STUDY OF THE FOOD CROP DRYING PROCESS BY USING PHASE CHANGE MATERIAL(PCM) SOLAR COLLECTOR

MASTER OF SCIENCE IN ENERGY TECHNOLOGY

M.Sc. Engg. (ET)

Submitted By

Anup Tarafder

ID No:18MET001F

INSTITUTE OF ENERGY TECHNOLOGY

CHITTAGONG UNIVERSITY OF ENGINEERING AND TECHNOLOGY

JUNE 2023

STUDY OF THE FOOD CROP DRYING PROCESS BY USING PHASE CHANGE MATERIAL(PCM) SOLAR COLLECTOR

A Thesis submitted in partial fulfillment of the requirements for award the degree of

MASTER OF SCIENCE IN ENERGY TECHNOLOGY

M.Sc. Engg. (ET)

Submitted By

Anup Tarafder

ID No:18MET001F

Supervised By

Dr. Md. Tazul Islam

Professor, Dept. of ME, CUET

INSTITUTE OF ENERGY TECHNOLOGY

CHITTAGONG UNIVERSITY OF ENGINEERING AND TECHNOLOGY

JUNE 2023

APPROVAL

The thesis titled " **Study of the Food Crop Drying Process by Using Phase Change Material (PCM) Solar Collector**" submitted by **Anup Tarafder**, ID: 18MET001F, Session: 2018-2019, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Science in Energy Technology on 6th June 2023.

BOARD OF EXAMINERS

…………………………………………………………………	**Chairman**
Dr. Md. Tazul Islam	(Supervisor)
Professor,	
Department of Mechanical Engineering, CUET.	
…………………………………………………………………	**Member**
Director	(Ex-officio)
Institute of Energy Technology**,** CUET**.**	
…………………………………………………………………	**Member**
Amita Singha	(Internal)
Research Assistant Professor,	
Institute of Energy Technology, CUET	
…………………………………………………………………	**Member**
Dr. Kazi Afzalur Rahman	(External)
Professor,	
Department of Mechanical Engineering, CUET.	

DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Name: Anup Tarafder

ID: 18MET001F

Dedicated to

My Father & Mother

ACKNOWLEDGMENT

The author like to express his heartfelt gratitude to all those who have contributed to the successful completion of this thesis book.

Then the author like to express his greatest appreciation to his thesis supervisor, Dr. Md. Tazul Islam, Professor, Department of Mechanical Engineering, Chittagong University of Engineering and Technology, Chattogram-4349, for his invaluable guidance, support, and encouragement throughout the research process. His expertise, constructive feedback, and constant motivation have been instrumental in shaping the direction and scope of this research work.

The author extends his heartfelt thanks to the Director, Institute of Energy Technology, faculty members, officers, and staffs who have provided his with the resources, facilities, and opportunities to pursue this research and achieve his academic goals.

The author like to express his sincere appreciation to the members of the examination board for their insightful comments and observations which have helped to improve the thesis.

The author is writing to express his deepest gratitude for the scholarship that he has been granted under the project 'Development of Chittagong University of Engineering & Technology'. This scholarship has not only helped financially but has also motivated his to work harder and strive for excellence in his studies.

The author is grateful to his family and friends, who have been a constant source of inspiration and motivation throughout this journey.

ABSTRACT

Solar dryers are a sustainable and cost-effective alternative to traditional drying methods for various food items. The basic components of a solar dryer include a solar collector, a hot air circulation system, and a drying chamber. The solar collector absorbs and converts solar radiation into thermal energy, which is used to heat the air that circulates through the drying chamber. Three types of solar collectors have been used in this research experimental solar crop dryer. They are Copper plate, Aluminum plate and Galvanized iron sheet coated with black paint for maximizing solar heat absorption. The size of three plates are 1m^2 and thickness is 1mm. Three types of food crops potato, normal paddy and boil paddy (each 500gm) were dried in solar dryer and in open sun at the same time. The product dries faster in solar dryer when Copper plate uses as a solar collector. This happens due to the thermal conductivity of copper plates is higher than aluminum and galvanized iron sheet. Open sun drying took 1.5 hours longer to dry than using the experimental solar dryer. The air circulation system helps to distribute the heated air evenly around the food material, promoting efficient drying. The solar dryer was operated at four air velocity 1.8m/s, 2.2m/s, 2.5m/s and 2.7 m/s. Crops dry faster at 2.5 m/s velocity because they can absorb better moisture. At 2.5 m/s air velocity in the experimental solar dryer dry potato, normal paddy and boil paddy (each 500gm) take drying time of 1.5 hours,1.5 hours and 1 hour which is shorter drying time than open sun drying. Paraffin waxes are used as a phase change material(PCM) (100gm/m^2,200gm/m^2, 300gm/m^2 and 400 gm/m^2) in this research experiment. When 300 gm/m^2 phase change material (PCM) is used as a heat storage medium then it took the least drying time than other amounts of phase change material (PCM). Experimental solar dryer using 300gm/m^2 PCM as heat storage in copper plate collector, potato, normal paddy and boil paddy (each 500 gm) take drying time 2 hours ,2 hours and 1.5 hours respectively which is shorter drying time than open sun drying. The maximum collector efficiency of copper plate solar collector and with PCM were found 21% and 25% respectively which is higher than aluminum plate solar collector (18%) and with PCM (21%) respectively. The highest drying efficiency with copper plate solar collector and with PCM were determined to be 8.5% and 14.4%, respectively, which is greater than aluminum plate solar collector (7%) and with PCM (12.9%) respectively. The co-relation among the drying chamber temperature, absorber plate temperature, and solar intensity is (F_{dct}) = 36.49229+0.012944t_{APT} -0.05424 S_i and the co-relation

among drying time, amount of PCM, air velocity and drying chamber temperature(^{0}C) is (F_{dt})=7.9375-0.008125W_{PCM}+2.51A_v+0.3125Tdtem. Proximate analysis (Moisture, Protein, Crude Fiber (CF), Crude Fat (EF), Ash) is done to check the quality of the product. The value of proximate analysis was found to be better in dryer than open sun.

Pearson’s Correlation coefficient was found within the range (0.76-0.98) for all cases. PCM-based solar dryers use materials that can store and release large amounts of thermal heat energy during the phase change, providing a stable and consistent drying temperature and humidity even in variable weather conditions. Additionally, PCM can be used to store excess thermal heat energy generated during peak sunlight hours, which can be released later to maintain the drying temperature during periods of low sunlight.

সারাংশ

সোলার ড্রায়ার বিভিন্ন খাদ্য আইটেমের জন্য ঐতিহ্যগত শুকানোর টেকসই এবং সাশ্রয়ী পদ্ধতি । সোলার ড্রায়ার পণ্য শুকানোর জন্য তার চারপাশের বায়ুকে তাপ সঞ্চালন করে সৌর শক্তির মাধ্যমে। একটি সোলার ড্রায়ারের মৌলিক উপাদানগুলোর মধ্যে রয়েছে একটি সৌর সংগ্রাহক, একটি গরম বায়ূ সংঞ্চালন ব্যবস্থা এবং একটি শুকানোর চেম্বার। সৌর সংগ্রাহক সৌর বিকিরনকে তাপ শক্তিতে শোষন করে এবং রূপান্তর করে, যা শুকানোর চেম্বারের মধ্য দিয়ে সঞ্চালিত বাতাসকে গরম করতে ব্যবহৃত হয়। এই গবেষনায় পরীক্ষামূলক সোলার ক্রপ ড্রায়ারে তিন ধরনের সোলার কালেক্টর ব্যবহার করা হয়েছে । এগুলো হলো কপার প্লেট, অ্যালুমিনিয়াম প্লেট এবং গ্যালভানাইজ শিট। সৌর তাপ শোষনকে সবাধিক করার জন্য কালো রং এর প্রলেপ দেওয়া হয়েছে। তিনটি প্লেটের আকার ১ মিটার^২ এবং পুরুত্ব ১ মিলিমিটার। তিন ধরনের খাদ্য শষ্য আলু, সাধারন ধান এবং সিদ্ধ ধান (৫০০ গ্রাম) একই সময়ে সোলার ড্রায়ারে এবং খোলা রোদে শুকানো হয়েছে। কপার প্লেট সৌর সংগ্রাহক হিসেবে ব্যাবহার করলে সোলার ড্রায়ারে পন্যটি দ্রুত শুকায়। কপার প্লেটের তাপ পরিবাহিতা অ্যালুমিনিয়াম এবং গ্যালভানাইজ শীটের চেয়ে বেশি হওয়ার কারনে এটি ঘটে। খোলা রোদ থেকে সোলার ড্রায়ারে শুকাতে ১.৫ ঘন্টার কম সময় লাগে। বায়ু সঞ্চালন ব্যবস্থায় খাদ্য উপাদানের চার পাশে সমান ভাবে উত্তপ্ত বায়ু বিতরন করতে সাহায্য করে। সোলার ড্রায়ারটি চারটি বায়ু বেগে ১.৮ মিটার/সেকেন্ড, ২.২ মিটার/সেকেন্ড, ২.৫ মিটার/সেকেন্ড ও ২.৭ মিটার/সেকেন্ড চালিত হয়েছিল। ফসল ২.৫ মিটার/সেকেন্ড এ দ্রুত শুকিয়ে যায় কারন এই বেগে বায়ুর আদ্রতা ভালো ভাবে শোষন করতে পারে। ২.৫ মিটার/সেকেন্ড বাতাসের গতিবেগে, আলু, সাধারন ধান এবং সিদ্ধ ধান (প্রতিটি ৫০০ গ্রাম) শুকাতে যথাক্রমে ১.৫ ঘন্টা, ১.৫ ঘন্টার এবং ১ ঘন্টার কম সময় নেয় খোলা রোদে শুকানো থেকে সোলার ড্রয়ারে। এই গবেষনা পরীক্ষায় প্যারাফিন মোম একটি ফেজ পরিবর্তন উপাদান (পিসিএম) (১০০গ্রাম, ২০০ গ্রাম, ৩০০ গ্রাম , ৪০০ গ্রাম) হিসেবে ব্যবহৃত হয়েছে। যখন ৩০০ গ্রাম ফেজ পরিবর্তন উপাদান (পিসিএম) তাপ সঞ্চয় মাধ্যম হিসেবে ব্যবহার করা হয়েছে তখন ফসল শুকাতে সবচেয়ে কম সময় লেগেছে। কপার প্লেট সংগ্রাহকে ৩০০ গ্রাম পিসিএম তাপ সঞ্চয় মাধ্যম হিসেবে ব্যবহার করে আলু, সাধারন ধান এবং সিদ্ধ ধান (প্রতিটি ৫০০ গ্রাম) খোলা রোদে শুকানোর চেয়ে সময় কম লাগে যথাক্রমে ২ ঘন্টা, ২ ঘন্টা এবং ১.৫ ঘন্টা। সর্বোচ্চ কালেক্টর কর্মদক্ষতা কপার প্লেট সোলার কালেক্টর এবং উইথ পিসিএম যথাক্রমে ২১% এবং ২৫% যা অ্যালুমিনিয়াম প্লেট সোলার কালেক্টর(১৮%) এবং উইথ পিসিএম(২১%) থেকে বেশি। সর্বোচ্চ ডাইং কর্মদক্ষতা কপার প্লেট সোলার কালেক্টর এবং উইথ পিসিএম যথাক্রমে ৮.৫% এবং ১৪.৪% যা অ্যালুমিনিয়াম প্লেট সোলার কালেক্টর(৭%) এবং উইথ পিসিএম(১২.৯%) থেকে বেশি । শুকানোর চেম্বার এর তাপমাত্রা সংগ্রাহক প্লেটের তাপমাত্রা এবং সৌর তীব্রতার মধ্যে সহ সম্পর্ক হলো $(F_{dct}) = 36.49229+0.012944t_{APT} -0.05424\, S_i$. এবং শুকানোর সময় , পিসিএম এর পরিমান , বাতাসের বেগ এবং শুকানোর চেম্বার এর তাপমাত্রা (ডিগ্রী সেলসিয়াস) এর মধ্যে সহ সম্পর্ক হলো $(F_{dt})=7.9375-0.008125W_{PCM}+2.51A_v+0.3125T_{dtem}$. পিয়ারসন কোরিলেশন কোফিশিয়েন্ট সবসময় (০.৭৬.০.৯৮)এই সীমার মধ্যে পাওয়া গিয়েছে। পিসিএম ভিত্তিক সৌর ড্রায়ারগুলি ফেস পরিবর্তন এর সময় প্রচুর পরিমান তাপ শক্তি সঞ্চয় করতে পারে এবং ছেড়ে দিতে পারে। পরিবর্তনশীল আবহাওয়ায় এটি স্থিতিশীল, সামঞ্জস্যপূর্ন শুকানোর তাপমাত্রা এবং আদ্রতা প্রদান করে। সর্বোচ্চ সূর্যাআলোকের সময় পিসিএম তাপ সঞ্চয় করে রেখে পরবর্তীতে কম সূর্যাআলোকের সময় সেই তাপ ব্যবহার করে ডাইং চেম্বারের তাপমাত্রা অপরিবর্তীত রাখা যেতে পারে।

TABLE OF CONTENT

LIST OF FIGURE

LIST OF TABLE

NOMENCLATURE

Symbol	Meaning
K	Thermal Conductivity(w/m.k)
Q	Heat Transfer(kw)
PCM	Phase Change Material
T_{Hot}	Higher Temperature(^{0}C)
T_{Cold}	Cold Area Temperature(^{0}C)
A	Cross Sectional Area of Plate (m^2)
d	Material Thickness of Plate (m)
Q	Heat Loss
Cu	Copper
Al	Aluminum
GI	Galvanized Iron
F_{dt}	Function of Drying Time
W_{PCM}	Weight of Phase Change Material
A_v	Air Velocity
T_{dtem}	Drying Chamber Temperature
F_{dct}	Function of Drying Chamber Temperature
S_i	Solar Intensity

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND:

Nowadays, fossil fuels provide a portion of the world's energy demands. In light of their depletion rates and emission regulations, these fossil fuels should be gradually replaced by renewable energy sources. Using renewable energy sources can lower the amount of pollutants released into the atmosphere. Particularly, the study of solar energy has great potential for both developed and developing nations. Solar energy is the radiation from the sun that reaches the earth. It is among the planet's most plentiful and accessible sources of renewable energy. Solar energy has been employed since prehistoric times, when humans used magnifying glasses to concentrate the sun's beams and light fires. The photovoltaic effect, which was discovered by scientists in the 19th century, served as the inspiration for the creation of contemporary solar panels. It is the energy source that is most easily accessible. The sun is the planet's power plant and the origin of all energy. In recent years, research into how to capture solar energy for many uses has grown crucial. By recognizing the potential of solar energy resources, Bangladesh may be able to fulfill its enormous energy demand while also enhancing energy security.

Bangladesh is ideally situated to save solar energy, being located between 241 0' 0'' N and 901 0' 0'' E [1,2]. In Bangladesh, the daily average fluctuation of solar discharge varies between 4 and 6.5 kWh per square meter, according to the pattern of the dry and rainy seasons. The months with the most radiation are March and April, while the months with the least are December and January. The average number of hours of sunshine per day varies from 6.69 to 7.6 in the winter, 6.16 in the summer, and 4.81 in the monsoon seasons. Figure 1.1 shows the average solar radiation in six categories. The graph shows that the months of March through May have the greatest expected solar radiation values, with a 1 square meter area having the capacity to produce 4-5 kWh/m2/day. Whereas the range of reported maximum sunshine hours in Barisal is 2.65 to 8.75 hours, it ranges from 2.86 to 9.04 hours in Khulna [4,6]. Bangladesh therefore has a tremendous chance to utilize solar energy.

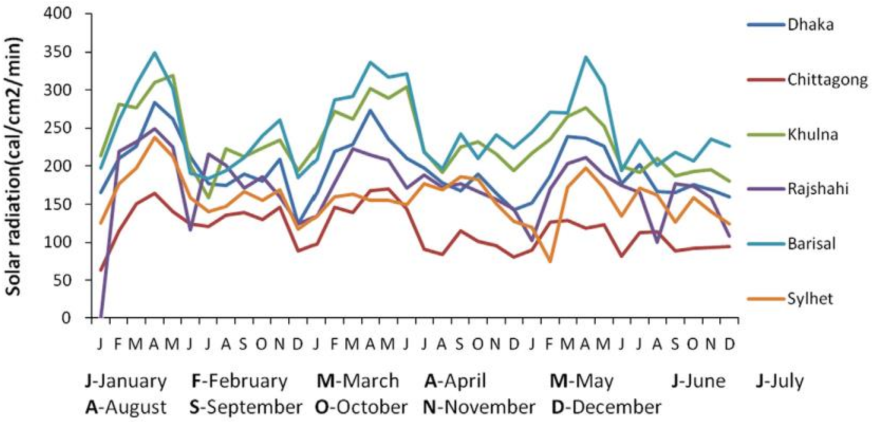


Figure1.1: Average Solar Radiation in the Six Divisions in Bangladesh [5].

1.2 MOTIVATION:

Solar energy is sunlight that has been transformed into thermal or electrical energy. The most plentiful and cleanest renewable energy source is solar energy. Solar technology can capture this energy for a range of purposes, such as power generation, interior lighting, and water heating for household, commercial, and industrial usage. Our carbon footprint may be significantly reduced by using solar energy. Nothing about solar energy pollutes the environment. It also doesn't emit any greenhouse gases. It is therefore secure and ecologically responsible. The sun is a practically infinite supply of solar energy that may be accessible at any one time from any place on earth. The elimination of moisture from an agricultural or culinary product is referred to as drying. Enhancing the product's durability is necessary for long-term storage according to uses. Potato, paddy, wheat, maize, rice, vegetables, groundnuts, garlic, cauliflower and broccoli, peas, sesame seeds, cotton, almonds, dry fruits, spices, coffee and tea, sunflower, and other agricultural goods are the key items that need to be preserved. The majority of crops need to be dried in order to increase food durability. Nonetheless, the material's moisture content is significantly reduced. One of the most popular techniques for drying grain, fruits, and fish for preservation has been solar drying for many years. Drying is a technique that uses standard energy sources on a commercial scale. There are issues with using this sort of resource, such as environmental damage, source unavailability, expensive transportation costs, etc. There are many different dryer types available today, but they are not often used in rural regions because of their high initial costs, ongoing costs, and lack of access to electricity.

Using renewable energy sources, such as solar energy wind, wave, biomass, geothermal and nuclear is important to solve these issues. One of the finest energy sources is solar energy, which is inexpensive, abundant, clean, and simple to acquire. Using a solar dryer is an additional strategy. The energy source used by solar dryers is free, renewable, and safe for the environment. The solar dryer is an alternative to hot air and conventional drying techniques, especially in places like coastal regions that get plenty of sunlight during harvest time. For thousands of years, people have dried food and harvests using the sun. Nevertheless, this approach has a variety of disadvantages, such as product spoiling brought on by moisture, wind, rain, or dust. Additionally, the method requires a large space to spread the fruit out to dry and is time- and labor-intensive. In industrialized areas and industries, mechanized dryers with boilers to heat incoming air and fans to force it through at a high space have mostly replaced outdoor drying. Compared to open-air drying, mechanical drying is quicker, more compact, and results in higher-quality products. Artificial mechanical drying is a costly, energy-intensive procedure that ultimately drives up the cost of the finished item.

The use of solar drying technology increases efficiency while conserving resources and saving the environment. A solar dryer works on the straightforward premise that heat from the sun may be used to remove moisture from the materials being dried. A drying chamber, a ventilation system, and a solar collector are the usual components of a dryer. The goods to be dried are placed in the drying chamber, where the solar collector transmits the energy that was captured by the sun. In order to remove the moisture that is evaporating, the ventilation system assists to move air through the drying chamber. A solar dryer offers a lot of advantages. First and foremost, since it uses solar energy, which is a renewable resource, rather of fossil fuels to dry objects, it is an ecologically responsible method. Because that it doesn't run on electricity or gas, it may also be more affordable than other drying techniques. Moreover, solar dryers are quite adaptable and may be used to dry a variety of products, including cereals, fruits, vegetables, garments, and even vegetables.

Phase change materials (PCMs) coupled with solar dryers offer a sustainable and efficient method of drying agricultural products. A PCM is a substance that can store and release large amounts of thermal energy during a phase change process. When a PCM absorbs heat, it undergoes a phase change from a solid to a liquid or a liquid to a gas. When it releases heat, it undergoes a phase change from a liquid to a solid or a gas to a liquid.

Overall, the use of solar energy to power a solar dryer is a sustainable and efficient way to dry a wide range of items while reducing our reliance on fossil fuels. successful drying depends on:

- Enough heat to draw out moisture, without cooking the food
- Dry air to absorb the released moisture
- Adequate air circulation to carry off the moisture.

1.3 SPECIFIC OBJECTIVES AND POSSIBLE OUTCOME:

Specific Objectives

1.Design and fabrication of food crop drying system.
2.Experimental data analysis and compare drying time between with PCM and without PCM.
3.Performance analysis of the solar dryer.

Possible Outcome

1.Overcome the drawback of conventional solar dryer.
2.Increase the drying process during off sunlight and night period.
3.Increasing the efficiency of solar dryer.

1.4 SOLAR DRYER:

Solar dryer is a devices that use solar energy to dry substances, especially food. Solar dryers use the heat from sun to remove the moisture content of food substances. A simple solar drying system is shown in Figure 1.2.

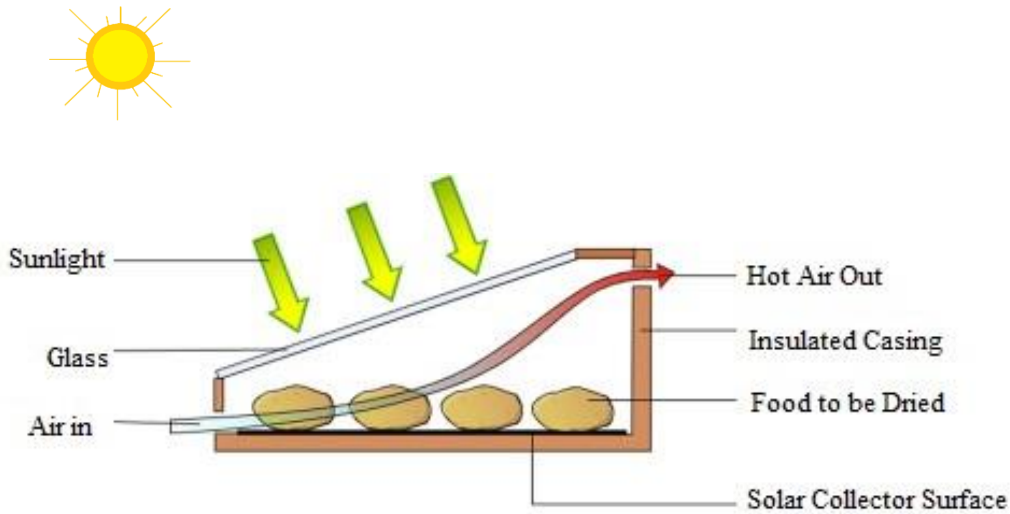


Figure 1.2: Simple Drying System.

Here collector plate of a solar crop dryer plays a critical role in the drying process by absorbing solar radiation and converting it into heat energy that can be transferred to the crop being dried. The main function of the collector plate is to efficiently absorb solar radiation and convert it into heat, which is then transferred to the crop through convection. The collector plate is typically made of a material with high thermal conductivity and low reflectivity, such as metal or ceramic. It is painted black to maximize its ability to absorb solar radiation. The glass on the absorber plate also helps to trap the heat inside the dryer by preventing heat loss through convection and radiation.

1.5 DRYING METHODS:

Figure 1.3 shows the detailed classification of food crops drying methods, which are of relevance to regions of world.

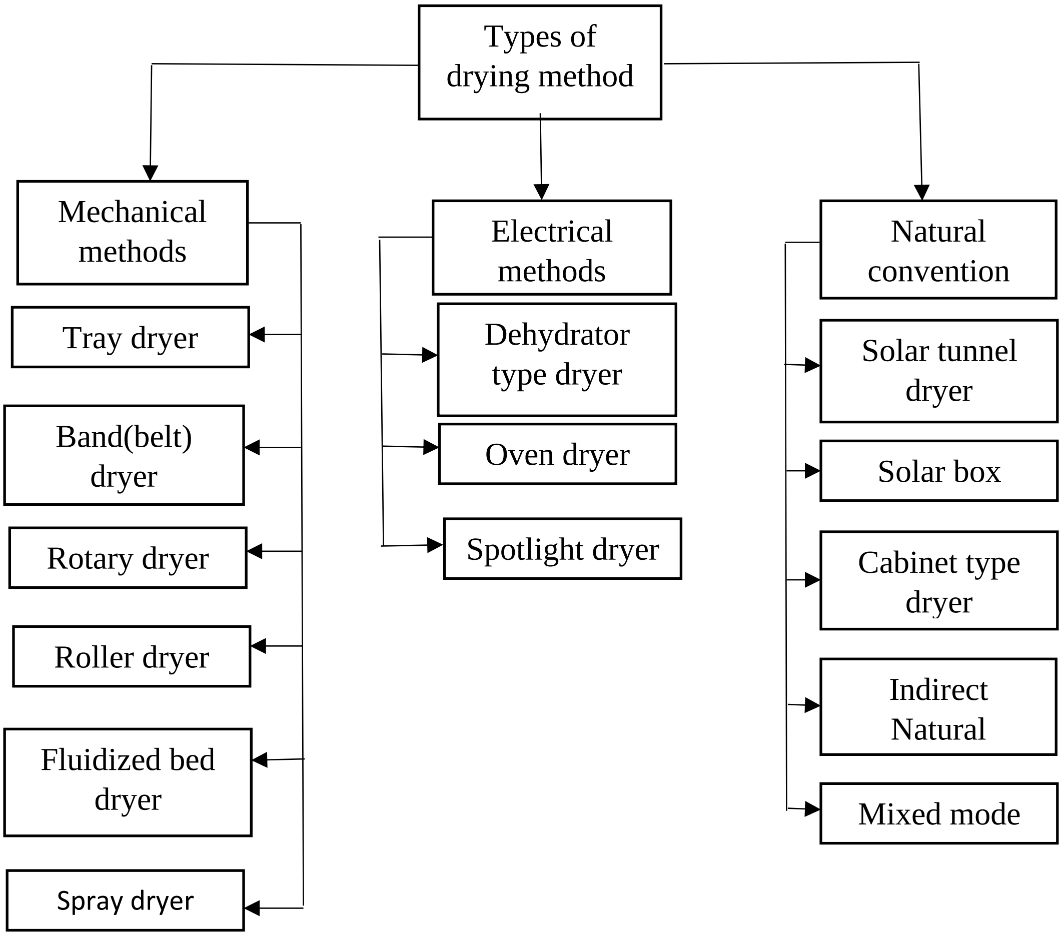


Figure 1.3: Different Types of Food Crops Drying Methods Flow Chart.

1.5.1 Mechanical Methods:

A huge chamber with a conveyor belt or auger that transports the produce through the drying process is the usual design of a mechanical crop drier. A constant stream of hot air is applied to the crop as it passes through the drier, removing moisture from the crops. A burner that burns propane or natural gas produces the heated air. The air is heated by the burner before being blasted by a fan into the drying chamber. Sensors and automatic controls keep an eye on and manage the dryer's temperature and humidity levels. By exposing the crop to a mix of heat and wind, the mechanical crop drier works to dry out the crops' moisture. The crop is exposed to heated air, which causes the crop's moisture to evaporate and be swept away by the air current. The mechanical method of drying crops is quite effective and can swiftly dry enormous amounts of crops. It is also highly reliable since the crops are dried uniformly and thoroughly thanks to the dryer's ability to be continuously monitored and adjusted for temperature and humidity.

1.5.2 Band (Belt) Dryer:

When drying fairly coarse particles, a band dryer (Figure 1.4) is recommended (i.e. between 5 to 10 mm). Evenly dispersed particles entered the perforated belt, which was traveling at a leisurely 5mm/s. Warm gas descends through the layer as the belt goes into a drying cabinet. When it is impossible to suspend the particles in the drying gas, this sort of drier is used. Because of the need for bound moisture to escape via the pellet, the dryer must provide a residence time, say 15 minutes. [6]

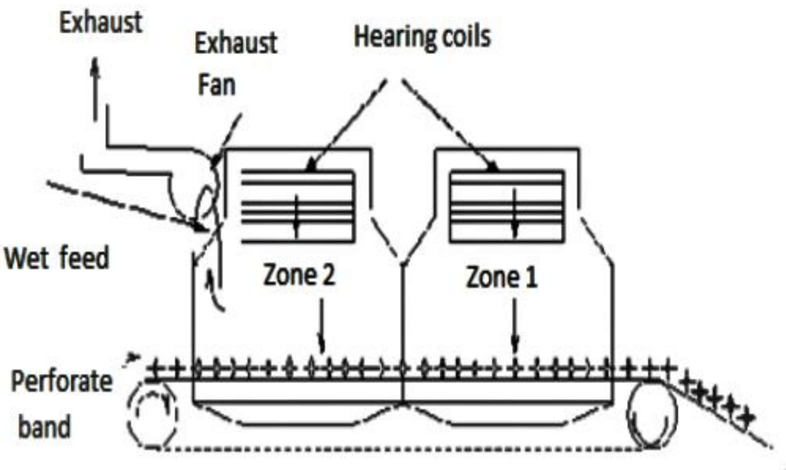


Figure 1.4: Band Dryer. [6]

1.5.3 Rotary Dryer:

The cylindrical shell of the rotary dryer (Figure 1.5) is either horizontal or slightly angled toward the exit. They are heated by

a) Direct contact of air or gas with the solids,

b) By hot gasses passing through an external

jacket on the shell, or,

c) By steam condensing in a set of longitudinal tubes mounted on the inner surface of the shell.

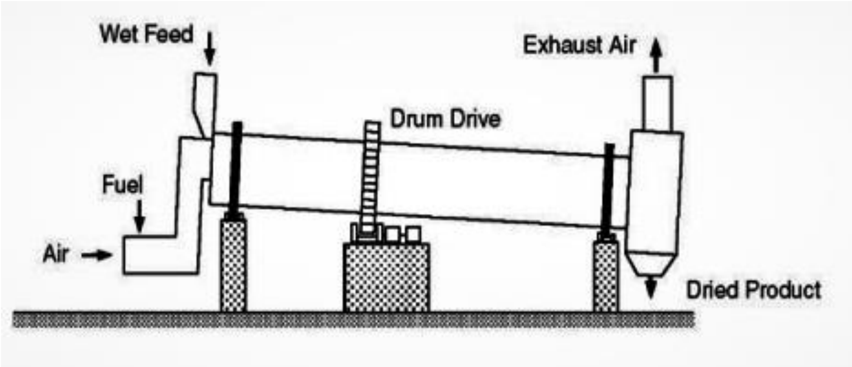


Figure 1.5: Rotary Dryer. **[7]**

The product is supplied into the upper aperture and moved through the cylinder while being mixed. Regardless of the heating technique, air is used to remove the water. The drawback of rotary dryers is the significant power losses that take place when the product is finely ground. Product losses may be considerably decreased by installing particle/gas separation (e.g., cyclones) near the moist air outflow. [7]

1.5.4 Roller Dryer:

A cylinder that has been inside heated by stream makes up a roller drier. The substance is sprayed in a thin layer on the cylinder's outside, where it is heated up while the cylinder turns. The ultimate water content of the product and the pace of drying are impacted by the

a) Rotational spread of the roller,
b) Steam pressure,
c) Thickness of the film, and
d) Properties of the product.

The roller dryer is particularly suited to heat-sensitive items because of the long sort contact time combined with high drying temperature. Common uses include paper band drying in paper mills and fabric drying in the textile industry. [8]

1.5.5 Fluidized Bed Dryer:

The particles in a boiling bed unit are fluidized by air or gas in a fluidized-bed drier (Figure 1.6). A particle typically remains in a bed for between 30 and 60 seconds on average. If there are fine particles, cyclones and bag filters are required for their recovery as there may be significant solids carried over with the exit gas.

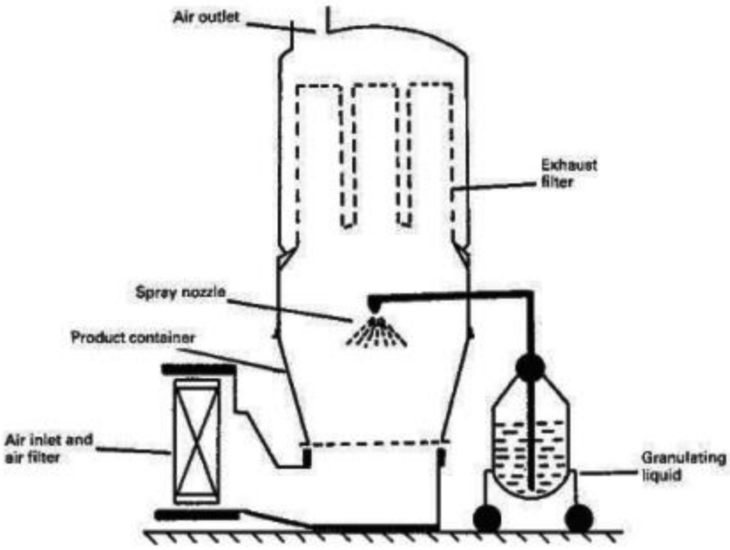


Figure 1.6: Fluidized Bed Dryer. [8]

1.5.6 Electrical Methods:

Oven Dryer:

The easiest method for drying food is oven drying (Figure 1.7), which requires absolutely no extra equipment. Also, it is quicker than using a food drier or the sun. Therefore, oven drying can only be applied on a modest scale. Just 4 to 6 pounds of food may fit in a standard kitchen oven at once. Pre-heat the oven to 140 ^{0}F using the lowest setting available (60 ^{0}C.). The food on the top tray of an electric oven may dry out too rapidly if you use the broiler function. If it doesn't have a separate control, take the unit out. Certain gas ovens may maintain a pilot light to keep the oven heated enough to dry the food.

Figure 1.7: Oven Dryer.

It's crucial to maintain the oven's temperature between 140 and 160 0F. (60 to 70 ^{0}C.). Put an oven thermometer where you can readily see it on the top tray, approximately halfway back. About once every half hour, check the temperature. On each tray, spread out 1 to 2 pounds of the prepared food in a single layer. Each oven rack should have one tray. In order for air to flow all around the trays in the oven, leave 1-1/2 inches of space between them on all sides, the front, and the rear. Use blocks of wood in the corners of the racks to hold the trays at least 1 inch apart so you can stack more trays in the oven. At a time, dry no more than four trays of food. An empty load takes longer to dry than a heavy load. When drying, leave the oven door slightly a jar. A heated pad, a block of wood, or a roll of newspaper will leave the oven door slightly ajar, allowing wet air to escape while maintaining the heat within. Nevertheless, use a thermometer to monitor the oven temperature to ensure it stays at 140 ^{0}F. For electric ovens, four to six inches or one to two inches of spacing are often sufficient for ventilation. To keep the air moving, position an electric fan in front of the oven door. Because the temperature is not constant, shifting the trays frequently is crucial for equal drying. [8]

1.5.7 Natural Convection Method:

Open yard sun drying is a traditional method of drying various agricultural products, including grains, fruits, vegetables, and spices. In this method, the products are spread out in a thin layer on a clean and dry surface in an open yard, exposing them to the sun and wind for several days until they are completely dry. The open yard sun drying method is simple and inexpensive, requiring only a clean and dry surface and the natural heat and light of the sun. It is commonly used in rural areas where access to electricity or other drying equipment may be limited. Additionally, this method is considered an eco-friendly way of preserving food as it does not require the use of any artificial preservatives or chemicals. However, the open yard sun drying method also has some limitations. The drying process is dependent on the weather conditions, and if it is cloudy or rainy, it can significantly slow down or halt the drying process, leading to spoilage or degradation of the products. Moreover, open yard sun drying may not be suitable for drying certain products that require controlled temperature and humidity conditions. In conclusion, open yard sun drying is a simple and low-cost method of preserving agricultural products, which is suitable for areas with abundant sunlight and low humidity levels. However, it may not be appropriate for all products or in areas with unpredictable weather conditions. [8]

Figure 1.8: Open Yard Sun Drying. [8]

1.6 THERMAL CONDUCTIVITY & CONDUCTION HEAT TRANSFER:

In Figure 1.9 shows the thermal conductivity across a temperature difference. Thermal conductivity is the ability of a material to conduct heat. Metals are good at heat conduction. The thermal conductivity of a material is a defining property that aids in the development of effective heating/cooling technologies. A value for thermal conductivity can be determined by measuring the rate at which heat can pass through a material.

