Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

Design, Manufacturing and Performance Evaluation of Modified Solar Bubble Dryer for Pepper-Vegetable Crop

A Thesis

Submitted to the School of Graduate Studies
Addis Ababa University in Partial Fulfillment of the
Requirements for the Degree of Masters of
Science in Mechanical Engineering
(Thermal and Energy Conversion Chair)

By: Mengistu Zelalem Zewdu

Supervisor: Kamil Dino Adem (PhD)

October 2021

Addis Ababa, Ethiopia

Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

School of Graduates Students

Design, Manufacturing and Performance evaluation of

Solar Bubble Dryer for Pepper Vegetable Crop

This is to certify that the thesis presented by Mengistu Zelalem Zewdu, titled as "Design, Manufacturing and Performance Evaluation of Solar Bubble Dryer for Pepper Vegetable Crop" and submitted to the School of Mechanical and Industrial Engineering in the partial fulfillment of the requirements for the award of the degree of masters of science in Thermal Engineering with the regulations of the university, and meet accepted standards with respect to originality and quality.

Approved by Board of Examiners

Kamil Dino Adem (PhD)	_____	_____
Advisor	Signature	Date
Abdulkadir Aman Hassen (PhD)	_____	_____
Thermal Engineering chair	Signature	Date
Abdulkadir Aman Hassen (PhD)	_____	_____
Internal Examiner	Signature	Date
Muaz Bedru Hussen (PhD)	_____	_____
External Examiner	Signature	Date
Yilma Taddese (PhD)	_____	_____
Dean of SMiE	Signature	Date
Ermias Tesfaye (PhD)	_____	_____
Director of Post Graduate Program	Signature	Date

Declaration

I hereby confidently declare that the work which is being presented this MSc thesis entitled as “Design, Manufacturing and Performance Evaluation of Solar Bubble Dryer for Pepper-Vegetable Crop” is the original work of my own, has not been presented for a degree of any university and all the resource of materials used for this thesis have been duly acknowledged.

.

Mengistu Zelalem _____ _____

Name Signature Date

This thesis has been submitted for examination with the approval of a university advisor.

Kamil Dino Adem (PhD) _____ _____

Advisor Signature Date

Acknowledgment

First and foremost I would like to thank God for everything he has done for me and for the courage and strength he gave me to be at this level of higher education. I feel a proud pleasure and privilege to express my deepest and heartfelt thanks with respect to my Mom the Blessed Virgin Mary for keeping all circumstances in favor to me for completing this thesis successfully.

I express my sincere gratitude for my advisors Dr. Kamil Dino Adem (Addis Ababa university institute of technology) for his continuous assistance, guidance, suggestions, critical comments and encouragement to overcome all the challenges during this thesis. This thesis would not have come to completion without his unreserved support and follow up and instructions from the very begging throughout the progress of the thesis work.

My special thanks also goes to all members of Addis Ababa University, AAiT, SMiE staffs and members of SMiE, electrical and Chemical workshops staffs who helped me a lot. Especially Mr. Antenhe Tadiwos, Mr. Masresha Wondimu, Mr. Sema Baye, Mr. Yohannes Mengistu, Mr. Selomon Zegeye, Mr. Kassaye Negash, Miss. Belaynesh G/medehen, Mr. HinsaSelassie Seifu, and Mr. Feysel Abdela were really kind and helpful. Without their comments, support and suggestion, would have been difficult to complete this research.

Last but not least, I would like to express my thankfulness, respect and appreciation to my family and friends for their support and encouragement.

.

Abstract

Capsicum (Red pepper) is a spice type plant having major role in Ethiopians daily dish and plays an important role in the national economy. On average 79% of pepper production goes to market and this results employment for urban and rural workers. For anyone who produces fruit or vegetables on a commercial basis, one of the most serious challenges is getting their products to market and selling before it spoils. The objective of this study was to design and manufacture modified solar bubble dryer to minimize and overcome the post-harvest loss of pepper vegetable crop.

The experimental result showed that the efficiency of the dryer and the mass flow rate was found to be 22.6%, 3.53 x10^{-4} kg /s. In addition to this the modified solar bubble dryer is portable, easy to operate and can also be used to dry any kind of vegetable. It reduces the moisture content of the pepper from about 71% to its safe storage condition of 13% in 20 hours of operation. This result was achieved within five days of experiment for four hours per day at a drying rate of 0.1 kg /hr.

It was observed that, the modified solar bubble drier performance was 10% greater than other similar drier, and the drying time is 20% lower than that of open sun dryer. It was also observed that a uniform temperatures distribution was noticed through the drier and the temperature inside the drying chamber was greater than that of ambient temperature by an average of 3 to 5°C. Therefore, it is recommended that the modular feature of the solar bubble dryer is an option to dry vegetables to reduce the alarming rate of postharvest losses in the country.

Keywords: Solar bubble dryer, Pepper vegetable crop, performance evaluation

Table of Contents

Declaration.....i

Acknowledgment.....ii

Abstract.....iii

Table of Contents.....iv

List of Table.....vii

List of Figure.....viii

Chapter One Introduction.....1

1.1. Background.....1

1.2. Statement of the problem.....5

1.3. Research objectives.....6

1.3.1. General objective.....6

1.3.2. Specific objective.....6

1.4. Delimitation.....7

1.5. Organization of the Thesis.....7

Chapter Two Literature Review.....8

2.1. Renewable Energy Resources.....8

2.1.1. Solar Energy.....8

2.1.2. Solar radiation.....8

2.2. Mode of heat transfer.....9

2.2.1. Conduction.....9

2.2.2. Convection.....10

2.2.3. Radiation.....10

2.3. Solar Drying Principle.....10

2.4. Classification of the solar drying system.....12

2.4.1. Open Sun or Natural Drying (OSD).....13

2.5. Controlled solar drying.....14

2.5.1. Direct type solar dryers (DSD).....15

2.5.2. Indirect type solar dryer (ITSD).....16

2.5.3. Mixed mode type solar dryer.....16

2.5.4. Hybrid Solar Drying (HSD).....17

2.6. Further Classifications.....18

2.6.1. Natural Circulation Type (Passive Mode).....18

2.6.2. Forced circulation type (Active mode) 18
2.6.3. Greenhouse solar dryer 19
2.6.4. Solar Tunnel Dryer 20
2.7. Factors Affecting Drying Performance 25
2.7.1. Effect of Air Temperature 26
2.7.2. Effect of Relative Humidity of the Air 26
2.7.3 Effect of Air Velocity 27
2.7.4. Duration or Time Spent in Dryer 28
2.7.5. Size or Thickness of the Drying Product 28
2.7.6. Drying Air Distribution 29
2.7.7. The nature of the drying product 29
2.7.8. Type of Dryer used 31
2.8. Gaps Identified in the Review 36
Chapter Three Materials and Methods 38
3.1. Materials 38
3.1.1 The Solar Collector: 38
3.1.2 Absorber: 38
3.1.3 Tray: 38
3.1.4 Support: 38
3.1.5 Dryer: 38
3.1.6. Linear Low Density Polyethylene (LLDPE) plastic 39
3.1.7. Solar panel 39
3.1.8. Air blowers/ Fan 39
3.2. Methods 40
3.3. Working principle of solar bubble dryer 41
Chapter Four Design of Solar Bubble Dryer 42
4.1. Design of Solar Bubble Dryer 42
4.2 Design Procedure for the Solar Dryers 44
4.3 Drying Chamber Design 45
4.4 Sizing of the fan power 48
4.5 Sizing of the PV modules 48
4.6 Design of Chimney 49
4.7 Performance Evaluation of the Crop Dryers 50

4.8 Design Calculations result....52
Chapter Five Construction and Experimental setup....56
5.1 Construction of the dryer....56
5.2. Dryer Setup and Test Location of solar bubble dryer. 58
5.3. Lab VIEW program design 58
5.3.1 Design of serial communication program 59
5.4. Lab view system configuration 59
5.4.1. System Components....59
5.4.2 Instruments Used for Data Collection....60
5.5. Sensor positioning of the dryer 62
Chapter Six Result and Discussion....64
6.1 No load test....65
6.1.1 Relative humidity, temperature and solar radiation variation....65
6.1.2 Temperature and relative humidity....65
6.2 Load test 67
6.2.1 Temperature distribution....67
6.2.2 The drying temperature, relative humidity and solar radiation....68
6.2.3. Moisture distribution....68
6.2.4 Moisture removal rate of SBD....70
6.2.5 Drying performance....71
Chapter Seven Conclusion and Recommendations 74
7.1 Conclusion 74
7.2 Recommendations....74
Reference 75

List of Table

Table 2.1: Moisture Contents of Solar Drying of Various Agricultural Produces (A. Fudholi et al., 2010; Getahun et al., 2020; Prakash et al., 2013; J. Singh, 2015) 27
Table 2.2: Mareko Fana fruit characteristics (Delelegn, 2011; Kahsay, 2018; Tesheshigo et al., 2019) 31
Table 2.3: Summary of literature 37
Table 7 Instrument used for data collection 61
Table 5.8: Weighing Balance and Velocity and Temperature Measuring Device 62
Table 5.9: desiccator and plastic bag used for saving the sample of pepper for overnight 62

List of Figure

Figure 2.1: Effects of clouds on the Earth's Energy Budget (Campillo et al., 2014).....9
Figure 2.2: Conduction through a solid or a stationary fluid (Rohsenow et al., 1998).....9
Figure 2.3: Convection from a surface to a moving fluid (Aliyu et al.; Netzsch, 2014; Rohsenow et al., 1998).....10
Figure 2.4: Net radiation heat exchange between two surfaces (Aliyu et al.; Netzsch, 2014; Rohsenow et al., 1998) 10
Figure 2.5 Heat and mass transfer process on a food surface (J. Singh, 2015) 12
Figure 2.6: Classification of solar drying system (Lingayata et al., 2020).....13
Figure 2.7: Working principle of open sun drying (Visavale, 2014).....14
Figure 2.8: Direct Type Solar Dryer Layout and Its Operation Principle (Boh, 2013) ...15
Figure 2.9: Schematic view of the indirect type solar dryer (ITSD) (Lingayata et al., 2020) 16
Figure 2.10: Sectional view of the mixed-mode solar dryer (A. Fudholi et al., 2010).....17
Figure 2.11: Hybrid solar drying of combined solar and biomass burner (Hii et al., 2012; Okoroigwe et al., 2013) 17
Figure 2.12: Natural Convection Solar Dryer (Tomar et al., 2017).....18
Figure 2.13: Forced convection type indirect solar dryer (Prakash et al., 2013).....19
Figure 2.14**:** Solar energy flow process of greenhouse dryer (Kumar et al., 2006).....20
Figure 2.15: Schematic of Solar Tunnel Dryer (Thakre et al., 2016b) 21
Figure 2.16: Schematic diagram of Solar Bubble Dryer (SBD) (Hung et al., 2020).....22
Figure 2.17 Times required reaching equal moisture contents at two drying temperatures (Getahun et al., 2020).....26
Figure 2.18 Effects of air velocity on the drying of peppers at 50ºC (Mercer, 2014) 28
Figure 2.19 Effects of thickness on the drying of pepper.....29
Figure 3.1. Methods for implementing modified solar bubble dryer.....40
Figure 34 Final moisture content of pepper vegetable crop on both SBD and OSD.....71

List of Symbols

M_w −Weight of wet material
M_d − Weight of dry material
$MC(d.b)\%$ − Moisture content in dry base
I - total radiation incident on the absorbers surface$(\mathrm{W/m^2})$

$\mathrm{A_C}$ - Collector area $(\mathrm{m^2})$

$\mathrm{L_v}$- Latent heat of vaporization of water (kJ/kg).

$\mathrm{M_r}$ − Mass of water evaporated from the pepper vegetable crop (kg)

$\mathrm{M_p}$ − Pepper vegetable weight (kg)

$\mathrm{M_i}$ −Initial moisture content (%)

$\mathrm{M_f}$ −Final moisture content %

$\mathrm{T_d}$ − Temperature of outgoing air from the drying chamber (k)

$\mathrm{T_a}$ − Ambient air temperature (k)

$\mathrm{T_c}$ −Temperature of air at the collector outlet (k)

P_a −Partial pressure of dry air in the atmosphere, $(\mathrm{N/m^2})$

$\mathrm{C_p}$ −Specific heat capacity of air, (kJ/kg K)

R − The gas constant = 0.287(kpa $\mathrm{m^3/kgk}$)

$\mathrm{I_T}$ − Total solar radiation incident on the collector, $(\mathrm{N/m^2})$

$\mathrm{T_o}$ − Temperature of outgoing air from the collector, (k)

$\dot{\mathrm{m}}_\mathrm{a}$ − Mass flow rate of air, (kg/s)

a, b, c, n - empirical constants in the drying models

$k, k_{0,} k_{1,}$ −Empirical constants in the drying models

n - Number constants

N- Number of observations

MR- moisture ratio

M_e −Equilibrium moisture content, (% dry basis)

M_o −Initial moisture content, (% dry basis)

M_t −Moisture content (% dry basis)

t_d − Drying time, (s)

Chapter One
Introduction

1.1. Background

Capsicum (Red pepper) is a spice type plant, native to tropical America, which belongs to the family of solanceae that includes tomato, potato and tobacco (Esayas et al., 2011). Knowledge about Capsicum was available from initial stages of civilization and been incorporated since 7500 BC in the human diet. The crop is also produced in all the continents except Antarctica and originated from Latin America, to Africa in general. Although, its history in Ethiopia may be the most ancient than any other vegetable products, the specific time of its introduction cannot be established. Production of pepper is well known in Ethiopia Moreover, it has been cultivated for long time which resulted having a strong attachment to dark red pepper and the fine-powdered pungent product is an indispensable flavoring and coloring ingredient in the common traditional sauce "stew or Wot (Gebrtsadkan et al., 2018). Red pepper/Chilli pepper, in Ethiopia usually referred to as "pepper". The most commonly grown type is the Marekofana variety of dark red appearance (Committee, 2010). Furthermore, in many Ethiopian households, pepper provides the only needed flavor to enhance the intake of otherwise bland diets. The range of food products that contain pepper or its chemical constituent is broad, and it includes ethnic foods, meat, salad dressings, mayonnaise, dairy products, and candies, packed foods, slack foods, salsa, and hot sauces as well as it is used for cosmetic production, condiment and medicine, and ornamentals in the garden (Gobie, 2019).

Agriculture is the backbone of Ethiopia's economy and it provides all the necessary dietary foods, raw materials for food industries and quality products for export market. The country's agricultural potential for food production is known to be huge and over 90 percent of its export earnings come from this sector. Coffee, oil seeds, spices, fresh fruit and vegetables contribute the largest portion of the export earnings (Admassu, 2015). Among the agricultural vegetable crops red pepper is the world's second important vegetable ranking after tomatoes and it is the most produced type of spice flavoring and color to food while providing essential vitamins and minerals. The nutritional value of red pepper quality needs special attention. It is a rich source of vitamin C which helps to

prevent flu colds than any other vegetable crop as well as vitamin A and E. In addition to this its color and flavor is useful as the raw material for different industries (Gobie, 2019). The antioxidant vitamins have a very important function to protect the human body against oxidative damage and to prevent various diseases such as cancer and cardiovascular viruses (Mansour-Gueddes et al., 2010). It's an important crop, not only because of its economic importance, but also due to the nutritional and medicinal value. The fruit of pepper is an excellent source of natural colors and antioxidant compounds whose intake is an important health protecting factor by prevention of widespread human diseases (Hunde, 2020) and this result a general belief among Ethiopians that a person who frequently consumes hot pepper has resistance to various diseases due to that it is in the daily diet of most Ethiopians. The average daily consumption of red pepper by Ethiopian adult is estimated 15g, which is higher than tomatoes and most other vegetables (Gebrtsadkan et al., 2018).

Ethiopia also cultivates pepper but its share in the world is insignificant compared to other nation like India and china. Pepper is widely cultivated in different regions of Ethiopia. The Ethiopian Export Promotion Agency (EEPA, 2003) has carried out a Spice Potential Market Study in Amhara, Oromiya and SNNPRS, and identified that the land coverage for pepper in the three regions accounts for 34% of the total spices production of the country. In addition to having major role in Ethiopians daily dish, it also plays an important role in the national economy as on average 79% of pepper production is for market and generates employment to urban and rural workers (Esayas et al., 2011). It is a crop of high value in both domestic and export markets. Oleoresin (coloring) and capsaicin (Getahun et al.) are extracted from red pepper for export purpose. The deep red colored and large podded cultivars (sweet/hot) have a very high processing demand in our country (Mussema, 2006).

To anyone who produces fruit or vegetables on a commercial basis, one of the most serious challenges is getting their produce to market and selling it before it spoils. It is an unfortunate fact of life that as soon as fruits or vegetables reach the proper stage of maturity, they begin to deteriorate. One of the technique to overcome post harvesting loss is that a proper drying system. Drying is defined as a process of moisture removal due to simultaneous heat and mass transfer. It is a classical method of food preservation, which

provides longer shelf-life, weight loss for transportation and small space for storage (Sebaii et al., 2012).

Farmers growing horticultural crops are facing high economic loss, because they have no alternative options and appropriate methods to increasing the shelf life of produced crops. The handling, processing and preservation of crop products at and after harvesting may be designated as "Post-harvest Management". Improved post-harvest management depends on the quality, quantity and efficiency of handling, processing and preservation techniques are important. Draying is one of the important posts harvesting management process of agricultural products which is the oldest way to preserve and keep them for long time (Admassu, 2015). It can extend shelf life of the harvested products, improve quality and the bargaining position of the farmer to maintain relatively constant price. This products reduces post- harvest losses and lower transportation costs since most of the water are taken out or removed from the product during the drying process. Post-harvest loss is a “measurable quantitative and qualitative loss of a product at any moment during the postharvest chain and includes change in the availability, edibility, wholesomeness or quality of the food that prevents its consumption (Kereth et al., 2013). Post-harvest loss of fruits and vegetables estimated to be 30-40% in developing countries (Bateno et al., 2018) and particularly about 20 – 30% of bell and hot pepper are lost at post-harvest stage every year (Olayemi et al., 2010). This losses can be quantitative as measured by decreased weight or volume, or can be qualitative, such as reduced nutrient value and unwanted changes to taste, color, texture, or cosmetic features of the product. The quantitative loss is caused by the reduction in weight due to factors such as spillage, consumption by pest and also due to physical changes in temperature, moisture content and chemical changes as well (Gangwar et al., 2014).

Among all renewable energy sources, such as air, wind, and water, solar energy has the least impact on the environment. Therefore, in many tropical and subtropical areas in the world, open sun drying is still used. However, despite the fact that it is inexpensive, the final quality of the dried products is not up to international standard. Open sun drying also has other disadvantages. First, it is labor intensive. Second, the products being dried can be spoiled because of rain, wind, moisture, and dust. Third, the quantity of the product may be reduced when birds, animals, or insects used the products being dried. Fourth, this process fully depends on excellent weather conditions (Mustayen et al., 2014).

Traditionally, red pepper or chili is dried directly under the sun. Direct sun drying requires an area with a large, open space and long drying times. It is highly dependent on the availability of sunshine and is predisposed to contamination with foreign materials insects, and fungal infestations, which reduce the quality of the product. Red pepper is harvested when it is fully red and starts to dry. After harvesting, pepper is recommended to be dried in a Shade drying for high quality oleoresin (Mussema, 2006). The initial and final moisture content of the pepper vegetable crop is 71% and 13% wet basis respectively (J. Singh, 2015). According to local producers, sun dehydration of pepper requires about seven consecutive days in winter, and the fruits suffer undesirable fermentation, with consequent reduction in the sales value (Darvishi et al., 2014).

However, the direct sun drying results in low-quality products. As an alternative to open sun drying, solar drying is one of the most attractive and promising applications of solar energy systems. It uses renewable and environment-friendly technology and is economically viable in most developing countries. Much recent research has reported on solar drying of agricultural fruits and vegetables (Ahmad Fudholi et al., 2013b).

Among this a tunnel type called the Inflatable Solar Dryer (ISD) or Solar Bubble Dryer (SBD) is one of an innovative, solar drying technology used to dry agricultural products developed at the University of Hohenheim UHOH, IRRI, and GrainPro Inc. After tunnel drying tested in Philippines in 1989 by the University of Hohenheim (UHOH) as it is stated, the performance depends on solar radiation, the relative humidity of the ambient air, and moisture content of the agricultural materials (Udomkun et al., 2020b). It is mobile, easy to set up and to operate as well as completely independent of using fuel or the power grid. A report of IRRI in 2016 showed that the ISD takes less time than conventional sun drying and improves the traditional sun-drying process and eliminates all losses due to spoilage, animals, birds, insects, the weather, and vehicles running over the grains (Grainpro, 2011).

Even though this drying has valuable advantage and substitute the traditional sun-drying process. It is not yet widely applicable and its efficiency is not yet raised beyond 12.2% in the rainy season (Alam et al., 2020). This stimulate and attract the researcher to modify the technology and further improve the efficiency of the technology first by reducing the width of the drying floor/ black canvas carpet to make sure that the peppers vegetable

crop laying on are equally exposed to solar radiation second by eliminating the mixing process which avoid the heat loss during the time of mixing and thirdly reducing the cost by using locally available materials which is suited for this technology as solar panel price is getting lower. The modified solar bubble dryer could be used for both small and large scale capacity. Producers may considering its advantage, portability, easy to set up to dry any vegetable crop in the field of the farm land in order to minimize post harvesting losses as well as transportation cost due to the moisture content of the vegetable crop.

1.2. Statement of the problem

The post-harvest loss of fruits and vegetables estimated to be 30-40% in developing countries Bateno et al. (2018) and particularly about 20 – 30% of bell and hot pepper are lost at post-harvest stage every year (Olayemi et al., 2010). These losses can be quantitatively measured by decreased weight or volume, or can be qualitative, such as reduced nutrient value and unwanted changes to taste, color and texture. The quantitative loss is caused by the reduction in weight due to factors such as spoilage, consumption by pest were as qualitative changes due to physical changes in temperature, moisture content as well chemical changes (Gangwar et al., 2014).

Inadequate method of preserving agricultural produce which is usually produced in larger quantities during harvest has remained one of the main problems of farmers. This loss are due to fungi attacks, insects, birds, rodent encroachment and unpredictable weather effects such as dust, rain, and the wind have remained some of the inherent limitations of the traditional open sun drying method widely being practiced by rural farmers (Eze et al., 2011). The open sun drying also results in physical and structural changes such as unnecessary shrinkage, case hardening and loss of volatiles and nutrient components (Rajkumar, 2007). Therefore, a control mode of drying which preserves the color, nutrient components and unnecessary shrinkage of the agro-produce is necessary. One of these control modes involves constructing a solar crop dryer. Different types of dryers were developed at different times. The problem of most of these dryers is the variation of the final moisture content of the dried product at different trays position due to the poor airflow distribution, especially in a typical solar bubble dryer. As the drying air goes throughout the drying floor, the drying rate and the hot moisture content become decreases. This is due to inadequate air circulation in the solar bubble dryer with respect

to the drying product. This result air temperature getting lower at the back than the front drying floor and also the drying air is relatively wet. Thus, modifying and improving the existing solar bubble dryer that can resolve this problem of non-uniform drying method for vegetable crop.

1.3. Research objectives

1.3.1. General objective

The main objective of the study is designing, manufacturing and testing of modified solar bubble dryer for drying of pepper vegetable crop using locally available materials in order to reduce the a post-harvesting loss.

1.3.2. Specific objective

The specific objective of the research includes:-

- To design modified solar bubble dryer for drying pepper vegetable crop.
- To manufacture the prototype of modified solar bubble dryer for pepper vegetable crop.
- To conduct the performance evaluation of modified solar bubble dryer
- Identify the suitable drying kinetics model of pepper vegetable crop.
- To evaluate the economic analysis of the solar bubble dryer.

1.4. Significance of the study

Modifying the existing solar drying will substitute the traditional way of drying system as well as enhancing the productivity in terms of both quality and quantity of the pepper vegetable crop. This is due to by overcoming the problems of traditional dryer such as dust, dirt, animals and microbes, birds, rodents, which may cause and lead to post-harvest loss. In addition to this adverse weather conditions like unexpected rain may damage the drying vegetable crop and lead to post-harvest losses. Traditional open sun drying needs labor for stirring the pepper vegetable crop and to prevent the crop from external factors like birds, insects and rain that must be done frequently in order to maintain the quality and quantity the vegetable crop (Chen, 2019). Thus, the significance of the study is to overcome all the above problems by designing, manufacturing and testing of a modified solar bubble dryer which ultimately reduce the drying time and enhance the drying quality and quantity of pepper vegetable crop.

1.4. Delimitation

The scope of this research work is limited to design, construction and performance evaluation of a modified solar bubble crop dryer. Performance evaluation covered determination of the amount of moisture loss, drying rate, collector efficiency and drying efficiency. In addition to this the modified solar bubble dryer is not active at night.

1.5. Organization of the Thesis

The first chapter describes the introduction of the research while chapter two is the literature review that describes about the type and classifications of solar dryers are briefly described. Then finally the pervious works on solar bubble dryer is listed. Chapter three is a material and method section. That describes and compares the materials used for the construction of the dryer. The other part also describes the methods used in this research. Chapter Four is about a design of solar bubble dryer. It contains the data gathering and analyzing part and it describes the main designing parameters. Beside that the 3D model of the dryer developed using solid work software is shown. Chapter Five is manufacturing and experimental set up of the solar bubble dryer. It describes the dimension of each material and procedures used for the construction of the dryer. Then show the ways and methods of assembling the dryer. Chapter Six is the result and discussion section. It describes the final achievement of the experiment. Chapter Seven is conclusion and recommendation section. This part describes the conclusion of the overall research and what are not specifically done on this paper. Finally it recommend for other researchers to do what is not done on this research.

Chapter Two

Literature Review

2.1. Renewable Energy Resources

Renewable resources are unlimited and natural resources that can be replenished in a short period of time. It is energy generated from natural resources such as sunlight, wind, rain, tides and geothermal heat which are renewable (naturally replenished). Among these resource solar power is one of the best renewable energy sources available. It is one of the cleanest sources of energy (Gorjian, 2018). Solar energy is the energy obtained from the sun and it is converted into thermal or electrical energy. Modern technology can utilize this energy for different uses, such as generating electricity, providing light, having a comfortable interior environment, and heating water for the use of domestic, commercial, or industrial areas (Balcioglu et al., 2017).

2.1.1. Solar Energy

The energy from the sun can be exploited directly in the form of heat or first converted into electrical energy and then applied for different to the energy obtained either thermal or photovoltaic. It is classified in to solar thermal and solar photovoltaic (Shakya, 2015). Solar thermal has numerous applications like water heating, drying vegetables and agricultural products, cooking etc. The solar PV is extensively used not only in the developing countries but also in highly developed countries since its application is virtually unlimited. The solar PV can be considered the only form of electricity that can be generated anytime and anywhere as long as sunshine is available. The earth receives more energy from the sun in just one hour than the world uses in a whole year. The annual total amount of solar energy incident on the surface of the earth is estimated to be about 795 x 1012 MWh, which is 8300 times greater than the global energy demand in 1991 (Shakya, 2015).

2.1.2. Solar radiation

It is the set of electromagnetic radiation emitted by the Sun. The Sun behaves almost like a black body which emits energy according to Planck's law at a temperature of 6000 K. The solar radiation ranges goes from infrared to ultraviolet. Not all the radiation reaches Earth's surface, because the ultraviolet wavelengths, that are the shorter wavelengths, are absorbed by gases in the atmosphere, primarily by ozone. The atmosphere acts as a filter

to the bands of solar spectrum, and at its different layers as solar radiation passes through it to the Earth's surface, so that only a fraction of it reaches the surface. The atmosphere absorbs part of the radiation reflects and scatters the rest some directly back to space, and some to the Earth, and then it is irradiated. All of this produces a thermal balance, resulting in radiant equilibrium cycle as shown in figure 2.1 (Campillo et al., 2014).

