A DESIGN AND CONSTRUCTION OF A SOLAR DRYING SYSTEM FOR MUSHROOM PRESERVATION

Chandan Thakuria [1]

[1]*M.Tech, Department of Energy Engineering, Assam Science and Technology University, Tetelia Road, Near Assam Engineering College, Jalukbari, Guwahati, Assam-781013*

Abstract- *Drying of mushroom in both rural and urban areas is a preservation activity done by farmers and herbal practitioners. The most common way to do this is to place the leaves on a mat, floors etc. and leave it in the open to dry. This process takes a long time and makes the mushroom subjected to attack by the weather, animals, insects and sand. It also affects the quality, nutritional values and the potency level of the mushroom when exposed to the direct sunlight. This paper outlines systematic design and construction of mixed-mode solar dyer system for mushroom preservation. A drying time of 24-30 hours is assumed for the anticipated test location (Guwahati, latitude= 26.145^{o}N) with an calculated average solar irradiance of 675.12 W/m^{2} and ambient conditions of 35^{o}C and optimum temperature for drying mushroom is 65^{o}C. A minimum of 0.547 m^{2} of solar collector area was calculated and fabricated. The dryer will be constructed using locally available material, so that it can easily made in rural areas for food preservation by villagers.*

Keywords: Design and Fabrication, Drying mushroom, moisture content, dryer efficiency, and thermal analysis.

1. INTRODUCTION

The sun is the most important source of heat and light in the universe. During primitive times, the sun was solely used for its heat and light for all day to day activities, when there was no electricity. With increased usage of fossil fuel and thermal electricity, there is now a risk of global warming. It is being feared that if Earth progresses at the rate at which it is currently moving on, there will not be much of resources left for our future generations. All this has led the world incline towards alternative sources of power. While wind and hydro energy are also making progress, it is solar energy that has become the favored one amongst masses, mainly due to its increased affordability.

A solar dryer is another application of solar energy, used immensely in the food and agriculture industry. Though sun is still used as the direct source for drying food items and clothes in certain parts of the world. An indirect source of solar power can also be used for the same purpose in the form of a solar dryer. The main disadvantage of drying directly under the sun is contamination – dirt, animals, insects etc. Also there is a fear of sudden change in weather conditions like wind or rain. Drying is an excellent way to preserve foods. Drying was probably the first ever food preserving method used by mans. It involves the removal of moisture from agricultural product so as to provide a product that can be safely stored for longer period of time.

In solar drying, solar dryers are specialized devices that control the drying process and protect agricultural product from damage by insect, dust and rain. In addition, it takes up less space, takes less time and relatively inexpensive compared to artificial mechanical drying method. Thus, solar drying is a better alternative solution to all the drawbacks of natural drying and artificial mechanical drying.

The solar dryer can be seen as one of the solutions to the world's food and energy crises. With drying, most agricultural product can be preserved and this can be achieved more efficiently through the use of solar dryer.

Solar dryers are a very useful device for:

- Agricultural crop drying.
- Food processing industries for dehydration of fruits and vegetables.
- Fish and meat drying.
- Dairy industries for production of milk powder.
- Seasoning of wood and timber.
- Textile industries for drying of textile materials, etc.

Thus, the solar dryer is one of the many ways of making use of solar energy efficiently in meeting man's demand for energy and food supply, total system cost is a most important consideration in designing a solar dryer for agricultural uses. No matter how well a solar system operates, it will not gain widespread use unless it presents an economically feasible alternative to other available energy sources.

