried is wet coffee beans with the moisture content range 50% to 75%. Let we take the initial moisture contents 55% and final moisture contents 11%. We assume the mass of coffee to be dried is 50kg.

Now,

$$m_w = 50\ kg * \left(\frac{55\% - 11\%}{100 - 11}\right)$$

$= 24.7kg\ water\ will\ lost$

$h_{fg}$ from saturated water temperature-table at average temp at Bale Robe 13.5°C found by interpolation between 10 degree Celsius and 15 degree Celsius and found to be 2468.94kJ/kg. The amount needed is a function of temperature and moisture content of the crop. The latent heat of vaporization is calculated from Youcef-Ali et al. (2001) as follows:

$h_{fg} = 4.186(597 - 0.56(T_p)$

Where,

$T_p$=product temperature, °C in this case 13.5°c

Therefore $h_{fg}$ =2467.39kj/kg

$$Q = 24.7kg * 2468.94kj/kg$$

$$Q = 60{,}982.818\ KJ$$

$$\underline{Q = 16.94KW - hours}$$

**c) Area of the solar collector**

From the total useful heat energy required to evaporate moisture and the net radiation received by the tilted collector, the solar collector area $A$

$$A_c I\eta = m'(h_f - h_i)t_d \ldots\ldots\ (4)$$

Therefore, the solar collector area is

$$A_c = \frac{E}{I\eta}\ \ldots\ldots\ldots\ldots\ (5)$$

Where;

$E = m'(h_f - h_i)t_d$

$m' = massflow\ rate\ of\ air\ in\ \frac{kg}{hr}$

$A_c = is\ the\ solar\ drying\ system\ collector\ area$, m$^2$

E is the total useful energy received by the drying air, KJ

I is the total global radiation on the horizontal surface during the drying period, KJ/m$^2$

$\eta = is\ the\ collector\ efficiency, 20\%\ (vincent\ serem, 1987).$

To calculate the collector area let us calculate drying rate.

Drying rate;

$$m_{dr} = \frac{m_w}{t_d} \ldots\ldots\ldots\ldots\ (5a)$$

Where;

$m_{dr}$; is mass drying rate in kg/hr.

$m_w$; Amount of water to be removed of water, kg;

$T_d$; drying time in hours

Let drying time could be two days(2 days), 16 hours and we have amount of water to be removed is 24.7kg.

$$m_{dr} = \frac{24.7kg}{16hrs}$$

$$\boldsymbol{m_{dr} = 1.54kg/hrs}$$

let initial relative humidity = 55% and final relative humidity =11%.

Now; at the temperature (average temp) found at the site which is equals to 13.5°c.

Moisture contents on dry basis can be calculated by;

$$m = \frac{m_w}{m_c - m_w} \ldots\ldots\ldots\ldots (5b)$$

$$= \frac{24.7kg}{50kg - 24.7kg}$$

$\underline{= 0.9763\text{kg of } H_2O\text{/kg of dry air}}$

Mass flow rate of air;

$$m' = \frac{m_{dr}}{w_f - w_i} \ldots\ldots\ldots\ldots (5c)$$

Where;

$w_f$ is specific humidity at final relative humidity, kg of water/kg of dry air

$W_i$ is specific humidity at initial relative humidity, kg of water/kg of dry air

From psychometric chart at;

R.H $_{initial}$ =55% and $T_{av.}$=13.5°c , R.H $_{final}$ =11%

$W_f$=0.0010568734kg of $H_2O$/kg of dry air

Wi =0.00532kg of $H_2O$/kg of dry air.

Now mass flow rate;

$$m' = \frac{m_{dr}}{w_f - w_i}$$

$$= \frac{1.54}{0.004263}$$

$= \frac{361.23kg}{hr}$ or $\underline{m' = 0.1003kg/sec}$

Therefore; area of solar collector is

$A_c I\eta = m'(h_f - h_i)t_d = E$

From psychometric chart we get enthalpy of air at given moisture contents and temperature.

