INDIRECT DRYING FOOD PRESERVATION TECHNIQUE ON AGRICULTURAL PRODUCTS

A Project report submitted in partial fulfilment of

the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

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CERTIFICATE

This is to certify that the Project Report entitled **"INDIRECT DRYING FOOD PRESERVATION TECHNIQUE ON AGRICULTURAL PRODUCTS"** submitted by **SHAIK SALEEL** (318126520163), **VAYILETI CHANDRAMOULI** (318126520168), **TALADA KUSUMA KUMAR** (318126520167), **PILLA MANIKANTA** (318126520153) in partial fulfilment for the award of the degree of Bachelor of Technology in Mechanical Engineering. It is the work of Bonafide, carried out under the guidance and supervision of **Dr. V R LENIN,** Assistant Professor, Department of Mechanical Engineering during the academic year of 2018 to 2022.

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ABSTRACT

In developing countries, using traditional energy sources to dry agricultural products is an expensive process. Food preservation is achieved primarily by reducing the moisture content of the food product to the desired level. Since ancient times, solar drying has been one of the most popular methods of food drying. However, it has a number of drawbacks. The aim of the work is to dry the agricultural product (ginger) through an indirect drying process for extending the lifespan of the food product without affecting its quality. In order to achieve that, a solar simulator along with waste materials (cooldrinks empty can) has been used as an absorber plate for producing hot air. The inlet of the drying chamber has connected with the outlet of the absorber plate along with a different layer of mesh arrangements. The parameters considered are the weight of the product, solar radiation, air temperature, humidity ratio, absorber plate Inlet and outlet area. The results show that the loss of moisture content in the ginger is about 85%, at the same time the change in the texture is insignificant.

Keywords: *Food preservation, indirect drying, solar simulator, waste material, hot air, moisture content*

CHAPTER 1
INTRODUCTION

1.1 Open sun drying

Open sun drying is one of the ancient food preserving techniques. This is one of the cheapest methods practiced by most developing and underdeveloped countries, especially where good sunshine hours prevail throughout the year. However, every preserving technique has its own disadvantages since this technique is to dry the food products in direct sunlight, in this case food product spoils due to direct radiation emitted by the sun, loss due to over-drying, nearby vegetation (for example birds, insects), rain, dust, etc. So, some of these problems can be solved using indirect drying which is often referred to as absorbing heat radiation by any form of equipment, in our case a solar simulator along with waste tin materials has been used as an absorber plate for producing hot air. The inlet of the drying chamber has connected with the outlet of the absorber plate along with different layers of mesh arrangements.

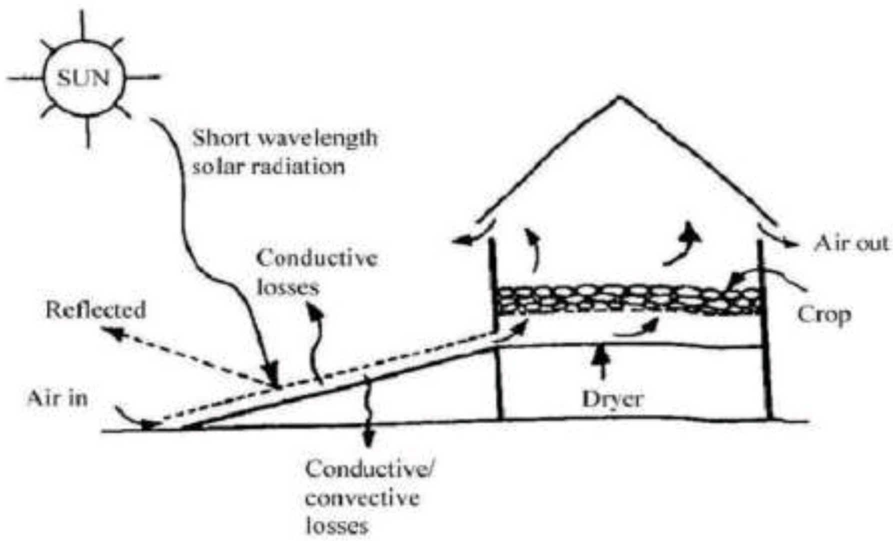

Figure-1.1 Indirect sun drying

Which reduces the above problems and processes the food products in a clean way and improves quality and texture. Fruits and vegetables are an essential part of the human diet providing micronutrients, vitamins, enzymes, and minerals. Most fruits and vegetables have a high moisture content and water activity. This makes them vulnerable to microbial and other spoilages due to biochemical reactions, such as enzymatic activity, respiration, and senescence. Therefore, preventive measures are taken to lower water content. Drying or dehydration is one such method. Drying is a process of removal of water from the food to inhibit biochemical processes and microbial growth. Drying increases the shelf-life of the product, so that it can be available during off season. Shelf life is defined as the length of time a product may be stored without becoming unsuitable for use or consumption. Drying can be done at high temperature, such as hot air drying or dielectric heating, at low temperature, such as freeze drying, or at ambient temperature, such as desiccant drying. Nevertheless, it is an energy intensive process. With the depletion of fossil fuels and hike in energy prices, more and more emphasis is being given to utilize renewable energy sources for drying.

Drying is removal of heat and mass transfer that occurs on the surface and inside of the drying material. It enables to reduce the internal moisture of the material, inhibit internal microbial growth, material mildew and chemical changes during storage, which extends the shelf life of dried materials, improves the quality of material, and reduces the cost of storage and transportation. The drying process is mainly embodied in two ways of water transfer, one is the water transfer from the inside to the surface of materials through internal pores; the other is the water diffusion from the material surface to the environment through evaporation.

Solar energy is derived from the sun. It is proven clean and safe for use without negative impact to the environment and society. The total annual solar radiation received by Earth is more than 7500 times the world's total annual primary energy consumption of 450 EJ. The abundance of solar energy supply particularly in the tropical countries creates a huge potential for its application in the domestic and industrial sector. Historically, humans have been using solar energy for daily usage such as in initiating fire, cooking, drying of food and clothes and water heating. Since then, there have been many studies and developments on solar energy to suit the application into the modern world. As a result, it can be seen today that solar energy is utilized for drying, steam and power generation, water distillation and desalination, heating, cooling and refrigeration.

Sun drying is still widely used in many tropical and subtropical countries. Sun drying is the cheapest method, but the quality of the dried products is far below the international standards. Improvement of product quality and reduction of losses can only be achieved by the introduction of suitable drying technologies. However, increase of purchasing power of the farmers and the reflection of the quality in the price of quality dried products are the important prerequisites for acceptance by the farmers and introduction of improved drying technologies. As long as there is no or only slight difference in the price for high- and low-quality products, the additional expenses for new preservation techniques will never be paid back and the new drying technologies will not be acceptable by the farmers. However, for adoption of the improved technology field level demonstration of the technology and advertisement of the quality dried products are essential. Micro-credit may also be needed and an extension model which is also an extension of the microcredit approach of Grameen Bank may be adopted. Furthermore, for sustainability of the improved drying technology marketing channels must be established.

Since the late 19th century, many other techniques were developed in order to improve the efficiency of the drying without damaging the quality of the products. A few examples are vacuum drying, freeze-drying, and fluidized bed drying. However, in order to minimize organoleptic changes during drying, the conditions are kept as mild as possible and many microorganisms may survive the dehydration process. Although microbial growth is prevented or retarded in dry products, when a sufficient number of pathogenic microorganisms are present after the drying process this may pose a threat to the consumer. Once in a desiccated state, microbial growth is inhibited, but vegetative cells and spores can remain viable for months. Moreover, when dried materials are used to prepare foods with a high final water activity, the growth of surviving organisms may be promoted. This can lead to a quicker spoilage and/or a higher risk of consumer infection. The preparation of semi dried foods without a pretreatment and/or posttreatment is even more questionable because the drying conditions are milder, thus potentially increasing the number of microbial survivors and the risk of human infection.

More than 80% of the food is produced by small farmers in developing countries. These farmers dry the food products under the sun, i.e., natural sun drying is being practiced.

Except that the solar energy is available for free, there are several disadvantages with the natural sun drying process. Some of the demerits include degradation due to wind-blown debris, rain, insect infestation, rodents, birds, over/under drying, etc. Further, due to prolonged drying, there is danger of aflatoxin contamination of cereal grains. In other words, the quality of the finished product is poor. Apart from the quality there exist some strange cases where natural sun drying cannot be adopted, e.g., cardamom cannot be sun dried as the sun will fade the green colour.

A main cause for food spoilage is more moisture content. Moisture content refers to the number of water molecules that become incorporated into a food product. This makes them vulnerable to microbial and other spoilages. Moisture can enter into a product in any number of ways, it could be related to the production method of the product, the atmospheric moisture in the food production area, the packaging method of the product, or it can be related to the method of food storage. Moisture content can have dramatic effects on the quality of a food product. It can impact the taste, texture, and look of a product. A reduced moisture content will reduce the growth of microbes on the food products. As we discussed above, the moisture content should be removed in order to preserve the food products. Fresh fruits and vegetables comprise more than 80% moisture.

Also, the moisture we are trying to remove should be a particular percentage as if we go below maximum permissible water loss the product will be damaged regardless of removing moisture. Moisture content should be as low as possible to preserve food products. Below is the table containing moisture content & maximum permissible water loss of some fruits and vegetables we use in our daily life. The agricultural sector is a major sector where drying has been extensively used in preserving cereals, fruits and vegetables. Moisture is the main substance in the wet materials that causes the microbial and bacterial reaction which leads to the material spoilage. The reduction of the moisture content (MC) up to a safe level, reduces the growth and reproduction of microorganisms and it can be achievable only by drying. Thermal energy is a source mostly used for the drying process. Most of the time, conventional energy sources such as fossil fuel and electric energy were used for drying.

Table-1.1 Moisture Content in some fruits and vegetables.