1.1 Solar Energy

The use of solar energy in recent years had reached a remarkable edge. The continuous research for an alternative power source due to the perceived scarcity of fuel fossils is its driving force. It had become even more popular as the cost of fossil fuel continues to rise. Of all the renewable sources of energy available, solar energy is the most abundant one and is available in both direct as well as indirect forms. Solar energy applications were divided mainly into two categories: the first is the direct conversion to electricity using solar cells (electrical applications). The second is the thermal applications. The latter include solar heating, solar cooling, solar drying, solar cooking, solar ponds, solar distillation, solar furnaces, solar thermal power generation, solar water heating, solar air heating, etc. Detailed description, fundamentals and previous work performed on solar dryers and solar air heaters, as the vital element for the indirect and mixed modes of solar dryers. Solar air heater is a type of energy collector in which the energy from the sun, solar insolation, is captured by an absorbing medium and used to heat air. Solar air heating is a renewable energy heating technology used to dry the agricultural products effectively and efficiently. A simple solar air collector consists of an absorber material, sometimes having a selective surface, to capture radiation from the sun and transfers this thermal energy to air via conduction heat transfer. This heated air is then ducted to the agricultural products such as chilies, grapes etc. Drying or dehydration of material means removal of moisture from the interior of the material to the surface and then to remove the moisture from the surface of drying material. Drying of seeds prevents germinations and growth and fungi and bacteria. The traditional age old practices of drying food crops in developing countries like India, Bangladesh etc. is spreading food products in open sun termed as open sun drying or natural sun drying. This natural sun drying is simple and economical but suffers from many drawbacks such as there is no control over the drying rate discoloration. However, being unprotected from rain, wind-borne dirt and dust, infestation by insects, rodents and other animal, products may be seriously degraded to the extent that sometimes become inedible and the resulted loss of food quality in the dried Products may have adverse economic effects on domestics and international markets. Some of the problems associated with open-air sun drying can be solved through the use of a solar dryer which comprises of collector, a drying chamber and sometimes a chimney. The use of solar technology has often been suggested for the dried fruit industry both to reduce energy costs and economically speed up drying which would be beneficial to final quality dried grapes, okra, tomato and onion using solar energy. They concluded that drying time reduced significantly resulting in a higher product quality in terms of colour and reconstitution properties. They also believe that as compared to oil or gas heated dryers, solar drying facilities are economical for small holders, especially under favorable meteorological conditions. [Solar dryers used in agriculture for food and crop drying, for industrial drying process, dryers can be proved to be most useful device from energy conservation point of view. It not only save energy but also save lot of time, occupying less area, improves quality of the product, makes the process more efficient and protects environment also. Solar dryers circumvent some of the major disadvantages of classical drying. Solar drying can be used for the entire drying process or for supplementing artificial drying systems, thus reducing the total amount of fuel energy required. There are several advantages of controlled drying of grains such as product quality, storage capability and hygiene improvement, reduced wastage, time and space improved transportability. To dry materials a supply of heat energy is essential to evaporate the water and supply of air to carry away the water vapor produced. For control drying of food we use fuels like electricity, natural gas or coal etc. Due to scarcity of fossil fuels and many environmental problems associated with these uses energy engineers are searching of alternating sources of energy. Solar energy is best solution or appropriate alternative sources of energy. Solar energy is clean, safe and abruptly available. An improved technology in utilizing solar energy is the use of 'solar dryers, where the air heated in a flat plate solar collector and then heated air is pass through drying chamber.

1.2 Sun Drying

Sun drying is the earliest method of drying farm produce ever known to man and it involves simply laying the agricultural products in the sun on mats, roofs or drying floors. This has several disadvantage since the farm produce are laid in the open sky and there is greater risk of spoilage due to adverse climatic situation like wind, rain, moist and dust, loss of product to insects, birds and rodents; totally dependent on good weather and very slow drying rate with danger of mould growth thereby causing deterioration and decomposition of the product. The process also requires large area of land, takes time and highly labour intensive.

Drying by the sun under an open sky for preserving food and agricultural crops has been practiced since ancient times. Conversely, this process has many disadvantages, i.e., products get spoiled due to rain, wind, moisture, and dust; loss of produce due to birds and animals; deterioration in the harvested crops due to putrefaction, insect attacks, and fungi. Apart from this, this process is labor intensive and time consuming, and requires a large area for spreading the produce out to dry. Recently developed artificial mechanical drying is energy intensive. But eventually it increases the product cost. The modern trend of solar drying equipment offers an exceptional method that can process the vegetables and fruits in clean, disinfected, and hygienic conditions to national and international standards with zero energy costs. It uses optimum energy and time and occupies less area. It improves product quality. It makes the process more efficient and protects from the environment.

1.3 Background to the Drying Concept

The idea of using solar energy to produce high temperature dates back to ancient times. The solar radiation has been used by man since the beginning of time for heating his domicile, for agricultural purposes and for personal comfort. Reports abound in literature on the 18th century works of Archimedes on concentrating the sun's rays with flat mirrors; Modern research on the use of solar energy started during the 20th century. Developments include the invention of a solar boiler, small powered steam engines and solar battery, but it is difficult to market them in competition with engines running on inexpensive gasoline. During the mid 1970's shortages of oil and natural gas, increase in the cost of fossil fuels and the depletion of other resources stimulated efforts in the United States to develop solar energy into a practical power source.

1.4.1 Capturing Solar Energy

Solar radiation can be converted either into thermal energy (heat) or into electrical energy. This can be done by making use of thermal collectors for conversion into heat energy or photovoltaic collectors for conversion into electrical energy. Two main collectors are used to capture solar energy and convert it to thermal energy, these are flat plate collectors and concentrating collectors. In the course of this project, emphasis is laid much on the flat plate collectors which are also known as non-focusing collectors.