$E = 361.23 * 13 * 8$

$\boldsymbol{E = 10.43kw}$

Now;

$$A_c = \frac{E}{I\eta}$$

$$A_c = \frac{10.43}{5.86 * 8 * 0.2}$$

$\underline{A_c = 1.11m^2}$

**d. Air vent area and the air-flow rate**

Relative humidity (R.H) =55% at 13.5°c, $w_f$ =0.00532 kg of water/kg of dry air

Relative humidity (R.H) =11% at 13.5 °c, wi =0.00105689 kg of water/kg of dry air

The drying potential can be;

$= 0.00532\text{kg of water/kg of dry air} - 0.00105689$

kg of water/kg of dry air

$= 0.004263$ kg of water/kg of dry air

From psychometric chart the specific volume for this condition is;

$$= \frac{0.81m^3}{kg}$$

Hence the drying potential =4.263*10$^{-3}$/0.81

$= 5.263 * 10^{-3}$ kg of water/m$^3$of air

$$\frac{m_w}{d_p} = \frac{24.7}{5.263 * 10^{-3}}$$

Where;

dp is the drying potential, kgof water/m$^3$of air

$$= 4.693 * 10^3 m^3 of\ air$$

If the drying period is 2days and 8hrs per day, air flow rate will be;

$$v_a = \frac{m_w}{d_p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.6$$

$$v_a = \frac{4.693 * 10^3}{16 * 60}$$

$\therefore air\ flow\ rate = \frac{4.888m^3}{min}$ **or 0.08147m$^3$/sec**

Now, air vent area can be calculated by dividing the volumetric air flow rate by wind speed.

$$A_v = \frac{v_a}{v_w} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.7$$

Where;

$A_v$ is the area of the air vent, m$^2$.

$V_w$ is the wind speed, m/sec

$V_a$ volumetric air flow rate, m$^3$/sec

Form the data we gathered (NASA); wind speed average of October to January is =4.3525m/sec

$$A_v = \frac{0.08147}{4.3525}$$

$$\underline{A_v = 0.0187m^2}$$

**e. dynamic pressure**

The pressure difference across the coffee bed will be solely due to the speed of the heated air and the density difference between the hot air inside the dryer and the ambient air. The operation of a fan is often expressed in the terms of pressure;

$$P_d = \frac{\rho v_a{}^2}{2} \ldots\ldots\ldots\ldots.8$$

Where;

$P_d$ *is the dynamic pressure in pascal*

$\rho$ *is density of air*, $\frac{kg}{m3}$

$v_a$ *is air flow rate in* $m^3/sec$

$$V_{max} = \frac{V_a}{A_v} \ldots\ldots\ldots\ldots\ldots\ldots 9$$

$$V_{max} = \frac{0.08147}{0.0187}$$

$$V_{max} = 4.357m/sec$$

$$P_d = \frac{1.225 * 4.357^2}{2}$$

$$\underline{P_d = 11.63P}$$

**Drying Efficiencies**

❖ **Efficiency of a solar collector**

The efficiency of a solar collector is defined as the quotient of usable thermal energy versus the received solar energy. The performance evaluation of the collector, which is significant for its dimensioning, is based on the Hottel-Whiller equation on the assumption that it is applicable to this design. In the steady state, the thermal efficiency Ƞ is defined by;

$$\eta = \frac{Mc_p(T_d - T_a)}{A_c I_t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..10$$

Where;

M is the mass of the product in kg

$c_p$ *is the specific heat of the product in* $kJkg^{-1}k^{-1}$

$T_d$ *is the dryer temperature in* $o_C$

$T_a$ *is the ambient temperature in degree celcuius*

$A_c$ *is the solar collector area in* $m^2$

$I_t$ *is the total incident radiation in* $kw/m^2$

Now efficiency of the collector can be;

$$\eta = \frac{Mc_p(T_d - T_a)}{A_c I_t}$$

$$\eta = \frac{50 * 1.005 * (32 - 13.5)}{1.11 * 19.06}$$

$$\underline{\eta = 39.2\%}$$

❖ **Pick up Efficiency**

The pick-up efficiency, Ƞ is defined as the ratio of the moisture removed or picked-up by the drying air to the theoretical capacity of the air to absorb moisture. Mathematically;

$$\eta_p = \frac{w_o - w_i}{w_a - w_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.11$$

**Where**;

$w_i$ and $w_o$ is the absolute humidity of air entering and leaving the drying chamber respectively. $W_a$ is the adiabatic saturation humidity of air entering the dryer.

The numerator of this equation could also be written as:-

$$\frac{M_o - M_t}{V\rho} \ldots\ldots\ldots\ldots\ldots..12$$

Where;

$M_o$ and $M_t$ are the mass of the commodity at time t=0 and t=t respectively.