Fruit/Vegetable	Weight	Moisture Content(%)
Apple	200	84
Orange	130	87
Ginger	23	83-94
Grape	8	81-91
Mango	1000	74.2
Papaya	110	88
Carrot	72	87
Potato	160	79
Tomato	200	94

Since, open sun drying has been used as a preservative strategy for agricultural and other products, including fruits and vegetables, especially in tropical countries. This method is cheap because the source of energy is free and renewable. However, this drying technique often entails contamination, insect infestation, microbial attack, nutritional deterioration and other problems. Some of the problems associated with open-air drying can be solved through the use of a solar dryer which comprises a collector, a drying chamber and, sometimes, a chimney. In most collector designs, the absorber plates seem to be fixed with respect to the collector frame. Fixed absorber plates restrict the adjustment of the collector thermal characteristics, to achieve the desired collector outlet temperature under varying solar radiation levels arising particularly from seasonal changes. There is spoilage of fruits and other fresh foods that could be preserved using dehydration techniques in Malawi and other developing countries. Seasonal fruits like mangoes (Mangifera indicus) are not presently dried for export, or for local consumption during periods of scarcity. The objective of the present investigation was to develop a solar dryer that had a simple mechanism for adjustment of the collector thermal characteristics and retained a high proportion of moisture in the dried food product.

Solar-drying technology offers an alternative which can process the vegetables and fruits in clean, hygienic and sanitary conditions to national and international standards with zero energy costs. It saves energy, time, occupies less area, improves product quality, makes the process more efficient and protects the environment. Solar drying can be used for the complete drying process or as a supplement to artificial drying systems, in the latter case reducing the fuel energy required. Solar dryer technology can be used in small-scale food processing industries to produce hygienic, good quality food products. At the same time, this can be used to promote renewable energy sources as an income-generating option. Further, this solar technology is ideally suited for women since they can place a load in the dryer and then get on with their other numerous tasks. Environment for an extended period of time. Many food industries dealing with commercial products employ state-of-the-art drying equipment such as freeze dryers, spray dryers, drum dryers and steam dryers. The prices of such dryers are significantly high and only commercial companies generating substantial revenues can afford them. Therefore, because of the high initial capital costs, most of the small-scale companies dealing directly with farmers are not able to afford the price of employing such high-end drying technologies that are known to produce high quality products. Instead, cheaper, easy-to-use and practical drying systems become appealing to such companies or even to the rural farmers themselves. It is also useful to note that in many remote-farming areas in Asia, a large quantity of natural building material and bio-fuel such as wood are abundant but literacy in science and technology is limited.

Solar drying is a potential decentralized thermal application of solar energy particularly in developing countries. However, so far, there has been very little field penetration of solar drying technology. In the initial phase of dissemination, identification of suitable niche areas for using solar dryers would be extremely helpful towards their market penetration. In this context, one of the possible areas of immediate intervention in developing countries appears to be the solar drying of cash crops such as tobacco, tea, coffee, grapes raisin, small cardamom, chilli, coriander seeds, ginger, turmeric, black pepper, onion flakes, and garlic flakes, etc. For such crops, even with the capital-intensive nature of solar dryers, the unit cost of solar drying is expected to be a small fraction of the selling price of the dried product. In this paper, an attempt has been made towards potential assessment of solar drying of some cash crops in India. The resulting net mitigation of CO_2 emissions due to realization of the estimated potential of solar drying of the selected cash crops has also been estimated. Solar drying is often differentiated from ‘‘sun drying’’ by the use of equipment to collect the sun’s radiation in order to harness the radiative energy for drying applications. Sun drying is a common farming and agricultural process in many countries, particularly where the outdoor temperature reaches 30-8C or higher. In many parts of South-east Asia, spice crops and herbs are routinely dried. However, weather conditions often preclude the use of sun drying because of spoilage due to dehydration during unexpected rainy days. Furthermore, any direct exposure to the sun during high temperature days might cause case hardening, where a hard shell develops on the outside of the agricultural products, trapping moisture inside. Therefore, the employment of solar dryers taps on the freely available sun energy while ensuring good product quality via judicious control of the radiative heat. Solar energy has been used throughout the world to dry food products. Such is the diversity of solar dryers that commonly solar-dried products include grains, fruits, meat, vegetables and fish.

A typical solar food dryer improves upon the traditional open-air sun system in five important ways:

(1) It is faster. Foods can be dried in a shorter period of time. Solar food dryers enhance drying times in two ways. Firstly, the translucent, or transparent, glazing over the collection area traps heat inside the dryer, raising the temperature of the air. Secondly, the flexibility of enlarging the solar collection area allows for greater collection of the sun’s energy.

(2) It is more efficient. Since foodstuffs can be dried more quickly, less will be lost to spoilage immediately after harvest. This is especially true of products that require immediate drying such as freshly harvested grain with high moisture content. In this way, a larger percentage of food will be available for human consumption. Also, less of the harvest will be lost to marauding animals and insects since the food products are in safely enclosed compartments.

(3) It is hygienic. Since foodstuffs are dried in a controlled environment, they are less likely to be contaminated by pests, and can be stored with less likelihood of the growth of toxic fungi.

(4) It is healthier. Drying foods at optimum temperatures and in a shorter amount of time enables them to retain more of their nutritional value such as vitamin C. An added bonus is that foods will look and taste better, which enhances their marketability and hence provides better financial returns for the farmers.
(5) It is cheap. Using freely available solar energy instead of conventional fuels to dry products, or using a cheap supplementary supply of solar heat, so reducing conventional fuel demand can result in significant cost savings.

The widest among drying methods is convective drying (whereby heating takes place by convection between the hot air and the products surface), i.e., drying by flowing heated air circulating either over the upper side, bottom side or both, or across its mass. Hot air heats up the product and conveys released moisture to the atmosphere. Thus, drying psychrometry is of importance because it refers to the properties of air–vapor mixture that controls the function of drying. In direct solar drying called “sun drying” the product is heated directly by the sun’s rays and moisture is removed by natural circulation of air due to density differences.

1.2 Advantages of open sun drying

- It is one of the oldest and least expensive drying methods.
- It is also simpler to implement when compared to other ways.
- There is no need for power, reducing the consumption of fossil fuels.
- Large quantities of product can be dried at once.

1.3 Disadvantages of open sun drying

- The biggest issue with sun drying is that efficiency and ultimate product quality are at the discretion of nature.
- This procedure can only be carried out when there is plenty of sunshine. Furthermore, there is no control over the operating parameters.
- A lengthy period is necessary. Under adverse operational settings, it might take several days to finish, affecting the end product's quality.

- The danger of contamination with dust, sand, and infection with insects, their eggs when drying in the sun.
- The shelf life of the end product is not very lengthy, and in most situations, a low-quality final product is generated.

1.4 Motivation

Many drying methods came but most of them are not cost effective and dryer designs were made with costly materials none of them looked into cheaper designs. So that they are easily accessible for small-scale farmers. So, the project aim is to design an indirect solar simulator using waste materials. Also looking into reduction of moisture content without affecting the texture and quality of the product.

CHAPTER 2
LITERATURE REVIEW

2.1 Literatures

A. Madhlopa et al Experimented on a solar air heater with composite–absorber systems for food dehydration. The performance of the dryer was evaluated by drying fresh samples of mango (Mangifera indicus). Both fresh and dried mango samples were analyzed for moisture content (MC), pH and ascorbic acid. During the dehydration period, meteorological measurements were made. The air heater converted up to 21.3% of solar radiation to thermal power, and raised the temperature of the drying air from about 31.7°C to 40.1°C around noon. The dryer reduced the MC of sliced fresh mangoes from about 85% (w/w) to 13% (w/w) on wet basis, and retained 74% of ascorbic acid. It was found that the dryer was suitable for preservation of mangoes and other fresh foods. And said that a solar air heater with two systems for solar absorption has been designed and tested. One of the absorbers, which can be made from different types of materials including metals and plastics, was interchangeable to achieve the desired temperature for food dehydration under the prevailing meteorological conditions. Heat was transferred from the collector to the drying chamber through natural convection. The air heater achieved efficient drying of slices of fresh mangoes and a relatively high retention of ascorbic acid. The dehydrated fruits could therefore be preserved for consumption during the times of scarcity.

Simeon Bourdoux et al Experiment on performance of drying technologies to ensure microbial safety of dried fruits and vegetables. His review presents traditional and emerging technologies to dry fruits, vegetables, herbs, and spices and discusses their potential to inactivate bacteria and viruses throughout the drying process. Overall, the microbial inactivation effect of the presented technologies has not yet been thoroughly assessed, even for traditional methods like solar drying, conventional air drying, or freeze-drying. Emerging technologies such as dielectric (assisted) drying and low-pressure superheated steam drying have been shown to reduce microbial populations; however, the number of studies is still low. Very few studies have focused on viral inactivation during drying processes and observed that dried fruits, vegetables, herbs, and spices are increasingly traded and consumed as such or are used as ingredients in various ready-to-eat foods throughout the world. There have been several outbreaks and recalls due to the presence of microbial hazards associated with these products and, although some studies have assessed microbial reduction after drying, there is a lack of information on the inactivation induced by drying processes. Moreover, most of these studies have focused on bacteria and the virus inactivation has not really been assessed. Even for bacteria, only a few species or pathogens have been addressed. The results should be verified with a wider range of bacterial species or specific strains thereof, because they may differ in sensitivity to the treatment as it is the case for heat pasteurization. It is also known that the heat resistance of microorganisms increases upon dehydration.

Zhihan Deng et al Experimented on the drying quality of agricultural products using solar drying technologies. This paper provides a guided technological tour on solar drying through literature research. An overview about the drying technologies to evaluate the drying quality, such as traditional sun drying, solar tunnel drying, solar greenhouse drying, solar-assisted drying system, is presented to demonstrate advances and application potential of solar drying. Finally, variable temperature drying is preliminarily proposed and tested to verify its superiority of energy saving and drying quality improvement. The literature research in this paper gives a reference on the effective application of solar drying through specifying the mechanisms of quality transformation. Using solar energy to dry and improve the quality of agricultural products has been the hot spot of many drying studies. There are many solar drying technologies that have been used in this field and these drying technologies show an improvement in quality, energy saving and shorter drying time. Among them, variable temperature drying shows certain potential in saving energy and shortening drying time. Since the agricultural products are sensitive to high temperature, in order to get high quality materials, combining pretreatment with mild temperature in solar drying is a good choice. Agricultural products are sensitive to drying parameters and pretreatment, resulting in the different color and chemical composition of drying materials under different drying conditions. In addition, types of material, the harvest season, and planting areas have an influence on the drying quality of materials. Therefore, agricultural materials in different areas require specific harvesting, processing and drying methods.