1.4.2 Importance of Solar Dried Food

For centuries, people of various nations have been preserving fruits, other crops, meat and fish by drying. Drying is also beneficial for hay, copra, tea and other income producing non-food crops. With solar energy being available everywhere, the availability of all these farm produce can be greatly increased. It is worth noting that until around the end of the 18th century when canning was developed, drying was virtually the only method of food preservation. (that the energy input for drying is less than what is needed to freeze or can, and the storage space is minimal compared with that needed for canning jars and freezer containers.

1.5 Mushroom Drying

Mushroom are important group of vegetables that are either cultivated or grow naturally in the forest. Edible mushroomis freely harvested in the forest and sold fresh, but these days' short shelf life. In order to preserve these for future use, fresh edible mushroom is usually dried on the ground in the open air. However, open air dried products contains sand and other contaminants which is not hygienic for human consumptions and making it un-attractive to the traders and consumers in both the rural and urban areas. Hence, there is need to develop edible mushroom preservation and dehydration techniques that would ensure proper drying and storage of the products so that it is safe and attractive to both consumers and traders. So, we use solar dryer to dry edible mushroom which is environtally free and free of cost.

1.6 Types of Solar Dryer

1.6.1 Direct Solar Dryer

In these dryers, the material to be dried is placed in a transparent enclosure of glass or transparent plastic. The sun heats the material to be dried, and heat also builds up within the enclosure due to the 'greenhouse effect.' The drier chamber is usually painted black to absorb the maximum amount of heat.

1.6.2 Indirect Solar Dryer

This method does not expose the crop directly to the sunlight. The solar radiation is absorbed and converted into heat by another surface (like a black top) usually called the collector. Air that will be used for drying is passed over this surface and gets heated, which is then used to dry the food item inside the dryer. The main advantage of indirect mode of drying is that the temperatures can be controlled.

1.6.3 Mixed-mode dryers

In these dryers, the combined action of the solar radiation incident on the material to be dried and the air preheated in solar collector provides the heat required for the drying operation.

1.6.4 Hybrid solar dryers

In these dryers, although the sun is used to dry products, other technologies are also used to cause air movement in the dryers. For example fans powered by solar PV can be used in these types of dryers.

1.7 Advantages and Disadvantages of Solar Drying System

1.7.1 Advantages

- Better Quality of Products are obtained
- It Reduces Losses and Better market price to the products.
- Products are protected against flies, rain and dust; product can be left in the dryer overnight during rain, since dryers are waterproof.
- Prevent fuel dependence and Reduces the environmental impact
- It is more efficient and cheap.

1.7.2 Disadvantages

- Quality of products are not obtained in some cases.
- Adequate solar radiation is required.
- It is more expensive
- 4)Require more time for drying.

1.8 Objectives

The main objectives of this paper is:

1) To Design and construct a mixed mode solar dryer system for mushroom preservation with the calculated consideration.
2) To Determine the Thermodynamic Analysis of a Mixed-Mode Solar Dryer for Mushroom preservation.
3) To evaluate the solar dryer's performance.

2. LITERATURE REVIEW

Some of the literature has been read regarding the present work are given below:

1. *Sansaniwal et al., (2017)* showed designed and developed an indirect solar dryer to investigate the drying kinetics of ginger in terms of convective heat transfer coefficients, moisture removing rates and collector efficiency under natural and forced convection drying modes. The convective heat transfer coefficients obtained under natural and forced convection drying modes were reported to vary from 0.59 to 5.42 W/m^2°C and 2.52 to 6.33 W/m2°C respectively. Further, the average collector efficiency under natural convection drying mode was calculated to be varied from 14.97 to 16.14%. However, it was obtained to be higher in forced convection drying mode and found to lie in between 27.90 to 33.92%, respectively. Therefore, the

forced convection drying method was recommended for the drying of products having high moisture contents and requires either immediate consumption or quick preservation. [1]

2. *Halewadimathet al., (2015)* studied designed of a solar air dryer with a collector area of $2m^2$ dries agricultural products from 89.6% to 13% moisture content under ambient conditions during harvesting period from February to April. Experiments was performed on solar air heater, the maximum temperature rise is 20°C and the solar intensity was found to be in the range of 402-509 w/m^2. Maximum collector efficiency of 55.15% was obtained for forced convection. Drying time was less in forced convection than the natural convection. So forced convection is preferred than natural convection for drying of agricultural products. [3]