**V** is the volume flow rate

$\rho$ is the density of air

Now the pickup efficiency can be;

$$\eta_p = \frac{w_o - w_i}{w_a - w_i}$$

$$\eta_p = \frac{44 - 11}{90 - 11}$$

$$\eta_p = 41.7$$

❖ **System Efficiency**

The system drying efficiency Ƞ or system efficiency is the ratio of the energy required to evaporate the moisture of the commodity to the heat supplied by the dryer. Mathematically;

$$\eta_s = \frac{w_o L}{I A_c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.13$$

Where;

$Wo$ is the mass of moisture evaporated;

$L$ is the latent heat of vaporization of water at the dryer temperature

$I$ is the total global radiation on the horizontal surface during the drying period, kJ/$m^2$

$Ac$ is the solar drying system collector area, $m^2$

$$\eta_s = \frac{24.7 * 2468.94}{5.86 * 8 * 3600 * 1.11}$$

$$\eta_s = 32.3\%$$

**NOTE:** System efficiency is a measure of the overall effectiveness of the drying system. Typical values are 10-15 % for natural convection dryers, while a system efficiency of 20-35 % could be expected for forced convection dryers

### A. *Fan Selection*

A fan is defined as a rotary, bladed machine maintaining a continuous of air. A fan has a rotating impeller invariably carrying blades of some kind. These blades exert force on the

Table:4. Fan specifications

air and thereby maintaining the flow and raising the total pressure of the air. Most commercial fan use for the work may be placed in one of the three general types based upon construction and air flow patterns.

These types are:

1. Centrifugal
2. radial flow fan and
3. Axial flow fan

**Centrifugal fans** have flow within the rotating wheel or rotor that is substantially radial to the shaft, with the rotor operating in scroll type casing.

**Axial flow fans** have flow within the wheel that is substantially parallel to the shaft and operate within cylindrical ring-type housing.

To select a fan it is necessary to know the capacity and total pressure requirement of the system, nature of its load (variable or steady), and noise constraints must also be considered. It is usual for manufacturers to catalogue fan performance in terms of fan static pressure and it is customary to select fans on this basis, thus

Fan total pressure = System total pressure loss

= Fan static pressure + Fan velocity pressure

The assumption is often made that the fan velocity pressure is very nearly system discharge velocity pressure. Since there is no ductwork, the pressure losses are that only on the heating apparatus, filter, and the fan intake and fan outlet.

In the air heater there is generally as much interest in the pressure drop associated with flow across a bank of tube.

It may be expressed as [1] and the pressure losses in different apparatus are tabulated in the following table.

Table 3.1 pressure loss in different apparatus

Source: Refrigeration and Air Conditioning for Engineers Prof. P.S. Dasai

Therefore; Static pressure consists of pressure losses:

1.At intake or entry to the fan =12.865KPa

2.On the air heater = 26.73KPa

3.On the air filter = 73.55KPa

4.At the fan outlet = 18.4KPa

Then the static pressure is equal to= $P_s$ = 73.55+18.4+26.73+12.865=131.535KPa

Again in addition to this there is pressure loss in the drying chamber is determined according to the depth for 1ft depth or 100mmdepth.

$\Delta P_{loss}$=0.01*25.4*1.25kg/m3*9.81=3.114675KPa

$$\Delta P_{....} = \Delta P_{......} + \Delta P_{......} = 0.132kpa + 3.114675kpa = 3.2472KPa$$

**Fan Air Power**

The power output of a fan is expressed in terms of air power. It represents the power output by the fan. It is the power required to move a given volume of air against a given pressure. Based on total pressure, fan air powers is Fan total air power.

$$Total\ air\ power = Q * \Delta Ploss + Q * v2 * \rho * 0.5$$

Where;-

p is the desist of the air i.e is equal to 1.25m3

Q is the discharge rate.

