Faculty of Mechanical Engineering

STUDY THE ABSORPTION AND REGENERATION OF DESICCANT MATERIAL

Chua Lian Kai

Bachelor in Mechanical Engineering

2018

STUDY THE ABSORPTION AND REGENERATION OF DESICCANT MATERIAL

Chua Lian Kai

A thesis submitted
in fulfilment of the requirements for the degree of Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I hereby declare that this project entitled "Study the absorption and regeneration of desiccant material" is the results of my own work except as cited in the references.

Signature : ………………

Name : Chua Lian Kai

Date : ………………

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

SUPERVISOR DECLARATION

I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for award of the degree of Bachelor of Mechanical Engineering

Signature : ……………………….

Name : Dr. Suhaimi bin Misha

Date : ……………………….

اونيؤمرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ABSTRACT

Desiccant drying has been widely used in many industries such as shoes, food, flower and many more in the whole world. It can absorb water molecule and maintain at very low humidity for the aim to preserve the item or product for storing a longer period. Mixed mode Solar and Desiccant Dyer is designed to have both drying ability by using solar energy during the day while desiccant material continues the drying process at the night to improve the efficiency and improve drying rate of the product. 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 and desiccant dryer is an essentially depends on the temperature and humidity inside the drying chamber. There is various type of desiccant dryer have been developed and are classified based on the type of desiccant such as liquid desiccant flowing system, solid wheel desiccant dryer and solid recycle drying chamber. Therefore, in this study mixed mode dryer integrated with desiccant material been developed have been used to study the performance of the desiccant material. Solid desiccant that been chosen which is the silica gel are very attractive to water molecule and can absorb up to 30% of its own weight depend on which types of silica gel used. On the other hand, silica gel also can be regenerated naturally under certain temperature produce by the hot sun. It can be reused, and it is a kind of renewable source for drying products. Moreover, silica gel acts as a drying agent in agriculture field nowadays, to optimize the performance of the silica gel. Experiments need to be carried on for the optimization the ability of silica gel in drying process. In addition, data collected form the results by using Anemometer had been calculated to plot the temperature and humidity profile and analysis the trend of the performance. In results of the finding, the higher the temperature in the closed system, the lower the ambient air humidity, then will affect the drying rate to be higher throughout the whole drying process. On the other hand, regeneration requires a high and constant heating temperature, low surrounding air humidity, and a constant air flow to obtain the optimum regeneration rate for the silica gel.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ABSTRAK

Bahan pengering telah banyak digunakan di banyak industri seperti kasut, makanan, bunga dan banyak lagi di seluruh dunia. Ia boleh menyerap molekul air dan mengekalkan kelembapan yang sangat rendah untuk tujuan mengekalkan item atau produk untuk menyimpan masa yang lebih lama. Mesin pengering mod bercampur direka untuk mempunyai keupayaan pengeringan dengan menggunakan tenaga solar pada siang hari manakala bahan pengering meneruskan proses pengeringan pada masa malam untuk meningkatkan kecekapan dan meningkatkan kadar pengeringan produk. Sistem ini telah sentiasa dibangunkan dalam beberapa tahun kebelakangan ini untuk memperoleh hasil yang lebih baik dan prestasi pengeringan. Kecekapan prestasi pengering suria dan pengering adalah pada dasarnya bergantung pada suhu dan kelembapan di dalam ruang pengeringan. Terdapat pelbagai jenis pengering desiccant yang telah dikembangkan dan dikelaskan berdasarkan jenis pengering seperti sistem aliran pengeringan cecair, pengering desiccant roda pepejal dan ruang pengeringan kitar pepejal. Oleh itu, dalam kajian ini, pengering mod bercampur yang disepadukan dengan bahan desiccant yang telah dibangunkan telah digunakan untuk mengkaji prestasi bahan desiccant. Bahan pengering padat yang dipilih ialah gel silika yang sangat menarik untuk molekul air dan dapat menyerap sehingga 30% dari beratnya sendiri bergantung pada jenis gel silika yang digunakan. Sebaliknya, gel silika juga boleh diregenerasi secara semula jadi di bawah suhu tertentu yang dihasilkan oleh matahari panas. Ia boleh digunakan semula dan ia adalah sejenis sumber yang boleh diperbaharui untuk pengeringan produk. Selain itu, gel silika bertindak sebagai agen pengeringan di bidang pertanian pada masa kini, untuk mengoptimumkan prestasi gel silika. Eksperimen perlu dijalankan untuk mengoptimumkan keupayaan gel silika dalam proses pengeringan. Di samping itu, data yang dikumpulkan membentuk keputusan dengan menggunakan Anemometer akan dikira untuk merancang profil suhu dan kelembapan dan menganalisis trend prestasi. Dalam hasil penemuan, semakin tinggi suhu dalam sistem tertutup, semakin rendah kelembapan udara ambien, maka akan mempengaruhi kadar pengeringan menjadi lebih tinggi sepanjang keseluruhan proses pengeringan. Sebaliknya, penjanaan semula memerlukan suhu pemanasan yang tinggi dan berterusan, kelembapan udara persekitaran yang rendah, dan aliran udara malar untuk mendapatkan kadar pertumbuhan semula optimum untuk gel silika.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ACKNOWLEDGEMENT

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 continuous encouragement towards the completion of this thesis. I really appreciate his guidance from the initial to the final level that enabled me to develop an understanding of this final year project thoroughly. Without his advice and assistance, it would be a lot tougher to completion. I also sincerely thanks for the time spent proofreading and correcting my mistakes.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I am really thankful for their sacrifice, patience, and understanding that were inevitable to make this work possible. Their sacrifice had inspired me from the day I learned how to read and write until what I have become now. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to achieve my dreams.

Lastly, I would like to thank any person which contributes to my degree final year project directly or indirectly. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TABLE OF CONTENTS

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF TABLES

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF FIGURES

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Drying is defined as a process which reduce the level of dampness of the grain and ensure it to be secure for storing purpose over a long period of time. Theoretically, drying involves heat and mass transfer among the particles of air and the product itself. Temperature plays an important role during the drying process. For the normal drying process, heat energy will be transferred to the product with the increasing in temperature. As the temperature increases, heat energy increase, water molecule reaches the boiling point, evaporation starts to occur until the product completely dry. In fact, the heat transfer rate will be proportional to the temperature. Other than temperature, the mass is also transferred and called mass-transfer coefficient (R.L.Earle, 2018). High temperature dry air is used to dry the product, and totally remove all the moisture content inside it. The result can be clearly seen by experiment and plotting moisture content versus function of time graph. In the industrial field over the world, drying process used up to 12% of total energy. Moreover, the increasing in fuel price will lead to reduce the income of industries who involved in drying (Misha S. M., 2012).

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Based on the Figure 1.1 below, it is the post production system of food or agriculture field industry. Normally, it always before the storage process and called in-store drying and usually is the last step and a simple step in production. If drying process does not carry up properly, industries will face high losses although storage is done perfectly. Why is drying so important? A good drying will increase the quality of the product. If the products are wet always, it does not preserve long and lead to bad quality issues. At last, the industry will have less profits.