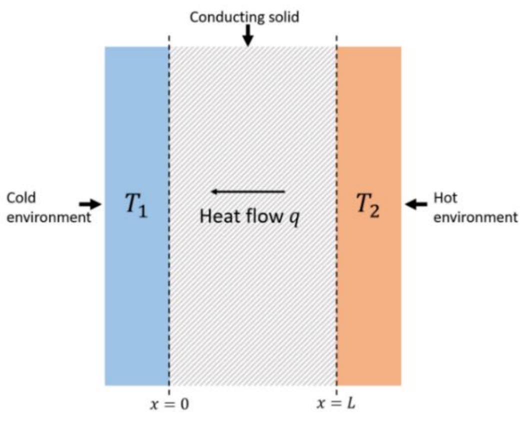


Figure 1.9: Thermal Conductivity Across a Temperature Difference.

For metals at low temperatures the heat is carried mainly by the free electrons. In this case the mean velocity is the Fermi velocity which is temperature independent. The mean free path is determined by the impurities and the crystal imperfections which are temperature independent as well. So the only temperature-dependent quantity is the heat capacity k, which, in this case, heat capacity is proportional to temperature. So ($k = k_0 T$) (Metal at low temperature)

where k_0 a constant. For pure metals such as copper, silver, etc. k_0 is large, so the thermal conductivity is high. At higher temperatures the mean free path is limited by the phonons, so the thermal conductivity tends to decrease with temperature. In alloys the density of the impurities is very high and, consequently k, are small. Therefore, alloys, such as stainless steel, can be used for thermal insulation.

The conduction calculator deals with the type of heat transfer between substances that are in direct contact with each other. Heat exchange by conduction can be utilized to show heat loss through a barrier.

For a wall of steady thickness, the rate of heat loss is given by:

$$Q = \frac{KA(T_{Hot} - T_{Cold})}{d} \qquad (1.1)$$

Where:

Q = Conduction heat transfer (W), K = Materials thermal conductivity (W/mK), A = Cross sectional area of plate (m^2),T(Hot) = Higher temperature (°C),T(Cold) = Colder temperature (°C) and d = Material thickness of plate (m)

Table 1.1: List of Thermal Conductivities of Different Materials.

Table shows thermal conductivities of different materials. [9]

Material	**Thermal Conductivity (W/m, ºK)**
Silver	429
Copper	398
Aluminium	247
Brass	109
Galvanized steel	50
Stainless steer	17
Glass(crown)	1.05
Glass(flint)	0.84
Indian rubber	0.19
Card board	0.064

1.7 PHASE CHANGE MATERIAL(PCM):

Phase Change Materials or PCMs are those that can absorb, store and release large amounts of energy, in the form of latent heat, over a narrowly defined phase change range, during which the material changes state.

Broadly, Heat energy are of two types:

1.Sensible Heat 2. Latent Heat

PCMs changes its phase at a constant temperature, by storing a large amount of latent heat and again changes back its phase by releasing the stored heat, which is used for heating or drying purpose. [4] Normally Solid-Liquid PCMs are used. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. Initially, these solid–liquid PCMs perform like conventional storage materials; their temperature rises as they absorb heat. [3] PCMs absorb and release heat at a nearly constant temperature. They store 5–14 times more heat per unit volume than sensible storage materials such as water.

1.7.1 Types of PCM:

Figure 1.10 shows different types of phase change material. [9]

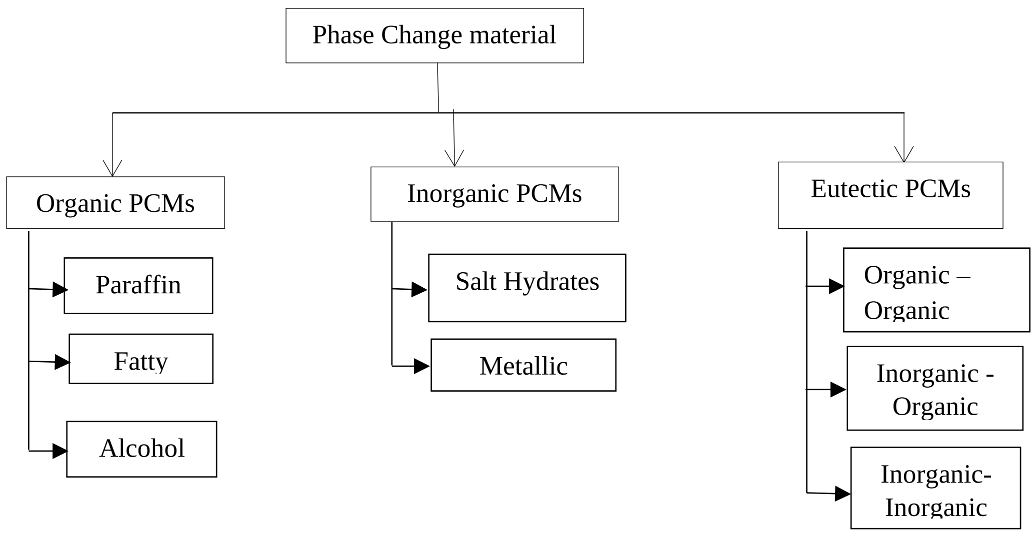


Figure1.10: Different Types of Phase Change Material.

Advantages of Organic Phase Change Materials.

1. Non-corrosive
2. Good chemical and thermal stability
3. No super cooling
4. High heat of fusion
5. Nontoxic

Disadvantages of Organic Phase Change Materials.

1. Low thermal conductivity
2. Low phase change enthalpy
3. High change in volume during the phase transition

Advantages of Organic Phase Change Materials.

1. Non-flammable
2. Inexpensive
3. High heat of fusion
4. Good thermal conductivity

Disadvantages of Inorganic Phase Change Materials.

1. Corrosion
2. Phase decomposition
3. High super cooling effect
4. Insufficient thermal stability
5. Weight problem

Latent heat of different PCM materials:

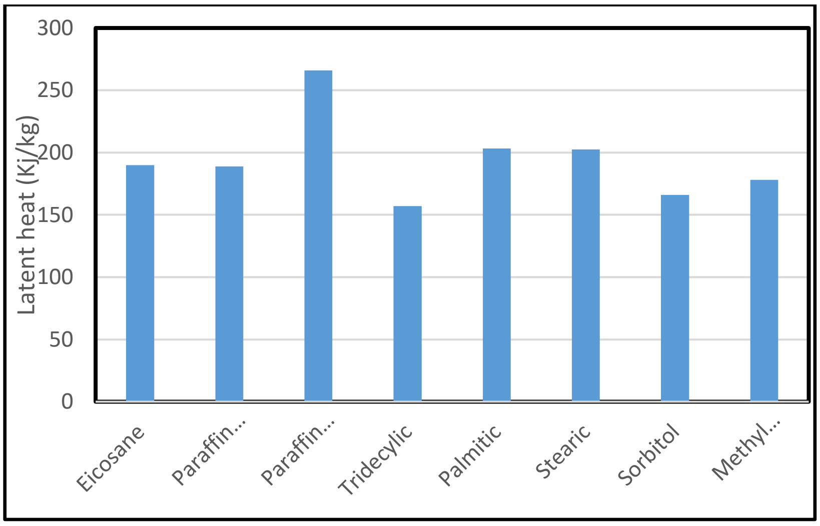


Figure 1.11: Latent heat of different PCM materials. [9-16]

Figure 1.11 Shows that the value of latent heat of different PCM materials. The value of latent heat of paraffin wax (266 kj/kg) is higher than other. Then higher value of latent heat is Palmitic (203.4 kj/kg) and Stearic (202.5 kj/kg). So we can say paraffin wax, palmitic acids and stearic are a good PCM for energy storage of solar dryer.

1.8 ROLE OF AIR VELOCITY IN MOISTURE REMOVAL FROM CROPS:

Optimum air velocity refers to the ideal airflow rate at which moisture removal from a product is most efficient without causing detrimental effects such as product damage or excessive drying. The determination of the optimum air velocity depends on several factors specific to the product being dried. Here are some considerations:

1. Product characteristics: Different products have varying sensitivities to airflow. Some products may be more delicate or sensitive to high velocities, while others may require more airflow to promote effective moisture removal. Factors such as product density, porosity, surface area, and moisture absorption/release properties should be taken into account to determine the optimum air velocity.
2. Moisture diffusion: Optimum air velocity should ensure sufficient diffusion of moisture from the interior of the product to its surface. If the airflow is too low, the moisture diffusion process may be slower, leading to prolonged drying times. Conversely, if the airflow is too high, it may disrupt the moisture diffusion process and cause uneven drying or damage to the product.
3. Heat transfer: Optimal air velocity should support efficient heat transfer to enhance the evaporation of moisture. Heat is essential for increasing the vapour pressure and facilitating moisture evaporation. The air velocity should be sufficient to carry heat effectively across the product's surface while maintaining a controlled and uniform temperature distribution.
4. Uniformity of drying: The air velocity should be adjusted to ensure uniform drying throughout the product. Adequate airflow patterns should be established to avoid the formation of stagnant air pockets that impede moisture removal. Considerations should be made to distribute the airflow evenly across the product to achieve consistent drying results.

Determining the exact optimum air velocity for a specific product often requires experimentation. It involves testing different airflow rates and monitoring the drying progress, product quality, and energy consumption. Additionally, consulting specialized drying guidelines or experts in the field can provide valuable insights and recommendations for achieving the optimal air velocity for moisture removal in a particular product drying process.

1.9 ADVANTAGES OF SOLAR DRYER: [17]

1. Heat intensity is double than open sun's heat a solar dryer can get inside temperature like 50°C while the outdoor temperature is still 32°C. This makes the dryers take away moisture from food products and dry it rapidly which is 5 times faster than sunlight heating. This will increase operational productivity with a reduced drying period.
2. Can be used even on rainy days – A Rainy climate is not suitable for open sun drying process. But using solar dryers can retain heat up to a maximum of 46°C compared to a mere outside temperature of 26°C. Reducing the reliance on labor to keep and store products in case of rain and strong winds can be avoided.
3. Normal drying methods not only attract flies, dust, and other microbes, it also hassles during the rainy season. As Solar dryers have enclosed space this is no longer a problem. Farmers will get a higher and better-quality yield. This will ultimately increase farmer's income.
4. Reducing the operational cost. As Solar dryers are a one-time investment you won't get any other operational cost. Maintenance costs also very much negligible.
5. It occupies less area. Unlike conventional solar heating where you need a lot of space to spread the food products for drying, in solar dryers, you can stack products in trays and place one above another occupying very little space. You can stack how much you need and it is easily movable.
6. Solar dryers last longer and it is estimated that the average like is around 15-20 years.

7. No Color degradation due to UV rays. Since a layer is present between the food product and the sunlight source, the color and value of the food products are preserved.

1.10 DISADVANTAGES OF OPEN SUN DRYING: [18]

1. It is an unregulated technique.
2. That is impossible if there is no sunlight.
3. This method requires large area.
4. A vast space is needed for this procedure.
5. It's possible for birds, chickens, or other animals to destroy crops.
6. This process takes long time.
7. Normally grain did not dry uniformly.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION:

The sun has been used to dry food and crops for thousands of years. However, this method has a number of drawbacks, including product spoilage caused by dust, moisture, wind or rain. Furthermore, the technique is time consuming and labor intensive, and it need a big area to spread the fruit out to dry. Outdoor drying has mostly been replaced by mechanical driers with boilers to heat incoming air and fans to drive it through at a high pace in industrialized regions and industries. Mechanized drying is faster than open-air drying, takes up less space, and produces a higher-quality product. Artificial mechanical drying is an energy-intensive and expensive process that eventually raises the cost of the product. Solar-drying technology saves energy, time, space, increasing efficiency, and protecting the environment. Drying reduces the moisture content to a level below which the product will not deteriorate and can be stored for an extended period of time.

The appendix A shows maximum allowable temperature of different crops. If the temperature is given more than this, the quality of the crop will be damaged. The lowest value of maximum allowable temperature is for wheat and the highest value maximum allowable temperature is for potatoes.

2.2 SOLAR DRYING PERFORMANCE ANALYSIS OF DIFFERENT PRODUCTS:

2.2.1. Potato

Devahastin, et al. (2006) [17] evaluated Indirect forced convection solar dryer for potato and airflow rates 2 m/s. The study made use of the LHS prototype, which utilized paraffin wax as a phase transition medium. In this paper looked at the properties of heat transmission, temperature profiles, and the impact of incoming air temperature and velocity on charge and discharge times. It was discovered that melting occurred from top to bottom points in the axial direction and that melting occurred from the center of the LHS to a distant point in the radial direction. Melting was found to be dominated by heat conduction, followed by free convection. However, the process of solidification was primarily driven by heat conduction. Due to heat loss to the surroundings, PCM froze from the LHS tank's exterior to interior portions. Inlet air temperature and air velocity increases result in a reduction in charge time. When employing inlet air velocities of 2 m/ s, the amount of extractable energy per unit mass flow rate of ambient air at the inlet was 1920 and 1386 kJ min kg1, respectively.

Vigneshkumar, et al (2021) [18] evaluated Indirect solar dryer for potato. The tests were conducted throughout the research in two cases, a solar dryer without PCM (Plain Dryer) and a solar dryer with PCM (PCM Dryer), for a total of nine hours from 10:00 a.m. to 7:00 p.m. For two additional hours following the sunshine time, the absorption of PCM inside the solar collector dramatically increased the dryer room intake temperature. In the case of a dryer without PCM (Plain Dryer), the moisture content of sliced potatoes was reduced to 8.2% whereas it was reduced to 13.3% in the case of a dryer with PCM incorporated (PCM Dryer). As a result, paraffin-based PCM increased the percentage weight of moisture removal from potato slices by 5.1% each day.

Gunasekaran, et al. (2012) [19] developed a sun drier combined with biomass energy. Using a natural convection step type solar drier, the drying performance of unbalanced and blanched beans was investigated. When utilizing unbalanced beans, the hot air temperature differential in the dryer from top to bottom trays was between 1 and 3 degrees Celsius and between 4 and 6 degrees Celsius. When utilizing unbalanced beans, drying efficiency was found to be 15.85%; when using blanched beans, it was found to be 18.75%. The dryer efficiency was determined to be 40.92%. When blanched beans were dried, the drying rate was greatly increased, producing beans of high quality.

Nayak, et al. (2012) [20] studied the economic analysis of a PV-based hybrid solar dryer and revealed a total energy payback period of 5.6 years with advantages of Rs. 362/kg for dried product (cauliflower). Nevertheless, benefits also increased as product quantities used for drying increased.

The effectiveness of a mixed mode sun dryer for drying yam chips was assessed by Bolaji and Olalusi (2008) [21]. The percentage of moisture removed (dry basis), collector effectiveness, and drying rate were all 0.62 kg/h, 57.5%, and 85.4%, respectively.

2.2.2. Paddy

Jain D, et al. (2004) [22] evaluated Indirect forced convection solar dryer for paddy and heat storage effect in the absence of sunlight. The Phase change material are used Granite grits. The grain temperature rises as the collector's length, width, and tilt angle increase until they reach their usual values. For agricultural drying applications, the thermal energy storage effect during the hours without sunlight is crucial. In order to assess the thermal efficiency of a flat plate solar air heater for the purposes of grain drying, the presented mathematical model is helpful. Predicting the moisture content, grain temperature, drying air humidity, and grain bed drying rate are also helpful.

Condori , et al. (1998) [23] two distinct greenhouse dryers' evaporation rates have been studied. One greenhouse features a single drying chamber, while another has two. These dryers were used to dry paddy. The twin chamber greenhouse dryer outperforms the competition by 87%, according to the results.

Om Prakash Jain, et al (2014) [24] evaluated Indirect forced convection solar dryer. The product took 7 hours to dry, and its final moisture content (measured on a dry basis) was 7%.The tent dryer has a temperature range of 31.2 to 54.7 degrees Celsius and a relative humidity of 22 to 34%.

Soponronnarit S, et al (1995) [25] evaluated a forced convection solar dryer put to the test drying paddy. The blower, drying bin, and collector make up the system. This dyer had dimensions of 4.48 m long by 3.74 m broad, a solar air heater, and a vertical fixed bed drying bin with a 12 t paddy capacity. According to drying testing, a tone of paddy might be dried from a moisture content of between 17% and 14% in one to four days, depending on the weather. A blower's typical electrical energy usage was calculated to be 7 kWh per drying batch.

Thongprasert, et al. (1985) [26] a solar dryer was built and put to the test at a farmer's home in the province of Pathumthani. It consisted of a vertical fixed bed drying bin with a capacity of 12 tons of rice and a solar air heater that was 3.74 m wide and 4.48 m long. According to drying testing, one ton of paddy might be dried from having a moisture content of 17.21% on a wet basis to 14% in a matter of days, depending on the weather. A blower's typical electrical energy usage was calculated to be 7 kWh per drying batch. Economic research demonstrated that the solar dryer was cost-effective when paddy loss was taken into account, but it was far less appealing when the only gain came from a higher price for dried paddy.

Soponronnarit et al., (1991) [27] invented a drying cabinet with 12 m2 of transparent glass on top and a 32 m^2 flat plate solar air heater made up the unit. When the system was in use, the solar collector drew warm air, which was then driven through a heat exchanger before entering the drying cabinet, where the drying product was exposed to sun radiation. According to experimental findings, the solar dryer's first-law efficiency was directly correlated with the dry mass and moisture content of bananas per unit sun receiving area. At an average moisture content of around 220 percent dry basis and a dry mass of banana of 3.7 kg/m2 of solar receiving surface, the efficiency reached a maximum of about 30 percent. According to a straightforward financial study, the payback period ranged from 1.5 to 5.4 years. Efficiency, moisture content, and dry mass are related in an empirical equation that was created. Each batch required 7 days (6 hours each day) to dry.

By using a mathematical model, Soponronnarit, et al. (1992) [28] explored the drying method for drying bananas. It was determined that a particular air flow rate of 10 kg/ h-kg dry paddy and a proportion of 90% air recycling were the proper operating conditions. If product quality had to be preserved, drying air temperature should be approximately 60^{o}C.

A study on the natural convection type solar dryer with latent heat storage was conducted by Sain, et al. (2013)[29]. The dryer was put through tests with both a full load and no load. Paddy was used to estimate the system's performance at full load. In 24 hours, the paddy's moisture content (w.b.) decreased from 74% to 18%. It was discovered that the daily average drying efficiency was 12.4%. The collector efficiency varied between 53 and 96 percent during the no load test and between 40 and 55 percent during the full load test. with a two-hour backup time. The solar dryer's total thermal efficiency was discovered to be 22.7.

2.2.3. Red Chili

Samreenet, et al. (2017) [30] evaluated the Forced ventilated solar greenhouse dryer for red chili. The amount of solar radiation is 355.45 W/m2- 931.25W/m2. The relative humidity of dryer varied from 30% to 58% whereas relative humidity inside the greenhouse dryer varies from 22% to 41%. The maximum airflow rate calculated is 99.43 m3 /min and minimum is 35.9 m3 /min.

M. A. Hossain, et al. (2013) [31] devised and built a red chili solar tunnel drier. Taking time 32 hours to decrease amount of moisture from 0.40 kg/kg (dry basis) to 0.09 kg/kg (dry basis) in a conventional dryer, but taking time 20 hours in an enhanced solar dryer to reduce amount of moisture from 2.85 kg/kg (dry basis) to 0.05 kg/kg (dry basis) (dry basis).For green chili, traditional drying takes 35 hours to obtain moisture content of 0.10 to 0.70 kg/kg (dry basis).Taking 22 hours to decrease the original moisture content of 7.6 kg/kg (dry basis) to 0.06 kg/kg (dry basis).When compared to open drying, blanching improves the product's quality and pungency while also shortening the drying time. There wasn't any significant difference between the enhanced and standard solar tunnel dryers, which could be due to blanching before drying. Solar dryer's internal temperature remained nearly constant, at 21.62^0 C higher than the atmospheric temperature. The color value of the solar dryer is improved by blanching red chilies.

For red chili, J. Banout et al. (2012) [32] A comparison of open sun drying, cabinet drying, and double pass drying solar dryers was made. Double pass dryers, open drying, and cabinet dryers, red chili taking time 32 hours, 93 hours, and 73 hours to dry at 10% moisture content, respectively. The ASTA color value of a double pass solar dryer is higher than that of a cabinet or open sun drier. When comparing costs, the building cost of a double pass solar dryer was determined to be higher than that of a cabinet drier. However, the cost of red chili is drying per kilogram is cheaper than that of using a cabinet dryer.

2.2.4. Grapes

Iihem Hamdi, et al. (2018) [33] developed a computational model and conducted an experimental study on grape drying in a chapel type mix-mode greenhouse solar system. Between 29.63 percent and 88.32 percent collector efficiency was recorded. It took 128 hours to lower the moisture content from 5.5 g/g (g water / g dry water) to

0.22 g/g (g water / g dry matter) throughout the drying process. The mathematical model was simulated using TRNSYS software. The experimental outcome was compared to the modeling results. The temperature inside the solar dryer was 55.97 degrees Celsius, while the temperature outside was between 24.54 and 35.71 degrees Celsius. The results were derived the experimental and using a model results are quite close to the model results.

Fadhel, et al.(2005) [34] were studied Grapes drying in natural convection, greenhouse tunnel dryer, and open sun. The solar tunnel greenhouse model produces excellent results when all three models are examined. Solar dryer, open sun dryer, and greenhouse drying took 77 hours, 200 hours, and 119 hours, respectively. Greenhouse drying has a lower initial investment and has no ongoing costs.

2.2.5 Fish

M. A. Basunia, et al. (2011) [35] built and tested a solar tunnel drier for drying fresh fish weighing 50-100 kilograms each batch. Half of the tunnel dryer's base is used for air heating and half is utilized for drying. The temperature of the dryer may be raised by 5–30 C by increasing the air velocity to 0.2 m/sec. Moisture was lowered from 66.5 percent to 15.5 percent (wet basis) after 30 hours (wet basis). The brightness, color, flavor, food, and taste value of the fish have all improved significantly. The dryer's efficiency was determined to be at 29.5 percent.

P. P. Bhor, et al. (2010) [36] investigated the use of a solar tunnel drier for the drying of fish. The drying rate of the solar tunnel drier was found to be greater than that of the open sun dryer. The temperature in the solar tunnel remained at 53.5 degrees Celsius throughout the drying process. Fish without and with salt were used as a drying sample. Within 32 hours, fish without salt reduced their moisture content to 19.05 percent in the upper tray and 19.90 percent in the lower tray. It taking time 37 hours to lower the moisture content of the product by 23.73 percent. Within 35 hours, fish with salt reduce their moisture content to 19.29 percent (dry basis) in the upper tray and 19.63 percent (dry basis) in the bottom tray. It took 39 hours to dry in the open sun, reducing the moisture content to 19.41% (dry).

2.3 PCM AS ENERGY STORAGE MEDIUM

Gopinath, et al. (2021) [37] found that the peak and Average temperature in the drying chamber of different drying method. When use PCM materials on solar dryer than average and peak temperature increased than solar dryer without PCM drying method. Again when PCM materials have been increased from 100 grams to 200 grams than average and peak temperature also increased.

T.S. Sreerag, et al. (2011) [38] Comparing the product's final masses on the chosen dates, they have found that the final mass of the system without PCMs is 0.580 kg, whereas the final mass of the system with PCMs is just 0.385 kg. As a result, the moisture removal rate has been increased since the system with PCMs can sustain a greater temperature. Approximately 15% to 20% of the dried product's moisture is what is desired. This cannot be done in a single day in the system without PCMs.

Bal, et al. (2009) [39] evaluated a solar dryer with a latent heat storage (LHS) with paraffin wax as a phase change material (PCM) to store excess solar energy during the day (using hot air at temperatures similar to those exhausted from a typical solar collector) and release it when the solar energy availability is insufficient or unavailable (by forcing ambient air through the energy storage to extract the stored energy).

A PCM was used in the development of an indirect solar dryer by Esakkimuthu, et al. (2013). [40] The dryer has a fan, a packed bed type PCM thermal energy storage unit, a drying container, and a solar air heater. Three panels made up the 6 m^2 collection area. The absorber plate was made of a V-corrugated aluminum sheet with a thickness of 1.1 mm, a corrugation height of 38 mm, and an included angle of 60^0c. The distance in height between the absorber and the floor is 15 cm. A 5 mm thick toughened glass was firmly set on rubber feet above the absorber surface. The bottom and two sides of the collection were insulating with 25 mm and 50 mm thick Rock wool, respectively. The 1.8 m long and 0.4 m wide thermal energy storage tank was constructed of galvanized iron sheet and glass wool insulation, and it is covered with aluminum to protect the insulation from wind and rain damage. Round capsules made of high-density polyethylene and filled with a PCM (HS 58) are maintained within the storage tank. It was determined that when the mass flow rate rose, the efficiency of the collector increased.

2.4 SUMMARY OF RESEARCH REGARDING SOLAR DRYER:

S. Tabassum et al. (2021) [41] built an indirect solar for drying potatoes and carrots. No thermal energy storage material was used in this experiment. Proximate analysis is done to check the quality of the product. In this experiment, the amount of protein was found to be 6.36% and the amount of protein was found to be 4.92%.

Mohanraj, M et al. (2020) [42] developed an Indirect forced convection solar drier for drying paddy. In this experiment Granite grits Used as a heat storage material. Drying time was found to be 7 hours to dry paddy. No proximate test of paddy has been done in this experiment and heat storage effect absence in off sunlight.

Ayyappan, S et al. (2018) [43] established a Solar greenhouse dryer for drying paddy. Used concrete, sand, and rock-bed as a heat storage material, it was discovered that the dryer's Drying efficiency was 9.5%, 11% and 11.65% respectively. No proximate test of paddy has been done in this experiment.

Devahastin, S. et al. (2014) [44] built an indirect solar for drying Ginger. Paraffin wax used as a heat storage material. The collector efficiency of the solar dryer was found to be 22.7%. No proximate test of Ginger has been done in this experiment.

Barone, G. S. et al. (2007) [45] built a Hybrid solar dryer for drying Mushrooms. No thermal energy storage material was used in this experiment. Drying efficiency was found to be 10%.

Reyes, A. S et al. (2006)[46]established an indirect dryer for drying paddy. Paraffin wax used as a heat storage material. Collector plate temperature increases 3-5^{0}C by using PCM. Dryer run only one air velocity.

In previous research, the protein and fiber content of potato was found to be 6.36 % and 4.92% respectively and in this research the protein and fiber content was 7.79% and 5.78% which is higher than the previous research. In previous research the highest drying efficiency was 11.65% and we found 14.40%. In previous research the highest collector efficiency was 22.70% and we found 25%.

CHAPTER 3
MATERIALS AND METHODOLOGY

3.1. INTRODUCTION:

This chapter includes design, fabrication and component details of solar dryer. Copper plate, aluminum plate, GI sheet and Phase change material (PCM) are used as a solar collector of solar dryer. In this experiment, different air flow has been applied. PCM material gives an advantage of storing the solar energy. It is possible to know which material will efficient as a solar energy collector of solar crop dryer by this experiment. This drying process will efficient and economics for drying agricultural products.

3.2 DESCRIPTION OF SOLAR DRYER EQUIPMENT:

3.2.1 Collector Plate:

Copper plate, aluminum plate and GI sheet are used as heat absorber of the solar air heater shown in Figure 3.1. Thickness of three plates is 1mm and it is coated with 80gm black paint shown in Figure 3.2. The solar air heater assembly includes air flow components. The value of thermal conductivity of copper plate 398(W/m, ^{o}K) is higher than aluminum plate and GI sheet. The detail specification of collector plate is given in the table 3.1.

Table3.1- Specification of Solar Collector Plate.

Collector area	1m^2
Absorber collector Plate thickness	1mm
Thermal conductivity of copper plate	398(W/m, ^{o}K)
Thermal conductivity of Aluminium plate	247(W/m, ^{o}K)
Thermal conductivity of GI sheet	50(W/m, ^{o}K)
No. of transparent glass	1
Thickness of glass	3mm
Black paint on copper plate, aluminium plate and GI sheet	80gm(each)

(a) (b) (c)

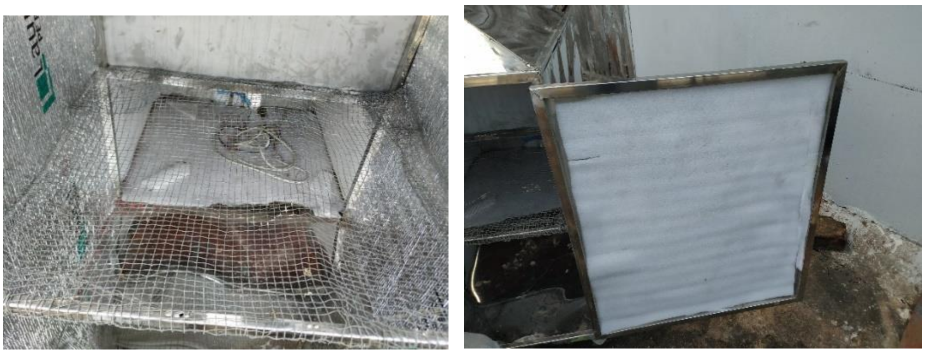
Figure3.1: Fresh (a)Copper Plate (b) Aluminum Plate and (c)Galvanized Sheet.

(a) (b) (c)

Figure3.2: Black Painted Surface of (a) Copper Plate (b)Aluminum Plate (c)GI sheet with Black Paint.

3.2.2 Drying Cabinet:

All of the components of the drying cabinet are stainless steel. Height of the drying cabinet is 2 feet. Thermocol which has a 4mm thickness, is the insulating material which will minimize heat loss. Two stainless trays are used in the drying cabinet to hold drying products; this tray is placed at the distance of 150mm between each tray. Drying cabinet and thermocol insulation shows in Figure 3.3.



(a) (b)

Figure3.3: (a)Drying chamber (b) Thermocol Insulation

3.2.3 Drying Trays:

The drying trays, which are used to hold grain samples within the drying chamber, are made of stainless steel mesh and have a somewhat open design to let drying air move through the sample items and prevent rusting.

3.2.4 Storage System:

The process of storing extra heat energy is known as thermal storage. When the sun isn't shining its brightest, this thermal storage keeps the temperature of the exhaust air steady. Phase change materials are used to achieve this. Paraffin wax is used as a PCM in this project. The storage units are made up of paraffin wax filled in the aluminum coated covers and is put in the absorber plate. And during the times when there is no sunlight, these aluminum-coated coverings are put in the drying chamber. Figure3.4 shows PCM filled in Aluminum Coated Cover.

Figure3.4: **PCM filled in Aluminum Coated Cover.**

Properties of paraffin wax.

Storage material	**PCM (paraffin wax)**
Melting point	56˚C
Thermal conductivity	0.15 W/m^{0}K
Latent heat	200-220 KJ/Kg
Specific heat	2.384 KJ/Kg ˚C

3.2.5 Blower:

Air must be blown into the air collector at a specific velocity using a blower. It is possible to regulate the air velocity at the solar air collector's input.

Specification of Blower.

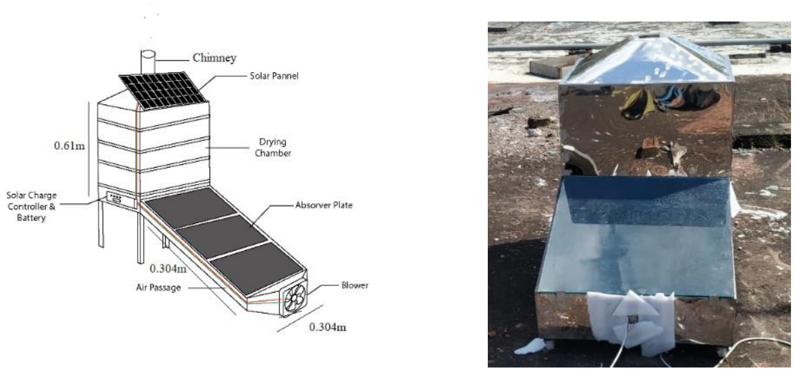
Type	Rating
Voltage	220 v
Frequency	50Hz
Speed	0-1500 rpm
Flow rate	$2.5m^3/s$
Power	60w

3.2.6 Fabrication of Solar Dryer:

Each component of the solar dryer is made according to the design and measurements by utilizing a variety of machining techniques. Drying chamber and frame of solar dryer constructed using 1 mm thickness stainless steel by cutting drilling and bending. The thickness of glass is 3 mm processing by cutting. Collector plate of solar dryer which thickness is 1mm processing by cutting.

3.3CONSTRUCTION DETAILS:

Each component of the solar dryer is made according to the design and measurements by utilizing a variety of machining techniques. Drying chamber and frame of solar dryer constructed using 1 mm thickness stainless steel by cutting drilling and bending. The thickness of glass is 3 mm processing by cutting. Collector plate of solar dryer which thickness is 1mm processing by cutting. The heat absorber of the solar air heater will be constructed using 1mm thick plate and area will be $1m^2$. Copper, aluminum and G.I sheet different material plate will be use as a solar energy collector and which will be coated with black paint as absorber coating. The solar air heater assembly consists of air flow channel enclose by transparent glass of thickness of 3mm.Copper is known to have high thermal conductivity ($398W/m^0K$). The thermal conductivity of aluminum and G.I sheet are respectively ($248\ W/m^0K$) and ($50\ W/m^0K$). In experimentally by using three materials it will be understood which one will be efficient for the use of solar crop dryer. Blower will be used for blowing air at a required velocity to the air collector. And measure the wind velocity by Anemometer. The drying cabinet will be makeup of stainless steel material. The insulation material is thermocol of 4mm thickness which will reduce the heat losses. Two stainless trays will be use in the drying cabinet to hold drying products; this tray will be placed at the distance of 150mm between each tray. The drying tray will be keep inside the drying chamber for holding the crop samples and will be construct from stainless-steel. Thermal storage is the process of storing the heat energy when available in excess. This thermal storage will be use to maintain the temperature of exist air when the sunshine in not at pick this make possible by the use of phase change material. Paraffin Wax will be use as phase change material. The heat storage units will be consisting of paraffin Wax fill in the aluminum coated covers. Drying temperature will be measure by thermometer and will see if it’s enough for remove moisture from crops. Using three materials solar energy collector will be see which material is removed moisture quickly from crops.



(a) **(b)**

Figure3.5: (a) Experimental Setup and (b) Schematic Diagram of Solar Crop Dryer.

(a) (b) (c)

Figure3.6: Raw Food Crop (a) Potato (b) Normal Paddy (c) Boil Paddy.

Dry Sample

(a) Potato (b) Boil Paddy (c) Normal Paddy

Figure 3.7: Dryer Drying.

(a) Potato (b) Boil Paddy (c) Normal Paddy

Figure 3.8: Open Sun Drying.

Sample Prepared:

Figure3.9: Sample preparation.