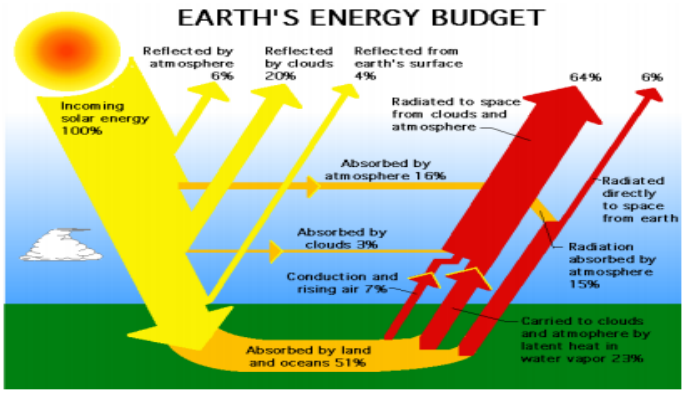


Figure 2.1: Effects of clouds on the Earth's Energy Budget (Campillo et al., 2014)

2.2. Mode of heat transfer

Heat transfer is the science that seeks to predict the energy transfer that may take place between material bodies as a result of a temperature difference. Thermodynamics states that this energy transfer is defined as heat, which is the energy that can be transferred from one system to another as a result of temperature difference. Heat can transfer between two mediums by conduction, convection and radiation where there is a temperature difference (Lienhard et al., 2001; Netzsch, 2014). However the transfer of heat is not simple as it is stated rather it is a quite complex phenomenon.

2.2.1. Conduction

It is the energy transfer across a system boundary due to a temperature difference by the mechanism of intermolecular interactions. Conduction needs matter and does not require any bulk motion of matter.

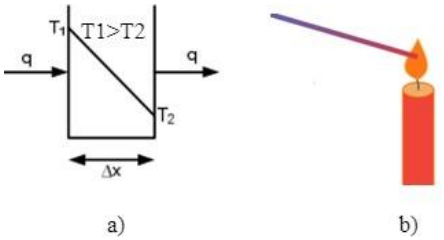


Figure 2.2: Conduction through a solid or a stationary fluid (Rohsenow et al., 1998)

2.2.2. Convection

It is the energy transfer across the system boundary due to a temperature difference by the combined mechanism of intermolecular interactions and bulk transport. It needs fluid matter in order to transfer the heat as it is shown in figure 2.3.

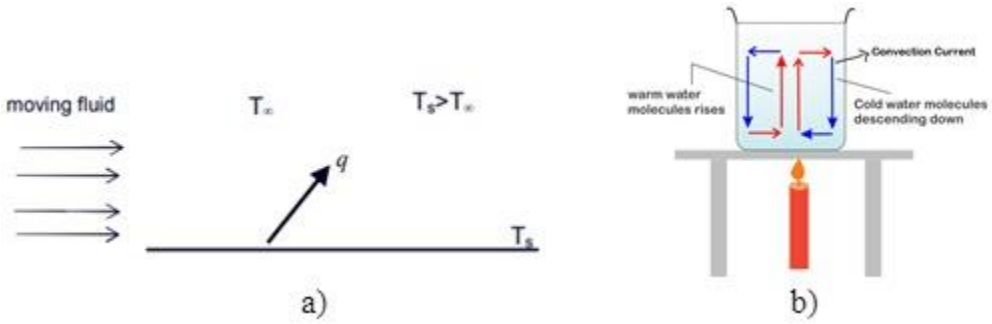


Figure 2.3: Convection from a surface to a moving fluid (Aliyu et al.; Netzsch, 2014; Rohsenow et al., 1998)

2.2.3. Radiation

Radiation heat transfer involves the transfer of heat by electromagnetic radiation that arises due to the temperature of the body. It does not need matter as it showed in figure 2.4.

Figure 2.4: Net radiation heat exchange between two surfaces (Aliyu et al.; Netzsch, 2014; Rohsenow et al., 1998)

2.3. Solar Drying Principle

Photovoltaic technology is a process of generating electrical energy from the energy of solar radiation Shakya (2015). The principle of conversion of solar energy into electrical energy is based on the effect called photovoltaic effect. The smallest part of the device that converts solar energy into electrical energy is called solar cell. Solar cells are in fact large area semiconductor diodes, which are made by combining silicon material with different impurities. The sand, a base material for semiconductor is the most abundantly

available raw material in the world. The ordinary sand (SiO_2) is the raw form of silicone. The solar energy can be considered as a bunch of light particles called photons. At incidence of photon stream onto solar cell the electrons are released and become free. The newly free electrons with higher energy level become source of electrical energy. Once these electrons pass through the load, they release the additional energy gained during collision and fall into their original atomic position to ready for next cycle of electricity generation. This process of releasing free electrons (generation) and then falling into original atomic position (recombination) is a continuous process as long as there is the stream of photons (solar energy) falling onto the solar cell surface (Shakya, 2015).

Solar drying has been used since time immemorial to dry plants, seeds, fruits, meat, fish, cloth, wood, and other agricultural, forest products. In order to benefit from the free and renewable energy source provided by the sun several attempts have been made in recent years to develop solar drying mainly for preserving agricultural and forest products. However, for large-scale production the limitations of open-air drying are well known. Among these are high labor costs, large area requirement, and lack of ability to control the drying process, possible degradation due to biochemical or microbiological reactions, insect infestation, and so on. The drying time required for a given commodity can be quite long and result more than 30% post-harvest losses. As it is stated by Jain and Tiwari (2003) solar drying of agricultural products in enclosed structures by forced convection is an attractive way of reducing post-harvest losses and better quality of dried products related to traditional open sun-drying methods. In many rural locations in most developing countries, grid-connected electricity and supplies of other non-renewable sources of energy are unavailable, unreliable or, too expensive. In such conditions, solar dryers appear increasingly to be attractive as a commercial propositions (Hii et al., 2012). The temperatures in a solar dryer are higher than in sun drying and this reduces the drying time and usually improves the final product quality. Crop losses and spoilage from rain and animals are prevented because the crop is protected within the solar dryer (Visavale, 2014).

Drying is a process of removing moisture through simultaneous heat and mass transfer and is a classical method of food preservation that provides longer shelf life, reduced weight and volume (Wakjira, 2010). The factors governing the rates of these processes determine the drying rate. The different 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, excluding of dielectric and microwave drying (Visavale, 2014).

When hot air is circulated over the moist product moisture will be removed from the product till the hot air is fully saturated i.e. means absolute humidity has been reached. But moisture removal is depends on the temperature. The higher the temperature the larger is the removal of moisture. If the air is warmed and the moisture contains in it remains the same, but the relative humidity falls so the air removes more moisture from the product. For getting economically better result, the drying rate must be high but without using excessive heat which tends to degrade the product. In the drying process heat is required to evaporate moisture from the product and flow of air is required to carry away the evaporated moisture (Chand et al., 2015).

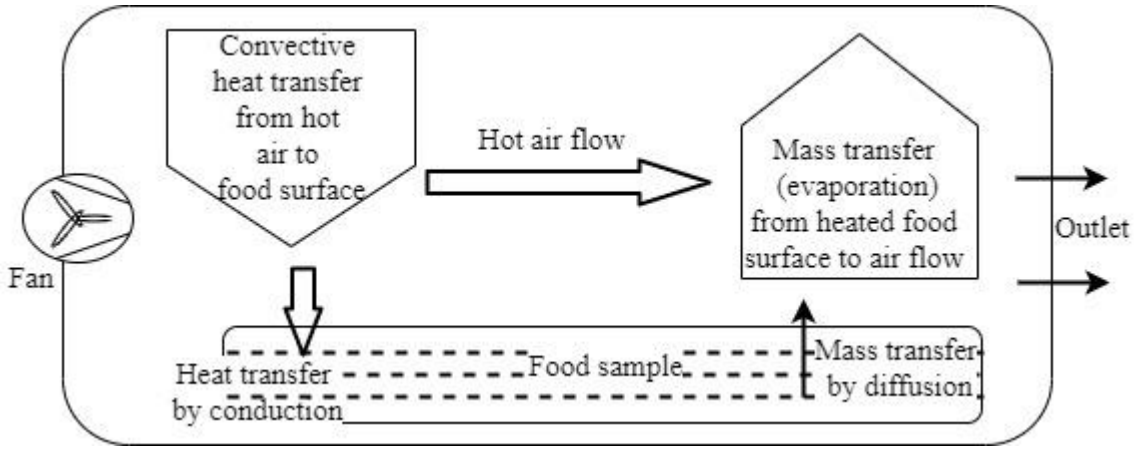


Figure 2.5 Heat and mass transfer process on a food surface (J. Singh, 2015)

2.4. Classification of the solar drying system

The main classification of solar drying system is shown in the figure below. According to the utilization of solar power, the drying system is classified into two groups; open sun drying (OSD) and controlled solar drying. These two groups are extensively discussed in figure 2.6.

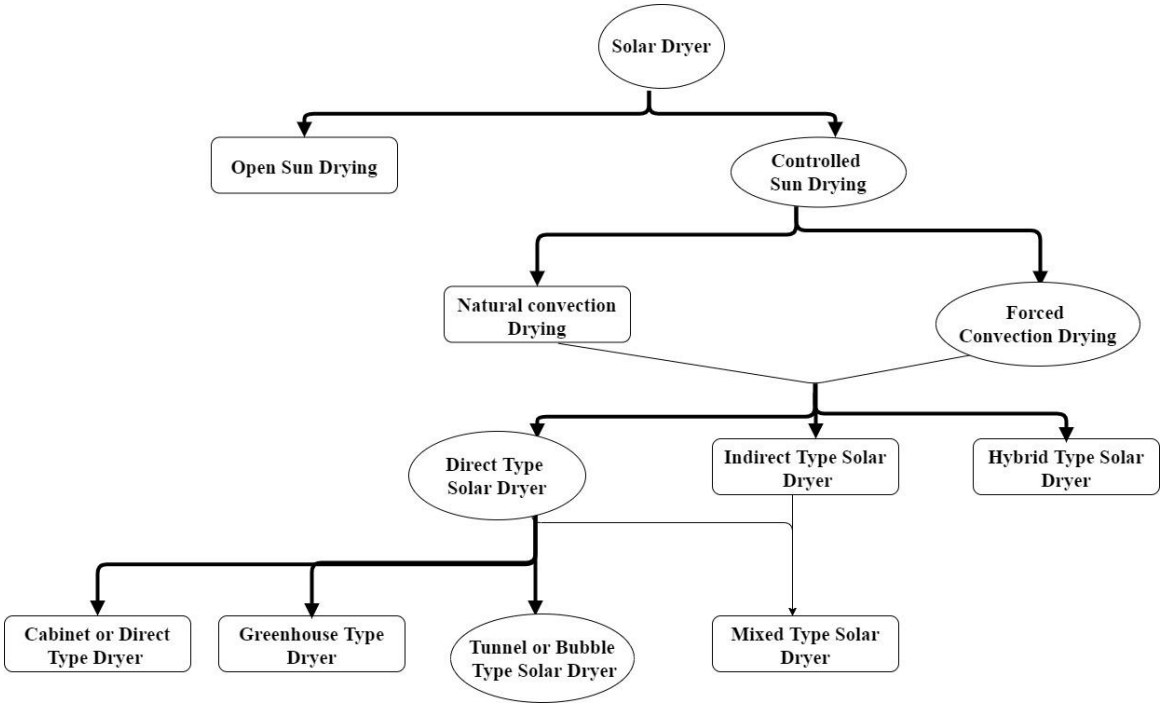


Figure 2.6: Classification of solar drying system (Lingayata et al., 2020)

2.4.1. Open Sun or Natural Drying (OSD)

Sun drying is the traditional method of drying in developing countries and it denotes the spreading of food stuff in the sun on a suitable surface such as mat, roof, or drying floors (Plate). Although it is the cheapest method even though the dry products are of poor quality due the exposure to contamination by insects, birds and dust. Moreover, the direct exposure to sunlight, or more precisely ultra-violet radiation, can greatly reduce the level of nutrients such as vitamins in the dried product. The resulting loss of food quality in the dried products may have negative effect on trade potential and economical worth of the product (Mongi, 2013).

There are some disadvantages and considerable losses while using open sun drying, such as dust, dirt, rodents, birds, insects and micro-organisms can fall or destroy the crop. Also there is a risk of unexpected rain or storm. Some of the characteristics for open sun drying are over drying result discoloring of crop, insufficient drying result mold. In general, international quality standards are not fulfilled by the final product when agricultural products are openly sun dried. This leads to rejection of the crop in the international market (Sahu et al., 2016).

As shown in the figure below the working principle of open sun drying by using only the solar energy. The crops are generally spread on the ground, mat, cement floor where they receive short wavelength solar energy during a major part of the day and also natural air circulation. A part of the energy is reflected back and the remaining is absorbed by the surface depending upon the color of the crops. The absorbed radiation is converted into thermal energy and the temperature of the material starts to increase. However there are losses like the long wavelength radiation loss from the surface of crop to ambient air through moist air and also convective heat loss due to the blowing wind through moist air over the crop surface. The process is independent of any other source of energy except sunlight and hence the cheapest method however has a number of limitations. In general, the open sun drying method does not fulfill the required quality standards and sometimes the products cannot be sold in the international market. There is no extra provision needed to dry the product and also it is the cheapest drying method and requirement of skilled labor is not necessary (Lingayata et al., 2020).

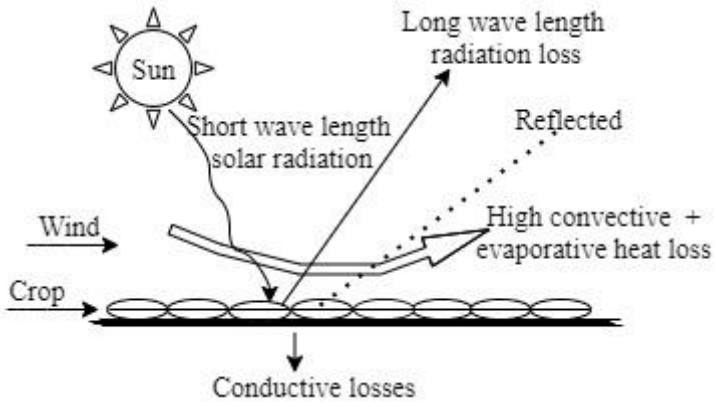


Figure 2.7: Working principle of open sun drying (Visavale, 2014)

2.5. Controlled solar drying

In open sun drying method, controlling of the drying parameters such as temperature, velocity, humidity etc. is difficult. With the awareness of inadequacies involved in open sun drying, a more scientific method of solar energy utilization for crop drying has emerged termed as solar drying. In controlled type of dryer, all this problems are resolved and a number of advantages such as good quality products and lower drying time as well as dust free products can be obtained. In the solar drying of agricultural goods, food quality depends on the working fluid temperature, humidity, velocity, etc. (Lingayata et al., 2020). It is possible to control these influencing parameters using various methods.

2.5.1. Direct type solar dryers (DSD)

In the direct type solar dryer, transparent glasses are used to transmit solar radiation directly to the food products. In these dryers, convective losses must be reduced and therefore, drying chamber temperature can be increased. Some direct solar dryers are; box type or solar cabinet dryer or glass roof solar dryer and greenhouse dryer (Lingayata et al., 2020).

The working principle of direct solar crop drying is shown in Figure below, also known as a solar cabinet dryer. Here the moisture is taken away by the air entering into the cabinet from below and escaping through at the top exit. In the cabinet dryer, of the total solar radiation imposing on the glass cover, a part is reflected back to atmosphere and the remaining is transmitted inside the cabinet. A part of the transmitted radiation is then reflected back from the crop surface and the rest is absorbed by the surface of the crop. That will causes the temperature to increase and there by emit long wavelength radiations which are not allowed to escape to atmosphere due to the glass cover. The overall phenomena cause the temperature above the crop inside the cabinet to be higher. The glass cover in the cabinet dryer thus serves in reducing direct convective losses to the ambient which plays an important role in increasing the crop and cabinet temperature as it showed in figure 2.8 (Visavale, 2014).

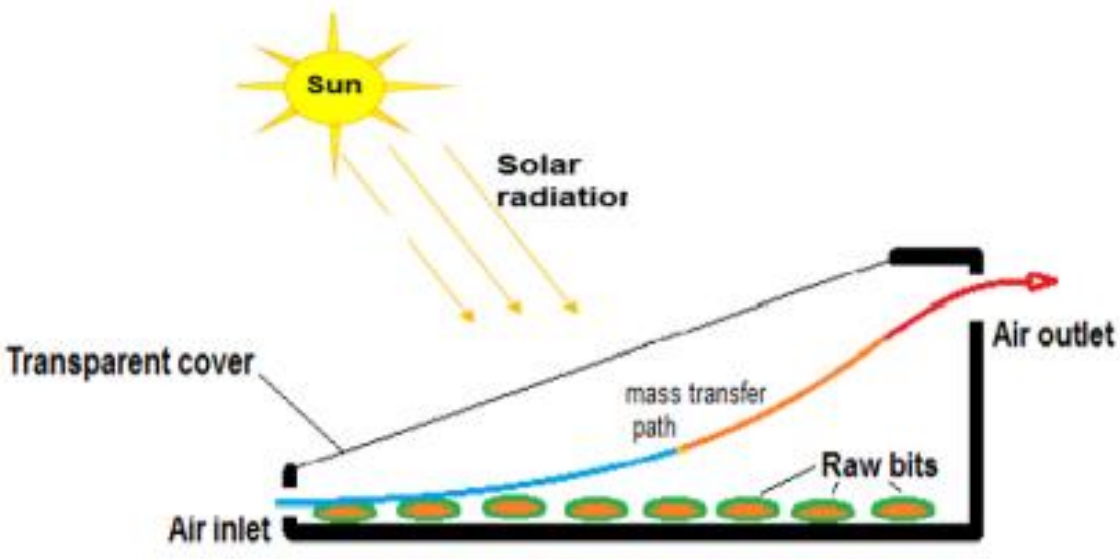


Figure 2.8: Direct Type Solar Dryer Layout and Its Operation Principle (Boh, 2013)

2.5.2. Indirect type solar dryer (ITSD)

Two methods of ITSD are noticed from the literature; it classified in to natural circulation type and forced circulation type (Kumarn et al., 2016; Lingayata et al., 2020). These differ from direct dryers with respect to heat transfer and vapor removal. The crops in these indirect solar dryers are located in trays or shelves inside an opaque drying cabinet and a separate unit termed as solar collector is used for heating of the entering air into the cabinet. The heated air is allowed to flow through/over the wet crop that provides the heat for moisture evaporation by convective heat transfer between the hot air and the wet crop. Drying takes place due to the difference in moisture concentration between the drying air and the air around the crop surface as it illustrated in figure 2.9 (Visavale, 2014).

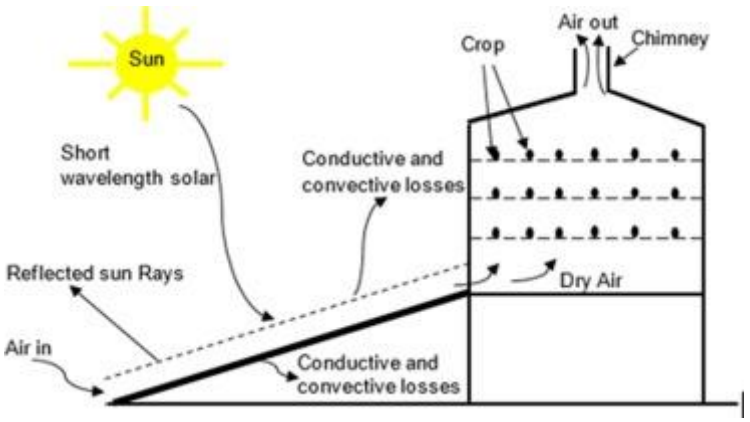


Figure 2.9: Schematic view of the indirect type solar dryer (ITSD) (Lingayata et al., 2020)

2.5.3. Mixed mode type solar dryer

It is a combined outcome of direct and indirect modes known as a mixed mode solar dryer (Subramanian et al., 2021). In this type of solar dryer the crop temperature is raised by both direct absorption of solar radiation and heat transferred from another solar absorber. While mixed mode solar dryers probably have superior performance to direct or indirect mode solar dryers, in practice the additional cost and complexity of these systems tend to make them uneconomical and less popular in practice than the other two modes of dryer (Fuller, 2010). It has the advantages of both direct type and indirect type dryer. Heat energy is absorbed by the product directly from the sun as well as indirectly from the solar air collector (Hii et al., 2012).

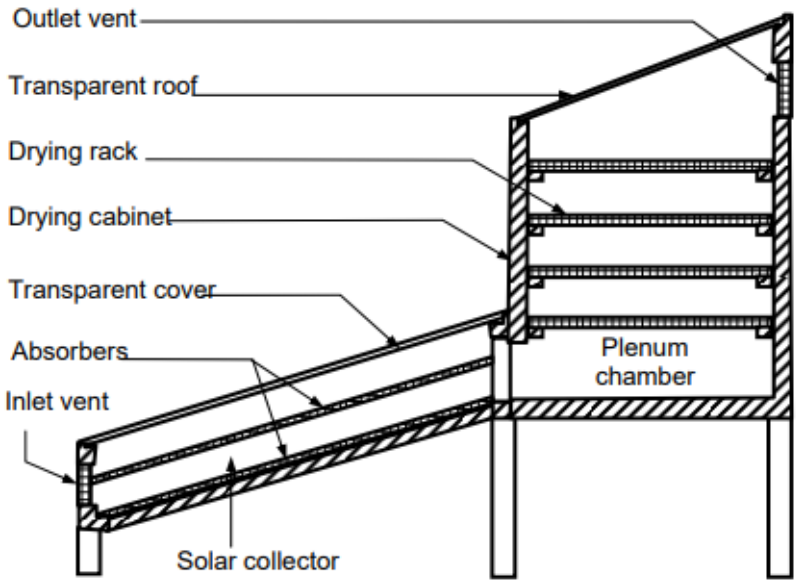


Figure 2.10: Sectional view of the mixed-mode solar dryer (A. Fudholi et al., 2010)

2.5.4. Hybrid Solar Drying (HSD)

The hybrid solar dryers combine the features of a solar energy with a conventional or some auxiliary source of energy and can be operated either in combination or in single mode with either source of energy. These dryers generally are medium to large installations operating in the range of 50-60%, and compensate the temperature fluctuations induced by the climatic uncertainties as it showed in figure 2.11 (Visavale, 2014).

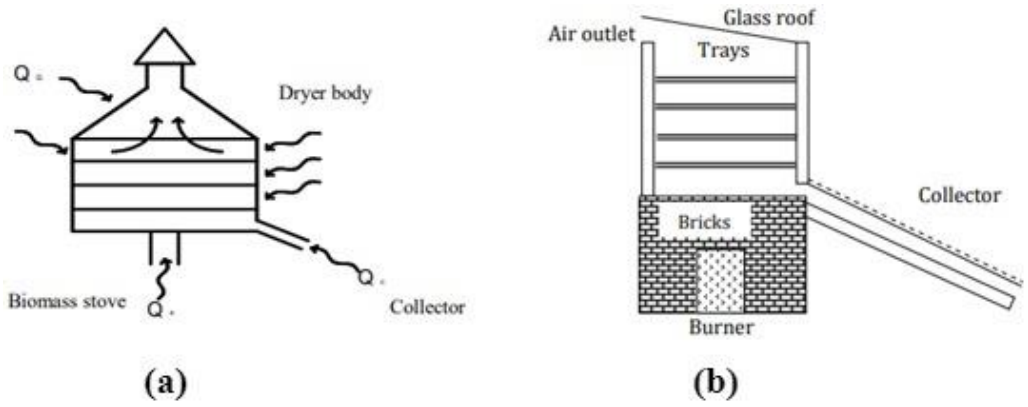


Figure 2.11: Hybrid solar drying of combined solar and biomass burner (Hii et al., 2012; Okoroigwe et al., 2013)

2.6. Further Classifications

All of the three principal solar dryer types (direct, indirect and mixed) can be further sub-divided depending on the method used to move air through the dryer, i.e., natural, convection and forced convection.

2.6.1. Natural Circulation Type (Passive Mode)

It is also recognized as passive solar dryer because of the natural circulation of air due to thermo-syphon effect. Food is heated because of hot air and then the moisture contained in the product is eliminated to outside air through the chimney which is placed at the top of the drying chamber by natural air circulation.

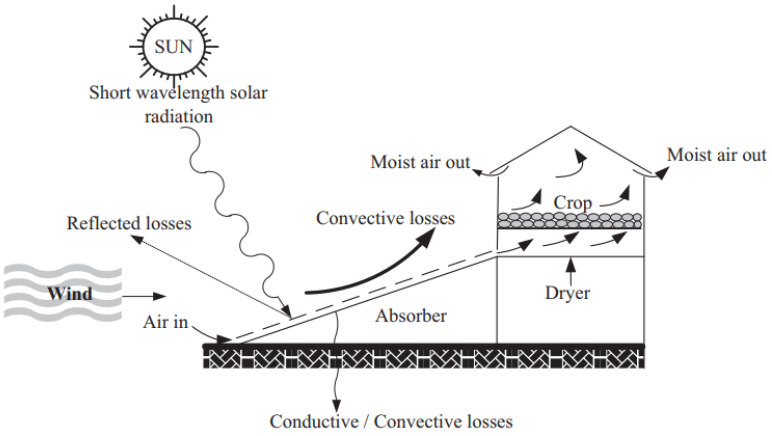


Figure 2.12: Natural Convection Solar Dryer (Tomar et al., 2017)

2.6.2. Forced circulation type (Active mode)

In a forced convection system, a fan is used to move air through the dryer. Higher air velocities - up to 3 m s-1 - through the crop usually improve drying rates especially in the constant rate drying period. The airflow rate can also be controlled and varied depending on the stage of drying. In addition, the quantity of the crop in the dryer can be increased because the fan can overcome any additional resistance to airflow. The disadvantages of a forced convection system are the increased capital and running costs as well as the requirement for electricity. In commercial solar drying systems however the advantages mentioned usually far outweigh the disadvantages and an electric fan is used if possible.

As it is illustrated in figure 2.13 the forced convection solar drying a small fan is attached to provide optimum air flow to enhance the drying rate much higher than those achieved by an indirect natural convection solar dryer. The fan can get the driving power either through electricity, solar, or fossil fuel. The PV operated system has the advantages that it can be operated independent of electric grid, biomass and fuel. It is main difference from natural circulation type is that the addition of a fan or blower. Some other types of solar dryers are: solar dryer with greenhouse collector and tunnel type dryer with integral collector (Lingayata et al., 2020).

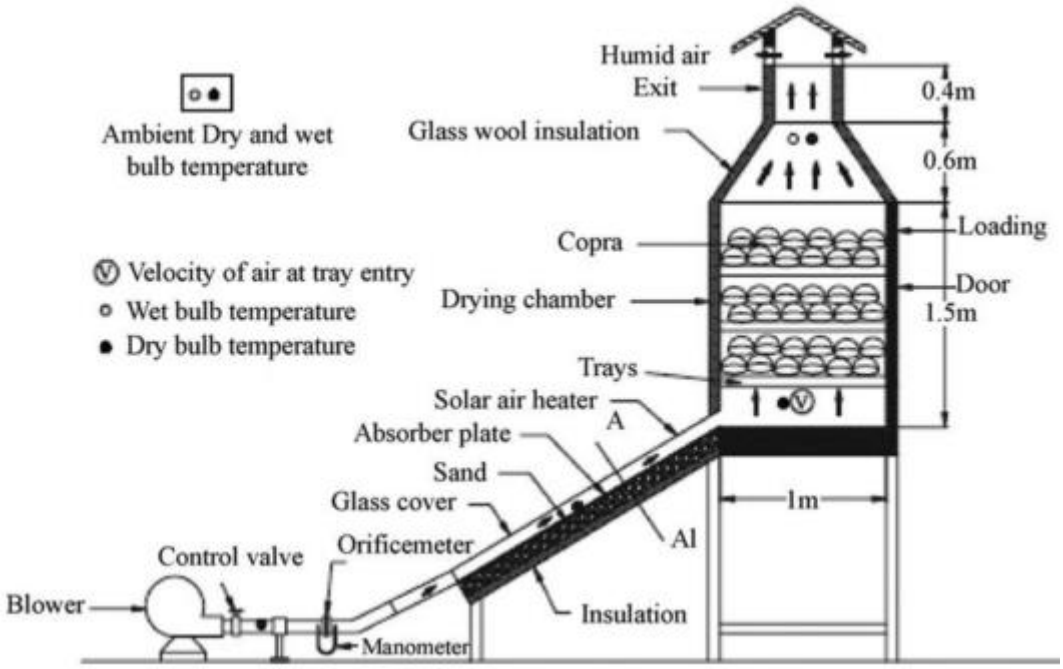


Figure 2.13: Forced convection type indirect solar dryer (Prakash et al., 2013)

2.6.3. Greenhouse solar dryer

Greenhouse solar dryer is basically an enclosed structure covered with stabilized UV resistant polythene sheets which perform and acts like both the a solar collector and drying chamber. Such dryers are used for drying of multiple agricultural products at low cost (Patil et al., 2016). A parabolic shape greenhouse with a black concrete floor is the essential parameters. The parabolic cross section helps to minimize the wind load in case of tropical rain storms. Galvanized iron bars are better for its structure. The roof is made with polycarbonate plates. The products are kept in a thin layer on two arrays of trays.