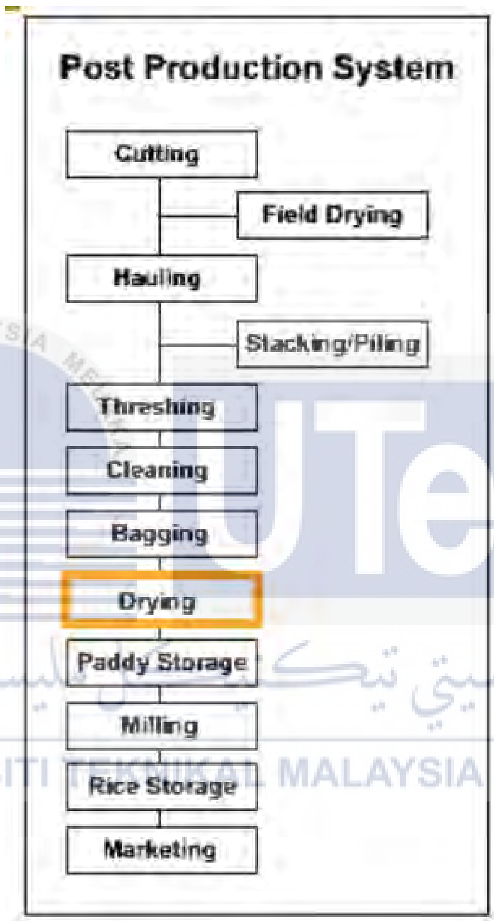


Figure 1.1 Post Production System (User.S, 2018)

The table 1.1 below shoes the perfect moisture content (MC) to store the paddy grain and seed. It also noted down all the possible problem that will be faced if the moisture content is not right (User.S, 2018).

Table 1.1 Moisture content and possible problem faced (User.S, 2018)

Storage period	Required MC for safe storage	Possible problems
2-3 weeks	14-18%	Molds, discoloration, respiration loss
8 to 12 months	13% or less	Insect damage
More than 1 year	9% or less	Loss of viability

For example, after harvesting wheat from the paddy field, rice will contain a total of 25% moisture. Without proper drying process before storage, many problems will be occurred such as changes in color, attract pests, and causes the rice to be decay. The rate of germination of the rice seed can also decrease. The perfect timing to dry the rice grain ideally is within 24 hours after harvesting. If not, there will be very bad quality and results in losses (Drying - IRRI Rice Knowledge Bank. , 2018).

Solar drying has been implemented worldwide since century ago. It is a traditional method and normally used for crops, fruits and vegetables. Solar drying happens anytime as long as the products is direct contact to the sun under the open sky. Solar energy is the main source for producing heat energy to the particular product. Either natural or forced convection occur and create an air flow. The heating process could be either preheated air flow cross over the product or the product direct expose to solar radiation or a mix of both (Ekechukwu, 1999). Solar energy is a renewable energy which can use only in daytime only. So many designs have been created with the aids of desiccant materials. It has a function of absorbing moisture from the surrounding no matter with or without solar energy.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Desiccant materials are often used in drying purposes. They are chemical who have good properties and special function. They are sensitive to moisture which mean that they can easily absorb or release the moisture. This is because vapour pressure between the surrounding air and the desiccant contact surface have changes. With the change of pressure until the desiccant surface is less than surrounding air, drying or dehumidification will happen. The process will continue till pressure equilibrium is achieved within desiccant material and surrounding air. Heat up the desiccant material is one of the methods to aid them for regeneration. When temperature increase, vapour pressure of desiccant surface will then larger than surrounding air and then regeneration started to occur (Jeong Jongsoo, 2011).

1.2 Problem Statement

The desiccant material chosen for the experiment is the silica gel. The experiment is carried up mainly focus on food or agriculture industry. During the process, air will be flow in through the fan and pass through the silica gel, all the water will be absorbed and produce dry air to the food. The problems faced on this experiment is the silica gel might not fully absorb the water molecule in the food and might give serious effect to health problem. In result, wet products cannot be kept for a longer time and faced quality issues. For this project, there are some question included:

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

1. What is the rate for the desiccant material to absorb the moisture content of the product?
2. What are the effects to the health when the dry air which water is been absorbed by the desiccant to the product?
3. What is the amount of desiccant required to run the drying process?

1.3 Objectives

The objectives of this project are as listed:

1. To conduct experiment on the performance of desiccant material
2. To analyze and discuss the performance of desiccant material with water
3. To study the absorption rate and regeneration rate of desiccant material

1.4 Scope of Project

The work scope of this study focused on two main components which are desiccant material (silica gel), and the circulation air flow of the chamber. Air flow temperature are uniformity inside the drying chamber along with the air velocity are the most important measured parameters. The relative humidity would be reduced during day time due to the high temperature. Some designs have been implemented to ensure that the air is dried and managed to absorb the water from the food sample until it reaches its moisture content level. Silica gel is chosen and aimed to be investigated in this study to achieve better and efficient drying of the food samples. The experiment work is carried up in UTEM lab at the faculty of mechanical engineering. After the drying process, final moisture content will be achieved based on different products. The regeneration rate and absorption rate of silica gel will be tested to ensure that it is efficient to be used for drying purpose. Agricultural product will be replaced by wet sponge that have been absorbed water to be dried. Drying rate will be tested throughout the experiment based on the wet sponge.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 2

LITRETURE REVIEW

2.1 Desiccant Materials

Desiccant defines as a drying agent which has a very high attraction towards the moisture content. It is a hygroscopic material that convince or assist the surrounding humidity or serves to keep up a condition of dryness; it's the inverse of a humectant, which serves to advance moisture retention. The purpose of desiccants used to wipe out humidity from the surrounding air. Desiccant materials mostly used in agriculture and food products. Choosing a desiccant material to use must be concerned. The reason behind this is the possibility of affecting the products quality or damaging them. The selection must base on different working parameters, including vapour pressure, boiling point elevation, energy storage density, thermo physical properties, regeneration temperature, availability, cost and many more (Shukla, 2017). A moisture removal process produces not just dried air but rise up thermal rate is obtained, because of the isothermal operation. When the thermal rate and moisture is very low, the drying process can be achieved by utilizing a material that can keep the color of the product fresh. The main function of desiccant in accordance to the concept of humidity transferring because of the vapor pressure with the air and the desiccant material (C.L. Hii, 2009). The invention of desiccants is counted as renewable energy, but it needed renewable or non-renewable energy to regenerate.

There are many types of desiccants and can be divided into many groups such as montmorillonite clay, silica gel, molecular sieve, calcium sulfate and calcium oxide.

Montmorillonite Clay is a natural occurring permeable adsorbent. It is a type of mined clay which is operated for utilize as a desiccant through careful drying. The clay can be used for many times at very low temperature without physical changes. Silica gel is a kind of polymeric colloidal silicic acid at incompletely dried out shape. On the surface of the silica gel contain lots of interconnected pores that will hold water, allowing it to absorbs up to 40% of its weight in water. Molecular sieves have a higher adsorption rate than silica gel or clay. Although molecular sieves are the best among all, but it is higher in cost and lack of support for further studies. Calcium oxide (CaO) also calls quick lime is efficient in keeping moisture content at very high temperature and have a moisture absorption level of not less than 28.5%. Calcium sulphate ($CaSO_4$) is invented to be broadly useful desiccant equipped. It is safe to use and chemical free although expose to high temperature. A comparison of the desiccants and graph of different desiccants showing their absorbing rate and capacity is shown in Fig 4. Selecting the suitable desiccant type can be done by comparing the features and capabilities of the desiccant in which the absorption rate and capacity are investigated in order to determine the suitability of the material for the specific application. From the studies of features, silica gel is the most suitable desiccant for application that requires high absorption rate. (Desiccant Chart Comparisons, 2018)