3.4 DETERMINATION OF PROXIMATE COMPOSITION OF DRIED SAMPLE:

Moisture, crude protein, crude fiber, crude fat and ash of dried sample were analyzed according to AOAC (AOAC, 2016) methods.

3.4.1 Testing Sample Preparation:

Then the sample was ground with an electric blender to make a homogeneous. This sample was used for proximate composition analysis.

3.4.2 Crude Protein Analysis:

The crude protein concentration was determined using the Kjeldahl technique. Among the reagents used were concentrated H_2SO_4, digestion mixture (Potassium sulfate 100gm+ Copper sulfate 10gm+ Selenium powder 1gm), NaOH solution (35%), 4 % boric acid solution, 0.1 gm mixed indication in 100 ml ethanol, combine bromocresol green and 0.1 g methyl red, and standard HCL (0.2N). The steps are followed for the estimation of protein:

3.4.3 Digestion: About 0.3 gm grinded sample was taken in the digestion tube. Then 8 ml of concentrated H_2SO_4 and 4gm digestion mixture was taken in the tubes. After that, digestion tubes were placed on the heating device of Kjeldahl apparatus (DK 20/26) and were heated for 1 to 1.5 hours at 400^0C. The end point of the digestion tube was cooled at room temperature before distillation.

3.4.4 Distillation: About 25 ml of distilled water was added to the digestion tube and 25 ml of NaOH was also added to the tube to make the solution adequately alkaline. Conical flasks containing 10 ml of boric acid with 2-3 drops of the mixed indicator were placed under the condenser to collect the distillate in the distillate unit (Figure 3). The distillation was completed within 4 minutes when the collected distillate was about 100ml and the distillate color shows dark greenish color.

Figure 3.10: Distillate Unit (VELP- UDK129)

3.4.5 Titration:

The collected distillate was titrated with standard HCL. The end point was indicated by light pinkish color. The protein content proportion was calculated using the following formula:

$$\text{Nitrogen (\%)} = \frac{(A-B)\times Normality\ of\ acid \times Milli\ equivalent\ weight\ of\ N2\ (0.014)}{Weight\ (g) of\ sample} \times 100 \qquad (3.3)$$

Where, A= ml of titrant of the sample, B=ml of titrant of the blank.

Crude protein (%) = Nitrogen (%) ×6.25

3.4.6 Fat Content Analysis:

A Soxhlet device was used to determine the fat content of these (Figure 4). At first, weigh the empty beaker, and then fill it with 75 ml of ether. Exactly 2 grams of sample was obtained in the thimble paper. Boiling was done for 15 minutes, rising for 25 minutes, and extraction was done for 10 minutes, with the temperature of the Soxhlet apparatus set at 100^0C throughout the operation. Most of the solvent had evaporated after about 10 minutes.

The following formula was used to calculate

$$\text{Fat content: } (\%) = \frac{W1-W2}{W} \times 100$$

Here, W_1 = weight of evaporated flask with the sample, W_2= weight of empty flask, W= weight of the sample

Figure 3.11: Soxhlet Device (FOOD ALYTRD40)

3.4.7 Ash Content Analysis:

3 grams of powdered material was placed in a pre-weighted porcelain crucible in triplicate. After that, the crucibles were placed in a muffle furnace (Figure 5) and heated to 550^{0}C for 6 hours. The crucibles were then placed in desiccators to cool for 30 minutes.

Figure 3.12: Muffle Furnace (Nabertherm-L9/13)

The percentage of residual components in each sample was calculated. It was calculated using the formula:

$$\text{Ash content (\%)} = \frac{\text{weight (gm) of ash}}{\text{Weight (gm) of sample}} \times 100$$

3.4.8 Moisture Content Analysis:

Empty crucibles were first dried in a hot air oven for 1 hour at 180^{0}C. The sample was then placed in a pre-weighed porcelain crucible using an electric balancer (Figure 6)

Figure 3.13: Hot Air Oven (BINDER-ED115)

After that, the crucible was placed in a hot air oven (BINDER-ED115) set to 105^{0}C for about 12 hours, or until the appropriate weight was reached. After that, the crucible was weighed once more. The moisture loss was determined from these weights using the following formula:

$$\text{Moisture Content (\%)} = \frac{Weight\ of\ wet\ material(g) - Weight\ of\ dry\ material(g)}{Weight\ of\ wet\ material\ (g)} \times 100$$

3.5 FLOW DIAGRAM OF EXPERIMENT

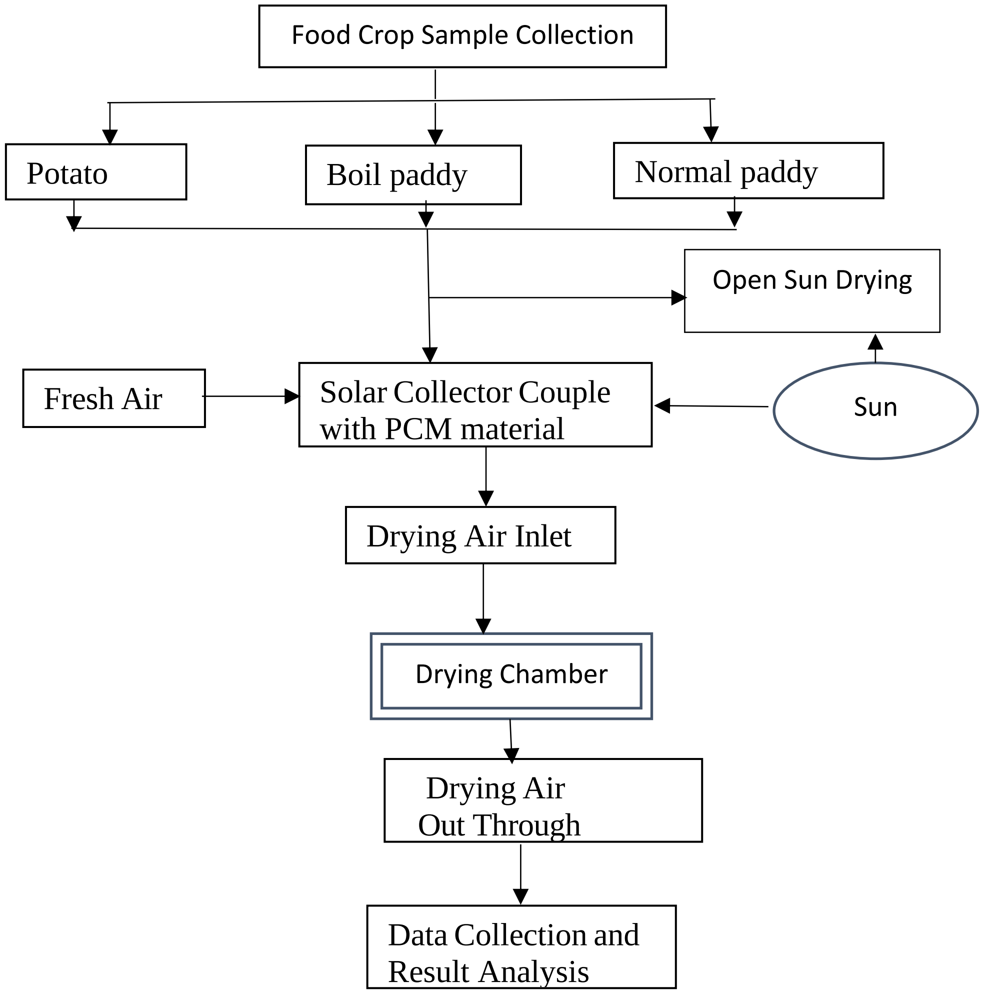


Figure 3.14: Flow Diagram of Experiment.

Potatoes are procured from local markets and paddy is procured from paddy fields. Potatoes are sliced for drying. Potato, normal paddy and boil paddy (each 500gm) were dried in solar dryer and in open sun at the same time. Data was collected every half hour.

Table 3.2: Meter Use for Measuring Data.

Name of Equipment	Function of Equipment	Picture
Anemometer Air velocity range (0.4m/s ~ 30.0m/s)	For air velocity Measurement	
Day star meter Range (0-1999 W/m^2)	For Solar Intensity Measurement	
Weight Balance Range (0-10Kg)	For Weight Measurement	
Digital Thermometer	For Temperature Measurement	 

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION:

Three types of products were dried.500gm of potato, 500gm of boil paddy and 500gm of normal paddy were dried in dryer and 500gm of boil paddy, 500gm were dried in open sun at same time. Data was collected through three types of collector plates i.e. copper plate, aluminum plate and GI sheet. Paraffin wax is used as heat storage. The solar dryer was operated at four different air velocity and the potatoes were dried. After extracting the specific velocity from here, the data is taken at that specific air velocity. In this chapter the data is analyzed.

4.2 GOVERNING EQUATION:

Moisture Content= $\frac{Weight\ of\ wet\ material(g) - Weight\ of\ dry\ material(g)}{Weight\ of\ wet\ material(g)}$ (4.1)

Pearson's correlation coefficient, $r_{xy} = \frac{\sum_{i=1}^{n}(\alpha_i - \bar{\alpha})(f_c - \bar{f_c})}{\sqrt{\sum_{i=1}^{n}(\alpha_i - \bar{\alpha})^2 \sum_{i=1}^{n}(f_c - \bar{f_c})^2}}$ (4.2)

Regression Analysis and Correlation Equation:

Regression analysis is one of the most powerful statistical method for developing the correlation between two or more of interest. The method most frequently employed by sociologists is that of linear equations. The multiple linear regression can be written in the form:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + \ldots\ldots\ldots\ldots\ldots\ldots + b_k X_k \quad (4.3)$$

Where Y is the dependent variable, which is to be determined, X_1, X_2, X_3,…… X_k are the known variables on which the predictions are to be made and a, b_1, b_2, b_3,…… b_k are the coefficients which are determined through the least R square's method.

Solar Collector Efficiency [54]

Using the following formula, the solar collector's efficiency was computed.

$$\eta_c = \frac{m_a C_{pa}(T_0 - T_i)}{A_c I_g} \quad (4.4)$$

$$m_a = V \times \frac{\Pi d^2}{4} \times \rho \quad (4.5)$$

Where, η_c=Efficiency, m_a= Mass flow rate of air (kg/s), C_{pa}= Specific heat (kJ/kg K), T_i=Inlet Temperature(^{0}C), T_o=Outlet Temperature(^{0}C), A_c= Collector surface area(m^2), V=Velocity of Air (m/s), ρ=Density of Air (kg/m^3)**,** I_g=Solar radiation ($W\ m^{-2}$)

Drying Efficiency [55]

Using the following formula, the solar drying efficiency was computed.

$$\eta_d = \frac{m_w l_v}{m_a C_{pa}(T_0 - T_i)} \quad (4.6)$$

$$m_w = m_a(w_0 - w_a) \quad (4.7)$$

Where, η_d=Drying Efficiency, m_w= Mass flow rate of moisture (kg/s), l_v= Water evaporation latent heat evaluated at air saturation temperature (kJ/kg), A_d=Dryer-collector surface(m^2), w_0= Dryer Outlet Absolute Humidity (kgw/kga), w_a= Ambient Absolute Humidity (kgw/kga).

4.3 EXPERIMENTAL DATA ANALYSIS:

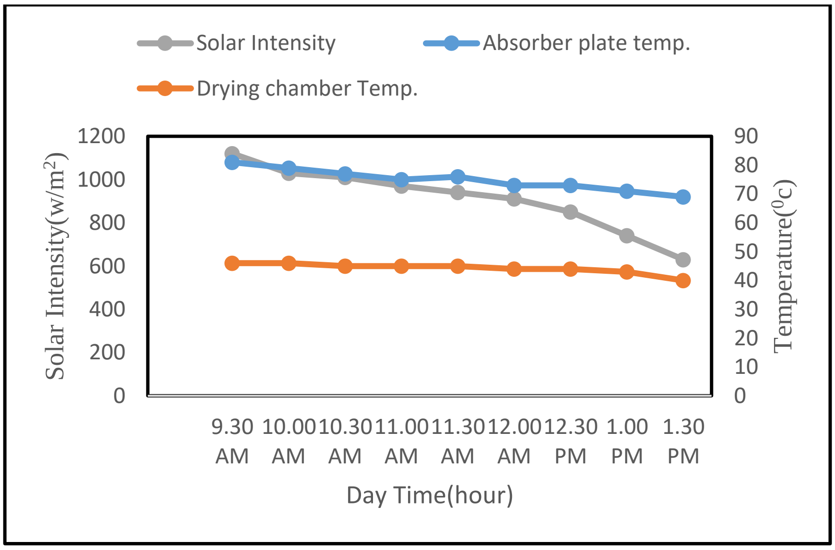


Figure4.1.-Solar Intensity, Absorber Plate Temperature and Drying Chamber Temperature Variation with Respect to Daytime. (Date-31-10-22)

The Figure.4.1 shows the variation of solar intensity, absorber plate temperature, and Drying Chamber Temperature, with respect to daytime. As the solar intensity increases and decreases, the absorber plate temperature and drying chamber temperature increase and decrease. The highest value of absorber plate temperature and drying chamber temperature are 81^0c and 46^0c while the value of Solar Intensity is 1120 w/m^2.

Pearson's Correlation Coefficient Calculation Data of Solar Intensity (w/m^2), Absorber Plate Temp and Drying Chamber Temperature (°C): (Date-31-10-22)

The relationship between the solar intensity and absorber plate temperature are given in appendix C1. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.97 for solar intensity and absorber plate temperature, which is within the range of $0.75< r_{x\,y} <1$[46]. There is a very strong positive correlation between solar intensity (W/m^2) and drying chamber temperature(°C). The relationship between the solar intensity and drying chamber temperature are given in appendix C2. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.95 for solar Intensity and drying chamber temperature, which is within the range of $0.75< r_{x\,y} <1$[46]. There is a very strong positive correlation between solar Intensity (W/m^2) and absorber plate temp.(°C)

Table 4.1: **Moisture Content of Potato Using Copper Plate as a Solar Collector at Velocity 1.8m/s.**

	Open Sun Drying		**Solar Dryer Drying**		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
			Date-6-11-22		
10.30 AM	0.67	37	0.66	81	46
11.00AM	0.63	38	0.61	79	46
11.30AM	0.59	36	0.58	77	45
12.00AM	0.57	36	0.55	75	45
12.30PM	0.54	35	0.53	76	45
1.00PM	0.5	33	0.48	73	44
1.30PM	0.47	31	0.45	73	44
2.00PM	0.46	30	0.44	71	43
2.30PM	0.45	29	0.43	69	40
			Date-1-11-22		
10.30 AM	0.43	36	0.41	80	45
11.00AM	0.40	37	0.41	78	45
11.30AM	0.36	36	0.34	76	44
12.00AM	0.303	35	0.28	76	43
12.30PM	0.23	34	0.19	75	43
1.00PM	0.17	33	0.11	73	42
1.30PM	0.13	30		72	43

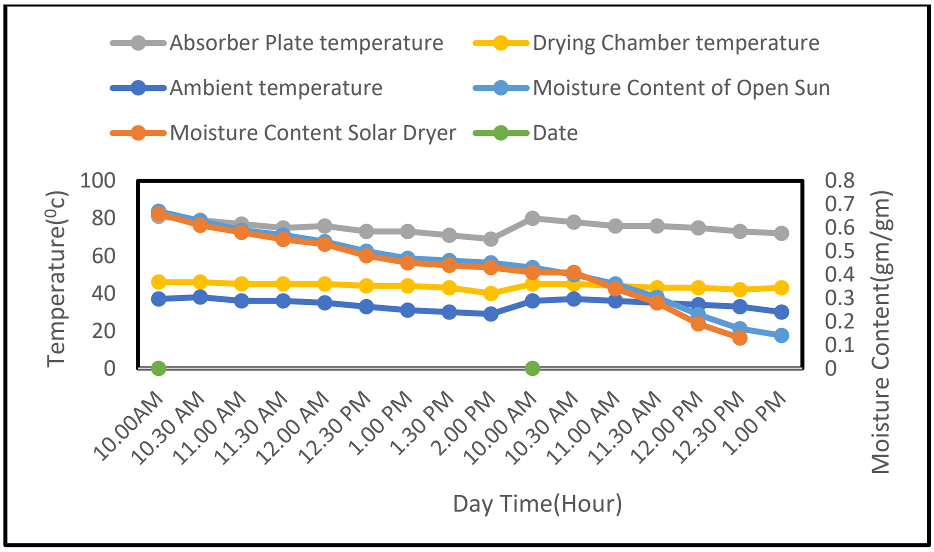


Figure4.2: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.2 shows the variation of absorber plate temperature, drying Chamber temperature, ambient temperature and moisture content with respect to daytime. As the absorber plate temperature increases, the drying chamber temperature also increases. The highest value of absorber plate temperature and drying chamber temperature are 81^0C and 46^0C respectively. When the moisture content(gm/gm) of potato reaches 0.12-0.14, the potato is dry. Moisture content of 500gm of slice potato in solar dryer drying reaches 0.11 at 1.00 pm and in open sun drying moisture content(gm/gm) reaches 0.14 at 1.30pm.500 gm of potatoes were dried in dryer 0.5 hours before open sun. The highest ambient temperature is 38^0C.

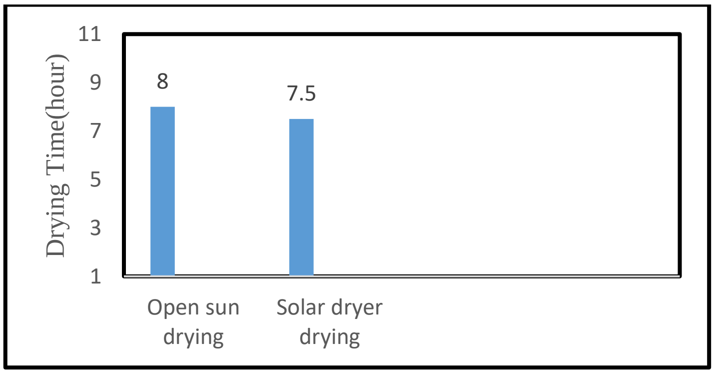


Figure4.3- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of potato between open sun drying and solar dryer using CU plate at velocity 1,8m/s is compared in Figure 4.3. The time difference between the two systems is 0.5 hours.

Pearson's Correlation Coefficient Calculation Data of Solar Intensity (w/m^2), Absorber Plate Temp and Drying Chamber Temperature (°C): (Date-2-11-22)

Appendix C3 contains a relation between solar intensity and the temperature of the absorber plate. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.98 for solar intensity and absorber plate temperature, which is within the range of $0.75 < r_{xy} < 1$[46]. There is a very strong positive correlation between solar intensity (W/m^2) and drying chamber temperature (°C). Appendix C4 contains a relation between solar intensity and the temperature of the drying chamber temperature. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.91 for solar Intensity and drying chamber temperature, which is within the range of $0.75 < r_{xy} < 1$[46]. There is a very strong positive correlation between solar Intensity (W/m^2) and absorber plate temperature(°C).

Table 4.2: Moisture Content of Potato Using Copper Plate as a Solar Collector at Velocity 2.2 m/s.

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content**	**Ambient temperature(°C)**	**Moisture Content**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-2-11-22					
10.30AM	0.67	38	0.66	81	47
11.00AM	0.63	37	0.60	80	46
11.30AM	0.60	36	0.58	77	46
12.00AM	0.57	36	0.54	76	45
12.30PM	0.54	35	0.52	76	45
1.00 PM	0.51	34	0.47	74	44
1.30 PM	0.49	32	0.44	73	44
2.00 PM	0.47	30	0.43	72	43
2.30 PM	0.45	29	0.41	69	41
Date-3-11-22					
10.30AM	0.44	38	0.40	82	47
11.00AM	0.40	37	0.27	80	47
11.30AM	0.36	36	0.29	77	45
12.00AM	0.31	35	0.20	75	44
12.30PM	0.24	35	0.16	75	44
1.00 PM	0.17	34	0.13	73	43
1.30 PM	0.15	32		74	44
2.00PM	0.12				

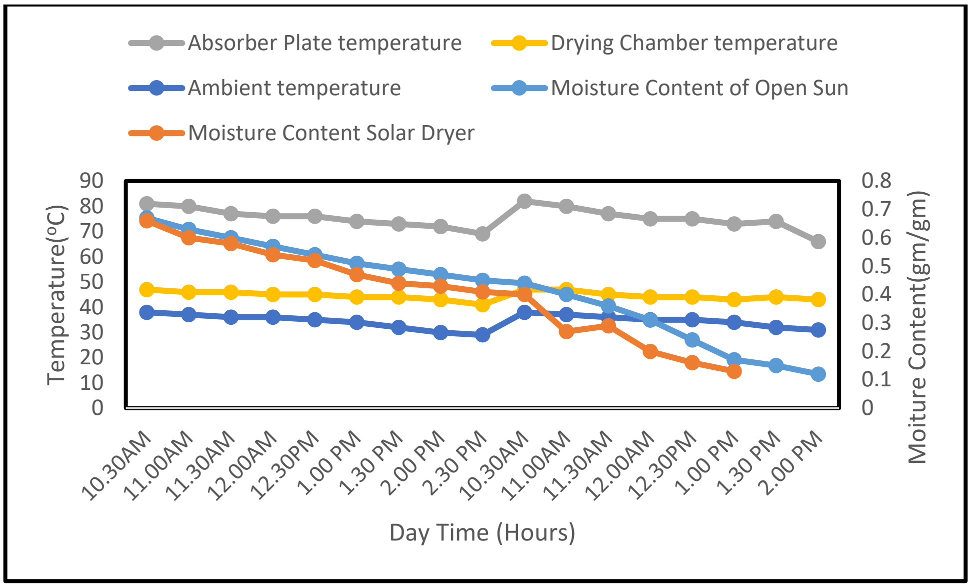


Figure4.4: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

Figure 4.4 illustrates how the moisture content, drying chamber temperature, ambient temperature and absorber plate temperature change during the day time. The drying chamber temperature rises together with the temperature of the absorber plate. The highest temperatures are 82^0C and 47^0C for the drying chamber and absorber plates, respectively. When the moisture content (gm/gm) of a potato is between 0.12 and 0.14, it is deemed dry. 500 grams of potato slices dried in a solar dryer to a moisture level of 0.10 at 12.30 p.m., whereas potatoes dried in the open sun to a moisture content of 0.11 at 1.30 p.m. 500 gm of potatoes were dried in dryer 1 hours before open sun. The highest ambient temperature is 38^0C.

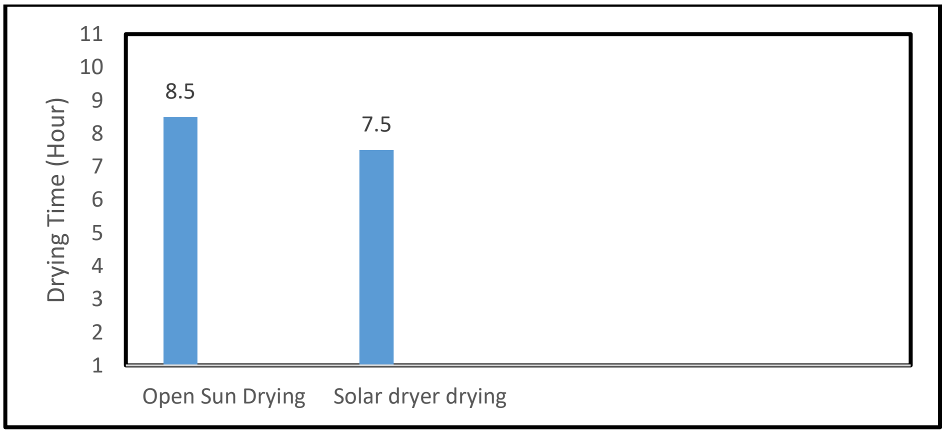


Fig4.5- Drying Time Between Open Sun Drying and Solar Dryer Drying.

Figure 4.5 compares the drying times of potatoes dried in the open sun and in a solar drier utilizing CU plates moving at a speed of 2.2 m/s. The time difference between the two systems is 1 hours.

Pearson's Correlation Coefficient Calculation Data of Solar Intensity (w/m²), Absorber Plate Temp and Drying Chamber Temp (°C): (Date-6-11-22)

The relationship between the solar intensity and absorber plate temperature are given in appendix C5. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.84 for solar intensity and absorber plate temperature, which is within the range of $0.75 < r_{x\,y} < 1$[46]. There is a very strong positive correlation between solar intensity (W/m^2) and drying chamber temperature(°C). The relationship between the solar intensity and drying chamber temperature are given in appendix C6. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.88 for solar Intensity and drying chamber temperature, which is within the range of $0.75 < r_{x\,y} < 1$[46]. There is a very strong positive correlation between solar Intensity (W/m^2) and absorber plate temperature(°C).

Table 4.3: Moisture Content of Potato Using Copper Plate as a Solar Collector at Velocity 2.5 m/s.

	Open Sun Drying		Solar Dryer Drying		
Time	**Moisture Content**	**Ambient temperature(°C)**	**Moisture Content**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-6-11-22					
10.30AM	0.67	36	0.664	80	45
11.00AM	0.63	35	0.60	79	43
11.30AM	0.60	35	0.57	77	44
12.00AM	0.58	34	0.54	75	44
12.30PM	0.55	35	0.51	76	43
1.00 PM	0.52	31	0.46	73	43
1.30 PM	0.49	32	0.44	73	42
2.00 PM	0.48	30	0.42	69	41
2.30 PM	0.46	28	0.40	66	41
Date-7-11-22					
10.30AM	0.44	35	0.32	79	43
11.00AM	0.40	36	0.26	78	42
11.30AM	0.37	32	0.21	79	45
12.00AM	0.33	33	0.18	77	42
12.30PM	0.27	34	0.13	75	41
1.00 PM	0.21	31		73	40
1.30 PM	0.19	32		73	41
2.00PM	0.13	31		70	40

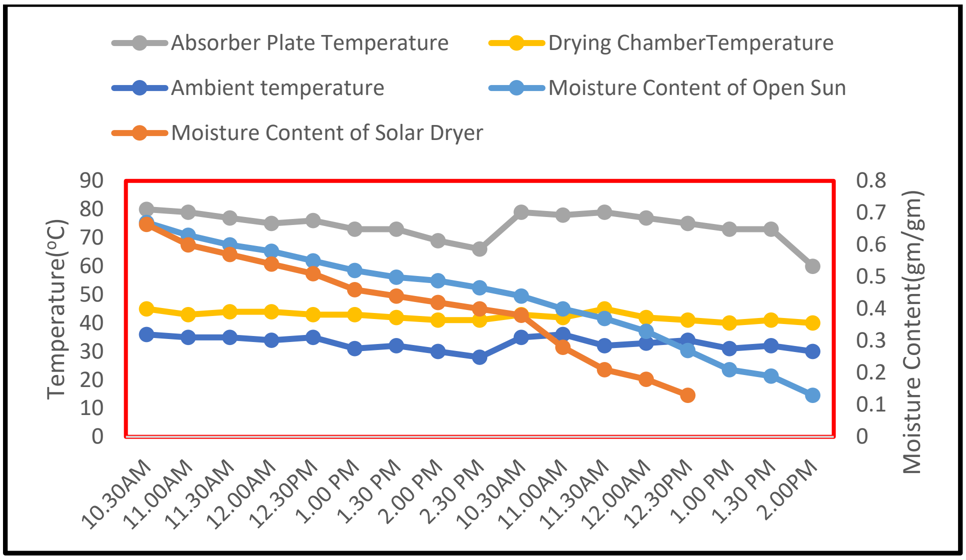


Figure4.6: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.6 shows the variation of absorber plate temperature, drying Chamber Temperature and moisture content with respect to daytime. The drying chamber temperature rises together with the temperature of the absorber plate. The highest value of absorber plate temperature and drying chamber temperature are 80^0C and 45^0C respectively. When the moisture content(gm/gm) of potato reaches 0.12-0.14, the potato is dry. Moisture content of 500gm of slice potato in solar dryer drying reaches 0.12 at 12.00 pm and in open sun drying moisture content(gm/gm) reaches 0.14 at 1.30pm.500 gm of potatoes were dried in dryer 1.5 hours before open sun. The highest ambient temperature is 36^0C.

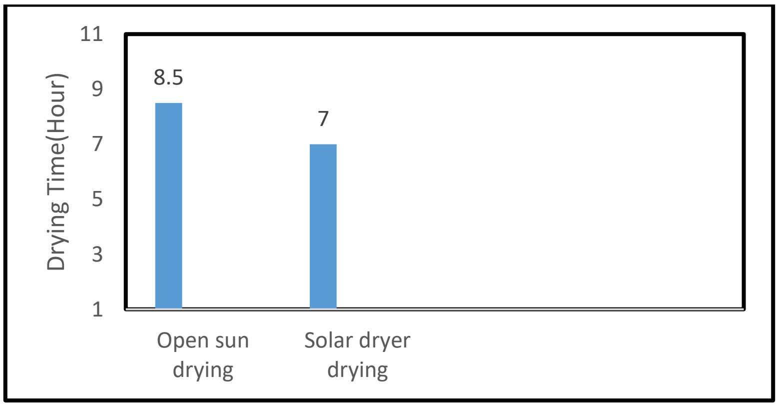


Fig4.7- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of potato between open sun drying and solar dryer using CU plate at velocity 2.5 m/s is compared in Figure.4.7. The time difference between the two systems is 1.5 hours.

Pearson's Correlation Coefficient Calculation Data of Solar Intensity (w/m^2), Absorber Plate Temp and Drying Chamber Temp (°C): (Date-9-11-22)

Appendix C7 contains a relation between solar intensity and the temperature of the absorber plate. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.97 for solar intensity and absorber plate temperature, which is within the range of 0.75< $r_{x\,y}$ <1[46]. There is a very strong positive correlation between solar intensity (W/m^2) and drying chamber temperature (°C). Appendix C8 contains a relation between solar intensity and the temperature of the drying chamber temperature. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.92 for solar Intensity and drying chamber temperature, which is within the range of 0.75< $r_{x\,y}$ <1[46]. There is a very strong positive correlation between solar Intensity (W/m^2) and absorber plate temperature(°C).

Table 4.4: Moisture Content of Potato Using Copper Plate as a Solar Collector at Velocity 2.7 m/s.

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-9-11-22					
10.30AM	0.67	37	0.66	80	45
11.00AM	0.64	36	0.61	79	46
11.30AM	0.61	36	0.58	78	45
12.00AM	0.59	35	0.55	75	45
12.30PM	0.56	34	0.53	76	46
1.00PM	0.53	33	0.49	73	45
1.30PM	0.50	32	0.47	71	44
2.00PM	0.48	30	0.45	69	43
2.30PM	0.47	29	0.44	68	41
Date-10-11-22					
10.30AM	0.45	36	0.42	78	46
11.00AM	0.41	35	0.27	79	45
11.30AM	0.37	35	0.30	79	45
12.00AM	0.32	32	0.20	78	44
12.30PM	0.28	32	0.13	76	43
1.00PM	0.24	33		74	43
1.30PM	0.15	31		72	42

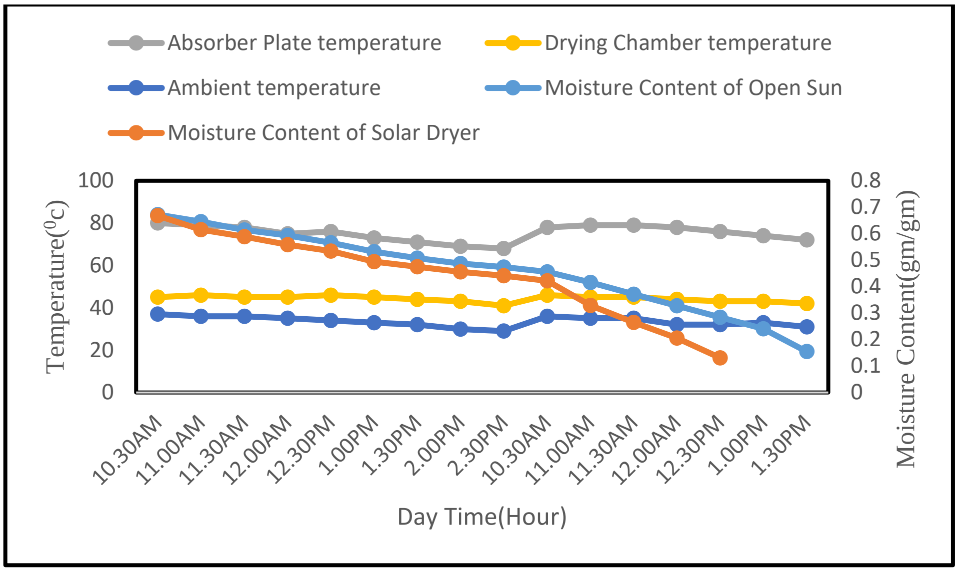


Figure4.8: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.8 shows the variation of absorber plate temperature, ambient temperature, drying Chamber Temperature and moisture content with respect to daytime. The drying chamber temperature rises together with the temperature of the absorber plate. The highest value of absorber plate temperature and drying chamber temperature are 80^0c and 46^0c respectively. When the moisture content(gm/gm) of potato reaches 0.12-0.14, the potato is dry. Moisture content of 500gm of slice potato in solar dryer drying reaches 0.13 at 12.30 pm and in open sun drying moisture content(gm/gm) reaches 0.15 at 1.30pm.500 gm of potatoes were dried in dryer 1.5 hours before open sun.500 gm of potatoes were dried in dryer 1 hours before open sun. The highest ambient temperature is 37^0C.

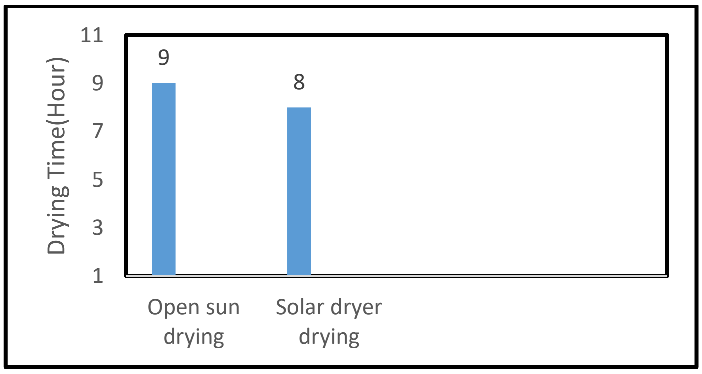


Fig4.9- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of potato between open sun drying and solar dryer using CU plate at velocity 2.7 m/s is compared in Figure4.9. The time difference between the two systems is 1 hours.

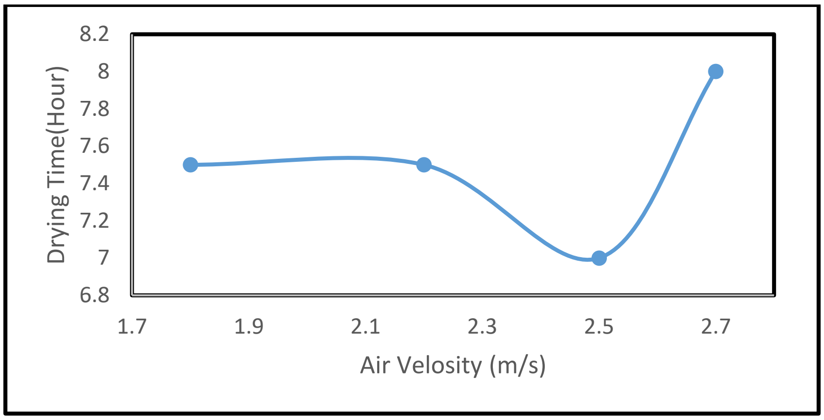


Figure 4.10: Drying Time at Different Velocity.

Figure 4.10 shows drying time with respect to different velocity. In 2.5m/s air velocity, more moisture is carried away from the surface being dried. So it can be ideal air velocity range to achieve the desired level of moisture removal in the shortest amount of time.

