INDUSTRIAL FOOD DEHYDRATOR

PROJECT REPORT

Submitted by

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To

ISHRAE

Department of Mechanical Engineering

FEDERAL INSTITUTE OF SCIENCE AND TECHNOLOGY (FISAT)®

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JUNE 2023

DECLARATION

I undersigned hereby declare that the project report **"INDUSTRIAL FOOD DEHYDRATOR"**, submitted to Ishrae. This submission represents my ideas in my own words and where ideas or words of others have been included, I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to academic honesty and integrity ethics and have not misrepresented or fabricated any data, idea, fact, or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained.

Place: Mookkannoor

Signature

Date: 22/05/2023

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ACKNOWLEDGEMENT

We take this moment to express our heartfelt gratitude to all those who have been a part of our journey in bringing this project to fruition. This endeavor would not have been possible without the unwavering support, guidance, and encouragement that we have received from various quarters.

First and foremost, we extend our sincere thanks to the Kochi chapter of ISHRAE (Indian Society of Heating, Refrigerating and Air Conditioning Engineers) for their invaluable support throughout this project. Our special gratitude goes to Mr. Sayed [Last Name], who has been instrumental in facilitating our association with ISHRAE India and for providing us with the essential research grant that made this project possible. This opportunity has allowed us to delve into a realm of innovation and learning that has been truly enriching.

Additionally, we would like to extend a heartfelt appreciation to the representatives of ISHRAE who played a pivotal role in awarding us the Student Research Project Grant. This financial support not only eased the practical aspects of our project but also provided a significant morale boost. The belief and investment shown by ISHRAE in our endeavors served as a constant source of motivation, instilling in us the confidence to overcome challenges and strive for excellence. The grant served as a reminder that our efforts were recognized and valued, and it greatly contributed to the positive trajectory of our project. We are truly grateful for the opportunity and encouragement provided by ISHRAE through this grant.

We wish to acknowledge the dedicated efforts of Mr. Renjith R, Assistant Professor in the Department of Mechanical Engineering at the Federal Institute of Science and Technology. His expert guidance, unwavering support, and insightful suggestions have been the cornerstone of our project's success. His willingness to share his knowledge and his constant encouragement have been a driving force in our pursuit of excellence.

We also extend our heartfelt thanks to the technical staff of our institution, whose assistance and cooperation were indispensable in carrying out the practical aspects of this project. Their expertise and willingness to assist have played a significant role in overcoming challenges and achieving our goals.

In conclusion, we extend our gratitude to all individuals and entities that have contributed in various capacities to the completion of this project. Each interaction, each piece of advice, and each moment of support has played a vital role in shaping this endeavor. We are deeply thankful for the collective efforts that have culminated in the successful realization of this project.

ABSTRACT

The coconut palm is considered the "tree of life" and has a significant cultural and economic importance in Kerala. Drying coconut is an important process that enhances its shelf life and preserves its nutritional value. However, traditional drying methods have several drawbacks, including high energy consumption, long drying times, and poor product quality. Therefore, there is a need for more efficient and sustainable drying methods, such as the heat pump assisted indirect solar dehydrator.This presents the development and performance evaluation of a heat pump assisted indirect solar dehydrator for drying coconut, which is an essential agricultural product in Kerala.

The developed system consists of a flat plate double pass solar collector and a heat pump system, both operating in a complementary manner to maximize energy efficiency. The optimal inclination angle of the solar collector was found to be 30 degrees, providing the highest temperature output during the day. The heat pump system, which is three times more efficient than conventional dryers, is utilized as an auxiliary system at night. Dehumidification is achieved through passing the humid air to the evaporator, where the air is cooled and moisture is released, followed by reheating in the condenser before being recirculated to the drying chamber. This process results in high-quality copra in less time and with lower operating costs. The system was tested under various conditions, and the results demonstrated its viability and efficiency in drying coconut.

In addition, the analysis of the drying chamber was conducted using ANSYS, which revealed that the temperature was slightly higher at the lower tray. This finding suggests that the placement of the coconut trays could be optimized to ensure uniform drying and quality of the copra.

Overall, this project provides a comprehensive analysis of the design, fabrication, and testing of the heat pump assisted indirect solar dehydrator, highlighting its potential as an efficient and sustainable solution for drying coconut. The system offers several benefits, including reduced energy consumption, faster drying times, and improved product quality, which can contribute to the economic growth and sustainability of the coconut industry in Kerala.

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ABBREVATIONS

HP : HEAT PUMP

SAHPD : SOLAR ASSISTED HEAT PUMP DRYER

Deff : DIFFUSION

DR : DRYING RATE

HRR : HEAT RECOVERY RATE

COP : COEFFICIENT OF PERFORMANCE

AHX : AIR HEAT EXCHANGER

GDP : GROSS DOMESTIC PRODUCT

DPSAC : DOUBLE-PASS SOLAR AIR COLLECTOR

CHAPTER 1

INTRODUCTION

Food preservation is an essential aspect of ensuring a steady supply of nutritious and safe food. In many parts of the world, dehydration is one of the most commonly used methods for preserving food, particularly fruits and vegetables. One such region is the Indian state of Kerala, where coconut, a widely cultivated fruit, is dehydrated for various purposes, including for its oil. In this paper, we explore the use of a solar-assisted heat pump dryer as an innovative solution for coconut dehydration in Kerala. Coconut cultivation and coconut oil have been an integral part of people's lives in Kerala for centuries. Coconut is a versatile fruit that provides a range of products, including oil, water, milk, and grated flesh. Coconut oil is an essential ingredient in traditional Kerala cuisine and is also used for cosmetic and medicinal purposes. Additionally, coconut farming provides livelihoods for thousands of people in the region, making it a crucial part of the local economy. Coconut drying is a complex process that requires careful consideration of various factors to achieve optimal results. The moisture content of coconuts before drying typically ranges from 50% to 60%. To effectively reduce this moisture content, precise control of drying parameters is essential. Temperature plays a critical role in the drying process, with recommended ranges between 50 to 60 degrees Celsius. This temperature range allows for efficient moisture evaporation while minimizing the risk of thermal degradation. Humidity control is equally important, with relative humidity maintained at around 40% to 50%. This controlled humidity level creates a favorable moisture gradient, promoting moisture migration from the coconut to the surrounding air. Other conditions, such as proper air circulation and ventilation, are crucial to ensure uniform drying and prevent the development of undesirable flavors or mold growth. Through meticulous management of these parameters and conditions, coconuts can be dried to a precise moisture content of approximately 5% to 7%, guaranteeing extended shelf life, preservation of nutritional value, and increased economic viability. One of the primary challenges faced by coconut farmers and processors is the need to dry coconut. Drying is necessary to remove excess moisture from the coconut, making it less susceptible to spoilage and contamination. Traditionally, coconut drying in Kerala has been done using various methods, including sun drying, oven or heater coil drying, and heat pump drying. These methods, while effective, have several drawbacks, including high energy consumption, long drying times, and the need for continuous supervision. To address these challenges, a solar-assisted heat pump dryer is proposed as a more sustainable and efficient alternative. This technology combines the use of solar energy with a heat pump system to create a hybrid dryer that can operate in both sunny and cloudy weather conditions. Solar collectors transfer the captured heat to a drying chamber, raising the temperature within the chamber and facilitating the drying process. The dryer can operate at a higher temperature than traditional drying methods, reducing drying time and energy consumption. There is currently no hybrid system in the market that is specifically designed for coconut drying. Developing such a system would require significant research and development, including studying the optimal operating parameters for drying coconut and developing a design that is cost-effective and easy to operate. The design procedure for the project involves optimizing the solar collector to maximize the absorption of solar radiation by considering atmospheric parameters such as solar radiation intensity, ambient temperature, and humidity. Various design techniques, such as selecting efficient materials, incorporating reflective surfaces, and adjusting the tilt angle, can be employed to enhance the collector's radiation absorption capabilities. Additionally, the design process entails carefully selecting the appropriate combinations of heat pump components, such as compressors, condensers, and evaporators, to ensure efficient heat transfer and energy utilization. Furthermore, an efficient circulation system is designed to enhance the flow of heat transfer fluids, enabling effective heat exchange between the solar collector and the drying chamber, thereby optimizing the overall performance of the system. The benefits of this technology over traditional drying methods are significant and include reduced drying time, energy consumption, and operating costs. The development of a hybrid system specifically designed for coconut drying would further improve the efficiency and sustainability of this important industry in Kerala.

1.1 **CURRENTLY AVAILABLE SYSTEM**

Drying is a process of removing moisture or water from a material, which can be achieved through various methods and technologies. There are different types of drying systems available, each with its own advantages and disadvantages, depending on the material being dried and the desired end result.

1.11 SUN DRYING

Figure 1 Traditional drying of coconut

Open sun drying of coconut is a traditional method used to remove moisture from coconut flesh and create dried coconut flakes.The process involves spreading the products out on a flat surface in a thin layer, exposing them to direct sunlight and air circulation.The sun's heat and the surrounding air promote evaporation, causing the moisture in the coconut flesh to gradually evaporate. The drying time can vary depending on factors such as the intensity of sunlight, humidity levels, and the thickness of the copra pieces.During the drying process, it is crucial to regularly turn and mix the copra to ensure even drying and prevent mold or fungal growth. This is typically done using wooden tools or by hand. Additionally, it is essential to protect the copra from rain or excessive moisture, as it can hinder the drying process and lead to spoilage.The drying time depends on the type of product, the size of the pieces, and the prevailing weather conditions. Generally, it takes between 1 to 7 days for the products to dry completely.

Open sun drying of copra, while a traditional and widely practiced method, does have its disadvantages. One significant drawback is its susceptibility to unfavorable weather conditions. If there is rainfall or high humidity, it can considerably extend the drying time and increase the risk of spoilage. The copra is vulnerable to mold growth, diminishing its quality and market value.

Furthermore, open sun drying is a time-consuming process. It often takes several days or even weeks to achieve the desired moisture content, depending on environmental factors. This can be a significant challenge for commercial producers who require efficient and timely processing to meet market demands.

The lack of control over the drying environment is another limitation. Unlike mechanical dryers, open sun drying relies on natural elements such as sunlight, temperature, and airflow. These factors can vary and are not easily adjustable, making it difficult to ensure consistent and uniform drying across batches. Inconsistencies in the drying process can lead to uneven quality and affect the overall product value.

Space requirement is also a consideration. Open sun drying necessitates ample space for spreading out the copra in thin layers. In densely populated areas or urban settings, finding suitable areas for drying can be a challenge. Additionally, measures must be taken to protect the copra from animals, insects, and contaminants, which can be difficult in an open and exposed environment.