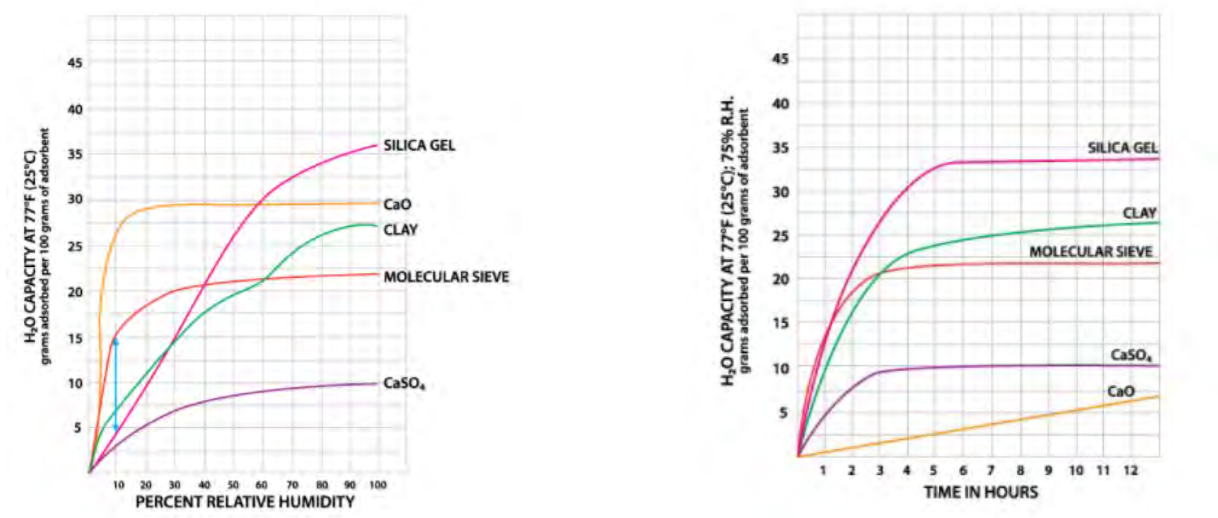


Figure 2.1 Absorbing rate and capacity of different desiccants (Desiccant Chart Comparisons, 2018)

2.2 Types of desiccant dryer

Desiccant materials consist of two types which are liquid or solid type. Both types have its own ability and properties. Every desiccant material has its own absorption rate and volume of moisture content. The best desiccant material has a high adsorption limit with respect to all scopes of relative moistness (humidification process) and can be recovered at low temperature. Different types of dryer need specific type of desiccant and will rely upon expected application. Normally, research stated that solid desiccant is more efficient than liquid desiccant. The reason of this statement might consider of the absorption rate, effective and easy to be found. Moreover, solid or liquid desiccant used in drying application is still new and normally used when sunlight is absence. If compared drying using solar or desiccant, solar energy still better than any desiccant material.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.2.1 Solid Desiccant Based Dryer

There are many experiments on desiccant material have been carried up in air conditioning system. Hazeeb Halib et al. had conducted an experiment by testing the temperature of the process air inlet and outlet of the system. They have designed a desiccant wheel dehumidifier by themselves as the Figure 2.2 below. The system is designed to be two paths for the air stream to pass through. There is a desiccant process area which design to be round container to put the desiccant material inside. The first air flow which is called process air will pass through the desiccant to be dried. During the process, desiccant will absorb the moisture content, heat of absorption will then deliver to the air. Second air flow of the system named reactivation or regeneration air. Its function is to dry off the desiccant by heating it up. They also claimed that the rotational speed will affect the absorption rate also. The higher the speed of rotation, the lower the absorption rate.

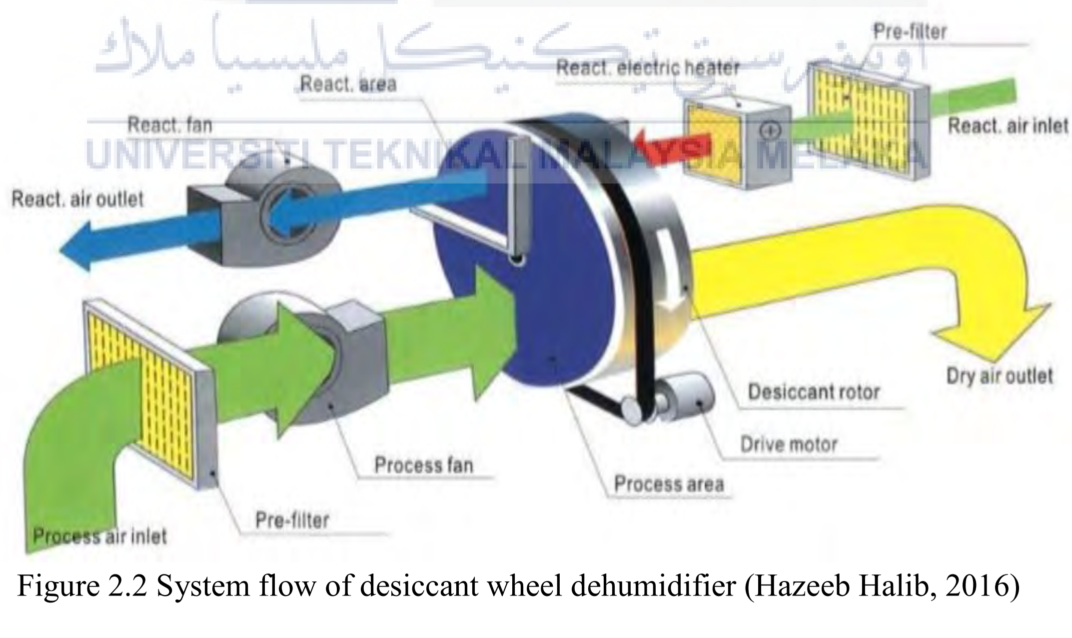


Figure 2.2 System flow of desiccant wheel dehumidifier (Hazeeb Halib, 2016)

Since the humidity is getting very low due to absorption by the desiccant, these will affect the temperature to increase too. This is because of the sensible heat created when the heat of sorption of moisture being reduce from the air. Other than that, during the regeneration process, desiccant is being heat up and remain hot. The heat energy will then transfer to the air when the dehumidifier process is carrying on. There will be around 80 to 90% of the increment of the temperature of the air flow from the heat of sorption. has analysis the temperature and recorded during experiment. The table 2.1 below show the temperature difference of inlet and outlet of the system. (Hazeeb Halib, 2016)

Table 2.1 Temperature difference with inlet and outlet (Hazeeb Halib, 2016)

Inlet Temperature(^{0}C)	Outlet temperature(^{0}C)
28.1	34.3
28.6	34.6
29.2	35.5
29.8	35.9
30.4	36.8
31.7	37.8
32.3	38.2
32.9	38.8

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Misha et al. designed a solar assisted solid desiccant dryer with the presence of solid desiccant wheel as in Figure 2.3. The purpose of creating this system is to ensure that product can also be dried even solar radiation is absence. Silica has been choosing as the desiccant material while kenaf core fiber as the drying product. When there is no sunlight, desiccant will play the role as a dehumidifier material to absorb the moisture content from the core fiber. Solid desiccant wheel is used at the drying chamber shown in Figure 2.4. The results showed that desiccant wheel was bad in performance, just 19% and 5% of value based on regeneration and dehumidification effectiveness. Besides, the experiments show that with the desiccant wheel, the temperature able to increase up to 38 degrees Celsius and decrease the average absolute humidity from 19.59 to 18.88g of water/kg dry air.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