Pearson's Correlation Coefficient Calculation Data of Solar Intensity (w/m^2), Absorber Plate Temp and Drying Chamber Temp (°C): (Date-21-11-22)

Appendix C9 contains a relation between solar intensity and the temperature of the absorber plate. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.95 for solar intensity and absorber plate temperature, which is within the range of $0.75 < r_{x\,y} < 1$[46]. There is a very strong positive correlation between solar intensity (W/m^2) and drying chamber temperature (°C). Appendix C10 contains a relation between solar intensity and the temperature of the drying chamber temperature. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.96 for solar Intensity and drying chamber temperature, which is within the range of $0.75 < r_{x\,y} < 1$[46]. There is a very strong positive correlation between solar Intensity (W/m^2) and absorber plate temperature(°C).

Table 4.5: Moisture Content of Boil Paddy Using Copper Plate as a Solar Collector at Velocity 2.5 m/s.

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-21-11-22					
10.30AM	0.44	32	0.44	77	44
11.00AM	0.41	27	0.41	76	45
11.30AM	0.38	32	0.37	77	45
12.00AM	0.36	32	0.36	74	43
12.30PM	0.33	33	0.33	72	44
1.00PM	0.30	33	0.30	68	42
1.30PM	0.28	30	0.28	63	42
2.00PM	0.27	28	0.25	62	43
2.30PM	0.26	27	0.20	60	40
Date-22-11-22					
10.30AM	0.25	32	0.17	78	43
11.00AM	0.24	28	0.079	76	42
11.30AM	0.23	33		77	44
12.00AM	0.18	33		75	42

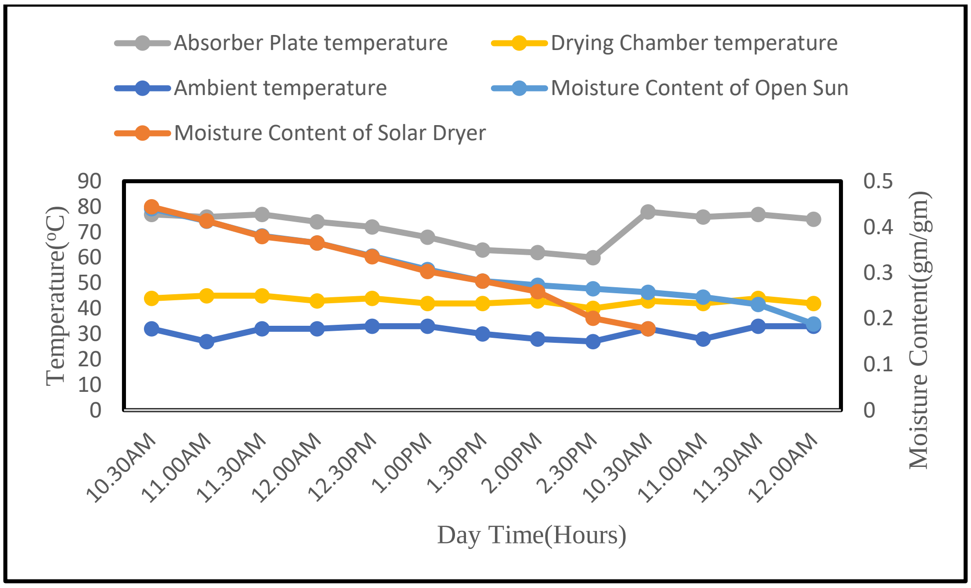


Figure4.11: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.11 shows the variation of three variables, absorber plate temperature, and drying Chamber Temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 77^0c and 45^0c respectively. When the moisture content(gm/gm) of boil paddy reaches 0.18-0.20, the boil paddy is dry. Moisture content of 500gm of slice boil paddy in solar dryer drying reaches 0.17 at 10.30 pm and in open sun drying moisture content(gm/gm) reaches 0.18 at 12.00 pm.500 gm of boil paddy were dried in dryer 1 hours before open sun. The highest ambient temperature is 33^0C.

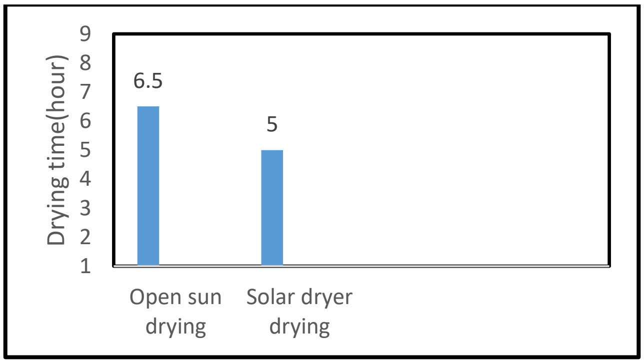


Fig4.12- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of boil paddy between open sun drying and solar dryer using CU plate at velocity 2.5 m/s is compared in Figure.4.12. The time difference between the two systems is 1.5 hours.

Table 4.6: Moisture Content of Normal Paddy Using Copper Plate as a Solar Collector at Velocity 2.5 m/s.

Open Sun Drying			Solar Dryer Drying		
Time	Moisture Content (gm/gm)	Ambient temperature(°C)	Moisture Content (gm/gm)	Absorber plate temperature (°C)	Drying chamber temperature (°C)
Date-21-11-22					
10.30AM	0.33	32	0.34	77	44
11.00AM	0.31	27	0.30	76	45
11.30AM	0.30	32	0.29	77	45
12.00AM	0.28	32	0.29	74	43
12.30PM	0.27	33	0.28	72	44
1.00PM	0.26	33	0.26	68	42
1.30PM	0.25	30	0.26	63	42
2.00PM	0.23	28	0.24	62	43
2.30PM	0.22	27	0.22	60	40
Date-22-11-22					
10.30AM	0.21	32	0.19	78	43
11.00AM	0.20	28	0.14	76	42
11.30AM	0.18	33		77	44
12.00AM	0.12	33		75	42

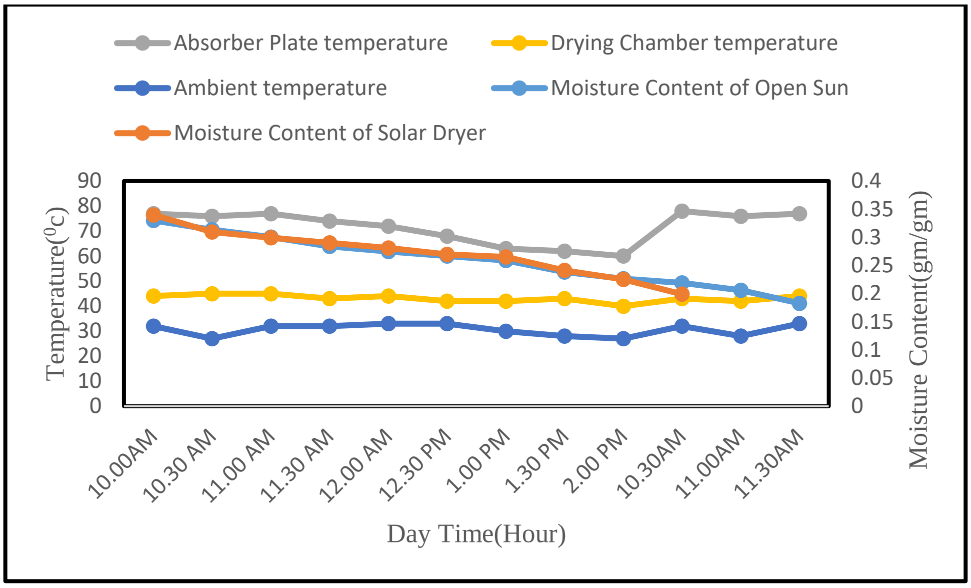


Figure4.13: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.13 shows the variation of three variables, Absorber plate temperature, and drying Chamber Temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 77^0c and 45^0c respectively. When the moisture content(gm/gm) of normal paddy reaches 0.18-0.20, the normal paddy is dry. Moisture content of 500gm of slice normal paddy in solar dryer drying reaches 0.19at 10.30 pm and in open sun drying moisture content(gm/gm) reaches 0.18 at 11.30pm.500 gm of normal paddy were dried in dryer 1 hours before open sun. The highest ambient temperature is 33^0C.

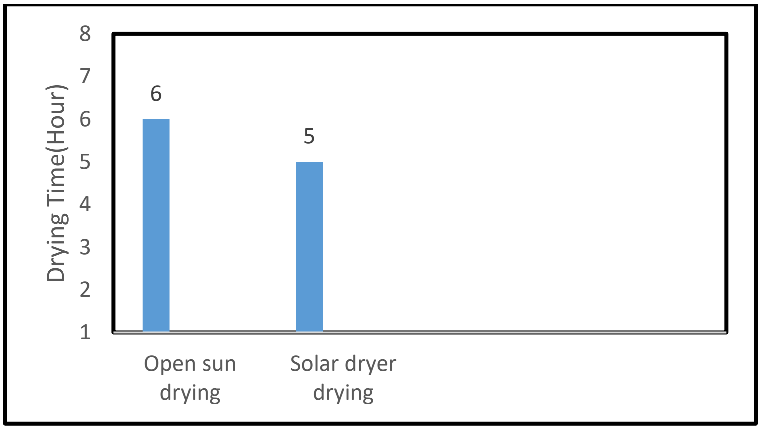


Fig4.14- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of normal paddy between open sun drying and solar dryer using CU plate at velocity 2.5 m/s is compared in Figure 4.14. The time difference between the two systems is 1 hours.

Pearson's Correlation Coefficient Calculation Data of Solar Intensity (w/m^2), Absorber Plate Temp and Drying Chamber Temp (°C): (Date-15-02-23)

Appendix C11 contains a relation between solar intensity and the temperature of the absorber plate. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.97 for solar intensity and absorber plate temperature, which is within the range of 0.75< $r_{x\,y}$ <1[46]. There is a very strong positive correlation between solar intensity (W/m^2) and drying chamber temperature (°C). Appendix C12 contains a relation between solar intensity and the temperature of the drying chamber temperature. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.77 for solar Intensity and drying chamber temperature, which is within the range of 0.75< $r_{x\,y}$ <1[46]. There is a very strong positive correlation between solar Intensity (W/m^2) and absorber plate temperature(°C).

Table 4.7: Moisture Content of Potato Using Copper Plate as a Solar Collector at Velocity 2.5 m/s. (100gm/m^2 PCM)

	Open Sun Drying		Solar Dryer Drying		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-15-02-23					
10.30AM	0.676	31	0.668	78	43
11.00AM	0.65	29	0.63	78	45
11.30AM	0.63	31	0.62	76	44
12.00AM	0.61	28	0.60	74	43
12.30PM	0.58	27	0.57	76	42
1.00PM	0.56	27	0.55	72	42
1.30PM	0.52	26	0.53	68	45
2.00PM	0.51	26	0.48	69	42
2.30PM	0.48	29	0.44	64	41
Date-15-02-23					
10.30AM	0.45	32	0.40	77	42
11.00AM	0.40	30	0.35	76	43
11.30AM	0.33	31	0.24	75	42
12.00AM	0.30	28	0.12	74	41
12.30PM	0.25	26		72	41
1.00PM	0.19	27		69	40
1.30PM	0.13	26		68	42

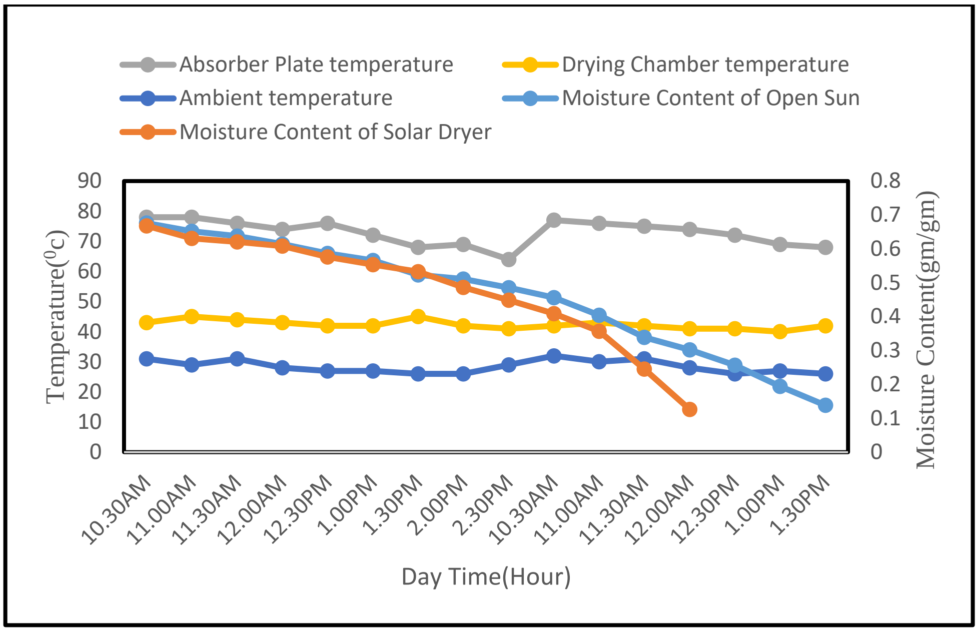


Figure4.15: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.15 shows the variation of three variables, Absorber plate temperature, and drying Chamber Temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 78^0c and 45^0c respectively. When the moisture content(gm/gm) of potato reaches 0.12-0.14, the potato is dry. Moisture content of 500gm of slice potato in solar dryer drying reaches 0.12 at 12.00pm and in open sun drying moisture content(gm/gm) reaches 0.13 at 1.30pm.500 gm of potato were dried in dryer 0.5 hours before open sun. The highest ambient temperature is 32^0C.

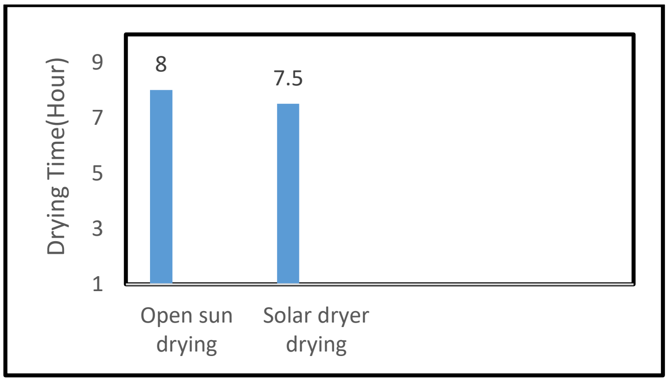


Figure4.16- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of potato between open sun drying and solar dryer using CU plate (100gm PCM) at velocity 2.5 m/s is compared in Figure4.16. The time difference between the two systems is 0.5 hours.

Pearson's Correlation Coefficient Calculation Data of Solar Intensity (w/m^2), Absorber Plate Temp and Drying Chamber Temp (°C): (Date-12-02-23)

Appendix C13 contains a relation between solar intensity and the temperature of the absorber plate. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.76 for solar intensity and absorber plate temperature, which is within the range of 0.75< $r_{x\,y}$ <1[46]. There is a very strong positive correlation between solar intensity (W/m^2) and drying chamber temperature (°C). Appendix C14 contains a relation between solar intensity and the temperature of the drying chamber temperature. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.76 for solar Intensity and drying chamber temperature, which is within the range of 0.75< $r_{x\,y}$ <1[46]. There is a very strong positive correlation between solar Intensity (W/m^2) and absorber plate temperature(°C).

Table 4.8: Moisture Content of Potato Using Copper Plate as a Solar Collector at Velocity 2.5 m/s. (200gm/m^2 PCM)

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-12-2-23					
10.30AM	0.67	30	0.67	78	43
11.00AM	0.65	28	0.63	79	46
11.30AM	0.63	31	0.625	77	46
12.00AM	0.61	29	0.60	75	43
12.30PM	0.59	27	0.58	76	45
1.00PM	0.57	28	0.55	76	44
1.30PM	0.53	26	0.53	77	45
2.00PM	0.52	27	0.49	74	43
2.30PM	0.50	29	0.45	68	42
Date-13-02-23					
10.30AM	0.46	29	0.43	78	42
11.00AM	0.42	27	0.39	78	43
11.30AM	0.37	28	0.34	77	42
12.00AM	0.33	31	0.29	76	42
12.30PM	0.31	30	0.23	75	41
1.00PM	0.28	30	0.19	76	43
1.30PM	0.25	29	0.12	74	42
2.00PM	0.19	30		72	41

2.30PM	0.13	27		72	41

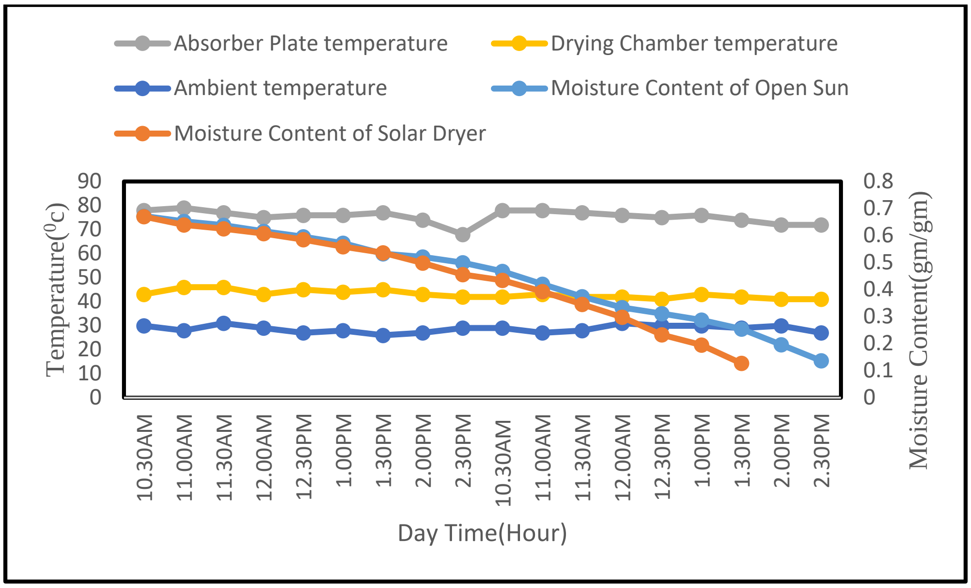


Figure4.17: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.17 shows the variation of three variables, Absorber plate temperature, and drying Chamber Temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 79^{0}c and 46^{0}c respectively.500 gm of potato were dried in dryer 1 hours before open sun. The highest ambient temperature is 31^{0}C.

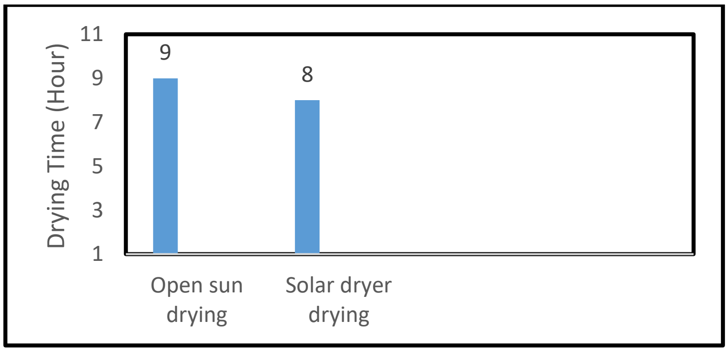


Figure4.18- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of potato between open sun drying and solar dryer using CU plate (200gm PCM) at velocity 2.5 m/s is compared in Figure4.18. The time difference between the two systems is 1 hours.

Pearson's Correlation Coefficient Calculation Data of Solar Intensity (w/m^2), Absorber Plate Temp and Drying Chamber Temp (°C): (Date-23-11-22)

Appendix C15 contains a relation between solar intensity and the temperature of the absorber plate. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.84 for solar intensity and absorber plate temperature, which is within the range of $0.75< r_{x\,y} <1$[46]. There is a very strong positive correlation between solar intensity (W/m^2) and drying chamber temperature (°C). Appendix C16 contains a relation between solar intensity and the temperature of the drying chamber temperature. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.75 for solar Intensity and drying chamber temperature, which is within the range of $0.75< r_{x\,y} <1$[46]. There is a very strong positive correlation between solar Intensity (W/m^2) and absorber plate temperature(°C).

Table 4.9: Moisture Content of Potato Using Copper Plate as a Solar Collector at Velocity 2.5 m/s. (300gm/m² PCM)

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-23-11-22					
10.00AM	0.62	27	0.66	82	47
10.30AM	0.65	29	0.63	81	46
11.00AM	0.63	33	0.60	80	47
11.30AM	0.61	32	0.57	80	48
12.00AM	0.58	32	0.56	80	46
12.30PM	0.563	30	0.51	76	45
1.00PM	0.54	28	0.47	72	43
1.30PM	0.51	27	0.44	70	43
2.00PM	0.48	26	0.42	69	43
2.30PM	0.45	26	0.38	69	43
Date-23-11-22					
10.00AM	0.41	31	0.30	81	47
10.30AM	0.37	29	0.241	80	47
11.00AM	0.32	31	0.20	79	46
11.30AM	0.27	28	0.12	79	45
12.00AM	0.25	27		79	45
12.30PM	0.19	27		75	42
1.00PM	0.16	26		73	45
1.30PM	0.13	26		72	43

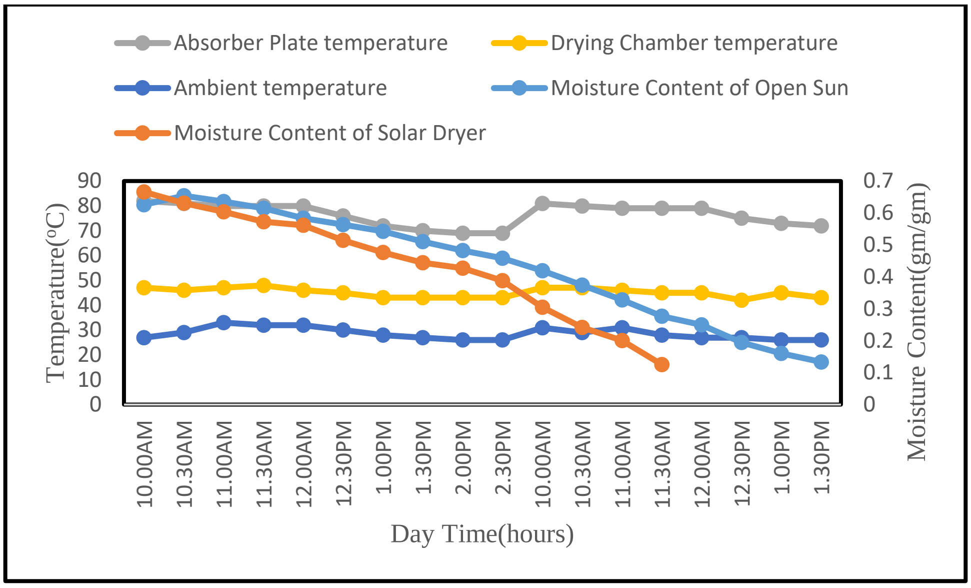


Figure4.19: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.19 shows the variation of three variables, Absorber plate temperature, and drying Chamber Temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 82^0c and 48^0c respectively. When the moisture content(gm/gm) of potato reaches 0.12-0.14, the potato is dry. Moisture content of 500gm of slice potato in solar dryer drying reaches 0.12 at 11.30 am and in open sun drying moisture content(gm/gm) reaches 0.13 at 1.30pm.500 gm of potato were dried in dryer 2 hours before open sun. The highest ambient temperature is 32^0C.

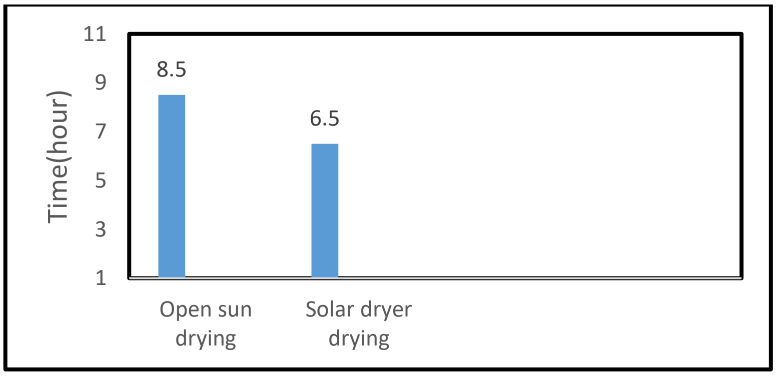


Figure4.20- Drying time between open sun and solar dryer.

The drying time of Potato between open sun drying and solar dryer using CU plate (300gm PCM) at velocity 2.5 m/s is compared in Figure4 .20. The time difference between the two systems is 2 hours.

Table 4.10: Moisture Content of Boil Paddy Using Copper Plate as a Solar Collector at Velocity 2.5 m/s. (300gm/m^2 PCM)

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-23-11-22					
10.30AM	0.43	27	0.44	82	47
11.00AM	0.41	29	0.41	81	46
11.30AM	0.38	33	0.37	80	47
12.00AM	0.36	32	0.36	80	48
12.30PM	0.34	32	0.33	80	46
1.00PM	0.31	30	0.30	76	45
1.30PM	0.29	28	0.28	72	43
2.00PM	0.27	27	0.26	70	43
2.30PM	0.26	26	0.25	69	43
Date-23-11-22					
10.30AM	0.25	31	0.22	81	47
11.00AM	0.23	29	0.18	80	47
11.30AM	0.23	31		79	46
12.00AM	0.21	28		79	45
12.30PM	0.19	27		79	45

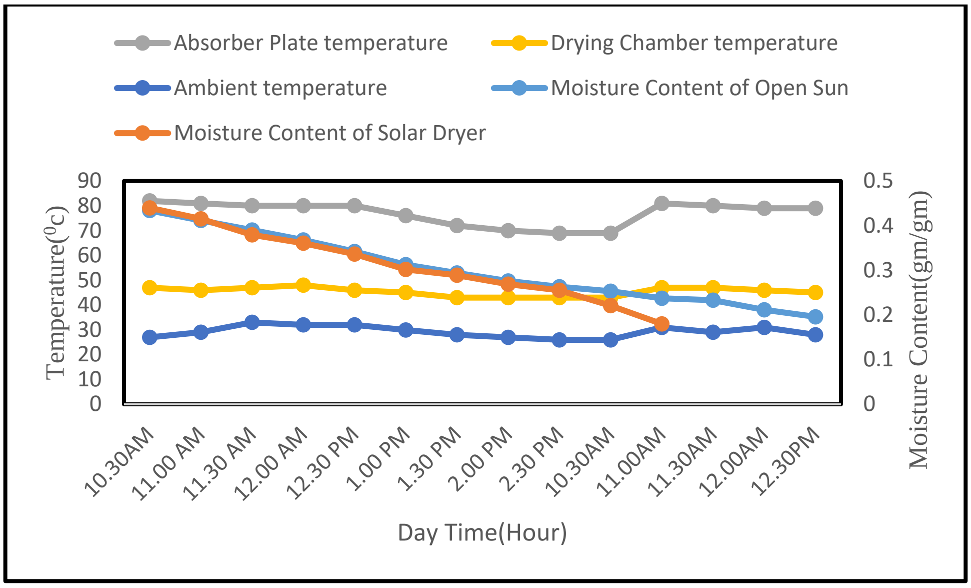


Figure4.21: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.21 shows the variation of three variables, absorber plate temperature, and drying Chamber Temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 82^0c and 48^0c respectively. When the moisture content(gm/gm) of boil paddy reaches 0.18-0.20, the boil paddy is dry. Moisture content of 500gm of slice potato in solar dryer drying reaches 0.18 at 11.00 am and in open sun drying moisture content(gm/gm) reaches 0.19 at 12.30pm.500 gm of boil paddy were dried in dryer 2 hours before open sun. The highest ambient temperature is 32^0C.

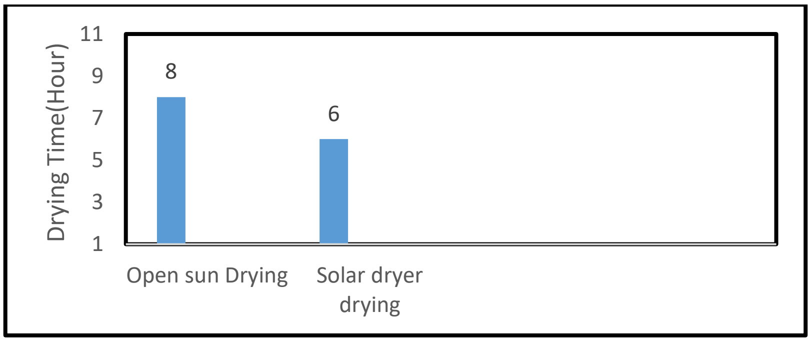


Figure4.22- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of boil paddy between open sun drying and solar dryer using CU plate (300gm PCM) at velocity 2.5 m/s is compared in Figure.5.22. The time difference between the two systems is 2 hours.

Table 4.11: Moisture Content of Normal Paddy Using Copper Plate as a Solar Collector at Velocity 2.5 m/s. (400gm/m^2 PCM)

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-23-11-22					
10.30AM	0.33	27	0.34	82	47
11.00AM	0.31	29	0.31	81	46
11.30AM	0.30	33	0.29	80	47
12.00AM	0.28	32	0.27	80	48
12.30PM	0.27	32	0.25	80	46
1.00PM	0.26	30	0.24	76	45
1.30PM	0.25	28	0.23	72	43
2.00PM	0.24	27	0.22	70	43
2.30PM	0.23	26	0.21	69	43
Date-24-11-22					
10.30AM	0.22	31	0.20	81	47
11.00AM	0.21	29	0.18	80	47
11.30AM	0.21	31		79	46
12.00AM	0.19	28		79	45

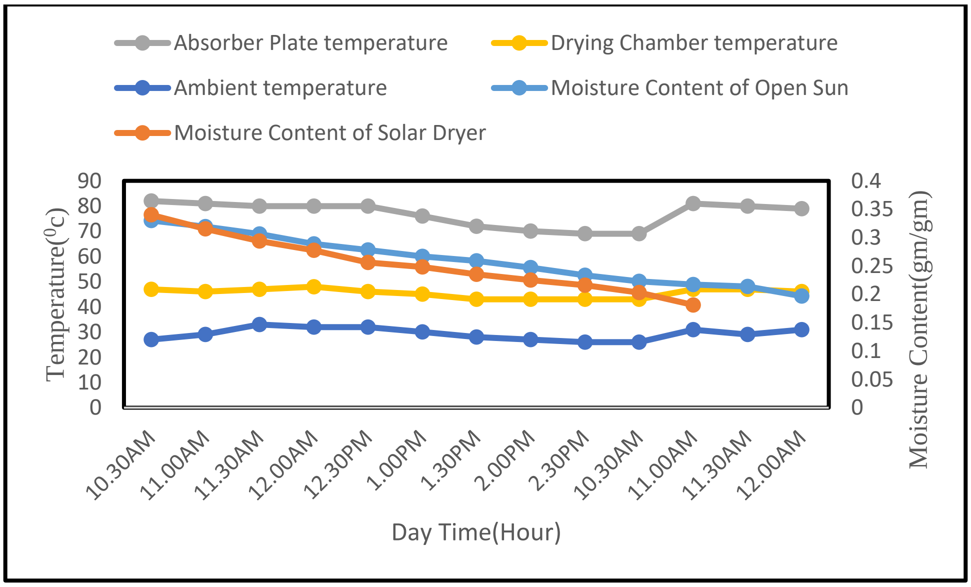


Figure4.23: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.23 shows the variation of three variables, absorber plate temperature, and drying Chamber Temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 82^0c and 48^0c respectively. When the moisture content(gm/gm) of normal paddy reaches 0.18-0.20, the normal paddy is dry. Moisture content of 500gm of slice normal paddy in solar dryer drying reaches 0.18 at 11.00 am and in open sun drying moisture content(gm/gm) reaches 0.19 at 12.00am.500 gm of normal paddy were dried in dryer 1.5 hours before open sun. The highest ambient temperature is 32^0C.

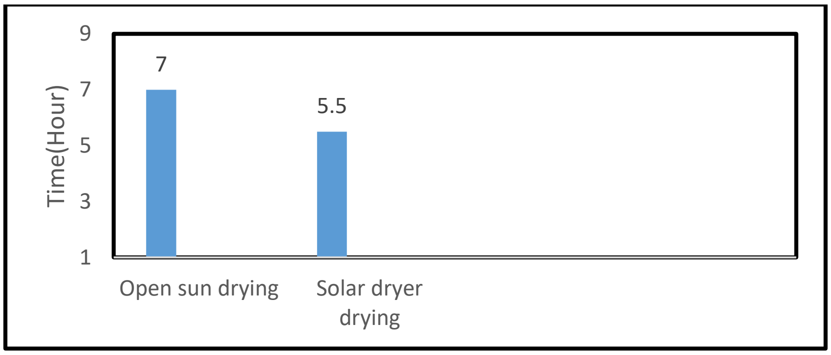


Figure4.24- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of paddy between open sun drying and solar dryer using CU plate (300gm PCM) at velocity 2.5 m/s is compared in Figure 4.24. The time difference between the two systems is 1.5 hours.

Pearson's Correlation Coefficient Calculation Data of Solar Intensity (w/m²), Absorber Plate Temp and Drying Chamber Temp (°C): (Date-27-11-22)

Appendix C17 contains a relation between solar intensity and the temperature of the absorber plate. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.97 for solar intensity and absorber plate temperature, which is within the range of 0.75< $r_{x\,y}$ <1[46]. There is a very strong positive correlation between solar intensity (W/m²) and drying chamber temperature (°C). Appendix C108contains a relation between solar intensity and the temperature of the drying chamber temperature. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.97 for solar Intensity and drying chamber temperature, which is within the range of 0.75< $r_{x\,y}$ <1[46]. There is a very strong positive correlation between solar Intensity (W/m²) and absorber plate temperature(°C).

Table 4.12: Moisture Content of Potato Using Copper Plate as a Solar Collector at Velocity 2.5 m/s. (400gm/m^2 PCM)

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-27-11-22					
10.30AM	0.67	28	0.67	78	43
11.00AM	0.65	28	0.63	77	42
11.30AM	0.63	32	0.62	77	44
12.00AM	0.61	32	0.60	76	45
12.30PM	0.59	31	0.58	74	43
1.00PM	0.56	31	0.55	76	45
1.30PM	0.53	29	0.53	71	43
2.00PM	0.52	27	0.48	66	43
2.30PM	0.50	27	0.45	65	42
Date-28-11-22					
10.30AM	0.46	27	0.43	77	43
11.00AM	0.41	27	0.39	78	43
11.30AM	0.35	28	0.32	78	43
12.00AM	0.30	31	0.26	77	42
12.30PM	0.27	32	0.17	76	44
1.00PM	0.25	32	0.12	77	45
1.30PM	0.19	32		75	45
2.00PM	0.16	31		76	43
2.30PM	0.13	29		73	42

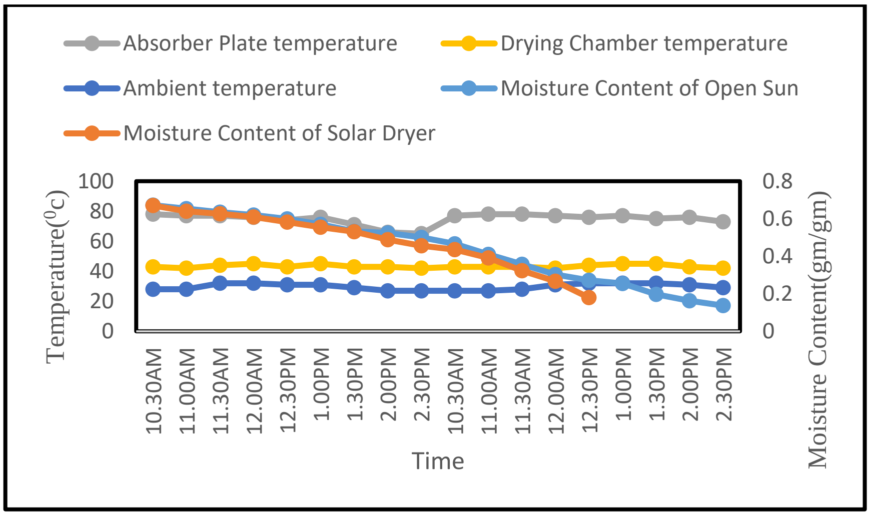


Figure4.25: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.25 shows the variation of three variables, absorber plate temperature, and drying Chamber Temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 78^0C and 45^0C respectively. When the moisture content(gm/gm) of potato reaches 0.12-0.14, the potato is dry. Moisture content of 500gm of slice potato in solar dryer drying reaches 0.12 at 1.00 pm and in open sun drying moisture content(gm/gm) reaches 0.13 at 2.30pm.500 gm of potato were dried in dryer 1.5 hours before open sun. The highest ambient temperature is 31^0C.

