
## Faculty of Mechanical Engineering

# DESIGN AND DEVELOPMENT OF AN OPTIMIZED MIXED MODE SOLAR DRYER

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**Master of Mechanical Engineering**

**(Energy)**

**2018**

# DESIGN AND DEVELOPMENT OF AN OPTIMIZED MIXED MODE SOLAR DRYER

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**A thesis submitted**
**in fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering**

**Faculty of Mechanical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2018**

## DECLARATION

I declare that this thesis entitles "**Design and Development of an Optimized Mixed Mode Solar Dryer**" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : 

Name : Ahmed Abdullah Ahmed Alqadhi

Date : 30/01/2018

## APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering (Energy)

Signature : 

Supervisor Name : Suhaimi Bin Misha

Date : 30/01/2018

## DEDICATION

To my beloved mother and father, to all my saplings, to all my friends.

## ABSTRACT

Solar drying is one of the methods that have been used since ancient times. This system has been constantly developed in the last few years to acquire better effective results and drying performance. The efficiency of the performance of a solar dryer is an essentially depends on the thermal distribution and uniformity of flow inside the drying chamber. There are various types of solar dryers have been developed and are classified based on the mode of air circulation (natural circulation and forced circulation), or based on the type of drying such as, direct solar drying, indirect solar drying and mixed mode solar drying etc. Relying on a single mode of these drying system might not provide the optimum results. Therefore, in this study a conceptual design of a mixed mode solar dryer which includes direct, indirect, and forced convection solar drying integrated with desiccant materials is developed and proposed. Some concepts of this design are new and others are inspired from recent works. Based on these, this mixed mode solar dryer is prospective to be superior in the rate of drying as well as air flow uniformity. Moreover, this improved drier which can be utilized for drying the diverse agricultural products is a simple system and might be manufactured locally. Moreover, a simulation of the system using CFD (Computational Fluid Dynamic) software was performed for the optimization of drying chamber configuration before fabrication by predicting the airflow distribution, temperature and velocity profiles throughout the dryer. This simulation process has the capability to resolve equations of mass conversation, energy and momentum utilizing numerical approach and it is a very useful tool to evaluate the temperature and velocity profiles in the various positions of the system and attain a uniform air flow with higher temperature inside drying cell or chamber. In addition, Simulation results are further validated against the experimental work results using data logger (Pico) device to plot temperature profile at diverse positions in the dryer.

## *ABSTRAK*

Pengeringan matahari adalah salah satu kaedah yang telah digunakan sejak zaman purba. Sistem ini telah dibangunkan secara konsisten dalam beberapa tahun kebelakangan untuk memperoleh hasil dan prestasi pengeringan yang lebih baik. Kecekapan prestasi pengering solar adalah bergantung asas pada pengedaran haba dan keseragaman aliran di dalam kebuk pengering Terdapat pelbagai jenis pengering suria yang telah dikembangkan dan dikelaskan berdasarkan cara peredaran udara (peredaran semulajadi dan paksaan), atau berdasarkan jenis pengeringan seperti, pengeringan suria langsung, pengeringan suria tidak langsung dan mod campuran pengeringan suria dan lain-lain. Bergantung pada satu mod sistem pengeringan ini mungkin tidak memberikan hasil optimum. Oleh itu, dalam kajian ini, reka bentuk konseptual dari pengeringan mod campuran yang terdiri daripada langsung tidak langsung dan paksa yang disepadukan dengan bahan-bahan pengering yang dibangunkan dan dicadangkan. Sesetengah konsep reka bentuk ini adalah baru dan yang lain diilhamkan daripada kekajian baru-baru ini. Berdasarkan ini, mod campuran pengering ini sesuai untuk menjadi lebih baik dalam kadar pengeringan serta keseragaman aliran udara. Tambahan pula pelbagai, pemanasan yang lebih baik ini boleh digunakan untuk mengeringkan produk pertanian, adalah system yang mudah dan boleh dihasilkan secara tempatan. Selain itu, simulasi sistem yang menggunakan perisian CFD (Computational Fluid Dynamic) dilakukan untuk mengoptimumkan konfigurasi kebuk pengeringan sebelum fabrikasi dengan meramal aliran udara, profil suhu dan halaju melalui pengering. Proses simulasi ini mempunyai keupayaan untuk menyelesaikan persamaan perubahan jisim, tenaga dan momentum menggunakan pendekatan berangka dan merupakan alat yang sangat berguna untuk menilai profil suhu dan halaju dalam pelbagai kedudukan sistem dan mencapai aliran hawa seragam dengan suhu yang lebih tinggi di dalam pengeringan sel atau ruang. Di samping itu, keputusan Simulasi disahkan terhadap hasil kerja menggunakan penyelog data untuk melakar profail susu di pelbagai kedudukan di dalam pengering.