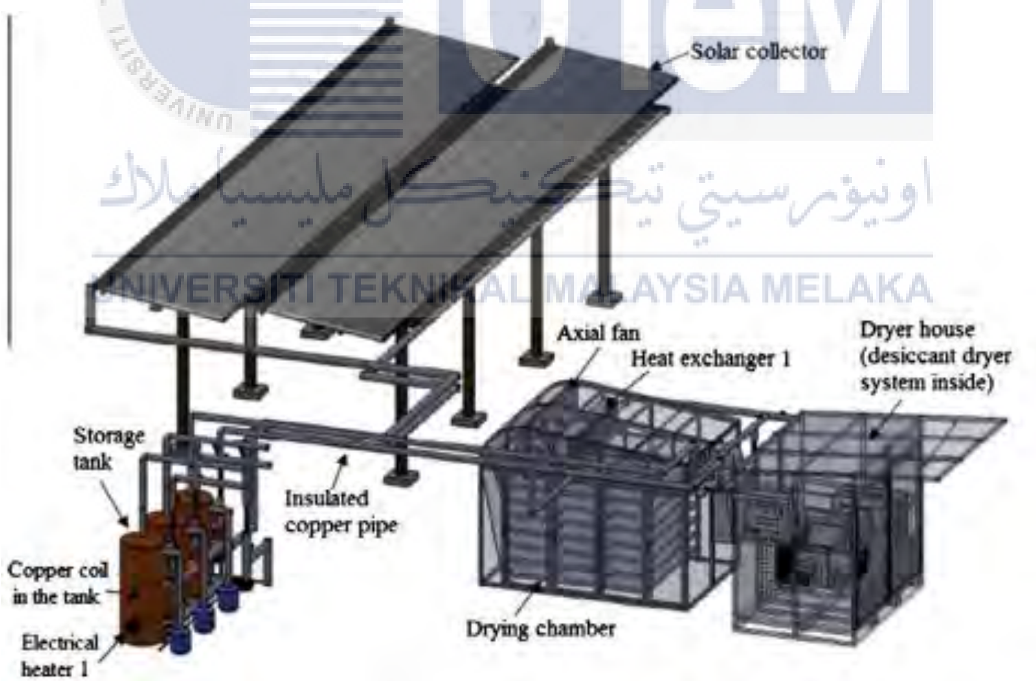


Figure 2.3 Solar assisted solid desiccant dryer (Misha S. M., 2015)

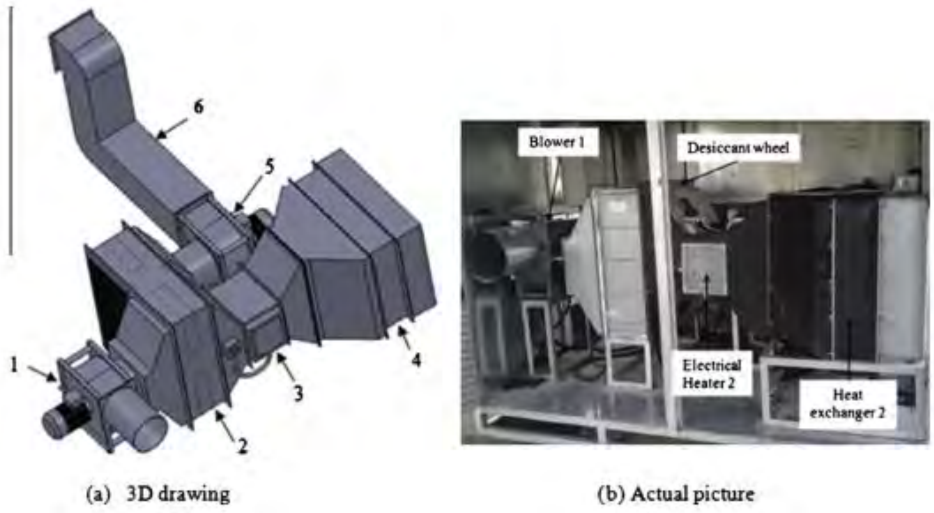


Figure 2.4 Solid desiccant Wheel in drying chamber (Misha S. M., 2015)

Shanmugam et al. built a solar dryer with indirect forced convection and desiccant incorporated as shown in Figure 2.5. It is designed to carry up to 75kg of calcium chloride-based desiccant material for drying purpose. There is a double glazing at the roof of the dryer chamber and a 50mm gap. A 30°C slanted as like flat plate collector for the purpose to decrease the net heat loss from the desiccant bed. In results, weight loss of the product used is about 70% through direct sunlight and the rest is dried up by the desiccants. When the thermal rate reaches the peak, flatted plates collectors heating the air, and blowers force the high thermal rate air to the desiccant by 20% and reduce dryer period by two hours fore produced the desiccant bed. The experiments conclude that using desiccant can continue drying the products during off-sunshine hours without solar drying and can enhance the quality of the drying product.

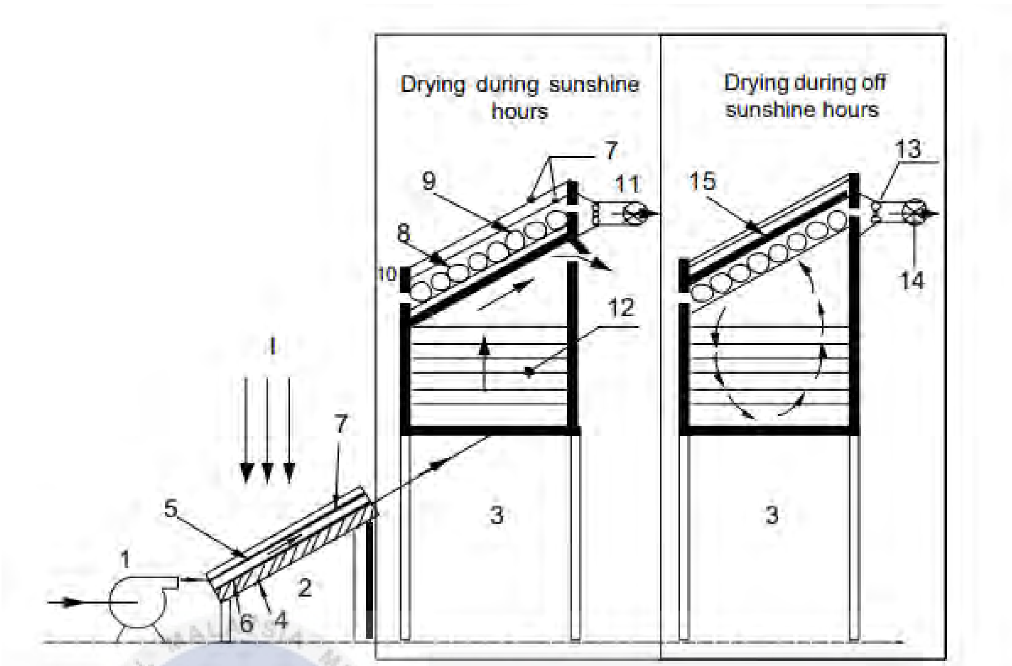


Figure 2.5 Solar dryer with indirect forced convection and desiccant incorporated (Shanmugam, 2006)

Chramsa-Ard et al. proposed and construct a desiccant-based bed solar dryer by using silica gel bed (SGB) suited when there is absence of solar energy for constant drying process as in Figure 2.6. They have designed 3 silica gel bed (SGB) in three directions; west, east and top with the consideration of the desiccant regeneration and capability to draw up moisture, high temperature will results decreasing on the regeneration process use only regeneration process and ability of desiccant to draw up moisture. Silica gel bed focus more on the air dehumidifying during the experiment. Different positions of silica gel bed will result in different absorption rate of silica gel by the highest at top, next is the west and last is the east silica gel bed. They found that the high moisture air is the air which has high humidity ratio. Based on the graph plotted, the parameter that direct effects the silica gel absorption rate is air temperature. The increment of temperature will result in decreasing of absorption rate and humidity ratio of humid air but increasing in absorption rate. By the presence of dehumidification system, they have concluded that shorter time need to dry product, less energy used and has more energy efficiency.