These arrays are placed on single level raised platforms with a passage in the middle for loading and unloading (Chand et al., 2015).

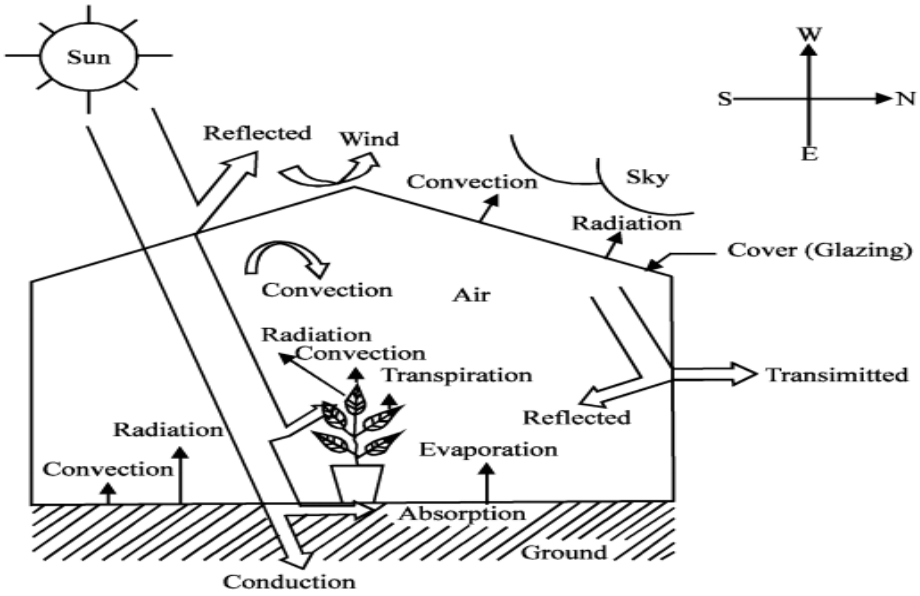


Figure 2.14**:** Solar energy flow process of greenhouse dryer (Kumar et al., 2006)

2.6.4. Solar Tunnel Dryer

It is developed in 1989 by the University of Hohenheim (UHOH) Germany for drying paddy rice and tested at the International Rice Research Institute and in the Philippines as it is reported by (Chand et al., 2015; Udomkun et al., 2020a). A solar tunnel dryer is a tunnel like framed structural covered with Ultra-violet (UV) stabilized polythene sheet, where widely used for drying various agricultural product and Industrial products could be dried under drying chamber or placed in the tunnel dryer (Thakre et al., 2016b). The solar tunnel drying system is simple in construction and consists of a collector as well as drying tunnel connected in series. Both collector and drying tunnel are covered with transparent glasses or plastic sheets (Patil et al., 2016). A flat plate air heating collector and a tunnel drying with a small fan are provide the optimum air flow over the product to be dried. The collector and the drying unit are covered with UV stabilized plastic sheet. This stabilized plastic sheet helps to facilitate the drying process and increase the efficiency of the dryer (Chand et al., 2015). It is proved that this solar dryer provided better quality and shorter drying period comparing to open sun drying (Prakash et al., 2013).

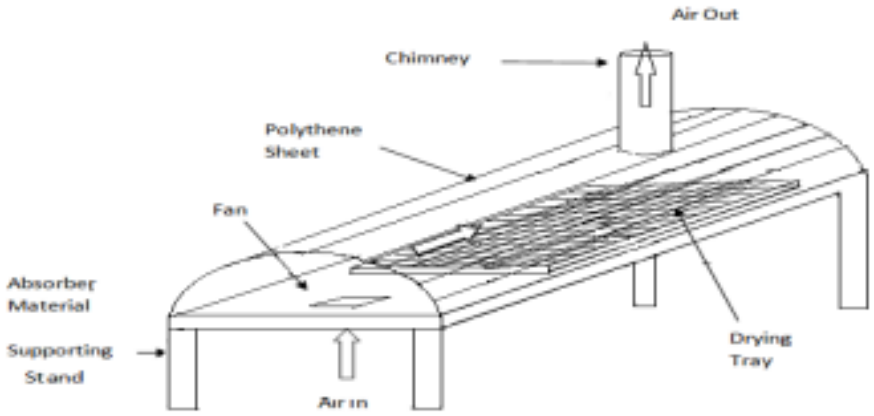


Figure 2.15: Schematic of Solar Tunnel Dryer (Thakre et al., 2016b)

The long and wide body of the area near to the air inlet is functioning as the solar collector and the remaining is the drying area. The UV-stabilized polythene translucent sheet is used as the covering wall along the dryer length. It is configured as a mixed mode solar dryer but fitted with axial fans at the inlet vent. The outlet is kept opened to let moist heated-air to escape. The food tray is placed in the drying area with a little rise. Typical operation temperature of the dryer has fallen between 30-80^{0}C with a volume flow rate of air four to twelve cubic meter per minute. The dryer operates by forcing the fresh air to pass through a long solar collector area before hitting the food tray across its top-side. Since the raw bits are spread in thin layer, a satisfactory result can be achieved easily. The dryer has proven work for many different food including meat, fish, crops and herbs. Since the power supply of the ventilation system for Hohenheim dryer is depending on the PV cells, the mass flow rate inside the dryer is closely proportionate to the heating capability that both are controlled by the amount of radiation reaching the dryer. This coincidence has contributed to the stability of thermal condition inside the dryer. Therefore, it offers better operating efficiency compared to other types of solar dryer under the same operating environment (Boh, 2013).

2.6.4.1 Solar Bubble Dryer (SBD)

The Inflatable Solar Dryer (ISD) or Solar Bubble Dryer (SBD), which is an innovative technology, was developed at the UHOH, IRRI, and GrainPro Inc. This dryer is a tunnel type (as shown in the figure below in which the performance depends on solar radiation, the relative humidity of the ambient air, and moisture content of the agricultural materials. The ISD is mobile and completely independent of fuel or the power grid. A

report of (IRRI, 2016) showed that the ISD takes less time than conventional sun drying and protects the commodities, especially seeds and grains, during drying. It can also be set up on concrete pavements, ground surfaces, and grassy areas to dry materials with a capacity of 0.5–1 ton, depending on the type of materials. As reported by Salvatierra-Rojas in 2017, when the ISD was applied to dry paddy rice, the targeted moisture content of 14% wet basis can be achieved within 26–52 h during the rainy season and between 4 and 26 h during the dry season which is a shorter time frame than for open-air sun drying and the schematic diagram shown in figure 2.16 (Udomkun et al., 2020b).

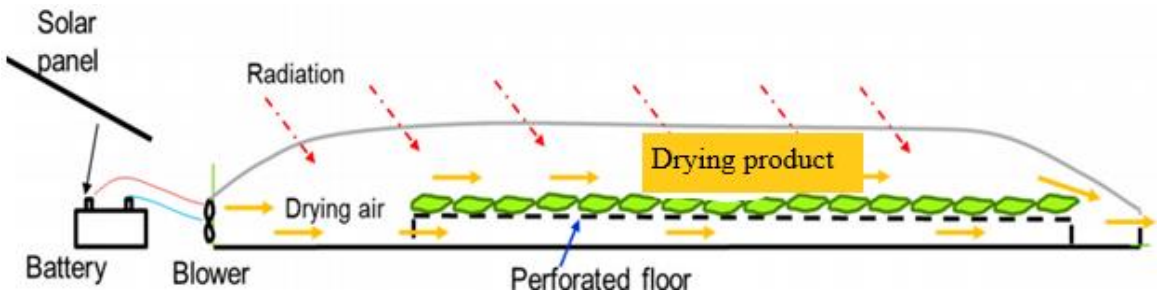


Figure 2.16: Schematic diagram of Solar Bubble Dryer (SBD) (Hung et al., 2020)

Salvatierra-Rojas et al. (2017) Developed an inflatable solar dryer (ISD or SBD) to improve the postharvest handling of paddy rice in humid climates. It was evaluated for paddy in the Philippines during both rainy and dry seasons and was subsequently optimized. Sun drying and shade drying were carried out in parallel for comparison and product was evaluated for moisture content and quality in terms of milling recovery and head rice yield. Moisture content was reduced from 23% to 14% within 26-52 h of continuous operation during the rainy season and 16% to 14% within 4-26 h of drying during the dry season.

Alam et al. (2020) Conducted experimental investigation of solar bubble dryer for rough rice drying in Bangladesh. The temperature was distributed uniformly throughout the dryer and was very much dependent on solar radiation. The hourly moisture removal rate was 0.6 and 0.4 % and the drying efficiency was found 25.2 and 12.3% during Boro and Aman season, respectively. In addition to this the operating cost of drying was observed to be Tk. 1.48 per kg which has corresponding rate of 0.55 birr in Ethiopian currency.

Mishra et al. (2020) Studied on the Performance evaluation of solar bubble dryer. The results showed that moisture content of paddy was reduced from about 16% to 12% in six hours of operation. However, the quality was almost similar in open sun drying methods and the initial cost of solar bubble dryer was high.

Seveda (2012) Design and developed a walk-in type natural convection solar tunnel dryer based on preliminary investigation of industrial product for drying di-basic calcium phosphate. Reduce the initial moisture content from 62.87% on dry basis to its desired moisture content 10.62% within two days. The performance of solar tunnel dryer for drying di-basic calcium phosphate was evaluated on both no-load and full-load conditions which tested in the summer and winter months. The temperature inside the solar tunnel dryer was higher than that of the ambient by 18–21°C. The drying rate for wet dibasic calcium phosphate varied with respect to solar insolation and the moisture reduced continuously with cumulative drying hours.

Thakre et al. (2016a) Designed and analyzed the performance of solar tunnel dryer using various absorber materials. It was used to dry chili as a drying product for evaluation. Experimental investigation has been carried out on three selected coating materials of black paint, graphite powder, and copper powder. It was observed that the use of copper powder as a coating material on the absorber resulted higher efficiency, which was higher than the other coating material as tested. The maximum efficiency of the collector was found to be 24.6 % and the percentage change in drying time was reduces by 46.64% while using copper powder as a coating material as compare to that of open Sun drying. In addition to this the percentage change in moisture removal rate was 64.24% as compared to the open sun drying.

Ahmad (2001) Proposed a simple solar air heater, which covered by cheap plastic film with air bubbles. It is used for various drying operations on a farm (grain, fruit, fish, etc.). The model used was a single-sheet cylindrical collector and, after it gained some heat, another layer of the plastic wrapping film with air bubbles was added at a later stage to decrease convection heat losses to the surroundings. Although the method used was simple, a considerable gain in the temperature of the airflow was obtained: a temperature difference of around 10°C was measured.

Chua et al. (2003) Reported on low-cost drying methods which able to be suitable for developing countries. Some of the important considerations based on low initial capital, easy-to-operate with no complicated electronic/mechanical protocol and effective in promoting better drying kinetics. The drying technologies that were selected include fluidized bed, spouted bed, infrared, solar, simple and low cost convective (SRR) and desiccant drying. A brief introduction on each drying technology has been presented followed by some technical details on their working operations. Examples of farming crops suitable for the employment of individual drying technology are provided to illustrate their potential application in agricultural product drying.

A. Fudholi et al. (2010) Proposed that drying for agricultural and marine products were one of the most attractive and cost-effective application of solar energy. Numerous types of solar dryers were designed and developed in various parts of the world, yielding varying degrees of technical performance. This paper was a review of these types of solar dryers with aspect to the product being dried, technical and economic aspects.

Gatea (2010) Designed and developed solar drying system for maize with V-groove collector of 2.04 m^2 area, drying chamber and blower. The thermal energy and heat losses from solar collector were calculated for each three tilt angles (30º, 45º, 60º). The results obtained during the test period denoted that the maximum gained energy occurred at 11 o'clock hour and then gradually declined since the maximum solar radiation occurred at this time. Other many important results are found. The theoretical thermal energy, the experimentally actual heats gain increase by increasing radiation intensity, the maximum values occurred at the 11 am and then gradually declined. The energy gained obtained at the angle tilt 45° is higher than the corresponding values obtained at 60°, 30° tilt angle.

Hodges et al. (2010) Reported that post-harvest loss varies from country to country as well as developed and developing country. It occurs at every stage in paddy production supply chain such as harvesting, threshing and cleaning, drying, storage, processing/milling, marketing and consumer level. The amount of post-harvest loss in traditional process is cutting and handling 1-5%, sun drying 3-5%, open storage 5-10%, village milling 20-30% whereas combine harvesting and machine threshing is 1-5%, mechanical drying 1-2%, sealed storage 1-2% and commercial milling 5-10%.

Vásquez et al. (2016) An advanced multivariable control system using fuzzy logic was implemented and applied to a solar dryer equipped with thermal energy storage system, with a capacity of 25 kg of agro-products. Two control systems were implemented: the first considering the ambient temperature and solar radiation as input variables, where the manipulated variables were the opening level of the solar panel and energy solar accumulator valves. The controlled variable in the second control system was the relative humidity content at the outlet of the drying chamber, and the manipulated variable was the opening of the air recirculation valve. The opening of the valves in both control systems was performed properly with variations of solar radiation, ambient temperature, and air moisture during the dehydration of mushrooms, plumbs, and peaches. Solar drying, together with a proper control system, reached 80% energy savings compared to open sun drying method.

Mohsin et al. (2011) Reported that natural convection solar drying has advantages over forced convection solar drying as it requires lower investment though it is difficult to control drying temperature and the drying rate may be limited. Due to low cost and simple operation and maintenance, natural convection solar drier appears to be the obvious option and popular choice for drying of agricultural products.

Erbay et al. (2010b) Designed a model of thin layer drying and the he theory of drying was given briefly and general modeling approaches for food drying were explained. Then, commonly used or newly developed thin layer drying equations were shown, and determination of the appropriate model was explained. Afterwards, effective moisture diffusivity and activation energy calculations were expressed. Finally, experimental studies conducted in the last 10 years were reviewed, tabulated, and discussed. It is expected that this comprehensive study will be beneficial to those involved or interested in modeling, design, optimization, and analysis of food drying.

2.7. Factors Affecting Drying Performance

There are numerous factors which must be taken into account for successful drying. Some of these are related to the characteristics of the product itself, while others pertain to design aspects of the dryer. A brief description of each is provided below (Mercer, 2014).

2.7.1. Effect of Air Temperature

The temperature of the air used in the drying process is one of the major factors influencing the rate of drying. Since water removal involves a change of state from the liquid to vapor form, increasing the energy input to a dryer by raising the temperature of the air will increase the rate of drying (Mercer, 2014). The maximum allowable temperature for drying of red pepper or chilli is 65^0C (Getahun et al., 2020). As shown in the figure bellow two different temperatures 50°C and 60°C were used and the speed of the air was kept constant at 0.50 m/s. While a graph of the weight of the pepper slices during the time the drying tests were run is shown in figure 2.17, there is a curve for each temperature. From the figure, it can be seen that the weight of the peppers decreases faster with the air temperature at 60°C than it does for 50°C. No actual values have been placed on the graph since it is the general trend that we would like to emphasize here. However, many people think that the hotter the air, the better it will be drying the food material. This is an incorrect assumption that can lead to some serious problems, in addition to destroying some of the nutrients contained within the food.

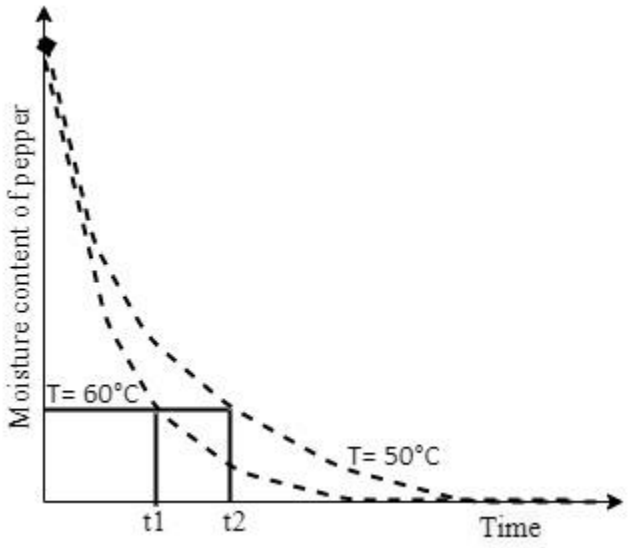


Figure 2.17 Times required reaching equal moisture contents at two drying temperatures (Getahun et al., 2020)

2.7.2. Effect of Relative Humidity of the Air

The actual amount of water present in a given material will influence how fast it may be dried to a desired final moisture level. Relative humidity is an indication of the amount of water vapor contained in a given amount of air divided by the maximum amount of water vapor which air could hold at that temperature. It is expressed as a percentage

value. The moisture content of air entering a dryer will have an effect on the water removal capabilities of the air once it is heated. If the relative humidity of the initial air is high before it is heated, then the water content of the air (measured in grams of water per kg of dry air) will be high. This means that when heated, the ability of the air to remove water will not be as great as if the air had lower initial water content (Mercer, 2014). The average moisture content of green, brown and red chili on a wet base was 85(±0.3) %, 80.3(±0.2) % and 79.8(±0.5) % respectively. Which were determined based on the standard method (Getahun et al., 2020).

Table 2.1: Moisture Contents of Solar Drying of Various Agricultural Produces (A. Fudholi et al., 2010; Getahun et al., 2020; Prakash et al., 2013; J. Singh, 2015)

Product	Moisture Content		Max. Allowable Temp. (0C)	Drying Time(h)
	Initial %	Final%		
Tomatoes	95	7	60	36
Potatoes	75	13	75	
Pepper	71	13	65	48
Rice	24	11	50	-
Chili	80	5	-	48

2.7.3 Effect of Air Velocity

When there is no movement of air across the surface of the pepper slices, air at the surface becomes saturated with water. As a result, water on the surface cannot be removed. If this saturated air is replaced by fresh unsaturated air, the unsaturated air can pick up more of the moisture from the pepper surfaces. It is important for the linear velocity of the drying air to be high enough so that it can sweep the moist air away from the surface of the material being dried and replace it with a fresh supply of warm dry air (Mercer, 2014). An air speed of 0.25 meters per second allows the peppers to dry reasonably well. However, when the speed is increased to 0.50 m/s, there is a noticeable improvement in how fast the drying occurs.

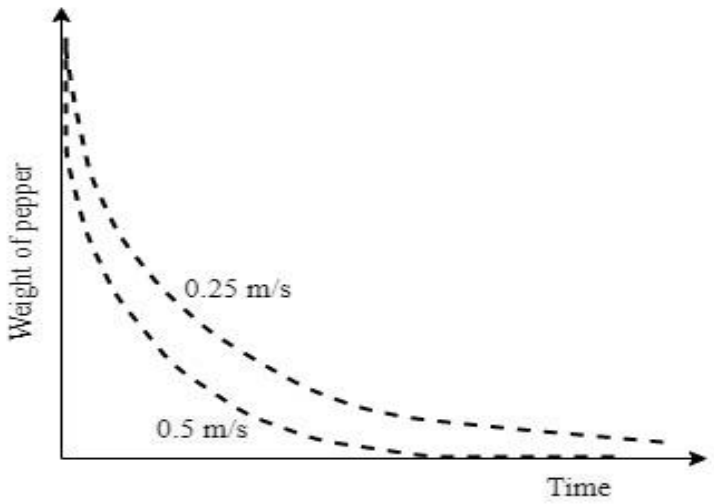


Figure 2.18 Effects of air velocity on the drying of peppers at 50ºC **(**Mercer, 2014)

2.7.4. Duration or Time Spent in Dryer

The length of time during which the product is exposed to heated air within a dryer has a major impact on the overall drying process. Drying time is frequently coupled with air temperature and air velocity as it is shown above to define the drying process of the system (Mercer, 2014).

2.7.5. Size or Thickness of the Drying Product

Water removal in a drying process depends on how far the water has to travel from the center of the material to its surface. For this reason, large pieces of food tend to dry more slowly than smaller pieces of the same food. To facilitate drying, it is often best to use pieces which have a small diameter or are not excessively thick. The important thing to recognize here is that as the slice of material gets thicker, the distance from the center of the slice to the surface increases. When the distance increases, the time it takes for the water to travel from the center to the surface also increases. This means that it will take longer for the product to be dry (Mercer, 2014).

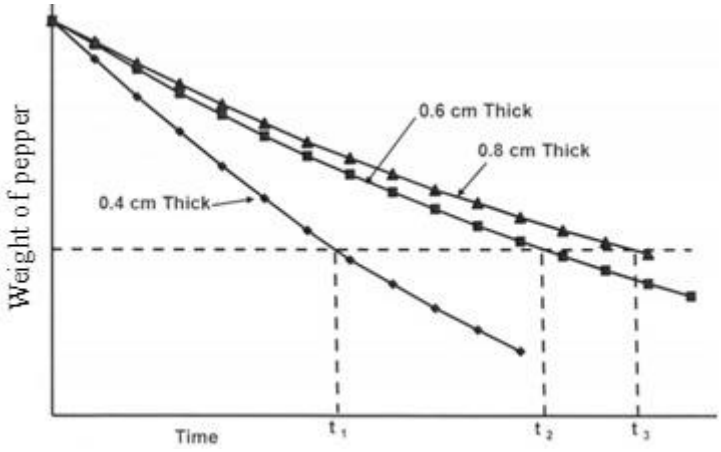


Figure 2.19 Effects of thickness on the drying of pepper

As it can be seen in the figure above, the 0.8 cm thick slices dry more slowly than the one having 0.4cm thinner slices. This is because water at the center of the slice has further to diffuse and reaches the surface in the thicker slices than it does in the thinner slices.

2.7.6. Drying Air Distribution

The flow patterns and uniformity of air flow in the drying chamber have important impact on the drying process as well as uniformity of the moisture content inside the final product. This could be obtained through a proper distribution and guidance of the drying air inside the drying unit. Non-uniform drying of product could be avoided by designing the drying chamber for air to moves only one tray per pass. Then the uniform drying of all trays would be obtained, due to the similar temperature and relative humidity of the air (Mercer, 2014).

2.7.7. The nature of the drying product

The constant demand of consumers for safer, "healthier," and processed food drives the development of technologies in food processing to achieve their needs. Food safety is one of the major challenges for technology, although many preservation processes and regulations are already available to control the microbiological and chemical integrity of food. Food drying is one among many of available technologies that contribute to improve the safety of food (Calado et al., 2014).

In Ethiopia, pepper is produced in several parts of the country as it is an important and a traditional constituent of Ethiopian societies' food menu because of its pungency and color. Moreover, hot pepper is a source of income for rural business since Ethiopia is

among those few developing countries that produce paprika and capsicum oleoresins for export (Gebrtsadkan et al., 2018). The species that are commonly harvested are Capsicum annum L. and Capsicum frutescens L. Mareko Fana and Bako Local (both belonging to Capsicum annum L.) are the major cultivars amongst others which have been developed through research. Mareko Fana pepper variety is a conical type of fruit that matures to a dark red color and has high extractable color intensity. Bako Local has a lengthened fruit shape and becomes red in the mature state. Production of chili has been increased from year to year in Ethiopia. According to the central statistics agency (CSA), 453,608.8 ha of land was used in Ethiopia for production of vegetable with an annual production rate of over 18 million quintals and amongst these productions, pepper accounted for about 70.93%. Moreover, according to the FAOSTAT in 2017 report, the estimated production of peppers in Ethiopia was 64, 041tonnes from 10,000 ha of land for the green form and 306,703 tons of dried pepper from an area of 162,849 ha (Getahun et al., 2020).

Figure 2.20: Mareko Fana red pepper (Getahun et al., 2020)

Mareko Fana cultivars are highly preferred by the local consumers owing to their pungency level, attractive color content and high powder yield and acceptable color. Particularly cultivar Mareko Fana is the only cultivar being used for a long time by the local factories for the extraction of capsicum oleoresin for the export market (Delelegn, 2011). The total yield per hectare of the hot pepper varieties shows a significance difference. Mareko Fana records highest (20 ton/ha) and the remaining three (Melka Shote, Melka Awaze and local check) varieties record minimum ranging from 12.33 to 15 ton/ha with no significance difference (Awel, 2017).

Table 2.2: Mareko Fana fruit characteristics (Delelegn, 2011; Kahsay, 2018; Tesheshigo et al., 2019)

Varieties	Length (cm) (Necmiye et al.)	Diameter (cm) (Necmiye et al.)	Thickness (cm) (Necmiye et al.)	Pungency	Weight (g) (Netzsch)
Mareko Fana	9-11.3	2-2.8	2	high	12.67
Baco Local	8-12.7	2.1	1	high	-
Melka zala	12-12.67	1.3-1.8	1	high	9.58
Melka shota	8-10.57	0.8-1.2	-	high	6.54

2.7.8. Type of Dryer used

The type of the dryer use for drying agricultural crop plays an important role in drying process and one should consider the economically and technically feasible before selecting a drier. Therefore, it is vital to develop a simple, practicable and economical dryer. Different authors recommended the selection parameters of solar drier and their suggestion includes manufacture cost, final product quality, safety considerations, lifetime, durability, thermal performance, environment condition, maintenance and ease of installation (Mercer, 2014).

2.7.9. Thin Layer drying model

Thin layer refers to a layer of sufficiently small product thickness in order that one could consider that air characteristics everywhere in the layer are identically uniform without variance. Thin layer drying process also refers to the drying of individual particles or grains of material which are fully exposed to the drying air .The process is often divided into two periods of drying which are the constant drying rate period and the falling drying rate period (Ikrang et al., 2014; F. Singh et al., 2014).