J. Wanyama et al Experimented on the solar fruit drying technologies for smallholder farmers in Uganda. This review critically examines existing solar drying technologies in Uganda, highlighting design constraints and plausible solutions for supporting the growing fruit drying industry. The common types of solar dryers in Uganda are the static-bed box type solar dryer model, the PPI tunnel solar dryer model, the NRI Kawanda cabinet solar dryer, the hybrid tunnel solar dryer and the UNIDO solar hybrid dryer model. Findings reveal that the challenges characterizing existing dryers in perspective of design are attributed to; poor material selection, poor mass and energy transfers, total dependence on solar energy, lack of capacity by local craftsmen to replicate new and improved models, difficulty to clean the dryers caused by inapt model configurations, and high cost of installation to mention a few. Therefore, a need exists to develop efficient and affordable designs using scientifically proven methods such as Computer Fluid Dynamics to pre-test and optimize the dryer and incorporate alternative energy sources in the design to ensure an all-weather dryer. Additionally, disseminate such innovations to farmers, retool local artisans with quality fabrication skill sets, and develop simple manuals with standards and fabrication procedures for the fruit dryers and came to know that from the critique of existing solar fruit drying technologies designs in Uganda, the following can be inferred. Firstly, there is recognition of the importance of solar drying technologies in the small-scale dried fruit producer industry. Secondly, evidence confirms that contrary to what is widely perceived, it is not humans that adapt to technology rather technology has to evolve in a manner that suits the human needs and conveniences. This calls for advancement and improvement of solar drying technologies, tailoring them to real time needs of farmers and consumers of the dried produce, and to simulate the near future needs. In addition, appropriateness of an improved solar drying system should be visible in terms of increased capacity of production, better quality of produce, easy to operate, and within the capacity of local technicians and craftsmen to precisely reproduce and maintain it. Improved solar dryers should translate into improved livelihood of farmer communities in terms of wealth enhancement and emancipation of women and children.

Azwin Kamarulzaman et al A review on global advancement of solar drying technologies and its future prospects. He provided a comprehensive review of works pertaining to solar thermal energy utilization in the drying process. In this article, the classification of solar dryers, the main components which includes solar collector, drying chamber and auxiliary systems, prospects, challenges, recent advancement and performance are discussed. The existing literature reported that solar dryer and solar collector maximum efficiency of 54% and 81% respectively, with superior product quality than the open solar drying. Solar drying is an economical method with a payback period of 0.54–4.69 years. Solar dryers can also reduce 34% of CO_2 emission to the atmosphere with less consumption of fossil fuel. Improvements such as in the design of solar collector, drying chamber, new auxiliary system, and material are essential to elevate the solar drying system performance. A review of the technologies can provide a base for the next generation of sustainable solar drying systems and helps policymakers to frame strategies aiming for clean technology and sustainable development. The importance of performance assessment and critical parameters of solar dryers have been highlighted including thermal performance, product quality, economic and environmental aspects. Solar dryers are an innovative method in agriculture products drying with maximum dryer efficiency and solar collector efficiency of 54% and 81% respectively. It is reported that the products dried in the solar dryer were of superior quality than those being dried by the open solar drying. By having the payback period of 0.54 to 4.69 years, a solar dryer is regarded as cost-effective when compared to its expected life of service. Using solar energy in drying application can reduce 34% of CO_2 emission to the atmosphere with less consumption of fossil fuel. Passive drying system is used for drying food crops, fruits, vegetables and preserving fish in a small quantity at temperature ranges of 40°C to 50°C.

Abhay Lingayat et al Reviewed-on applications of solar energy based drying technologies in various industries. This work provides a detailed analysis of solar-based dryers used in various industries namely agricultural, marine, tea, sugarcane, automobile, rubber, pulp, and paper industries. In addition, the utilization of solar energy for sewage drying, industrial waste drying, and lignite coal drying for power generation are reviewed. Different types of dryers presently available in the market are also discussed in the review work. Various parameters used for the performance of the dryers such as drying rate, amount of energy required for drying, collector efficiency, drying efficiency, specific energy consumption have been discussed. Economic, environmental, and social aspects of solar dryers are also presented, and recommendations are given in the paper. Said that the required drying period of the product was different for different industries and their materials. The essential drying factors for all the industries were moisture content (MC) of the product, temperature, velocity, humidity of drying air, and geographical location. The solar dryers assisted with thermal energy storage (TES) systems helped to decrease the total time required for drying. Also, the addition of the TES system increased the system performance, energy, exergy, solar-to-electric conversion efficiencies. The use of hybrid solar dryers (such as dryers with LPG water heaters, diesel burners, and biomass-fueled air heaters) helped to satisfy the electrical power requirement so that the dryer could work round-a-clock. Forced convection solar dryers (FCSD) gave better performance compared to NCSD setups, but they needed little artificial energy for running the fan or blower. FCSD setups could run with zero electrical power using solar photovoltaic panels to run fans or blowers.

B. K. Bala et al Experimented-on developments and potentials of solar drying technologies for drying of fruits, vegetables, spices, medicinal plants and fish. Previous efforts on solar drying of fruits, vegetables, spices, medicinal plants and fish are critically examined. Recent developments of solar dryers such as solar tunnel dryer, improved version of solar dryer, roof-integrated solar dryer and greenhouse type solar dryer for fruits, vegetables, spices, medicinal plants and fish are also critically examined in terms of drying performance and product quality, and economics in the rural areas of the tropics and subtropics. Field level tests demonstrated that pv ventilated solar dryers are appropriate for production of quality dried fruits, vegetables, spices, herbs and medicinal plants, and fish. In all the cases the use of solar drier leads to considerable reduction of drying time in comparison to sun drying and the quality of the product dried in the solar drier was of quality dried products as compared to sun dried products. However, the drying time increases with the increase in humidity of the ambient air. Solar dryers are simple in construction and can be constructed using locally available materials by the local craftsman. The solar drier can be operated by a photovoltaic module independent of the electrical grid. The photovoltaic driven solar driers must be optimized for efficient operation. The neural network prediction of the model has been found very good and can be used to predict the potential of the drier for different locations and can also be used in a predictive optimal control algorithm.

Ssemwanga Mohammed et al Experimented on the effect of traditional and improved solar drying methods on the sensory quality and nutritional composition of fruits. Investigated the effect of traditional and improved solar drying methods on the sensory quality and nutritional composition of the dried fruit products; using mangoes and pineapples, as a case study. The fruits were dried under five solar drying methods namely; open sun drying (OSD), black-cloth shade (BCS), white cloth shade (WCS), a conventional solar dryer (CSD), and a newly improved solar dryer (ISD) technology. The ISD unit was made of a modified solar concentrator plate containing multiple metallic solar collectors arranged in series. The ISD drying cabinet was also enclosed with specialized greenhouse cover materials. The drying operations were conducted following a completely randomized design (CRD) experimental procedure. The ISD technology was, therefore, recommended as a better fruit drying method than the traditional solar drying methods. Using the ISD method could be a feasible solution and a strategic pathway to addressing the high post-harvest losses of fruits as well as other perishable fresh produce in East Africa.

Sagar V. R. et al Experiment on recent advances in drying and dehydration of fruits and vegetables. Energy consumption and quality of dried products are critical parameters in the selection of the drying process. An optimum drying system for the preparation of quality dehydrated products is cost effective as it shortens the drying time and causes minimum damage to the product. To reduce the energy utilization and operational cost new dimensions came up in drying techniques. Among the technologies osmotic dehydration, vacuum drying, freeze drying, superheated steam drying, heat pump drying and spray drying have great scope for the production of quality dried products and powders. Many new dimensions came up in drying technology to reduce the energy utilization and operational cost. Among the technologies, osmotic dehydration, vacuum drying, freeze drying, SS drying, HPD drying, microwave drying and spray drying are offering great scope for the production of best quality dried products and powders. Due to their selective and volumetric heating effects, microwaves bring new characteristics such as increased rate of drying, enhanced final product quality and improved energy consumption. The quality of microwave dried commodities is often between air-dried and freeze-dried products. The rapidity of the process yields better color and aroma retention. Quality is further improved when vacuum is used since the thermal and oxidative stress is reduced. Due to high cost, using single unit operation to dry the produce is not cost effective. Therefore, cost effective alternate systems like combination/hybrid drying should be promoted to reap the advantage of sophisticated drying systems with minimum cost and simple technologies.

B. N. PRASAD et al Research on artificial roughness on heat transfer and friction factor in a solar air heater. An investigation of fully developed turbulent flow in a solar air heater duct with small diameter protrusion wires on the absorber plate has been carried out and expressions for prediction of average Stanton number and average friction factor have been developed. The results of these expressions have been compared with available data. The results have been found to compare with a mean deviation of 6.3% for friction factor and - 10.7% for the Nusselt number. The effect of height and pitch of the roughness elements on the heat transfer rate and friction has also been investigated. Law of the wall similarity can be assumed for correlating heat transfer and friction data in an artificially roughened solar air heater duct. Geometrically similar roughness (for a given p/e, e/D) produces the same effect on heat transfer and friction. Increase in the relative roughness height results in a decrease of the rate of heat transfer enhancement although the rate of increase of friction factor increases. Increase in the relative roughness pitch results is a decrease in the rate of both heat transfer and friction factor. Small diameter protrusion wires can be utilized on the collector plates in the solar air heaters to double the heat transfer coefficient. However, this is found to cause a higher increase in friction factor, which effectively quadruples with use of the wires.