1.12 DIRECT SOLAR DRYING

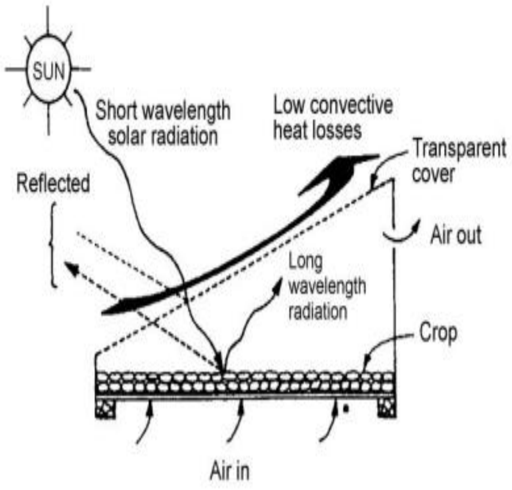

Figure 2 Direct solar drying

The principle of direct solar crop drying, also known as a cabinet dryer, is illustrated in Figure. In this method, a portion of the incident solar radiation on the glass cover is reflected back to the atmosphere, while the remaining portion is transmitted into the drying chamber. Some of the transmitted radiation is reflected back from the surface of the crop, while the rest is absorbed, causing an increase in the crop's temperature. This elevated temperature leads to the emission of long-wavelength radiation, which is trapped inside the chamber due to the presence of the glass cover, unlike in open sun drying. Consequently, the temperature inside the chamber rises. The glass cover also serves to reduce direct convective losses to the surrounding environment, further benefiting the increase in crop and chamber temperature.

However, there are limitations to using a cabinet dryer. Firstly, its small capacity restricts its use to small-scale applications. Secondly, direct exposure to solar radiation can result in discoloration of the crop. Additionally, moisture condensation can occur inside the glass covers, reducing their transmittivity.

In summary, the cabinet dryer provides a controlled environment for solar crop drying by utilizing the greenhouse effect. It offers advantages such as increased temperatures and reduced convective losses. However, its limitations include limited capacity, crop discoloration, and potential moisture condensation. These considerations should be taken into account when choosing a drying method for crop preservation.

1.13 INDIRECT SOLAR DRYING

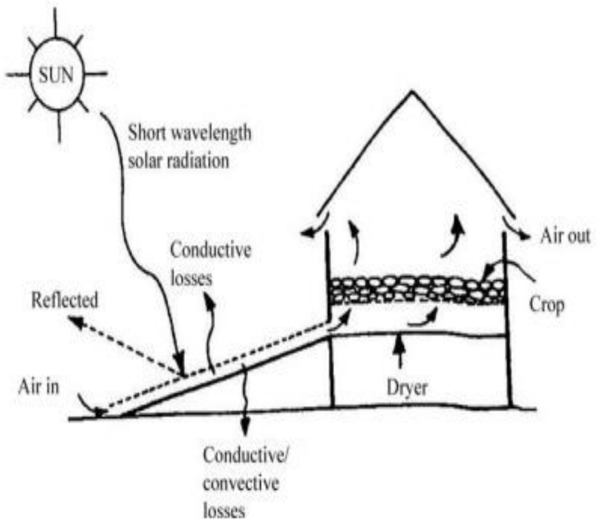

Figure 3 Indirect solar

An indirect solar dryer is a type of solar drying system that utilizes solar energy to dehydrate crops or other materials without direct exposure to sunlight. Unlike direct solar dryers, indirect solar dryers use a separate collector to capture solar radiation and transfer the heat to the drying chamber through a heat transfer medium.

The basic principle of an indirect solar dryer involves a collector, an air circulation system, and a drying chamber. The collector absorbs solar radiation and heats up a heat transfer medium such as air or water. This heated medium is then circulated through the drying chamber, where it releases heat to the crops or materials being dried.

The advantage of an indirect solar dryer is that it provides a controlled and more uniform drying environment compared to direct sun exposure. The heat transfer medium helps regulate the

temperature and humidity levels inside the drying chamber, promoting efficient drying and preventing direct sunlight from potentially damaging the crops or materials.
Indirect solar dryers are particularly useful in areas with high humidity or during unfavorable weather conditions. The separation of the drying chamber from direct sunlight reduces the risk of rain, dust, or other contaminants affecting the drying process. It also allows for drying to occur even on cloudy or overcast days, extending the drying season and improving overall drying efficiency.

Solar dryers have several advantages over other drying methods, including:

- Low cost: Solar dryers are relatively cheap to build and operate, as they do not require any fuel or electricity.
- Environmental-friendly: Solar dryers do not produce any harmful emissions or waste, making them a sustainable and eco-friendly option.
- Consistent quality: The controlled drying conditions ensure that the final product is of consistent quality, with minimal loss or spoilage.
- Easy to operate: Solar dryers are easy to operate and maintain, and can be used in remote areas where electricity is not available.

However, solar dryers also have some disadvantages, such as:

- Weather-dependent: The drying process is dependent on the weather, and drying times may vary depending on the season and the humidity levels.
- Limited capacity: Solar dryers are suitable for small-scale production and may not be suitable for large-scale operations.
- Slow drying times: The drying process may take longer compared to other drying methods, such as fuel-fired drying.
- Quality issues: The final product may not be of consistent quality, as it may be affected by uneven drying or contamination.

1.14 FUEL-FIRED DRYER

Figure 4 Fuel-fired dryer

A fuel-fired dryer is a type of dryer that uses a fuel, such as wood, coal, or natural gas, to heat the air that dries the coconuts. Fuel-fired dryers are typically more efficient than traditional methods of drying coconuts, such as sun drying or open fire drying. They can also dry coconuts in a shorter amount of time. The hot air is then blown into a drying chamber, where the products to be dried are spread out and exposed to the hot air. The process of fuel-fired drying is more controlled and efficient than open sun drying, making it suitable for large-scale production and industrial applications.

The working mechanism of a fuel-fired dryer is as follows:

- **Combustion chamber:** The fuel, such as diesel or natural gas, is burned in a combustion chamber, which produces heat and exhaust gases.
- **Blower:** A blower or fan is used to blow the hot air into the drying chamber.
- **Drying chamber:** The products to be dried are spread out in a thin layer on a conveyor belt or trays and exposed to the hot air.
- **Exhaust system:** The exhaust gases are released into the atmosphere through an exhaust system.

Fuel-fired dryers have several advantages over other drying methods, including:

- Reduced drying time: Fuel-fired dryers can dry coconuts in a shorter amount of time than traditional methods. This can help to reduce the risk of spoilage and improve the quality of the coconuts.

- Increased production: Fuel-fired dryers can increase production by allowing coconuts to be dried more quickly. This can help to meet the growing demand for coconut products.

- Consistent quality: The controlled drying conditions ensure that the final product is of consistent quality, with minimal loss or spoilage.
- Flexibility: Fuel-fired dryers can be used to dry a wide variety of products, including grains, seeds, nuts, and fruits.

drawbacks of using a fuel-fired dryer for coconut drying include:

- Increased cost: Fuel-fired dryers are typically more expensive to purchase and operate than traditional methods of drying coconuts.
- Increased pollution: Fuel-fired dryers can emit pollutants into the air, which can contribute to air pollution.
- Increased fire risk: Fuel-fired dryers can pose a fire risk, especially if they are not properly maintained.

1.15 HEAT PUMP DRYER

Figure 5 Heat pump drying of coconut

Heat pumps are devices that transfer heat from one place to another, and they can be used to dry coconuts in a more efficient and environmentally friendly way than traditional methods.
Heat pump coconut dryers work by circulating hot air through the coconuts. The hot air evaporates the moisture from the coconuts, and the heat pump then removes the moisture from the air. This process is repeated until the coconuts are dry.

Heat pump coconut dryers have several advantages over traditional methods of drying coconuts. They are more efficient, which means that they use less energy. They are also more environmentally friendly, because they do not produce any emissions. Heat pump coconut dryers can dry coconuts in a shorter amount of time than traditional methods.

Benefits of using a heat pump coconut dryer:

- More efficient: Heat pump dryers use less energy than traditional methods of drying coconuts, such as sun drying or open fire drying.
- More environmentally friendly: Heat pump dryers do not produce any emissions, which makes them a more sustainable option.
- Faster drying time: Heat pump dryers can dry coconuts in a shorter amount of time than traditional methods.
- Improved quality: Heat pump dryers can produce higher quality coconuts, with a lower moisture content and a longer shelf life.

1.2 SOLAR HEAT PUMP DRYING PROCESS. - OVERVIEW

The solar-heat pump system provides a compelling alternative to conventional processes for several reasons. Firstly, its utilization of renewable solar energy as a primary heat source ensures high energy efficiency and reduces reliance on conventional energy sources, resulting in lower energy consumption and operating costs. This, in turn, contributes to environmental sustainability by reducing greenhouse gas emissions and promoting clean energy practices.

Moreover, the solar-heat pump system offers significant cost savings over time. By harnessing freely available solar energy and leveraging the energy efficiency of heat pumps, it minimizes the need for expensive fuels or electricity, making it a cost-effective solution in the long run.

The versatility of the solar-heat pump system is another advantage, as it can be adapted to various applications and industries, including space heating, water heating, and industrial processes. This flexibility makes it a versatile and scalable solution that can cater to different heating and cooling needs.

The solar-heat pump system provides a degree of energy independence, reducing dependence on external energy suppliers and grid infrastructure. This is particularly beneficial in remote areas or regions with unreliable power supply, ensuring a consistent and reliable source of heating and cooling.

The durability and longevity of solar-heat pump systems make them a reliable and long-term solution. With proper maintenance, these systems can operate efficiently for many years, providing reliable heating and cooling solutions.

Considering these factors, the solar-heat pump system emerges as an attractive choice over conventional processes, offering energy efficiency, environmental sustainability, cost savings, versatility, energy independence, and durability. Its combination of solar energy and heat pump technology provides a compelling solution for those seeking a sustainable and efficient heating and cooling system.

WHY THIS SOLAR-HEAT PUMP

The use of a solar-assisted heat pump for drying coconut offers several advantages over traditional drying methods. In this project report, we will explore the benefits of this approach and the reasons why it is an ideal option for drying coconut.

Firstly, coconut is a commonly consumed food product that requires proper drying to ensure its long-term preservation and quality. Traditionally, coconut is dried using natural sun drying or fuel-fired dryers, which can be time-consuming, weather-dependent, and may result in inconsistent drying quality. In contrast, a solar-assisted heat pump dryer offers a controlled drying environment that can effectively dry coconut to a consistent quality, regardless of weather conditions.

Secondly, the use of a heat pump dryer reduces energy consumption and carbon emissions compared to traditional drying methods. A solar-assisted heat pump dryer uses the sun's energy to power the heat pump, which reduces the amount of electricity required to operate the dryer. This results in lower energy bills and a reduced carbon footprint, making it an eco-friendly option for drying coconut.

Furthermore, the solar-assisted heat pump dryer can be designed to operate in hybrid mode, using both solar energy and electricity from the grid. This allows for uninterrupted drying even during periods of low sunlight or at night. The dryer can also be equipped with sensors to monitor temperature, humidity, and airflow, which allows for precise control of the drying process and ensures consistent drying quality.

Finally, the use of a solar-assisted heat pump dryer can be beneficial for small-scale coconut farmers and businesses. As it requires less energy and is more efficient than traditional drying methods, the dryer can help to reduce operating costs and increase profitability. It also provides a more reliable and consistent drying method, which can help to improve the quality and shelf life of the coconut, leading to higher market value.

The use of a solar-assisted heat pump dryer for drying coconut offers several advantages over traditional drying methods. It is an energy-efficient, eco-friendly, and reliable option that can help to improve the quality and profitability of coconut farming and businesses.