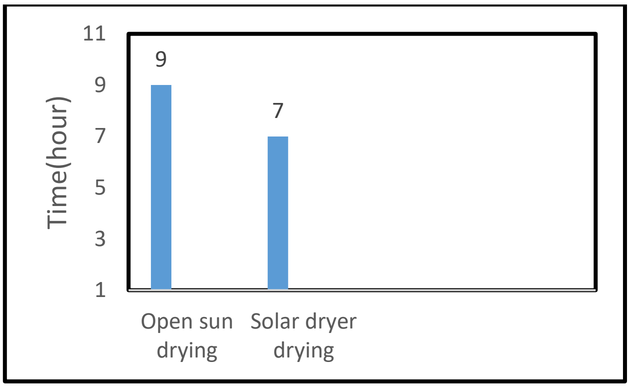


Figure4.26- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of Potato between open sun drying and solar dryer using CU plate (400gm PCM) at velocity 2.5 m/s is compared in Figure 4.26. The time difference between the two systems is 2 hours.

Table 4.13: Moisture Content of Boil Paddy Using Copper Plate as Solar Collector at Velocity 2.5 m/s. (400gm/m^2 PCM)

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-27-11-22					
10.30AM	0.43	28	0.43	78	43
11.00AM	0.42	28	0.39	77	42
11.30AM	0.40	32	0.37	77	44
12.00AM	0.38	32	0.35	76	45
12.30PM	0.34	31	0.32	74	43
1.00PM	0.34	31	0.29	76	45
1.30PM	0.31	29	0.27	71	43
2.00PM	0.29	27	0.25	66	43

2.30PM	0.27	27	0.24	65	42
Date-28-11-22					
10.30AM	0.27	27	0.23	77	43
11.00AM	0.25	27	0.20	78	43
11.30AM	0.23	28	0.18	78	43
12.00AM	0.22	31		77	42
12.30PM	0.21	32		76	44
1.00PM	0.20	32		77	45
1.30PM	0.18	32		75	45

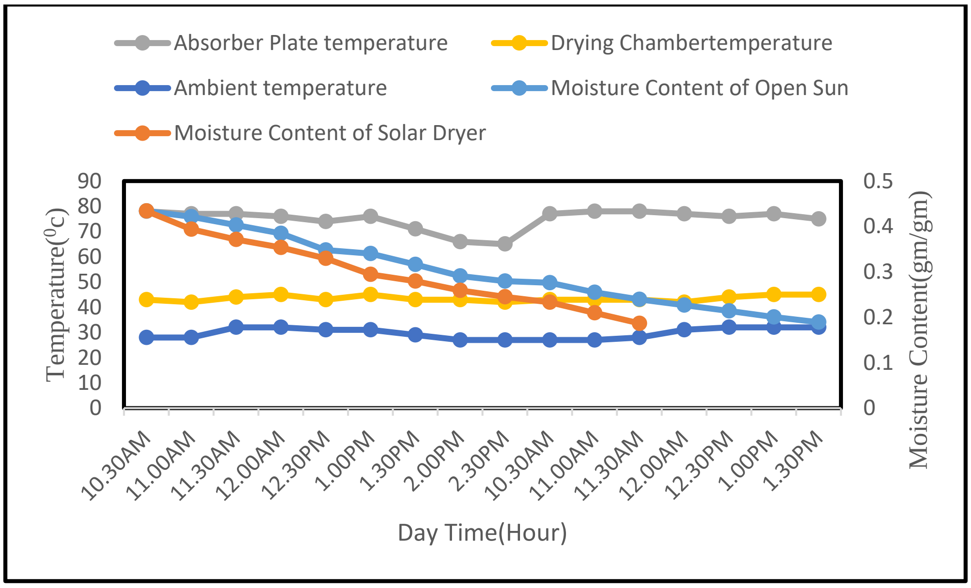


Figure4.27: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.27 shows the variation of three variables, absorber plate temperature, and drying Chamber Temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 78^{0}C and 43^{0}C respectively. When the moisture content(gm/gm) of boil paddy reaches 0.18-0.20, the boil paddy is dry. Moisture content of 500gm of boil paddy in solar dryer drying reaches 0.18 at 11.30 am and in open sun drying moisture content(gm/gm) reaches 0.18 at 1.30pm.500 gm of boil paddy were dried in dryer 1.5 hours before open sun. The highest ambient temperature is 32^{0}C.

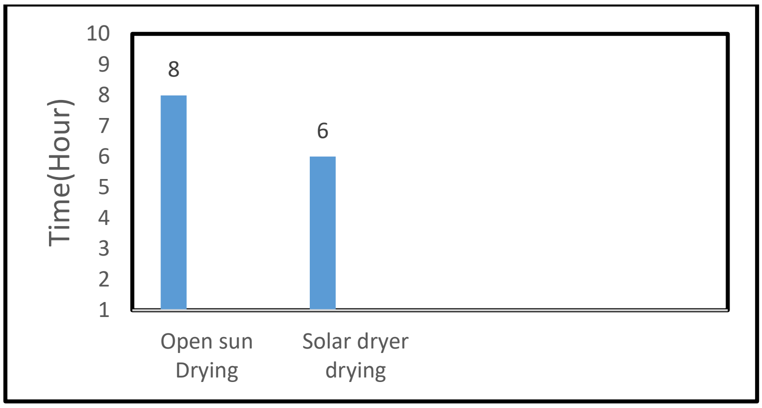


Figure4.28- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of boil paddy between open sun drying and solar dryer using CU plate (400gm PCM) at velocity 2.5 m/s is compared in Figure 4.28. The time difference between the two systems is 2 hours.

Table 4.14: Moisture Content of Normal Paddy Using Copper Plate as a Solar Collector at Velocity 2.5 m/s. (400gm/m^2 PCM)

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-27-11-22					
10.30AM	0.33	28	0.33	78	43
11.00AM	0.31	28	0.31	77	42
11.30AM	0.31	32	0.30	77	44
12.00AM	0.30	32	0.29	76	45
12.30PM	0.28	31	0.28	74	43
1.00PM	0.25	31	0.27	76	45
1.30PM	0.24	29	0.25	71	43
2.00PM	0.23	27	0.24	66	43
2.30PM	0.23	27	0.23	65	42
Date-28-11-22					
10.30AM	0.22	27	0.21	77	43
11.00AM	0.21	27	0.18	78	43
11.30AM	0.21	28		78	43
12.00AM	0.20	31		77	42
12.30PM	0.19	32		76	44
1.00PM	0.18	32		77	45

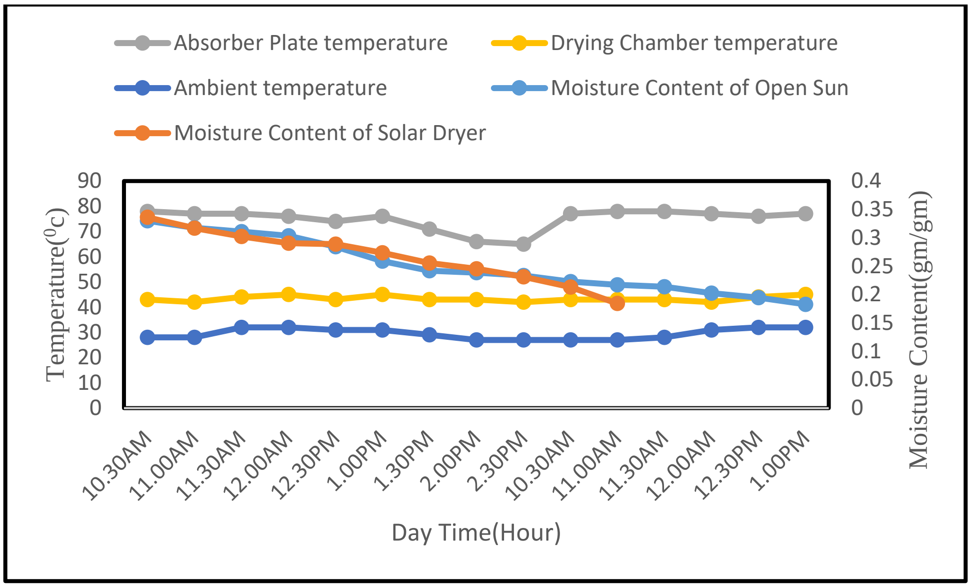


Figure4.29: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.29 shows the variation of three variables, absorber plate temperature, and drying Chamber Temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 78^{0}C and 45^{0}C respectively. When the moisture content(gm/gm) of normal paddy reaches 0.18-0.20, the normal paddy is dry. Moisture content of 500gm of normal paddy in solar dryer drying reaches 0.18 at 11.00 am and in open sun drying moisture content(gm/gm) reaches 0.18 at 1.00pm.500 gm of Normal paddy were dried in dryer 1.5 hours before open sun. The highest ambient temperature is 32^{0}C.

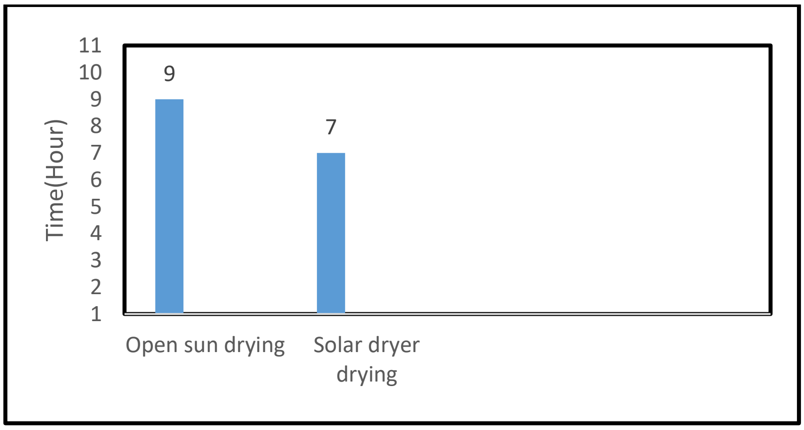


Figure4.30- Drying Time Between Open Sun Drying and Solar Dryer Drying

The drying time of paddy between open sun drying and solar dryer using CU plate (400gm PCM) at velocity 2.5 m/s is compared in Figure.4.30. The time difference between the two systems is 2 hours.

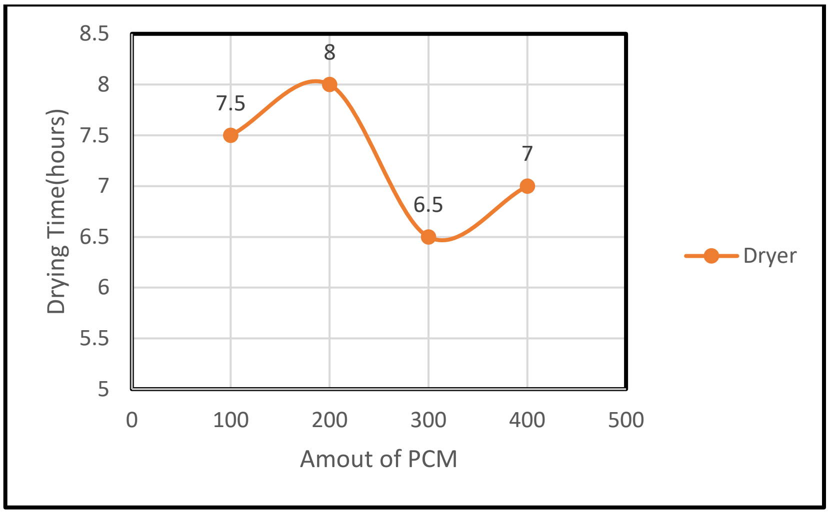


Fig4.31-Drying Time of Solar Dryer with Respect to Different Amount of PCM.

Figure 4.31 shows drying time in different amount of PCM. In 300 gm/m^2 of PCM, more moisture is carried away from the surface being dried. Dried 2 hours ago in dryer at 300 gm PCM from open sun. So it can be ideal amount to achieve the desired level of moisture removal in the shortest amount of time.

Pearson's Correlation Coefficient Calculation Data of Solar Intensity (w/m^2), Absorber Plate Temp and Drying Chamber Temp (°C): (Date-27-11-22)

Appendix C19 contains a relation between solar intensity and the temperature of the absorber plate. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.82 for solar intensity and absorber plate temperature, which is within the range of $0.75 < r_{xy} < 1$[46]. There is a very strong positive correlation between solar intensity (W/m^2) and drying chamber temperature (°C). Appendix C20 contains a relation between solar intensity and the temperature of the drying chamber temperature. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.75 for solar Intensity and drying chamber temperature, which is within the range of $0.75 < r_{xy} < 1$[46]. There is a very strong positive correlation between solar Intensity (W/m^2) and absorber plate temperature(°C).

Table 4.15: Moisture Content of Potato Using Aluminum Plate as a Solar Collector at Velocity 2.5 m/s.

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-29-11-22					
10.30AM	0.67	32	0.61	72	40
11.00AM	0.65	33	0.63	73	41
11.30AM	0.63	31	0.61	71	42
12.00AM	0.62	30	0.59	70	41
12.30PM	0.58	32	0.56	65	43
1.00PM	0.67	30	0.53	72	40
1.30PM	0.65	30	0.51	73	41
2.00PM	0.63	29	0.48	71	42
2.30PM	0.62	28	0.45	70	41
Date-30-11-22					
10.30AM	0.46	28	0.43	70	40
11.00AM	0.42	27	0.38	71	40
11.30AM	0.38	32	0.31	70	41
12.00AM	0.33	33	0.23	71	42
12.30PM	0.30	32	0.20	65	43
1.00PM	0.26	32	0.16	64	41
1.30PM	0.22	30	0.12	58	40
2.00PM	0.17	27	0.07	56	41
2.30PM	0.12	27		54	38
3.00PM	0.1	26		54	38

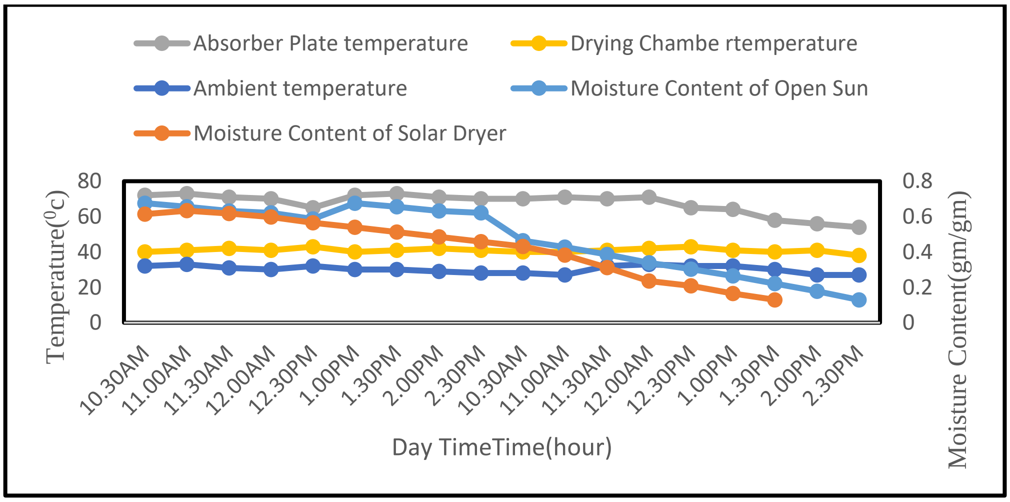


Figure4.32: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The figure 4.32 shows the variation of three variables, absorber plate temperature, and drying chamber temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 73^0c and 43^0c respectively. When the moisture content(gm/gm) of potato reaches 0.12-0.14, the potato is dry. Moisture content of 500gm of slice potato in solar dryer drying reaches 0.12 at 1.30 pm and in open sun drying moisture content(gm/gm) reaches 0.12 at2.30pm.500 gm of potato were dried in dryer 0.5 hours before open sun. The highest ambient temperature is 32^0C.

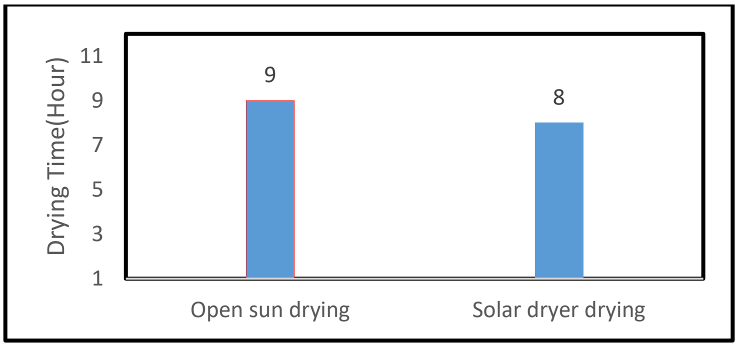


Fig4.33- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of Potato between open sun drying and solar dryer using AL plate at velocity 2.5 m/s is compared in Figure4.33. The time difference between the two systems is 0.5 hours.

Table 4.16: Moisture Content of Boil Paddy Using Aluminum Plate as a Solar Collector at Velocity 2.5 m/s.

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-29-11-22					
10.30AM	0.43	32	0.44	72	40
11.00AM	0.41	33	0.40	73	41
11.30AM	0.39	31	0.38	71	42
12.00AM	0.37	30	0.36	70	41
12.30PM	0.35	32	0.34	65	43
1.00PM	0.32	30	0.31	72	40
1.30PM	0.30	30	0.29	73	41
2.00PM	0.28	29	0.27	71	42
2.30PM	0.27	28	0.26	70	41
Date-30-11-22					
10.30AM	0.25	28	0.24	70	40

11.00AM	0.24	27	0.22	71	40
11.30AM	0.23	32	0.20	70	41
12.00AM	0.20	33	0.19	71	42
12.30PM	0.19	32	0.17	65	43
1.00PM	0.17	32		64	41

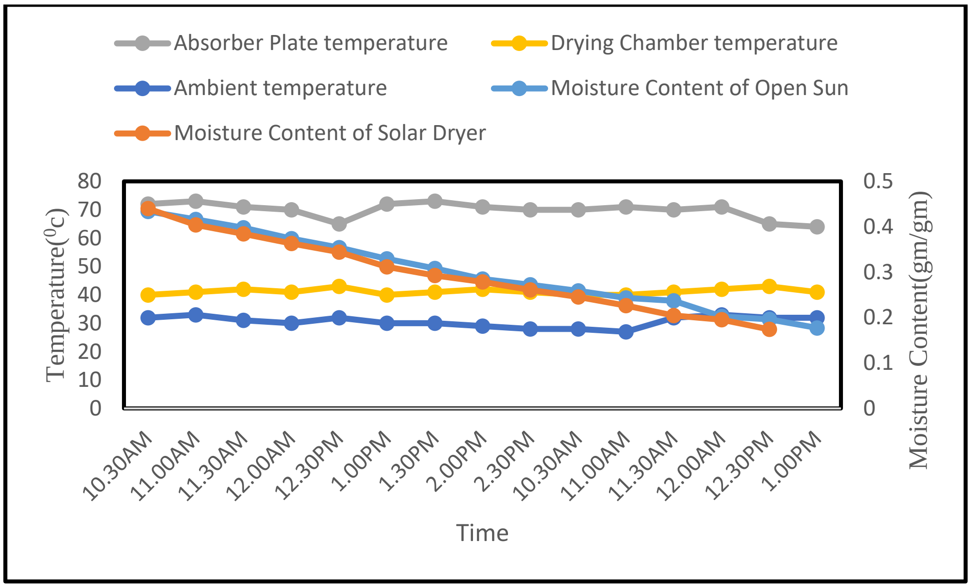


Figure4.34: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.34 shows the variation of absorber plate temperature, moisture content of boil paddy and drying chamber temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 73^0C and 43^0C respectively. When the moisture content(gm/gm) of boil paddy reaches 0.18-0.20, the boil paddy is dry. Moisture content of 500gm of boil paddy in solar dryer drying reaches 0.17 at 12.30 pm and in open sun drying moisture content(gm/gm) reaches 0.17 at 1.00pm.500 gm of boil paddy were dried in dryer 0.5 hours before open sun. The highest ambient temperature is 32^0C.

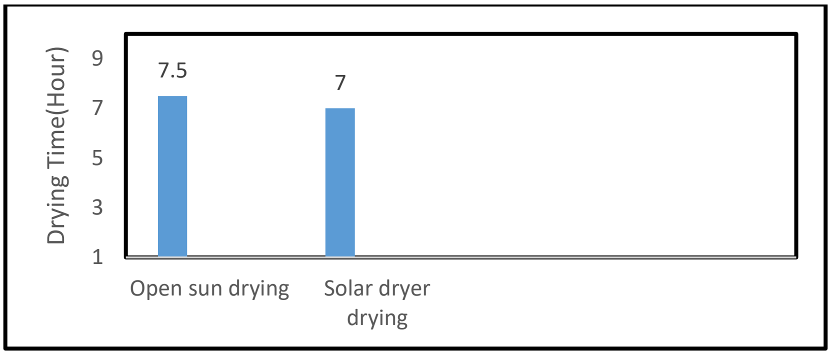


Figure 4 .35- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of boil paddy between open sun drying and solar dryer using AL plate at velocity 2.5 m/s is compared in Figure.4.35. The time difference between the two systems is 0.5 hours.

Table 4.17: Moisture Content of Normal Paddy Using Aluminum Plate as a Solar Collector at Velocity 2.5 m/s.

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-29-11-22					
10.30AM	0.33	32	0.34	72	40
11.00AM	0.31	33	0.31	73	41
11.30AM	0.31	31	0.30	71	42
12.00AM	0.29	30	0.29	70	41
12.30PM	0.28	32	0.28	65	43
1.00PM	0.26	30	0.27	72	40
1.30PM	0.25	30	0.26	73	41
2.00PM	0.23	29	0.25	71	42
2.30PM	0.23	28	0.22	70	41
Date-30-11-22					
10.30AM	0.22	28	0.21	70	40
11.00AM	0.21	27	0.19	71	40
11.30AM	0.21	32		70	41
12.00AM	0.19	33		71	42

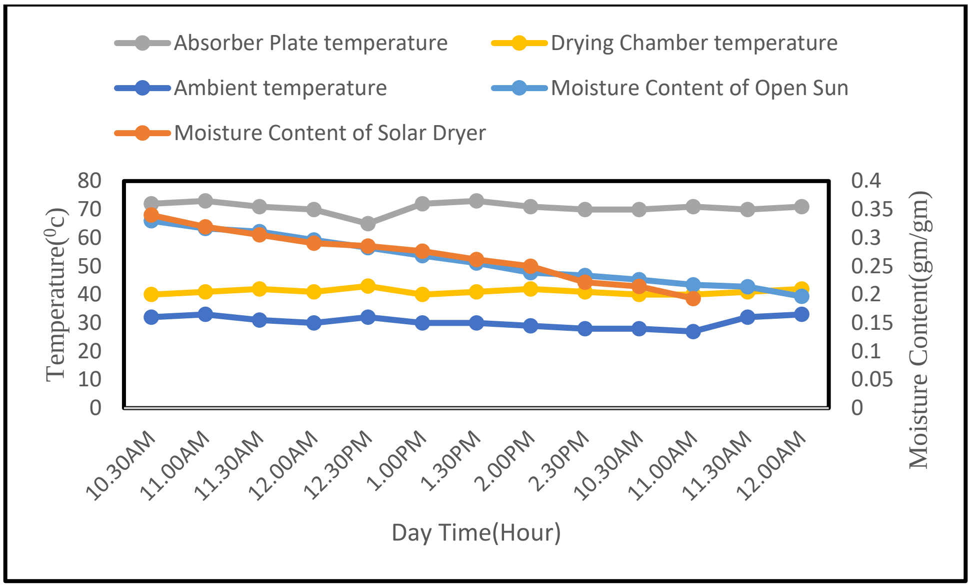


Figure4.36: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The fig.4.36 shows the variation of absorber plate temperature, moisture content and drying chamber temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 73^0c and 43^0c respectively. When the moisture content(gm/gm) of normal paddy reaches 0.18-0.20, the potato is dry. Moisture content of 500gm of normal paddy in solar dryer drying reaches 0.19 at 11.00 am and in open sun drying moisture content(gm/gm) reaches 0.19 at 12.00am.500 gm of normal paddy were dried in dryer 1 hours before open sun. The highest ambient temperature is 33^0C.

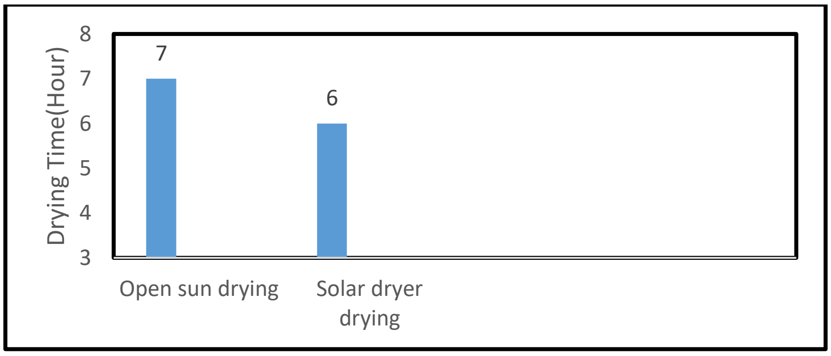


Figure4.37- Drying Time Between Open Sun Drying and Solar Dryer Drying. The drying time of normal paddy between open sun drying and solar dryer using AL plate at velocity 2.5 m/s is compared in Figure.4.37. The time difference between the two systems is 1 hours.

Pearson's Correlation Coefficient Calculation Data of Solar Intensity (w/m^2), Absorber Plate Temp and Drying Chamber Temp (°C): (Date-04-12-22)

Appendix C21 contains a relation between solar intensity and the temperature of the absorber plate. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.77 for solar intensity and absorber plate temperature, which is within the range of 0.75< $r_{x\,y}$ <1[46]. There is a very strong positive correlation between solar intensity (W/m^2) and drying chamber temperature (°C). Appendix C22 contains a relation between solar intensity and the temperature of the drying chamber temperature. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.88 for solar Intensity and drying chamber temperature, which is within the range of 0.75< $r_{x\,y}$ <1[46]. There is a very strong positive correlation between solar Intensity (W/m^2) and absorber plate temperature(°C).

Table 4.18: Moisture Content of Potato Using Aluminum Plate as a Solar Collector at Velocity 2.5 m/s. (300gm/m^2 PCM)

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content (gm/gm)**	**Ambient temperature(°C)**	**Moisture Content (gm/gm)**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-4-12-22					
10.30AM	0.67	27	0.66	75	43
11.00AM	0.65	28	0.63	74	44
11.30AM	0.63	32	0.61	74	43
12.00AM	0.61	31	0.59	71	42
12.30PM	0.58	32	0.56	70	42
1.00PM	.57	30	0.53	72	43
1.30PM	0.55	26	0.50	68	42
2.00PM	0.51	27	0.48	67	42
2.30PM	0.49	26	0.46	68	41
Date-5-12-22					
10.30AM	0.46	28	0.43	74	42
11.00AM	0.42	30	0.38	74	44
11.30AM	0.39	28	0.32	71	42
12.00AM	0.33	31	0.23	72	42
12.30PM	0.30	33	0.21	70	40
1.00PM	0.27	32	0.17	71	42
1.30PM	0.19	31	0.12	73	41
2.00PM	0.15	30		69	44
2.30PM	0.14	27		70	43
3.00PM	0.13	27		69	42

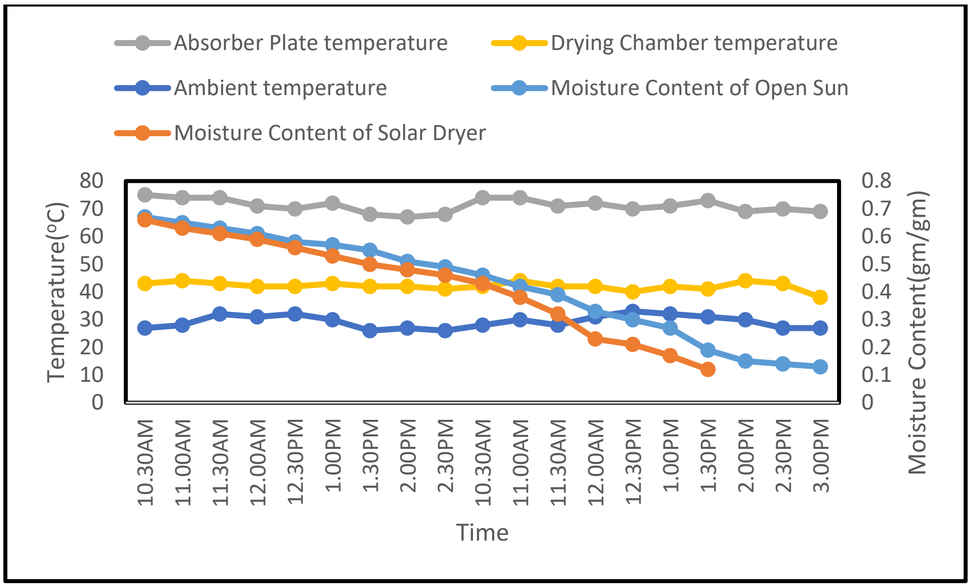
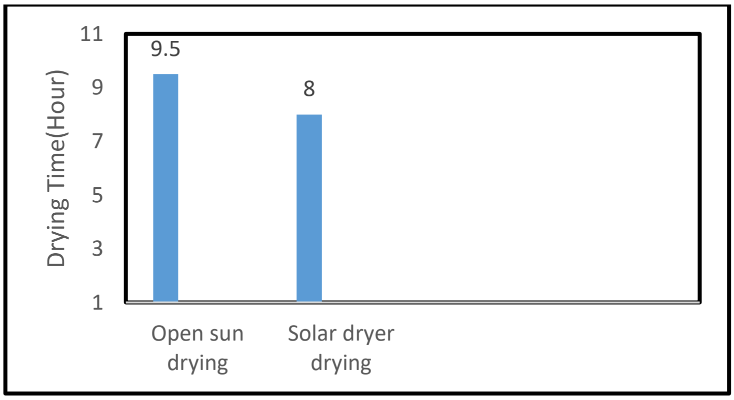


Figure4.38: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.38 shows the variation of ambient temperature, absorber plate temperature, moisture content and Drying Chamber Temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 75^0c and 44^0c respectively. When the moisture content(gm/gm) of potato reaches 0.12-0.14, the potato is dry. Moisture content of 500gm of slice potato in solar dryer drying reaches 0.12 at 1.30 pm and in open sun drying moisture content(gm/gm) reaches 0.13 at 2.30pm.500 gm of potato were dried in dryer 1 hours before open sun. The highest ambient temperature is 33^0C.



Figur4.39- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of potato between open sun drying and solar dryer using AL plate (300gm PCM) at velocity 2.5 m/s is compared in Figure.4.39. The time difference between the two systems is 1 hours.

Table 4.19: Moisture Content of Boil Paddy Using Aluminum Plate as a Solar Collector at Velocity 2.5 m/s. (300gm/m^2 PCM)

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content**	**Ambient temperature(°C)**	**Moisture Content**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-4-12-22					
10.30AM	0.43	27	0.43	75	43
11.00AM	0.41	28	0.40	74	44
11.30AM	0.39	32	0.38	74	43
12.00AM	0.37	31	0.36	71	42
12.30PM	0.34	32	0.34	70	42
1.00PM	0.33	30	0.30	72	43
1.30PM	0.31	26	0.28	68	42
2.00PM	0.29	27	0.27	67	42
2.30PM	0.27	26	0.25	68	41
Date-5-12-22					
10.30AM	0.25	28	0.24	74	42
11.00AM	0.24	30	0.22	74	44
11.30AM	0.23	28	0.20	71	42
12.00AM	0.21	31	0.19	72	42
12.30PM	0.20			70	40
1.00PM	0.19			71	42

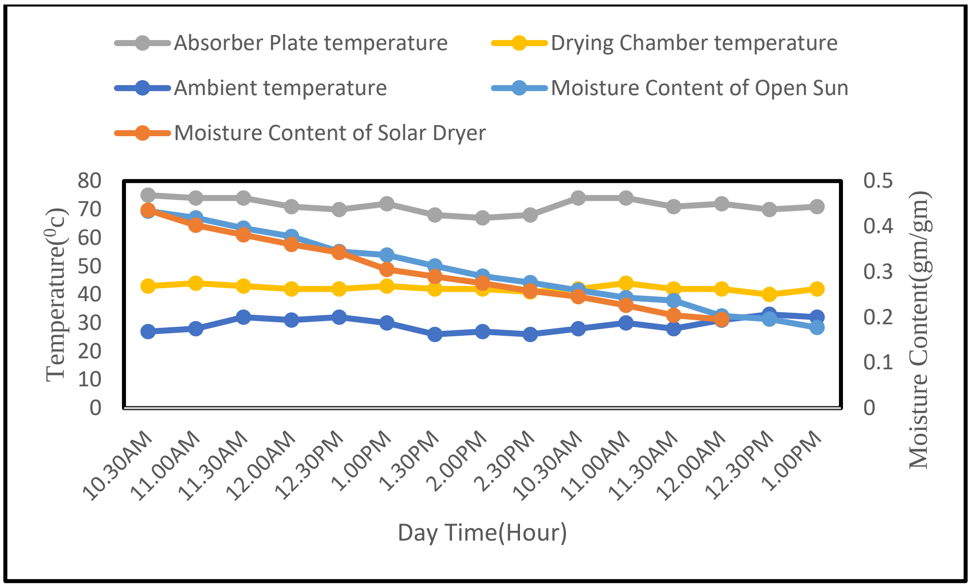


Figure4.40: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure 4.40 shows the variation of absorber plate temperature, ambient temperature, moisture content of and drying chamber temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 75^0c and 44^0c respectively. When the moisture content(gm/gm) of boil paddy reaches 0.18-0.20, the boil paddy is dry. Moisture content of 500gm of boil paddy in solar dryer drying reaches 0.10 at 12.00 am and in open sun drying moisture content(gm/gm) reaches 0.19 at 1.00pm.500 gm of boil paddy were dried in dryer 1 hours before open sun.