## ACKNOWLEDGMENTS

First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor Dr. Suhaimi Bin Misha from the Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka (UTeM) for his essential supervision, support and encouragement towards the completion of this thesis.

I would also like to express my greatest gratitude to Dr. Ali Bin Ibrahim from Faculty of Electronic and Computer Engineering, co-supervisor of this research for his advice and suggestions in evaluation of microwave absorption measurement. Special thanks to UTeM short term grant funding for the financial support throughout this project.

Particularly, I would also like to express my deepest gratitude to all my friends for their great help and efforts.

Special thanks to all my colleagues, my beloved mother, father and siblings for their moral support in completing this degree. Lastly, thank you to everyone who had been associated to the crucial parts of realization of this project.

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## LIST OF ABBREVIATION

CFD - Computational Fluid Dynamics

PCM - Phase Change Material

PV - Photovoltaic

RCCD - Rotary Column Cylindrical Dryer

PAU - Portable Solar Dryer

## LIST OF APPENDICES

## LIST OF PUBLICATIONS AND AWARDS

The research papers produced and published during the course of this research with awards are as follows:

1. A. Alqadhi, S. Misha, M. A. M. Rosli, and M. Z. Akop, "Design and Simulation of an Optimized Mixed Mode Solar Dryer Integrated With Desiccant Material," Int. J. Mech. Mechatronics Eng., 2017.
2. Silver medal from the innovation Carnival UTeMEX2017, November 8, FTK lobby and Samsung IOT.

# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background

Drying is an ancient method that utilizes solar energy to dry an object, in which the object is exposed to the sun radiation so that it can be evaporated[1]. Usually, drying is the final and simple step in production which includes removal of the moisture contents from a product prior to packaging and presenting it to the market. Solar drying system can save energy, consume less time, utilize less space, enhance the products quality , increase the efficiency of the process and save the environment [2].

In general, energy is the backbone of human lives which means different types of energy are required by human beings in order to live, develop and perform duties. Most of the used energy in human's life is generated utilizing conventional resources which have great impacts in the environments. In order to eliminate the influence of these resources, must consider developing renewable energy resources such as solar ,wind, thermal energy .Such energy resources have less impacts to the environments as well as can be produced at less costs [3]. One of the application of renewable energy (Solar) is to be utilized in drying process .Solar dryer systems can be categorized into three different classes which are direct, indirect and mixed mode in accordance to the passive mode of drying process. The crucial feature of the solar drying system can be visualized from the fact that they operate fully with renewable energy which environmentally friendly and free of pollution. The construction of solar dryer system can be achieved simply with existed materials. The presence of solar energy dryer system can emphasize that, solar technology is a promising energy system with less environmental effects and air pollution. This verifies that, the solar

energy is the promising energy resources which can reduce the negative impacts to environment and enhance the development of sustainable energy[4].

## 1.2 Types of drying method

Solar dryers can be divided into two types which are the passive and active mode of solar dryer as can be depicted in Figure 1.1. In the passive mode dryer two sub-types are presented direct and indirect model. The direct sub-type dryer can be defined as a model in where the product is being exposed to the solar radiation in direct way. This occurs with the placement of the drying product in diaphanous enclosure of a glass or a plastic or inclusion of reflecting radiation like drying box. The purpose of using this reflecting radiation is to rise up the thermal value of the drying box. For the indirect sub-type of dryer, the product being dried subjected to the solar radiations in indirect way, where the products preheated using preheaters or collectors in order to increase the air thermal value in the drying champers. Passive solar drying systems can be referred as naturalistic convectors where the liquid motion is produced by the difference in the liquid densities occurring because of thermal values[5][6] [7].