Irfan Kurtbas et al Experiment on the efficiency and exergy analysis of a new solar air heater. In This study, five solar collectors with dimensions of 0.9*0.4 m were used and the flow line increased where it had narrowed and expanded geometrically in shape. These collectors were set to four different cases with dimensions of 1*2 m. Therefore, heating fluids exit the solar collector after at least 4.5 m displacement. According to the collector geometry, turbulence occurs in fluid flow and in this way heat transfer is increased. The results of the experiments were evaluated on the days with the same radiation. The efficiencies of these four collectors were compared to conventional flat-plate collectors. It was seen that heat transfer and pressure loss increased depending on shape and numbers of the absorbers. The conclusions can be drawn from the experimental study of the new collectors designed, and show the efficiency of the collector improves with increasing mass flow rates due to an enhanced heat transfer to the air flow. The efficiency of air collectors increases depending on the surface geometry of the collector and extension of the air flow line. When the surface roughness is increased, the heat transfer and pressure loss increase.

The optimum slice number of the absorber can be determined for heat transfer and pressure loss changes the number of absorber slices in the collector. The exergy loss of the system decreases depending on the increase of the collector efficiency. There is a reverse relationship between dimensionless exergy loss and heat transfer, as well as pressure loss. The more important parameters in order to decrease the energy loss are the collector efficiency, temperature difference (T_o and T_i) of the air and pressure loss.

Taransum Bano et al Conducted research on innovative solar dryers for fruits, vegetables, herbs and ayurvedic medicines drying. India is primarily an agriculture-dependent country. However, the pace at which agricultural and economic activities are changing is so fast that traditional methods of working are increasingly being considered outdated. Modernization, with many innovations, is the order of the day, such as progress in the field of information technology, which has gone forward in leaps and bounds. The Indian rural economy is also improving at an accelerated rate with each passing day. The pattern of crops is changing fast with the farmers realizing that they cannot survive solely on conventional crops. This awareness is making farmers look towards horticultural crops such as fruits, vegetables, spices, etc., which yield high income. In fact, rural women have also turned into successful entrepreneurs by starting cottage industries and microenterprises that fetch attractive returns through DWACRA and other Self-Help Groups (SHGs). Therefore, A solar drying system, particularly for agro-products and marine products, is viable particularly in developing countries where labor costs are low and cost of fossil fuel energy is very high. In the future, larger systems could be designed utilizing solar, thermal, photovoltaic panels combined with wind power. As solar and wind energy is necessarily intermittent, advances in thermal and electrical energy storage are needed to make use of renewable energy viable in drying. To minimize use of oil or gas, biomass can be used for heating in the absence of insulation and wind. Farmers can use the locally available material for construction of solar dryers. The covering material should be carefully chosen.

Mahesh G. Bhong et al Conducted an experiment on advances in solar air drying. He discusses various techniques like active and passive drying, direct and indirect drying, using selective and non-selective absorber plates, porous and non-porous absorber plates, etc. Presented review leads to conclude with the scope available and future enhancements that can be carried out with these methods with the aim of reduction in cost, improving efficiency, and thermal performance. Solar drying devices can be economical to build or buy as well as use because of the availability of local material and energy from the sun. Available devices are not as efficient as farmers like it. The reason for this is because each time cold incoming air is allowed to absorb heat. Such new air cannot exceed a certain average temperature, thus, reduces the overall efficiency of the dryer. Various heat transfer augmentation techniques are used in lots of research papers, but again by utilizing some energy. Sun drying has many problems - it is difficult to maintain consistent quality, losses are high from contamination, insects and animals, it requires large land areas and it takes a long time to dry. For these reasons, many commercial drying operations have switched to other types of drying. The options like switching from oil to solar should be made available with consideration of economics behind it. Also preferred to have a quicker payback time to recover their investment.

R.S. Gill et al Experimented on low-cost solar air heaters. In their study two low-cost solar air heaters have been considered. One is with Single glazed and another one with double glazed were designed, fabricated and tested. Thermocole, ultraviolet stabilized plastic sheet, etc. were used for fabrication to reduce the fabrication cost. These were tested simultaneously at no load and with load both in summer and winter seasons along with a packed bed solar air heater using iron chips for absorption of radiation. The initial costs of single glazed and double glazed are 22.8% and 26.8% of the initial cost of a packed bed solar air heater of the same aperture area. It was found that on a given day at no load, the maximum stagnation temperatures of single glazed and double-glazed solar air heaters were 43.5°C and 62.5°C respectively. The efficiencies of single glazed, double glazed and packed bed solar air heaters corresponding to flow rate of 0.02 m^3 /s-m^2 were 30.29%, 45.05% and 71.68% respectively in the winter season. The collector efficiency factor, heat removal factor based on air outlet temperature and air inlet temperature for three solar air heaters were also determined. Single glazed low-cost solar air heater gives better thermal efficiency during summer while double glazing is better during winter for all flow rates. For flow rate of 0.020 m^3 /s per m^2 aperture area, the maximum average thermal efficiency was 37.45% for single glazed and 24.07% for double glazed solar air heater during summer. Corresponding figures for winter were 30.29% and 45.05% respectively. For flow rate of 0.020 m^3 /s per m^2 aperture area, the maximum rise in air temperature was 18°C for single glazed and 12°C for double glazed solar air heater during summer. Corresponding figures for winter were 19.5°C and 33.5°C respectively. The heat removal factor based on air outlet temperature (Fo), heat removal factor based on air inlet temperature (FR) and collector efficiency factor (F0) were found to be higher for packed bed solar air heater as compared to single- and double-glazed solar air heaters for summer as well as winter season. These factors for single glazed solar air heaters were more during summer, whereas in winter values of double-glazed solar air heaters were more. For the same initial investment, low-cost solar air heaters collect more energy than packed bed solar air heaters. For flow rate of 0.020 m^3 /s per m^2 aperture area, the solar energy gain per unit investment was 0.13 kJ per US$ for single glazed, 0.10 kJ per US$ for double glazed and 0.03 kJ per US$ for packed bed solar air heater during summer. Corresponding figures for winter were 0.08 kJ per US$, 0.07 kJ per US$ and 0.02 kJ per US$ respectively. Farmers need to use solar air heaters for drying for a short period after harvesting (1–2 months in a year). So, during off season this low-cost solar air heater can be stored inside as it is light weight too (6.8 kg per m^2 aperture area).

Abhay Bhanudas Lingayat et al Experimented indirect type solar dryers for agricultural crops, and its performance. Solar dryers of various sizes, capacities and designs are available for drying applications in agricultural industries. Indirect type solar dryer (ITSD) is one of the prominent dryers used to dry food products and this type of dryer with its unique features, types, and different techniques incorporated to improve its performance has not been investigated so far in any detail. The purpose of this work is to review the features and benefits of ITSD. A commonly used classification of different types of solar dryers is also presented. Heat transfer enhancement on ITSD and the influence of pre-treatment before drying are also effectively reviewed. Payback period and cost analysis of ITSD are discussed. Important findings on ITSD have been reviewed, discussed and tabulated. The most dominant parameters affecting the drying rate are air temperature and velocity, followed by solar radiation, type of product, initial moisture content and total mass of the product. Passive solar dryers were easy to fabricate compared to active dryers. The drying rate of pre-treated foods was high and the quality of the product remained intact after drying. This work provided a review of indirect type solar dryers (ITSD) by presenting different designs, the construction details and performance evaluation of the models. Dryer selection depends on a number of parameters such as solar insolation, ambient temperature, drying air velocity, humidity, type of product, moisture content in the product, mass of the product, etc. Drying time varied with different types of products as the drying curves were different for different products. Temperature and velocity of drying air affected the quality of the product. Two categories of ITSDs were identified; natural convection or passive solar dryers and forced convection or active solar dryers. Passive solar dryers were easy to fabricate and required lower cost than active solar dryers. Passive solar dryers were self-operated dryers but had no control over drying rate, unlike active solar dryers. Forced convection in ITSD offered excellent control over drying rate. From the various types of solar dryers, forced convection ITSD with double pass or triple pass provision and collector with reflector promised better performance and hence overall efficiency and drying quality of the product improved. Use of TES units and SH and LH storage material enhanced the continuous use of ITSDs, enabling solar dryers to function even after sunset. Use of TES helped to reduce the required time for drying. Use of photovoltaic panels helped to fulfill the requirement of electric power needed for the fan or blower to make the dryer as forced convection ITSD. Pre-treatment of the crops before drying was good for enhancement of drying rate and it also helped to maintain the quality of product. Solar energy is a clean and freely available energy system therefore, initial investment can be returned as early as possible (payback) through effective utilization of the dryer system.

Mahmood Ul Hasan at el Reviewed modern drying techniques in fruits and vegetables to overcome postharvest losses. It mainly focuses on reviewing crop-specific operations, its impact on quality, efficiency, cost-effectiveness, and nutrient retention ability. Finally came to know that the usage of dried FV products has now become a trend due to their nutritional value and consumer's high demand in the market. A number of drying approaches are being applied commercially for vegetables and fruits; all of the drying procedures can be clustered into different categories. Many of the new drying techniques developed internationally such as solar drying, microwave, vacuum drying, infrared drying, and oven as well as hybrid drying found to be more efficient in energy use and time as compared with traditional drying techniques (sun and open air).

Above discussed technologies are mostly used and adopted in food industries. More recently, industrialists, researchers, and other stockholders are focusing on the development of hybrid dryers which contribute to superior quality and cost-effectiveness. These advanced techniques including solar and microwave technologies (either simple or assisted) are gaining popularity day by day. However, several critical factors such as the quality of product, reduction in drying time, energy efficiency, and overall cost-effectiveness must be considered in the development of crop-specific future drying technologies.

L. M. Diamante et al. Studied mathematical modelling of the thin layer solar drying of sweet potato slices. Solar drying rate curves exhibited a constant rate period and one linear falling rate period. A mathematical model for solar drying of sweet potato slices was derived based on the simplified form of the Fick's diffusion equation. The mathematical model could satisfactorily describe the solar drying of sweet potato slices to a moisture content below 20% dry basis. The mean effective drying chamber temperature and sample thickness were the main factors that affected the solar drying process for sweet potato slices. The mean effective drying chamber temperature and the sample thickness were the main factors that affected the solar drying of sweet potato slices.