Some of the pros of using solar-assisted heat pump drying for coconut include

2 Energy-efficient: The use of solar energy and a heat pump makes this drying technology more energy-efficient than traditional drying methods, resulting in lower energy bills and reduced carbon emissions.

3 High quality: The controlled drying conditions ensure that the final product is of consistent quality, with minimal loss or spoilage.

4 Cost-effective: The technology is relatively inexpensive to build and operate, making it a cost-effective option for small-scale farmers and businesses.

5 Reduced drying time: The technology can significantly reduce drying time, resulting in increased productivity and faster turnaround times.

6 Versatile: Solar-assisted heat pump drying can be used to dry a variety of products, not just coconuts, making it a versatile option for small-scale farmers and businesses.

1 Sustainable: The use of renewable solar energy makes this technology a sustainable and environmentally-friendly option

CHAPTER 2

LITERATURE REVIEW

[1] **SOLAR ENERGY Principles of thermal collection and Storage Third edition**

The book "Solar Energy: Principles of Thermal Collection and Storage" by S.P. Sukhatme and J.K. Nayak is a comprehensive and well-written text on the subject of solar thermal energy. The book covers a wide range of topics, from the basics of solar radiation to the design and performance of solar collectors and thermal energy storage systems. The book is well-organized and easy to follow, and it includes a wealth of information and references.

One of the most useful aspects of the book is the detailed discussion of solar collector types. The authors discuss the principles of operation of a variety of solar collectors, including flat-plate collectors, evacuated tube collectors, and concentrating collectors. They also provide detailed information on the design and performance of these collectors. This information is essential for anyone who is interested in designing or installing a solar thermal system.

The book also includes a comprehensive discussion of thermal energy storage. The authors discuss the various types of thermal energy storage systems, including sensible heat storage, latent heat storage, and thermochemical heat storage. They also provide detailed information on the design and performance of these systems. This information is essential for anyone who is interested in designing or installing a solar thermal system that requires thermal energy storage.

Overall, "Solar Energy: Principles of Thermal Collection and Storage" is an excellent resource for anyone who is interested in learning more about solar thermal energy. The book is well-written, comprehensive, and informative. It is a valuable resource for students, engineers, and anyone else who is interested in this important renewable energy source.

[2] **Performance of a double-pass solar air collector**

The paper presents the results of experimental investigations on the performance of a double pass solar air collector with selective absorber and enhanced insulation. The collector was tested under different operating conditions, and the results were compared with those of a single-pass collector with a conventional absorber.

The results showed that the double pass collector with a selective absorber had a higher efficiency than the single pass collector with a conventional absorber. The efficiency improvement was attributed to the following factors:

* The selective absorber reduced the amount of solar radiation absorbed by the collector, which reduced heat losses.
* The enhanced insulation reduced heat losses from the collector.
* The double pass design increased the amount of time that the air was in contact with the absorber, which increased the amount of heat that was transferred to the air.

The paper concludes that the double-pass solar air collector with selective absorber and enhanced insulation is a promising technology for solar thermal applications.

Here are some of the key findings of the paper:

* The double pass collector with a selective absorber had a higher efficiency than the single pass collector with a conventional absorber.
* The efficiency improvement was attributed to the following factors:
    * The selective absorber reduced the amount of solar radiation absorbed by the collector, which reduced heat losses.
    * The enhanced insulation reduced heat losses from the collector.
    * The double pass design increased the amount of time that the air was in contact with the absorber, which increased the amount of heat that was transferred to the air.
* The double-pass solar air collector with a selective absorber and enhanced insulation is a promising technology for solar thermal applications.

[3] **Satellite-based solar energy potential analysis for southern states of India.**

The paper focus on the Satellite-based solar energy potential analysis for the southern states of India. Following are the conclusions drawn from the study.

The study revealed that there was a spatial shift of the accessible energy along the study area but the southwestern region of the area had ample potential regions of solar insolation.

The statistical summary reported that Direct Normal Irradiation values range from 3.72 kWh/m^2 to 5.59 kWh/m^2 with an average value of 5.18 kWh/m^2 and GHI values range from 4.91 kWh/m^2 to 5.99 kWh/m^2 with an average value of 5.71 kWh/m^2.

[4] **Experimental study on double pass solar air heater with thermal energy**

storage.

This paper focuses on the Experimental study of double-pass solar air heaters with thermal energy storage. Following are the conclusions drawn from the study.

The solar air heater with paraffin wax as energy storage material delivers comparatively high-temperature air throughout the day.

[5] **Design and Construction of the Flat Plate Solar Air Heater for Spray Dryer.**

This paper focus on the Design and Construction of the Flat Plate Solar Air Heater for Spray Dryer. Following are the conclusions drawn from the study.

Installing a solar air heater into a spray dryer uses 130.08 units of electricity over 8 hours. The solar heater 15 degrees angle is the best inclination angle. Operating at 8 hours per day can help reduce up to 30.12 units per hour. The thermal efficiency was achieved at 75.26 percent.

[6] **Performance of a heat pump drier for copra drying.**

The paper presents the results of an experimental study on the performance of a heat pump drier for drying copra. The heat pump drier was designed and fabricated by the authors, and it consists of a compressor, an evaporator, and a condenser. The evaporator is used to absorb heat from the copra, and the condenser is used to reject the heat to the ambient air.

The experiments were conducted at a drying air temperature of 40 °C and a velocity of 1.5 m/s. The results showed that the moisture content of the copra was reduced from 52.6 to 8.5% in 48 hours. The average coefficient of performance of the heat pump was estimated to be about 3.5. The specific moisture extraction rate was calculated to be about 0.85 kg/kW-hr.

The authors concluded that the heat pump drier was a successful drying system for Copra. The heat pump drier was able to reduce the moisture content of the copra to a level that is suitable for milling. The heat pump drier was also energy efficient, with an average coefficient of performance of about 3.5.

The paper is well-written and well-organized. The authors provide a clear and concise description of the experimental setup and the results. The paper is also well-referenced, and it provides a good overview of the state-of-the-art in heat pump drying.

The paper is a valuable contribution to the literature on heat pump drying. The results of the experiments show that heat pump driers can be used to dry copra in an efficient and effective manner. The paper is also a valuable resource for engineers and researchers who are interested in developing new heat pump drying systems.

[7] **QUALITY ANALYSIS OF COPRA DRIED AT DIFFERENT DRYING AIR TEMPERATURES.**

Following are the conclusions drawn from the study.

Help diversify the uses of coconut drying technology and accordingly, increase their profitability by drying coconut kernel during monsoon within a short duration. The results showed that the quality of coconut kernel can be effectively obtained by drying at a higher temperature. This technology will be more helpful for the industrialist and small-scale farmers to dry the copra in a short time with good quality nuts.

[8] **Hot air drying of coconut residue: shelf life, drying characteristics, and product quality.**

This paper focus on the Hot air drying of coconut residue: shelf life, drying characteristics, and product quality. Following are the conclusions drawn from the study.

For long shelf life for more than 140 days, coconut residue should have the moisture content not higher than 0.03 g water/g dry matter. Decrease in layer thickness had a more crucial effect on drying time than increase in drying temperature. As compared to fresh coconut residue, dried coconut residue with the drying time lower than 200 min was whiter (88.40- 90.51%) and all dried coconut residue had higher oil content (0.188-0.228 g oil/g dry matter).

[9] **Drying of copra in a forced convection solar drier.**

This paper focus on the Drying of copra in a forced convection solar drier. Following are the conclusions drawn from the study.

A forced convection solar drier is more suitable for producing high-quality copra for small holders. About 75% of high-quality copra (MCG1) could be produced. The average thermal efficiency of the solar air heater was estimated to be about 24%. A high drying rate at a rate of 4.2 g of water/g of dry matter was observed during the initial stage of drying.

[10] **Design and Fabrication of Solar Dryer System for Food Preservation of Vegetables or Fruit.**

This paper focus on the Design and Fabrication of Solar Dryer System for Food Preservation of Vegetables or Fruit. Following are the conclusions drawn from the study.

The approximate time of drying process is 12.5 h for apple slices, 23.5 h for kiwi and banana slices and 24 h for quince strips. Decrease in layer thickness had more crucial effect on drying time than increase in drying temperature. As compared to fresh coconut residue, dried coconut residue with the drying time lower than 200 min was whiter (88.40- 90.51%) and all dried coconut residue had higher oil content (0.188-0.228 g oil/g dry matter)

[11] **Heat pump heat recovery options for food industry dryers.**

The paper discusses the potential of heat pump heat recovery (HPHR) to improve the energy efficiency of food industry dryers. HPHR is a technology that uses a heat pump to transfer heat from a low-grade heat source, such as the exhaust air from a dryer, to a higher-grade heat sink, such as a hot water tank. This can help to reduce the amount of energy required to heat the dryer, which can lead to significant savings in operating costs.

The paper reviews the different types of HPHR systems that can be used in food industry dryers and discusses the factors that affect the performance of these systems. The paper also presents the results of a case study that was conducted to assess the potential of HPHR to improve the energy efficiency of a food industry dryer.

The results of the case study showed that HPHR can lead to significant reductions in energy consumption and operating costs. The study also showed that the payback period for HPHR systems is typically short, typically within 2-3 years.

The paper concludes that HPHR is a promising technology for improving the energy efficiency of food industry dryers. The paper recommends that food industry operators consider the use of HPHR systems to reduce their energy costs and improve their environmental performance.

In addition to the paper reviewed above, there are a number of other studies that have investigated the potential of HPHR for food industry dryers. These studies have shown that HPHR can lead to significant reductions in energy consumption and operating costs. For example, a study by the University of Nottingham found that HPHR could reduce the energy consumption of a food industry dryer by up to 70%. Another study by the University of California, Davis found that HPHR could reduce the operating costs of a food industry dryer by up to $50,000 per year.

[12] **Design and Performance Evaluation of a Solar Assisted Heat Pump Dryer Integrated with Biomass Furnace for Red Chili.**

This paper focus on the Design and Performance Evaluation of a Solar Assisted Heat Pump Dryer Integrated with Biomass Furnace for Red Chili. Following are the conclusions drawn from the study.

The averages of the solar collector efficiency, COP of the heat pump, and the efficiency were estimated to be about 35.1%, 3.84 respectively. The contributions of heat energy by the collector, condenser, and biomass furnace were estimated in the International Journal of Photoenergy 13 average to be about 14.74%, 47.39%, and 37.87%, respectively.

[13] **Experimental investigation of a new design solar-heat pump dryer under the different climatic conditions and drying behavior of selected products.**

This paper focus on the Experimental investigation of a new design solar-heat pump dryer under the different climatic conditions and drying behavior of selected products. Following are the conclusions drawn from the study.

Only the heat pump system or a combination of the solar collector and heat pump can be used in cases where insufficient solar energy is available and there were no significant differences were observed on dried products such as thermal damage, browning, shrinkage, and taste. Drying can be easily done with only the solar collector when the outside weather conditions of a high temperature and low relative humidity.

[14] **Refrigeration and Air Conditioning.**

This book deals with the Principles of Refrigeration and Air Conditioning. Following are the conclusions drawn from the study:

Primary resistance to heat and mass transfer is at the surface. When the surface appears to develop dry patches, the rate of drying begins to decrease, as internal resistance becomes significant. Applicable for optimizing heat pump capacity in order to remove moisture.