In the constant rate drying period, the material contain so much water that liquid surfaces exist and will dry in a manner comparable to an open faced body of water. The water and its environment, not solid will determine the rate of drying. Wet sand, soil, pigment and washed seeds are examples of materials that initially dry at constant rate. Radiation, conduction or convection provides the energy needed for drying. In actual practice,

drying of agricultural produce takes place in the falling rate period. The falling rate period is bounded by equilibrium moisture content of an equilibrium moisture curve between zero and nearly 100% relative humidity. Drying in the falling rate period involves two processes namely; the movement of moisture within the material to the surface and removal of moisture from the surface (Henderson et al., 1997). Furthermore, thin layer drying could be viewed as the drying of one layer of sample particles or slices in abundant supply of drying air with appropriate physical characteristics. Thin layer drying is also described as the process of removal of moisture from a porous media by evaporation in which excess drying air is passed through a thin layer of a material until the equilibrium moisture content is reached (Omid et al., 2006; Ronoh et al., 2010). Thin-layer drying equations fall into three categories namely, theoretical, semi-theoretical, and empirical models.

i) Theoretical Method

Theoretical models only consider the internal resistance in transfer of moisture while the other two categories are considered to study the external resistance to moisture transfer between air and product (Whitaker et al., 1969). The theoretical models are derived from Fick's second law of diffusion (Panchariya et al., 2002). While semi-theoretical models are generally derived from Fick's second law and its modifications and also, from Newton's law of cooling (Erbay et al., 2010a). Fick's second law of diffusion is the most commonly used theoretical model. Theoretical models are inadequate and tend to generate erroneous results and are complex for practical applications. The theoretical models make too many assumptions leading to a considerable number of errors thus limiting their utilization in the design of dryers (Onwude et al., 2016). A theoretical equation gives a better understanding of the transport processes but an empirical equation gives a better fit to the experimental data without any understanding of the transport processes involved (Pandey et al., 2015) .

ii) Empirical Method

The empirical method is a method based on experimental data and dimension less analysis. The empirical models of drying show a direct relationship between average moisture content and drying time (Fernando et al., 2016). However, this method omits the fundamentals of the drying process and its parameters have no physical meaning, therefore it does not provide an accurate view of the important processes that occur

during the phenomenon while describing the drying curves for certain experimental conditions (Coradi et al., 2014). Empirical models fails to take into account the fundamentals of drying process and is able to explain only the drying curve for drying condition but not the processes that occurs during drying. Empirical models help to understand the trend of experimental/process variables both dependent and independent. The main challenges faced by the empirical models are that they depend largely on experimental data and provide limited information about the heat and mass transfer during the drying process (Erbay et al., 2010a).

iii) Semi-Empirical Method

Semi theoretical models have been developed to ease the use and to fit the drying data of the food material to be dried (Kemp, 2011). Much emphasis has been given to developing semi theoretical models for achieving harmony between theory and ease of use. Such models are generally based on Newton's Law of Cooling applied to mass transfer. When applying this law it is assumed that conditions are isothermal and resistance to moisture transfer is confined only to the surface of the product (Ahmed, 2009). Semi theoretical models are the simplified general series solutions of the Fick's second law. These models, however works only when temperature, relative humidity, air velocity and moisture are in the range at which the models are developed. Time requirement is less and shapes of the material dried are not considered in semi theoretical models (Parry, 1985). Among semi-theoretical models are the model of two terms, the Henderson and Pabis, Lewis, Page and Modified Page (Panchariya et al., 2002).

Iv) Equilibrium moisture content (Me)

A crop has a characteristic water vapor pressure at a particular temperature and moisture content. The equilibrium moisture content is the moisture content at which the product is neither gaining nor losing moisture. It is a dynamic equilibrium which changes with relative humidity and temperature. Moisture ratio is one of the important criteria to determine the drying characteristics of agricultural product. Moisture content was expressed as percentage wet basis and then converted to grams of water per gram of dry matter. The experimental drying data for red chili were fitted to exponential thin layer drying models using nonlinear regression analysis MR can be determined according to external conditions. If the relative humidity of the drying air is constant during the drying

process, then the moisture equilibrium is constant too. In this respect, MR is determined as in Eq (Akpinar et al., 2003 b; Shanmugama et al., 2006).

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad \text{.....2.1}$$

Where M_t, M_o and M_e are moisture content at any time of drying (kg water/kg dm), initial moisture content (kg water/ kg dm) and equilibrium moisture content (kg water/kg dm), respectively. The values of M_e are relatively small compared to M_t and M_o for long drying times (Soysal et al., 2006). If the relative humidity of the drying air continuously fluctuates, then the moisture equilibrium continuously varies so MR is determined as in Eq.(7) given by (Meziane, 2011; Pandey et al., 2015).

$$MR = \frac{M_t}{M_o} \quad \text{.....2.2}$$

v) Drying rates

Agricultural products differ from most other materials dried frequently, such as textiles in a Laundry, sand, stone, dust or paper. Agricultural products (which are hygroscopic) has always some residual moisture after the drying while for non-hygroscopic material drying continued up to zero moisture content. Because of hygroscopic products moisture is trapped in closed capillaries. The rate of moisture flow is only approximately proportional to its vapor pressure difference with the environment because of the crop resistance to moisture flow. There are two main drying rate regimes for agricultural products, namely the constant drying rate period and the falling drying rate period (Darvishi et al., 2014).

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad \text{.....2.3}$$

Where, M_{t+dt} is moisture content at $t + dt$ (kg water/kg dm),

$t -$is time (min) and

$DR -$ is the drying rate (kg water/kg dm min).

Moisture ratio data obtained with Equations 2.1 for each sample were fitted to six thin layer drying equations (Table 1) to assess their suitability as models for thin layer drying kinetics of pepper in tray dryer. Coefficient of determination (R2) was used to determine the appropriateness of the model while the accuracy of fits was assessed using Chi square (x^2) and root mean square error (RMSE). For quality fit, R2 value should be closed to one while x^2 and RMSE values should be closed to zero.

Table 2.3 Widely used drying kinetics models (Alibas, 2012; Arslan et al., 2020)

No	Model name	Mathematical equation
1	Newton or Lewis	$MR = \exp(-kt)$
2	Henderson and Pabis	$MR = a\ x\ \exp(-kt)$
3	Logarithmic	$MR = a\ x \exp(-kt) + c$
4	Two-term	$MR = a\ x \exp(-k_0 t) - b\ x \exp(-k_1 t)$
5	Page	$MR = \exp(-kt^n)$
6	Wang and Singh	$MR = 1 + at + bt^2$

Where a, b, c, n and k are constants specific to the type of grain, and "t" is the elapsed time since the beginning of the thin layer drying test.

Where k is the drying constant in (s−1), MR is the moisture ratio, M is the dry basis moisture content at any time t, M0 is the initial dry basis moisture content of the sample, and Me is the equilibrium moisture content. a, b and c are dimensionless empirical constants.

vi) Correlation coefficients and error analysis

The regression coefficient (R^2) was primary criterion for selecting the most suitable equation to describe the drying curves of Chili peppers. The correlation can be used to test the linear relation between measured and estimated values, which can be calculated from the equation:

$$R^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{exp_{mean,i}})^2 - (MR_{pre,i} - M_{R_{exp,i}})^2}{\sum_{i=1}^{N}(MR_{exp,i} - MR_{exp_{mean,i}})^2} \quad \text{.....2.4}$$

Where R^2 is called the coefficient of correlation, ($MR_{exp,i}$) stands for the experimental moisture ratio found in any measurement, ($MR_{pre,i}$)is the predicted moisture ratio fort this measurement and N is the total number of observations.

The root mean square error (RMSE) may be computed from the following equation which provides information on the short term performance.

$$RMSE = \sqrt{\frac{[\sum_{i=1}^{N}(MR_{exp,i}) - \sum_{i=1}^{N}((MR_{pre,i})]^2}{N}} \quad \text{.....2.5}$$

Chi square x^2 is the mean square of the deviations between the experimental and predicted moisture levels. The lower are the values of the reduced x^2, the better is the goodness of fit (Ertekin et al., 2015).

$$x^2 = \frac{[\sum_{i=1}^{N}(MR_{exp,i}) - \sum_{i=1}^{N}((MR_{pre,i})]^2}{N - n_i} \quad \text{.....2.6}$$

The highest correlation coefficient (R^2) and the lowest chi square (x^2) and root mean square error ($RMSE$) values are required to select the best suitable model to explain the thin drying process. Once the drying curves obtained from the experimental data, then it will be fitted to the different semi-theoretical thin layer drying models. The model which satisfies these requirements will be selected to represent the thin layer behavior of the product.

2.8. Gaps Identified in the Review

Based on the above types of dryer and summery of literature forced type solar inflated or bubble dryer is not yet studded for pepper vegetable crop. The direct solar dryers are commonly used in areas where direct sunlight is received for longer periods during the day (Mustayen et al., 2014). Even though, direct solar dryers have some limitations such as, having small crop handling capacity, reduction in quality (Sebaii et al., 2012). The modified design is targeted at eliminating or reducing non-uniformity of drying and increases dryer efficiency. The gap identified in the literatures reviewed helped in identifying the objectives of this study. Therefor this study will carried out to address the limitations and overcome the post harvesting problem by modifying and improving the efficiency of solar bubble dryer particularly tested for pepper vegetable crop.

Table 2.3: Summary of literature

No.	Title	Types of dryer	Moisture content		Drying time	Temperature		Drying Capacity (kg)	Efficiency		Reference
			M_i (%)	M_f (%)		Collector (°C)	Dryer (°C)		η_c (%)	η_d (%)	
1	Technical Performance of an Inflatable Solar Dryer for Drying Amaranth Leaves in Kenya	Open sun	80	24.7			45.4				(Romuli et al.)
		ISD	80	11.6	68.08hr		63.4				
2	Development of an inflatable solar dryer for improved postharvest handling of paddy rice in humid climates	Open sun	24	17							(Salvatierra-Rojas et al., 2017)
		ISD	24	14	16hr	42	63	1000			
3	Performance Evaluation of Solar Bubble Dryer	SBD	16%	12%	6hr						(Mishra et al., 2020)
4	Experimental investigation of solar bubble dryer for rough rice drying in Bangladesh SBD	Boro Season (May-June)	25.6	13.7	19.8hr	39±1.9	39±1.9	1000		25.2	(Alam et al., 2020)
		Aman Season (Nov-Des)	20.1	14.5	16.7	29±2.1	29±2.1	1000		12.3	
5	Development and Performance Investigation of an Inflatable Solar Drying Technology for Oyster Mushroom	ISD	90	10	10hr			500			(Nguyen-Van-Hung et al., 2019)
6	Drying Performance and Aflatoxin Content of Paddy Rice Applying an Inflatable Solar Dryer in Burkina Faso	ISD	15.6			40.8	55.3	80			(Romuli et al., 2020)
7	A Solar Tunnel Dryer for Drying Red Chilly as an Agricultural Product	Open sun	75	5	24hr/3day		33.7 - 44.	5			(Dhanore et al., 2014)
8	Performance Analysis of solar Tunnel Dryer	Open sun	85	15	18hr						(P.Gandhimutha et al., 2016)
		Tunnel	85	15	11hr			4			
9	Design and Testing of a Natural Convection Solar Tunnel Dryer for Mango	Tunnel	85.5	13	9.5hr	65.8	49.1		25	12.8	(Simate et al., 2017)
10	Design and Development of Walk-In Type Hemi cylindrical Solar Tunnel Dryer for Industrial Use	Tunnel	62.87	10.62			58-62	1500			(Seveda, 2012)
11	Solar Drying Of Fruits And Vegetables: Dryers' Thermal Performance, Quality And Shelf Life Of Dried Mango, Banana, Pineapple and Tomato	Tunnel	79	16	32hr		73		57.5		(MONGI, 2013)
		Cabinet			55hr		55		32		
		Mixed			54hr		50		34		
12	Drying of hot chilli using solar tunnel drier	Tunnel	85	5	20hr						(Hossain et al., 2007)
		Open sun	85	9	32hr						

Chapter Three

Materials and Methods

3.1. Materials

The Solar Bubble dryer (SBD) is one of the types of dryer which have drying floor, top cover, and solar panel. It completely operates independent from fuel or the power grid. The following materials were used for the construction of solar bubble dryer.

3.1.1 The Solar Collector: The collector which is essentially the air heating area which used to increase the temperature in order to remove the moist air or water in the pepper vegetable crop. It is a transparent plastic. It is exposed to for both solar radiation and wind velocity which drawn by the fan in order to force the heated air forward to the dryer so as to remove the water in the pepper vegetable crop.

3.1.2 Absorber: it is made of black painted plastic, which absorbs the solar radiation. The black paint enhances the absorptivity of the plastic. A good absorber is needed to raise the temperature of the collector. Foste (2013) Describes a good absorber as one that absorbs almost all the incoming radiation, lose a small portion to the surroundings and efficiently transfer the absorbed solar energy to the passing air within the collector.

3.1.3 Tray: The try is made of a fabric mesh or mosquito net and RSH that designed to slides easily on the frame of the drying bed for cleaning, loading, and unloading as well as maintenance purpose. The fabric mesh or mosquito net is used in order to avoid food contamination and corrosion of the try.

3.1.4 Support: The supporting structure allows the try to slide on it and hold the transparent plastic cover to prevent the pepper vegetable crop from external factors like dust, rain and insects. It is made of RSH material.

3.1.5 Dryer: The drying chamber consists of chimneys, trays and transparent plastic. It is the place where the fabric meshes tray slides to spread the pepper vegetable crop. It contains chimney used to facilitate and control the convective flow of air in the dryer. The top surface of the dryer is covered by plastic like the collector. This is reasonably to increase increases the convective air flow and additional heating necessary for drying.

Were as, the bottom surface of the dryer was painted black to enhance the temperature in order to enhance the drying rate of the pepper vegetable crop.

The chimney used to generate buoyant forces on the air, thereby increasing the rate of air flow through the dryer. The chimneys were fabricated from PVC.

3.1.6. Linear Low Density Polyethylene (LLDPE) plastic

Low density polyethylene LDPE is one of the most used materials and its utilization for agricultural greenhouse covers is a common application. The main properties that have ensured its success are especially its lightness and transparency (Dehbi et al., 2011). This is used for plastic bags and utilized in most traditional markets to store foods (especially grains) and water (Sackey et al., 2015). They have a lifetime of 2-4 years before being degraded by UV radiations. Low-density polyethylene (LDPE) has a relatively high solar transmittance and but also the highest thermal transmittance of all cover materials without additives material (Bastien, 2015). It permits the solar radiation into the system but resists the flow of heat energy out of the systems. UV resistance and transparent cover of the dryer, since it is relatively chipper than glass and easily folded and weight less than glass. Plastic glazing of various types is still used on some solar collectors to reduce weight and cost (Alghoul et al., 2005).

3.1.7. Solar panel

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels. Solar cells are described as being photovoltaic irrespective of whether the source is sunlight or an artificial light. They are used as a photo detector (for example infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity (Bagher et al., 2015).

3.1.8. Air blowers/ Fan

A fan is a mechanical device that uses energy inputs to move air, and can be described as the ‘heart’ of a mechanical ventilation system. The two general types of fan are axial-flow and centrifugal. Axial-flow fans are normally divided into propeller and tube-axial types.

They move air parallel to the shaft and are the most widely used types. Centrifugal (radial flow) fans (blowers) discharge air at right angles to the shaft and often operate at substantial pressures.

3.2. Methods

The overflow drying process happens when the air streams over the spread products while flowing through the bubble drying tunnel, which is inflated by the blowers. The solar bubble is made of plastic film with a transparent plastic cover on the top and a black reinforced polyvinyl chloride (PVC) underneath; it functions as weather protection and as a trap for solar radiation to generate heat. The drying air is heated up when flowing through this bubble tunnel and, consequently, the relative humidity will reduced to better remove moisture from the product (Van Hung et al., 2020). This will be carried out by evaluating the data using excel for the prototype to achieve the objective of the study as well as to make the outcome of the pepper effective easily practicable.

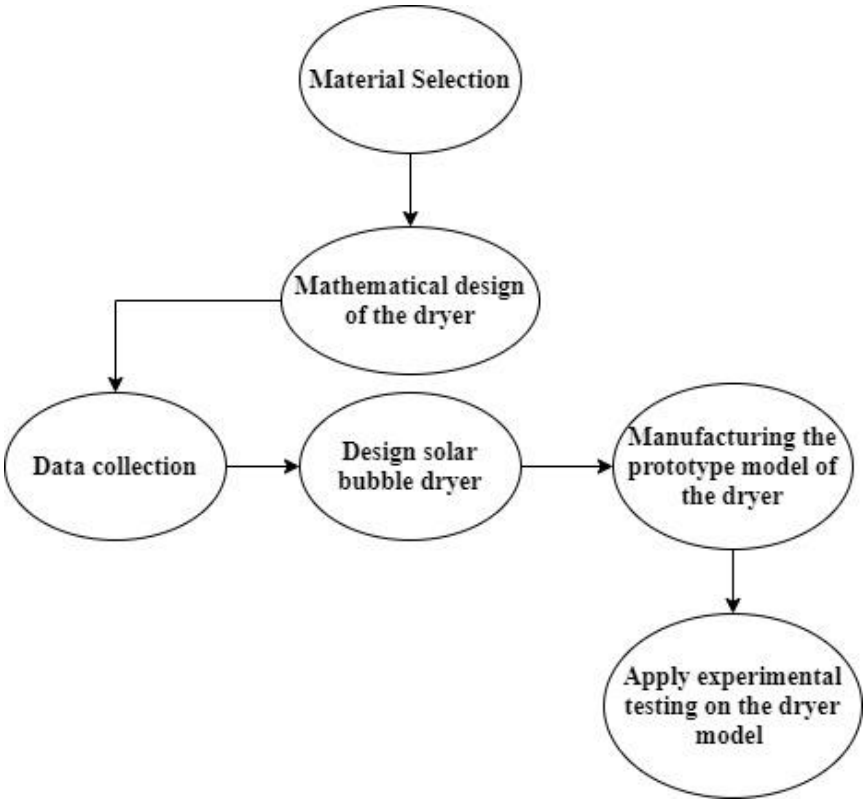


Figure 3.20. Methods for implementing modified solar bubble dryer

3.3. Working principle of solar bubble dryer

The SBD uses the solar energy from the sun in two ways. Firstly, the drying tunnel serves as a solar collector to convert energy from the sun's rays which enters through the transparent top of the drying tunnel to heat energy. This helps to increase the temperature of the air and enables the faster drying process. Secondly, the SBD consists of a photovoltaic system which has solar panels for generating electricity to drive one small blower or fan to inflate the drying tunnel and move air through it. The hot air helps to remove water evaporating from the pepper vegetable crop inside the tunnel and the evaporating water will forced to leave the drying area due to the air comes from the fan and let it out through the chimney. The SBD dryer is mobile and completely independent from fuel or the power grid and comes in different sizes of batch capacity.

This modified technology has different parts used to dry a given drying product like drying floor, solar panel, fan and so on. Moisture content measuring meter, temperature reader, humidity measuring meter and air flow meter are used as additional accessories for drying operation. The drying tunnel also provides a safeguard for the temperature and protects the grains from overheating, because it is common during sun drying at noon. It eliminates the damage of pepper during rain and losses due to animals, dust, insect, birds which result the degradation of quality and quantity of the pepper. Depending on the weather the drying rate during daytime is 0.5-1% per hour. Drying time depends on the weather and the initial moisture content of the peppers. Skin-dry peppers are often dried to 14% moisture content within a sunny day. However in cloudy days the drying might take two or three days. During rain and in the dark when the ratio of the air is high, the drying process stops as it illustrated in figure 3.2.

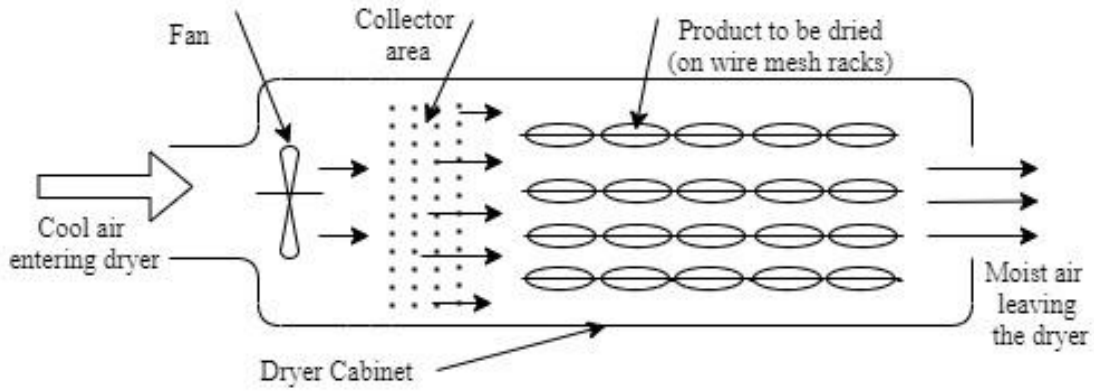


Figure 3.2 A typical forced air dryer

Chapter Four
Design of Solar Bubble Dryer

4.1. Design of Solar Bubble Dryer

The following points are considered generally in design of direct, natural or forced convection type solar drying system: A solar dryer was designed for drying pepper vegetable crop based on the procedure described by (M. A. Hossain et al., 2007). The procedure described and proposed the design constraints that will be applicable to naturals/forced convection type dryer based on previous research work to further assist in validating these dryer systems, some of which includes by (Tonui et al., 2014).

Table 4.1 Design assumption of solar bubble dryer

Specification	Values	Reference
Initial moisture content (M_i)	71%	(Getahun et al., 2020; Prakash et al., 2013)
Final moisture content (M_f)	13%	
Yearly average solar radiation (I_T)	560W/m^2	National metrology agency
Yearly average ambient temperature (T_a)	21°C	National metrology agency
Yearly average wind speed (v_w)	1.5m/s	National metrology agency
Sample weight (M_p)	3kg	Assumption
Latent heat (L_v)	2320/kg	(M. Z. Hossain et al., 2015)
Density of air (ρ_a)	1.225 kg/m^3	(Dixon, 2007)
Spreading density	1.5kg/ m^2	Assumption
Specific heat capacity of pepper (C_p)	3.81kJ/kg $^{\circ}$C	(M. Z. Hossain et al., 2015)
Drying time(t_d)	20hr	(Hossain et al., 2007)
Diameter of the tunnel (d)	0.5m	Assumption

i. Declination Angle (δ)

The declination is the angular position of the sun at solar noon, with respect to the plane of the equator. Its value in degrees is given by Cooper's equation (Çengel et al., 2015).

$\delta = 23.45\sin[\frac{360}{365}(284+n)]$……..……..(1)

n=228(Aug. 17th, recommended average day)

Where, n is the day of year (i.e. n =1 for January 1, etc.).

Declination varies between -23.45° on December 21 and +23.45° on June 21.

ii. Sunset Hour Angle (ω_s)

The sunset hour angle ω_s is the solar hour angle corresponding to the time when the sun sets. It is given by the following equation (Thet et al., 2018)

$\omega_s = \cos^{-1}(-\tan\phi\tan\delta)$ ……...(2)

iii. Hour angle (ω)

Hour angle (ω) is the hour angle of a point on the earth's surface. It is defined as the angle through which the earth would turn to bring the meridian of the point directly under the sun. Hour angle and solar time in hour are related as follows and for this case one can calculate hour angle at 1: 30 PM (Zubairu et al.).

ω = (ST-12) x15^o ……

iv. Zenith angle(θz)

Zenith angle is the angle between the sun's ray and the perpendicular line to a horizontal plane.

$\cos\theta z = \cos\phi\cos\delta\cos\omega + \sin\delta\sin\phi$……..……(Kamble et al.)

v. Incidence and Tilt Angles

Incidence angle (Θ) is the angle between the radiation falling on the surface directly and the normal of that surface. If incidence angle is steep to the sun lights, it is (=0^o). On the other hand if this angle is parallel to the sun lights, it is (=90^o). The incidence and tilt angles are shown in Figure 4 (Karafil et al., 2016).

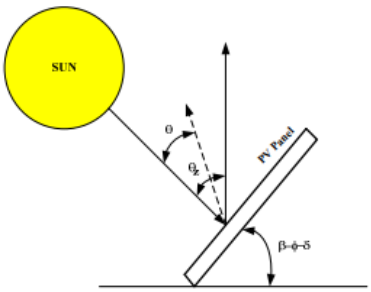


Fig. 4.1 Incidence and tilt angels (Duffie et al.)

Incidence angle is used in the design of solar energy systems. It is calculated by the following equation.

$\theta = \cos^{-1}[\cos(\delta).\cos(\phi).\cos(\omega) + \sin(\delta).\sin(\phi)]$ ……(5)

Tilt angle (β) is the angle between the panels and the horizontal plane. This angle is south oriented in the northern hemisphere and north oriented in the southern hemisphere. Tilt angle varies between 0º and 180º. For best average summer performance, a collector should be mounted at approximately φ – 15°, and for best average winter performance, it should be mounted at φ + 15°. For optimum spring or fall performance or optimum annual performance, the collector should be mounted at about 0.9φ°. Since normally it is acceptable to orient a collector for optimal seasonal or, perhaps, annual performance, many tables of irradiation on collectors are available for collector tilts of either φ, φ + 15°, or φ – 15 ° at various locations on the globe. It shows how monthly performance depends on collector tilt angle. Different locations will show different relative monthly performance, depending on local weather seasonal behavior (Ventre, 2005). Therefore the tilt angle of the solar panel is that,

β= φ + 15°……..…….(6)

Were, φ- latitude of Addis Ababa 9.2°

4.2 Design Procedure for the Solar Dryers

i). Dimensions of Solar Tunnel Dryer

Area of solar collector equals area of semi cylindrical shape of solar tunnel dryer. Area of hemi cylindrical shape of solar tunnel dryer was calculated as follows:

$A_{Tunnel} = \pi \times r(r + L)$ ……(7)

Were, r- radius

L- length of the dryer

Diameter (d) of solar tunnel dryer 0.5 m is kept as constant for easy entry and other convenience. Radius of solar tunnel dryer was calculated as follows:

$r = \frac{d}{2}$……(8)

Length of solar tunnel dryer was calculated as follows:

$L = \frac{a - \pi r^2}{\pi r}$…….....…(9)

Floor area (drying area) of solar tunnel dryer was calculated as follows:

$A = L \times d$……(10)

(ii) Solar Collector Area

In solar drying system design, one of the methods of sizing the collector is based on meteorological and crop parameters. The required surface area of the transparent cover for crop drying depends primarily on the heat load of the drying system given by (Kamble et al., 2013)

$A_C = \frac{Q_{load}}{\eta_c I_T t_d}$……(11)

Where, t_d = drying time (hrs.)

I_T = the total solar radiation incident on the collector surface(W/m^2)

I_T =H×R (Ahmad Fudholi et al., 2013a)

H= horizontal radiation (W/m^2)

R= ratio of solar radiation on tilted surface to that on the horizontal, (dimensionless)

η_c= efficiency of the collector

4.3 Drying Chamber Design

(i) Energy Balance for Drying Process

The total energy required for drying a given quantity of food items can be estimated using the basic energy balance equation for the evaporation of water (Bolaji, 2005)

$m_w L_v = \dot{m}_a C_p (T_d - T_a)$……(12)

Were, L_v= Latent heat of vaporization of water (kJ/kg).

m_w = mass of water evaporated from the pepper vegetable crop (kg)

T_d = temperature of outgoing air from the drying chamber (°C)

T_a = ambient air temperature (°C)

(ii) Drying Heat Load

The heat load is determined by the amount of crop to be dried, it's initial and final moisture contents and the time required to complete the drying operation (Kamble et al., 2013)

$Q_{load} = M_r L_v$……(13)

Where, M_r= amount of moisture to be removed (kg)

L_v= latent heat of vaporization of water from the surfaces of pepper vegetable crop, 2320 kJ/kg

(iii) Mass of Water to be evaporated from the pepper vegetable crop

Moisture content of agricultural product is expressed as a percentage of moisture based on wet weight (wet basis) or dry matter (dry basis). Wet basis moisture content is generally used in commercial use were as dry basis used primarily in research (Hellevang, 1994). The mass of water M_r to be evaporated is estimated from the initial moisture content initial and the final desired moisture content Mf. The total mass flow of air required for drying is determined from the amount of moisture loss from the crop. The quantity of moisture to be removed is given by the following relationship:

$$M_r = M_P\left[\frac{(M_i - M_f)}{(1 - M_f)}\right] \quad \text{.....(14)}$$

where, M_P = mass of the wet pepper vegetable crop (kg)

M_i,= initial moisture content on wet basis (% wb).

M_f = final moisture content on wet basis (% wb)

Wet Basis Moisture:- One way of expressing how much water is present in the pepper vegetable crop is to divide the amount of water present in pepper by the total weight of the pepper and multiplying this value by 100%. The result is the percent moisture of the product which contains moisture or water. Since the total weight of the pepper contains the weight of water and solids in the pepper vegetable crop as a result the value which referred to percent of moisture or water is called wet basis moisture content (Mercer, 2014). Such that:-

$$MC(w.b)\% = \frac{M_w - M_d}{M_w} x100 \quad \text{.....(14a)}$$

Were, $MC(w.b)$ -moisture content in wet basis, %;

M_w -weight of moisture in the product, kg;

M_d -weight of dry matter in the product, kg;

Dry Basis Moisture:- The second method of expressing how much water is present in the pepper is “dry basis moisture”. Although it is not as commonly used as the “wet basis moisture”, it is much more important in most drying-related calculations. To calculate the dry basis moisture, you need to divide the amount of water present in the pepper vegetable crop by the weight of dry material present in the pepper vegetable crop (Mercer, 2014). If you know the percent moisture present in the pepper, you can easily calculate the percentage of solids present, based on the relationship shown below:

$MC(d.b)\% = \frac{M_w - M_d}{M_d} x100$ ……..…….(14b)

Where, $MC(d.b)$ -moisture content in dry basis, %

(v) Volume of Air Required for Removing the Moisture

The total volume of air required for removing the moisture from 3 kg of pepper vegetable crop is evaluated from the equation given by (Forson et al., 2007)as:

$V_a = \frac{M_r h_{fg} R_a T_a}{P_a C_p (T_o - T_f)}$……..…….(15)

Where, T_f= temperature of air leaving the drying bed obtained from the following relationship.