Abdullah Akbulut et al. Conducted a study on drying parameters of mulberry grown in Elazig e drying experiments were conducted at seven different drying mass flow rates varied between 0.0015 and 0.036 kg/s. And also presents a new mathematical modeling of thin layer solar drying of mulberry samples. The effect of the convective solar dryer on drying of mulberries under seven different mass flow rates was studied successively. The drying time considerably decreased when the mass flow rate increased. In the present study, 10 different mathematical drying models, available in the literature for the fruits and vegetables, were fitted to experimental data obtained when mulberry was dried in the range of mass flow rates from 0.0015 to 0.036 kg s1 in the convective solar dryer. The drying process occurred in the falling rate period. Apart from these models, the newly developed mulberry model was applied to the drying process. It is concluded that the newly developed model under the convective solar dryer condition can adequately describe the drying behavior of the mulberry. Correlation coefficients, w2, RMSE and EF for all models and the newly developed model considered were estimated. All the drying models considered in this study could adequately represent the drying behavior of mulberry, although the newly developed model and the Midilli–Kucuk model were better than the other models. The moisture diffusivity of mulberry was found to range between 1.38 109 and 1.09 1013 m2 s 1 within the mass flow rate range of 0.0015–0.036 kg/s. In order to explain the drying kinetics of the other selected products under the thin layer forced solar drying process, the new model developed in this study can be used sufficiently for the thin layer forced solar drying behavior.

M. A. Hossain et al. Developed a prototype of a hybrid solar dryer for drying tomatoes. It consists of a flat-plate concentrating collector, heat storage with auxiliary heating unit, and drying unit. It has a loading capacity of 20 kg of fresh half-cut tomatoes. The dryer was tested in different weather and operating conditions. The performance of the dryer was compared with an open sun-drying method. Drying performance was evaluated in terms of drying rate, color, ascorbic acid, lycopene, and total flavonoids. Tomato halves were pretreated with UV radiation, acetic acid, citric acid, ascorbic acid, sodium metabisulphite, and sodium chloride. Sodium metabisulphite (8g L–1) was found to be effective to prevent microbial growth at lower temperature (45°C).

2.2 Literature Summary

- Many reviews, studies and experiments were performed with many techniques for drying food products in order to remove moisture content and retain its quality. At the same time other contents like protein, carbohydrates that are required to maintain to meet its requirement in order to serve its purpose. Previous studies were aimed to explore the new techniques for food drying.
- Most of the studies reveal that solar drying is an economical method, whose payback period is ranging from 0.54 to 4.69 years for small and medium range of driers respectively.
- It is also reported that solar dryers can also reduce 34% of CO_2 emission to the atmosphere with less consumption of fossil fuel.
- Some recent studies have developed a prototype of a hybrid solar dryer for drying vegetables. It consists of a flat-plate concentrating collector, heat storage with auxiliary heating unit, and drying unit.

- The mass flow rate was an important factor for the drying process, it is revealed that the drying time considerably decreased when the mass flow rate increased.
- Indirect drying process many parameters like inlet area, outlet area, glass to absorber plate, colour of the absorber plate, material of the absorber plate, solar radiation, intensity of solar radiation, inlet air temperature, inlet moisture content, surface enhancement, vortex generator and many studies have considered and performed the experiment.
- There are many fruits and vegetables (food products such as tomato, mango, grapes, greens, etc.) have dried and its quality and texture have been verified with its standards prescribed limits.
- Some of these studies are primarily concerned with optimizing flat plate collectors and fabricating them from waste such as plastic and scrap metals products, as well as the effects of various parameters such as radiation, intensity, and so on collector efficiency and effectiveness.
- Some of them discuss how developing such things can benefit poor countries. Where the agriculture sector has not developed. There is also discussion of microbial growth on food products, how it spoils them, and methods to reduce such microbial growth.

2.3 Research Gap

- Most of the studies claim that indirect solar drying is an economical method for food preservation with quality. But there is a need for new material to construct equipment which leads to additional cost.
- Very little research has been done on vegetables, most of the work has been done on fruits.
- Many studies performed experiments on the single layer drying process. But there is a scope to perform multi-layer experiments.
- Majority of the farmers cultivate vegetables whose life-span is less which need to increase without compromising its quality.

2.4 Objective

- The purpose of this research is to develop an indirect solar drying method with a simple mechanism that generates hot air to dry the food product (Ginger). Also looking into the most cost-effective and low-cost method to develop drying equipment.
- To remove a high proportion of moisture content from food products (Ginger).

CHAPTER 3
METHODOLOGY

3.1 Introduction

The absorber plate is made up of empty aluminium tins that have been black coated in order to absorb as much heat energy or radiation as possible from the source. The following formulas show the efficiency of the absorber plate, mass of air required for the moisture removal process, energy required for drying, and moisture content.

3.2 Theoretical Formulae

3.2.1 Flat plate collector efficiency

$$\eta = mC_p(t_c - t_i)/AG$$

Where

A=collector area (m^2)

C_p=specific heat capacity of air at constant pressure (J/kg°C)

G=solar radiation incident on the collector (Wm^2)

m=air flow rate (kg/s)

t_i=temperature of the inlet air (°C)

t_c=temperature of the outlet air (°C).

3.2.2 The mass of air needed for the moisture removal process can be calculated using

$$m_a = m_w/(\varphi_f - \varphi_i)$$

Where

m_w=Mass of water

m=Mass of air

φ_f=Final Humidity Ratio

φ_i=Initial Humidity Ratio

3.2.3 Energy required for drying

$$Q_d = m_a C_p\left(T_{co} - T_f\right) = m_w L_w$$

Where

m_w=mass of water removed in kg

L_w=latent heat at a mean temperature [(T_{co}+T_f)/2] in J/kg

T_{co}=Collector outlet air temperature (°C)

T_f=air temperature at exit of the chamber in (°C).

3.2.4 Moisture content formula

$$MC\% = \left(\frac{m_{wet} - m_{dry}}{m_{dry}}\right) * 100$$

Where

MC%=Moisture Content

m_{wet}=Mass of wet product

m_{dry}=Mass of dry product

The following figure shows the 2-D schematic diagram of the assembly of the drying chamber and the absorber plate representing all the parameters of our project.

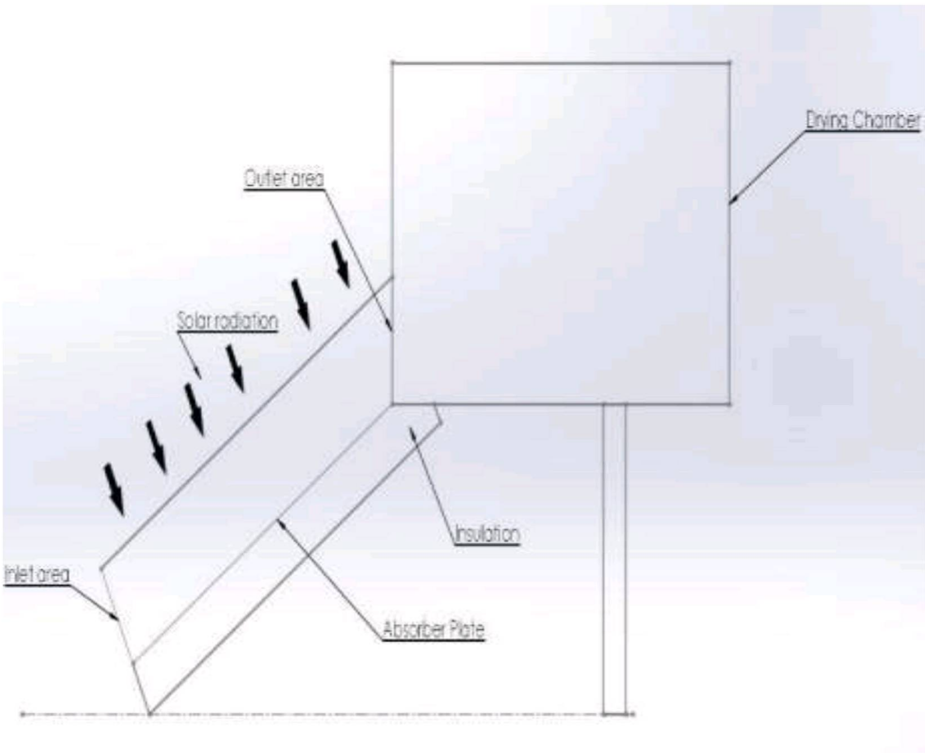

Figure-3.1 2D Model of equipment consists of drying chamber and absorber plate

3.3 Experiment Details

3.3.1 Solar simulator

A solar simulator (also known as an artificial sun or sunshine simulator) is a device that simulates natural sunlight. The solar simulator's objective is to provide a controlled indoor test facility under laboratory settings. It may be used to evaluate any photosensitive process or material, such as solar cells, photosynthesis, water treatment, crude-oil deterioration, and free radical production. Solar simulators are utilized in a variety of study fields such as photobiology, photooxidation, photodegradation, photovoltaics, and photocatalysis.

The following figures shows 1000-Watt Halogen Lamp and Shield that has been used in experiment.

Figure-3.2 Halogen lamp shield

Figure-3.3 1000W Halogen lamp

Halogen lamps are utilized in headlights, under-cabinet illumination, and work lights. Furthermore, halogen reflectors such as MR and PAR lamps are frequently used for directed illumination such as spotlights and floodlights. They are also becoming a more efficient alternative to incandescent reflectors.

A Halogen lamp of 1000 Watts has been used in this experiment, which gives a lot of heat output when turned ON.It is provided with a shield as a measure of security.

The following figures show different views of the drying chamber that we have used in our experiment.