3. *Prakash et al., (2014)* studied concerned with performance analysis of solar drying system for Guntur red chili where Chili was dried to final moisture content of 9 % w.b from 80% w.b within 24 hrs.Their Experimentation period was conducted from 9:30 AM to 5:30 PM daily basis, the daily mean values of the drying chamber air temperature, drying Chamber and solar radiation ranged from 30 ^{0}C to 57 ^{0}C, and $180W/m^2$ to $950W/m^2$. The drying temperature and relative humidity under solar drying continuously varied with increasing drying time. The efficiency of the solar collector is 71.4%, drying system is 42.18%, at the solar radiation of 950 w/m^2 and a mass flow rate of 0.01 kg/sec. [4]

4. *Amedorme et al., (2013)* studied designed and Construction of an indirect forced convention solar crop dyer for the purpose of drying moringa samples using locally available materials. A batch of moringa leaves 2 kg by mass, having an initial moisture content of 80% wet basis from which 1.556 kg of water is required to be removed to have it dried to a desired moisture content of 10% wet basis, is used as the drying load in designing the dryer. A drying time of 24-30 hrs was assumed for the anticipated test location (Kumasi; 6.7^{o}N, 1.6^{o}W) with an expected average solar irradiance of 320 W/m^2 and ambient conditions of 25^{o}C and 77% relative humidity. A minimum of 0.62 m^2 of solar collection area, according to the design, is required for an expected drying efficiency of 25%. They recommended that a test under full loading conditions should be carried out in order to know if all the design parameters have been met and laboratory experiment should also be done to know the effects on the nutritional values of the moringa leaves when sun dried and solar dried. [5]

5. *Research by Om Prakash & Anil Kumar (2013) showed*an comprehensive review of the various designs, details of construction, and operational principles of the wide variety of practical designs of solar energy drying systems has been described. Two major groups of solar dryers can be identified, viz., passive or natural-circulation solar dryers and active or forced convection solar dryers. Some easy-to-construct and user-friendly dryers that can be suitably employed at small-scale factories or at rural farming villages has been presented. These low-cost food drying technologies can be readily used in rural areas to reduce spoilage and improve product quality thus resulting in overall processing hygiene. Scientifically designed active solar dryers are generally found to be more effective and more controllable than the natural-circulation types. In most of the active solar dryers, the fan is driven by the solar photovoltaic cell. It makes the active dryer totally independent from the dependency over fossil fuel/electricity. Therefore, solar photovoltaic-thermal (PV/T) dryer is agreed to be suitable for remote rural village farm application in most developing countries. [6]

Summary from the above literature review :

From the above literature review, an idea of an mixed mode solar dryer has been considered for the future work for this project. The data was collected, assumed and calculated from the above literature review and calculation has been done based on this literature review. Also, further design and analysing are done based on the above paper studies.

3. MATERIALS AND METHODS

3.1 Materials

The following materials were used for the construction of the mixed mode solar dryer:

1. Wood– Wood were selected for entire casing fabrication, because it is light in weight, easily available and cheaper in cost then other material and also corrosion free.

2. Glass – we choose the toughened glass of 4mm for upper covering of the solar dryer chamber and solar collector chamber, because it easily allows the rays to go inside and heat the plane sheet and it resist the heat to go outside.
3. Absorber Plate – GI-Sheets of 1mm was used as absorber plate in the center of the solar collector and painted black color for maximum solar absorption.
4. Drying Trays and wooden skewers – Net and wooden skewers was used for constructing the trays for placing the product in the drying chamber.
5. Accessories required – Cutter, nails, glue and fevicol glue as fasteners and adhesives were required for the construction.
6. Plywood were required for the Insulation purpose in the design.
7. Hinges and handle for the dryer's door.
8. Black Paint.
9. Toughened transparent Glass.
10. Exhaust fan to remove the moisture.

3.2 Design Consideration

1. **Temperature -** The minimum temperature for drying mushroom is 35°C and the maximum temperature is 65°C, therefore, 50°C and above is considered average and normal for drying of mushrooms.The design was made for the optimum temperature for the dryer to dry mushroom T_0 of 65°C and the air inlet temperature or the ambient temperature of dryer was taken as T_a = 35°C (approximately outdoor temperature)
i.e, $T_a = T_i$ = 35°C.

2. **Efficiency -** This is defined as the ratio of the useful output of a product to the input of the product.

3. **Air gap -** It is suggested that for hot climate passive mixed mode solar dryers, a gap of 5 cm should be created with the view of allowing more air flow into the dryer and decreasing it temperature in order to remove the free water molecules which is important at the initial stage of drying.