$T_f = T_a + 0.25(T_c - T_a)$ ……..……(16)

Where, R_a = gas constant (kJ/kgK)

T_c= temperature of air at the collector outlet (°C)

P_a= partial pressure of dry air in the atmosphere, (N/m^2)

C_p= specific heat capacity of air, (kJ/kgK)

(vi) Mass Flow Rate of Air Needed to Effect the Drying

The mass flow rate is given by (Tonui et al., 2014)

$\dot{m}_a = \dot{\upsilon}_a \rho_a$……(17)

Where $\dot{\upsilon}_a = \frac{V_a}{t_d}$ ……(18)

t_d = Drying time per day (hrs)

ν_a = total volume of air required for removing the moisture (m^3)

$\dot{\upsilon}_a$= volume flow rate of the drying air (m^3/s)

ρ_a= density of air at ρ_a = 0.97kg $/m^3$@ 2400m above sea level (Tulapurkara, -)

(vii) Drying Chamber Capacity and Other Dimensions

The width of the collector (W) was considered equal to the width of the drying chamber. The volume of pepper vegetable crop can be obtained from equations given by (Shitu Abubakar, 2017) as:

$\nu_y = W_T L_T Y_l$……..(19)

Total volume of the pepper vegetable on the trays in the drying chamber obtained as;

$\nu_T = n\nu_y = nW_T L_T Y_l$……..(20)

Were, n- Number of try

Also, the total volume can be related to the bulk density as:

$M_p = \rho_b \nu_T$…….…….(21)

Y_l = Thickness of the pepper vegetable crop in the drying chamber, (m)

W_T= width of the tray which is equal to the width of the drying chamber, (m)

L_T= Length of tray, (m)

M_p = Total mass of pepper vegetable crop, (kg)

ρ_b= Bulk density of pepper vegetable, $402.1(kg/m^3$ (Necmiye et al., 2010; Rokayya et al., 2016)

The length of the drying chamber is approximately equal to the length of the tray,

$L_d \cong L_T$ ……(22)

4.4 Sizing of the fan power

The ASHRAE recommended a thermal comfort range of 50-100mcfm for fan. Therefore designing for air volume flow rate of $100\text{cfm} = 0.0491747 m^3/s$ (Ismail et al., 2014).

Since, $1cfm = 4.91747 \text{x} 10^{-4} m^3/s$Fan horse

power=$(\text{Air flow} \times \text{Static pressure})/(6320 \times \text{Fan efficency}$……(23)

From literature, most industrial fans have efficiency ranging from 70-85% as described and an efficiency of 85% fan selected and to ensure proper distribution of air to the drying chamber and for effective heat distribution, an axial flow fan with 0.02 HP and 110mm of water static pressure was used.

4.5 Sizing of the PV modules

Different size of PV modules produce different amount of power. To find out the correct size of a PV module, the total peak watt produced needs was determined. The peak watt (Wp) produced depends on size of the PV module and climate of site location. Also we have to consider "panel generation factor" which is different in each site location the panel generation factor 2.5 is reasonable (Axtell). The 20W DC fan is expected to run for 8 hours per day. Therefore, daily energy consumption is calculated (Ibrahim et al., 2016).

$\text{Daily energy consumption} = \text{power x time}$ ……(24)

For PV Module Sizing a factor of 2.5 is reasonable (Axtell).

$$\text{Total PV Module needed} = \frac{Total\ dayily\ energy\ consumption}{PV\ corection\ factor} \text{……(25)}$$

$$\text{No. of PV Module} = \frac{\text{Total PV Module needed}}{\text{Standard PV Module}} \text{……...…(26)}$$

There for the dryer is powered by 60W PV module.

4.6 Design of Chimney

All solar dryers should have a means to let out the exhaust air. Most solar dryers have a chimney to let out the hot air that picked up moisture from the produce kept in the dryer to be dried. When the air inside the chimney has a temperature greater than the ambient air such that the density of air outside the chimney is greater than inside, there would be a flow through the chimney (Ekechukwu et al., 1995). The chimney increases the amount of air flow, through the solar dryer by speeding up the flow of the exhaust air (Al-Neama et al., 2016). Since airflow in the dryer takes places due to the draft caused by the density difference between outside cold air and inside hot air, a natural draft uses the basic law that warm air rises. Air as it is warmed expands and becomes lighter in mass. Colder, heavier air pushes in under it and forces it up. This causes a draft. Mass of air needed for removing of water was calculated using the following equation (Dadi et al., 2016):

$$M_a = \frac{M_r \times L_v}{C_a(T_{ch} - T_a)} \quad \text{.....(27)}$$

Were, M_a- Mass of exit air (kg)

M_r – Mass of water to be removed (kg)

C_a- Specific heat of air (kJ/kg°C)

T_a- Ambient air temperature (°C)

T_{ch}- Temperature inside the chimney of dryer (°C)

L_v- Latent heat of vaporization of water (m^2)

Mass of exit air was calculated as follows:

$$M_e = M_r + M_a \quad \text{.....(28)}$$

Were, M_e- mass of exit air (kg)

Density of inlet air was calculated as follows:

$$\rho_i = \rho_o \times \frac{T_o}{T_a} \quad \text{.....(29)}$$

Were, ρ_i - Density of inlet air (kg/m^3)

ρ_o - Density of air at 0°C (kg/m^3)

T_a- Ambient air temperature (°C)

T_{ch}- Temperature inside the chimney of dryer (°C)

Produced draft in chimney (Height of chimney assumed to be 2 m)

$$D_P = (\rho_i - \rho_e) \times H \times g \quad \text{.....(30)}$$

Were,D_P-Produced draft (kg/ms^2)

ρ_i - Density of inlet air (kg/m^3)

ρ_e - Density of exit air (kg/m^3)

g- gravity (m/s^2)

But actual draft was calculated as follows:

$V_e D_a = 0.75 \times D_P$……..…..……(31)

D_a- Actual draft (kg/ms^2)

Velocity of exit air was calculated as follows:

$V = \sqrt{\frac{2D_a}{\rho_e}}$……(32)

Were, V- velocity of exit air (m/s)

Volume of exit air was calculated as follows:

$V_e = \sqrt{\frac{M_e}{\rho_e}}$……..……(33)

Rate of exit air was calculated as follows:

$Q_c = \frac{Q_a}{n}$……..……(34)

Were, Q_a - Rate of air required(m^3/s)

n- Number of chimney (assumed to be 1)

Thus if assumed this exit air is being carried by n number of chimney.

Rate of exit air for single chimney was calculated as follows:

$\dot{\upsilon}_{ch} = \frac{Q_a}{n}$……(35)

Were, $\dot{\upsilon}_{ch}$ - Rate of air flow in chimney (m^3/s)

Area of chimney was calculated using following equation:

$a_{ch} = \frac{Q_a}{V}$……(36)

Were, a_{ch} - Diameter of chimney (m)

Diameter of chimney was calculated as follows:

$d_{ch} = \sqrt{\frac{4 \times a_{ch}}{\pi}}$……..……(37)

Were, d_{ch} - Diameter of chimney (m)

4.7 Performance Evaluation of the Crop Dryers

The performance of the drying system was evaluated using the solar collector efficiency, drying rate, moisture loss, and drying efficiency of the dryer.

(i) Solar Collector Efficiency

Efficiency of a solar collector is the ratio of heat gained by the air leaving the collector to the incident solar energy over a particular time period (Bolaji, 2005). The steady state thermal efficiency of the solar collector is given by Hottel-Whillier- Bliss equation (Forson et al., 2007) as:

$$\eta_c = \frac{\dot{m}_a C_p (T_d - T_a)}{A_C I_T} \quad \text{.....(38)}$$

Were, I_T = total solar radiation incident on the top surface, (N/m^2)

T_a = ambient air temperature, (°C)

T_o = temperature of outgoing air from the collector, (°C)

$\dot{m}_a$ =Mass flow rate of air, (kg/s)

(ii) Dryer Efficiency

Thermal performance or drying rates of the products are the key factors used for the evaluation of the solar drying system efficiency (Leon, 2002). For natural convection solar dryer, the system efficiency can be expressed as given by (FrankSchiavone, 2011) as:

$$\eta_d = \frac{M_r L_v}{A_d I_T} \quad \text{.....(39)}$$

Where; M_r = mass of water evaporated, (kg)

L_v= latent heat of vaporization of water, 2320 kJ/kg (Kilanko et al., 2019; Sengar et al., 2012)

A_C= Collector area, (m^2)

(ix) Percentage Moisture Loss

The quantity of moisture in percentage of the initial mass of a material can be represented on wet and dry basis and expressed as percentage given by (Mohanraj et al., 2009) as:

$$MC = \left[\frac{M_i - M_f}{M_i}\right] \times 100\% \quad \text{.....(40)}$$

Were, M_i = Initial mass of the yam slices, (kg)

M_f = Final mass of the yam slices, (kg)

(x) Average Drying Rate:

The quantity of moisture removed from the food item over the drying time is given as:

$$m_{dr} = \frac{M_r}{t_d} \quad \text{.....(41)}$$

Were, M_w = mass of water evaporated from the yam slices, (kg)

t_d = drying time per day, (hr)

4.8 Design Calculations result

Table 4.2 gives the numerical values of the dimensions of the solar drying system, obtained using the equations explained above.

Table 4.2 Numerical values of the dryer

Design equation	**Given value**	**Result**
Mass of water to be evaporated from 5 kg of red pepper. From equation (14) $M_r = M_p[\frac{(M_i - M_f)}{(1 - M_f)}]$	M_p= 3kg M_i=71% M_f=13%	M_r=2kg
Temperature of air leaving the drying bed From equation (16) $T_f = T_a + 0.25(T_c - T_a)$	T_c = 50°C T_a= 21°C	T_f =28.25°C
Drying Heat Load From equation (13) $Q_{load} = M_r L_v$	M_r= 2 kg L_v= 2320 kJ/kg	Q_{load} =4640 kJ/kg
Solar Collector Efficiency From equation (38) I_T=356.3 W/m^2 /day $\eta_d = \frac{Q_{load}}{I_T A_{Tunnel} t_d}$	A_C =0.175 m^2 $A_d = 2m^2$ I_T=560 W/m^2	$\eta_d = 0.207$
Volume of Air Required for Removing the Moisture from red pepper. From equation (20) $V_a = \frac{M_w h_{fg} R_a T_a)}{P_a C_p (T_o - T_f)}$	C_p= 1005 J/ kg K P_a = 101325 (N /m^2) R_a = 287J/kgK h_{fg} = 2358.794 kJ/kg	V_a=12.4 m^3
Volume Flow Rate of Air Needed to Effect the Drying From equation (23) $\dot{\upsilon}_a = \frac{V_a}{t_d}$	V_a=12.4 m^3	$\dot{\upsilon}_a$= 1.72 x 10^{-4} (m^3 /s
Mass Flow Rate of Air Needed to Effect the Drying From equation (22)	ρ_a = 0.97kg /m^3 Density of air @	$\dot{m}_a$ = 1.67 x

$\dot{m}_a = \dot{\upsilon}_a \rho_a$	2300m above sea level.	10^{-4} kg /s
Required Drying Rate From equation (35) $m_{dr} = \frac{M_r}{t_d}$	M_r = 2 kg t_d = 20 hrs	m_{dr}= 0.1kg/hr
Total Volume of the pepper vegetable crop on the Trays in the Drying Chamber From equation (21) $W_p = \rho_b \nu_T$	ρ_b= 402.1 kg/m^3 W_p = 3 kg	ν_T =0.0075 m^3
Mass of exit air, $M_a = \frac{M_r \times L_\nu}{C_a(T_{ch} - T_a)}$ $M_e = M_r + M_a$ $\rho_i = \rho_o \times \frac{T_o}{T_a}$ Produced draft in chimney (Height of chimney assumed 2 m) $D_P = (\rho_i - \rho_e) \times H_{ch} \times g$ But actual draft was calculated as follows: $D_a = 0.75 \times D_P$, $Q_c = \frac{Q_a}{n}$, $\dot{\upsilon}_{ch} = \frac{Q_a}{n}$, $a_{ch} = \frac{Q_a}{V}$, $d_{ch} = \sqrt{\frac{4 \times a_{ch}}{\pi}}$	$H_{ch} = 2m$ $n = 1$ ρ_a =0.97kg /m^3 V= 3.32m/s	$D_a = 0.25$ kg/ms^2 $\dot{\upsilon}_{ch} = 1.542$ m$^3/s$ a_{ch}=0.046m^2 $D_P = 0.34$ kg/ms^2 d_{ch}=0.076m
Floor area (drying area) of solar tunnel dryer was calculated as follows: $A_{tunnel} = \pi \times r(r + L)$ $L_{tunnel} = \frac{A_{tunnel} - \pi r^2}{\pi r}$ $A_d = L \times d$	d=0.5 m $r = \frac{d}{2}$ $L_{tunnel} = 4m$ $L_d \cong L_T$	A_{tunnel}=3.34m^2 $\cong$ 4m^2 $A_d = A_T = 2m$

Calculating the power of a solar cell The maximum theoretical power from our solar cell, P_{max}, is the product of the V_{oc} and I_{sc}. $P_{max} = V_{oc} * I_{sc}$ The actual power, P_{actual}, delivered by the solar cell to the fan, in practice, is equal to the voltage across the fan, V, times the current through the fan, I. P_{actual},= $V * I$	V_{oc} = 21.8V * I_{sc} = * 3.6A V = 20.35V I =0.16A	P_{max} = 78.5W P_{actual}, = 3.26W
Calculate the solar cell's efficiency The efficiency of the solar cell is the electrical power out divided by the solar power in. First, calculate the solar power arriving at the solar cell by multiplying the intensity of the sun by the area of the solar cell. The solar power, P_s, intercepted by a cell this size is The maximum theoretical efficiency, E, of the solar cell is estimated to be The actual efficiency of the solar cell when providing power to the motor was	Length =1m Width=0.51 I_T=560 W/m^2 $P_s = S_i * A$ = 560W/m^2 * 0.51m^2 =285.6W $\eta_{theortical} = P_{max} / P_s$ = 78.5W / 285.6W = 0.275 $\eta_{actual} = P_{actual} / P_s$ = 3.25W / 285.6W = 0.0114	A=0.51m^2 P_{actual} =3.26W P_{max} = 78.5W P_s =285.6W $\eta_{theortical}$=0.275 $\eta_{solar\ cell}$=0.0114
Therefore for the overall dryer efficiency is that, the difference of the dryer efficiency to that of the solar cell efficiency:-	$\eta_{overall} = \eta_d - \eta_{solar\ cell}$	$\eta_{overall} = 0.0922$ 19.5%

4.9 3D modeling of the dryer

After sizing and analyzing the design of the dryer, the overall design is determined. The material type and specification for selection are listed above. The 3D modeling design of the dryer was designed using Solid work software tool. Each parts of the dryer are designed in detail and assembled based on the schematic diagram as it shown in figure 4.2 and the detail and assembly of this solar bubble dryer referred in the appendix of this paper.

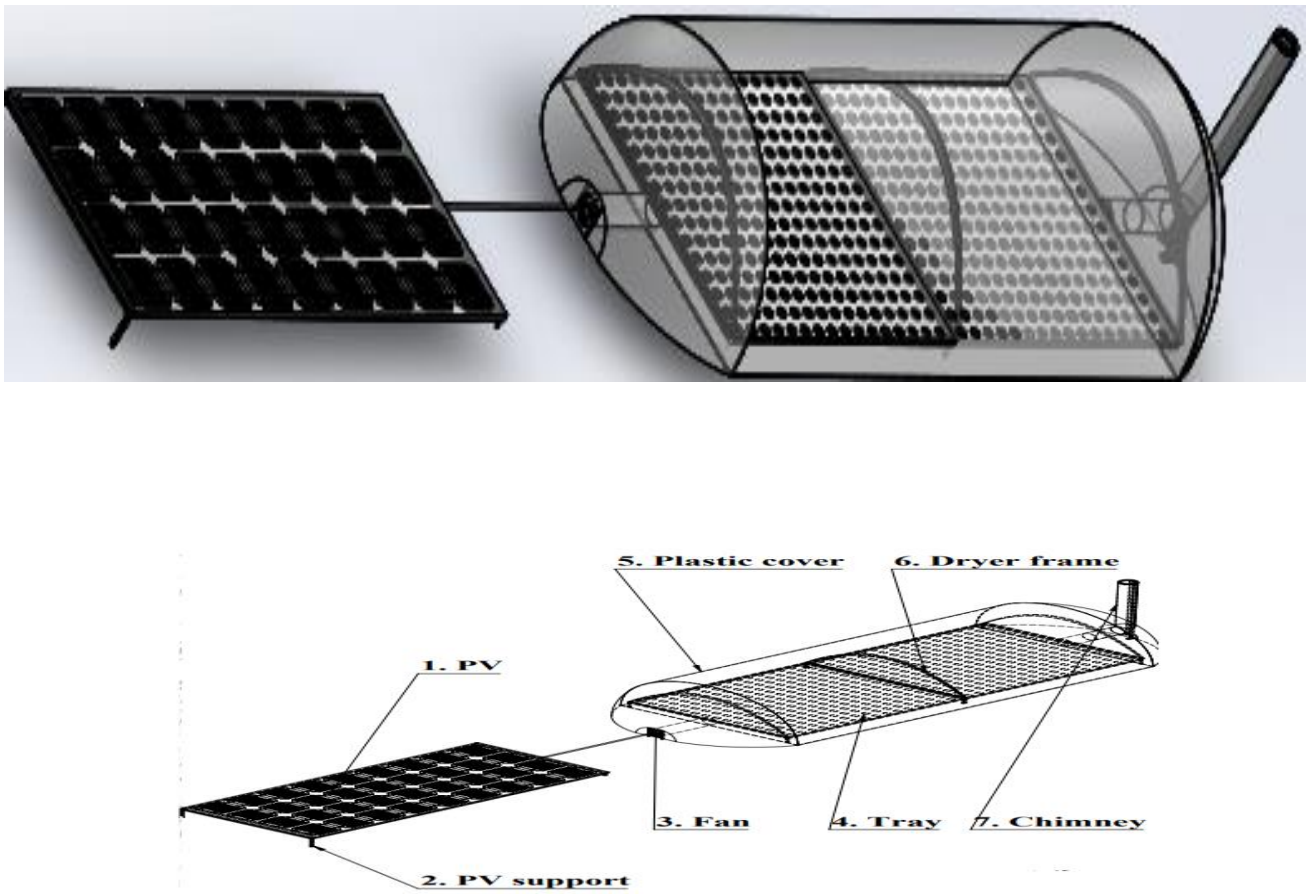


Figure 4.2: 3 D design of solar bubble dryer developed using solid work

Chapter Five

Construction and Experimental setup

5.1 Construction of the dryer

The drying chamber is where the drying sample will be placed and heated by the hot air that comes from the collector. The drying chamber frame is constructed from RHS metal that has a thickness of 1 mm. The main reason to use a 1 mm thickness is that to easily bend it using bending machine and to have low weight to transport or holed it from place to place. The total area of the drying chamber is 2000 mm*620 mm and has a height of 500 mm. The dryer has one try used to dry the sample having a dimension of 2000mm x 56mm positioned at the center of the dryer. It is made of fabric mashed as showed in the figure below to avoid corrosion and contact between the drying sample and the metal frame as well as the plastic cover of the dryer which result quality and healthy dried products. It has very tiny holes used to transfer solar radiation in order to have a uniform heat transfer between the upper and bottom area of the dryer. This result increase improves both the performance and quality of the pepper vegetable crop. In addition to this solar panel used to drive the fan that helps to inflate the plastic top cover. It enhance the quality by preventing impurities like, dust, insect and so on as well as insuring proportional air movement to achieve the objective of this research. The chimney used to facilitate the moist air to leave the dryer by enhancing its pressure.

In this research the main part which is differing from the existing dryer was the fabric meshes try which is located at the center of the dryer so as to expose the drying pepper for heat that generated from the direct solar radiation and the absorber. In addition to this it allow the air circulating in the dryer. It improves the moisture removal rate increase the efficiency of the dryer. The other part is the chimney, which pressurize the exit air so as to live the drying chamber before it creates dew. This insures that the proportional drying rate of the sample throughout the dryer.

Figure 5.1 Parts of SBD and materiyals used

Figure 5.2 SBD and open sun drying

The solar dryer has a solar collector, drying chamber and the Air ventilation. Each parts of the dryer listed and discussed in previous chapter. In this section the dryer setup, the test location, the sensor setup on the dryer and the instruments used while measuring the data are showed in the figure below.

Table 5.1 Materials used for prototype model

No.	Part name	Material	Dimension
1	Collector and dryer cover	Plastic	4mx0.65mx0.5m
2	Dryer and tray support	(rectangular hallow steel)RHS	2mx0.62mx0.5m
3	DC Fan for air circulation	-	-
4	Solar panel	-	-
5	Fabric or mosquito net	Tray	2mx.59m
6	Chimney	PVC	2m
7	Wheel for movement	Plastic made small wheel	

5.2. Dryer Setup and Test Location of solar bubble dryer.

The dryer location is Addis Ababa with geographical location of latitude, 9.2N and Longitude, 38.7E. The solar collector has faced south with east-west orientation and has tilted at 24.2°.

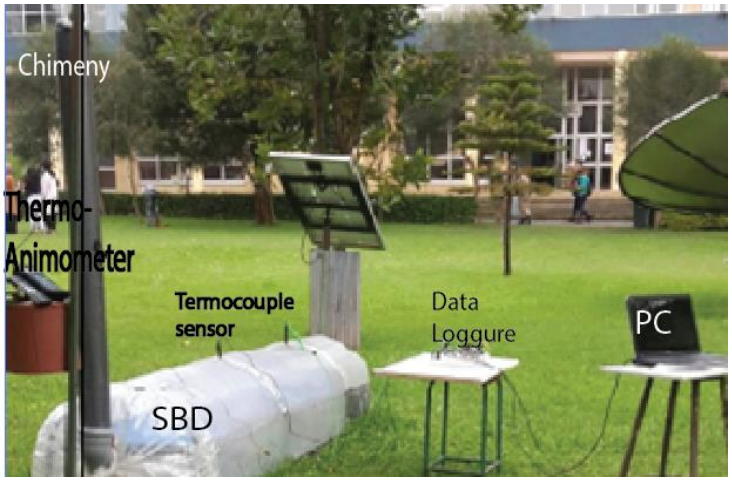


Figure 5.3 Experimental setup of SBD

5.3. Lab VIEW program design

Lab VIEW (Laboratory Virtual Instrument Engineering Workbench) is a virtual instrument software development platform based on graphics compile or graphics language. It has data acquisition, data analysis, signal generation, signal processing, input-output control and other functions. As the first graphic programming system uses the virtual panel user interface and the block diagram to establish virtual instrument, Lab VIEW is widely accepted by the industry, academic and research laboratory. It is regarded as a standard data acquisition instrument and instrument control software.

Virtual instrument generally has two parts: hardware and software. It includes computer, application software and equipment hardware. Lab VIEW software programmer flow is shown on Fig1 and hardware signal transmission is shown below.

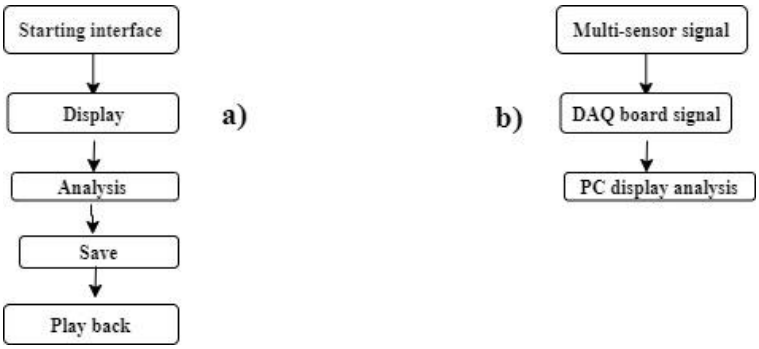


Figure 5.4: Lab view software programing flow (a) and hardware signal transmission (b)

5.3.1 Design of serial communication program

Serial communication is a very important way of communication. It is widely used in various occasions. Virtual Instrument Software Architecture system, which is short for VISA, is a working platform for all of the Lab VIEW control. The selection of time and equipment I/O can be ignored under such standard because driver software is compatible with each other and because VISA function modules are included in the Lab VIEW Instrument I/O's VISA sub-module. The configuration is shown below and is configured by setting the parameters such as the termination character, the resource name, baud rate, data bits and stop bits to VISA. Then it reads and uploads data to the computer through the string to the serial port.

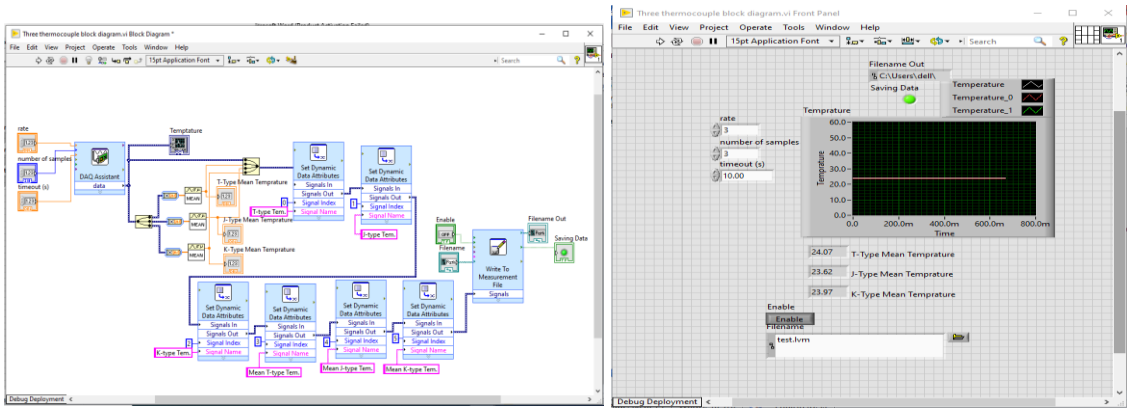


Figure 5.5: Lab view data processing design and Program interface

5.4. Lab view system configuration

5.4.1. System Components

The system mainly consists of two parts, data acquisition system and data analysis system. Transmit the data collected by the size measurement tools through data acquisition card to the computer, then calculate and analyze the data through data analysis system on the computer, so that the data displayed. Program interface includes open source control, numerical display controls, storage controls, chart controls and indicator control. Operator can choose the spreadsheet files from the open source control, select the storage path of calculation results from the storage control, observe the result and variation trend of the data from numerical display controls and chart controls, and determine whether the parts size data reaches dangerous range from indicator control (Guoqing et al., 2015).

5.4.2 Instruments Used for Data Collection

The front panel and block diagram used in this study is shown in Figure 5.2 below. The temperatures at various positions of the dryer were measured with K-type thermocouples (accuracy ±0.2C). Three temperature sensors were used to measure the temperature by locating or positioning them on three different places using three thermocouple temperature sensors on the solar bubble dryer and connected to a PC through a Data Acquisition system (DAQ). The thermocouples were place at the inlet, middle and outlet of the dryer to measure the temperature inside the dryer.