V is the air velocity

$$Total\ air\ power = Q * 3.2472KPa + Q * (1.25)2 * 0.5$$
$$= 0.95KW + 0.0003KW$$
$$= 0.953KW$$

| Item | Pressure loss, Pa |
|---|---|
| 1. Air intake or fan entry | 1.23 to 24.5 |
| 2. Air washer | 49.1 to 85.8 |
| 3. Air filter | 49.1 to 98.0 |
| 4. Outlet | 12.3 to 24.5 |
| 5. Miscellaneous, screens, grills etc | 24.5 to 49.0 |

**FAN TOTAL PRESSURE = SYSTEM TOTAL PRESSURE LOSS**

= Fan static pressure + Fan velocity pressure

$$The\ formula\ pressure\ velocity = p(Vm)2/2$$

Where;

Vm is the velocity of the air and p is the air desity but the maximum velocity for the the air range between the 4.7-6.2 m/s and we take the values for the air velocity is 4.74m/s

$$= 1.25 * (4.74\ m/s)2/2$$
$$= 14.04m/s$$

There for the flow rate is calculated; $Q = A * v$

$$= 14.04m/s * 0.001 = 14.04\ m3/s\ or\ 8.4\ m3/min$$

The assumption is often made that the fan velocity pressure is very nearly system discharge velocity pressure. The discharge velocity is neglected and the resulting total taken as the required fan static pressure.

Since there is no ductwork, the pressure losses are that only on the cooling apparatus, filter, and the fan intake and fan outlet.

Therefore;

Static pressure consists of pressure losses:

1. At intake or entry to the fan = 10KPa
2. On the air cooler = 35KPa
3. On the air filter = 65KPa
4. At the fan outlet = 15KPa

Then the static pressure is equal to

$$Ps = 10 + 35 + 65 + 15 = 125KPa$$

Assuming the fan diameter 40mm then the area of the fan is calculated;

$$A = \frac{\pi r^2}{4}$$
$$= 3.14 * (0.02)2/4$$
$$= 3.14 * (0.004) = 0.0001m2$$

1) *Fan Air Power*

The power output of a fan is expressed in terms of air power. It represents the power output by the fan. It is the power required to move a given volume of air against a given pressure.

Based on static and total pressure, fan air powers are

(a) Fan static air power

(b) Fan total air power

$$Static\ air\ power = Q * Ps/60{,}000\ \ KW$$
$$= 0.0142 * 0.125/60000$$
$$= 0.00292Kw$$

$$Total\ air\ power\ = Q * Pt/60{,}000\ \ KW/min$$

Where;
Q = air volume flow rate $m^3/min = 0.01404 m^3/sec$
$P_s$ = static pressure Pa
$P_t$ = total pressure Pa
Since the velocity pressure is neglected the static air power is equal to the fan total air power.

$$Total\ air\ power\ = 0.0140504 * 125/60000$$
$$= 0.0573KW\ = 57.3W$$

Therefore a proper fan with a capacity of $0.0842504 m^3/min$ and total air power of 57.3W is used.

*Batteries*

Batteries are energy source storage device that are particularly useful for powering. Batteries is used in the application are engineering to meet unique design constant imposed by these different application. The term battery refers to the system of one or more cells.

**Batteries capacity**

**Batteries** capacity is published by the manufacturer as a nominal rating for given set of discharge condition. The discharge condition includes rate of discharge temperature and minimum cell voltage. the batteries below the minimum voltage can reduce batteries capacity.
The batteries performance parameterizes can includes voltage, amps-hours capacity and rate of capacity

**Effective temperatures on service life of batteries**

High temperatures have negative effects on the batteries life cycles.

**Table 5. temperature effect on batteries**

| Average temperature | AGMP batteries cycles in year Or VRLA in year | GEL batteries in year | GAL long batteries in years |
|---|---|---|---|
| 20°C | 7-10 | 12 | 20 |
| 30 °C | 4 | 6 | 10 |
| 40°C | 2 | 3 | 5 |

Victron VRLA batteries can therefore be stored for up to a year without recharging, if kept under cool conditions.
Among different types of batteries we use VRLA TECHNOLOGY batteries that have the voltage 12v and 90 A.H
We have 8hrs from above calculation
Where;
90Ah is batteries capacity and
$12V\ is\ voltage.$
$Watts\ = amp * volts$
$Capacity\ = 90\ AMP/HRS/8\ HRS$
$= 11.25\ apms$
$Watts\ = amps * volts$
$= 11.25\ amps * 12\ volts$
$= 135watts$
The batterie capacity is calculated as;
$Amps * hrs$
$= 11.25amps * 12V$
$= 135amp/hrs$

### *5.4. Design Of System Component*

**1) Solar collector unit**

From theoretical computations, a collector area of $1.11m^2$ was arrived at. To achieve this collector area, a collector measuring 1000mm by 300mm was designed. The solar collector unit measuring long by 4 mm wide and 2 mm deep was designed utilizing locally available materials.
The various collector components are as follows:

- ✓ A transparent glass top to allow solar irradiation into the collector unit and prevent loss of thermal energy.
- ✓ The bottom of the collector unit is composed of an absorber. The absorber is made of a thick black painted galvanized iron sheet (1 thick). This is the surface used absorb incoming solar radiation. The under-side of the absorber is covered with a 10 mm insulating foam material to prevent loss of thermal energy.
- ✓ An insulation (10 mm thick) at the bottom and on the sides of the collector to prevent loss of thermal energy. The insulating material utilized for all the linings was dense foam.