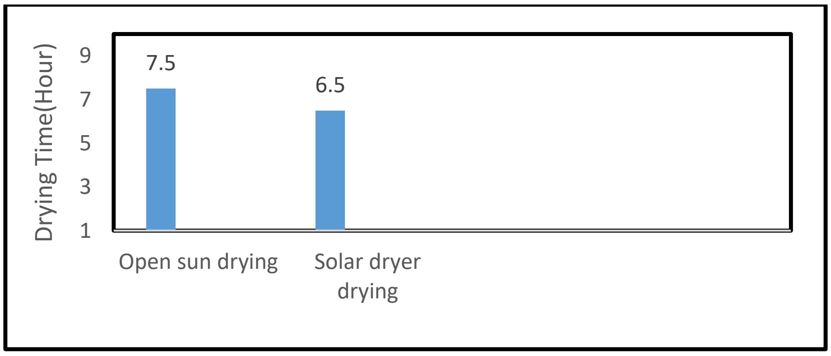


Fig4.41- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of boil paddy between open sun drying and solar dryer using AL plate

(300gm PCM) at velocity 2.5 m/s is compared in Figure.5.41. The time difference between the two systems is 1 hours.

Table 4.20: Moisture Content of Normal Paddy Using Aluminum Plate as a Solar Collector at Velocity 2.5 m/s. (300gm/m^2 PCM)

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content**	**Ambient temperature(°C)**	**Moisture Content**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-4-12-22					
10.30AM	0.33	27	0.33	75	43
11.00AM	0.31	28	0.31	74	44
11.30AM	0.31	32	0.30	74	43
12.00AM	0.30	31	0.291	71	42
12.30PM	0.28	32	0.28	70	42
1.00PM	0.27	30	0.27	72	43
1.30PM	0.25	26	0.25	68	42
2.00PM	0.23	27	0.24	67	42
2.30PM	0.22	26	0.23	68	41
Date-5-12-22					
10.30AM	0.22		0.21	74	42
11.00AM	0.21		0.18	74	44
11.30AM	0.21			71	42
12.00AM	0.19			72	42
12.30PM	0.18			70	40
1.00PM	0.16			71	42

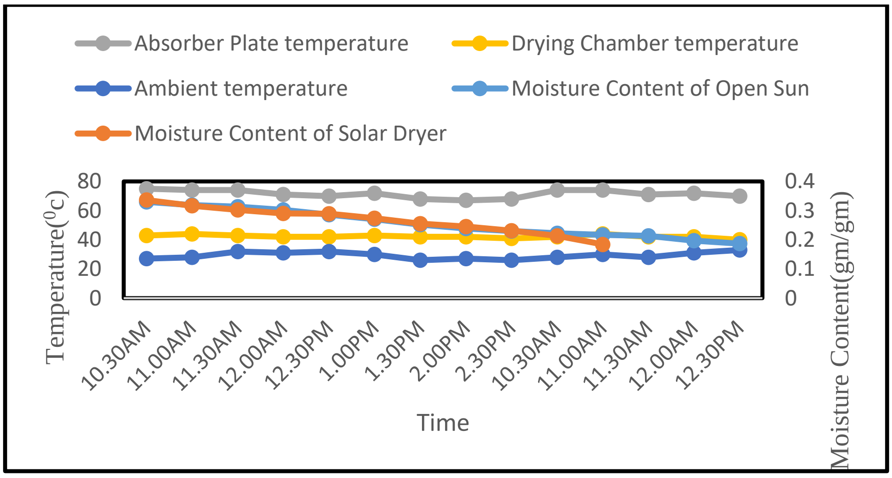


Figure4.42: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure4.42 shows the variation of ambient temperature, absorber plate temperature, moisture content and drying chamber temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 75^0c and 44^0c respectively. When the moisture content(gm/gm) of normal paddy reaches 0.18-0.20, the potato is dry. Moisture content of 500gm of slice potato in solar dryer drying reaches 0.18 at 11.00 am and in open sun drying moisture content(gm/gm) reaches 0.18 at 12.30pm.500 gm of normal paddy were dried in dryer 1 hours before open sun.

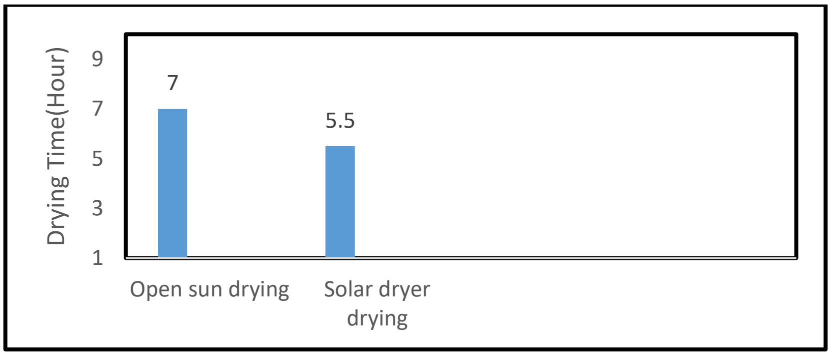


Fig4.43- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of potato between open sun drying and solar dryer using AL plate (300gm PCM) at velocity 2.5 m/s is compared in Figure4.43. The time difference between the two systems is 1.5 hours.

Pearson's Correlation Coefficient Calculation Data of Solar Intensity (w/m^2), Absorber Plate Temp and Drying Chamber Temp (°C): (Date-27-11-22)

Appendix C25 contains a relation between solar intensity and the temperature of the absorber plate. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.97 for solar intensity and absorber plate temperature, which is within the range of $0.75 < r_{x\,y} < 1$[46]. There is a very strong positive correlation between solar intensity (W/m^2) and drying chamber temperature (°C). Appendix C26 contains a relation between solar intensity and the temperature of the drying chamber temperature. The experimental result has been verified by Pearson's Correlation Coefficient, r_{xy} is found to be 0.95 for solar Intensity and drying chamber temperature, which is within the range of 0.75< $r_{x\,y}$ <1[46]. There is a very strong positive correlation between solar Intensity (W/m^2) and absorber plate temperature(°C).

Table 4.21: Moisture Content of Potato Using Galvanized Sheet as a Solar Collector at Velocity 2.5 m/s.

Open Sun Drying			Solar Dryer Drying		
Time	**Moisture Content**	**Ambient temperature(°C)**	**Moisture Content**	**Absorber plate temperature (°C)**	**Drying chamber temperature (°C)**
Date-6-12-22					
10.30AM	0.67	28	0.67	44	33
11.00AM	0.65	29	0.64	43	32
11.30AM	0.63	28	0.63	42	32
12.00AM	0.61	30	0.61	44	33
12.30PM	0.58	29	0.58	42	31
1.00PM	0.56	30	0.55	41	31
1.30PM	0.54	28	0.54	40	30
2.00PM	0.50	27	0.50	40	31
2.30PM	0.49	27	0.48	41	30
Date-7-12-22					
10.30AM	0.45	29	0.45	43	32
11.00AM	0.42	29	0.42	42	33
11.30AM	0.39	27	0.39	41	32
12.00AM	0.33	28	0.32	43	34
12.30PM	0.29	30	0.28	42	32
1.00PM	0.25	31	0.24	41	31
1.30PM	0.18	28	0.16	41	31
2.00PM	0.14	27	0.13	41	31
2.30PM	0.12	28	0.11	41	30

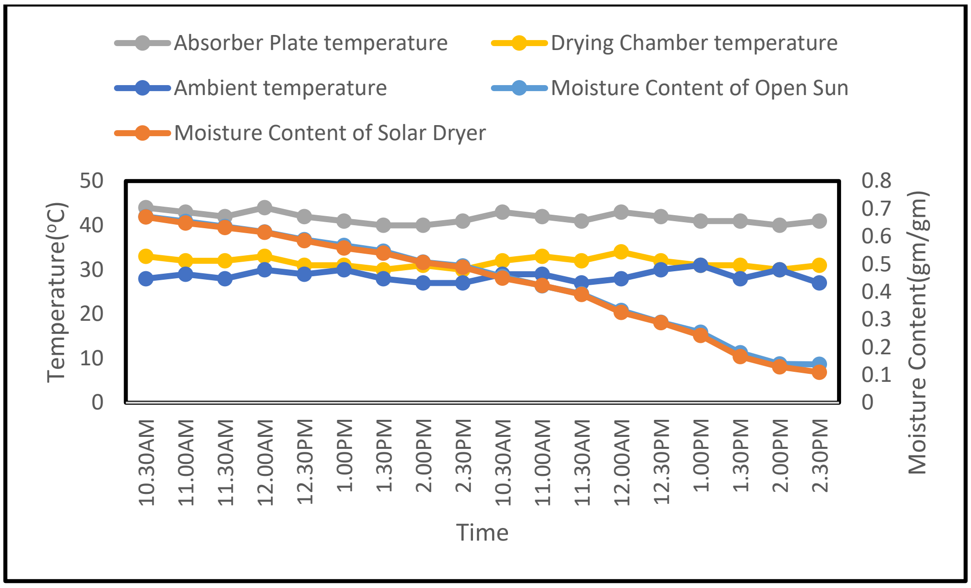


Figure4.44: Absorber Plate Temperature, Drying Chamber Temperature and Moisture Content Variation with Respect to Daytime.

The Figure.5.44 shows the variation of ambient temperature, moisture content absorber plate temperature, and drying chamber temperature, with respect to daytime. The highest value of absorber plate temperature and drying chamber temperature are 44^{0}c and 33^{0}c respectively. When the moisture content(gm/gm) of potato reaches 0.12-0.14, the potato is dry. Moisture content of 500gm of slice potato in solar dryer drying reaches 0.10 at 2.30 pm and in open sun drying moisture content(gm/gm) reaches 0.12 at 2.30pm. There has no time difference between open sun drying and dryer.

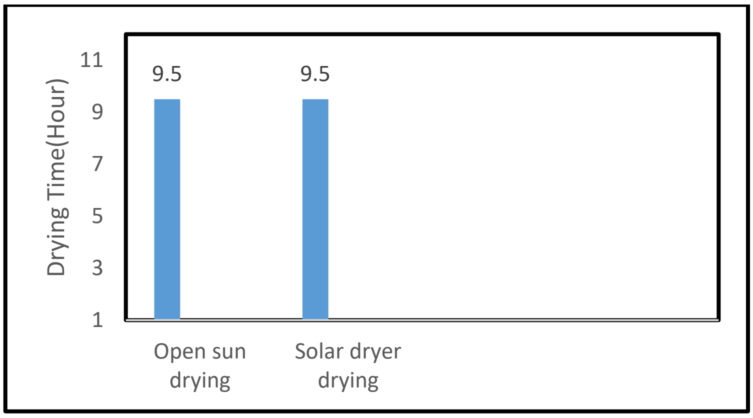


Figure4.45- Drying Time Between Open Sun Drying and Solar Dryer Drying.

The drying time of potato between open sun drying and solar dryer using GI sheet at velocity 2.5 m/s is compared in Figure.5.45. There has no time difference between open sun drying and dryer.

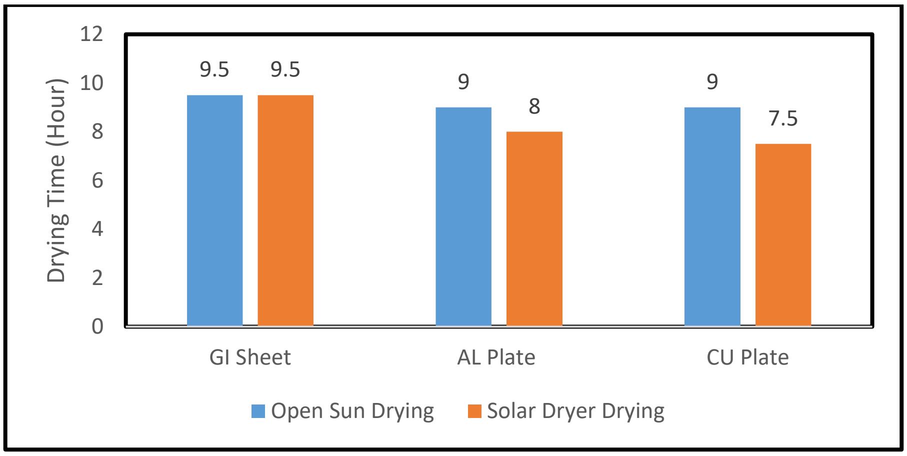


Figure 4.46: Compare Drying Time Between Open Sun drying and Solar Dryer Drying by Using Three Collector Plate.

Figure 4.46 drying time of three collector plate. When use copper plate as a solar collector on solar dryer then it took less time to dry potato than other plate. The time difference between open sun drying and solar dryer using copper plate is 1.5 hours.

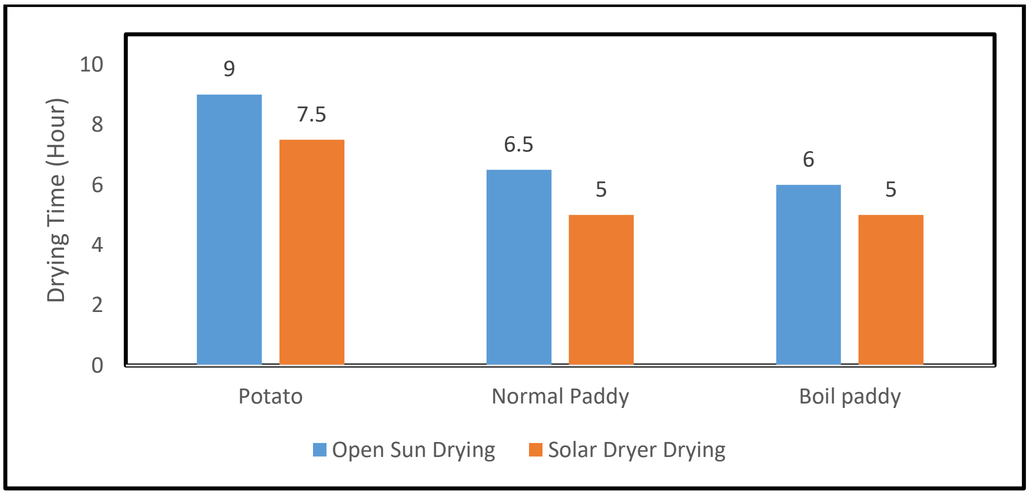


Figure 4.47: Drying Time of Three Food Crops.

Figure 4.47 Shows drying time of three food corps. Drying time of potato in solar dryer is 7.5 hours. Drying time of normal paddy and boil paddy in solar dryer are 5 hours. The moisture content of potato is higher than paddy, so it takes longer time to dry than paddy. Paddy takes 4-26 h [46] of drying during the dry season, drying time vary by varying mass of product. P.P. Tripathy [48] found drying time of 500gm potato of 6 hours.

Table 4.22: Collector Efficiency of Different Collector Plate.

	m_a (kg/s)	C_{pa} (kJ/kg K)	ρ (kg/m^3)	T_i (^{0}C)	T_0 (^{0}C)	T_c (^{0}C)	A_c (m^2)	I_g (kw/m^2)	η_c %
Copper Plate	0.0048	1.005	1.06	36	80	45	1	1.01	21
Aluminum Plate				33	73	41		1.07	18
Galvanized Sheet				28	44	33		0.800	9.6
Copper Plate with PCM				27	82	47		1.040	25
Aluminum Plate with PCM				27	75	43		1.10	21

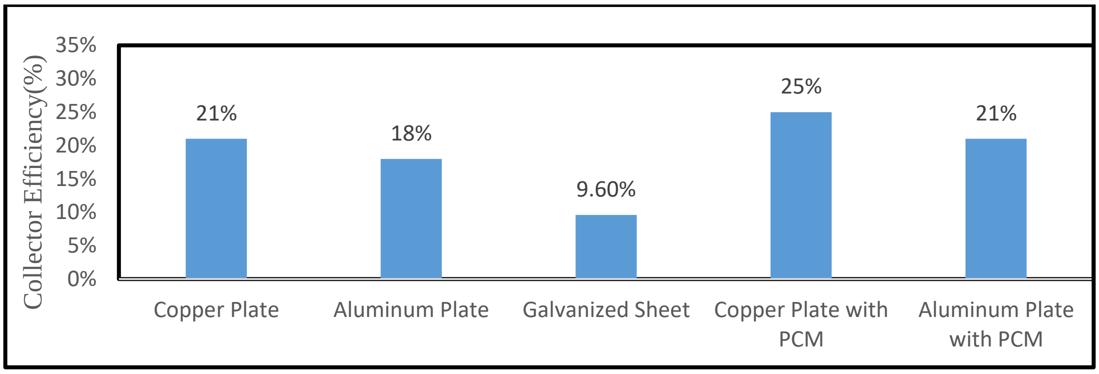


Figure 48: Collector Efficiency of Different Plate.

Figure48 shows the collector efficiency of different plate. The maximum efficiency of copper plate with PCM is 25% and minimum efficiency galvanized sheet is 9.60%. Abhay lingayat, et al. (2016) [49] found the collector efficiency of copper plate with PCM is 31.5%. May be due to lack of proper insulation we have got efficiency 25%.

Table 4.23: Drying Efficiency of Different Collector Plate.

	T_o	T_i (^{0}C)	T_c (^{0}C)	Humidity %	W_o	W_a	m_w (kg/s)	l_v (Kj/Kg)	η_d %
Copper Plate	80	36	45	15	0.065	0.047	0.000086	210	8.5
Aluminum Plate	73	33	41	15	0.052	0.034	0.0000864	162	7
Galvanized Sheet	44	28	33	46	0.033	0.031	0.0000096	113	1.4
Copper Plate with PCM	82	27	47	10	0.071	0.033	0.0001824	210	14.4
Aluminum Plate with PCM	75	27	43	10	0.058	0.024	0.0001632	184	12.9

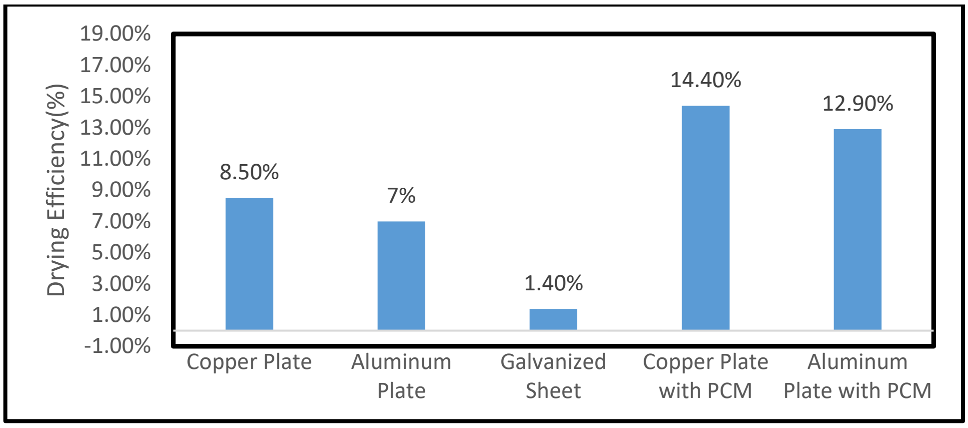


Figure49: Drying Efficiency of Different Plate.

Figure 49 shows the drying efficiency by different plate. The maximum drying efficiency of copper plate with PCM is 14.40 % and minimum efficiency galvanized sheet is 1.40%. The drying efficiency with energy storage are in the range of 2.85−42% [50] for various food materials.

Table 4.24: Proximate Composition of Dried Potato.

Component	Dryer Drying	Open Sun Drying	Standard Value	Ref
Moisture (%)	12.71	11.43	13	[51]
Protein (%)	7.79	6.66	6.58-14.12	[51]
Crude Fiber (CF) (%)	5.78	4.04	3-6	[52]
Crude Fat (EF) (%)	Nil	Nil		
Ash (%)	1.86	1.33	1-3	[52]

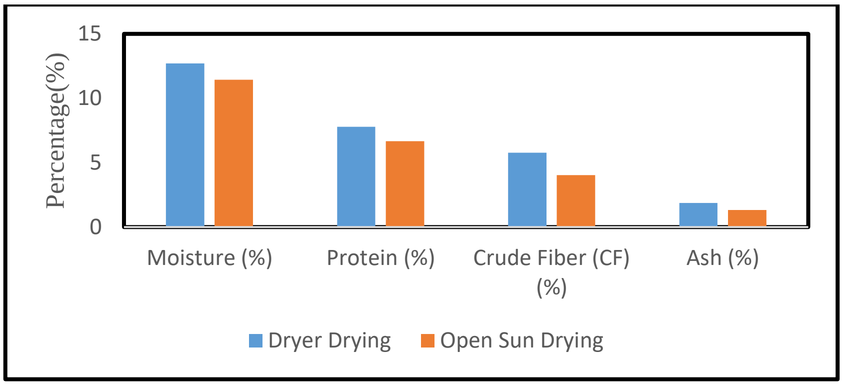


Figure 50: Proximate Composition of Potato.

The Table 4.24 and Figure 50 shows the proximate composition of potato protein, crude fiber, ashes are found such as (12.71%, 7.79%, 5.78%, 1.86% respectively) for dryer drying and (11.43%, 6.66%,4.04% and 1.33% respectively) for open sun drying but Protein 7.79 %, and Crude Fiber (CF) 5.78% was found higher than open sun drying. In case of potato, the maximum proximate compositions were found better values when product dry on dryer.

Table 4.25: Proximate Composition of Dried Boil Paddy.

Component	**Dryer Drying**	**Open Sun Drying**	**Standard Value(Mohamaya Paddy)**	**Ref**
Moisture (%)	10.29	11.22	16	[53]
Protein (%)	8.01	7.81	6.73	[53]
Crude Fiber (CF) (%)	12.72	12.63	3.74	[53]
Crude Fat (EF) (%)	3.42	2.25	3.62	[53]
Ash (%)	2.63	3.23	1.04	[53]

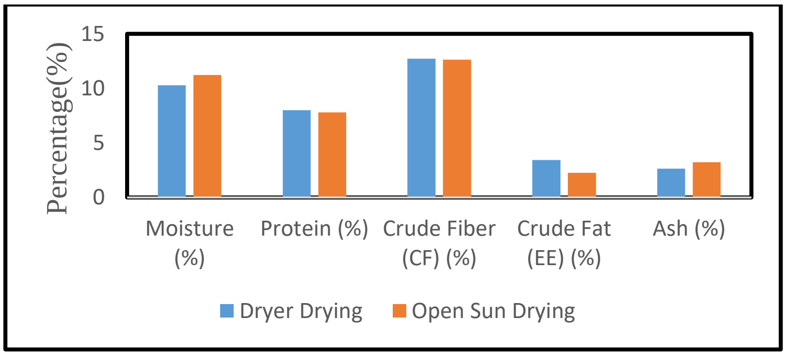


Figure 51: Proximate Composition of Boil Paddy.

The Table 4.25 and Figure 51 shows the proximate composition of potato protein, crude fiber, crude fat, ashes are found such as (10.29%, 8.01%, 12.72%,3.42% and 2.63 % respectively) for dryer drying and (11.22 %, 7.81%,12.63%,2.25% and3.23%respectively) for open sun drying but Protein 8.01 %, and Crude Fiber (CF) 12.72 % was found higher than open sun drying. In case of boil paddy, the maximum proximate compositions were found better values when product dry on dryer.

Table 4.26: Proximate Composition of Dried Normal Paddy.

Component	Dryer Drying	Open Sun Drying
Moisture (%)	10.81	10.29
Protein %	7.93	7.79
Crude Fiber (CF) (%)	14.23	13.73
Crude Fat (EF) (%)	3.33	2.08
Ash (%)	3.82	4.18

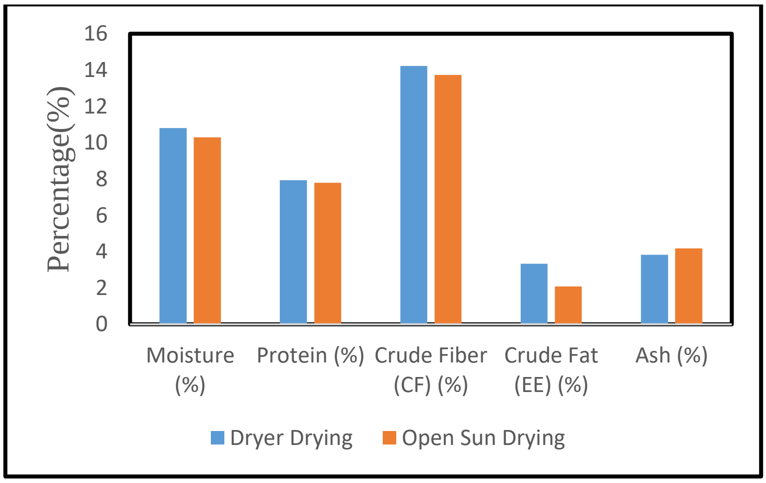


Figure 52: Proximate Composition of Boil Paddy.

The Table 4.26 and Figure 52 shows the proximate composition of potato protein, crude fiber, crude fat, ashes are found such as (10.81%, 7.93%, 14.23%,3.33% and 3.82 % respectively) for dryer drying and (10.29 %, 7.79%,13.73%,2.08% and 4.18%respectively) for open sun drying but Protein 7.79 %, and Crude Fiber (CF) 13.73 % was found higher than open sun drying. In case of boil paddy, the maximum proximate compositions were found better values when product dry on dryer.

Table 4.27: Multiple Correlation Regression Model for Drying Time, Amount of PCM, Air Velocity and Drying Temperature(^{0}C).

Model No.	Form of Equation	Equation constants		Multiple R	R Square	Adjusted R Square
		m_i	k_1			
1	$(F_{dt}) = m_1 A_{PCM} + k_1$	m_1= 0.0025	1	0.6742	0.654545	0.4235
F_{dt}=1+0.0025 $A_{,PCM}$						
2	$(F_{dt}) = m_1 A_v + k_1$	m_1= 0.76087	-0.75	0.7298	0.632609	0.598913
F_{dt}=0.75-0.0025 A_v						
3	$(F_{dt}) = m_{1Tdtem.} + k_1$	m_1= 0.35	-13.25	0.94388	0.890909	0.836364
F_{dt}=13.75-0.35 T_{dtem}						
4	$(F_{dt}) = m_1 A_{,PCM} + m_1 A_v + m_1 T_{dtem.} + K_1$	m_1=0.008125; m_2=2.5; m_3=0.312;	-7.9375	0.74388	0.690909	0.536364
(F_{dt})= 7.9375-0.008125$A_{,PCM}$+2.5$_1 A_v$ + 0.3125T_{dtem}						

Regression Analysis of Drying Time, Amount of PCM, Air Velocity and Drying Temperature(deg.)

Based on experimental data as shown in table 4.27, the four different correlation models were developed using regression method which are: i) model 1- correlation between drying time and amount of phase change material; ii) model 2- correlation between drying time and air velocity; iii) model 3- correlation between drying time and drying temperature; iv) model 4- correlation among drying time and amount of phase change material, air velocity, drying time. A total of 4 tests run were performed per regression model. The R square, adjusted R square of the corresponding regression model are given in table 4.27 In model 1, R^2 value was found 0.654545. It is seen that the values of R square and adjusted R^2 were 0.654545and 0.632609, respectively, these values were very close which can be claimed that it was a perfect relationship between the drying time and amount of PCM.

Similarly, model-2, model-3, model-4, shows a perfect relationship between the dependent and independent variables because the correlation R-square values 63.26%, 89.09%and, 69.09% for model 2, 3, and 4 respectively were tending towards 1. From these results it can be said that the proposed regression model has maintained a good correlation between dependent variable (drying time) and independent variable (amount of phase change material, Air velocity, Drying temperature) from the experimental data. The relation among drying time, amount of PCM, air velocity and drying temperature(deg.) is (F_{dt})= 7.9375-0.008125$A_{,PCM}$+2.5$_1A_v$ + 0.3125T_{dtem}

Table 4.28: Multiple Correlation Regression Model for Drying Chamber Temperature(^{0}C), Absorber Plate Temperature(^{0}C) and Solar Intensity.

Model No.	Form of Equation	Equation constants		Multiple R	R Square	Adjusted R Square
		m_i	k_1			
1	$(F_{dct}) = m_1 t_{APT} + k_1$	m_1= 0.438213	11.40494	0.902542	0.814581	0.788093
F_{dct} =11.40494+0.438213t_{APT}						
2	$(F_{dct}) = m_1 S_i + k_1$	m_1= 0.011631	33.62666	0.949508	0.901566	0.887504
F_{dct} =33.62666+0.011631S_i						
3	$(F_{dct}) = m_1 t_{APT} + m_1 S_{i+} k_1$	m_1= 0.012944 m_2= -0.05424	36.49229	0.950026	0.902549	0.870066
F_{dct} = 36.49229+0.012944t_{APT} -0.05424 S_i						

Regression Analysis of drying chamber temperature, amount of phase change material, solar intensity and solar intensity.

Based on experimental data as shown in table 4.28, the three different correlation models were developed using regression method which are: i) model 1- correlation between drying chamber temperature and absorber plate temperature; ii) model 2- correlation between drying chamber temperature and solar intensity; iii) model 3- correlation among drying chamber temperature and absorber plate temperature, solar intensity. A total of 3 tests run were performed per regression model. The R square, adjusted R square of the corresponding regression model are given in table4.25 In model 1, R^2 value was found 0.814581. It is seen that the values of R square and adjusted R^2 were 0.8145815and 0.901566, respectively, these values were very close which can be claimed that it was a perfect relationship between drying chamber temperature and absorber plate temperature.

Similarly, model-2, model-3, shows a perfect relationship between the dependent and independent variables because the correlation R-square values 90.15% and 90.25% for model 2and 3respectively were tending towards 1. From these results it can be said that the proposed regression model has maintained a good correlation between dependent variable (drying chamber temperature) and independent variable (amount of phase change material, solar intensity, solar intensity) from the experimental data. The relation among analysis of drying chamber temperature, amount of phase change material, solar intensity and solar intensity is F_{dct} = 36.49229+0.012944t_{APT} -0.05424 S_i.

Summary of Research Regarding Solar Dryer

Year	Type of Dryer	Thermal energy storage material	Product	Findings	Limitations	Ref
2021	Indirect forced convection solar drier	----------	Potato	Protein=6.36% Fiber=4.92%	--------------	[41]
2020	Indirect forced convection solar drier	Granite grits	Paddy	Drying time was 7 hours	Heat storage effect absence in off sunlight. No proximate test of product	[42]
2018	Solar greenhouse dryer	Concrete, Sand, and Rock-bed	Paddy	Using concrete, sand, and rock-bed, respectively, it was discovered that the dryer's Drying efficiency was 9.5%, 11% and 11.65%.	No proximate test of product	[43]
2014	Natural Convection Type Solar Dryer	Paraffin wax	Ginger	The collector efficiency of the solar dryer was found to be 22.7%	No proximate test of product	[44]

2007	Hybrid solar dryer	-----------	Mushrooms	Drying efficiency found 10%	No proximate test of product	[45]
2006	Indirect forced convection	Paraffin wax	Potato	Collector plate temperature increases 3-5 0C by using PCM.	Dryer run only one air velocity.	[46]

Year	Type of Dryer	Product	Thermal energy storage material	Findings
Proposed Method 2023	Indirect forced convection	Potato, Boil paddy, Normal Paddy	Paraffin wax	• Protein=7.79% Fiber=5.78% • Drying efficiency 14.40% Collector efficiency 25% • Collector plate temperature increases 3-8 0C by using PCM • Dryer run at different 4 air velocity. • Dryer run at different 3 collector plate • Dryer run at different 4 amount of PCM • Drying time of potato was 7.5 hours • Drying time of boil paddy 5 hours • Drying time of normal paddy 5 hours

CHAPTER 5

CONCLUSION AND RECOMENDATION

5.1 CONCLUSION:

This thesis book has explored the performance and potential benefits of solar crop dryer. The research presented in this thesis has shed light on the importance of sustainable and efficient drying methods. Through extensive literature review, experiment investigations, and data analysis, this thesis has demonstrated that solar dryer are a promising technology with numerous advantages. Solar dryers have been shown to reduce drying time and improve the overall quality of dried products. The thesis has examined various aspects of solar crop dryer including solar collector technologies, airflow management, integration of PCMs, and proximate analysis of products. The thermal energy stored in the PCM during sunlight hours can be utilized during periods of low solar radiation, allowing for continuous and uninterrupted drying operations. This can result in improved product quality, reduced drying time, and enhanced overall system performance.

The product dries faster in a solar dryer when the Copper plate is used as a solar collector. This happens due to the thermal conductivity of copper plate is higher than aluminum and galvanized iron sheet. Open sun drying took 1.5 hours longer to dry than using the experimental solar dryer. The air circulation system helps to distribute the heated air evenly around the food material, promoting efficient drying. Crops dry faster at 2.5 m/s air velocity because this air velocity absorbed better moisture. Paraffin waxes are used as a phase change material (PCM) in this research experiment. When 300 gm/m^2 of phase change material (PCM) is used as a heat storage medium then it takes the least drying time than other amounts of phase change material (PCM).

The maximum collector efficiency of copper plate solar collector and with PCM were found 21% and 25% respectively. The highest drying efficiency with copper plate solar collector and with PCM were determined to be 8.5% and 14.4%, respectively. Proximate analysis (Moisture, Protein, Crude Fiber (CF), Crude Fat (EF), Ash) is done to check the quality of the product. The value of proximate analysis was found to be better in the dryer than the open sun.

The co-relation among the drying chamber temperature, absorber plate temperature, and solar intensity is (F_{dct}) = 36.49229+0.012944t_{APT} -0.05424 S_i. The co-relation among drying time, amount of PCM, air velocity and drying chamber temperature is (F_{dt})= 7.9375-0.008125W_{PCM}+2.51A_v+0. 3125Tdtem.Pearson's Correlation coefficient was found within the range (0.76-0.98) for all cases.

5.2 RECOMMENDATION:

Use of PCM in the solar dryer system reduced the drying time, and improved the quality of the dried products. The use of renewable energy sources like solar power for drying decrease greenhouse gas emissions. The combination of PCM and solar energy can lead to sustainable and eco-friendly drying practices, which can benefit farmers, food industries, and the environment.

REFERENCE

[1] Mondal MAH. Implication of renewable energy technologies in the Bangladesh power sector: Long term planning strategies, Ph.D. thesis, Center for Development Research (ZEF). Germany: University of Bonn; 2010.

[2] Jilani T, Gomi K, Matsuoka Y. Integration of sustainable and low carbon society towards 2025 in Bangladesh, in: international conference on climate change effects and energy development in Bangladesh, Germany; July 2011.

[3] Ahmed AU. Bangladesh climate change impact and vulnerability: a synthesis. Department of Environment and Forestry, Government of Bangladesh; 2006.

[4] Islam T, Neelim A. Assessing fluctuations of temperature, in climate change in Bangladesh: a closer look into temperature and rainfall data. Bangladesh: The University Press Limited; 80

[5] Rahman, A, Alam, M, Mainuddin, K, Ali, L, Alauddin, SM, Rabbani, M.G.et al. The probable impacts of climate change on poverty and economic growth and the options of coping with adverse effect of climate change in Bangladesh,

[6] Ayyappan and Mayilsamy, 'Experimental investigation on asolar tunnel drier for copra drying' Journal of Scientific &Industrial Research Vol.69, pp 635 – 638, 2010.

[7] Emily F. Shanahan et al, 'Evaluation of Pathogen Removal in a Solar Sludge Drying Facility Using Microbial Indicators' International Journal of Environmental Research and Public Health,7,565-582, 2010

[8] M.Veerakumar1, KCK.Vijayakumar2, P.Navaneethakrishnan3 Different Drying Methods for Agriculture Products and Eatables – A Review International Journal of Mathematical Sciences and Engineering (IJMSE), December 2014 ISSN 2278 – 1447 Volume – 3, Issue-2

[9] Kazem**, Miqdam T Chaichan* and Hussein A. Using Aluminium Powder with PCM (Paraffin Wax) to Enhance Single Slope Solar Water Distiller Productivity in Baghdad – Iraq Winter Weathers. 2015, Vol. 5.