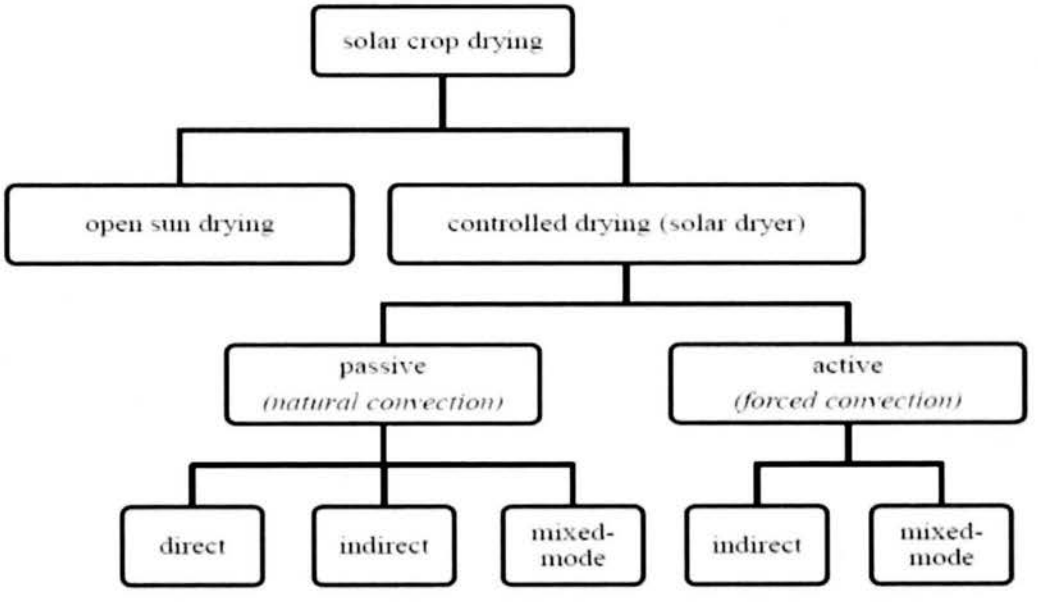
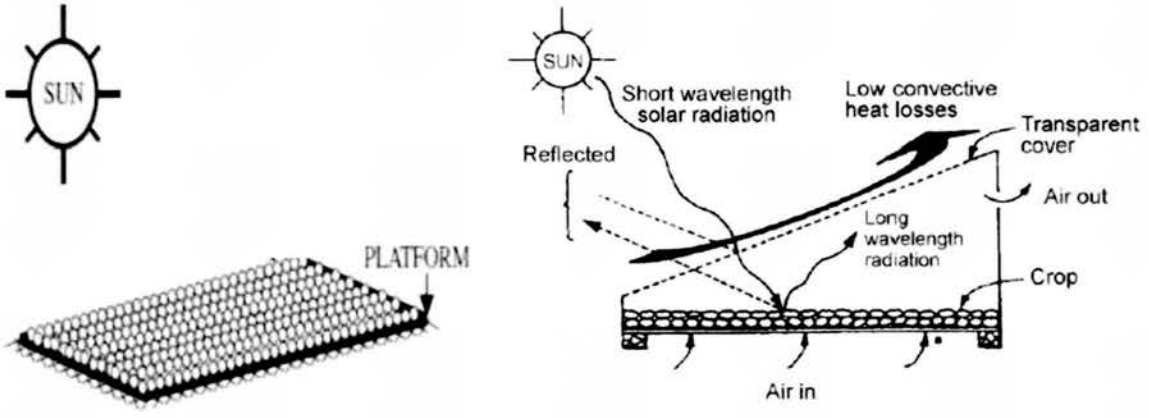



Figure 1.1 Classification of crop drying using solar energy. (Chen, 2009 and Bhattacharya)

### 1.2.1 Open Sun Drying

Drying products utilizing solar energy has been used as traditional method since long time ago. In these methods, the products are exposed to sun radiation in direct way in order to evaporate and heat them, so they can be dried. These conventional drying approaches also referred as open sun drying, the products are put on the floor or flat space, in which they are in direct way subjected to the sun's radiations and wind's air. Even though, this method can utilize sun radiations existed in the surrounding environments, less capital and human's individuals are required. In contrast, these methods can present some drawbacks such as poor product qualities, possible products loss due to external factors in the surrounding environment like rain, animals and birds hitting. The open sun dying method can be depicted in Figure 1.2[8] [9].




(a) (b)

Figure 1.2 (a) An open sun drying.,(b) Working principle of direct sun drying by using solar energy[4]

According to Chen et al. (2009)[4], he has observed that the shorted wavelengths solar radiations energy subjected to the crops surfaces that are reflecting and absorbing partially based on the crop color. The absorbing radiations will rise up the crop thermal value and make the humidity of the crops surface to be evaporated because of the increment of air in surrounded area. Direct solar drying is the simplest approach of solar of drying using solar energy; but, it consists of many drawbacks like:

a) Directly subjecting to sun radiation minimizes the quality of the items and decreases the beneficial ingredients from them.