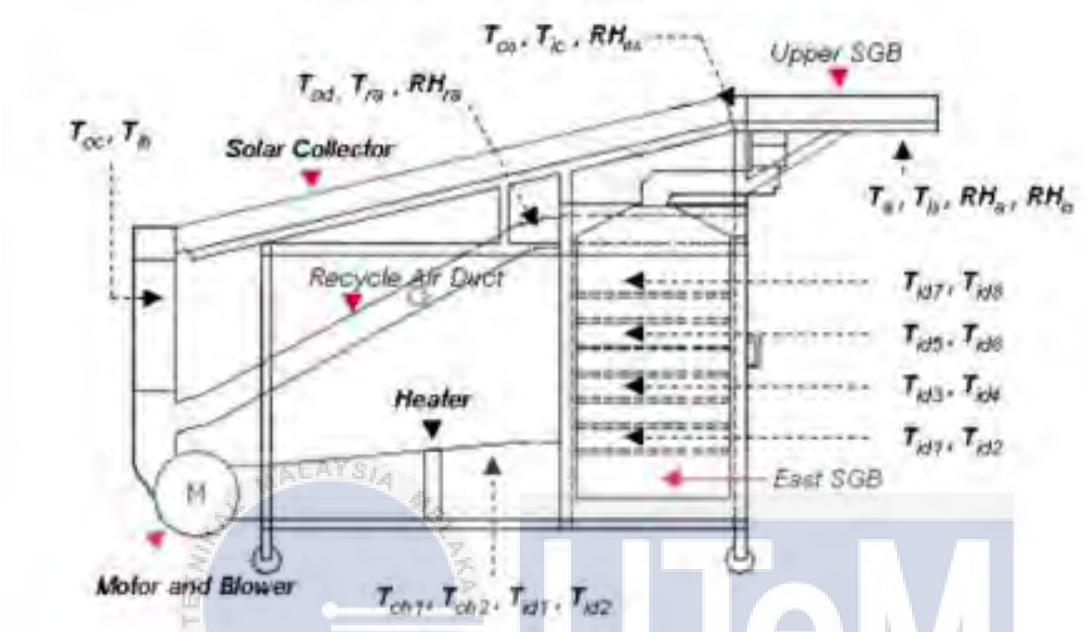


Figure 2.6 Desiccant-based bed solar dryer (Chramsa-Ard, 2013)

UTeM
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Thoruwa et al. fabricated a solar dryer which a solar drying system incorporated with desiccant materials for drying grains in large scale as in Figure 2.7. The solar dryer can be used for day and night. During the daytime, drying process is running utilizing the air heated by solar and independent simultaneous regeneration of the desiccant bed. Meanwhile at night, desiccant material plays its role to absorb moisture by utilizing coercive air circulation across the grains and through the desiccant bed. The desiccant bed is designed as a shallow tray with a perforated bottom located above of the maize bed as in Figure. In 24 hours', time of experiment, the drying system able to dry 90kg of maize grain from 38% to 15%.

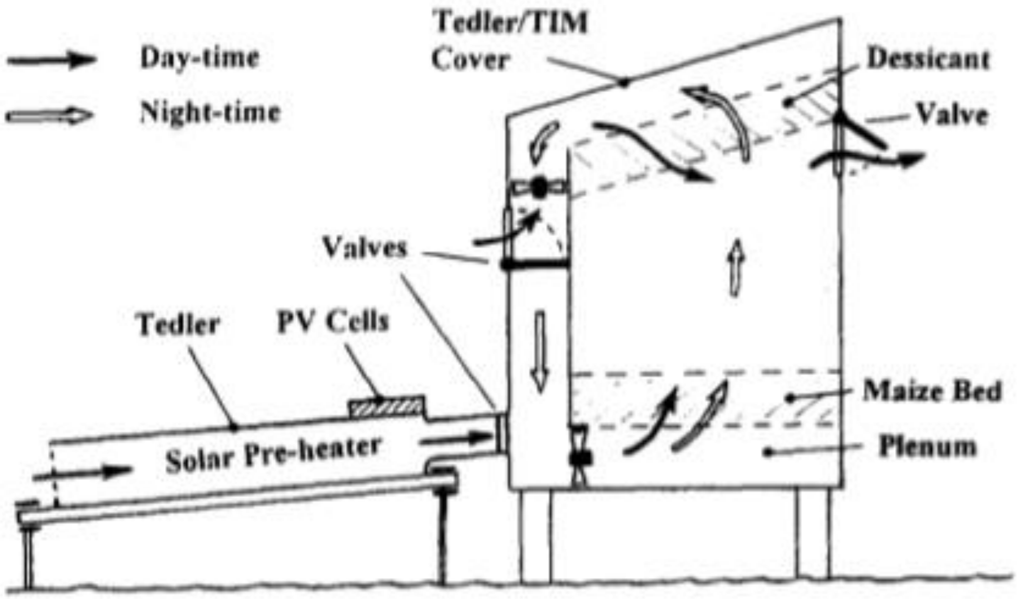


Figure 2.7 Operation Solar desiccant mixed dryer (Thoruwa, 1996)

Sari Farah Dina et al. proposed and built the solar dryer coherent with desiccant materials thermal storage to dry freshy cocoa beans as in Figure 2.8. The main purpose of the dryer is to effectively continuous drying the freshy cocoa beans for day and night. The solar dryer is divided into two chambers; solar collector; and thermal energy storage. When the sun is available, solar collector absorb solar energy to heat up the air and dry the freshy cocoa bean inside the drying chamber. Direct solar energy also will heat up the thermal storage in order to keep the heat and to remove moisture content. So, when sunlight is absence during night time, the thermal storage which placed inside the drying chamber along with the freshy cocoa beans will continue the drying process. The decreasing in temperature does not effect on the drying process as the desiccant still can absorb the moisture and dry up the freshy cocoa beans. The Figure shows that at nighttime, the sensors will trigger and close the entrance of the drying chamber. So that air circulation can happen to circulate the dried air from the desiccant and continue drying process.

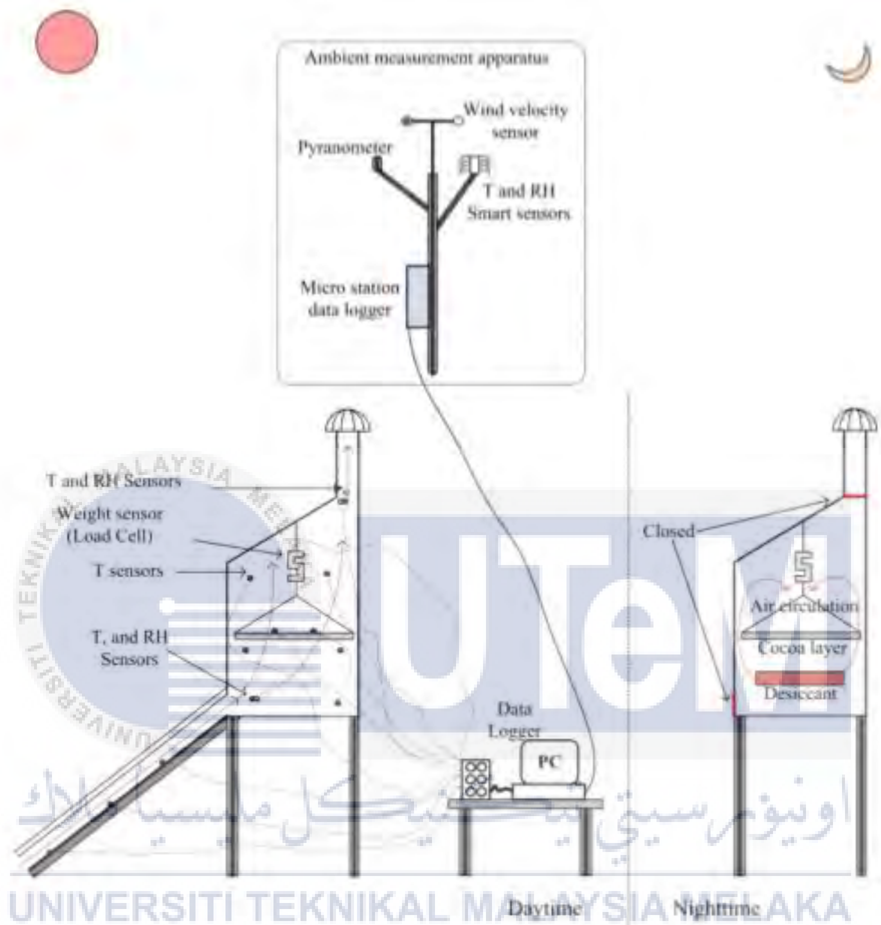


Figure 2.8 Solar dryer coherent with desiccant materials thermal storage (Dina, 2015)