[15] **Experimental analysis of hybrid dryer combined with spiral solar air heater and auxiliary heating system: Energy, exergy and economic analysis.**

This paper focus on Experimental analysis of hybrid dryer combined with spiral solar air heater and auxiliary heating system: Energy, exergy and economic analysis. Following are the conclusions drawn from the study.

The approximate time of drying process is 12.5 h for apple slices, 23.5 h for kiwi and banana slices and 24 h for quince strips. Thermal efficiency, drying process exergy, produced exergy and SMER of quince strips are higher than those of other products. Among the sliced products, banana slice has better conditions in terms of thermal efficiency, drying process exergy, produced exergy and SMER. The maximum and the minimum drying rate are related to apple crop which is 0.3224 kg/h and kiwi slice which is 0.188 kg/h respectively.

2.1. PROBLEM DESCRIPTION

- The traditional methods followed in India are sun and kiln drying. They produce poor-quality copra and are time consuming. With kiln drying, smoke is in direct contact with the coconut cups.
- Copra produced by this method is of poor quality as dust particles settles onto coconut halves, birds and rodents eat the coconut kernel. The direct sunlight can cause depletion of nutrients in fruits and vegetables, along with discoloration which is not desirable.
- The oil extracted from poor-quality copra also requires additional refinement to meet international standards.

2.2. OBJECTIVE

- To design and fabricate a heat pump assisted Solar Dehydrator for Drying Coconut.
- To identify Parameters like temperature distribution, airflow in the drying chamber using CFD analysis.
- To design CAD model of solar collector, Drying Chamber, Heat pump.

CHAPTER 3

METHODOLOGY

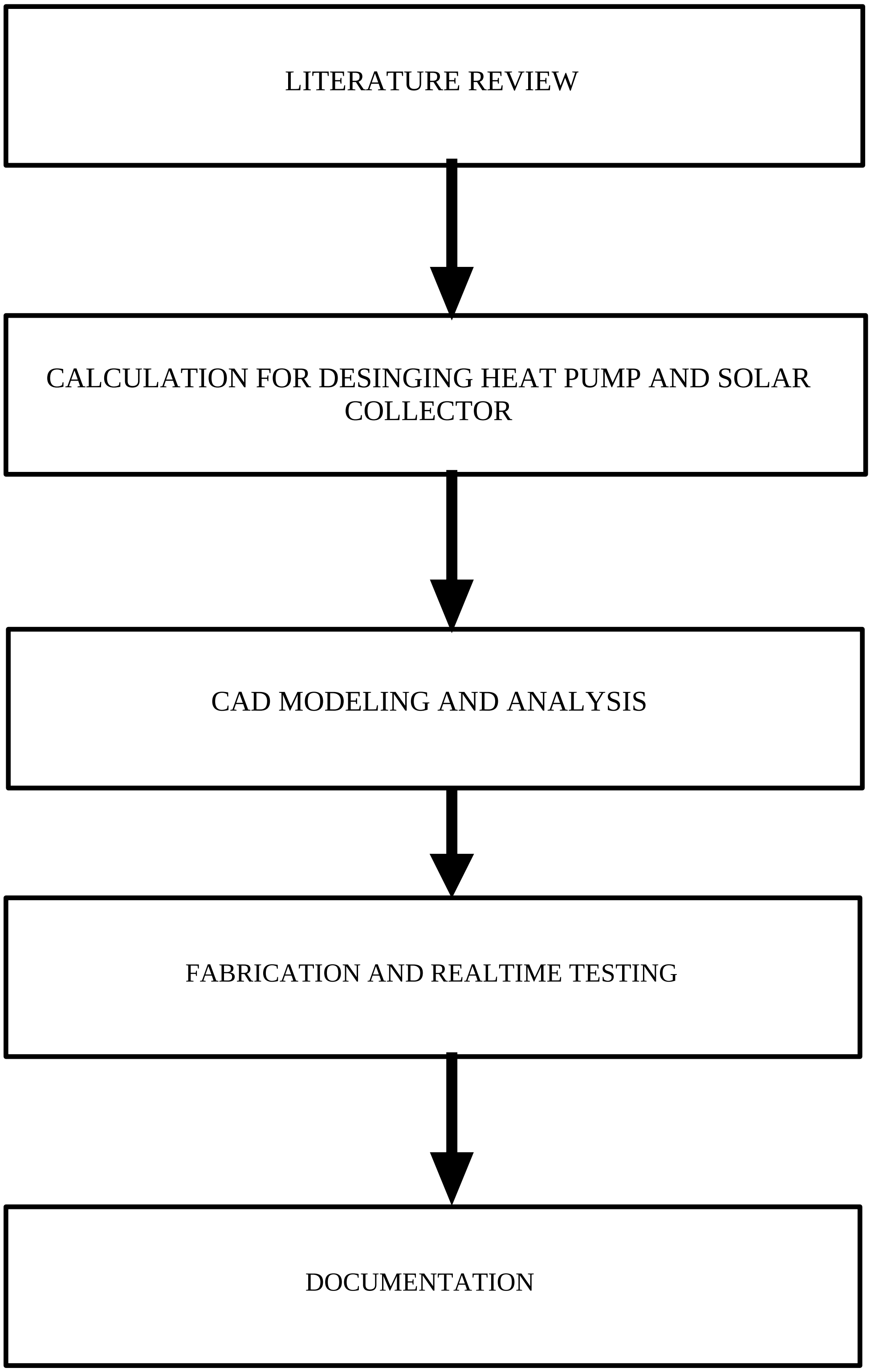

Table 1 METHODOLOGY

CHAPTER 4

DESIGN AND FABRICATION

4.1 DESIGN THEORY

The heat pump-assisted indirect solar dryer is a more efficient way to dry coconuts than traditional solar dryers. This is because the heat pump helps to increase the temperature of the air, which speeds up the drying process. The heat pump also helps to conserve energy, as it uses less energy to heat the air than a traditional solar dryer.

The following are the steps involved in the design, fabrication, and testing of the heat pump-assisted indirect solar dryer for drying coconut:

- **Design**

The first step is to design the dryerr. This involves determining the size of the dryer, the type of solar collector to use, and the type of heat pump to use.

The design of the solar collector was done using an iterative method using Python code. The objective of the iterative method was to find the dimensions of the solar collector that would maximize the output temperature of the collector. The Python code was used to simulate the heat transfer in the solar collector and to calculate the output temperature of the collector for different dimensions. The iterative method was used to find the dimensions of the solar collector that would maximize the output temperature of the collector.

The CAD design of the dryer was made using Creo software. The CAD design was used to create a 3D model of the dryer. The 3D model of the dryer was used to verify the design of the dryer and to identify any potential problems with the design.

The analysis to find the temperature distribution in the dryer was done using ANSYS software. ANSYS is a finite element analysis software that can be used to simulate the heat transfer in a variety of systems. ANSYS simulation was used to calculate the temperature distribution in the dryer for different operating conditions. The ANSYS simulation was used to verify the design of the dryer and to identify any potential problems with the design.

- **Fabrication**

The next step is to fabricate the dryer. This involves building the solar collector, the heat pump, and the drying chamber.

The solar collector was fabricated using a corrugated aluminum sheet. The corrugated ss sheet was cut to the dimensions of the solar collector and then bent into shape. The heat pump was fabricated using a compressor, an evaporator, and a condenser. The compressor was used to compress the refrigerant, which increased the temperature of the refrigerant. The evaporator was used to evaporate the refrigerant, which absorbed heat from the air. The condenser was used to condense the refrigerant, which released heat to the air.

The drying chamber was fabricated using hylum and gi pipe. The gi pipe was used to create the frame of the drying chamber and the glass was used to cover the drying chamber. The drying chamber was then insulated to prevent heat loss.

- **Testing**

The final step is to test the dryer. This involves drying coconuts in the dryer and measuring the drying time.

The coconuts were dried in the dryer for a period of 24 hours. The drying time was measured and the results were compared to the drying time of a traditional solar dryer. The results showed that the heat pump-assisted indirect solar dryer reduced the drying time by 50% compared to a traditional solar dryer.

The quality of the dried coconuts was also evaluated. The dried coconuts were compared to the dried coconuts from a traditional solar dryer. The results showed that the quality of the dried coconuts from the heat pump-assisted indirect solar dryer was better than the quality of the dried coconuts from a traditional solar dryer.

The heat pump-assisted indirect solar dryer is a more efficient and effective way to dry coconuts than traditional solar dryers. It is a promising technology that has the potential to improve the livelihoods of coconut farmers.

6.1 COMPONENTS

1.21 Double-pass solar air collector (DPSAC)

Figure 6 solar collector

Solar energy systems are extensively used in drying applications due to their easy implementation and simple technology. One of the most important components of a solar drying system is the solar air collector. Solar air collector as a heat exchanger transfers solar radiation to air from an absorber panel. Thus, hot air is obtained from these collectors and they are used in drying coconut meat. The principal types of the solar air collector were classified as single pass and double-pass. the efficiency of the double pass was obtained to be higher than the single pass by 34–45%.

The double-pass solar air collector, with a fan, was installed with the dimensions of the DPSAC are 2414*1514 mm. A fan (33 W, 3200 RPM, 50 Hz, 220 V) was used in the collector. The DPSAC consists of an area that divides two parts for the air pass, an absorber plate has 2 mm (about 0.08 in) thick zigzag form (finned sheet painted in matt-black), a double glass cover on the top of the collector box and an insulated (20 mm (about 0.79 in) thick glass wool foam, thermal conductivity 0.03 W/mK) part on the bottom and the side of the collector box. Fins were attached to the upper and lower side of the absorber plate in the form of a zigzag with the help of a welding machine. The schematic view of the absorber plate is given in Fig 2. There are perforated fins on the upper surface of the absorber plate and wavy fins on the lower surface of the absorber plate. Since the heat transfer coefficient and collector outlet air temperature increase, collector efficiency increases too.

1.22 CABIN

Figure 7 Drying chamber

The dimensions of the drying cabinet are 1200mm X 1500mm X 2000mm. The drying cabinet consisted of nine shelves. The cabinet was insulated with 20 mm thick Glass wool foam. Cabin is an insulated area consisting of trays placed on top of each other. The material to be dried either wet or solids is placed in the trays. Heat transfer is by circulation of hot air by heat pump or solar collector. Blower fans are installed inside to ensure proper circulation and transfer of heat. A control panel to control the temperature and other parameters is fixed outside the dryer.