Figure 5.6: Front Panel and Block Diagram used in Lab view

The weight of the sample was measured by using Analytical balance of model No. JF2004, Max. Capacity: 200g and have readability of 0.0001g. The outlet wind velocity and temperature was measured by using EXTECH instruments, heavy duty CFM Thermo-Anemometer of Model 407113, which contain an anemometer and thermistor on it with a resolution 0.01 m/s and 0.1 °C and accuracy ± 0.03 m/s and ± 1.2°C respectively. The other instrument used for measuring relative humidity and ambient temperature is named as Temperature-humidity –Instrument with dew point calculation. Its technical data shows that the measuring range is varied from -40 - +70°C and display resolution of 0.1°C with an accuracy of ± 0.5°C were as the humidity instrument have a measuring range of 0 - 99% and its display resolution 0.1% and have an accuracy of ± 3% (20-90%).

Table5.2 Instrument used for data collection

Instrument/ measurement type		Range	Resolution	Accuracy(%rdg)
EXTECH Heavy duty CFM Thermo-Anemometer		Air velocity	0.50-40m/s	0.01m/s $\pm(2\% + 0.2m/s)$
	Air flow	0-999900m^3/m	0.001-100	0-9999m^2
Dew point Pro	Exit Air temperature	0-80°C	0.1°C	0.8°C
Temperature-Humidity-Instrument	Ambient Temperature	-40-+70°C	0.1°C	$\pm$0.5°C
	Humidity	0-99%rF	0.1%	$3\%(20-90\%)$
Analytical weighting Balance	Weight	0-200g	0.0001g	
General Moisture Meter	Moisture	5-50		
Data logger	Temperature	As required		As required

Ambient temperature and humidity are measured using Temperature-humidity-instrument were as wind velocity and out let temperature of the dryer were measured using EXTECH Heavy duty CFM Thermo-Anemometer and General Moisture Meter used to measure the moisture content of the product from wet base. It has two sensors so the product has to contact both sensors to detect the wet content of the product. In addition to this the weight of the sample was measured by using Analytical weighing balance with accuracy of ±0.0001 g. The resolution, accuracy and rage of the instrument are illustrated and explained both in table and figure bellow respectively.

Table 5.7: Weighing Balance and Velocity and Temperature Measuring Device

In addition to this both open sun dryer and solar bubble dryer are depends on solar radiation they are effective when there is sunshine otherwise the sample may gain moisture due to unfavorable weather condition and this may result increasing the drying time of the sample. In order to avoid this problem desiccator is important laboratory equipment used to prevent and maintain the amount of moisture of the sample. Note that drying time was considered when solar radiation was available to investigate the technical performance of SBD dryer. Drying time is directly affected by ambient air temperature and relative humidity. Low ambient air temperature and higher relative humidity decreased the drying rate.

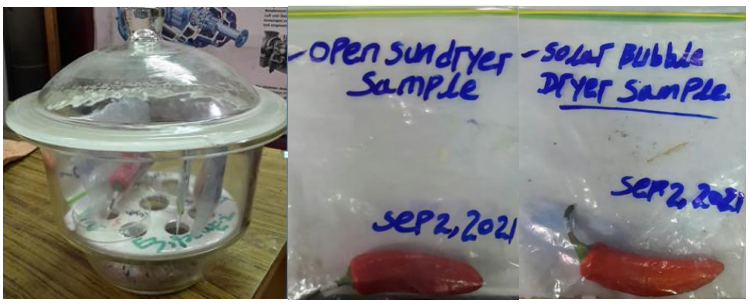


Table 5.8: desiccator and plastic bag used for saving the sample of pepper for overnight

5.5. Sensor positioning of the dryer

The main objective of this research is to evaluate the performance of the solar bubble dryer by overcoming the limitations of the traditional type open sun drying type. In order to obtain this objective the temperature sensing T, J, K type thermocouples are located on

three different places on the dryer so as to sense and transfer data in to the data logger as shown in the figure below. So the measuring system was installed in and around the dryer. Figure 5.2 shows the positioning of the sensors used while measuring the temperature performance. Which is represented by bold dotes are the instrument used to measure the temperature integrated with the instrument called National Instrument NI cDAQ-9172. The tilt angle of the solar panel is designed to be 24.2 to the south facing as shown in the figure below were calculated in the previous chapter.

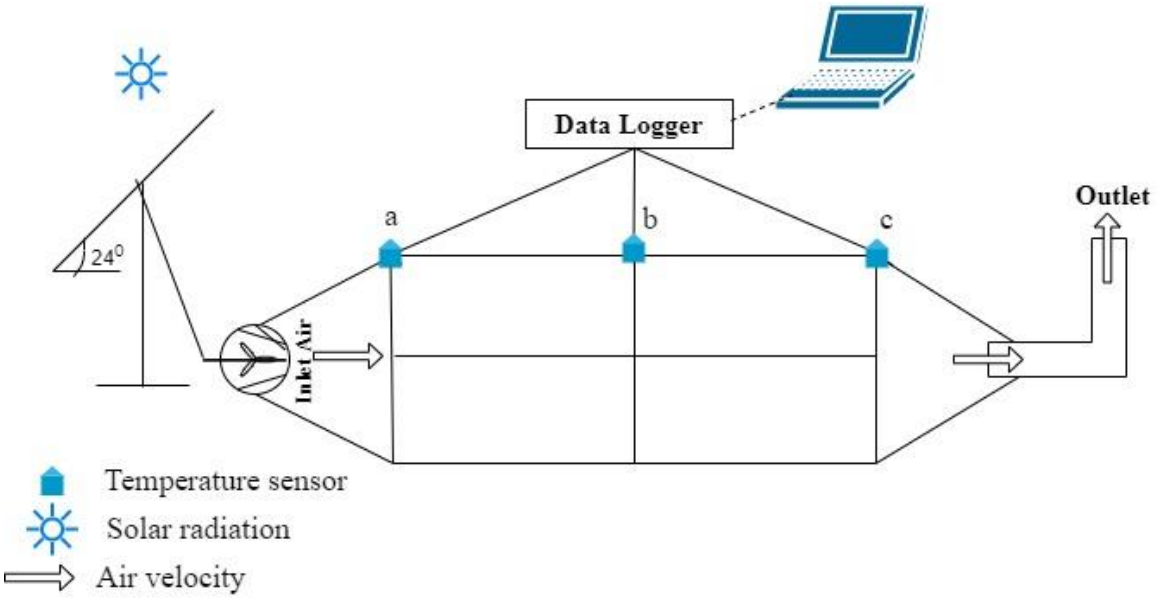


Figure 5.9: Sensor positioning and Layout of SBD experimental set up

Chapter Six

Result and Discussion

This section describes the output of the evaluation and discusses each result. It specifically describes the solar radiation, temperature variation and the humidity variation in the drying chamber and finally the efficiency of the overall dryer will be discussed. The experiment was conducted for five days for both with and without load. Three thermocouple tests were used with load to evaluate the performance of the solar dryer using pepper vegetable crop as a sample. Then after measuring the inlet and final temperature of the collector, the collector efficiency, dryer chamber efficiency of the dryer is discussed. Each sample has a weight of 3kg. While measuring the performance of the dryer the test was conducted for four hours per day because of the rain on the afternoon since it is rain season.

Figure 6.1: Schematic diagram of modified solar bubble dryer

Figure 6.1a shows the schematic diagram of the modified SBD for drying pepper vegetable crop. The existing SBD originally used for paddy grain drying is modified with an additional perforated floor for elevating the pepper vegetable crop (Figure 6.1b). This perforated floor or try consists of a fabric (mosquito net) and supporting frame made of RSH frame. This modification enables the drying air moving both on the top and underneath of the pepper vegetable crop to increase drying efficiency and prevent them from sticking on the bottom plastic film if the modification of SBD does not have a perforated floor. The drying tunnel bubble is maintained by the blower and chimney during its operation by facilitating a convenient air circulation in the dryer and remove the moist air before it getting wet (Figure 3c). As the result the drying efficiency of the dryer increase comparing to the existing one which reported by (Alam et al., 2020).

6.1 No load test

6.1.1 Relative humidity, temperature and solar radiation variation

The no load test was performed during the month of August to September 2020 in the mechanical Engineering Workshop, Addis Ababa University, Addis Ababa Institute of Technology. The variation of solar radiation, temperature and relative humidity distribution through the drier (Romuli et al., 2019). The result shows in figure 6.2 that the maximum and minimum temperature recorded 28.6 and 21°C respectively were as the relative humidity ranging in the rage of 41- 51.4% which lies in the range reported by (Hussein et al., 2017).

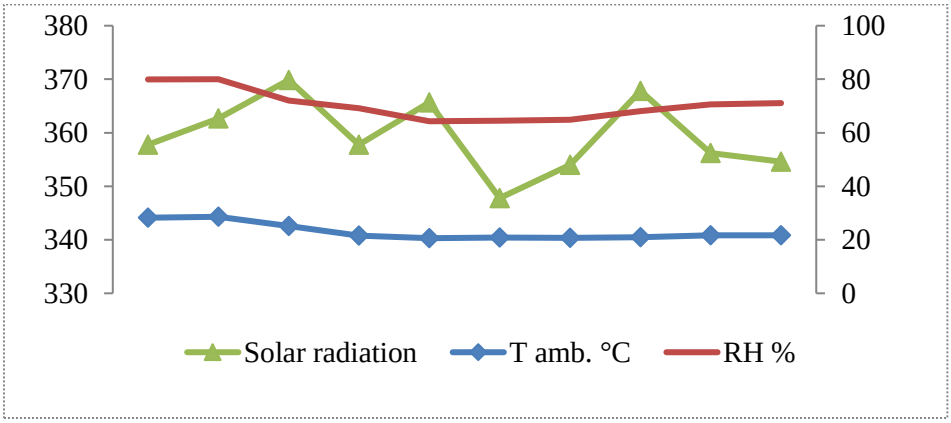


Figure 6.2: Relative humidity, temperature and solar radiation variation

As it is illustrated in the above figure the temperature distribution varies with respect to the ambient temperature. The average ambient temperature, tray temperature, outlet temperature and relative humidity recorded as20°C, 25.12°C, 22.4°C and 49.1% respectively. The maximum tray temperature was found and recorded 35°C at 11:25am on Friday August 27,2021were as the ambient temperature was 25°C and the outlet temperature was 30.8°C this temperature variation happen because of the dryer has also used as a collector to raise the temperature inside the dryer.

6.1.2 Temperature and relative humidity

In the SBD at different distances from the SBD inlets at a particular time, where the SBD inlets were represented as 0 m, are presented in Figure below. A rapid increase of temperature from the collector to half the length of the dryer was detected. As it is seen on the graph the tray temperature was getting higher in the time of 11:10-15 to 11:20-25am, from 22 to 29°C as reported by (Romuli et al., 2020). Subsequently, the

temperature was slightly lower near the outlet than the temperature in the middle of the dryer. On the other hand, the relative humidity was varied with respect to the ambient temperature along the dryer.

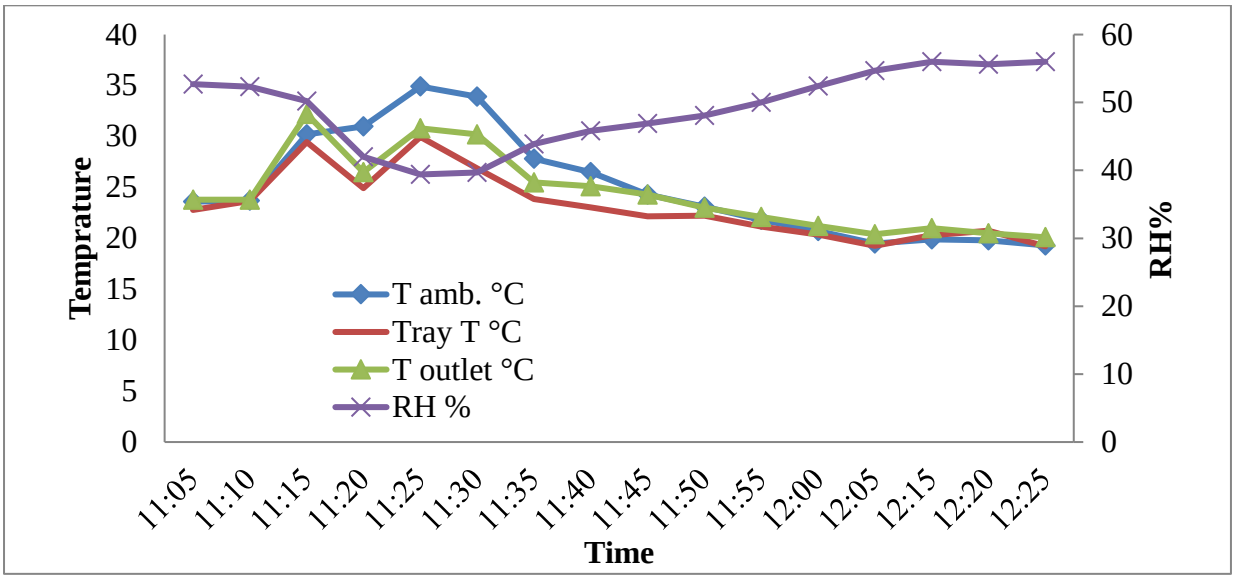


Figure 6.3: Temperature variations in the drying chamber of the SB dryer no load test

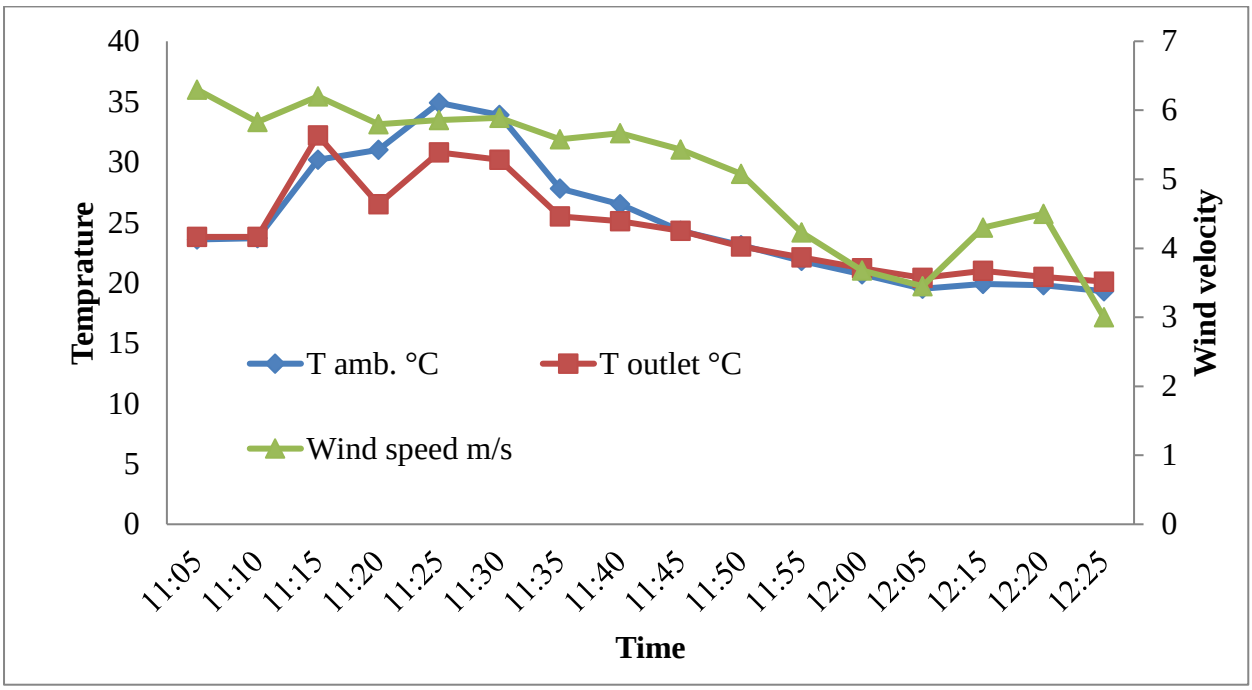


Figure 6.4: No load test wind velocity vs. temperature variation

6.2 Load test

6.2.1 Temperature distribution

Experimental testing was continued until it attains the safe storage moisture content for the pepper vegetable crop. The measurement was taken both manually and automatically for four hours for recording temperature during the drying process. The figure below shows the relationship of drying air temperature variation at different locations of SB dryer with ambient air temperature of rainy or winter season. It is observed that the temperature inside the drying chamber was greater than that of ambient temperature of air by an average of 3 to 5°C using three thermocouple temperature sensors. Seveda (2012) Reported that the maximum temperature gradient between the ambient air and drying air inside the dryer was observed in summer month and minimum was observed in winter month for drying industrial product in a solar tunnel dryer. The maximum temperature variation occurs in mid-day from 11:10AM to 11:40AM. This resulted in a maximum variation of drying air increases the drying rate of pepper vegetable crop. It is indicated that the temperature was relatively higher at middle point of the dryer by about 5°C compare to entrance and end point with no significant difference. It proves that air temperature uniformly distributed all over the drying section. Related type of result was also reported for development and performance evaluation of hybrid dryer for quality grain seeds by Hossain et al. (2012) and experimental investigation of solar bubble dryer for rough rice drying in Bangladesh by (Alam et al., 2020).

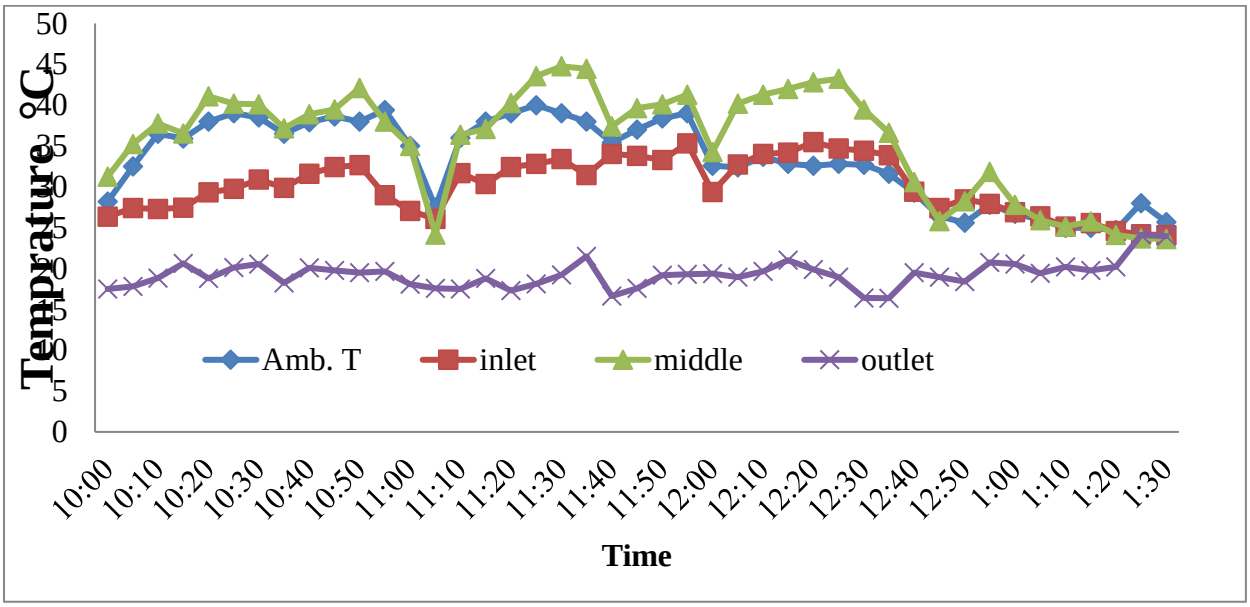


Figure 6.5: Temperature variations in the drying chamber of the SB dryer load test

6.2.2 The drying temperature, relative humidity and solar radiation

Based on the figure bellow the results illustrate that the drying temperature was greater than the ambient temperature, whereas the relative humidity under this system was lower than the ambient relative humidity. In addition, the drying temperature and relative humidity values significantly differed at approximately 15°C and 30%, respectively, within the drying period (Ahmad Fudholi et al., 2013a). This explicitly indicates that the DR in solar drying is higher than that in open sun drying. On the other hand, the efficiency of the collector varied with the average value of approximately 15%, at the drying air flow rate of 3.53 x10^{-4} kg /s. The collector and dryer thermal efficiency rates for the 5 days of drying are shown in figure, which illustrates that the thermal efficiency of the collector is increased at low solar radiation as it is clearly reported by (Ahmad Fudholi et al., 2013b).

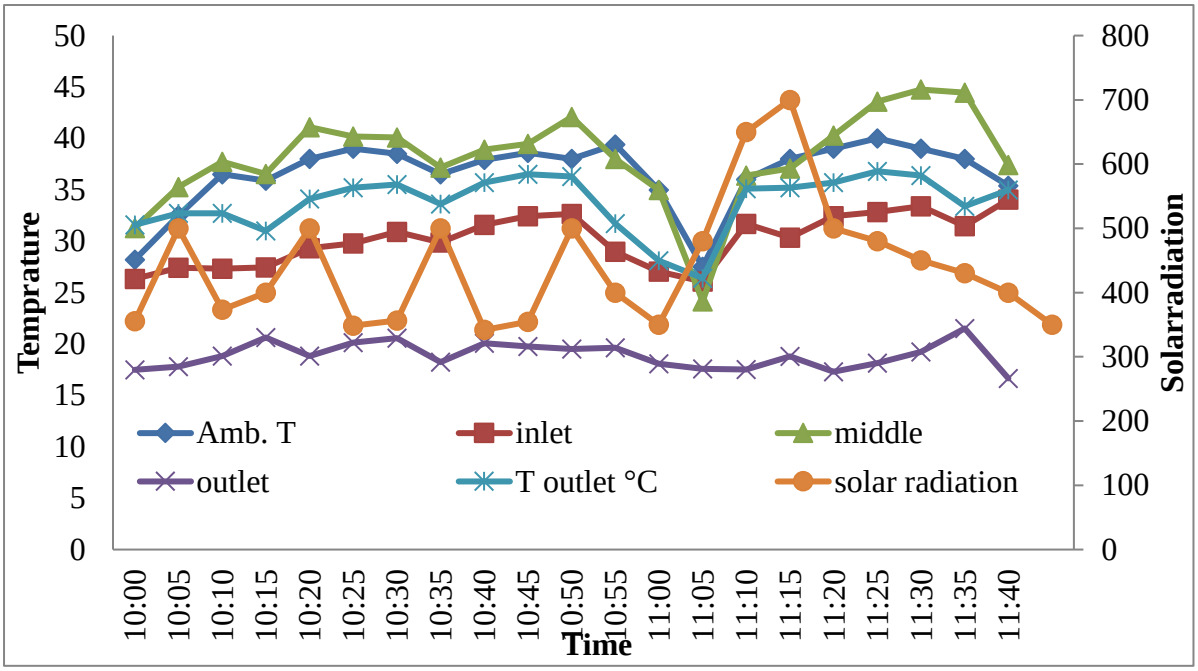


Figure 6.6: Temperature, relative humidity vs. solar radiation variation

6.2.3. Moisture distribution

The moisture distribution of the pepper vegetable crop in the solar bubble dryer was faster than that of the open air dryer. The weight loss were recorded every half an hour interval in order to realize the reduction weight of the drying sample. As it is known that the moisture content reduces in day time but increases in next morning because of entering high humid air over the pepper layer at night time. The re-wetting phenomena of the crop occurred during the night time if the drying is not completed in one day (Ashfaq et al.,

2015). But this problem was resolved using the equipment called dissector that helps to contain the moisture or weight of the sample until the next day experiment. This equipment resolves the re-watering phenomena of the pepper vegetable crop and helps to accurately conduct the experimental process of the drying product.

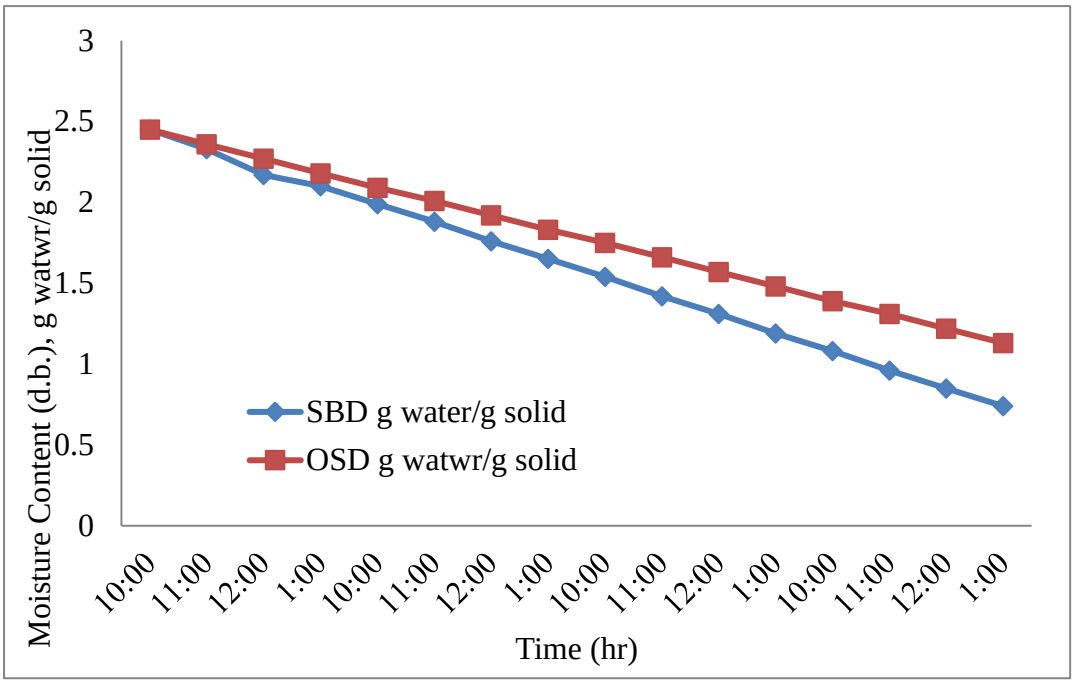


Figure 6.7**:** Moisture content (d.b) of pepper vegetable crop for SBD & OSD

The drying curve of pepper vegetable crop inside the SBD and under sun drying is presented in the figure above. The total drying time was 20 h, whereas the final moisture content of the pepper dried in the SBD and sun drying was 13.6% and 17.7% wet base respectively as it similarly reported by (S. Abubakar et al., 2016). The average drying rate of the pepper vegetable crop was found more than that of open sun dryer which was 3.53 $x10^{-4}$ kg /sand it takes 5days of 4hr/day to be at its safe storage condition (Kilanko et al., 2019). It can be seen that the SBD showed a good drying performance than the traditional sun drying, in addition to this the physical appearance of the dried product is more attractive and looks better as well as drayed in a proportional manner as it is observed during the experiment. This is due to the air blows at the center of the dryer and circulates the hot temperature proportionally on both top and bottom surface of the tray than that of the open sun drying.

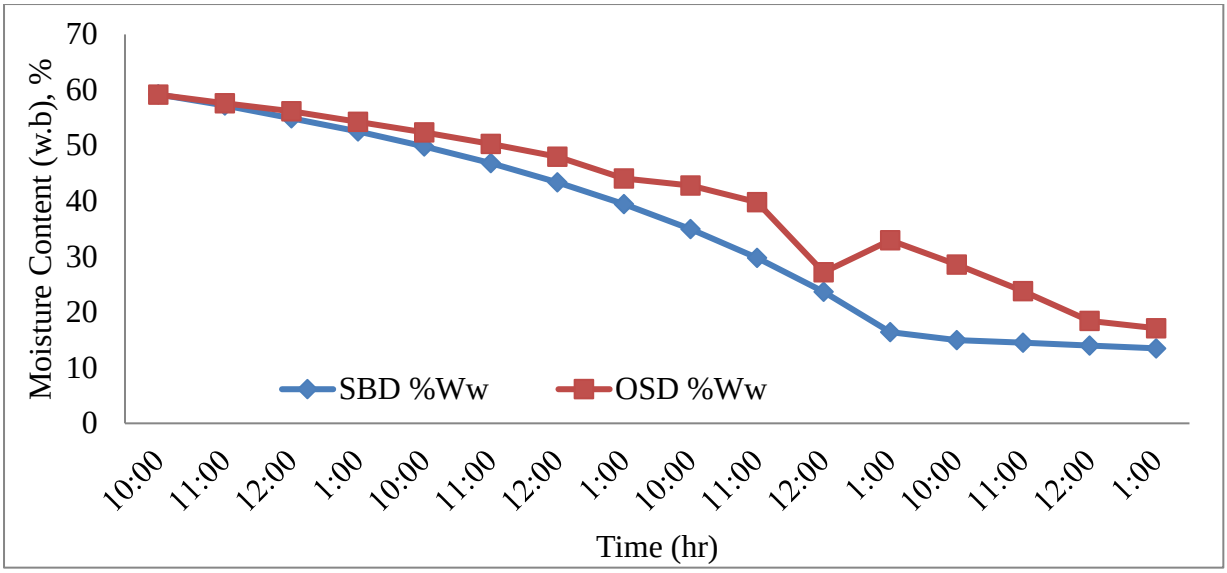


Figure 6.8: Moisture content (w.b) with time of pepper vegetable crop for SBD & OSD

It can be seen that the SBD showed a better drying performance than sun drying, particularly after day 3. A visible reduction of the moisture content in the pepper vegetable crop under sun drying was detected between 10:00 and 12:00am on day 3. This might be due to lower relative humidity of the ambient air which was observed during the experiment. A lower relative humidity of the air causes a higher vapor pressure deficit of the air, which accelerates the drying rate as similar result were reported by (Bala, 2009; Romuli et al., 2019).