4. **Glass and flat plate solar collector** – we will use Solar Collector Glazing Materials. Collectors glazing is exposed to high temperatures, long time outdoor exposure, impacts from hail and/or vandals, while also requiring high light transmission and reasonable cost. It suggested that the glass covering should be 4-5mm thickness. In this work, 4mm thick toughened transparent glass was used.

5. **Design of Drying Chamber**– It is recommended that a constant exchange of air and a roomy drying chamber should be attained in solar food dryer design, thus the design of the drying chamber was made as spacious as possible of average dimension of 0.4 × 0.5 × 0.45 m with air passage (air vent) out of the cabinet of 0.5 × 0.05 m^2.

6. **Design of Solar Collector** – The design of the solar collector was made as spacious as possible of average dimension of 1 × 0.5 × 0.10 m. The solar collector and drying chamber are painted black because black color is a good absorber of heat and it is poor radiator of heat, so it absorbs the solar energy falling on the solar collector and coverts it to heat energy required for drying of mushroom in the drying chamber.

7. **Insulation** –The insulating material was selected to be plywood of 1.5 cm, as it is a good insulator as well as environmentally friendly. It also does not have any carcinogenic effects and also corrosion free than other popular insulating materials like polystyrene sheets and mineral wool have.
8. **Absorber plate** – GI Sheets were used as absorber plate placed inside the solar collector and painted black color for better solar absorption. The dimensions of the absorber plate will be (1 × 0.5 × 0.001) m.

9. **Conventional Net-trays and wooden skewers**– Net type tray were selected as the dryer screen or trays to aid air circulation within the drying chamber. Three trays were placed to keep mushroom for drying purpose. The tray dimension is height of 1cm and length of 40 cm. The gap between each tray is 15 cm.

10. **Moisture Outlet**– An exhaust fan was used to remove the extra moisture from the solar dryer chamber.

3.3 Design Specifications

Sl No.	Materials	Specifications
1	Solar Collector :	(1 x 0.5 x 0.10) m
2	Solar Drying Chamber:	(0.4 x 0.5 x 0.45) m
3	Area of Collector	0.547 m^2
4	Absorber plate material	GI Sheet
5	Absorber plate dimensions	(1 x 0.5 x 0.001) m
6	Glass cover Thickness	0.004 m
7	Insulating materials	Plywood
8	Insulating thickness	1.5 cm
9	Air height gap	0.05m
10	Air vent area	(0.5 x 0.05) m^2
11	Number of trays	3 trays
12	Trays and wooden skewers dimensions	40 x 1 cm
13	Distance between each trays	15 cm
14	Tilt angle of the collector	36.14^o
15	Dried Items	Fresh Mushroom
16	Mass of the food items	2-3 kg of fresh mushroom

Table- 3.3.1 Design specification of the overall mixed-mode solar dryer

3.4 Components to construct the Mixed-Mode Solar Dryer and Approximate Cost Estimation

Sl no.	Component	Specifications	Materials	Quantity	Price
1	Solar Collector Frame & walls	(1 x 0.5 x 0.10) m	Iron & Wood	03	Rs. 1500
2	Solar Drying Chamber Frame	(0.4 x 0.5 x 0.45) m	Iron & Wood	04	Rs. 1400
3	Absorber plate material	GI Sheet	GI Sheet	01	Rs. 380
4	Transparent Glass	0.004 m	Solar toughened glass	02	Rs. 650
5	Insulating materials	1.5 cm	Plywood	01	Rs. 250
6	Drying Net	(0.4 x 0.5) m	plastic net	03	Rs. 200
7	Exhaust fan	12V exhaust fan	Exhaust fan	01	Rs. 600
8	Electric wire	5 m long	Copper wire	01	Rs. 50
9	putting	2 kg	Putting	01	Rs. 150
10	Black Paint & Brown Paint	1 tin	Black & Brown Paint	01	Rs. 640
11	Nails, Pins, Door hook & Aluminium foil	2 packet	Nails and Pin	01	Rs. 300
12	Glue & Adhesives	1 piece	Fevicol & Cello tape	01	Rs. 250
				TOTAL	Rs. 6,370 /-

Table- 3.4.1 Components of the mixed mode solar dryer and the Cost estimation

3.5 FORMULAS AND CALCULATIONS

1. Angle of tilt (β) of solar collector:

Angle of tilt (β) of solar collectors is given by [2]
$\beta = 10^o + \text{lat } \Phi$ --(1.1)
Where, lat Φ = latitude of the place that the solar drier was designed, which is Assam Science and Technology University Campus, Guwahati, Assam. Here, latitude of our place is 26.1445° N.
Hence, the suitable value of β use for the collector is given as,
$\beta = 10^0 + 26.1445^o = 36.14^o$ facing due to South direction.