[10] Suhanyaa S. Magendran a, Fahad Saleem Ahmed Khan a, N.M. Mubarak a,∗, Mahesh Vaka b,. Synthesis of organic phase change materials (PCM) for energy storage applications: A review. 2019

[11] Bal L.M., Satya S. and Naik S.N., 2010, Solar dryer with thermal energy storage systems for drying agricultural food products: A review, Renewable and Sustainable Energy Reviews 14,2298–2314.

[12] Riffat S. Mempouoa B and Fangb W.,2013; Phase change materialdevelopments: A Review, International Journal of Ambient Energy.

[13] Hale DV, Hoover MJ, and O'Neill MJ.,1971; Phase change materials hand book, Alabaa Marshal Space Flight Center.

[14] Paris, J., Falardeau, M., & Villeneuve, C. (1993). Thermal storage by latent heat: a viable option for energy conservation in buildings. Energy Sources, 15(1), 85–93.

[15] Abhat, A. (1983). Low temperature latent heat thermal energy storage: Heat storage materials. Solar Energy, 30(4), 313– 332.

[16] Dincer, I., & Rosen, M. (2002).Thermal energy storage: systems and applications. John Wiley & Sons.

[17]Devahastin, S., &Pitaksuriyarat, S. (2006).Use of latent heat storage to conserve energy during drying and its effect on drying kinetics of a food product.Applied Thermal Engineering, 26, 1705-1713.

[18] N. Vigneshkumar , M. Venkatasudhahar , P. Manoj Kumar , A. Ramesh , Ram Subbiah, Investigation on indirect solar dryer for drying sliced potatoes using phase change material (PCM). 26 May 2021. https://doi.org/10.1016/j.matpr.2021.05.562

[19] Gunasekaran K, Shanmugam V, Suresh P. Modelling and analytical experimental study of hybrid solar dryer integrated with biomass dryer for drying coleus forskohlii stems. IACSIT Coimbatore conferences 2012; p. 28.

[20] Nayak S, Naaz Z, Yadav P, Chaudhary R. Economic analysis of hybrid photovoltaic–thermal (PVT) integrated solar dryer. Int J Eng.Invent 2012;1(11):21–7.

[21]Bolaji B, Olalusi A. Performance evaluation of a mixed mode solar dryer. Technical Report, vol. 11; 2008. p. 225–31

[22] Jain, D., & Jain, R. K. (2004).Performance evaluation of an inclined multi-pass solar air heater with in-built thermal storage on deep-bed drying application. Journal of Food Engineering, 65(4), 497–509.

[23]Condori M, Saravia L. The performance of forced convection greenhouse driers. Renewable Energy 1998;13(4):453–69.

[24] Om Prakash n, Anil Kumar. Solar greenhouse drying: A review 24 August 2013. 29 (2014) 905–910

[25]Soponronnarit S. Solar drying in Thailand. Energy for Sustainable Development 1995;2(2):19–

[26] Thongprasert, S., Thongprasert, M., Boonyavanichkul, S., and Mahittafongkul, I., 1985. ''An economic study on solar rice dryer'', Report submitted to National Energy Administration of Thailand, Bangkok (in Thai).

[27] Soponronnarit, S., Assayo M., and Rakwichian, W., 1991. ''Performance evaluation of a solar banana dryer'', RERIC International Energy Journal, 13(2), pp. 71-79.

[28] Soponronnarit, S., Dussadee, N., Hirunlabh, L., Namprakai, R., and Thepa, M., ‘‘Computer simulation of solar assisted fruit cabinet dryer’’, RERIC International Energy Journal, 14(1), pp. 59-70.

[29] Sain, P., Songara, V., Karir, R., &Balan, N. (2013). Natural convection type solar dryer with latent heat storage. In Renewable Energy and Sustainable Energy (ICRESE), 2013 International Conference on (pp. 9–14). IEEE.

[30] Samreen , M. Madhava and A. Rama Rao. Drying of Red Chilli in Photovoltaic Powered Greenhouse Dryer. 20172:394 – 3386.

[31] A. Fudholi, M.Y. Othman, M.H. Ruslan, K. Sopian, Drying of Malaysian Capsicum annuum L. (Red Chili) Dried by Open and Solar Drying, Int. J. Photoenergy.(2013 (2013)) 1–9,

[32] Khan S, Towfiq R, Hossain S. A brief study of the prospect of solar energy in generation of electricity in Bangladesh. Cyber Journals: Multidisciplinary Journals in Science and Technology, Journal of Selected Areas in Renewable and Sustainable Energy (JRSE), June edition; 2012.

[33] I. Hamdi, S. Kooli, A. Elkhadraoui, Z. Azaizia, F. Abdelhamid, A. Guizani, Experimental study and numerical modeling for drying grapes under solargreenhouse, Renew. Energy. 127 (2018) 936–946,27

[34] A. Fadhel, S. Kooli, A. Farhat, A. Bellghith, Study of the solar drying of grapes by three different processes, Desalination 185 (2005) 535–541

[35] M.A. Basunia, H.H. Al-Handali, M.I. Al-Balushi, M.S.R. and O. Mahgoub, Drying of Fish Sardines in Oman Using Solar Tunnel Dryers, J. Agric. Sci. Technol. 1 (2011) 108–114

[36] P.P. Bhor, Y.P. Khandetod, A.G. Mohod, S.H. Sengar, Performance study of solar tunnel dryer for drying of fish variety Dhoma 2 (2010) 222–227

[37] Gopinath Radhakrishnan Govindan, Experimental Study of Solar Dryer with Thermal Energy Storage System for Drying of Agro Products. 2021

[38] Cakmak G, Yidiz C. The drying kinetics of seeded grape in solar dryer with PCM-based solar integrated collector. Food Bioprod Process 2011;89:103–8.

[39] Bal LM, Sudhakar P, Satya S, Naik SN. Solar dryer with latent heat storage systems for drying agricultural food products. In: Proceedings of the International Conference on Food Security and Environmental Sustainability; 2009.

[40] Esakkimuthu, S., Hassabou, A. H., Palaniappan, C., Spinnler, M., Blumenberg, J., &Velraj, R. (2013). Experimental investigation on phase change material based thermal storage system for solar air heating applications. Solar Energy, 88, 144–153.

[41] S. Tabassum1*, M. S. Bashar1, M. S. Islam1, A. Sharmin1, S. C. Debnath1, S. Parveen2, S. A. A. Khanom2 and M. Khanam .Design and development of solar dryer for food preservation. 54(2), 155-160, 2019

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

20. Jain, D., & Jain, R. K. (2004).Performance evaluation of an inclined multi-pass solar air heater with in-built thermal storage on deep-bed drying application.Journal of Food Engineering, 65(4), 497–509.

[43] Ayyappan, S., Mayilsamy, K., &Sreenarayanan, V. V. (2015). Performance improvement studies in a solar greenhouse drier using sensible heat storage materials. Heat and Mass Transfer, 1–9.

[44] Devahastin, S., &Pitaksuriyarat, S. (2006).Use of latent heat storage to conserve energy during drying and its effect on drying kinetics of a food product.Applied Thermal Engineering, 26, 1705-1713.

[45]Barone, G., Gatta, G. Della, Ferro, D., &Piacente, V. (1990).Enthalpies and entropies of sublimation, vaporization and fusion of nine polyhydric alcohols.Journal of the Chemical Society, Faraday Transactions, 86(1), 75–79.

[46] Reyes, A., Mahn, A., &Vásquez, F. (2014).Mushrooms dehydration in a hybrid-solar dryer, using a phase change material.Energy Conversion and Management, 83, 241–248.

[47] Shalaby, S. M., Bek, M. A., & El-Sebaii, A. A. (2014). Solar dryers with PCM as energy storage medium: A review. Renewable and Sustainable Energy Reviews, 33, 110–116.

[48] Sain, P., Songara, V., Karir, R., &Balan, N. (2013). Natural convection type solar dryer with latent heat storage. In Renewable Energy and Sustainable Energy (ICRESE), 2013 International Conference on (pp. 9–14). IEEE.

[49] Ana Salvatierra-Rojas1*, Marcus Nagle1, Martin Gummert2,Tom de Bruin3, Joachim Müller Development of an inflatable solar dryer for improved postharvest handling of paddy rice in humid climates. May, 2017 Vol. 10 No.3 269.

[50] P.P. Tripathy, S. Kumar, Determination of temperature dependent drying parameters for potato cylinders and slices during solar drying, Energy Conversion and Management. 49 (2008) 2941-2948

[51] Ainara Lópeza,*, Silvia Arazuria, Carmen Jaréna, Jesús Mangadoa, Pedro Arnala, José Ignacio Ruiz de Galarretab, Patrick Rigab, Raquel Lópezb . Crude Protein content determination of potatoes by NIRS technology. (2013) 488 – 492

[52] George Abong, Michael Okoth Ntrient contents of raw and processed products from Kenyan potato cultivars. https://www.researchgate.net/publication/237556586

[53] Rahul Dahare, Tankesh Kumar Nishad and Bhupendra Sahu.Evaluation of some proximate, chemical and functional properties of Chhattisgarh popular paddy varieties for suitability of flaked rice (*Poha*) . Vol. 8, Issue 3 (2019)

[54] Abhay Lingayat*, Chandramohan V.P., V.R.K. Raju. Design, Development and Performance of Indirect Type Solar Dryer for Banana Drying. 109 (2017) 409 – 416

[55] Masnaji R. Nukulwar. A review on performance evaluation of solar dryer and its material for drying agricultural products. 2021, Pages 345-349

APPENDIX

Appendix A: Maximum permitted drying temperature of different crops. [19-20]

SL No	Crop	Moisture content in the beginning(%, w.b.)	Final moisture content (%, w.b.)	Max. allowable temp. (^{0}C)
1	Corn	24	14	50
2	Rise	24	11	50
3	Oil seed	20-25	7-9	40-60
4	Cauliflower	80	6	65
5	Green beans	70	5	75
6	Garlic	80	4	55
7	Sweet potato	75	7	75
8	Chilies	80	5	65
9	Apricot	85	18	65
10	Bananas	80	15	70
11	Okra	80	20	65
12	Tomatoes	96	10	60
13	Paddy, raw	36	18-20	50
14	Wheat	20	16	45
15	Maize	35	15	60
16	Green peas	80	5	65
17	Carrots	70	5	75
18	Onions	80	4	55
19	Cabbage	80	4	55
20	Potatoes	70	12-14	75
21	Boil Paddy	50	18-20	50

Appendix B: Atmospheric Data, Absorber Plate Temperature, Weight of product and Drying Chamber Temperature.

Appendix B1: Atmospheric Data, Absorber Plate Temperature, Weight of Potato and Drying Chamber Temperature of Dryer Using Copper Plate as a Solar Collector at Air Velocity 1.8m/s.

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2)	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-31-10-22								
10.30	81	46	1120	37	47	0.2	500	500
11.00	79	46	1029	38	42	0.1	446	430
11.30	77	45	1010	36	31	0.3	410	400
12.00	75	45	970	36	29	0.2	385	375
12.30	76	45	940	35	32	0.3	360	354
1.00	73	44	910	33	30	0.1	330	322
1.30	73	44	850	31	32	0.2	312	306
2.00	71	43	740	30	31	0.1	308	300
2.30	69	40	630	29	32	0.2	300	292
Date-1-11-22								
10.30	80	45	1010	36	43	0.1	294	285
11.00	78	45	1002	37	42	0.1	279	270
11.30	76	44	900	36	30	0.2	258	255
12.00	76	43	970	35	31	0.3	237	232
12.30	75	43	901	34	32	0.1	216	205
1.00	73	42	880	33	31	0.2	199	187
1.30	72	43	820	30	33	0.2	192	
2.00	62	42	730	31	31	0.4	180	
2.30	61	40	610	29	30	0.2		

Appendix B2: Atmospheric Data, Absorber Plate Temperature, Weight of Potato and Drying Chamber Temperature of Dryer Using Copper Plate as a Solar Collector at Air Velocity -2.2 m/s.

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2)	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-2-11-22								
10.30	81	47	1220	38	42	0.2	500	500
11.00	80	46	1100	37	41	0.2	450	427
11.30	77	46	1000	36	31	0.4	415	402
12.00	76	45	990	36	30	0.1	390	371
12.30	76	45	930	35	32	0.3	365	349
1.00	74	44	920	34	30	0.3	337	317
1.30	73	44	820	32	32	0.2	327	302
2.00	72	43	730	30	33	0.1	316	295
2.30	69	41	660	29	31	0.1	302	285
Date-3-11-22								
10.00	82	47	1200	38	50	0.2	296	281
1030	80	47	1102	37	48	0.1	275	258
11	77	45	1030	36	43	0.1	259	238
11.30	75	44	970	35	37	0.1	242	211
12	75	44	940	35	31	0.2	218	187
12.30	73	43	820	34	38	0.1	200	
1.00	74	44	850	32	31	0.1	186	
1.30	66	43	710	31	35	0.1	180	
2.00	61	40	630	28	27	0.2		

Appendix B3: Atmospheric Data, Absorber Plate Temperature, Weight of Potato and Drying Chamber Temperature of Dryer Using Copper Plate as a Solar Collector at Air Velocity - 2.5 m/s

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2)	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-6-11-22								
10.30	80	45	1010	36	15	0.5	500	500
11.00	79	43	980	35	22	0.4	453	422
11.30	77	44	940	35	36	0.2	419	398
12.00	75	44	930	34	39	0.1	398	372
12.30	76	43	910	35	39	0.2	372	344
1.00	73	43	890	31	32	0.4	344	314
1.30	73	42	860	32	31	0.3	329	301
2.00	69	41	840	30	32	0.12	322	291
2.30	66	41	730	28	37	0.1	309	281
Date-8-11-22								
10.30	79	43	990	35	42	0.1	299	271
11.00	78	42	960	36	41	0.1	278	247
11.30	79	45	1010	32	51	0.2	266	213
12.00	77	42	970	33	39	0.1	247	192
12.30	75	41	910	34	31	0.2	228	
1.00	73	40	810	31	32	0.1	211	
1.30	73	41	890	32	31	0.2	192	
2.00	60	40	610	30	31	0.1	176	
2.30	56	39	420	28	37	0.1		

Appendix B4: Atmospheric Data, Absorber Plate Temperature, Weight of Potato and Drying Chamber Temperature of Dryer Using Copper Plate as a Solar Collector at Air Velocity -2.7 m/s

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2)	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-9-11-22								
10.00	80	45	1180	37	59	0.2	500	500
10.30	79	46	1022	36	42	0.1	463	432
11.00	78	45	1010	36	39	0.2	425	403
11.30	75	45	970	35	48	0.2	403	376
12.00	76	46	980	34	45	0.1	378	356
12.30	73	45	950	33	31	0.2	350	328
1.00	71	44	810	32	32	0.2	333	316
1.30	69	43	740	30	31	0.3	320	305
2.00	68	41	730	29	32	0.2	312	297
Date-10-11-22								
10.30	78	46	1090	36	67	0.4	301	287
11.00	79	45	940	35	52	0.2	281	262
11.30	79	45	1010	35	51	0.3	261	239
12.00	78	44	970	32	39	0.1	244	209
12.30	76	43	840	32	42	0.5	229	191
1.00	74	43	910	33	20	0.2	216	
1.30	72	42	750	31	42	0.1	194	
2.00	71	40	740	29	31	0.4	172	
2.30	61	39	530	28	32	0.3		

Appendix B5: Atmospheric Data, Absorber Plate Temperature, Weight of Boil Paddy and Drying Chamber Temperature of Dryer Using Copper Plate as a Solar Collector at Air Velocity -2.5 m/s

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-21-11-22								
10.30	77	44	960	32	47	0.2	500	500
11.00	76	45	950	27	42	0.7	477	474
11.30	77	45	980	32	31	0.3	452	448
12.00	74	43	940	32	29	0.4	441	438
12.30	72	44	960	33	32	0.3	422	418
1.00	68	42	850	33	30	0.4	404	399
1.30	63	42	550	30	32	0.5	390	387
2.00	62	43	500	28	31	0.4	385	375
2.30	60	40	530	27	32	0.2	381	348
Date-22-11-22								
10.30	78	43	980	32	44	0.3	377	338
11.00	76	42	955	28	41	0.4	372	302
11.30	77	44	970	33	33	0.5	364	
12.00	75	42	960	33	28	0.6	345	
12.30	72	45	725	33	31	0.2	322	
1.00	68	43	612	33	30	0.1		
1.30	64	42	550	31	32	0.3		
2.00	63	43	530	28	32	0.3		
2.30	62	40	520	27	30	0.4		

Appendix B6: Atmospheric Data, Absorber Plate Temperature, Weight of Normal Paddy and Drying Chamber Temperature of Dryer Using Copper Plate as a Solar Collector at Air Velocity -2.5 m/s

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
				Date-21-11-22				
10.30	77	44	960	32	47	0.2	500	500
11.00	76	45	950	27	42	0.7	488	478
11.30	77	45	980	32	31	0.3	479	471
12.00	74	43	940	32	29	0.4	468	465
12.30	72	44	960	33	32	0.3	462	459
1.00	68	42	850	33	30	0.4	457	452
1.30	63	42	550	30	32	0.5	452	449
2.00	62	43	500	28	31	0.4	440	435
2.30	60	40	530	27	32	0.2	433	426
				Date-22-11-22				
10.30	78	43	980	32	44	0.3	429	412
11.00	76	42	955	28	41	0.4	422	387
11.30	77	44	970	33	33	0.5	410	
12.00	75	42	960	33	28	0.6	385	
12.30	72	45	725	33	31	0.2		
1.00	68	43	612	33	30	0.1		
1.30	64	42	550	31	32	0.3		
2.00	63	43	530	28	32	0.3		
2.30	62	40	520	27	30	0.4		

Appendix B7: Atmospheric Data, Absorber Plate Temperature, Weight of Potato and Drying Chamber Temperature of Dryer Using Copper Plate as a Solar Collector at Air Velocity -2.5 m/s (100gm/m^2 PCM)

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-14-02-23								
10.30	78	43	1035	31	42	0.2	500	500
11.00	78	45	940	29	31	0.1	465	450
11.30	76	44	900	31	28	0.1	447	437
12.00	74	43	810	28	31	0.3	420	424
12.30	76	42	830	27	33	0.1	392	392
1.00	72	42	710	27	37	0.2	373	372
1.30	68	45	720	26	32	0.3	340	355
2.00	69	42	710	26	30	0.1	331	323
2.30	64	41	630	29	33	0.2	315	301
Date-15-02-23								
10.30	77	42	1080	32	50	0.1	298	281
11.00	76	43	960	30	32	0.2	272	258
11.30	75	42	910	31	33	0.1	245	220
12.00	74	41	900	28	35	0.4	232	190
12.30	72	41	860	26	38	0.2	218	
1.00	69	40	720	27	32	0.1	201	
1.30	68	42	730	26	40	0.2	188	
2.00	69	41	720	27	31	0.1		
2.30	64	42	630	28	32	0.2		

Appendix B8: Atmospheric Data, Absorber Plate Temperature, Weight of Potato and Drying Chamber Temperature of Dryer Using Copper Plate as a Solar Collector at Air Velocity -2.5 m/s (200gm/m^2 PCM)

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-12-02-23								
10.30	78	43	900	30	40	0.1	500	500
11.00	79	46	960	28	30	0.2	472	457
11.30	77	46	990	31	25	0.2	453	440
12.00	75	43	800	29	31	0.5	427	420
12.30	76	45	850	27	32	0.2	405	398
1.00	76	44	700	28	33	0.3	383	374
1.30	77	45	720	26	34	0.1	351	356
2.00	74	43	710	27	32	0.2	342	329
2.30	68	42	600	29	35	0.1	328	303
Date-13-02-23								
10	78	42	995	29	30	1.0	308	292
10.30	78	43	976	27	42	0.9	283	272
11.00	77	42	948	28	31	1.1	262	252
11.30	76	42	930	31	44	0.9	246	235
12.00	75	41	948	30	43	0.4	238	215
12.30	76	43	957	30	42	0.3	230	205
1.00	74	42	760	29	44	0.5	220	189
1.30	72	41	605	30	45	0.6	204	
2.00	72	41	615	27	32	0.4	190	
2.30	66	42	320	26	30	0.7		
3.00	65	41	450	25	31	0.3		
3.30	65	41	460	26	28	0.5		

Appendix B9: Atmospheric Data, Absorber Plate Temperature, Weight of Potato and Drying Chamber Temperature of Dryer Using Copper Plate as a Solar Collector at Air Velocity -2.5 m/s (300gm/m^2 PCM)

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-23-11-22								
10.30	82	47	1040	27	10	0.1	500	500
11.00	81	46	920	29	16	0.4	473	460
11.30	80	47	950	33	28	0.2	447	442
12.00	80	48	960	32	28	0.3	422	418
12.30	80	46	600	32	32	0.2	395	382
1.00	76	45	605	30	36	0.5	377	364
1.30	72	43	505	28	35	0.4	360	342
2.00	70	43	460	27	32	0.2	331	328
2.30	69	43	450	26	35	0.1	320	313
Date-23-11-22								
10.30	81	47	1035	31	42	0.2	300	297
11.00	80	47	940	29	31	0.1	280	273
11.30	79	46	900	31	28	0.1	269	249
12.00	79	45	810	28	31	0.3	244	220
12.30	79	45	830	27	33	0.1	233	214
1.00	75	42	710	27	37	0.2	222	203
1.30	73	45	720	26	32	0.3	200	192
2.00	72	43	710	26	30	0.1	192	
2.30	68	41	630	29	33	0.2	188	

Appendix B10: Atmospheric Data, Absorber Plate Temperature, Weight of Boil Paddy and Drying Chamber Temperature of Dryer Using Copper Plate as a Solar Collector at Air Velocity -2.5 m/s (300gm/m^2 PCM)

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-23-11-22								
10.30	82	47	1040	27	45	0.1	500	500
11.00	81	46	920	29	41	0.4	481	479
11.30	80	47	950	33	30	0.2	459	451
12.00	80	48	960	32	28	0.3	448	438
12.30	80	46	600	32	32	0.2	430	422
1.00	76	45	605	30	36	0.5	412	401
1.30	72	43	505	28	35	0.4	401	394
2.00	70	43	460	27	32	0.2	391	383
2.30	69	43	450	26	35	0.1	384	376
Date-23-11-22								
10.30	81	47	1035	31	42	0.2	379	359
11.00	80	47	940	29	31	0.1	371	349
11.30	79	46	900	31	28	0.1	369	
12.00	79	45	810	28	31	0.3	359	
12.30	79	45	830	27	33	0.1	352	

Appendix B11: Atmospheric Data, Absorber Plate Temperature, Weight of Normal Paddy and Drying Chamber Temperature of Dryer Using Copper Plate as a Solar Collector at Air Velocity -2.5 m/s (300gm/m^2 PCM)

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-23-11-22								
10.30	82	47	1040	27	45	0.1	500	500
11.00	81	46	920	29	41	0.4	492	482
11.30	80	47	950	33	30	0.2	483	474
12.00	80	48	960	32	28	0.3	471	463
12.30	80	46	600	32	32	0.2	464	459
1.00	76	45	605	30	36	0.5	457	451
1.30	72	43	505	28	35	0.4	452	443
2.00	70	43	460	27	32	0.2	445	437
2.30	69	43	450	26	35	0.1	437	421
Date-23-11-22								
10.30	81	47	1035	31	42	0.2	431	414
11.00	80	47	940	29	31	0.1	428	403
11.30	79	46	900	31	28	0.1	426	
12.00	79	45	810	28	31	0.3	417	

Appendix B12: Atmospheric Data, Absorber Plate Temperature, Weight of Potato and Drying Chamber Temperature of Dryer Using Copper Plate as a Solar Collector at Air Velocity -2.5 m/s (400gm/m^2 PCM)

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-27-11-22								
10.30	78	43	950	28	44	0.2	500	500
11.00	77	42	940	28	43	0.2	474	458
11.30	77	44	900	32	31	0.1	450	441
12.00	76	45	920	32	22	0.3	430	422
12.30	74	43	620	31	31	0.2	409	395
1.00	76	45	615	31	32	0.3	381	371
1.30	71	43	525	29	31	0.4	351	352
2.00	66	43	430	27	32	0.2	345	322
2.30	65	42	450	27	34	0.1	328	303
Date-28-11-22								
9.30	77	43	995	27	45	0.3	307	292
10.00	78	43	984	27	44	0.2	278	271
10.30	78	43	949	28	43	0.2	255	244
11.00	77	42	925	31	41	0.3	235	225
11.30	76	44	956	32	33	0.2	225	201
12.00	77	45	964	32	23	0.1	220	
12.30	75	45	655	32	33	0.2	204	
1.00	76	43	605	31	32	0.4	196	
1.30	73	42	555	29	34	0.3	190	
2.00	68	46	466	26	34	0.1		

Appendix B13: Atmospheric Data, Absorber Plate Temperature, Weight of Boil Paddy and Drying Chamber Temperature of Dryer Using Copper Plate as a Solar Collector at Air Velocity -2.5 m/s (400gm/m^2 PCM)

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-27-11-22								
10.30	78	43	950	28	44	0.2	500	500
11.00	77	42	940	28	43	0.2	489	467
11.30	77	44	900	32	31	0.1	469	450
12.00	76	45	920	32	22	0.3	460	438
12.30	74	43	620	31	31	0.2	434	422
1.00	76	45	615	31	32	0.3	429	401
1.30	71	43	525	29	31	0.4	414	393
2.00	66	43	430	27	32	0.2	399	382
2.30	65	42	450	27	34	0.1	393	375
Date-28-11-22								
9.30	77	43	995	27	45	0.3	391	369
10.00	78	43	984	27	44	0.2	380	358
10.30	78	43	949	28	43	0.2	372	348
11.00	77	42	925	31	41	0.3	366	
11.30	76	44	956	32	33	0.2	360	
12.00	77	45	964	32	23	0.1	354	
12.30	75	45	655	32	33	0.2	349	
1.00	76	43	605	31	32	0.4		
1.30	73	42	555	29	34	0.3		
2.00	68	46	466	26	34	0.1		

Appendix B14: Atmospheric Data, Absorber Plate Temperature, Weight of Normal Paddy and Drying Chamber Temperature of Dryer Using Copper Plate as a Solar Collector at Air Velocity -2.5 m/s (400gm/m^2 PCM)

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-27-11-22								
10.30	78	43	950	28	44	0.2	500	485
11.00	77	42	940	28	43	0.2	491	475
11.30	77	44	900	32	31	0.1	486	465
12.00	76	45	920	32	22	0.3	481	463
12.30	74	43	620	31	31	0.2	468	456
1.00	76	45	615	31	32	0.3	452	447
1.30	71	43	525	29	31	0.4	442	440
2.00	66	43	430	27	32	0.2	440	424
2.30	65	42	450	27	34	0.1	437	420
Date-28-11-22								
9.30	77	43	995	27	45	0.3	431	409
10.00	78	43	984	27	44	0.2	428	332
10.30	78	43	949	28	43	0.2	426	
11.00	77	42	925	31	41	0.3	420	
11.30	76	44	956	32	33	0.2	416	
12.00	77	45	964	32	23	0.1	410	
12.30	75	45	655	32	33	0.2		
1.00	76	43	605	31	32	0.4		
1.30	73	42	555	29	34	0.3		
2.00	68	46	466	26	34	0.1		

Appendix B15: Atmospheric Data, Absorber Plate Temperature, Weight of Potato and Drying Chamber Temperature of Dryer Using Aluminum Plate as a Solar Collector at Air Velocity -2.5 m/s

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-29-11-22								
10.30	72	40	964	32	20	0.2	500	500
11.00	73	41	1070	33	16	0.5	470	458
11.30	71	42	933	31	18	0.6	441	440
12.00	70	41	945	30	24	0.3	427	417
12.30	65	43	666	32	35	0.4	392	386
1.00	67	41	605	30	34	0.5	375	500
1.30	58	38	765	30	33	0.6	358	458
2.00	57	39	566	29	33	0.3	334	440
2.30	56	38	530	28	32	0.4	317	417
Date-30-11-22								
10.30	70	40	990	28	40	0.3	379	295
11.00	71	40	980	27	41	0.3	371	272
11.30	70	41	970	32	32	0.4	369	244
12.00	71	42	980	33	23	0.3	359	220
12.30	65	43	897	32	34	0.4	352	212
1.00	64	41	666	32	35	0.2	302	201
1.30	58	40	555	30	34	0.2	283	193
2.00	56	41	522	27	35	0.3	264	182
2.30	54	38	444	27	33	0.2	245	
3.00	53	38	400	26	31	0.1	232	

Appendix B16: Atmospheric Data, Absorber Plate Temperature, Weight of Boil Paddy and Drying Chamber Temperature of Dryer Using Aluminum Plate as a Solar Collector at Air Velocity -2.5 m/s

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-29-11-22								
10.30	72	40	964	32	44	0.2	500	500
11.00	73	41	953	33	46	0.5	485	470
11.30	71	42	933	31	33	0.6	465	455
12.00	70	41	945	30	24	0.3	452	440
12.30	65	43	666	32	35	0.4	438	427
1.00	67	41	605	30	34	0.5	422	407
1.30	58	38	765	30	33	0.6	409	396
2.00	57	39	566	29	33	0.3	396	388
2.30	56	38	530	28	32	0.4	389	379
Date-30-11-22								
10.30	70	40	990	28	40	0.3	382	371
11.00	71	40	980	27	41	0.3	374	362
11.30	70	41	970	32	32	0.4	371	352
12.00	71	42	980	33	23	0.3	355	348
12.30	65	43	897	32	34	0.4	352	339
1.00	64	41	666	32	35	0.2	344	
1.30	58	40	555	30	34	0.2	329	

Appendix B17: Atmospheric Data, Absorber Plate Temperature, Weight of Normal Paddy and Drying Chamber Temperature of Dryer Using Aluminum Plate as a Solar Collector at Air Velocity -2.5 m/s

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-29-11-22								
10.30	72	40	964	32	44	0.2	500	500
11.00	73	41	953	33	46	0.5	490	470
11.30	71	42	933	31	33	0.6	486	455
12.00	70	41	945	30	24	0.3	476	440
12.30	65	43	666	32	35	0.4	467	427
1.00	67	41	605	30	34	0.5	458	407
1.30	58	38	765	30	33	0.6	450	396
2.00	57	39	566	29	33	0.3	440	388
2.30	56	38	530	28	32	0.4	437	379
Date-30-11-22								
10.30	70	40	990	28	40	0.3	433	371
11.00	71	40	980	27	41	0.3	428	362
11.30	70	41	970	32	32	0.4	426	
12.00	71	42	980	33	23	0.3	417	

Appendix B18: Atmospheric Data, Absorber Plate Temperature, Weight of Potato and Drying Chamber Temperature of Dryer Using Aluminum Plate as a Solar Collector at Air Velocity -2.5 m/s (300gm/m^2 PCM).

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-4-12-22								
10.30	75	43	1100	27	12	0.1	500	500
11.00	74	44	290	28	18	0.1	473	460
11.30	74	43	800	32	26	0.2	447	442
12.00	71	42	910	31	23	0.3	422	418
12.30	70	42	720	32	33	0.1	395	382
1.00	72	43	609	30	32	0.2	377	364
1.30	68	42	525	26	35	0.1	360	342
2.00	67	42	440	27	31	0.2	331	328
2.30	68	41	420	26	34	0.1	320	313
Date-5-12-22								
9.30	74	42	1120	28	22	0.2	300	297
10.00	74	44	990	30	44	0.1	280	273
10.30	71	42	980	28	47	0.3	269	249
11.00	72	42	930	31	43	0.4	244	220
11.30	70	40	950	33	35	0.2	233	214
12.00	71	42	940	32	29	0.4	222	203
12.30	73	41	654	31	35	0.5	200	192
1.00	6	44	635	30	33	0.1	192	
1.30	70	43	643	27	34	0.2	188	
2.00	69	40	420	28	36	0.3		
2.30	66	32	440	26	32	0.2		

Appendix B19: Atmospheric Data, Absorber Plate Temperature, Weight of Boil Paddy and Drying Chamber Temperature of Dryer Using Aluminum Plate as a Solar Collector at Air Velocity -2.5 m/s(300gm/m^2 PCM).

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-4-12-22								
10.30	75	43	950	27	41	0.1	500	500
11.00	74	44	290	28	40	0.1	487	472
11.30	74	43	800	32	31	0.2	464	456
12.00	71	42	910	31	23	0.3	455	441
12.30	70	42	720	32	33	0.1	432	429
1.00	72	43	609	30	32	0.2	427	406
1.30	68	42	525	26	35	0.1	412	397
2.00	67	42	440	27	31	0.2	399	389
2.30	68	41	420	26	34	0.1	391	380
Date-5-12-22								
9.30	74	42	1120	28	52	0.2	300	371
10.00	74	44	990	30	44	0.1	280	362
10.30	71	42	980	28	47	0.3	269	352
11.00	72	42	930	31	43	0.4	244	348
11.30	70	40	950	33	35	0.2	233	
12.00	71	42	940	32	29	0.4	222	

Appendix B20: Atmospheric Data, Absorber Plate Temperature, Weight of Normal Paddy and Drying Chamber Temperature of Dryer Using Aluminum Plate as a Solar Collector at Air Velocity -2.5 m/s (300gm/m^2 PCM).

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-4-12-22								
10.30	75	43	950	27	41	0.1	500	500
11.00	74	44	290	28	40	0.1	492	486
11.30	74	43	800	32	31	0.2	488	476
12.00	71	42	910	31	23	0.3	480	468
12.30	70	42	720	32	33	0.1	469	467
1.00	72	43	609	30	32	0.2	459	457
1.30	68	42	525	26	35	0.1	448	446
2.00	67	42	440	27	31	0.2	440	440
2.30	68	41	420	26	34	0.1	435	432
Date-5-12-22								
9.30	74	42	1120	28	52	0.2	431	422
10.00	74	44	990	30	44	0.1	428	407
10.30	71	42	980	28	47	0.3	426	
11.00	72	42	930	31	43	0.4	417	
11.30	70	40	950	33	35	0.2	412	
12.00	71	42	940	32	29	0.4	400	

Appendix B20: Atmospheric Data, Absorber Plate Temperature, Weight of Potato and Drying Chamber Temperature of Dryer Using Galvanized sheet as a Solar Collector at Air Velocity -2.5 m/s

Time	Absorber plate temperature (°C)	Drying chamber temperature (°C)	Solar Intensity (W/m^2	Ambient temperature(°C)	Humidity of atm. %	Air Velocity m/s	Open Sun Drying	Solar Dryer Drying
							W (gm)	W (gm)
Date-6-12-22								
9.30	44	33	800	28	46	0.2	500	500
10.00	43	32	760	29	44	0.2	474	469
10.30	42	32	650	28	42	0.1	450	449
11.00	44	33	830	30	41	0.1	427	429
11.30	42	31	750	29	38	0.2	399	398
12.00	41	31	630	30	25	0.2	373	374
12.30	40	30	440	28	39	0.3	362	359
1.00	40	31	550	27	33	0.1	333	334
1.30	41	30	620	27	38	0.1	324	323
2.00	40	29	420	28	38	0.2	301	300
2.30	38	28	330	26	31	0.3	284	286
Date-7-12-22								
9.30	43	32	805	29	42	0.1	270	271
10.00	42	33	710	29	49	0.1	246	245
10.30	41	32	670	27	42	0.1	231	232
11.00	43	34	780	28	46	0.2	220	218
11.30	42	32	740	30	51	0.1	200	198
12.00	41	31	630	31	25	0.2	191	190
12.30	41	31	430	28	38	0.1	187	185

Appendix C: Pearson's Correlation Coefficient.