6.2.4 Moisture removal rate of SBD

The moisture removed from the sample is measured in two ways, by using the measurement device called moisture meter and the second is using analytical balancing machine or analytical weighting scale. Moisture content of pepper was observed by applying both open sun and solar bubble dryer methods in order to understand the difference between them by recording the result on the data spread sheet every 30 minute interval. The moisture content of pepper vegetable crop does not build up in every next day since it was packed in a zipped plastic. Which will not let it to loss or gain moisture over night as well as the zipped plastic were stored in a spatial container called desiccator which do not loss or gain moisture due to temperature difference. As it is clearly seen on the picture above the final moisture content of the sample pepper vegetable crop dried in both solar bubble dryer and open or traditional type dryer are 13.6% and 17.7% and also having a weight of 7,2233g and 10.6163g respectively.

Figure 21 Final moisture content of pepper vegetable crop on both SBD and OSD

6.2.5 Drying performance

Dryer performance of SB dryer was evaluated in winter season compared with traditional sun drying method. The pepper vegetable crop was dried from initial weight 23.8745 to final weight 7.2233g during the time of practical experiment. The total drying time for obtain this result is five days of each day have four experiment hours because, it is raining almost all afternoons of the time as it is rainy season in Ethiopia. The moisture removal rate and drying efficiency was varied in different trials due to variations of sunshine hour, temperature and relative humidity. The initial moisture content of sample was also an important factor in drying period. The less initial moisture content required less drying time (Ahmad Fudholi et al., 2013a). The moisture removal rate was increased with the increasing drying temperature of pepper vegetable crop. On the other hand, drying rate and drying efficiency were observed less in winter season than that of summer season due to the effect of rain, cold and foggy weather as well as low temperature. Aghbashlo et al. (2015) Explained that the drying rate of the dryer getting higher when the drying air temperature provided by the solar collector getting high. This is due to the intensive heat and mass transfer followed by a high rate of water evaporation.

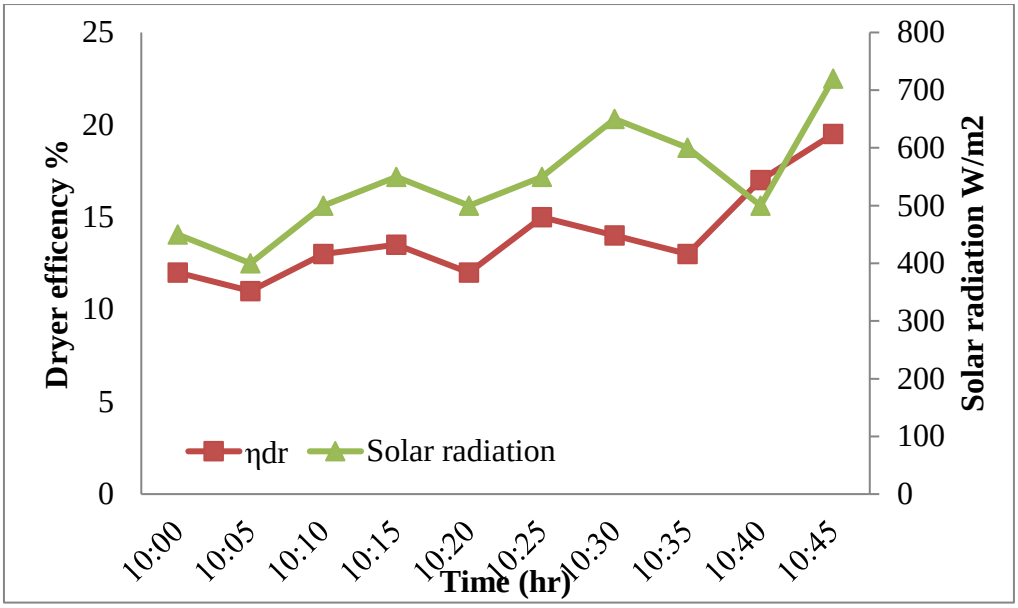


Figure 6.9: Dryer efficiency vs. solar radiation variation

Drying of red chili in solar drying reduced the moisture content from approximately 71% to approximately 13% in 20 h. At the average solar radiation of 356.3 W/m2 and mass flow rate of 3.53 x10^{-4} kg /s, and the collector and drying system efficiencies were 15%, and 22.6%, respectively. Even though the initial moisture content of pepper vegetable crop and rice are too different, but this dryer efficiency much more efficient and faster than what it reported by (Alam et al., 2020).

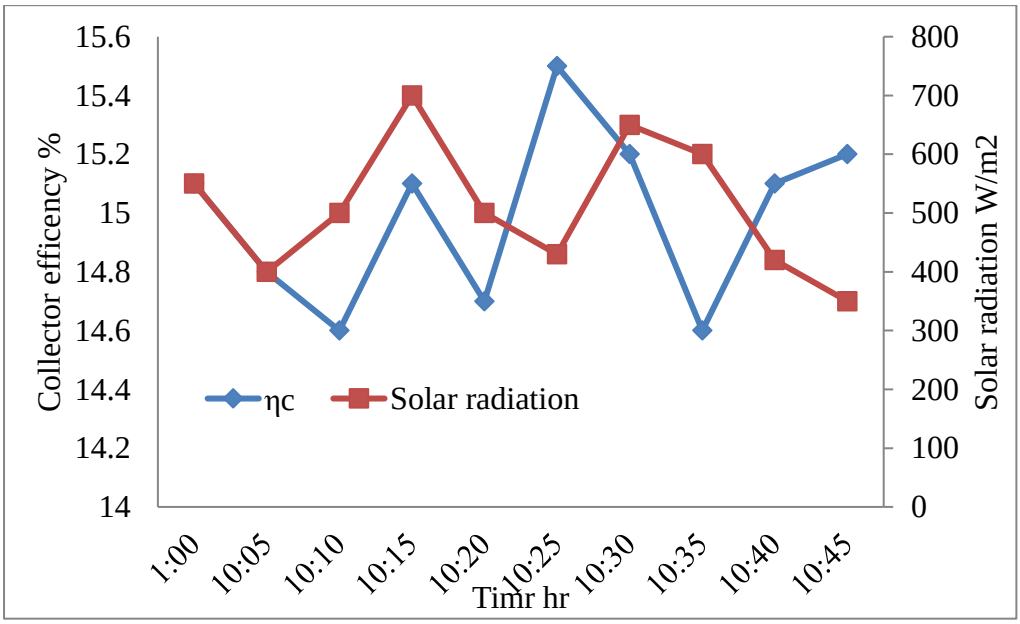


Figure 6.10: variation of Collector efficiency vs. solar radiation

Table 6.1 shows the widely used kinetics models of pepper vegetable crop which may fits for drying pepper vegetable crop. In order to normalize the drying curves, the data involving the dry basis moisture content versus drying time were transformed to a dimensionless parameter called the moisture ratio versus time. The drying data as the moisture ratio (MR) versus drying time were fitted to the six drying models presented by previous workers (Table1). The results of the statistical analysis under taken on these models for solar drying in the solar bubble dryer models were evaluated based on R^2, $x^2$and RMSE .The model that best predicts the drying process will have higher value of R^2 and lower values of $x^2$and RMSE. The logarithmic model was found to be suitable model for describing the drying curve of the thin layer of red pepper drying process, and the same result were reported by (Fadhel et al., 2014).

Table 6.1: Drying kinetics models of pepper vegetable crop

Model no.	Model constant	x^2	R^2	$RMSE$
1	k=0.05837	0.00837	0.88904	0.09149
2	a=0.94208, k=0.05531	0.00824	0.89229	0.09076
3	**a=0.98796, k=0.04359, c=0.08125**	**0.00533**	**0.96552**	**0.05003**
4	a=0.47104, k_0=0.0552972, b=0.47104, k_1=0.0553017	0.00847	0.89229	0.09203
5	k=0.00688, n=1.164944	0.00817	0.90123	0.07028
6	a=0.01023, b=0.00025	0.00824	0.90032	0.08973

Chapter Seven

Conclusion and Recommendations

7.1 Conclusion

Proper drying of pepper vegetable crop has been one of the major problems in Ethiopia. The performance evaluation of SBD dryer was conducted in AAiT mechanical engineering workshop in winter season. The results showed that the moisture content of pepper vegetable crop was reduced from about 71 to 13% in 20 hours of operation. The temperature distribution and moisture removal rate was uniform in all locations of SBD dryer during drying time. The total drying time of the dryer was 20 hours which saves 20% of the drying time of the pepper vegetable crop when it was comparing with open sun dryer. The drying rate and the efficiency of the dryer and the collector were found 3.53 x10^{-4} kg /s, 22.6%, 15% respectively. The logarithmic thin layer drying model fits for pepper vegetable crop than other model based on the value ofR^2, $x^2$and RMSE. It was economical feasible when compared to walk-in type hemi cylindrical solar tunnel dryer. And also the technical performance and the experimental observation resulted that the pepper vegetable crop sample used to dry in the dryer has better quality, quantity and proportional drying profile than open sun drying. Therefore, it was conclude that the modified solar bubble dryer can be one of the options for drying of pepper vegetable crop. It is recommend that this dryer will be an option to dry vegetables to reduce the alarming postharvest losses in the country.

7.2 Recommendations

The performance of the dryer can further be enhanced by making modifications on:-

- The modular feature of solar bubble dryer can minimize the postharvest loss of pepper vegetable crop.
- The dryer should also tested by other vegetables than pepper to evaluate and compare the performance of the dryer.
- The dryer should be tested for a year in order to investigate the different outcomes with respect to the season of the country.
- Integrated with backup heat storage in order to reduce the drying time.

Reference

Abubakar, S. (2017). *Design, simulation, construction and performance comparison of mixed mode solar crop dryers with and without thermal storage.*

Abubakar, S., Anafi, F. O., Umaru, S., & Sahabi, A. A. (2016). Performance evaluation of a natural convection solar crop dryer. *ResearchGate*.

Admassu, S. (2015). Post-harvest sector challenges and opportunities in Ethiopia *Food Technologist, Ethiopian Agricultural Research Organization Addis Ababa, Ethiopia*.

Aghbashlo, M., Muller, J., Mobli, H., Madadlou, A., & Rafiee, S. (2015). Modeling and Simulation of Deep-Bed Solar Greenhouse Drying of Chamomile Flowers. *Drying Technology: An International Journal*, *0*, 1-12.

Ahmad, N. T. (2001). Agricultural solar air collector made from low-cost plastic packing fil. *Renewable Energy, 23*, 663–671.

Ahmed, Z. A. A. (2009). *Mathematical Modeling of Thin layer Solar Drying of*

of Gum of Acacia senegal and Acacia seyal. (PHD), University of Khartoum.

Akpinar, Bicer, Y., & Yildiz, C. (2003 b). Thin layer drying of red pepper. *Journal of Food Engineering, 59*, 99-104.

Al-Neama, M. A., & Farkas, I. (2016). Influencing of solar drying performance by chimney effect. *HUNGARIAN AGRICULTURAL ENGINEERING, 30*(11).

Alam, M. A., Saha, C. K., Alam, M. M., Manir, M. R., Hasan, M., & Rashid, M. M. (2020). Experimental investigation of solar bubble dryer for rough rice drying in Bangladesh. *Journal of Bioscience and Agriculture Research*, *23*(02), 1920-1930.

Alghoul, M. A., Sulaiman, M. Y., Azmi, B. Z., & Wahab, M. A. (2005). Review of materials for solar thermal collectors. *Anti-Corrosion Methods and Materials ·, 52*(4), 199-206.

Alibas, I. (2012). Selection of a the Best Suitable Thin-Layer Drying Mathematical Model for Vacuum Dried Red Chili Pepper. *Journal of Biological and Environmental Sciences, 6*(17).

Aliyu, E., & S.J. Applied Thermodynamics *Heat Transfer*.

Arslan, A., Soysal, Y., & Keskin, M. (2020). Mathematical Modeling, Moisture Diffusion and Color Quality in Intermittent Microwave Drying of Organic and Conventional Sweet Red Peppers. *AgriEngineering, 2*, 393–407.

Awel, M. (2017). Adaptability Study of Hot Pepper (Capsicum spps.) Varieties at Senegal, Southern Ethiopia. *Journal of Plant Sciences, 5*(5), 130-133. doi:10.11648/j.jps.20170505.11

Axtell, B. *Small Solar Tunnel Dryer*.

Bagher, A. M., Vahid, M. M. A., & Mohsen, M. (2015). Types of Solar Cells and Application. *American Journal of Optics and Photonics, 3*(5), 94-113.

Bala, B. K. (2009). Solar drying of fruits, vegetables, spices, medicinal plants and fish: Developments and Potentials. *International Solar Food Processing Conference*.

Balcioglu, H., EL-Shimy, M., & Soyer, K. (2017). Renewable Energy– Background. *Research Gate Economics of Variable Renewable Sources for Electric Power Production*, 17-34. doi:10.6084/m9.figshare.6169460

Bastien, D. (2015). *Methodology for Enhancing Solar Energy Utilization in Solaria and Greenhouses.* (Doctor of Philosophy (Building Engineering) at Concordia University), Montréal, Québec, Canada.

Bateno, T., & Buke, T. (2018). Postharvest Losses and Management Assessment of Commercial Fruit and Vegetable at Wolaitazone, at Sodo Market. *International Journal of Research and Innovations in Earth Science, 5*(3).

Boh, L. T. (2013). *Analytical Study and Fabrication of a Solar Based Dryer for Pepper-Drying (Agricultural Product Drying).* (Submitted for the degree of Master of Engineering), Swinburne University of Technology Sarawak Campus, Malaysia.

Bolaji, B. O. (2005). Performance Evaluation of a Simple Solar Dryer for Food Preservation. *The 6th Annual Engineering Conference Proceedings*.

Calado, T., Venancio, A., & Luıs´Abrunhosa. (2014). Irradiation for Mold and Mycotoxin Control A Review. *ComprehensiveReviewsinFoodScienceandFoodSafety, 13*. doi:10.1111/1541-4337.12095

Campillo, C., Fortes, R., & Prieto, M. d. H. (2014). Solar Radiation Effect on Crop Production. *Research Gate Solar Radiation*, 167-194. doi:10.5772/34796

Çengel, Y. A., & Boles, M. A. (2015). *Thermodynamics an engineering approach*.

Chand, T. K., M.K.Mohanty, & R.C.Mohanty. (2015). An Overview of Solar Energy and its Application in Solar Dryers with Brief Concept of Energy and Energy Analysis. *International Journal of Research (IJR), 2*(1).

Chen, M. (2019). *Development of pico solar dryer (POD) for farm level grain drying by small holder farmers in Africa.* (Master of Science), School of Agricultural & Biological Engineering West Lafayette, Indiana.

Chua, K. J., & Chou, S. K. (2003). Low-cost drying methods for developing countries. *Trends in Food Science & Technology, 14*, 519–528.

Committee, S. S. S. C. (2010). *Spice Sub-Sector Strategy for Ethiopia* Retrieved from

Coradi, P. C., Melo, E. d. C., & Rocha, R. P. d. (2014). Mathematical modeling of the drying kinetics of the leaves of lemon grass (Cymbopogon citratus Stapf) and its effects on quality. -, *32*(4), 43-56.

Dadi, J. F., Jujara, I. H., Malek, J. I., Patel, P. S., S., P., Bhadoriya, & Patel, V. M. (2016). A Review Paper on Solar Dryer. *International Journal of Modern Trends in Engineering and Research (IJMTER), 03*(03).

Darvishi, H., Asl, A. R., Asghari, A., Azadbakht, M., Najafi, G., & Khodaei, J. (2014). Study of the drying kinetics of pepper. *Journal of the Saudi Society of Agricultural Sciences, 13*, 130-138.

Dehbi, A., Mouradb, A.-H. I., & Bouaza, A. (2011). Ageing Effect on the Properties of Tri-Layer Polyethylene Film Used as Greenhouse Roof. *Procedia Engineering, 10*.

Delelegn, S. (2011). *Evaluation of elite hot pepper varieties (capsicum species) for growth, dry pod yield and quality under jimma condition, south west ethiopia.* (M.Sc. Thesis), Jimma University.

Dixon, J. C. (2007). *The Shock Absorber Handbook* (Second Edition ed.).

Duffie, J. A., & Beckman, W. A. (2013). *Solar Engineering of Thermal Processes* (Fourth Edition ed.). Canada: John Wiley & Sons, Inc., Hoboken, New Jersey.

Ekechukwu, O. V., & Norton, B. (1995). Design and measured performance of a solar chimney for natural-circulation solar-energy dryers. *International Centre for Theoretical Physics, Trieste, Italy*.

Erbay, Z., & Icier, F. (2010a). A Review of Thin Layer Drying of Foods: Theory, Modeling, and Experimental Results. *Critical Reviews in Food Science and Nutrition, 50*(5), 441 - 464.

Erbay, Z., & Icier, F. (2010b). A Review of Thin Layer Drying of Foods: Theory, Modeling, and

Experimental Results *Critical Reviews in Food Science and Nutrition, 50*(5), 441 - 464.

Ertekin, C., & Firat, M. Z. (2015). A Comprehensive Review of Thin Layer Drying Models Used in Agricultural Products. *Critical Reviews in Food Science and Nutrition*.

Esayas, K., Shimelis, A., Ashebir, F., Negussie, R., Tilahun, B., & Gulelat, D. (2011). Proxmate Composition, Mineral Content and Antinutritional Factors of Some Capsicum(Capsicum annum) Varieties Grown in Ethiopia *Chemical Society of Ethiopia*, *25*(3), 451-454.

Eze, J. I., & Agbo, K. E. (2011). Comparative studies of sun and solar drying of peeled and unpeeled ginger. *American Journal of Scientific and Industrial Research, 2*(2), 136-143.

Fadhel, A., Kooli, S., Farhat, A., & Belghith, A. (2014). Experimental Study of the Drying of Hot Red Pepper in the Open Air, under Greenhouse and in a Solar Drier. *International Journal of Renewable Energy & Biofuels, 2014*, 1-14.

Fernando, J. A. K. M., & Amarasinghe, A. D. U. S. (2016). Drying kinetics and mathematical modeling of hot air drying of coconut coir pith. *Fernando and Amarasinghe SpringerPlus, 5*(807).

Forson, F. K., Nazha, M. A. A., Akuffo, F. O., & Rajakaruna, H. (2007). Design of mixed-mode natural convection solar crop dryers: Application of principles and rules of thumb. *Renewable Energy, 32*, 2306-2319.

Foste, S. A. (2013). *Construction and Performance Testing of a Mixed Mode Solar Food Dryer for Use in Developing Countries.* (Theses and Dissertations), Brigham Young University. (3442)

FrankSchiavone, D. (2011). *Development and evaluation of a natural-convection solar dryer for mango in rural haitian communities.*

Fudholi, A., Othman, M. Y., Ruslan, M. H., & Sopian, K. (2013a). Drying of Malaysian Capsicum annuum L. (Red Chili) Dried by Open and Solar Drying. *International Journal of Photoenergy*.

Fudholi, A., Othman, M. Y., Ruslan, M. H., & Sopian, K. (2013b). Drying of Malaysian Capsicum annuum L. (Red Chili) Dried by Open and Solar Drying. *Hindawi Publishing Corporation International Journal of Photoenergy*, 9.

Fudholi, A., Sopian, K., Ruslan, M. H., Alghoul, M. A., & Sulaiman, M. Y. (2010). Review of solar dryers for agricultural and marine products. *Renewable and Sustainable Energy Reviews, 14*(1), 1-30. doi:10.1016/j.rser.2009.07.032

Fuller, R. J. (2010). Solar drying - A technology for sustainable agriculture and food production. *SOLAR ENERGY CONVERSION AND PHOTOENERGY SYSTEMS, 3*.

Gangwar, R. k., Tyagi, S., Kumar, V., Singh, K., & Singh, G. (2014). Food Production and Post Harvest Losses of Food Grains in India. *Food Science and Quality Management, 3*(1).

Gatea, A. A. (2010). Design, construction and performance evaluation of solar maize dryer. *Journal of Agricultural Biotechnology and Sustainable Development, 2*(3), 039-046.

Gebrtsadkan, G., Tsehaye, Y., Libanos, W. G., Asgele, K., G/Micael, Y., Hagos, H., & Abreha, E. (2018). Enhancing productivity of Pepper (Capsicum annuum L.) by using improved varieties. *agricultural-science-botany, 2*(2), 6-9.

Getahun, E., Gabbiye, N., Delele, M. A., Fanta, S. W., Gebrehiwot, M. G., & Vanierschot, M. (2020). Effect of maturity on the moisture sorption isotherm of chili pepper (Mareko Fana variety). *Heliyon, 6*.

Gobie, W. (2019). A seminar review on red pepper (Capsicum) production and marketing in Ethiopia. *Cogent Food & Agriculture, 5*(1). doi:1647593

Gorjian, D. S. (2018). An Introduction to the Renewable Energy Resources. *Research Gate Renewable Energy Technologies*, 1-43. doi:10.13140/RG.2.2.27055.53928 Grainpro, A. o. h. g. c. g.-b.-d. (2011). Solar Bubble Dryer.

Guoqing, W., Yiping, L., & Hongjuan, R. (2015). Bearing Fault Prediction System Design Based on LabVIEW. *The Open Mechanical Engineering Journal*, *9*, 246-250.

Hellevang,D.K.J.(1994).Graindrying.*https://www.researchgate.net/publication/279463815*.

Henderson, S. M., Perry, R. L., & Young, J. H. (1997). *princeple of process engineering* (4th ed. ed.).

Hii, C. L., Jangam, S. V., Ong, S. P., & Mujumdar, A. S. (2012). *Solar Drying Fundamentals, Applications and Innovations.*

Hodges, R. J., J.C.Buzby, & Bennett, B. (2010). Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. *Journal of Agricultural Science*.

Hossain, Hassan, M. S., Islam, M. S., Hossain, M. A., & Rahman, M. S. (2012). Development and performance evaluation of hybrid dryer for quality grain seeds. *International Journal of Energy Machinery, 5*(1), 42-52.

Hossain, M. A., & Bala, B. K. (2007). Drying of hot chilli using solar tunnel drier. *Solar Energy, 81* 85-92.

Hossain, M. Z., Hossain, M. A., Awal, M. A., Alam, M. M., & Rabban, A. H. M. M. (2015). Design and Development of Solar Dryer for Chilli Drying. *International Journal of Research (IJR), 2*(1).

Hunde, N. F. (2020). Yield response and nutrient use efficiencies of hot pepper (Capsicum annuum L.) to inorganic fertilizers in Ethiopia. *International Journal of Research in Agronomy, 3*(1), 25-32.

Hung, N. V., Fuertes, L. A., Balingbing, C., Roxas, A. P., Tala, M., & Gummert, M. (2020). Development and Performance Investigation of an Inflatable Solar Drying Technology for Oyster Mushroom. *Energies, 13*(4122), 1-12

Hussein, J., Hassan, M., Kareem, S., & Filli, K. (2017). Design, Construction and Testing of a Hybrid Photovoltaic (PV) Solar Dryer. *International Journal of Engineering Research & Science (IJOER), 3*(5).

Ibrahim, M. B., Mohammed, A., & Abubakar, H. (2016). Development of a Solar Powered Standing Dc Fan Using Three Phase. *American Journal of Engineering Research (AJER), 5*(12), 148-154.

Ikrang, G., E., Okoko, J. U., Obot, M. S., & Akubuo, C. O. (2014). Modeling of Thin Layer Drying Kinetics of Salted Fish Fillets (Tilapia Zilli) in a Direct Passive Solar Dryer. *IOSR Journal Of Environmental Science, Toxicology And Food Technology (IOSR-JESTFT), 8*(1), 16-24.

Ismail, S. O., Ojolo, S. J., Orisaleye, J. I., & Olusegun, F. A. (2014). Design of an Office Table Solar-Dc Powered Fan. *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS), 5*(1), 1-5.

Kahsay, Y. (2018). Evaluation of Hot Pepper Varieties (Capsicum species) for Growth, Dry pod Yield and Quality at M/Lehke District, Tigray, Ethiopia. *Journal of Nature and Natural Sciences, 2*(2), 25-34.

Kamble, A. K., I.L.Pardeshi, Singh, P. L., & Ade4, G. S. (2013). Drying of chilli using solar cabinet dryer coupled with gravel bed heat storage

system. *JOURNAL OF FOOD RESEARCH AND TECHNOLOGY, 1*(2), 87-94.

Karafil, A., Ozbay, H., Kesler, M., & Parmaksiz, H. (2016). Calculation of Optimum Fixed Tilt Angle of PV Panels Depending on Solar Angles and Comparison of the Results with Experimental Study Conducted in Summer in Bilecik, Turkey. *ResearchGate*.

Kemp, I. C. (2011). Drying Models, Myths, and Misconceptions. *Chemical engineering technology, 34*(7), 1057-1066.

Kereth, G. A., Lyimo, M., Mbwana, H. A., Mongi, R. J., & Ruhembe, C. C. (2013). Assessment of Post-harvest Handling Practices: Knowledge and Losses of Fruits in Bagamoyo District of Tanzania. *Food Science and Quality Management, 11*.

Kilanko, O., Ilori, T. A., Leramo, R. O., Babalola, P. O., Eluwa, S. E., Onyenma, F. A., Ameh, N. I., Onwordi, P. N., Aworinde, A. K., & Fajobi, M. A. (2019). Design and Performance Evaluation of a Solar Dryer. *International Conference on Engineering for Sustainable World, 1378*.

Kumar, A., Tiwari, G. N., Kumar, S., & Pandey, M. (2006). Role of Greenhouse Technology in Agricultural Engineering. *International Jornal of Agricultural Research, 1*(4), 364-372.

Kumarn, M., Sansaniwal, S. K., & Khatak, P. (2016). Progress in solar dryers for drying various commodities. *Renewable and Sustainable Energy Reviews, 55*, 346-360.

Leon, M. (2002). Renewable and Sustainable Energy Reviews. *Renewable and Sustainable Energy Reviews, 6*, 367-393.

Lienhard, J. H. I., & V, J. H. L. (2001). *A Heat Transfer Textbook* (Third Edition ed.). Cambridge, Massachusetts, U.S.A.

Lingayata, A. B., Chandramohana, V. P., Rajua, V. R. K., & Medab, V. (2020). A review on indirect type solar dryers for agricultural crops – Dryer setup, its performance, energy storage and important highlights. *Applied Energy, 258*.

Mansour-Gueddes, S. B., Tarchoun, N., Silva, J. A. T. d., & Saguem, S. (2010). Agronomic and Chemical Evaluation of Seven Hot Pepper (Capsicum annuum L.) Populations Grown in an Open Field. *Fruit, Vegetable and Cereal Science and Biotechnology Global Science Books, 4*(1), 93-97.

Mercer, D. G. (2014). *An Introduction to the Dehydration and Drying of Fruits and Vegetables*: Departement of Food Science University of Guelph Ontario, Canada.