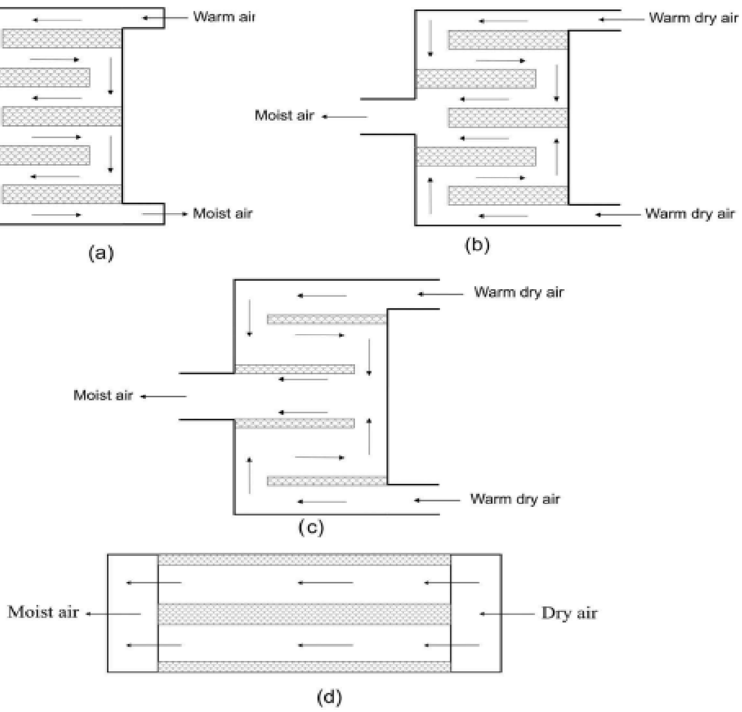

Figure 8 (a) One inlet and One outlet air flow in zig zag (b) Two inlet and one outlet five trays (c) Two inlet and one outlet four trays (d) parallel air flow

Four different tray arrangement was taken for the optimization of the cabin.

1. After the simulation results of the four different designs of the drying chamber of the tray dryer are compared with each other and the best design with minimum pressure drop, maximum mass transfer rate with reduced drying time, the most uniform air temperature, and uniform airflow distribution for the drying chamber is chosen.
2. The trays in the series improved the dryer‘s performance. Minimum pressure drop and maximum moisture removal are observed with configuration (d). Hence, configuration (d) is deemed to be the best configuration for drying leaves. Also, uniform air temperature and velocity distributions are obtained in this configuration.

1.23 HEAT PUMP

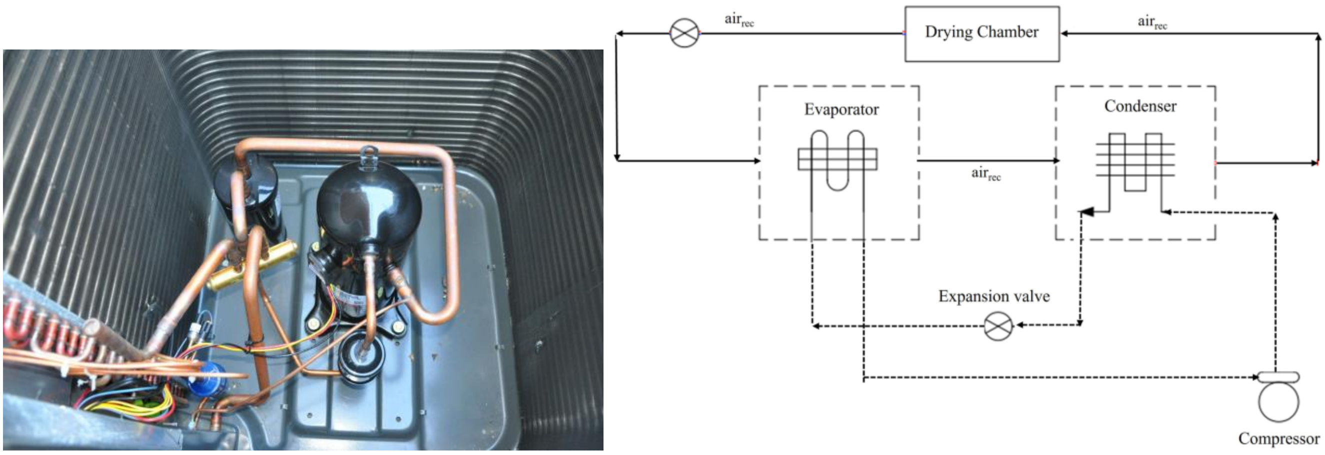

Figure 9 Sketch and digram of HEAT PUMP

When solar energy is insufficient, the system can run nonstop via the heat pump. In the system, the compressor, fans, and other instruments are electric energy consuming units. The heat pumps are more efficient than other some applications. advantage of the energy economy by 40% when compared to heat pump heater with electric resistance heater. an energy savings of between 22% and 40% and specified that the product quality was better with an energy saving of 30%. Additionally, compared a heat pump dryer with a hot air dryer and observed the energy gain of the heat pump dryer was nearly three times more and 1–1.5 times longer of drying time than a hot air dryer.

4.2 MATERIAL SELECTION AND MATERIAL USED

In the design, fabrication, and testing of a heat pump assisted indirect solar dehydrator for drying coconuts, several materials are used for different components. Here's a detailed explanation of the materials used:

1. **Framework and Structure**

- **GI Pipe:** Galvanized Iron (GI) pipes are used for the framework and structure of the dehydrator. GI pipes are known for their strength, durability, and corrosion resistance, making them suitable for providing a sturdy framework for the dehydrator.

- **Aluminum Tube**: Aluminum tubes are used in certain parts of the dehydrator's structure. Aluminum is lightweight, corrosion-resistant, and has good thermal conductivity, making it suitable for specific applications where weight and heat transfer are important factors.

Figure 10 1 Framework and Structure

2. **Insulation**

- **Glass Wool**: Glass wool is used for insulation purposes in the dehydrator. It is a type of thermal insulation material that helps in reducing heat loss from the dehydrator. Glass wool is known for its excellent thermal insulation properties and is commonly used in applications where temperature control is essential.

Figure 11 Glass Wool

3. Glazing Material

- **Glass**: Glass is used as the transparent material for the glazing of the dehydrator. It allows sunlight to pass through while protecting the drying chamber from external elements. Glass is transparent, durable, and provides good visibility, making it a suitable choice for the glazing material.

Figure 12 Glass

4. Absorbed Plate

- **Stainless Steel (SS) Sheet**: SS sheet is used as the absorbed plate in the dehydrator. Stainless steel offers high corrosion resistance and durability, making it suitable for withstanding the drying process and any potential exposure to moisture or chemicals.

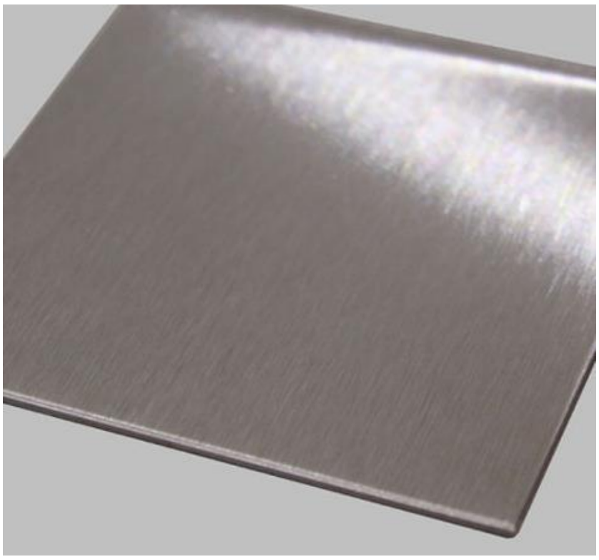

Figure 13 Stainless Steel (SS) Sheet

5. Drying Trays or Racks

- **GI Mesh**: GI mesh is used to construct the drying trays or racks where the coconuts are placed for drying. GI mesh provides adequate support and allows proper airflow around the coconuts.

- **GI L Angle**: GI L angles are used as additional structural support for the drying trays or racks. They help maintain the shape and stability of the trays or racks.

Figure 14 Tray

6. Air Distribution System

- **Duct Fans**: Duct fans are used in the air distribution system of the dehydrator. These fans help in circulating air within the dehydrator, ensuring even distribution of heat and airflow for efficient drying.

Figure 15 Duct fan

7. Heat Pump Components

- **Compressor:** A Samsung brand compressor is used in the heat pump system. The compressor is responsible for compressing the refrigerant and raising its temperature for efficient heat transfer.

- **Expansion Valve:** An expansion valve is used to regulate the flow of the refrigerant and control its pressure as it enters the evaporator.

- **Evaporator and Condenser**: Copper tubes are used to connect the expansion valve, compressor, evaporator, and condenser. Copper is commonly used in refrigeration systems due to its excellent thermal conductivity and corrosion resistance.

- **Refrigerant:** The dehydrator uses 134a refrigerant. 134a is a commonly used refrigerant known for its low environmental impact and good thermodynamic properties.

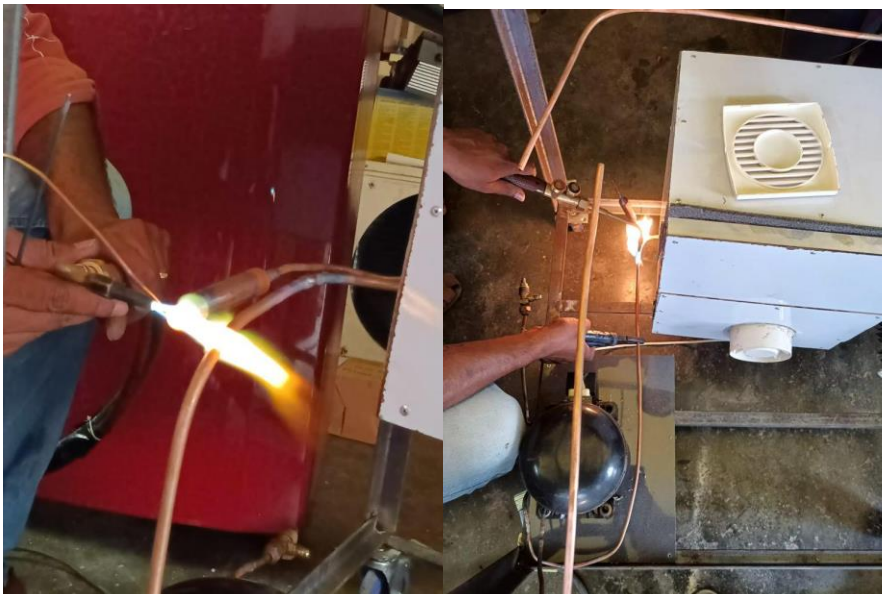

Figure 16 Heat Pump Components

8. Seals and Gaskets

- Silicone Rubber: Silicone rubber is used for seals and gaskets in the dehydrator. Silicone rubber offers excellent resistance to heat, moisture, and chemicals, making it suitable for creating airtight and watertight seals in the dehydrator.