3.2.2 Drying chamber

Figure-3.4 Chamber front view

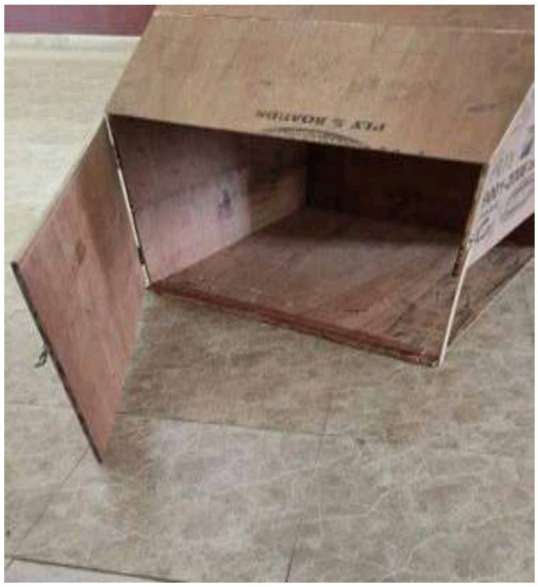

Figure-3.5 Chamber side view

Figure-3.6 Chamber top view

3.3.3 Assembly

Figure-3.7 Assembly

3.4 Instrumentation

3.4.1 Solar power meter

A solar power meter is a device that can measure solar power or sunlight in units of W/m^2, either through windows to verify their efficiency or when installing solar power devices.

Figure-3.8 Solar power meter

3.4.2 Digital Thermocouple

A digital thermocouple thermometer needs two measurements to determine temperature. First, it has a sensor to measure the temperature where the thermocouple connects to it – this is known as “cold-junction compensation (CJC). Secondly, it measures the mV signal from the thermocouple. In order to determine the temperature at the end away from the thermometer, it subtracts the CJC temperature from the hot end signal and then converts that voltage to temperature.

Figure-3.9 Digital Thermocouple

3.4.3 Weighing Machine

It is used to measure the weight of the product we want to remove moisture content. There will be thermocouples all over the drying chamber and flat plate collector to measure temperature. And a solar power meter to measure solar power or sunlight in units of W/m^2.

Figure-3.10 Weighing Machine

3.4.4 Dry bulb, Wet bulb thermometer

An instrument to measure the dew point, relative humidity, and vapour pressure. It essentially consists of two ordinary, accurate, mercury thermometers. One has thin muslin wrapped around it and is kept wet; it is called a wet bulb thermometer. The other is a dry-bulb thermometer. The dry-bulb thermometer shows the current temperature, whereas the wet-bulb thermometer shows a somewhat lower temperature, the result of the latent heat of evaporation, which depends on the relative humidity of the air.

Figure-3.11 Dry bulb, Wet bulb thermometer

3.5 PROCEDURE

Energy is collected from the heat released by the halogen lamps which use electricity mounted on a stand to make them parallel to the absorber plate at a distance of 16inches from the top surface of the plate. To receive maximum energy, the plate collector is angled at 30 degrees from horizontal (Ground Surface). After absorption, some of the energy is lost to the ambient air after reflecting through a glass cover, and the remaining is transferred inside the collector. After passing through the glass, heat is trapped inside the collector and heats up the air. Because hot air has a low mass, it rises, and the vacancy is filled by cold air, which has a higher mass, and this cycle continues indefinitely. Because of the difference in densities, the raised hot air is directed to the drying chamber (housing) as the cold air pushes the hot air. The hot air circulates through the food product in the drying chamber. After the air vents through a hole provided at the top of the drying chamber, the product is heated and moisture is removed. Following the drying process, the dried product is removed and weighed to determine the amount of moisture removed. The product is then stored in a specific chamber for later use. The products we are experimenting with are GINGER because it has a low moisture content. The parameters considered here are weight of the product, solar radiation, air temperature, humidity ratio, absorber plate Inlet and outlet area. To reduce discoloration and cracking on the product's surface, the product is not directly exposed to solar radiation. The drying chamber keeps the product safe and free of dust and debris. Under the glass cover, black-coated cans (waste tins) are placed to receive the heat energy. A total of seven (7) thermocouples were placed all over the setup to measure the temperatures. Two (2) were placed at the inlet and outlet of the absorber plate to read the air in and exit temperatures. And another three (3) were placed in the chamber as one just below the bottom mesh and another goes just above the top mesh and third one goes to the vent. And an extra one for the indoor room temperature.

And a dry bulb wet bulb thermometer is placed both indoor and outdoor for 2 days. And measured the relative humidity of the air indoor and outdoor. Relative humidity (RH) is a measure of how much water vapour is in a water-air mixture compared to the maximum amount possible.

Figure- 3.12 Ginger

Figure-3.13 Slicer

CHAPTER-4
RESULT

Measuring Weight

Figure-4.1 Measuring Weight

Mesh Layers

Figure-4.2 Mesh Layers

The results show that loss of moisture content in the food product is about 85%, at the same time the change in texture of the food product is insignificant.

4.1 Day 1 drying under fan

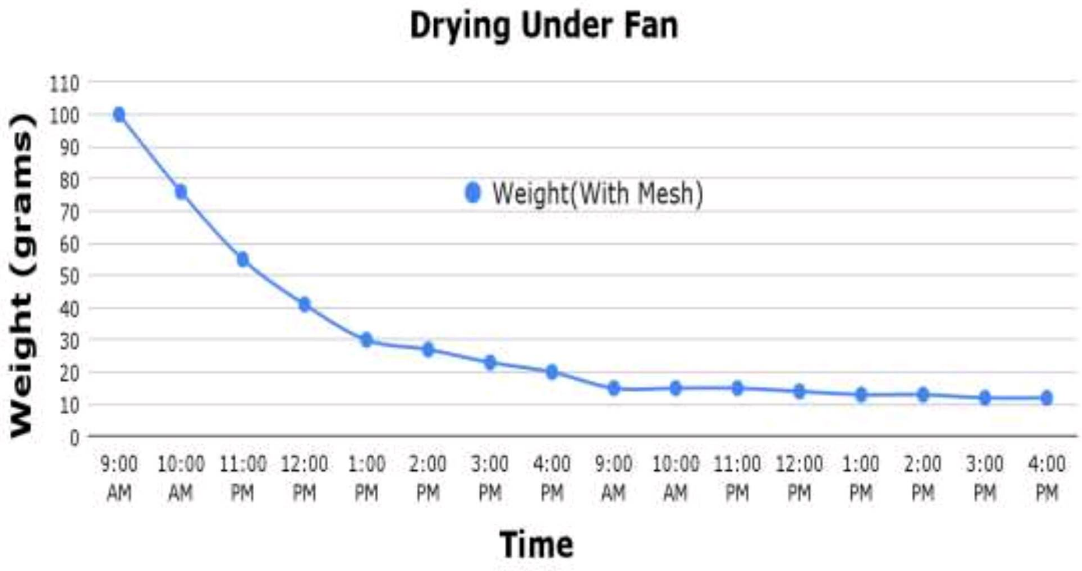

Figure-4.3 Day 1 drying under fan

The graph above depicts the drying of 100 grams of ginger in the presence of a fan. There is a significant decrease in the weight of the ginger in the first five hours, followed by a slow descent. Because air molecules moving fast they absorb more moisture after 1PM since the maximum amount of moisture is evaporated there is less moisture in the remaining ginger.

4.2 Day 1 Drying under No Fan

The graph below shows the exact same amount of ginger in the presence of shadow (No fan). But here there is no sudden descent because there is no air motion to remove the moisture fast compared to under fan drying.

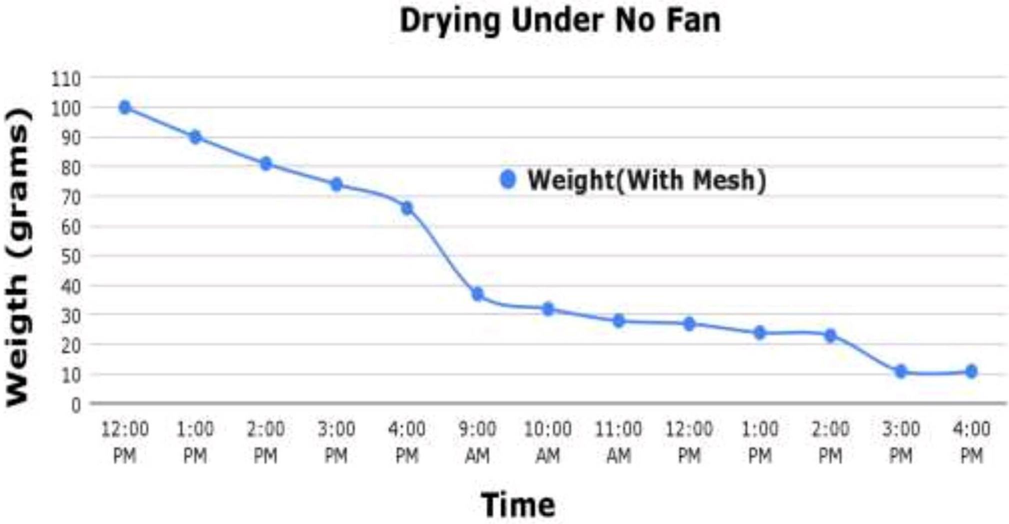

Figure-4.4 Day 1 Drying under No Fan

4.3 Relative Humidity

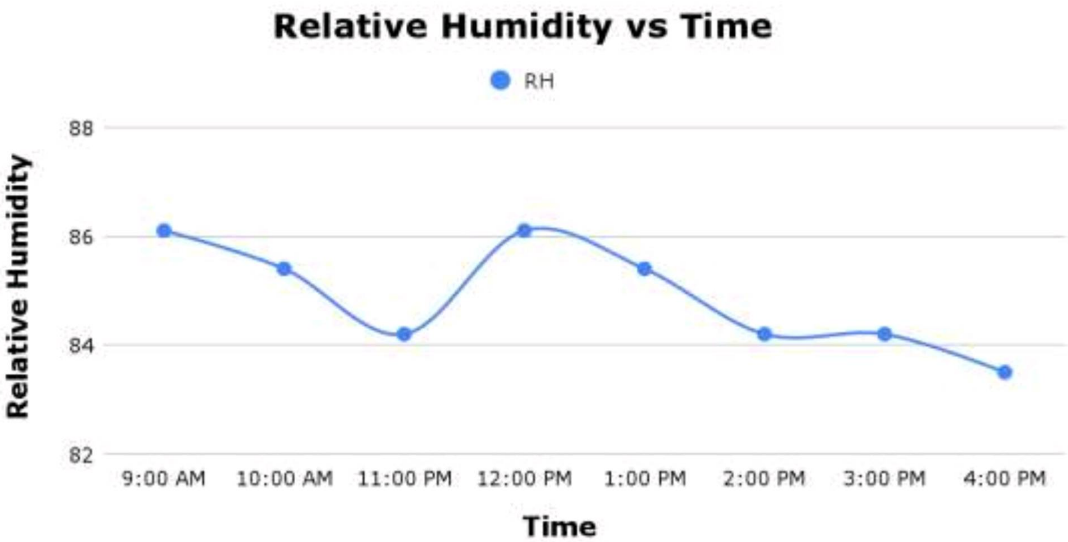

Figure-4.5 Relative Humidity

Relative humidity (RH) is a measure of the water vapour content of air. The above graph shows how much water vapour is there in the atmospheric air throughout the day.The above temperatures of dry bulb and wet bulb are taken indoors.