2. Insolation on the Collector Surface Area.

We have collect the data from SAM software and we found,
Global horizontal,G = 4.72 kwh/m²/day
Direct normal beam radiation, I_b = 3.57 kwh/m²/day
Diffuse horizontal radiation, I_d = 2.28 kwh/m²/day
Solar Irradiance is given as, [Data Handbook]
$E_{solar} = U_{e.m.f} / S$ W/m² -- (2.1)
Where, $U_{e.m.f}$is the Output voltage reading from multi-meter in μv.
S is the Sensitivity and is given on the instrument data handbook = 72.5 μv/Wm^{-2}.
E_{solar} is the Irradiance in W/m².
Now, we have taken the reading from pyranometer and multimeter in required place, we get
$U_{e.m.f}$ = 0.042 V
= 0.042 × 10⁶μv
S = 72.5 μv/wm^{-2}
Substitute these values in above equation 2.1, we get
E_{solar} = 0.042× 10⁶ / 72.5
= 580 W/m²
Also we can witten as, H = 580 W/m²
Therefore, Insolation o n the Collector Surface Area is given as [2]
$I_C = H \times R$ --- (2.2)
Where, R is the average effective ratio of solar energy on tilted surface to that on the horizontal surface which is given as [12],
$R = (1\text{-}D/G)\, r_b + D/G[(1+\cos\beta)/2] + [\rho(1\text{-}\cos\beta)]/2$
Where, $r_b = \cos\theta / \cos\theta_z = 1.375$
R = (1-2.28/4.72)1.375 + 2.28/4.72(0.90) + [0.2(1-0.807)]/2; ρ is the ground reflectance,usually taken to be 0.2 when there is no snow. [12],
R = (1-0.483) 1.375 + 0.4347 + 0.0193
R = 1.164
Substitute the value of R in the above equation (2.2), we get
$I_C = H \times R$
$I_C = 580 \times 1.164$
I_C = 675.12 W/m²
Hence, Insolation on the Collector Surface Area is 675.12 W/m²

3. Determination of Collector Area and Dimension.

The average air wind speed V_a = 0.2 m/s (data collected from SAM Software).
Also, the air gap height (h) was taken as 5cm = 0.05 m and width (w) of the solar collector was taken as 50cm = 0.5m.
Thus, volumetric flow rate of air is given as [2]
$V'_a = V_a \times h \times w$ --(3.1)
Therefore, $V'_a = 0.2 \times 0.05 \times 0.5 = 5 \times 10^{-3} m^3/s$
Thus, mass flow rate of the air is given as, $M_a = V'_a \rho_a$ ---(3.2)
Density of air (ρ_a) is taken as 1.225 kg/m³
Therefore, $M_a = 5 \times 10^{-3} \times 1.225 = 6.125 \times 10^{-3}$kg/s

Now, area of the collector A_C is given as [3], $A_c= Q_U / Ic\eta_C$ --(3.3)
where, $Q_U = m_a c_p \Delta T$ --- (3.4)
Here, m_a is the mass flow rate of the air,
c_p is the specific heat capacity of the air at stp = 1005 J/kg°C
ΔT is the temperature difference i.e $\Delta T = (T_o - T_a)$°C ---(3.5)
= (65 - 35) °C
= 30 °C
Now, the efficiency of the solar collector is given as,
$\eta_C = m_a c_p \Delta T / A_c I_c$ --(3.6)
where, η_C is the efficiency of the solar collector
m_a is the mass flow rate of the air
c_p is the specific heat capacity of working fluid
ΔT is the temperature difference
A_c is the area of the Collector Assembly
I_c is the overall solar insolation at the collector plate.
Substitute the values in the above equation 3.6, we get
$\eta_C = (6.125 \times 10^{-3} \times 1005 \times 30) / (0.547 \times 675.12)$
$\eta_C = 0.50004$
hence, the efficiency of the solar collector is 50 % .
Therefore, $A_c = m_a c_p \Delta T / Ic\,\eta_C$ ---(3.7)
Substitute the values in above equation we get,
$A_C = (6.125 \times 10^{-3} \times 1005 \times 30)/(675.12\times 0.50)$
$= 0.547\ m^2$
Now, the length of the solar collector (L) was taken as;
$L = A_c$ / width(w)---(3.8)
= 0.547 / 0.5
= 1.04 m
Thus, the length of the solar collector was taken approximately as 1m.