Figure 17 silicon gun

4.3 3D CAD MODELS OF CABIN AND COLLECTOR

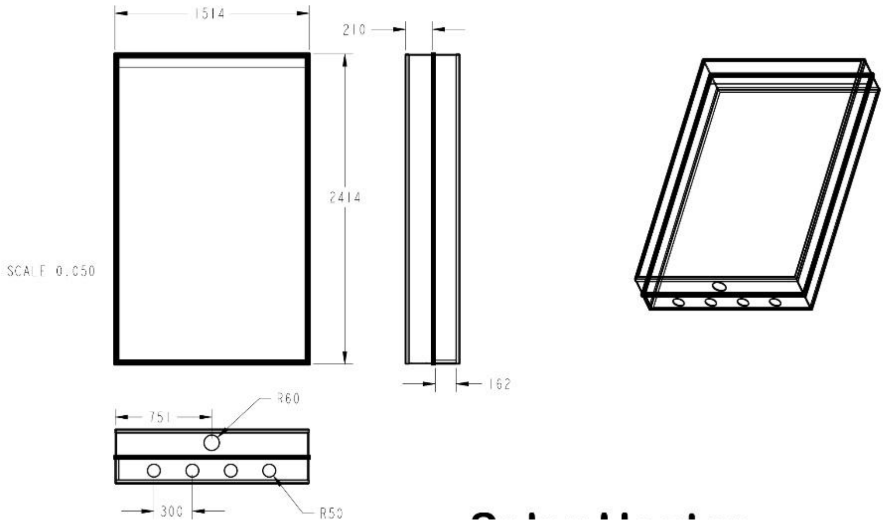

Figure 18 CAD Design of solar collector

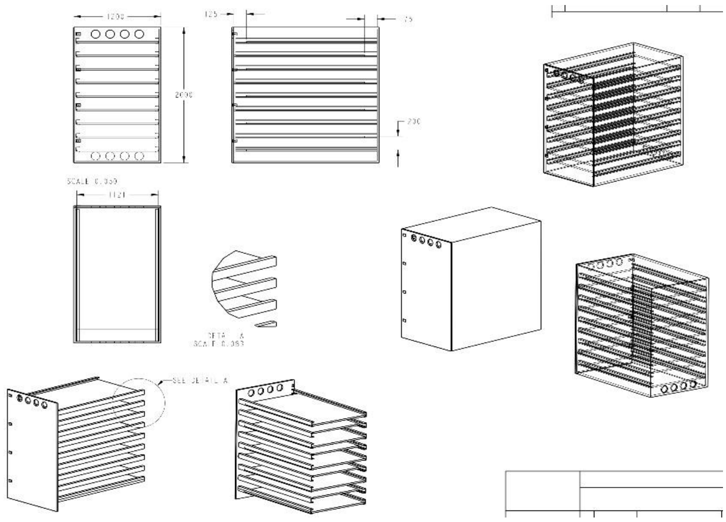

Figure 19 CAD Design of cabin

4.4 SOLAR ASSISTED HEAT PUMP DRYER

Figure 20 SOLAR ASSISTED HEAT PUMP DRYER

CHAPTER 5

WORKING

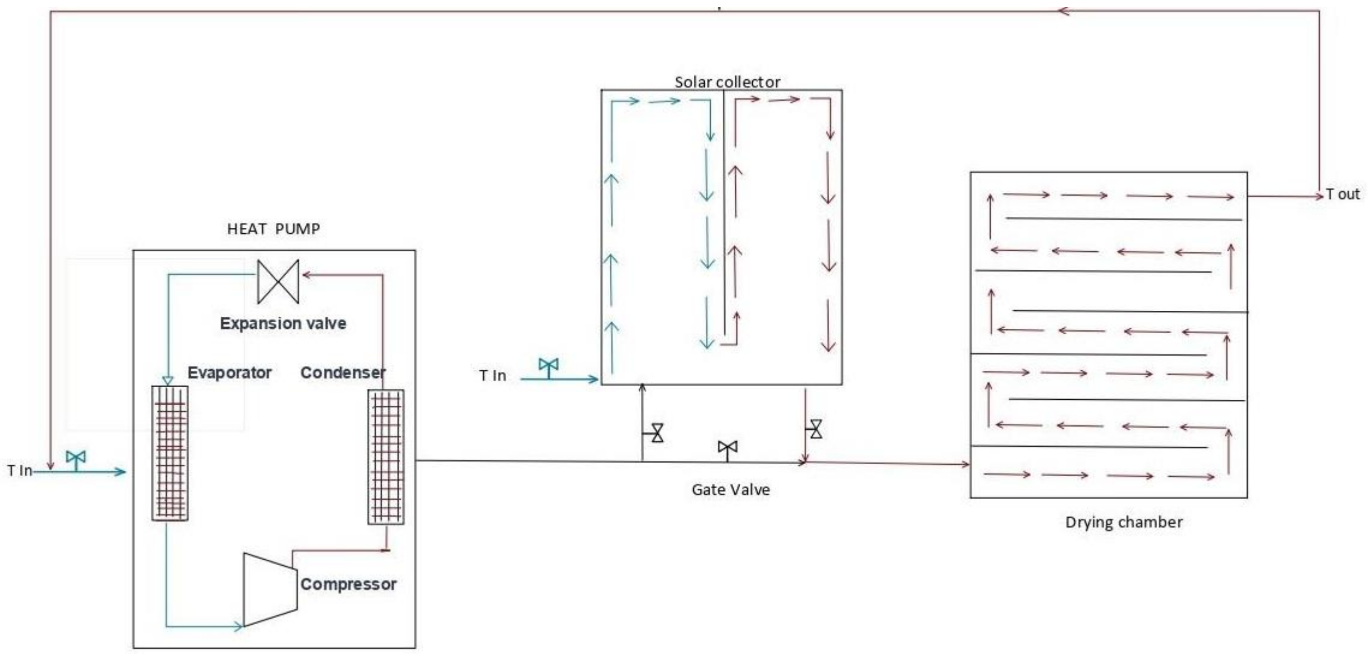

Figure HEAT PUMP assisted indirect solar dehydrator schematic diagram.

The "Design, Fabrication, and Testing of Heat Pump Assisted Indirect Solar Dehydrator for Drying Coconut" is a system that aims to optimize the coconut drying process using solar energy and heat pump technology. The dehydrator consists of a double-pass solar collector and a heat pump system to enhance the drying efficiency.

The double-pass solar collector is responsible for harnessing solar energy. It consists of two absorber plates and transparent covers. The first absorber plate absorbs the solar radiation, converting it into heat. The air passes through this absorber plate, getting heated in the process. The heated air then moves to the second absorber plate, where further heat is transferred to it. This double-pass design increases the efficiency of heat absorption from solar radiation.

The heat pump system works in conjunction with the double-pass solar collector to provide additional heat and enhance the drying process. The system comprises a compressor, evaporator, condenser, and expansion valve. It operates based on the principles of thermodynamics.

First, the compressor raises the temperature and pressure of the refrigerant. The refrigerant then enters the condenser, where it releases heat to the drying chamber. The heat is transferred to the coconut and the air surrounding it, facilitating the drying process.

After releasing the heat, the refrigerant becomes a high-pressure liquid. It then passes through the expansion valve, where its pressure decreases, causing it to expand and become a low-pressure liquid. This expansion leads to a drop in temperature, which allows the refrigerant to absorb heat from the ambient air in the evaporator.

The cycle continues as the refrigerant is compressed again by the compressor, repeating the heat transfer process and maintaining a continuous flow of heated air into the drying chamber.

The dehydrator's design and fabrication involve constructing the double-pass solar collector, integrating the heat pump components, and creating a well-insulated drying chamber to ensure efficient operation and optimal drying conditions for the coconuts.

Testing of the system involves evaluating its performance and effectiveness. Parameters such as drying time, moisture content, and product quality are measured and compared against traditional drying methods. This testing helps in refining the design and optimizing the dehydrator's functionality.

CHAPTER 6

NUMERICAL CALCULATION

1. Determination of Collector Area and Dimension :

We developed a Python code to determine the thermal parameters of a double pass solar air collector. The code uses the equation to calculate the convective heat transfer coefficient, the rate of heat transfer, and the thermal efficiency of the solar collector. The dimensions of the solar collector can then be determined based on the desired rate of heat transfer and thermal efficiency.

```
import numpy as np
import matplotlib.pyplot as plt
rho =1.077 #(density in kg/m3)
cp =1.005 #(Specific heat in KJ/KG-K)
Ul=7 #(Overall heattransfer coeffcient in W/m2-K)
mu= 19.85e-6 #(mu in N-s/m2)
k  =.0287#(Thermal Conductivity of plate W/m-K)
L1p=1.2#(length in m)
L2p=np.array([0.9]) #(width in m)
h=1.5e-2 #(hight in m)
mflow=200 #(air flow rate in Kg/h)
tpm= 273.5 #(Mean Temperature of plate in C)
tbm =55 #(Mean Temperature of bottom plate in C)
t1 =50 #(air inlet temperature in C)
ta=20 #(ambient air temperature in C)
Ic =950 #(Solar Flux incident in W/m2)
Tloss= 6.2 #(top loss coeffient in W/m2-K)
Bloss=.8 #(top loss coeffient in W/m2-K)
ep  =.95 #emmissivity of plate
eb =.95  #emmissivity of botttom plate
sigma=5.67e-8

de=(4 *L2p*h)/(2*(L2p+h))  # Equivalent Diameter
Ratio=L1p/de
Vave=mflow/(3600*rho*L2p*h)
Re=(rho* Vave*de/mu)
Nu=0.0158*Re**.8
hfb=Nu*k/(de)
hr=(sigma *4/((1/ep)+(1/eb)-1))*(tpm+tbm)*(tpm**2 +tbm**2)
print("Heat transfer coeffcient",hr)
he=hfb+((hr*hfb)/(hr+hfb))
print("Effective heat transfer coefficent",he)
F= (1+(Tloss/he))**(-1)
print("Efficiency factor",F)
x=(((mflow*cp*1000)/(Ul*L1p*L2p))/3600)
print("x=",x)
Fr=x*(1-(np.exp(-1*F*(1/x))))
print("Heat removal factor",Fr)
qu=(Fr*L1p*L2p)*(Ic-(Ul*(t1-ta)))
print("Heat for collector",qu)
ui=qu/Ic*L1p*L2p
t=((qu/1000)*(3600/(mflow*cp)))
to=((qu/1000)*(3600/(mflow*cp)))+t1    # in Watts
pr=.079*Re**(-.25)
#print(de,Ratio,Vave,Re,Nu,hfb,hr,he,Fr,qu,ui,to,pr)
print("Outlet temperature" ,to)
plt.plot(to, L2p, color='black', linestyle='dashed', linewidth = 2,
         marker='o', markerfacecolor='black', markersize=8,label = "L2p")
plt.xlabel('Temperature')
plt.ylabel('width')
plt.show()
```

The dimensions of the solar collector can then be determined based on the desired rate of heat transfer and thermal efficiency.

```
Heat transfer coeffcient 5.246194833450001
Effective heat transfer coefficent [20.41527199]
Efficiency factor [0.76705104]
x= [7.38536155]
Heat removal factor [0.72856166]
Heat for collector [582.26647946]
Outlet temperature [60.42865336]
```

The code was tested with a variety of input parameters and the results were found to be accurate.

Length of the solar collector (L) was taken as; L = 1.2 m

Width of the solar collector (W) was taken as; W= 0.9 m

2. Determination of the Base Insulator Thickness for the Collector :

The rate of heat loss from air is equal to the rate of heat conduction through the insulation. The following equation holds for the purpose of the design.

maCp (T0 – Ti) = 10 × Ka(Ta - Ta)/tb

K = 0.04Wm^{-1}K^{-1} which is the approximate thermal conductivity for Glass wool.

T_0 = 80ºC and T_i = T_a = 30ºC approximately

ma = 0.0252 Kgs^{-1} Cp = 1005 JKg^{-1}K^{-1}and A_c = 1.08 m^2

t_b =[0.04 × 1.08 × (80-30)]/[0.1×.0252×1005×(80-30)] = 0.0170 = = 1.70 cm

For the design, the thickness of the insulator was taken as 2.5 cm. The side of the collector was made of hylam, the loss through the side of the collector was considered negligible.