4.4 Dry bulb and wet bulb temperatures

On any given day, there will be no consistent pattern in dry bulb and wet bulb temperatures. On sunny days, the atmospheric air has a low humidity ratio, allowing it to absorb more moisture, but on rainy days or in the winter, the air already contains moisture, preventing it from absorbing more moisture.

The graph below depicts the Day-1 dry bulb wet bulb temperatures both indoor and outdoor as they relate to the time of day. And it is clear that neither the dry bulb nor the wet bulb temperatures have changed significantly.

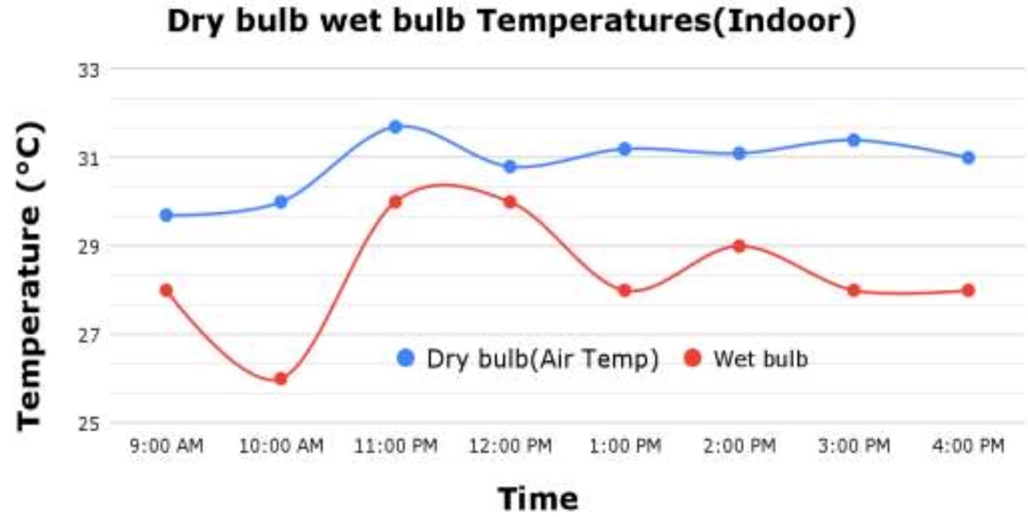

Figure-4.6 Indoor Dry bulb and wet bulb temperatures

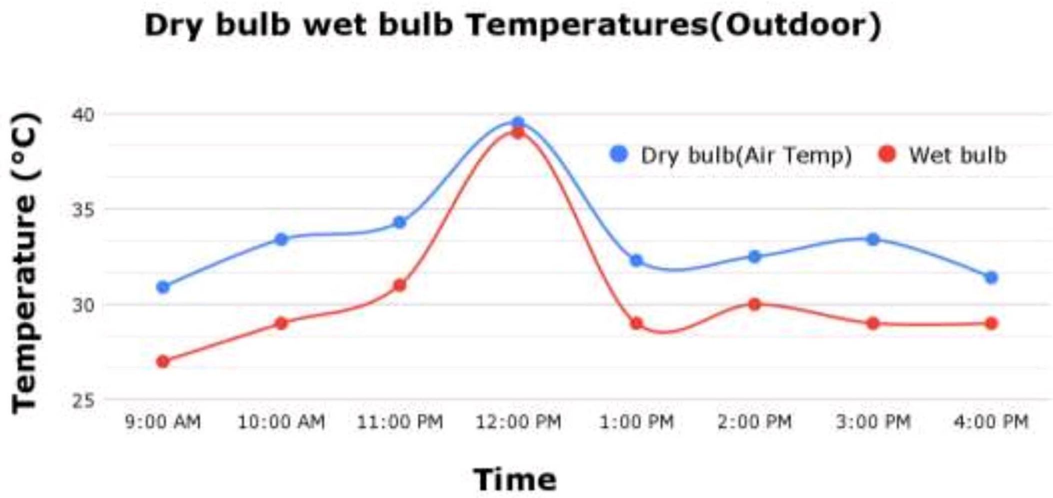

Figure-4.7 Outdoor Dry bulb and wet bulb temperatures

However, the graph outside rises at noon 12:00 PM due to the maximum temperature at that time and gradually decreases to the evening time. Dry and wet bulb temperatures both reach around 40°.

4.5 Day 1 Chamber Observation

Time vs Weight

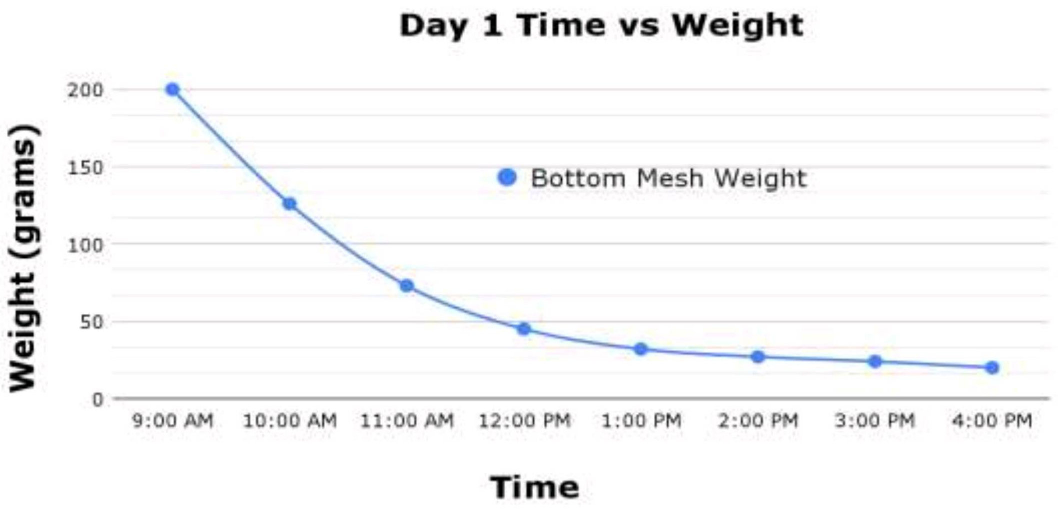

Figure-4.8 Day 1 Chamber Observation

On day 1, 200 grams of ginger is placed on the bottom mesh and measured while the light setup is turned on, and the results are shown above. The moisture removal rate during the early hours is nearly 33%, while it is negligible during the later hours.

Time vs Chamber Temperatures

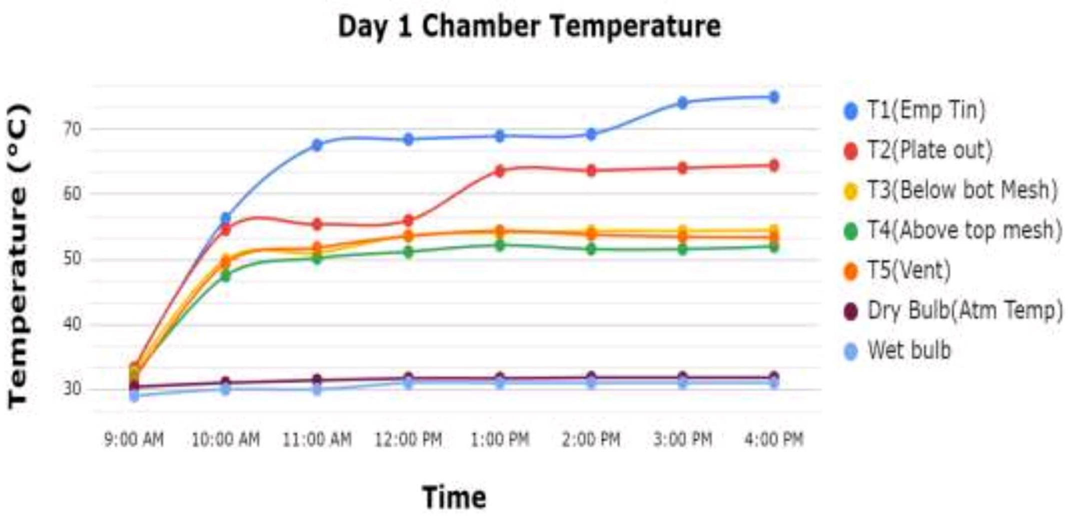

Figure-4.9 Day 1 Time vs Chamber Temperatures

The graph above shows the Day 1 temperature changes for each hour as we can see starting hours raised slowly and all the temperatures reached above nearly 47 degrees and later on the temperatures of bottom mesh, top mesh and vent are almost equal. But the tin temperature and plate outlet temperature keeps rising. And dry bulb and wet bulb temperatures are measured indoors.