2.2.2 Liquid Desiccant Based Dryer

Milind V. Rane et al. developed a liquid desiccant-based dryer (LDBD) and studied on the energy efficiency on drying system as in Figure 2.9. An aqueous solution of calcium chloride has been chosen as the liquid desiccant in the two-stage regeneration and it is utilizing to enhance the energy efficiency. Two stage regeneration consists of high temperature regenerator (HTR) and low temperature regenerator (LTR). At the first stage, steam is generated then transfers its latent heat of condensation to liquid desiccant in the second stage. Total water evaporated is twice times of the single stage for the same heat enter in first stage during the regeneration process. The dryer can work at very low liquid throughout. When the process is going, there is no mixing between process air and liquid desiccant, so it is suitable for drying food products. Results show that the energy effectiveness have increase to 42%. It still can be increase by enlarge the area and lower down flow rate of liquid desiccant. Any products that sensitive to heat can be dried, this is because the process air temperature in the dryer will not exceed 50°C. However, the LDBD is ecofriendly and techno-economically superior as it saves in primary fuel and resultant CO_2 emission at least 56%.

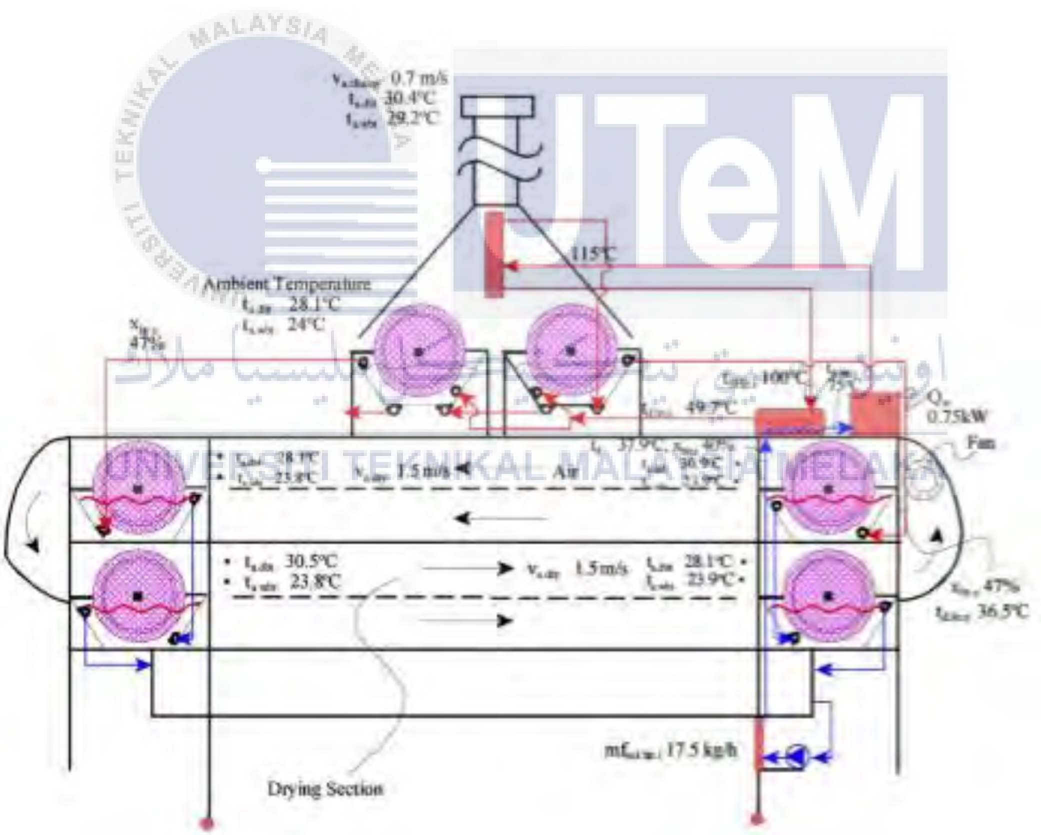


Figure 2.9 Liquid desiccant-based dryer (LDBD)

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Yonggao Yin et al. investigated on coupled heat and mass transfer coefficient and designed an air-drying system utilizing liquid desiccant as in Figure 2.10. They have selected lithium chloride aqueous solution (LiCL-H_2O) as the liquid desiccant drying agent. Liquid desiccant flows rate is being controlled by the pressure meter pump, then dispense over the product packing evenly, flowing oppose direction to the humid air. There are differences in temperature and vapor pressure among the pressurized liquid desiccant and compressed air, so heat and mass transfer will start happen in the dryer chamber. In results, moisture content in the humid air will be absorbed after meeting up desiccant with low surface vapor pressure. The increment in mass flow rate of the desiccants can maintain low vapor pressure and renew desiccant surface, which effect the mass transfer coefficient to increase. However, heat transfer coefficient will decrease accordingly. Besides, the higher the temperature of the liquid desiccant, the higher the vapor partial pressure. This show that high temperature does not give benefits in drying. The heat and mass transfer coefficient increase linearly when the concentration of the solution is increased after the experiments. They also proved that dehumidification performance is the best when liquid desiccant has a high concentration.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

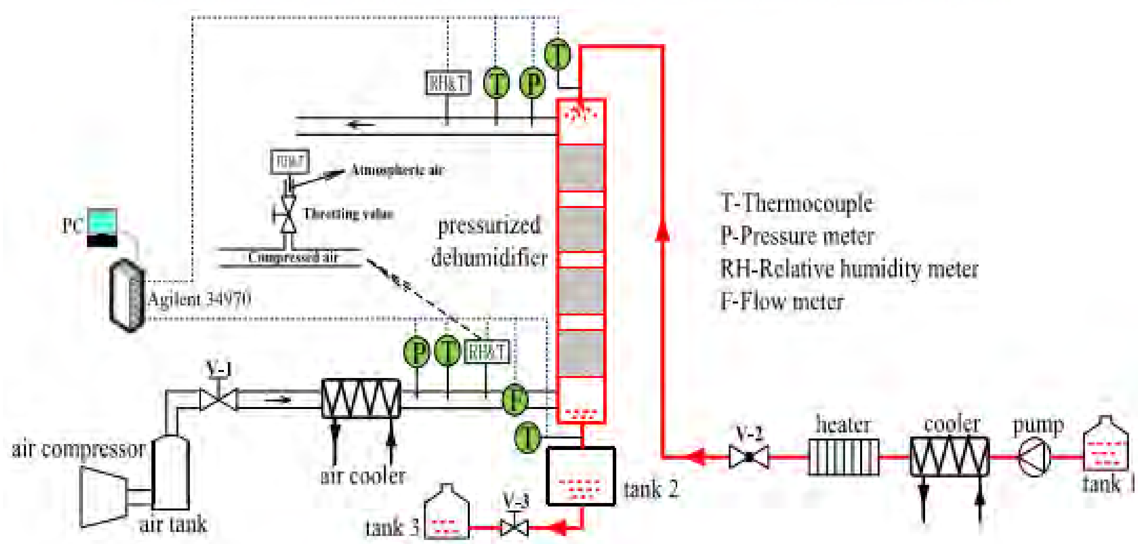


Figure 2.10 Air-drying system utilizing liquid desiccant

Yonggao Yin et al. stated and proposed some advancements of using liquid desiccant for dehumidification process in air conditioning systems. Recently the dehumidification technology has become common as it is highly effective utilization of low-grade heat and very efficient in dehumidification. The most important parts which play roles is the dehumidifier and regenerator. The differences in vapor pressure among the air and liquid desiccants is where heat and mass transfer process start to occur. The liquid desiccant can be regenerated by solar energy at around 50°C. Solar collectors can be used directly and indirectly for desiccant regeneration. There are three components which are solar collector, air dehumidifier and evaporative cooler which needed in solar liquid desiccant cooling system. Y. Jiang et al. developed a multi-stage dehumidifier with an auxiliary cooling module that can cool down the desiccant solution, as in Figure 2.11. Based on the Figure 2.11, the liquid desiccant was cooled by the external cold source, to improve the dehumidification performance. Followed by the second system, the high thermal heat force about 26–30°C, can be cancel off by the normal cooling source and the cold water with the temperature of 18–21°C can cool the liquid desiccant in the low moisture content part. The advantages of this was reduced the energy of the cold water.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