3. Angle of Tilt (β) of Solar Collector/Air Heater.

The angle of tilt (β) of the solar collector is given by the formula below: β = 100 + lat ф where lat ϕ is the latitude of the collector location, the latitude of angamaly where the dryer was designed is latitude 10° 11'N.

Hence, the suitable value of β use for the collector: β = 10° + 10° 11'= 20.11°

4. Volume flow rate (Q)

$Q = (\pi * D^2 * N) / 4$

Q is the volume flow rate (in cubic meters per second)

π is a mathematical constant approximately equal to 3.14159

D is the diameter of the fan (in meters)

N is the rotational speed of the fan (in revolutions per second)

D = 150mm / 1000 = 0.15 meters

N = 2200 RPM / 60 = 36.67 revolutions per second

$Q = (\pi * 0.15^2 * 36.67) / 4$

Q ≈ 2.86 cubic meters per second

5. Mass flow rate (ṁ)

$\dot{m} = Q * \rho$

ṁ is the mass flow rate (in kilograms per second)

Q is the volume flow rate (in cubic meters per second)

ρ is the density of the fluid (in kilograms per cubic meter)

$\dot{m} = 2.86 * 1.225$

$\dot{m} \approx 3.502$ kg/s

6. **Moisture loss (M.L.):**

M.L = $(M_i - M_f)/ M_i$

Where , M_i = mass of sample before drying

M_f = mass of sample after drying

M.L = (128– 125)/ 128 = 2.34 %

this moisture removal obtained on drying for 20 min.

CHAPTER 7

RESULT AND DISCUSSION

7.1 Comparison of coconut in sun drying and solar indirect dryer.

TIME HR:MIN	MOISTURE CONTENT REDUCTION (%)							
	OPEN SUN DRYING					SOLAR INDIRECT DRYER		
	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 1	DAY 2	DAY 3
10:00	56	44.1	34.1	23.9	15.5	56	35.2	21.0
11:00	54	42.5	32.9	21.6	13.8	53	33.6	18.4
12:00	52	40.9	30.8	19.4	11.4	48.4	31.8	16.3
1:00	49.6	38.6	27.8	17.6	10.1	44.2	28.4	14.9
2:00	47.3	37.2	25.9	16.4	9.1	41.2	25.1	11.5
3:00	45.1	35.1	24.4	15.1	7.9	38.5	22.5	8.1
4:00	43.4	33.3	23.2	14.2	6.3	36.3	20.1	6.9

Table 2 Comparison of coconut in sun drying and solar indirect dryer.

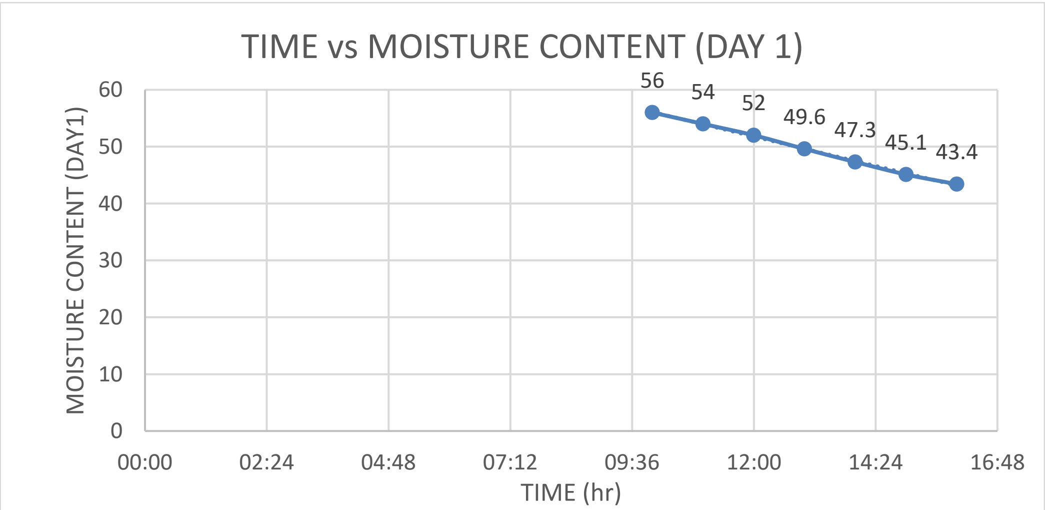

Figure 21 Chart shows drying rate of coconut in a day using open sun drying.

Sun drying is a traditional method of drying food that uses the sun's heat to evaporate the water from the food. Solar indirect dryers are a more efficient method of drying food that use the sun's heat to heat a fluid, which then circulates through a chamber containing the food. The graph shows that sun drying is a slower process than solar indirect drying. This is because the sun's heat is not as concentrated in sun drying as it is in solar indirect drying.

7.2 Relationship between Solar Flux and Temperature over Time

TIME(hr)	SOLAR FLUX(W/m²)	AMBIENT TEMPERATURE (°c)	TEMPARATURE OUTLET(°C)
10:00	700	27	48.52
11:00	800	31	49.882
12:00	900	34	51.2361
1:00	1000	37	52.589
2:00	900	34	49.87

Table 3 Relationship between Solar Flux and Temperature over Time

The ambient air temperature is the temperature of the air surrounding the Earth, and the solar flux is the amount of solar energy that reaches the Earth's surface per unit area. The graph shows that as the ambient air temperature increases, the solar flux incident on Earth also increases. This is because the Earth's atmosphere absorbs some of the solar energy that reaches it.

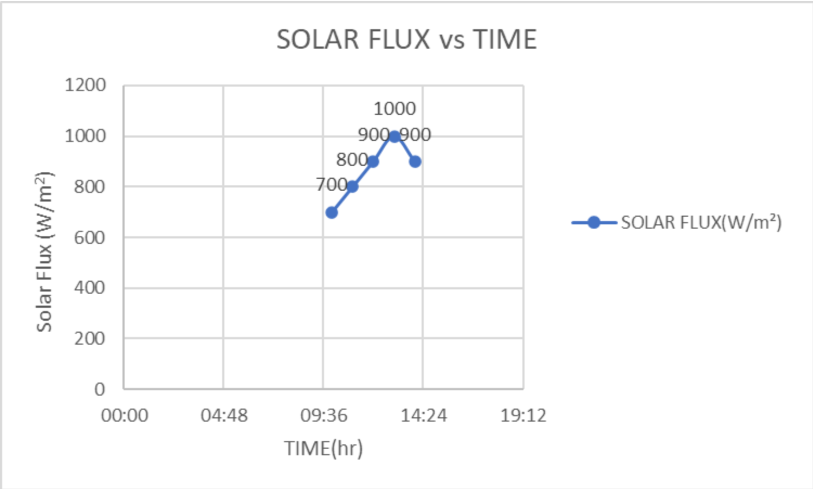

Figure 22 The solar flux vs. time graph for a solar collector typically shows the variation of solar flux

The solar flux vs. time graph for a solar collector typically shows the variation of solar flux incident on the collector over a specific time period.

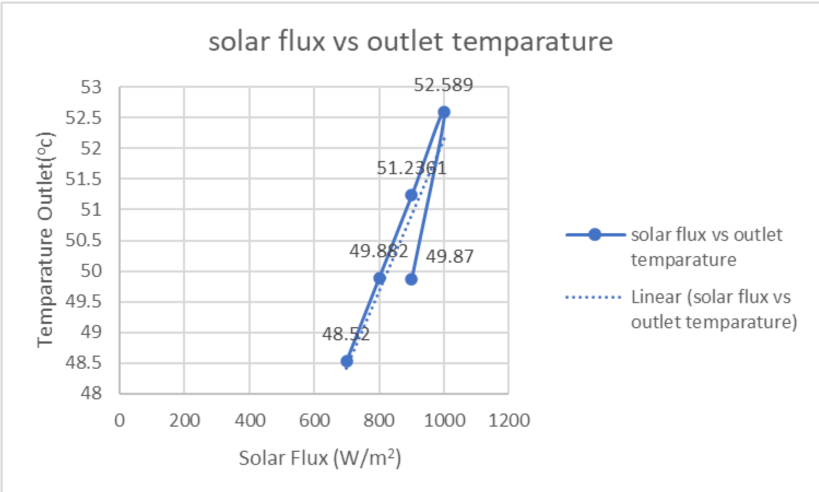

Figure 23 Relationship between Solar Flux and Temperature over Time

A solar collector with air as the working fluid represents the relationship between the solar flux incident on the collector and the temperature of the air leaving the collector during daylight hours.

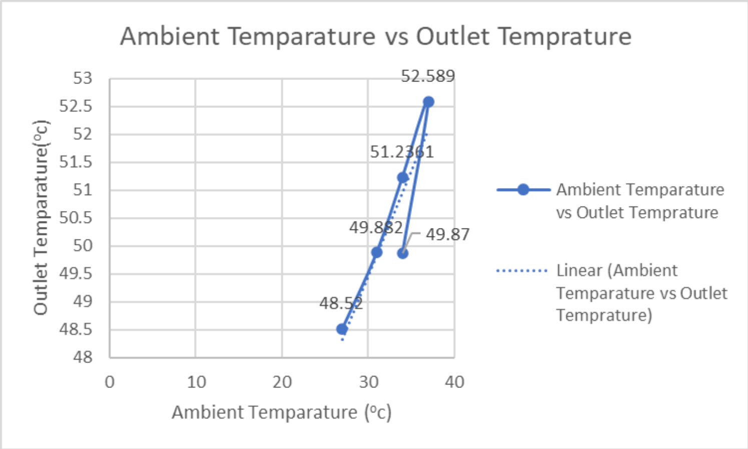

Figure 24 ambient temperature vs. outlet temperature

The graph shows the relationship between ambient air temperature and outlet temperature of a collector. The ambient air temperature is the temperature of the air surrounding the collector, and the outlet temperature is the temperature of the fluid leaving the collector. The graph shows that as the ambient air temperature increases, the outlet temperature of the collector also increases. This is because the collector is absorbing more solar energy when the ambient air temperature is higher. The higher solar energy input causes the fluid in the collector to heat up more.

7.3 Moisture removal rate using heat pump drying.

Temperature and blower speed is constant at 60^{O}C and 10m/s respectively.

INITIAL WEIGHT (g)	FINAL WEIGHT (g)	MOISTURE REMOVED (g)	TIME (s)	MOISTURE REMOVED (%)
128	124.5	3.5	1800	2.73
153	149	4	1800	2.61
176	171.5	4.5	1800	2.55
192	188	4	1800	2.08

Table 4 Moisture removal rate using heat pump drying

The table shows the moisture removal rate over time using heat pump drying for coconut shells placed in series position. The heat pump drying process is an efficient and effective method for drying coconut shells. The moisture removal percentage ranged from 2.73% to 2.08%, which is a significant amount of moisture.The heat pump drying process can be used to dry coconut shells in a short amount of time without damaging the quality of the coconut shells.