Day 2 Chamber Observation

Time vs Weight

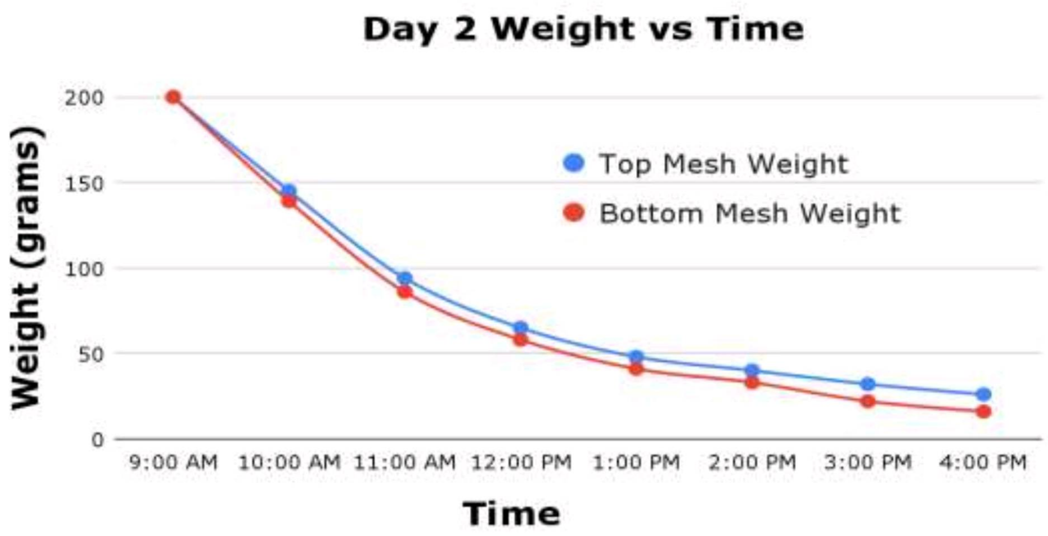

Figure-4.10 Day 2 Chamber Observation

On day 2, two layers of mesh arrangements are placed, one at the top and one at the bottom, with the same 200 grams of ginger on each mesh. And the results were nearly identical; the difference between them is insignificant.The moisture removal rate during the early hours is nearly 26%, while it is negligible during the later hours.

Time vs Chamber Temperatures

The graph below shows the Day2 temperature changes for each hour as we can see starting hours raised slowly and all the temperatures reached above nearly 49 degrees and later on the temperatures of vent, top mesh are almost equal. But the tin temperature and plate outlet temperature keeps rising. And dry bulb and wet bulb temperatures are measured indoors.

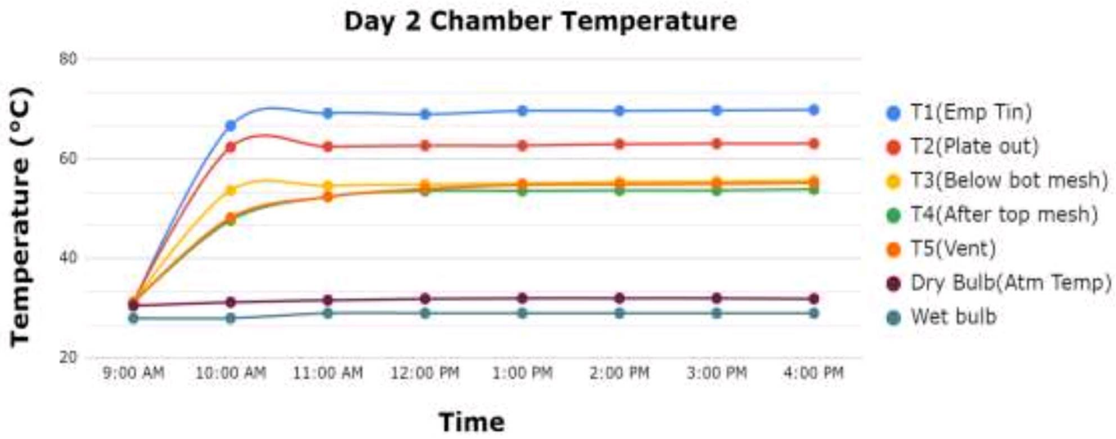

Figure-4.11 Day 2 Time vs Chamber Temperatures

Day 3 Chamber Observation

Time vs Weight

Placed all three layers, top, bottom, and middle, 200 grams of ginger each, and the results are shown in the graph below.After the start the start losing weight in increasing order bottom, middle and top. And after 12PM they reverse and start losing weight in decreasing order top, middle and bottom.

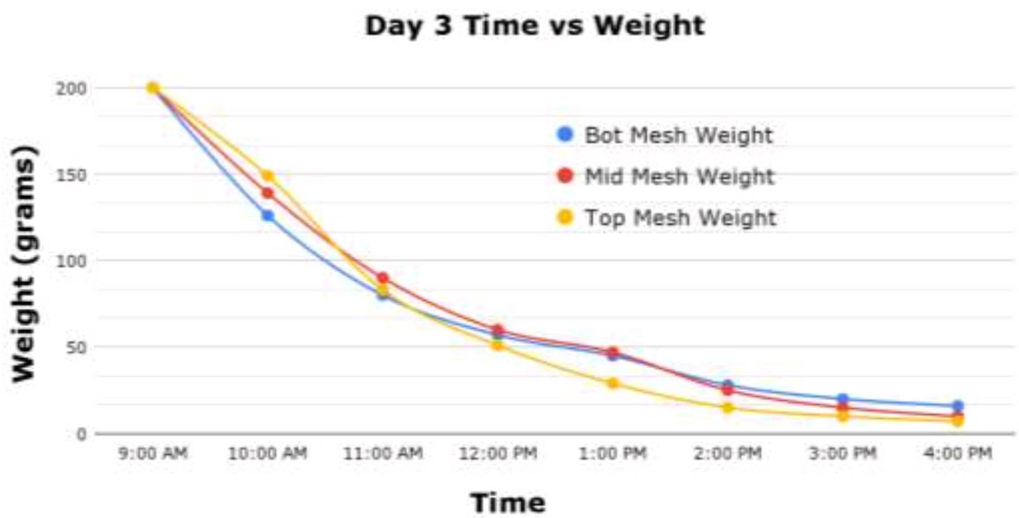

Figure-4.12 Day 3 Chamber Observation

Time vs Chamber Temperatures

The graph below shows the Day 3 temperature changes for each hour as we can see starting hours raised slowly and all the temperatures reached above nearly 45 degrees and later on the temperatures of vent, top mesh are almost equal. But the tin temperature and plate outlet temperature kept rising and became constant after 12PM. And dry bulb and wet bulb temperatures are measured indoors.

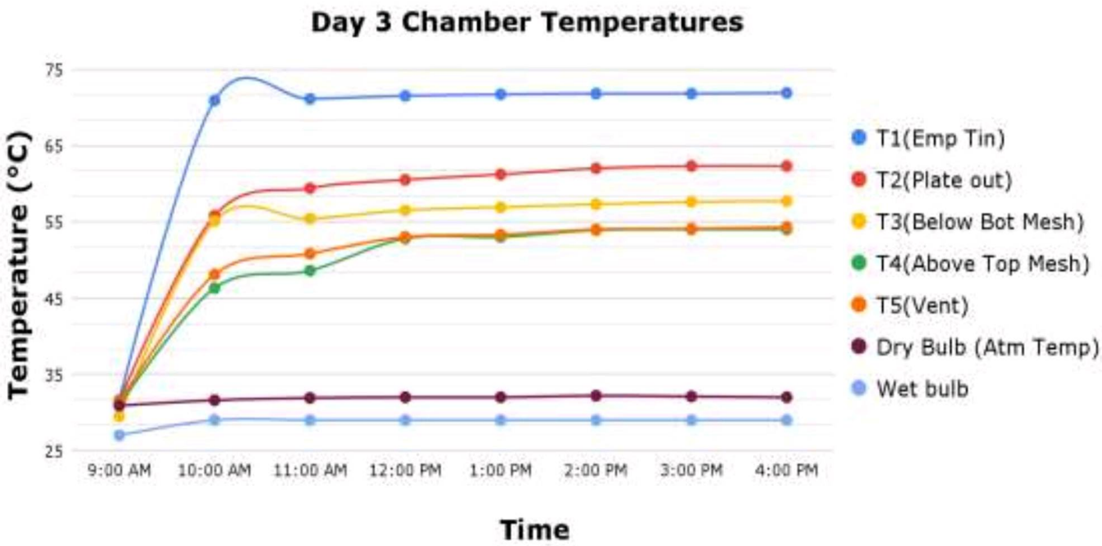

Figure-4.13 Day 3 Time vs Chamber Temperatures

CHAPTER-5
CONCLUSION

The indirect drying systems a thorough examination of the design, construction details, and operating principles of practically realised designs has performed and the following conclusions can be made from the experiment

- This work provided a review of product quality and moisture content using indirect type solar dryers (ITSD) by presenting design, the construction details of the model.
- Drying under shadow is much slower than drying under the fan because under the fan more air comes and touches the product so more moisture will be removed which is not a case in shadow.
- When the food product is dried in the chamber it is noticed that the loss of moisture content in the food product is about 90% which is quicker than the forced drying through fan arrangements, at the same time the change in texture of the food product is insignificant.
- It is noted that multilayer mesh drying also plays a significant role in product drying, the distance between mesh arrangements (8cm) had an effect on the drying on the top and middle mesh. So, the distance between the meshes should also be taken care of. Because there is an additional moisture accumulation on the top mesh which is removed from the bottom and middle mesh.

5.1 FUTURE SCOPE

Indirect solar drying systems that are extremely efficient, innovative, and intelligent may be built for small-scale farmer development, agriculture sector development, food drying, and space heating. To accomplish successful drying using indirect drying systems, heat (or cold) must be stored efficiently for long periods of time, necessitating the development of efficient and cost-effective tiny storage solutions.

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