The design incorporated a cold air inlet positioned perpendicular to air-flow and connected to the wire before the fan. The device was for regulating the temperature of the air by letting in cold air whenever the temperature becomes higher than required. It was to be operated manually.
The angle of inclination of the solar collector was taken as 45°.Recommended for maximum solar energy collection.

**3) Drying Chamber**

A 50 kg mass of coffee requires an area of $1.11m^2$ of drying space on the closed drying trays .for wet parchment at a depth of 12.5mm.For main drying trays, the requirement is $20m^2$ per to mass of mass at a depth of 25mm.when forced circulation system is used the area requirement reduces by 3:1 compared to main beds limit. The forced indirect system requires the same area per mass of coffee for an extra depth in the ratio 1:4. It is common practice in coffee factories to base the sizing of these drying.

Therefore, for forced indirect system an area of $1.11m^2$ will be needed for depth of 100mm of wet coffee .A bin drying area of 1000m by 300m was provided to meet this requirement.it can dry up to a mass of coffee, but can be scaled upwards to meet more capacity.to dry 500 kg of wet coffee at 100 mm, a demarcation grate which is fitted into the drying coffee is used to confine the area to the required one. This way, any quantities less than a mass, can be confined in proportional areas of the drying coffee and drying conducted. The drying chamber houses the coffee-holding mass measuring.

The drying chamber is 1020mm long by 800 mm wide and 1520mm high. Its foundation is made of 500 mm wooden block which is treated and properly cured to ensure it can withstand environmental elements. The wooden base is ideal for preventing thermal loss through the cold floor.

The fan is connected to the to transport hot-air duct just below the drying chamber. The fan speeds up the flow of heated air through the wet coffee berries, reducing the drying time by three times compared to the natural circulating system.

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There is a out let at the roof of the chamber to allow moisture ridden exhaust air to escape. This is important to ensure the moisture does not accumulate at the top of the chamber and to create the suction effect ideal for faster drying.

The floor of the coffee was made from a coffee tray wire material. The openings of the tray wire were much greater than 4 % of the area of the floor and hence resistance to air-flow was negligible. The top side of the chamber was left open for moisture to escape.

The various properties of the drying air were to be measured along the hol. The measuring devices were inserted into an inlet made in the hole.for the measurement of temperature, relative humidity, and the air-flow rate.

## VI. RESULTS AND ANALYSIS

### *6.1 Performance of The Solar Collector*

Parchment coffee is dried in the months of October and January. Most of the days within these months have moderate weather conditions and are sunny

The incident angle of solar radiation varies throughout the year. However, the difference in the amount of energy received is small during most of the time in a year. This is because of the fact that Ethiopia is situated near the equator with the sun near the zenith year round and the tilted angle of the collector is small, 45°.

The solar collector has an efficiency of 35 % when the system operating at full capacity (i.e.50 kg of wet parchment at 100 mm depth). This efficiency is well within the range of 20 to 35 % for the corresponding collector area.

As the collector heats up, thermal losses from it will reduce its efficiency, resulting in increased radiation, primarily infrared. This is countered in two ways. First, the glass top helps to create the green-house effect. It readily transmits solar radiation in the visible and ultraviolet spectrum, but does not transmit the lower frequency infrared re-radiation very well. Second, the glass top also traps air in the space, thus reducing the heat loss by convection.

### *6.2. Performance of The Solar Dryer*

For moderate weather conditions, the moisture content of the parchment in the drying wet coffee will be reduced from an initial value of 55 % w. to 11 % w. within 2 days ( 24 hours daily), or with an effective drying time of approximately 8 hours. The drying time, however, will vary according to the actual conditions at the site.

The drying air is forced through the coffee parchment with an air speed of 0.08174 m/s. The pressure of the drying air drops but it depends on the depth of the bed of the products. For this case, a depth of 100 mm is recommended. For 50 kg of fresh parchment coffee, its bed depth will decrease due to shrinkage of the coffee parchment.