Appendix C1: Relation between Solar Intensity(W/m^2) and Absorber plate temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-31-10-22)

Solar Intensity (W/m^2) X (xi)	Absorber plate temp. (°C) Y1 (yj)	$xi - \bar{x}$	$yj - \bar{y}$	$(xi - \bar{x}) * (yj - \bar{y})$	$(xi - \bar{x})^2$	$(yj - \bar{y})^2$	r_{xy}
1120	81	209.00	8.11	1695.22	43681	65.7901235	0.97
1029	79	118.00	6.11	721.11	13924	37.345679	
1010	77	99.00	4.11	407.00	9801	16.9012346	
970	75	59.00	2.11	124.56	3481	4.45679012	
940	76	29.00	3.11	90.22	841	9.67901235	
910	73	-1.00	0.11	-0.11	1	0.01234568	
850	73	-61.00	0.11	-6.78	3721	0.01234568	
740	71	-171.00	-10.89	1862.00	29241	118.567901	
630	69	-281.00	-12.89	3621.78	78961	166.123457	
$\bar{x}$=911.00	$\bar{y}$=72.89			8515.00	183652.00	418.89	

Appendix C2: Relation between Solar Intensity(W/m^2) and Drying Chamber Temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-31-10-22)

Solar Intensity (W/m^2) X (xi)	Drying Chamber Tem. (^{0}c) (°C) Y (y2)	$xi - \bar{x}$	$Y2 - \bar{y}$	$(xi - \bar{x}) * (y2 - \bar{y})$	$(xi - \bar{x})^2$	$(y2 - \bar{y})^2$	r_{xy}
1120	46	209.00	1.78	371.56	43681	3.160493827	0.95
1029	46	118.00	1.78	209.78	13924	3.160493827	
1010	45	99.00	0.78	77.00	9801	0.604938272	
970	45	59.00	0.78	45.89	3481	0.604938272	
940	45	29.00	0.78	22.56	841	0.604938272	
910	44	-1.00	-0.22	0.22	1	0.049382716	
850	44	-61.00	-0.22	13.56	3721	0.049382716	
740	43	-171.00	-1.22	209.00	29241	1.49382716	
630	40	-281.00	-4.22	1186.44	78961	17.82716049	
$\bar{x}$=911.00	$\bar{y}$=72.89			2136.00	183652.00	27.56	

Appendix C3: Relation between Solar Intensity(W/m^2) and Absorber plate temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-2-11-22)

Solar Intensity (W/m^2) X (xi)	Absorber plate temp. (°C) Y1 (yj)	$xi-\bar{x}$	$yj-\bar{y}$	$(xi-\bar{x})*(yj-\bar{y})$	$(xi-\bar{x})^2$	$(yj-\bar{y})^2$	r_{xy}
900	79	44.00	4.44	195.56	1936	19.7530864	0.98
1000	80	144.00	5.44	784.00	20736	29.6419753	
1010	80	154.00	5.44	838.44	23716	29.6419753	
910	77	54.00	2.44	132.00	2916	5.97530864	
902	76	46.00	1.44	66.44	2116	2.08641975	
930	77	74.00	2.44	180.89	5476	5.97530864	
802	73	-54.00	-1.56	84.00	2916	2.41975309	
720	67	-136.00	-7.56	1027.56	18496	57.0864198	
530	62	-326.00	-12.56	4093.11	106276	157.641975	
$\bar{x}$=856.00	$\bar{y}$=74.56			7402.0	184584.00	310.22	

Appendix C4: Relation between Solar Intensity(W/m^2) and Drying Chamber Temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-2-11-22)

Solar Intensity (W/m^2) X (xi)	Drying Chamber Tem. (^{0}c) (°C) Y (y2)	$xi-\bar{x}$	$Y2-\bar{y}$	$(xi-\bar{x})*(y2-\bar{y})$	$(xi-\bar{x})^2$	$(y2-\bar{y})^2$	r_{xy}
900	43	140.78	-0.22	-9.78	1936	0.04938272	0.91
1000	44	132.78	0.78	112.00	20736	0.60493827	
1010	45	30.78	1.78	273.78	23716	3.16049383	
910	44	100.78	0.78	42.00	2916	0.60493827	
902	43	31.78	-0.22	-10.22	2116	0.04938272	
930	44	10.78	0.78	57.56	5476	0.60493827	
802	44	-49.22	0.78	-42.00	2916	0.60493827	
720	42	-139.22	-1.22	166.22	18496	1.49382716	
530	40	-259.22	-3.22	1050.44	106276	10.382716	
$\bar{x}$=911.0	$\bar{y}$=43.22			1640.00	184584.00	17.56	

Appendix C5: Relation between Solar Intensity(W/m^2) and Absorber plate temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-6-11-22)

Solar Intensity (W/m^2) X (xi)	Absorber plate temp. (°C) Y1 (yj)	$xi - \bar{x}$	$yj - \bar{y}$	$(xi - \bar{x}) * (yj - \bar{y})$	$(xi - \bar{x})^2$	$(yj - \bar{y})^2$	r_{xy}
1100	80	283.11	10.89	3082.77	80151.9012	118.567901	
980	79	185.11	8.89	1645.43	34266.1235	79.0123457	
940	77	113.11	5.89	666.10	12794.1235	34.6790123	
930	75	53.11	3.89	206.54	2820.79012	15.1234568	
910	76	23.11	3.89	89.88	534.123457	15.1234568	
890	73	-96.89	1.89	-183.01	9387.45679	3.56790123	0.84
860	73	-66.89	2.89	-193.23	4474.12346	8.34567901	
840	69	-206.89	-7.11	1471.21	42803.0123	50.5679012	
730	66	-286.89	-31.11	8925.43	82305.2346	967.901235	
$\bar{x}$=916.89	$\bar{y}$=71.11			15711.11	269536.89	1292.89	

Appendix C6: Relation between Solar Intensity(W/m^2) and Drying Chamber Temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-6-11-22)

Solar Intensity (W/m^2) X (xi)	Drying Chamber Tem. (^{0}c) (°C) Y (y2)	$xi - \bar{x}$	$Y2 - \bar{y}$	$(xi - \bar{x}) * (y2 - \bar{y})$	$(xi - \bar{x})^2$	$(y2 - \bar{y})^2$	r_{xy}
1100	45	191.11	2.11	403.46	36523.4568	4.45679012	
980	43	71.11	0.11	7.90	5056.79012	0.01234568	
940	44	31.11	1.11	34.57	967.901235	1.2345679	
930	44	21.11	1.11	23.46	445.679012	1.2345679	
910	43	1.11	0.11	0.12	1.2345679	0.01234568	
890	43	-18.89	0.11	-2.10	356.790123	0.01234568	0.88
860	42	-48.89	-0.89	43.46	2390.12346	0.79012346	
840	41	-68.89	-1.89	130.12	4745.67901	3.56790123	
730	41	-178.89	-1.89	337.90	32001.2346	3.56790123	
$\bar{x}$= 908.89	$\bar{y}$= 42.89			978.89	82488.89	14.89	

Appendix C7: Relation between Solar Intensity(W/m^2) and Absorber plate temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-9-11-22)

Solar Intensity	Absorber plate temp.	$xi - \bar{x}$			$(xi - \bar{x})^2$	$(yj - \bar{y})^2$	

(W/m²) X (xi)	(°C) Y1 (yj)		$yj{-}\bar{y}$	$(xi - \bar{x}) * (yj{-}\bar{y})$			r_{xy}
1180	81	247.56	6.56	1622.86	61283.7531	42.9753086	
1022	79	89.56	4.56	407.98	8020.19753	20.7530864	
1010	78	77.56	3.56	275.75	6014.8642	12.6419753	
970	75	37.56	0.56	20.86	1410.41975	0.30864198	
980	76	47.56	1.56	73.98	2261.53086	2.41975309	0.97
950	73	17.56	-1.44	-25.36	308.197531	2.08641975	
810	71	-122.44	-3.44	421.75	14992.642	11.8641975	
740	69	-192.44	-5.44	1047.75	37034.8642	29.6419753	
730	68	-202.44	-6.44	1304.64	40983.7531	41.5308642	
$\bar{x}$= 932.44	$\bar{y}$= 74.44			5150.22	172310.22	164.22	

Appendix C8: Relation between Solar Intensity(W/m²) and Drying Chamber Temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-9-11-22)

Solar Intensity (W/m²) X (xi)	**Drying Chamber Tem. (^{0}c) (°C) Y (y2)**	$xi - \bar{x}$	$Y2{-}\bar{y}$	$(xi - \bar{x}) * (y2{-}\bar{y})$	$(xi - \bar{x})^2$	$(y2 - \bar{y})^2$	r_{xy}
1180	47	247.56	2.33	577.63	61283.7531	5.44444444	
1022	46	89.56	1.33	119.41	8020.19753	1.77777778	
1010	45	77.56	0.33	25.85	6014.8642	0.11111111	
970	45	37.56	0.33	12.52	1410.41975	0.11111111	
980	46	47.56	1.33	63.41	2261.53086	1.77777778	
950	45	17.56	0.33	5.85	308.197531	0.11111111	0.92
810	44	-122.44	-0.67	81.63	14992.642	0.44444444	
740	43	-192.44	-1.67	320.74	37034.8642	2.77777778	
730	41	-202.44	-3.67	742.30	40983.7531	13.4444444	
$\bar{x}$=932.44	$\bar{y}$=44.67			1949.33	172310.22	26.00	

Appendix C9: Relation between Solar Intensity(W/m²) and Drying Chamber Temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-10-11-22)

Solar Intensity (W/m²) X (xi)	**Drying Chamber Tem. (^{0}c)** (°C) Y	$xi - \bar{x}$	$Y2{-}\bar{y}$	$(xi - \bar{x}) * (y2{-}\bar{y})$	$(xi - \bar{x})^2$	$(y2 - \bar{y})^2$	r_{xy}

	(y2)						
1090	46	225.56	3.00	676.67	50875.3086	9	
940	45	75.56	2.00	151.11	5708.64198	4	
1010	45	145.56	2.00	291.11	21186.4198	4	
970	44	105.56	1.00	105.56	11141.9753	1	
840	43	-24.44	0.00	0.00	597.530864	0	
910	43	45.56	0.00	0.00	2075.30864	0	0.95
750	42	-114.44	-1.00	114.44	13097.5309	1	
740	40	-124.44	-3.00	373.33	15486.4198	9	
530	39	-334.44	-4.00	1337.78	111853.086	16	
$\bar{x}$=864.44	$\bar{y}$=43.00			3050.00	232022.22	44.00	

C10: Relation between Solar Intensity(W/m^2) and Absorber plate temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-21-11-22)

Solar Intensity **(W/m^2)** X (xi)	**Absorber plate temp.** (°C) Y1 (yj)	$xi-\bar{x}$	$yj-\bar{y}$	$(xi-\bar{x})*(yj-\bar{y})$	$(xi-\bar{x})^2$	$(yj-\bar{y})^2$	r_{xy}
1180	81	247.56	6.56	1622.86	61283.7531	42.9753086	
1022	79	89.56	4.56	407.98	8020.19753	20.7530864	
1010	78	77.56	3.56	275.75	6014.8642	12.6419753	
970	75	37.56	0.56	20.86	1410.41975	0.30864198	
980	76	47.56	1.56	73.98	2261.53086	2.41975309	
950	73	17.56	-1.44	-25.36	308.197531	2.08641975	0.96
810	71	-122.44	-3.44	421.75	14992.642	11.8641975	
740	69	-192.44	-5.44	1047.75	37034.8642	29.6419753	
730	68	-202.44	-6.44	1304.64	40983.7531	41.5308642	
$\bar{x}$=932.44	$\bar{y}$=74.44			5150.22	172310.22	164.22	

Appendix C11: Relation between Solar Intensity(W/m^2) and Absorber plate temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-15-02-23)

Solar Intensity **(W/m^2)** X (xi)	**Absorber plate temp.** (°C) Y1 (yj)	$\boldsymbol{xi-\bar{x}}$	$\boldsymbol{yj-\bar{y}}$	$\boldsymbol{(xi-\bar{x})*(yj-\bar{y})}$	$\boldsymbol{(xi-\bar{x})^2}$	$\boldsymbol{(yj-\bar{y})^2}$	**r_{xy}**

1080	77	245.56	5.44	1336.91	60297.5309	29.6419753	0.97
960	76	125.56	4.44	558.02	15764.1975	19.7530864	
910	75	75.56	3.44	260.25	5708.64198	11.8641975	
900	74	65.56	2.44	160.25	4297.53086	5.97530864	
860	72	25.56	0.44	11.36	653.08642	0.19753086	
720	69	-114.44	-2.56	292.47	13097.5309	6.5308642	
730	68	-104.44	-3.56	371.36	10908.642	12.6419753	
720	69	-114.44	-2.56	292.47	13097.5309	6.5308642	
630	64	-204.44	-7.56	1544.69	41797.5309	57.0864198	
$\bar{x}$=834.44	$\bar{y}$=71.56			4827.78	165622.22	150.22	

Appendix C12: Relation between Solar Intensity(W/m^2) and Drying Chamber Temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-15-02-23)

Solar Intensity **(W/m^2)** X (xi)	**Drying Chamber Tem. (^{0}c)** (°C) Y (y2)	$xi - \bar{x}$	$Y2 - \bar{y}$	$(xi - \bar{x}) * (y2 - \bar{y})$	$(xi - \bar{x})^2$	$(y2 - \bar{y})^2$	**r$_{xy}$**
1080	42	245.56	0.44	109.14	60297.5309	0.19753086	0.77
960	43	125.56	1.44	181.36	15764.1975	2.08641975	
910	42	75.56	0.44	33.58	5708.64198	0.19753086	
900	41	65.56	-0.56	-36.42	4297.53086	0.30864198	
860	41	25.56	-0.56	-14.20	653.08642	0.30864198	
720	40	-114.44	-1.56	178.02	13097.5309	2.41975309	
730	42	-104.44	0.44	-46.42	10908.642	0.19753086	
720	41	-114.44	-0.56	63.58	13097.5309	0.30864198	
630	42	-204.44	0.44	-90.86	41797.5309	0.19753086	
$\bar{x}$=803.33	$\bar{y}$=41.56			377.78	165622.22	6.22	

Appendix C13: Relation between Solar Intensity(W/m^2) and Absorber plate temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-12-02-23)

Solar Intensity **(W/m^2)** X (xi)	**Absorber plate temp.** (°C) Y1 (yj)	$xi - \bar{x}$	$yj - \bar{y}$	$(xi - \bar{x}) * (yj - \bar{y})$	$(xi - \bar{x})^2$	$(yj - \bar{y})^2$	**r$_{xy}$**
900	78	96.67	2.44	236.30	9344.44444	5.97530864	
960	79	156.67	3.44	539.63	24544.4444	11.8641975	

990	77	186.67	1.44	269.63	34844.4444	2.08641975	
800	75	-3.33	-0.56	1.85	11.1111111	0.30864198	
850	76	46.67	0.44	20.74	2177.77778	0.19753086	
700	76	-103.33	0.44	-45.93	10677.7778	0.19753086	0.76
720	77	-83.33	1.44	-120.37	6944.44444	2.08641975	
710	74	-93.33	-1.56	145.19	8711.11111	2.41975309	
600	68	-203.33	-7.56	1536.30	41344.4444	57.0864198	
$\bar{x}$=803.33	$\bar{y}$=75.56			2583.33	138600.00	82.22	

Appendix C 14: Relation between Solar Intensity(W/m^2) and Drying Chamber Temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-12-02-23)

Solar Intensity (W/m^2) X (xi)	**Drying Chamber Tem. (^{0}c)** (°C) Y (y2)	$xi - \bar{x}$	$Y2{-}\bar{y}$	$(xi - \bar{x}) * (y2{-}\bar{y})$	$(xi - \bar{x})^2$	$(y2 - \bar{y})^2$	**r$_{xy}$**
900	43	96.67	-1.11	-107.41	9344.44444	1.2345679	
960	46	156.67	1.89	295.93	24544.4444	3.56790123	
990	46	186.67	1.89	352.59	34844.4444	3.56790123	
800	43	-3.33	-1.11	3.70	11.1111111	1.2345679	
850	45	46.67	0.89	41.48	2177.77778	0.79012346	
700	44	-103.33	-0.11	11.48	10677.7778	0.01234568	0.76
720	45	-83.33	0.89	-74.07	6944.44444	0.79012346	
710	43	-93.33	-1.11	103.70	8711.11111	1.2345679	
600	42	-203.33	-2.11	429.26	41344.4444	4.45679012	
$\bar{x}$= 803.33	$\bar{y}$= 44.11			1056.67	138600.00	16.89	

Appendix C15: Relation between Solar Intensity(W/m^2) and Absorber plate temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-23-11-22)

Solar Intensity (W/m^2) X (xi)	**Absorber Tem. (^{0}c)** (°C) Y (y2)	$xi - \bar{x}$	$Y2{-}\bar{y}$	$(xi - \bar{x}) * (y2{-}\bar{y})$	$(xi - \bar{x})^2$	$(y2 - \bar{y})^2$	**r$_{xy}$**
940	78	230.00	3.33	766.67	52900	11.1111111	
920	77	210.00	2.33	490.00	44100	5.44444444	
950	80	240.00	5.33	1280.00	57600	28.4444444	

960	79	250.00	4.33	1083.33	62500	18.7777778	0.84
600	77	-110.00	2.33	-256.67	12100	5.44444444	
605	76	-105.00	1.33	-140.00	11025	1.77777778	
505	72	-205.00	-2.67	546.67	42025	7.11111111	
460	68	-250.00	-6.67	1666.67	62500	44.4444444	
450	65	-260.00	-9.67	2513.33	67600	93.4444444	
$\bar{x}$=710.00	$\bar{y}$=74.67			7950.00	412350.00	216.00	

Appendix C16: Relation between Solar Intensity(W/m^2) and Drying Chamber Temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-23-11-22)

Solar Intensity (W/m^2) X (xi)	Drying Chamber Tem. (^{0}c) (°C) Y (y2)	$xi-\bar{x}$	$Y2-\bar{y}$	$(xi-\bar{x})*(y2-\bar{y})$	$(xi-\bar{x})^2$	$(y2-\bar{y})^2$	r_{xy}
940	78	230.00	-1.33	-306.67	52900	1.77777778	0.75
920	78	210.00	0.67	140.00	44100	0.44444444	
950	77	240.00	2.67	640.00	57600	7.11111111	
960	76	250.00	1.67	416.67	62500	2.77777778	
600	75	-110.00	0.67	-73.33	12100	0.44444444	
605	76	-105.00	0.67	-70.00	11025	0.44444444	
505	74	-205.00	-1.33	273.33	42025	1.77777778	
460	72	-250.00	-1.33	333.33	62500	1.77777778	
450	72	-260.00	-2.33	606.67	67600	5.44444444	
$\bar{x}$=710.00	$\bar{y}$=44.33			1960.00	412350.00	22.00	

Appendix C17: Relation between Solar Intensity(W/m^2) and Absorber plate temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-07-11-22)

Solar Intensity (W/m^2) X (xi)	Absorber plate temp. (°C) Y1 (yj)	$xi-\bar{x}$	$yj-\bar{y}$	$(xi-\bar{x})*(yj-\bar{y})$	$(xi-\bar{x})^2$	$(yj-\bar{y})^2$	r_{xy}
980	78	224.22	7.44	1669.21	50275.6049	55.4197531	
955	76	199.22	5.44	1084.65	39689.4938	29.6419753	
970	77	214.22	6.44	1380.54	45891.1605	41.5308642	
960	75	204.22	4.44	907.65	41706.716	19.7530864	

725	72	-30.78	1.44	-44.46	947.271605	2.08641975	
612	68	-143.78	-2.56	367.43	20672.0494	6.5308642	0.97
550	64	-205.78	-6.56	1348.99	42344.4938	42.9753086	
530	63	-225.78	-7.56	1705.88	50975.6049	57.0864198	
520	62	-235.78	-8.56	2017.21	55591.1605	73.1975309	
$\bar{x}$=755.78	$\bar{y}$=70.56			10437.11	348093.56	328.22	

Appendix C18: Relation between Solar Intensity(W/m^2) and Drying Chamber Temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-07-11-22)

Solar Intensity (W/m^2) X (xi)	Drying Chamber Tem. (^{0}c) (°C) Y (y2)	$xi-\bar{x}$	$Y2-\bar{y}$	$(xi-\bar{x})*(y2-\bar{y})$	$(xi-\bar{x})^2$	$(y2-\bar{y})^2$	r_{xy}
980	43	224.22	0.33	74.74	50275.6049	0.11111111	
955	42	199.22	-0.67	-132.81	39689.4938	0.44444444	
970	44	214.22	1.33	285.63	45891.1605	1.77777778	
960	42	204.22	-0.67	-136.15	41706.716	0.44444444	
725	45	-30.78	2.33	-71.81	947.271605	5.44444444	
612	43	-143.78	0.33	-47.93	20672.0494	0.11111111	0.97
550	42	-205.78	-0.67	137.19	42344.4938	0.44444444	
530	43	-225.78	0.33	-75.26	50975.6049	0.11111111	
520	40	-235.78	-2.67	628.74	55591.1605	7.11111111	
$\bar{x}$=755.78	$\bar{y}$=42.67			662.33	348093.56	16.00	

Appendix C19: Relation between Solar Intensity(W/m^2) and Absorber plate temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-29-11-22)

Solar Intensity (W/m^2) X (xi)	Absorber plate temp. (°C) Y1 (yj)	$xi-\bar{x}$	$yj-\bar{y}$	$(xi-\bar{x})*(yj-\bar{y})$	$(xi-\bar{x})^2$	$(yj-\bar{y})^2$	r_{xy}
995	77	151.89	0.67	101.26	23070.2346	0.44444444	
984	78	140.89	1.67	234.81	19849.679	2.77777778	
949	78	105.89	1.67	176.48	11212.4568	2.77777778	
925	77	81.89	0.67	54.59	6705.79012	0.44444444	
956	76	112.89	-0.33	-37.63	12743.9012	0.11111111	
964	77	120.89	0.67	80.59	14614.1235	0.44444444	0.82

655	75	-188.11	-1.33	250.81	35385.7901	1.77777778	
605	76	-238.11	-0.33	79.37	56696.9012	0.11111111	
555	73	-288.11	-3.33	960.37	83008.0123	11.1111111	
$\bar{x}$=843.11	$\bar{y}$=76.33			1900.67	263286.89	20.00	

Appendix C20: Relation between Solar Intensity(W/m^2) and Drying Chamber Temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-29-11-22)

Solar Intensity (W/m^2) X (xi)	Drying Chamber Tem. (^{0}c) (°C) Y(y2)	$xi - \bar{x}$	$Y2 - \bar{y}$	$(xi - \bar{x}) * (y2 - \bar{y})$	$(xi - \bar{x})^2$	$(y2 - \bar{y})^2$	r_{xy}
995	43	151.89	-0.33	-50.63	23070.2346	0.11111111	0.75
984	43	140.89	-0.33	-46.96	19849.679	0.11111111	
949	43	105.89	-0.33	-35.30	11212.4568	0.11111111	
925	42	81.89	-1.33	-109.19	6705.79012	1.77777778	
956	44	112.89	0.67	75.26	12743.9012	0.44444444	
964	45	120.89	1.67	201.48	14614.1235	2.77777778	
655	45	-188.11	1.67	-313.52	35385.7901	2.77777778	
605	43	-238.11	-0.33	79.37	56696.9012	0.11111111	
555	42	-288.11	-1.33	384.15	83008.0123	1.77777778	
$\bar{x}$=843.11	$\bar{y}$=43.33			184.67	263286.89	10.00	

Appendix C21: Relation between Solar Intensity(W/m^2) and Absorber plate temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-30-11-22)

Solar Intensity (W/m^2) X (xi)	Absorber plate temp. (°C) Y1 (yj)	$xi - \bar{x}$	$yj - \bar{y}$	$(xi - \bar{x}) * (yj - \bar{y})$	$(xi - \bar{x})^2$	$(yj - \bar{y})^2$	r_{xy}
964	70	194.33	6.56	1273.96	37765.4444	42.9753086	0.82
953	71	183.33	7.56	1385.19	33611.1111	57.0864198	
933	71	163.33	5.56	907.41	26677.7778	30.8641975	
945	70	175.33	4.56	798.74	30741.7778	20.7530864	
666	70	-103.67	-0.44	46.07	10746.7778	0.19753086	
605	71	-164.67	1.56	-256.15	27115.1111	2.41975309	
765	70	-4.67	-7.44	34.74	21.7777778	55.4197531	

566	68	-203.67	-8.44	1719.85	41480.1111	71.308642	
530	66	-239.67	-9.44	2263.52	57440.1111	89.1975309	
$\bar{x}$= 769.67	$\bar{y}$=65.44			8173.33	265600.00	370.22	

Appendix C22: Relation between Solar Intensity(W/m^2) and Absorber plate temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-04-12-22)

Solar Intensity (W/m^2) X (xi)	Drying Chamber Tem. (^{0}c) (°C) Y (y2)	$xi-\bar{x}$	$Y2-\bar{y}$	$(xi-\bar{x})*(y2-\bar{y})$	$(xi-\bar{x})^2$	$(y2-\bar{y})^2$	r_{xy}
990	70	211.78	5.67	1200.07	44849.8272	32.1111111	0.96
980	71	201.78	6.67	1345.19	40714.2716	44.4444444	
970	70	191.78	5.67	1086.74	36778.716	32.1111111	
980	71	201.78	6.67	1345.19	40714.2716	44.4444444	
897	65	118.78	0.67	79.19	14108.1605	0.44444444	
666	64	-112.22	-0.33	37.41	12593.8272	0.11111111	
555	58	-223.22	-6.33	1413.74	49828.1605	40.1111111	
522	56	-256.22	-8.33	2135.19	65649.8272	69.4444444	
444	54	-334.22	-10.33	3453.63	111704.494	106.777778	
$\bar{x}$=778.22	$\bar{y}$=64.33			12096.33	416941.56	370.00	

Appendix C23: Relation between Solar Intensity(W/m^2) and Drying Chamber Temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-04-12-22)

Solar Intensity (W/m^2) X (xi)	Drying Chamber Tem. (^{0}c) (°C) Y (y2)	$xi-\bar{x}$	$Y2-\bar{y}$	$(xi-\bar{x})*(y2-\bar{y})$	$(xi-\bar{x})^2$	$(y2-\bar{y})^2$	r_{xy}
990	40	211.78	-0.67	-141.19	44849.8272	0.44444444	0.77
980	40	201.78	-0.67	-134.52	40714.2716	0.44444444	
970	41	191.78	0.33	63.93	36778.716	0.11111111	
980	42	201.78	1.33	269.04	40714.2716	1.77777778	
897	43	118.78	2.33	277.15	14108.1605	5.44444444	
666	41	-112.22	0.33	-37.41	12593.8272	0.11111111	
555	40	-223.22	-0.67	148.81	49828.1605	0.44444444	
522	41	-256.22	0.33	-85.41	65649.8272	0.11111111	

444	38	-334.22	-2.67	891.26	111704.494	7.11111111	
$\bar{x}$=778.22	$\bar{y}$=40.67			1251.67	416941.56	16.00	

Appendix C24: Relation between Solar Intensity(W/m^2) and Absorber plate temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-4-12-22)

Solar Intensity (W/m^2) X (xi)	Absorber plate temp. (°C) Y1 (yj)	$xi-\bar{x}$	$yj-\bar{y}$	$(xi-\bar{x})*(yj-\bar{y})$	$(xi-\bar{x})^2$	$(yj-\bar{y})^2$	r_{xy}
950	73	320.67	3.44	1104.52	102827.111	11.8641975	
290	72	-339.33	2.44	-829.48	115147.111	5.97530864	
800	72	170.67	2.44	417.19	29127.1111	5.97530864	
910	71	280.67	1.44	405.41	78773.7778	2.08641975	
720	70	90.67	0.44	40.30	8220.44444	0.19753086	.88
609	69	-20.33	-0.56	11.30	413.444444	0.30864198	
525	68	-104.33	-1.56	162.30	10885.4444	2.41975309	
440	67	-189.33	-2.56	483.85	35847.1111	6.5308642	
420	64	-209.33	-5.56	1162.96	43820.4444	30.8641975	
$\bar{x}$= 629.33	$\bar{y}$=69.56			2958.33	425062.00	66.22	

Appendix C25: Relation between Solar Intensity(W/m^2) and Absorber plate temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-6-12-22)

Solar Intensity (W/m^2) X (xi)	Drying Chamber Tem. (^{0}c) (°C) Y (y2)	$xi-\bar{x}$	$Y2-\bar{y}$	$(xi-\bar{x})*(y2-\bar{y})$	$(xi-\bar{x})^2$	$(y2-\bar{y})^2$	r_{xy}
1120	70	248.67	0.33	82.89	61835.1111	0.11111111	
990	71	118.67	1.33	158.22	14081.7778	1.77777778	
980	71	108.67	1.33	144.89	11808.4444	1.77777778	
930	70	58.67	0.33	19.56	3441.77778	0.11111111	
950	70	78.67	0.33	26.22	6188.44444	0.11111111	
940	71	68.67	1.33	91.56	4715.11111	1.77777778	0.97
654	70	-217.33	0.33	-72.44	47233.7778	0.11111111	
635	68	-236.33	-1.67	393.89	55853.4444	2.77777778	
643	66	-228.33	-3.67	837.22	52136.1111	13.4444444	
$\bar{x}$=871.33	$\bar{y}$=69.67			1682.00	257294.00	22.00	

Appendix C26: Relation between Solar Intensity(W/m^2) and Drying Chamber Temp.(°C) the by Pearson's Correlation's Correlation Formula. (Date-6-12-22)

Solar Intensity (W/m^2) X (xi)	Drying Chamber Tem. (^{0}c) (°C) Y (y2)	$xi - \bar{x}$	$Y2 - \bar{y}$	$(xi - \bar{x}) * (y2 - \bar{y})$	$(xi - \bar{x})^2$	$(y2 - \bar{y})^2$	r_{xy}
1120	42	248.67	1.22	303.93	61835.1111	1.49382716	0.95
990	41	118.67	0.22	26.37	14081.7778	0.04938272	
980	42	108.67	1.22	132.81	11808.4444	1.49382716	
930	42	58.67	1.22	71.70	3441.77778	1.49382716	
950	40	78.67	-0.78	-61.19	6188.44444	0.60493827	
940	42	68.67	1.22	83.93	4715.11111	1.49382716	
654	41	-217.33	0.22	-48.30	47233.7778	0.04938272	
635	39	-236.33	-1.78	420.15	55853.4444	3.16049383	
643	38	-228.33	-2.78	634.26	52136.1111	7.71604938	
$\bar{x}$=871.33	$\bar{y}$=40.78			1563.67	257294.00	17.56	

Appendix D

CALCULATION

Copper Plate Collector Efficiency

$$\eta_c = \frac{m_a C_{pa}(T_o - T_i)}{A_c I_g}$$

m_a=V× $\frac{\Pi d^2}{4}$ × ρ   Where,

= 2.5× $\frac{\Pi(0.15)^2}{4}$×1.06   V=2.5 m/s , d=0.15 m, ρ=1.06 kg/m^3

=0.047 kg/s

= $\frac{0.047}{9.81}$

=0.0048kg/s

$\eta_c = \frac{m_a C_{pa}(T_o - T_i)}{A_c I_g} \times 100$ Where,

$=\frac{0.0048\times1.005(80-36)}{1\times1.01}\times100$ C_{pa}=1.005 kJ/kg K, T_o=80,T_i=36,A_c=1m^2,I_g=1.01kw/m^2

=21%

Drying Efficiency of Copper Plate

$$\eta_d = \frac{m_w l_v}{m_a C_{pa}(T_0-T_i)}$$

$m_w=m_a(w_0-w_a)$ Where,

=0.0048(0.065-0.047) m_a=0.0048kg/s, W_o= 0.065 kgw/kga,W_a=0.047 kgw/kga

=0.0000864kg/s

$\eta_d = \frac{m_w l_v}{m_a C_{pa}(T_0-T_i)}\times100$ Where,

$=\frac{0.0000864\times210}{0.0048\times1.005(80-36)}\times100$ C_{pa}=1.005 kJ/kg K,T_o=68(^{0}C) ,T_i=30(^{0}C) ,T_c=45(^{0}C),

=8.5% l_v=210kj

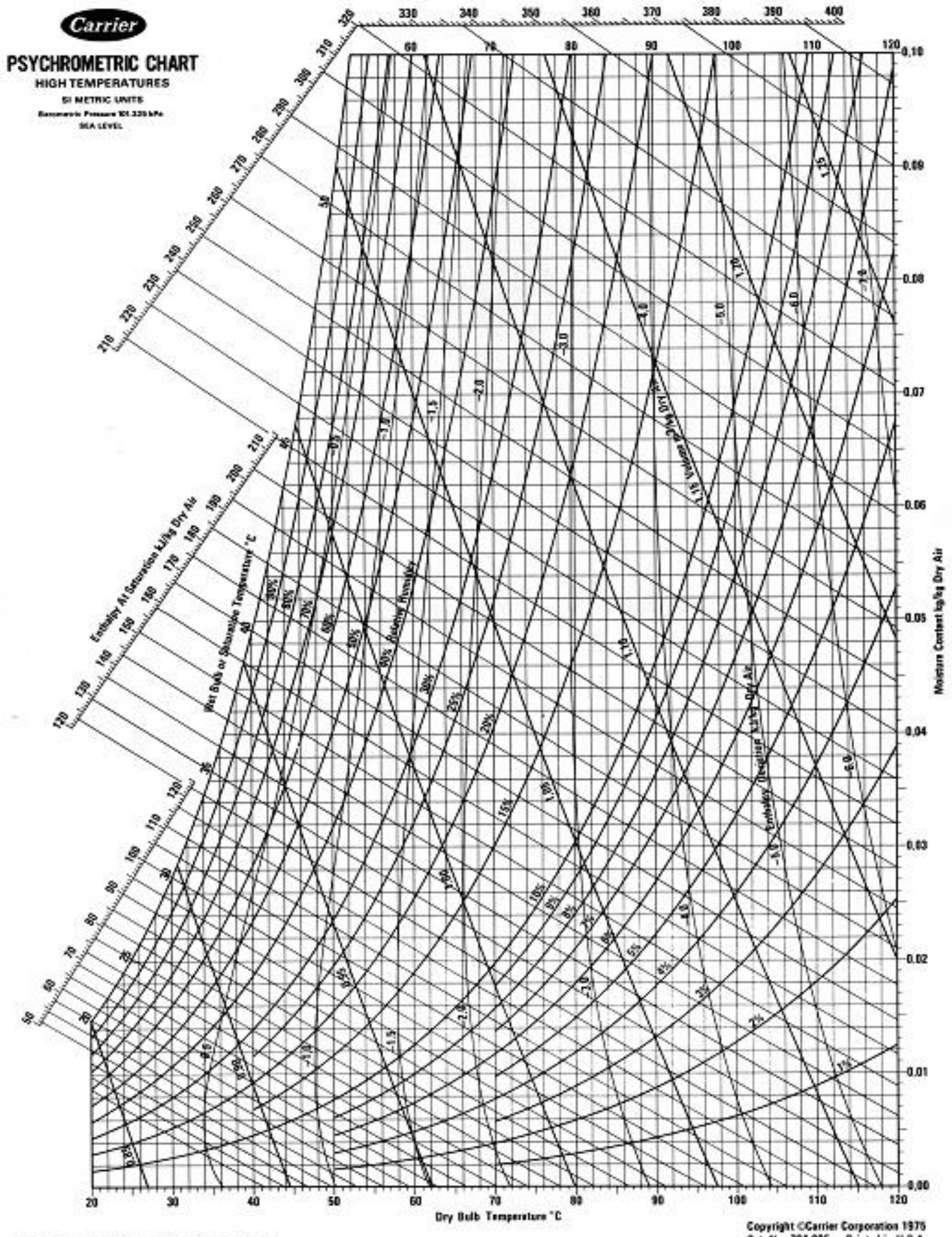


FIG. A.5. PSYCHROMETRIC CHART