4. Calculation of Heat Losses from the Solar Collector (Air Heater).

The total energy tranmitted and absorbed by the solar collector is given as [2],
$I_C A_C \tau \alpha = Q_U + Q_L + Q_S$---(4.1)
Where, Q_S is the energy stored which is considered as negligible [2]i.e $Q_S = 0$,
Therefore, $I_C A_C \tau \alpha = Q_U + Q_L$ ---(4.2)
Where, τ is the transmitivity of the tranparent glass [2] (assumed as $\tau = 0.86$)
α is the absorbivity of the glass [2] (assumed as $\alpha = 0.9$)
Here, $Q_U = m_a c_p \Delta T = 6.125 \times 10^{-3} \times 1005 \times 30 = 184.66$ W ---------------------------------------(4.3)
And $Q_L= U_L A_C \Delta T$ --(4.4)
Substitute all the values in the above equation no. (4.2), we get
$675.12\times 0.547 \times 0.86 \times 0.9 = 184.66 + Q_L$
$285.84 = 184.66 + Q_L$
$Q_L = 285.84 - 184.66$
$Q_L = 101.18$ W
Now substitute the values of Q_L and others values in the above equation no. (4.4), we get
$101.18 = U_L\times 0.547 \times 30$
$101.18 = U_L\times 16.41$
$U_L = 101.18 / 16.41$
$U_L = 6.164\ W/m^2\,°C$

5. Calculation of the Heat Removal Factor.

Heat removal factor is given as [2],
$F_R = Q_U / A_C [I_C \tau \alpha - U_L(T_0 - T_a)]$ ---(5.1)
Now substitute the above values in the above equation no. (5.1), we get
$F_R = 184.66 / 0.547 [(657.12 \times 0.86 \times 0.9) - 6.164 \times 30]$

$F_R = 184.66 / 177.08$
$F_R = 1.04$
Hence, Heat removal factor is 1.04

6. Determination of base insulator thickness for the solar collector.

To find the base insulator thickness we use the below equation [2],
$F_R\, m_a\, C_p\, (T_o - T_a) = K\, A_C\, (T_o - T_a) / t_b$ --(6.1)
Where, K = Thermal conductivity of the insulation material used in W/mK.

(a) Using *polystyrene sheets* as insulating material (K = 0.037 W/mK)

Now, substitute the values of F_R, m_a, C_P ,ΔT , K , and A_C in the equation no. (6.1), we get,
$1.04 \times 6.125 \times 10^{-3} \times 1005 \times 30 = (0.037 \times 0.547 \times 30) / t_b$
$192.06 = 0.607 / t_b$
$t_b = 3.164 \times 10^{-3}$ m
$t_b = 0.316$ cm

(b) Using *mineral wool* as insulating material (K = 0.045 W/mK)

Again substitute the values of F_R, m_a, C_P ,ΔT , K , and A_C in the equation no. (6.1)
$1.04 \times 6.125 \times 10^{-3} \times 1005 \times 30 = (0.045 \times 0.547 \times 30) / t_b$
$192.06 = 0.738 / t_b$
$t_b = 3.84 \times 10^{-3}$ m
$t_b = 0.384$ cm

(c) Using *plywood* as insulating material (K = 0.13 W/mK)

Again substitute the values of F_R, m_a, C_P ,ΔT , K , and A_C in the equation no. (6.1)
$1.04 \times 6.125 \times 10^{-3} \times 1005 \times 30 = (0.13 \times 0.547 \times 30) / t_b$
$192.06 = 2.133 / t_b$
$t_b = 0.015$ m
$t_b = 1.5$ cm

Therefore, by comparing from the above three insulator thickness we can conclude that 1.5 cm of plywood will be more suitable for the solar collector and solar dryer chamber because plywood has low thermal conductivity compared to polystyrene sheets and mineral wool. Therefore, we know that the material of low thermal conductivity has better insulation and it does not allow transferring heat to the surrounding. Hence, we used plywood for better insulation purpose in our solar dryer model.

3.6 WORKING PRINCIPLE

The main principle of this solar dryer is based on the greenhouse effect. Here the solar heat is trapped inside the drying chamber and thus increases the temperature level.

It is a mixed mode solar cabinet dryer. Here both the direct and indirect solar energy collected in the chamber heats up the food products as shown in the below images.

Direct solar energy collected in the chamber converted into the heat energy which heats up the food products i.e. mushroom and thus removes the moisture from the food product.