The average sunshine hours at the Bale robe site was found to be 8 hours per day. By using Angstrom Equation, the daily solar radiation at the site was found to be 5.86 kW/m$^2$ from NASA. By using a solar collector with a surface area of 1.11m$^2$, the total solar received was19.06 KW-hrs/m$^2$/day assuming 8 sunshine hours daily.

When the system is loaded with 50 kg of wet parchment mass of coffee and dried to 16.67 mass of coffee 24.74 kg of water is removed. This requires 2.3 KW-hrs of energy for evaporation. If 20 % collector efficiency is assumed, the drying operation would take about 2 days. The drying time however, will vary according to the actual conditions at the site.

The solar dryer has a collector efficiency of 35 %, a pick-up efficiency of 50 %, and a system efficiency of 32.34 %. The system efficiency is within the range of efficiency for forced convection dryers, that is, 20 to 35 %. The collector efficiency is within the range of 35 % for the given collector area.

The air flow rate into the drying coffee was found to be 0.81738m$^2$/s. It was assumed further in this calculation that the drying would take 8 hours a day, and that the rate of drying is constant.

### *6.3 Weather Conditions Analysis*

From the meteorological data collected from NASA world weather condition for October to January at the Bale Robe with longitude of seven degree north and forty-four degree south.

- The mean average day temperature 13.5.°C (d.b) and The average relative humidity at initial is 55% to finally 11 %.
- From the Psychometric chart 0.0127 kg Water/kg dry air.
- The mean average temperature in13.5°C (d.b) and
- The average relative humidity 80 %

### *6.4 Cost Analysis and Estimation*

***1) Engineering Bill of Quantities cost analysis and estimation for construction of the model is listed below.***

**Table 6. cost analysis and estimation**

| Item | Description | unit | quantity | Rate ETB | Amount ETB |
|---|---|---|---|---|---|
| Wood | Timber | M | 4 | 50 | 200 |
| Glass | Transparent glass | m$^2$ | 2 | 600 | 1200 |
| Metal sheet | Aluminum or iron sheet | m$^2$ | 3 | 100 | 300 |
| Paint | Black | L | 1bottle | 90+ 20 birr brush | 110 |
| Nails | 6cents | Kg | 1 | 50 | 50 |
| Fan | | | 1 | 400 | 1500 |
| Electric wire | | M | 8 | 5 | 40 |
| Battery | 12v | volt | | | 600 |
| **Total** | | | | | 4000 |

The project is simply done in the madda walabu university main campus from raw materials available and useless materials such as timber, sheet metal, nayils etc.

### 6.3.PART DRAWING AND ASSEMBLY DRAWING

**Table 7.collector leg description**

| Parameters | Length | Unit | Quantity |
|---|---|---|---|
| Collector leg | 300*50 | Mm | 2 |

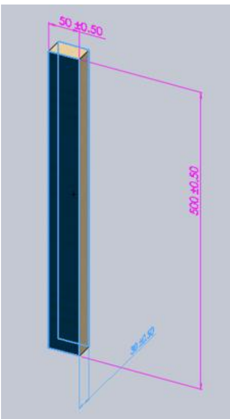

Figure 8  collector leg

Table 8. collector side description

| Parameters | Length | Unit | Quantity |
|---|---|---|---|
| Collector side | 300*1000 | Mm | 2 |

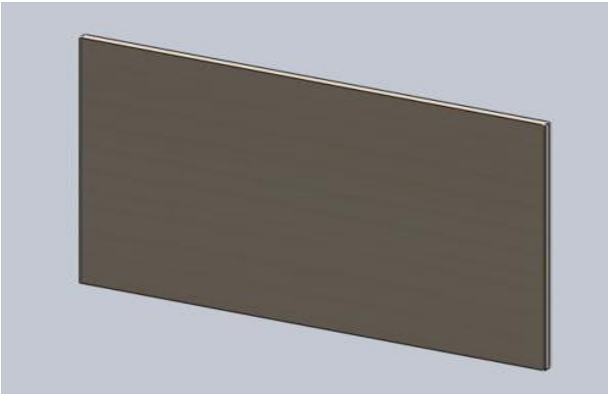

Figure 9 collector side

Table 9. collector bottom description

| Parameters | Length | Unit | Quantity |
|---|---|---|---|
| Collector bottom | 1000*300 | Mm | 1 |