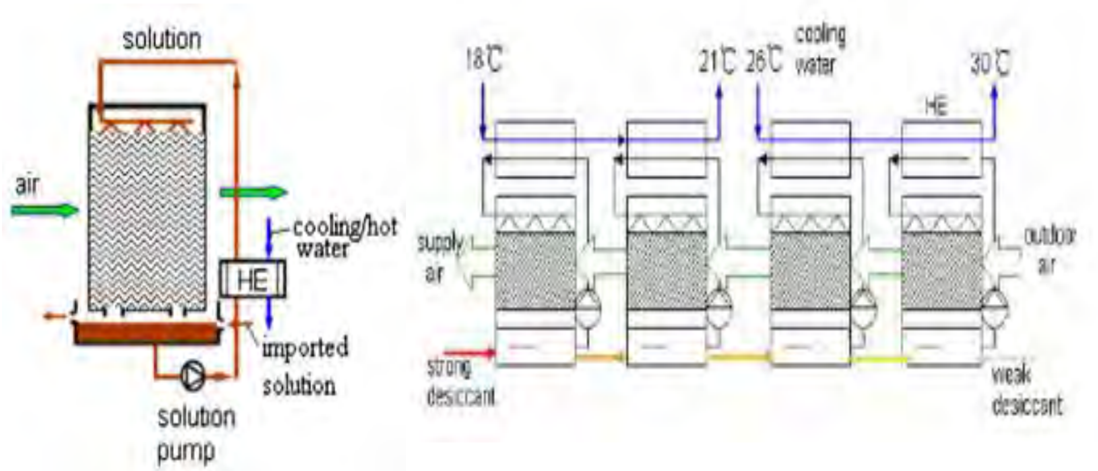


Figure 2.11 Multi-stage dehumidifier

Yin et al. proposed a liquid desiccant air conditioning system, the liquid desiccant evaporation cooling air conditioning system (LDCS) and is shown in Figure 2.12. The system consists of a dehumidifier, a regenerator and an evaporative cooler. At first, both air and liquid desiccant film with low temperature entered the dehumidifier, and the water vapor in the air then transferred to the desiccant film. In the regenerator, the weakened desiccant arrangement from the dehumidifier was warmed to a higher temperature by poor quality warmth source and the water vapor was exchanged from the desiccant solution for the air. The function of evaporative cooler is to cool and humidify the dehumidified air, and the air will transfer to the air conditioning chamber. The system can be function with solar energy and industrial waste heat with the temperatures between 60°C and 80°C.

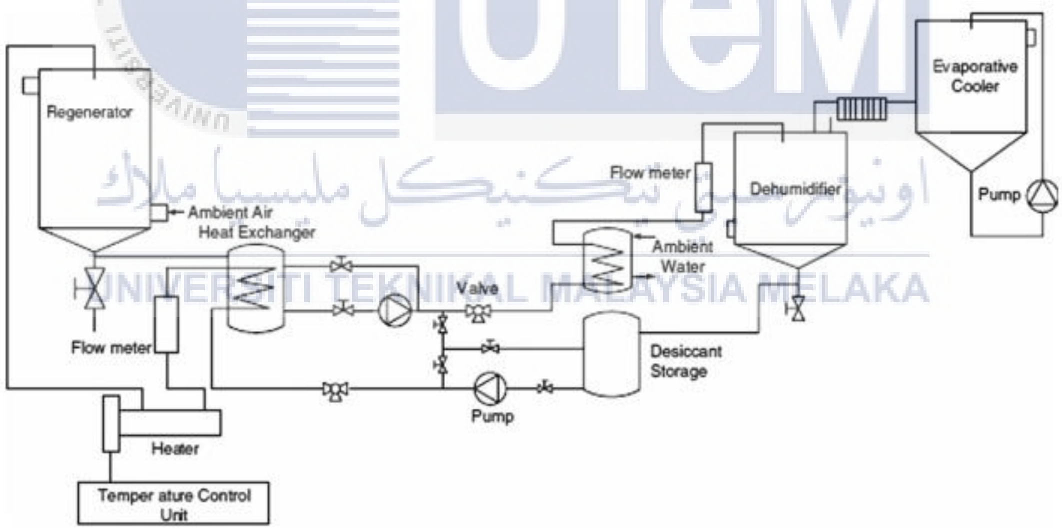


Figure 2.12 Liquid desiccant evaporation cooling air conditioning system (LDCS)

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Yin et al. also proposed a liquid desiccant air conditioning system and is shown in Figure 2.13. In the cooling system consisted of four units: liquid desiccant (LiCl–H2O) regeneration unit, air dehumidification unit, producing chilled water unit by evaporative cooling, and radiant cooling and dehumidified ventilation unit. The liquid desiccant recovery unit was utilized to concentrate the weakened liquid desiccant from the dehumidifier by sun powered vitality. The air dehumidification unit utilized liquid desiccant to create extremely dry air for evaporative cooling unit and to condition the space. The aerated and cooled space could be kept as a thermally agreeable condition by radiant cooling and ventilation with dry air. The dry air was a part of the dehumidifier. The other part of the dry air entered the evaporative cooler to produce chilled water for the radiant ceiling panels. The temperature of the chilled water could be as low as 12°C with good thermal performance.

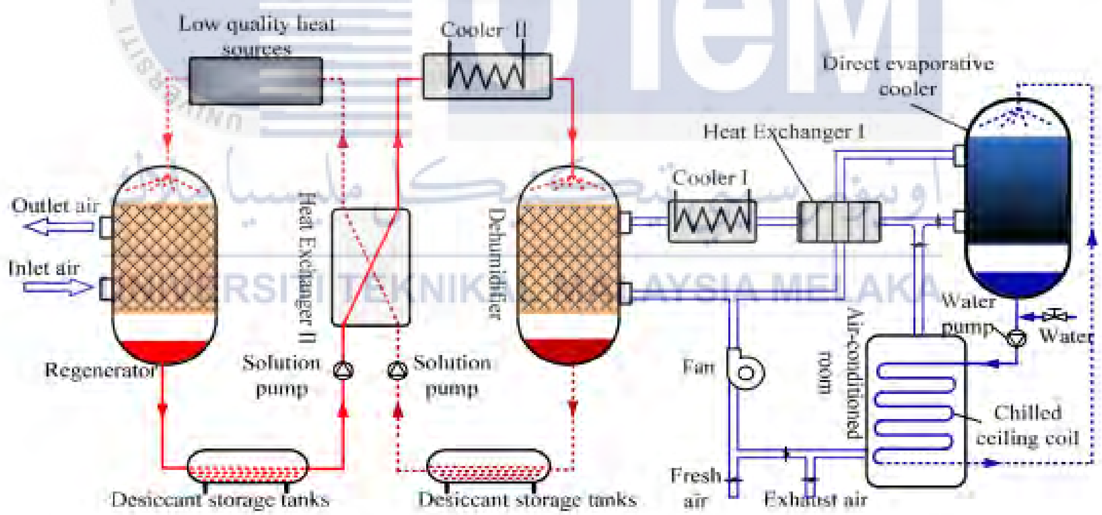


Figure 2.13 Liquid desiccant air conditioning system

Although the both system in Figure 2.12 and Figure 2.13 looks alike, the differences among both systems is that the humidity ratio of the air leaving the dehumidifier in Figure 2.13 should be much lower than that shown in Figure 2.12 after conducted experiments.