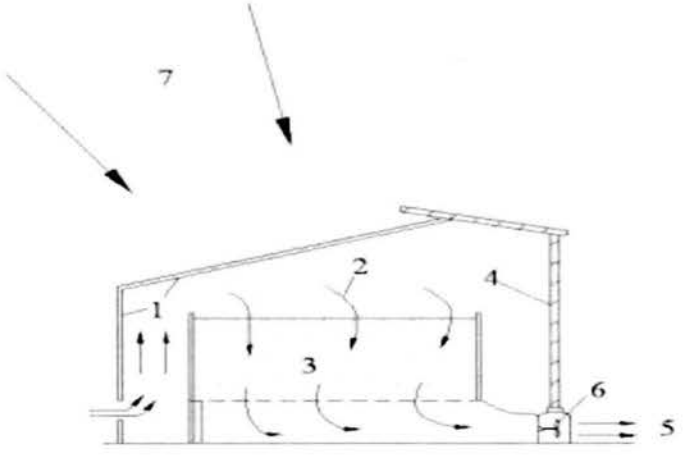
b) The drying rate is very low.

c) The drying rate is not controlled.

d) Products are subjected in direct way to frequent weather changes and low solar states.

### 1.2.2 Direct Solar Drying in Passive Mode

Direct solar drying basically comprises of a drying cell which wrapped by diaphanous coat from glasses or plastics. Therefore, this type of cover minimizes immediate convection loss to the nearby environment and rise up thermal within the dryer. The drying cell is a superficial, isolated box with hollows within it to enable air to get in and out the box. The items to be dried are located on a cribriform griddle that enables the air to inflow within it [10].




**1-Glazing; 2-Drying air; 3-Drying medium; 4-Drying wall; 5-Air exit; 6-Fan; 7-Incident solar radiation**

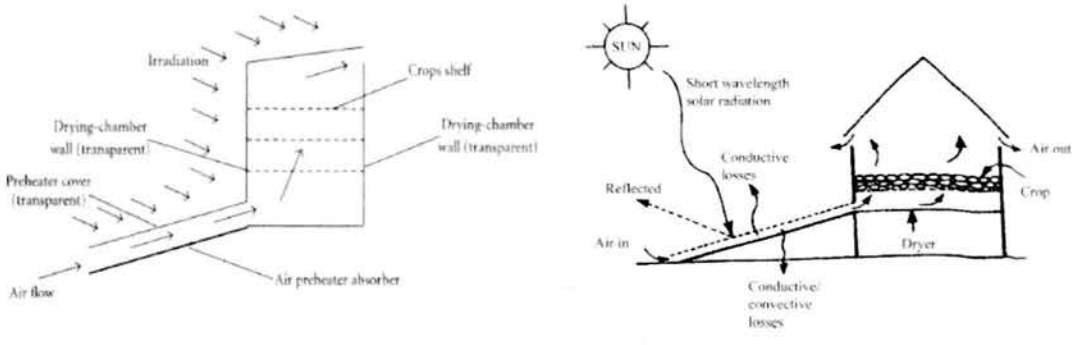
Figure 1.3 Cabinet dryer [10]

(Source: Gregoire (2009)

### 1.2.3 Indirect Solar Drying in Passive Mode

This type of dryer contain a cell for drying and collecting cell in which the sung energy is gathered in a separated tools referred as solar collectors which wrapped by diaphanous glass or plastic coating. A collection cell is utilized for solar energy gathering

for warming of coming air to the drying cell which in separate connection, where the item is located. The warmed air is can get through humid items. Where, the heat from humidity evaporating is produced by convection heat transfer with the heated air and the humid crops. Drying process is simply achieved due to the differentiation in humidity concentrating with the drying air and the air in the proximity of products. The products are indirectly subjected to sun radiations in order to reduce discoloring and crushing on the surface of the products. Figure 1.4 presents the basic construction of the indirect solar drying system with its working concept [11].




(a) (b)

Figure 1.4 (a) Indirect solar drying (b) Working principle of indirect solar drying [4]

(Source: Chen et.al (2009)

### 1.2.4 Mixed-Mode Solar Drying

This type of drying method is combining both direct and indirect drying method in which the hot air coming from the separated solar cell is transferred via a drying cell. This cell will be absorbing the solar energy via diaphanous coating simultaneously. The item being dried jointly by all radiations with conducting of heat via the diaphanous coating and the convective of the heat coming from the solar air heating. In contrast, mixed drying method can be also divided into two classes which is naturally convective class and coercive convective class. The advantages of such drying method are having less humidity