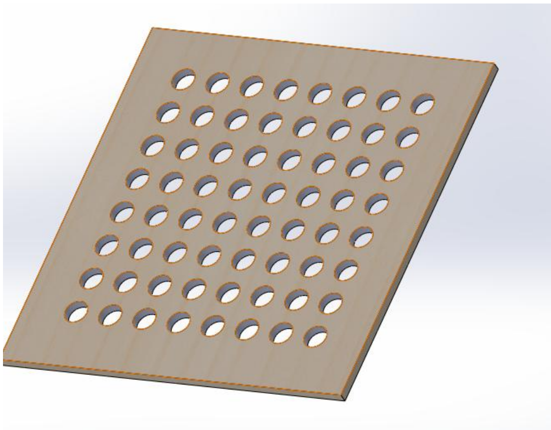

Figure 6 collector air inlet

Table 10. inlet parameters

| Parameters | Unit | Length | quantity |
|---|---|---|---|
| Inlet | mm | 300*300 | 1 |

Table.11. collector top parameters

| Parameter | Length | Unit | Quantity |
|---|---|---|---|
| Top cover | 500*500 | mm | 1 |

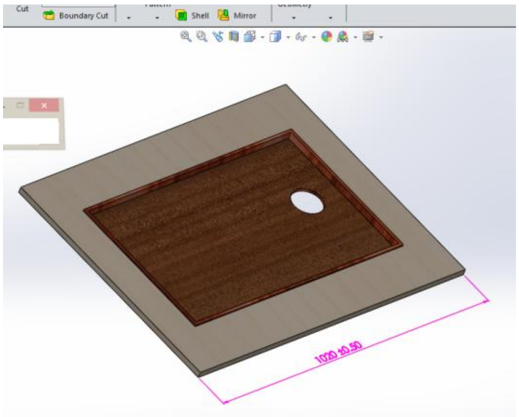

Figure 11 collector top

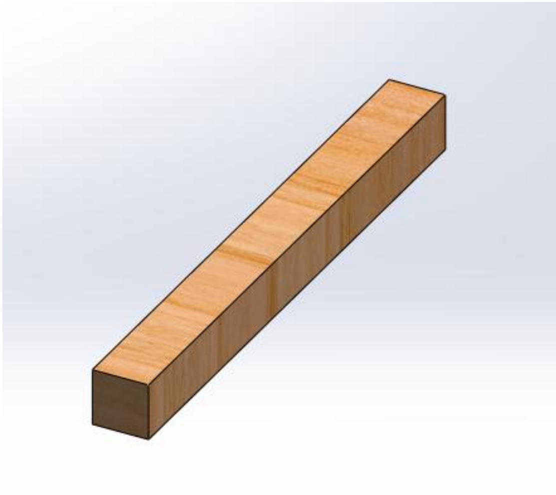

Figure 12 chamber leg

Table 12 chamber leg description

| Parameters | Length | unit | Quantity |
|---|---|---|---|
| Chamber leg | 500*50 | mm | 4 |

Table 13 chamber side view

| Parameters | Length | Unit | Quantity |
|---|---|---|---|
| Chmber side | 800*1020*30 | mm | 2 |

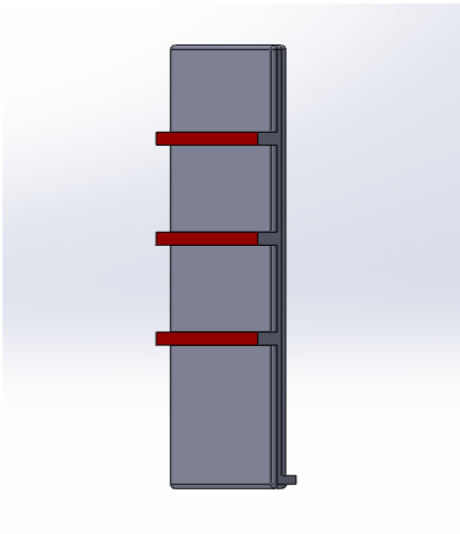

Figure 13 chamber side

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**Chamber back**

**Table 14. chamber back view**

| Parameters | Length | Unit | Quantity |
|---|---|---|---|
| back | 1020*800 | mm | 1 |