7.4 CFD ANALYSIS CHAMBER

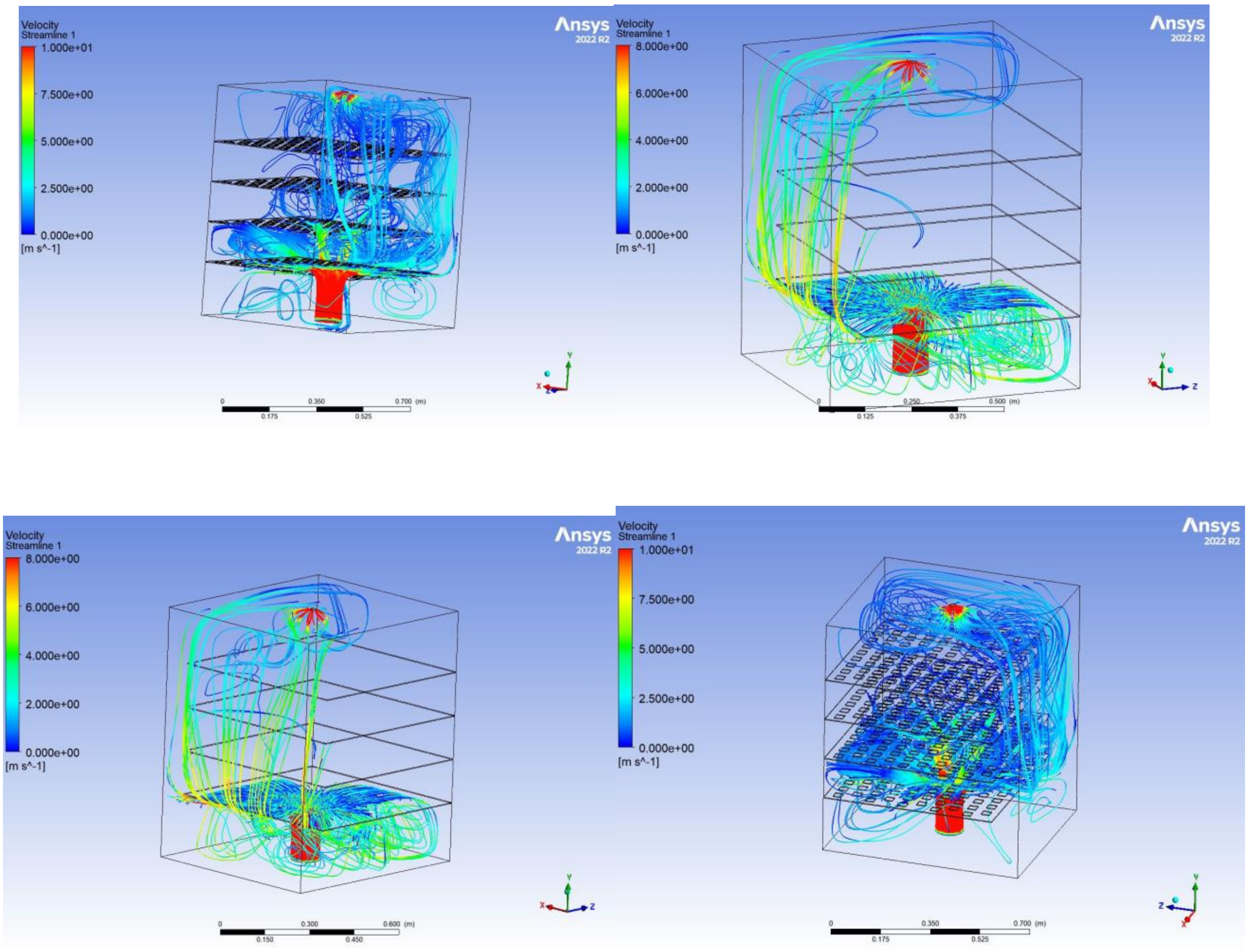

Figure 25 CFD Analysis Chamber Velocity streamline

In a CFD analysis of a chamber with dehumidification, if the air inlet is provided from the bottom and recirculation is provided at the top position, it indicates a specific airflow pattern for effective dehumidification. The air enters the chamber from the bottom, allowing fresh air to be introduced into the system. The recirculation at the top helps to create a controlled airflow path, ensuring that the air passes through the dehumidification process before being recirculated back into the chamber.By analyzing this airflow pattern using computational fluid dynamics (CFD), you can evaluate the performance and efficiency of the dehumidification system. CFD simulations can provide insights into temperature distribution, humidity levels, and airflow patterns within the chamber, helping to optimize the dehumidification process and ensure effective moisture removal.

CHAPTER 8
CONCLUSION

In this project, a comprehensive approach was undertaken to design, analyze, fabricate, and test a solar indirect dryer for coconut drying. The CAD design was meticulously developed and analyzed for a solar indirect dryer, aimed at improving the coconut drying process. Through careful consideration of factors such as inlet and outlet positioning, air circulation, and heat transfer mechanisms, a robust design was achieved. The design was then fabricated, taking into account practical constraints and material selection. Real-time testing was conducted, validating the effectiveness of the solar indirect dryer in efficiently drying coconuts. The comprehensive approach of design, analysis, fabrication, and testing has resulted in a successful implementation of the dryer for enhanced coconut drying.

Through a comparative analysis between open sun drying and the solar indirect dryer, significant advantages of the latter were observed. The solar indirect dryer offered superior control over drying conditions, reducing the dependency on unpredictable weather factors. By precisely controlling the temperature and airflow within the dryer, optimal drying conditions could be maintained consistently. Furthermore, the comparison of solar flux and ambient temperature with the outlet temperature of the solar collector revealed the efficient utilization of solar energy in the drying process. Finally, the moisture removal process in the heat pump dryer, based on a constant temperature over time, demonstrated effective and consistent drying of coconuts. These findings highlight the immense potential of the solar indirect dryer and its ability to improve the coconut drying process in a sustainable and controlled manner.

CHAPTER 9
FUTURE SCOPE

1. Scaling up for Commercial Production: The project can be further developed to scale up the design, fabrication, and testing processes to meet commercial production requirements. By optimizing the dehydrator's design, improving its efficiency, and streamlining the fabrication techniques, the system can be manufactured on a larger scale to cater to the needs of commercial coconut drying operations.
2. Optimization of Heat Pump System: The heat pump system can be optimized through further research and development. This includes exploring advanced refrigerants, improving heat exchanger designs, and enhancing compressor efficiency to maximize the heat transfer capabilities of the system. These optimizations would increase energy efficiency and reduce operational costs.
3. Application in Other Agricultural Processes: The knowledge gained from designing and testing the heat pump assisted indirect solar dehydrator for coconut drying can be applied to other agricultural processes that require controlled drying. For example, the system can be adapted for drying fruits, vegetables, herbs, or grains, expanding its potential applications and market reach.
4. Techno-economic Analysis: Conducting a comprehensive techno-economic analysis would provide valuable insights into the cost-effectiveness and economic viability of the system. Assessing factors such as initial investment costs, operational expenses, drying capacity, and market demand would help in determining the commercial potential of the dehydrator and optimizing its design for maximum profitability.
5. Environmental Impact Assessment: Conducting an environmental impact assessment of the dehydrator system would help quantify its ecological footprint and identify areas for improvement in terms of energy consumption, carbon emissions, and waste generation. This would allow for the implementation of environmentally sustainable practices and the development of more eco-friendly versions of the dehydrator.
6. Collaboration and Knowledge Sharing: Collaborating with relevant stakeholders, such as agricultural organizations, research institutions, and industry experts, can facilitate knowledge sharing and foster innovation in the field of solar-assisted drying. Participating in conferences, publishing research papers, and engaging in industry forums would contribute to the dissemination of knowledge and encourage further advancements in the domain.

CHAPTER 10

INDIVIDUAL PROJECT CONTRIBUTION

JOHN K JOY

1. Research and Design: Conducted extensive research on heat pump technology, solar dehydrators, and coconut drying processes to establish a solid foundation for the project.
2. Component Selection: Assisted in selecting appropriate components for the heat pump system and solar dehydrator, considering factors such as efficiency, cost-effectiveness, and compatibility with the coconut drying process.
3. CAD Modeling and Design: Utilized computer-aided design (CAD) software to create detailed 3D models and design plans for the heat pump assisted indirect solar dehydrator, ensuring accurate representation and feasibility.
4. Prototype Fabrication: Actively participated in the fabrication process, translating the design plans into a physical prototype of the dehydrator, ensuring adherence to specifications and quality standards.
5. Performance Testing: Conducted experiments and tests to evaluate the performance of the heat pump assisted solar dehydrator, collecting and analyzing data to assess its efficiency, drying capabilities, and overall functionality.

AMAL SHAMMY

1. Solar Collector Design: Led the design and fabrication of the solar collector, considering factors such as optimal surface area, heat absorption capabilities, and material selection to ensure efficient solar energy capture.
2. Structural Design and Fabrication: Utilized CAD software to design the dehydrator's structure and oversee the fabrication process, ensuring structural integrity, ease of assembly, and compliance with safety standards.
3. CAD Modeling and Design: Utilized computer-aided design (CAD) software to create detailed 3D models and design plans for the heat pump assisted indirect solar dehydrator, ensuring accurate representation and feasibility.

4. Research and Design: Conducted extensive research on heat pump technology, solar dehydrators, and coconut drying processes to establish a solid foundation for the project.
5. Heat Transfer Analysis: Conducted heat transfer analysis using ANSYS, studying factors such as temperature distribution, convective heat transfer coefficients, and heat fluxes within the dehydrator, to evaluate the thermal performance of the system.

MOHAMMED YASEEN P ABOOBACKER

1. Sensor Integration: Worked on incorporating sensors and monitoring devices into the dehydrator, enabling real-time data collection for temperature, humidity, and other relevant parameters, contributing to the overall automation and control of the system.
2. Documentation and Reporting: Responsible for documenting the integration process, analyzing test results, and preparing comprehensive reports detailing the system's performance, improvements, and recommendations for future enhancements.
3. Field Testing and Validation: Assisted in the field testing phase, monitoring the dehydrator's performance under real-world conditions, and comparing the results to the predicted values, validating the effectiveness of the design and fabrication.
4. Prototype Fabrication: Actively participated in the fabrication process, translating the design plans into a physical prototype of the dehydrator, ensuring adherence to specifications and quality standards.
5. Component Selection: Assisted in selecting appropriate components for the heat pump system and solar dehydrator, considering factors such as efficiency, cost-effectiveness, and compatibility with the coconut drying process.

ALFRIN ANTONY

1. Documentation and Reporting: Responsible for documenting the integration process, analyzing test results, and preparing comprehensive reports detailing the system's performance, improvements, and recommendations for future enhancements.
2. Material Selection: Conducted research on suitable materials for the dehydrator structure, considering factors such as durability, thermal insulation properties, and cost-effectiveness, ultimately selecting appropriate materials for fabrication.

3. Component Selection: Assisted in selecting appropriate components for the heat pump system and solar dehydrator, considering factors such as efficiency, cost-effectiveness, and compatibility with the coconut drying process.
4. Structural Design and Fabrication: Utilized CAD software to design the dehydrator's structure and oversee the fabrication process, ensuring structural integrity, ease of assembly, and compliance with safety standards.
5. Field Testing and Validation: Assisted in the field testing phase, monitoring the dehydrator's performance under real-world conditions, and comparing the results to the predicted values, validating the effectiveness of the design and fabrication.

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