Meziane, S. (2011). Drying kinetics of olive pomace in a fluidized bed dryer. *Energy Conversion and Management, 52*, 1644-1649.

Mishra, A., Jha, S. K., Bhandari, G. R., Khatri, S., Shrestha, S., & Ojha, P. (2020). Performance Evaluation of Solar Bubble Dryer. *International Journal of Scientific and Research Publications, 10*(1).

Mohanraj, M., & Chandrasekar, P. (2009). Performance of a forced convection solar drier integrated with gravel as heat storage material for chili drying *Journal of Engineering Science and Technology, 4*(3), 305-314.

Mohsin, A. S. M., Maruf, M. N. I., Sayem, A. H. M., Mojumdar, M. R. R., & Farhad, H. M. S. (2011). Prospect & Future of Solar Dryer: Perspective Bangladesh. *3*(2).

Mongi, R. J. (2013). *Solar drying of fruits and vegetables: dryers thermal performance, quality and shelf life of dried mango, banana, pineapple and tomato.* Unversity of Agriculture,Morogoro, Tanzania

Mussema, R. (2006). *Analysis of red pepper marketing: the case of alaba and siltie in snnprs of ethiopia.* (M. Sc. Thesis AGRICULTURAL ECONOMICS)), Haramaya University.

Mustayen, A. G. M. B., Mekhilef, S., & Saidur, R. (2014). Performance study of different solar dryers. *Renewable and Sustainable Energy Reviews, 34*, 463–470.

Necmiye, Ü., Kılıçkan, A., & Yalçın, I. (2010). Effects of moisture content on some physical properties of red pepper (Capsicum annuum L.) seed. *African Journal of Biotechnology, 9*(24), 3555-3562.

Netzsch. (2014). *Thermal Insulation Materials Analyzing & Testing*.

Okoroigwe, E. C., Eke, M. N., & Ugwu, H. U. (2013). Design and evaluation of combined solar and biomass dryer for small and medium enterprises for developing countries

International Journal of Physical Sciences, 8(25), 1341-1349. doi:10.5897/IJPS2013.3937

Olayemi, F. F., A., A. J., I., B. E., & M., D. A. (2010). Assessment of post- harvest challenges of small scale farm holders of tomatoes, bell and hot pepper in some local government areas of kano state, nigeria. *Bayero journal of pure and applied sciences, 3*(2), 39-42.

Omid, M., Yadollahinia, A. R., & Rafiee, S. (2006). A thin-layer drying model for paddy dryer. *Proceedings of the international conference on Innovations in Food and Bioprocess Technologies*.

Onwude, D. I., Hashim, N., Janius, R. B., Nawi, N. M., & Abdan, K. (2016). Modeling the Thin-Layer Drying of Fruits and egetables: A Review. *ComprehensiveReviewsinFoodScienceandFoodSafety, 15*.

Panchariya, P. C., Popovic, D., & Sharma, A. L. (2002). Thin-layer modelling of black tea drying process. *Journal of Food Engineering, 52*, 349-357.

Pandey, S. K., diwan, S., & soni, R. (2015). Review of mathematical modelling of thin layer drying process. *INTERNATIONAL JOURNAL OF CURRENT ENGINEERING AND SCIENTIFIC RESEARCH (IJCESR), 2*(11).

Parry, J. L. (1985). *Mathematical Modelling and Computer Simulation of Heat and Mass Transfer in Agricultural Grain Drying.* (PHD), Cranfield Institute of Technology.

Patil, R., & Gawande, R. (2016). A review on solar tunnel greenhouse drying system. *Renewable and Sustainable Energy Reviews, 56*, 196–214.

Prakash, O., & Kumar, A. (2013). Historical review and recent trends in solar drying systems. *International Journal of Green Energy, 10*, 690–738.

Rajkumar, P. (2007). *Comparative Performance of Solar Cabinet, Vacuum Assisted Solar and Open Sun Drying Methods.*, Department of Bioresource Engineering McGill University, Montreal, Canada.

Rohsenow, W. M., Hartnett, J. R., & Cho, Y. I. (1998). *HANDBOOK OF HEAT TRANSFER*.

Rokayya, S., & Khojah, E. (2016). Physical-mechanical Estimation of Pepper (Capsicum annuum L.) Fruit Varieties. *Journal of Northeast Agricultural University, 23*(3), 61-69.

Romuli, S., Schock, S., Nagle, M., Chege, C. G. K., & Müller, J. (2019). Technical Performance of an Inflatable Solar Dryer for Drying Amaranth Leaves in Kenya. *Applied sciences, 9*(3431). doi:10.3390/app9163431

Romuli, S., Schock, S., Somda, M. K., & Müller, J. (2020). Drying Performance and Aflatoxin Content of Paddy Rice Applying an Inflatable Solar Dryer in Burkina Faso. *Applied sciences, 10*(3533). doi:10.3390/app10103533

Ronoh, E., CL, K., JT, M., & Shitanda, D. (2010). Thin layer drying kinetics of amaranth (Amaranthus cruentus) grains in a natural convection solar tent dryer *African Journal of Food, Agriculture, Nutrition and Development, 10*(3).

Sackey, S. S., Vowotor, M. K., Owusu, A., Mensah-Amoah, P., Tatchie, E. T., BaahSefa-Ntiri, Hood, C. O., & Atiemo, S. M. (2015). Spectroscopic Study of UV Transparency of Some Materials. *Environment and Pollution, 4*(4).

Sahu, T. K., Gupta, D. V., & Singh, A. K. (2016). A Review on Solar Drying Techniques and Solar Greenhouse Dryer. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 13*(3), 31-37.

Salvatierra-Rojas, A., Nagle, M., Gummert, M., Bruin, T. d., & Müller, J. (2017). Development of an inflatable solar dryer for improved postharvest handling of paddy rice in humid climates. *International Journal of Agricultural and Biological Engineering*. doi:10.3965/j.ijabe.20171003.2444

Sebaii, A. A. E., & Shalaby, S. M. (2012). Solar drying of agricultural products. *Renewable and Sustainable Energy Reviews, 16*, 37– 43.

Sengar, S. H., Mohod, A. G., & Khandetod, Y. P. (2012). Experimental Evaluation of Solar Dryer for Kokam Fruit. *Global Journal of Science Frontier Research Agriculture & Biology, 12*(3).

Seveda, M. S. (2012). Design andDevelopment ofWalk-In TypeHemicylindrical Solar TunnelDryer for IndustrialUse. *International Scholarly Research Network ISRN Renewable Energy*, 9.

Shakya, S. R. (2015). Training Manual for Engineers on Solar PV System. *Research Gate*, 1-259. doi:10.13140/2.1.3156.9607

Shanmugama, V., & Natarajan, E. (2006). Experimental investigation of forced convection and desiccant integrated solar dryer. *renewable Energy Review Journal, 31*, 1239-1251.

Singh, F., Katiyar, V. K., & Singh, B. P. (2014). Mathematical Modeling to Study Drying Characteristic of Apple and Potato. *International Conference on Chemical, Environment & Biological Sciences*.

Singh, J. (2015). Review Paper of Study on Solar Dryer. *Journal of Mechanical and Mechanics Engineering, 1*(1), 14-24.

Soysal, Y., ztekin, S. O., & Eren, O. (2006). Microwave Drying of Parsley: Modelling, Kinetics, and Energy Aspects. *Biosystems Engineering*.

Subramanian, D. C., Kannan, D. P. C. D., Karthikeyan, L., Prakashraj, G., & Nadaraj, P. (2021). Performance enhancement of Waffles (Appalam) drying using mixed mode solar dryer. *International Research Journal on Advanced Science Hub (IRJASH), 03*(01), 40-45.

Tesheshigo, M., Yimenu, K., & Workineh, M. (2019). Evaluation of Hot Pepper Varieties (Capsicum species) for yield related traits, Quality and yield in Burie District, West Gojjam Zone, Ethiopia. *International Journal of Plant Breeding and Crop Science, 6*(3), 581-588.

Thakre, P. S., Deshmukh, P. S. S., & Jain, P. (2016a). Design, Fabrication and Performance Analysis of Solar Tunnel Dryer Using Various Absorber Materials. *International Advanced Research Journal in Science, Engineering and Technology, 3*(6).

Thakre, P. S., Deshmukh, P. S. S., & Jain, P. (2016b). Design, Fabrication and Performance Analysis of Solar Tunnel Dryer Using Various Absorber Materials. *IARJSET International Advanced Research Journal in Science, Engineering and Technology, 3*(6).

Thet, A. A., Latt, A. K., Htwe, S. Y., & Tin, T. S. (2018). Design of Mixed-mode Natural Convection for Solar Agricultural Crop Dryer. *ICONIC RESEARCH AND ENGINEERING JOURNALS, 2*(6).

Tomar, V., Tiwari, G. N., & Norton, B. (2017). Solar Dryers for Tropical Food Preservation: Thermophysics of Crops, Systems and Components. *Solar Energy*.

Tonui, K. S., Mutai, E. B. K., Mutuli, D. A., Mbuge, D. O., & Too, K. V. (2014). Design and Evaluation of Solar Grain Dryer with a Back-up Heater. *Research Journal of Applied Sciences, Engineering and Technology, 7*(15), 3036-3043.

Tulapurkara, E. G. (-). *Flight dynamics-I*: Dept. of Aerospace Engg., Indian Institute of Technology, Madras.

Udomkun, P., Romuli, S., Schock, S., Mahayothee, B., Sartas, M., Wossen, T., Njukwe, E., Vanlauwe, B., & Müller, J. (2020a). Review of solar dryers for agricultural products in Asia and Africa: An innovation landscape approach. *Journal of Environmental Management, 268*. doi:110730

Udomkun, P., Romuli, S., Schock, S., Mahayothee, B., Sartas, M., Wossen, T., Njukwe, E., Vanlauwe, B., & Müller, J. (2020b). Review of solar dryers for agricultural products in Asia and Africa: An innovation landscape approach. *Journal of Environmental Management, 268*.

Van Hung, N., Fuertes, L. A., Balingbing, C., Paulo Roxas, A., Tala, M., & Gummert, M. (2020). Development and Performance Investigation of an Inflatable Solar Drying Technology for Oyster Mushroom. *Energies, 13*(16). doi:10.3390/en13164122

Vásquez, J., Reyes, A., Mahn, A., & Cubillos, F. (2016). Experimental evaluation of fuzzy control solar drying with thermal energy storage system. *Drying Technology An International Journal*.

Ventre, R. A. M. J. (2005). *Photovoltaic Systems Engineering*. Boca Raton London New York Washington, D.C.: CRC PRESS.

Visavale, G. (2014). Principles, Classification and Selection of Solar Dryers. *Research Gate In Solar drying: Fundamentals*

Wakjira, M. (2010). Solar drying of fruits and windows of opportunities in Ethiopia. *African Journal of Food Science, 4*(13), 790-802.

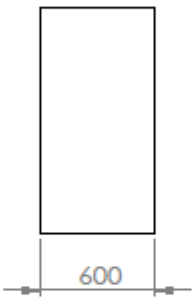
Whitaker, T., Barre, H. J., & Hamdy, M. Y. (1969). Theoretical and Experimental Studies of Diffusion in Spherical Bodies with a Variable Diffusion Coefficients. *Transactions of ASAE, 12*(5), 668-672.

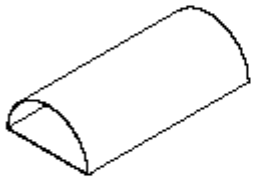
Zubairu, A., Audu, A., & 3Gimba, A. S. B. (2016). Design and Construction of a Mixed-Mode Natural Convection Solar Dryer with Back-Up System. *Nigerian Journal of Solar Energy, 27*.

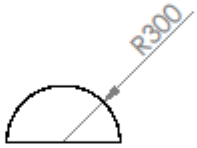
Appendix

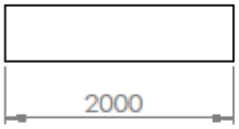
Data collection spreadsheet format

Raw data of the dryer chamber efficiency						
Augest 26, 2021						
Time interval	Tamb. °C	Tabs. 1°C	T tray 2°C	T outlet 3°C	RH %	Remark

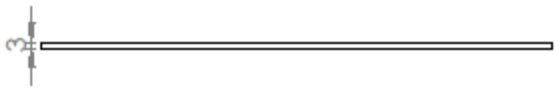


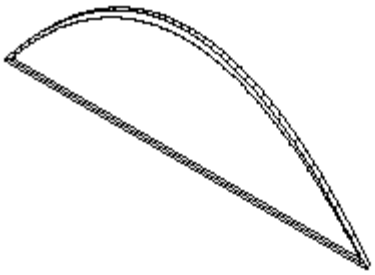


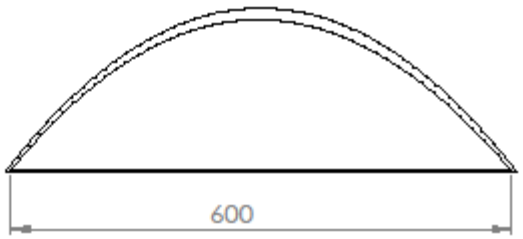




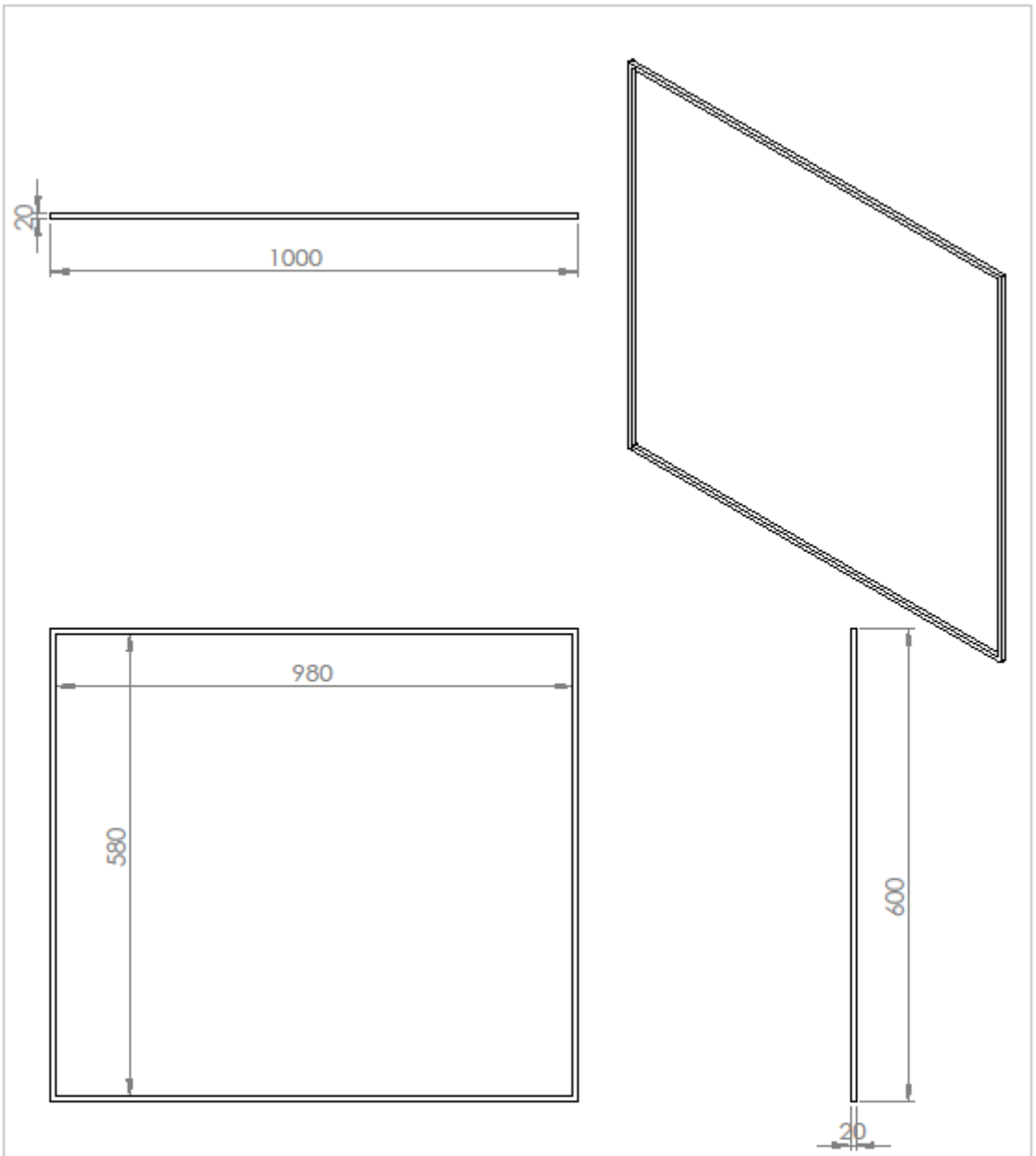
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:			FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE				TITLE: Dryer top cover	
DRAWN	Mengistu		7/10/2021					
CHK'D								
APPV'D								
MFG								
Q.A	1			MATERIAL: Plastic			DWG NO. SBD-001/2021	A4
				WEIGHT:			SCALE:1:1	SHEET 1 OF 1



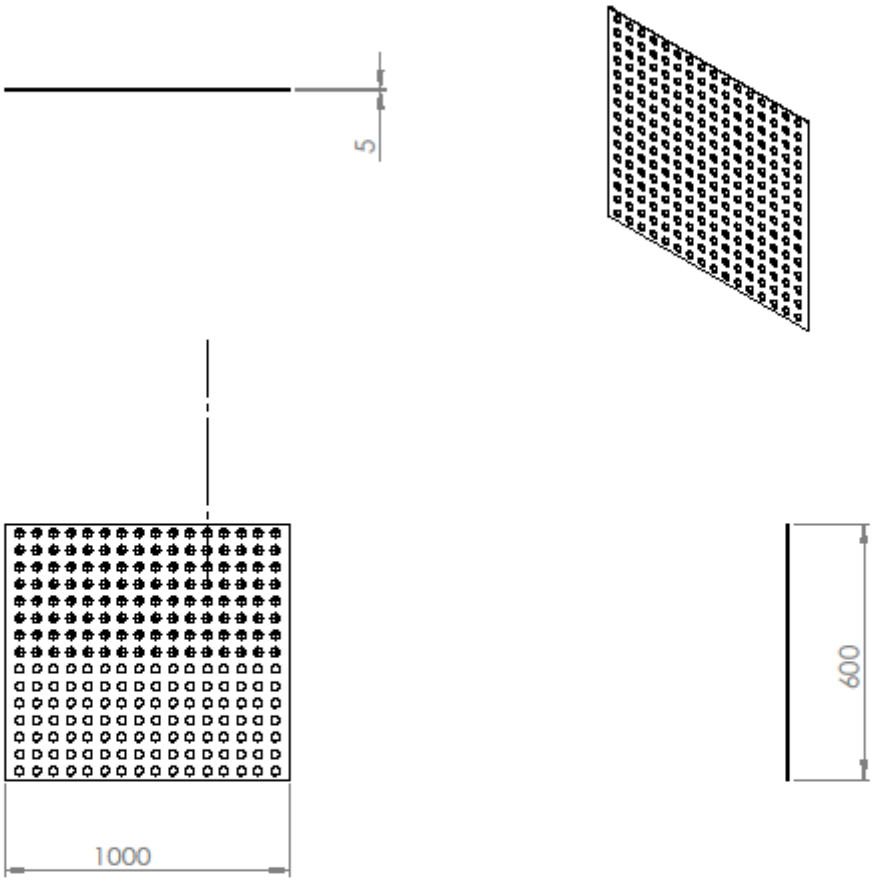




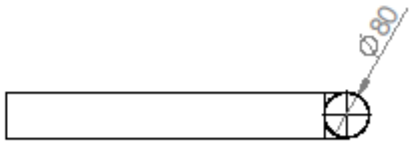
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:			DEBUR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE				TITLE: Bubble support	
DRAWN	Mengistu		7/10/2021					
CHK'D								
APPV'D								
MFG	4							
Q.A				MATERIAL: Sheet metal			DWG NO. SBD-005/21	A4
				WEIGHT:			SCALE:1:1	SHEET 1 OF 1

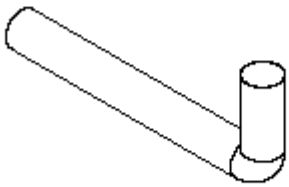


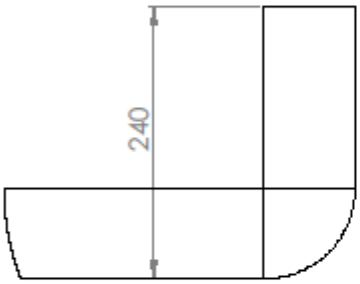
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:		DEBUR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING	REVISION	
	NAME	SIGNATURE	DATE			TITLE: Tray frame		
DRAWN	Mengistu		7/10/2021					
CHK'D								
APPV'D								
MFG								
Q.A	2			MATERIAL: RSH		DWG NO SBD-002/21		A4
				WEIGHT:		SCALE:1:1	SHEET 1 OF 1	



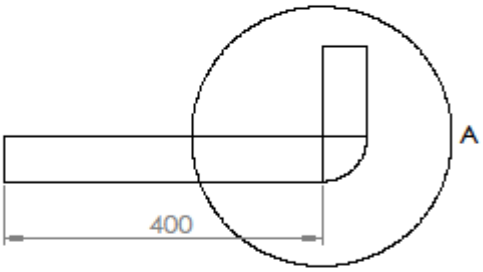
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
	NAME	SIGNATURE	DATE		TITLE: Tray		
DRAWN	Mengistu		7/10/2021				
CHK'D							
APPV'D							
MFG							
Q.A	2			MATERIAL: Mosquito net	DWG NO. SBD-004/21		A4
				WEIGHT:	SCALE:1:1	SHEET 1 OF 1	

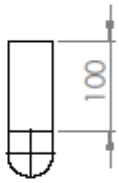




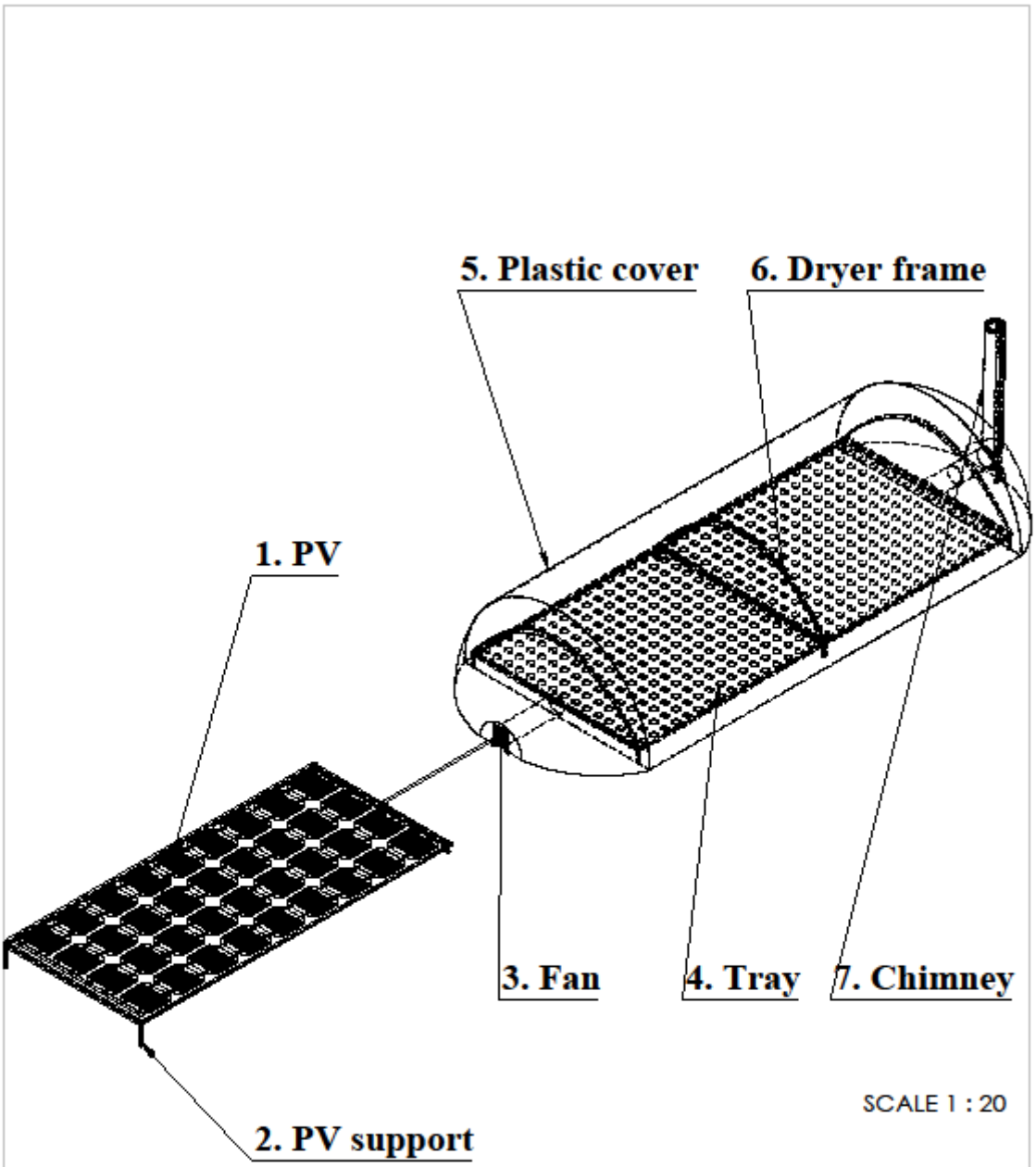


DETAIL A
SCALE 1 : 5

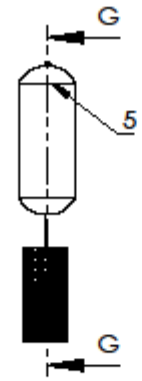




UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN **MILLIMETERS** SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:				FINISH:			DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE					TITLE:	
DRAWN	Mengistu		7/10/2021					Chimney	
CHK'D									
APPV'D									
MFG									
Q.A	1			MATERIAL:				DWG NO.	A4
				PVC				SBD-008/2021	
				WEIGHT:				SCALE:1:1	SHEET 1 OF 1

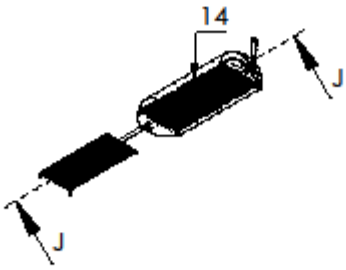


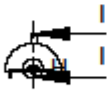
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
	NAME	SIGNATURE	DATE		TITLE: SBD-Assembly		
DRAWN	Mengistu		7/10/2021				
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL:	DWG NO. SBD-0017/21		A4
				WEIGHT:	SCALE:1:10	SHEET 1 OF 1	

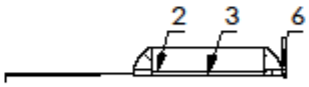


SECTION G-G

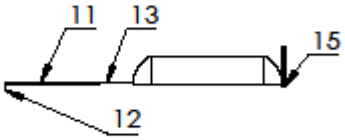
SECTION J-J

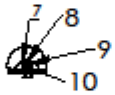






SECTION I-I





DETAIL H
SCALE 1 : 50

ITEM NO.	PART NUMBER	QTY.
1	Bubble shape	1
2	Tray frame	2
3	Leg	8
4	Tray	2
5	Outlet and inlet	2
6	Chimney	1
7	Fan support vertical	2
8	Fan supporter horizontal	2
9	Fan circular housing	1
10	DC fan	1
11	Solar pannel	1
12	Solar pannel support	1
13	Wire	1
14	Bubble support	4
15	Chimney support	1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBUR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION

	NAME	SIGNATURE	DATE
DRAWN	Mengistu		7/10/2021
CHK'D			
APPV'D			
MFG			
Q.A	1		

MATERIAL:
WEIGHT:

TITLE:
SBD-Assembly

DWG NO.
SBD-0016/21

A4

SCALE:1:1
SHEET 1 OF 1