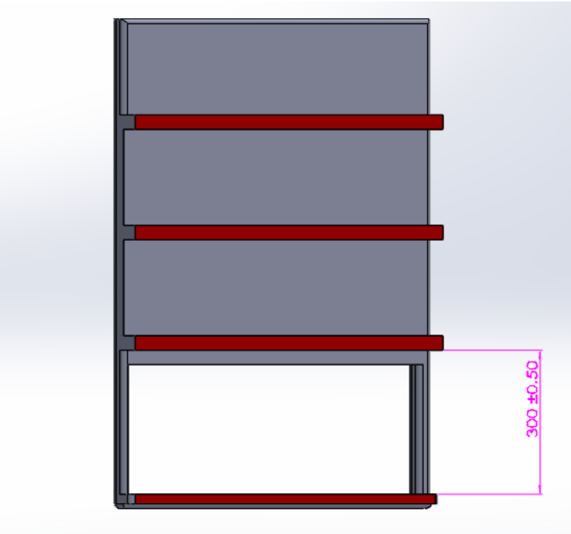


**Figure 14 chamber back view**

**Table 15 top of chamber**

| Parameters | Length | Unit | quantity |
|---|---|---|---|
| Top | 800*800 | mm | 1 |

**Figure 15 chamber top**

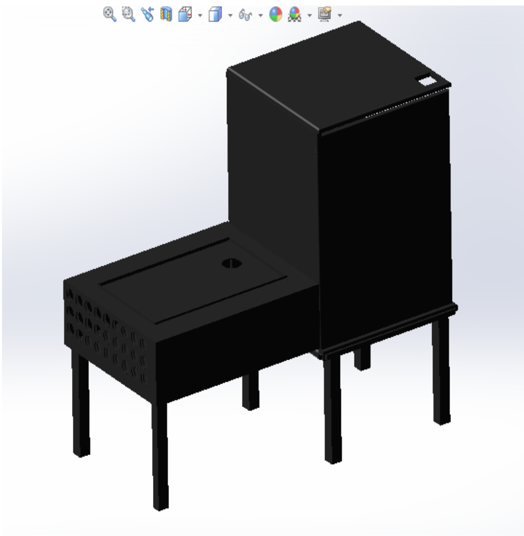

**Figure 16 assembly drawing**

## VII. CONCLUSION AND RECOMMENDATION

### *7.1. Conclusion*

The overall objective of this design project was to design an affordable solar coffee dryer system for drying parchment coffee to replace or reduce dependence on fuel-fired mechanical driers. In order to achieve this broad objective, several specific objectives were set as captured in the introduction section of this paper. The output of the design therefore, was a solar dryer system that addressed these design objectives.

The solar dryer, so designed, minimizes both space and labour requirements in the coffee drying while accomplishing successful drying. The capacity of this model dryer system is 50kg of wet parchment coffee per $m^2$.

The solar dryer reduces moisture content of parchment from 55 % to 11 % wet basis within a span of 4 days upon which the crop is stable for storage. The products being dried in this system are completely protected from rains, insects and other foreign matter that would compromise the quality of the final product. Consequently, the product achieved is of high quality and meets the market requirements.

The solar dryer has a collector efficiency of 32.5 %, a pick-up efficiency of 25 %, and a system efficiency of 24 %. The system efficiency is within the range of efficiency for forced convection dryers, that is, 20-30 %. The collector efficiency is within the range of 30-40 % for the given collector area. The Cost-Benefit ratio is 3.52 compared with a biomass fired dryer of the same capacity and 1.12 compared to natural sun drying. This implies that the project is economically feasible and a desirable option.

It can be concluded that the solar collector at defined rates and operational times increases drying efficiencies of parchment coffee about 20 to 40 %, that is, 3.4 times compared to natural sun drying. However, the solar collector needs to be cleaned from time to time to eliminate the deposits of dust which would ultimately lower the amount of solar irradiation into the collector.

### 7. Recommendations

We gratefully recommended that anyone who can offer to re-design and construct the system will be doing it since:

- Controlling air temperature manually is ineffective and can lead to overheating of the coffee. An automatic temperature regulating device is therefore very necessary and should be incorporated into the design for better results.
- An auxiliary energy source such as electricity should be incorporated into the system to provide energy when the weather conditions are unfavorable. It would also give harmony and uniformity of temperatures during drying.
- An alternative energy for driving the fan, most probably solar energy, should be tapped to reduce the cost of energy and hence the overall drying cost.
- There is need to carry-out further work in this design by producing the prototype and testing the system to see whether the theoretical results given here are consistent with the real system in operation.

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