Indirect heat energy collected in the solar collector heats up the fresh air entering from atmosphere through air inlet and is passed through the bottom of the drying chamber and it collects the moisture from the food products and exhausted through air outlet.

3.7 IMAGES OF MY FABRICATED MIXED MODE SOLAR DRYER DESIGN

Figure 1: Front view of the solar dryer.

Figure 2: Side view of the solar dryer.

Figure 3: Top View of the solar dryer chamber

Figure 4: Trays inside the solar dryer chamber

Figure 5: Back view of the solar dryer

Figure 6: During the fabrication in workshop

Figure 7: During the fabrication in workshop

Figure 8: During Painting in workshop

Figure 9: Painting black inside the dryer

Figure 10: Wooden skewers for drying

These are some of the images of my fabricated mixed-mode solar dryer by my own design considerations calculation.

3.8 CONCLUSION

A solar dryer is designed and constructed based on preliminary investigations of drying under controlled conditions). The constructed dryer is to be used to dry mushroom and to preserve it under controlled and protected conditions. The designed dryer with a collector area of 0.547 m^2 is expected to dry 2-3 kg of mushroom. A prototype of the dryer with 0.547 m^2 solar collector area was constructed to be used in experimental drying tests. Hence the practical usage of dryer is greatly increased by employing the water heating system along with dryer. This was demonstrated and the solar dryer designed and constructed expressed sufficient ability to dry mushroom to an appreciably reduced moisture level. This dryer was made by easily available materials which we will get in our market easily. This will go a long way in reducing food wastage and at the same time food shortages, since it can be used extensively for majority of the agricultural food crops. A drying time of 24-30 hours is assumed for the anticipated test location (Guwahati, latitude= 26.145^{o}N) with an expected average solar irradiance of 675.12 W/m^{2}and ambient conditions of 35^{o}C and optimum temperature for drying mushroom is 65^{o}C and a minimum of 0.547 m^{2}of solar collector area. The dryer will be constructed using locally available materials and also go a long way in reducing food wastage and at the same time food shortages, since it can be used extensively for majority of the agricultural food crops.

REFERENCES:

1. Sansaniwal, "Investigation of indirect solar drying of ginger rhizomes (zingiber officinale): a comparative study", journal of engineering science and technology vol.12, (7), 2017.
2. Halewadimath, "Experimental analysis of solar air dryer for agricultural products."India International Research Journal of Engineering and Technology (IRJET), Vol.2 (3) 2015.
3. Prakash, "Performance analysis of Solar Drying System for Guntur Chili". International Journal of Latest Trends in Engineering and Technology. Vol.4 (2), 2014.
4. Amedorme, "Design and construction of forced convection indirect solar dryer for drying moringa leaves", Scholars journal of engineering and technology, vol. 1 (3) pp 91-97, 2013.
5. Om Prakash and Anil Kumar "Historical Review and Recent Trends in Solar Drying Systems", International Journal of Green Energy, vol.(10), pp 690–738, 2013.
6. Vidyasagar "Design and Fabrication of Efficient Solar Dryer", Int. Journal of Engineering Research and Applications, Vol.3 (6), pp 1445-1458, 2013.
7. Mohanraj & Chandrasekhar, "Performance of a forced convection solar drier integrated with gravel as heat storage material for chili drying", journal of engineering science and technology,vol.4 (3), 2009.
8. Madlopa "Dehydrating edible mushrooms using a locally made solar dryer", Malawi journal of agricultural sciences, vol.2 (1), 2003.
9. Abdullahi and momoh, "design and construction of an adjustable and collapsible natural convection solar food dryer**",** International Journal of Computational Engineering Research. Vol. 3 (6), 2013.
10. Sodha, "Solar crop drying", Vol. I and II, 1987
11. Islam Ashraful, "Estimation of Solar Radiation on Horizontal and Tilted Surface over Bangladesh", Computational Water, Energy, and Environmental Engineering, vol.5, pp.54-69, 2016.
12. Ali youcef," Determination of the average coefficient of internal moisture transfer during the drying of a thin bed of potato slices", Journal of food engineering, vol. 48 (2) pp 95-101, 2011.
13. Brooker, "Drying and storage of grains and oil seeds". Avi, Van Nostrand Reinhold, USA, 1992.
14. SP Sukhatme, "Solar Energy-principles of thermal collection and storage" third edition.
15. John A. Duffie, " Solar engineering of thermal processes", fourth edition.
16. Ezekoye, " Development and performance evaluation of modified integrated passive Solar Grain Dryer", The pacific journal of science and technology, vol.7(2), pp.185, 2006.