2.3 Silica gel

Silica gel has a highest absorption rate among other solid or liquid desiccants. It is a tasteless, odorless, non-toxic, non-corrosive, and chemically inert substance. Its function is used to protect goods or product against high moisture content. If the moisture content is high, they can promote the growth of mold, spoilage and corrosion. Silica gel does not happen any chemical reaction during drying or absorption process. The main silica gel actually came from silica oxide before processed into small round pieces form. Silica gel as a desiccant has a strong affinity for water molecules. Silica gel also consist of two types of color which can be called indicating silica gel. They are blue and orange indicating silica gel. Their function is to give a fast detection that let people to quickly determine when solid desiccant needs to be regenerated or replaced when dying air and gas streams. Changing in color will show people their moisture content level.

2.3.1 White silica gel

Type of gel which is non-indicating silica gel which means that when silica gel absorbs moisture, there is no changing in color, it will continue to be white. Among all the silica gels, white silica gel beads are in higher humidity conditions with above 50% relative humidity. This results in the more water needed to be absorb by the silica gel when surrounding air have a higher humidity before the stability is reached. White silica gel commonly used in packet in food industries. It's possible to prevent system breakdowns due to the buildup of moisture by filtering the compressed air through desiccant filter. Table 1.2 show the appearance and the characteristic in detail of white silica gel.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Table 2.2 Description and properties of White silica gel

Description	Silica Gel White (Non-Indicating Type)
Shape / Sizes	Irregular or Spherical
Assay (as SiO_2)	Min 98%
pH	4 - 8
Bulk Density (g/ml)	0.55 - 0.65
Loss on Drying (%)	< 6
Adsorption Capacity @ 100% humidity	38-40 wt%
Friability	99.5
Chloride (as NaCl)	Max 0.5%
Sulfates (as Na_2SO_4)	Max 0.5%
Particle Beads size (mm)	2-5 mm, 3-5 mm, 5-8 mm
Particle Crystals size (mesh)	1-3 mesh, 3-4 mesh, 3-8 mesh, 5-8 mesh

2.3.2 Blue Silica gel

Blue silica gel is a self indicating type and it contains cobalt chloride inside the molecule, which lets the blue silica gel to vary its colour to pink when it reaches the optimum adsorption level. Then, it needs to be regenerated under heat to dry off all the moisture content. It is not allow to be used in food factory or company as the cobalt choride inside it is poisonous.

Figure 2.14 Color change with different moisture content

All indicating type have the same specification in absorbing the same amount of mosture up to 40% maximum of its weight in water content. Normally, blue silica gel is used as indicator for moisture absorption in sealed container.

Table 2.3 Description and Characteristic of Blue silica gel

Description	Silica Gel Blue (Indicating Type)
Assay (as SiO_2)	Min 98%
pH	4 - 8
Bulk Density (g/ml)	0.65 - 0.85
Loss on Drying (%)	< 6
Adsorption Capacity @ 100% humidity	34-38
Friability	99.5
Chloride (as NaCl)	Max 0.4%
Cobalt (as $CoCl_2$)	0.5%
Sulfates (as Na_2SO_4)	Max 0.5%
Particle Beads size (mm)	2-5 mm, 3-5 mm, 5-8 mm
Particle Crystals size (mesh)	1-3 mesh, 3-4 mesh, 3-8 mesh, 5-8 mesh

2.3.3 Orange Silica Gel

Orange silica gel is one of the indicating types and has methyl violet inside it. It comes with orange yellow in color when totally dry off while change to green when the moisture level is around 15% of its weight. It has a high absorption rate and can remove moisture content at temperature of 65°C (Indicating Silica Gel: Orange vs. Blue , 2017). But orange silica gel is toxic and might be poisonous to health even though it is used in some medical merits. Generally, it can absorb as high as 40% of its weight in water. The moisture content will fill up all the pores and once all the pores in used green color will be shown. Orange silica gel is not using in food industry as the product is very absorbent and may have a dying effect on skin and eyes.

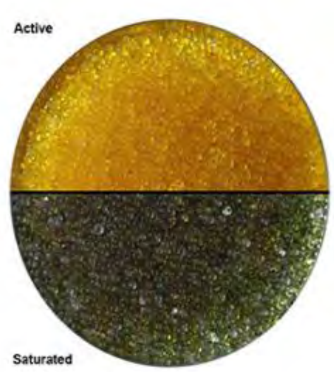


Figure 2.15 Color change with different moisture content

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Table 2.4 Description and Characteristic of Orange silica gel

Description		Silica Gel Orange (Indicating Type)
Shape		Spherical Beads
Adorption Capacity (%)	RH 20 %	9.0
	RH 50 %	22.0
Rate of Attrition (%)		Min 0.2
Granularity Eligibility (%)		Min 90%
Weight Loss After Heating		6-8%
Color Variation	RH 20 %	Orange - Light Orange
	RH 50 %	Light Orange - Light Green
	RH 90 %	Dark Green
Original Color		Orange
Available Sizes		2-5 mm, 3-5 mm, 4-8 mm

2.3.4 Effectiveness regeneration of Silica Gel

Silica Gel can be regenerated by carry out many ways including increase its temperature, decreasing the molar concentration of the adsorbate or lowering of the system pressure. For the desorption of water vapor process to occur from the silica, the temperature must be at least 100°C. The research stated and recommend the regeneration temperature must between 150°C and 175°C. However, the color indicator on the silica gel will be damage if the temperature exceeds the recommended regeneration temperature. (Giebel-adsorber.de, 2018) Ye Yao et al aim to improve regeneration rate of silica gel and studies of regeneration of silica gel with or without ultrasonic under low temperature. Four temperatures have been tested for silica gel to regenerate, including 35,45,55 and 65°C. During the experiments, the ambient air's humidity was kept at 75±5% while the temperature was kept at 24±0.5°C. When the silica gel regenerate at same temperature, the weight of silica gel undergoes ultrasonic drop faster than without ultrasonic. The regeneration temperature can decrease up to 10% by the presence of the ultrasonic effect at low-temperature which is under 65°C. Moreover, the regeneration speed of silica gel always depends on the effect of ultrasonics and regenerate temperature. It means that ultrasonics can significantly decrease the regeneration time for higher temperature from the starting value of 45% to 20, 15 and 10% and much of energy. Other than that, the experiment concludes that with the aid of ultrasonic in the regeneration efficiency will be affected by the moisture content ratio and regeneration temperature.

2.3.5 Absorption Rate

Silica gel has the ability in absorb moisture content, however, the rate of adsorption is depending on many aspects or variables such as gel size, air flow velocity, bed thickness and heat treatment, together with the impact of temperature, and humidity (Ahlberg, 1939). K.C. Ng et al. carried up an experiment of the moisture content adsorption of same temperature attribute of the silica gel. Three types of silica gel tested in the experiment. In the experiments, argon gas act as the gas to purge the entire vacuum system of ambient airs.

The total mass of moisture content or water vapour absorbed by the silica gel is formulate as follows:

$$M_{\mathrm{ads}} = M_{\mathrm{di}}(\Delta P_{\mathrm{i}}, T_{\mathrm{i}}) - M_{\mathrm{cd}}(\Delta P_{\mathrm{f}}, T_{\mathrm{f}}) = \frac{1}{R_{\mathrm{w}}}\left[\left(\frac{(P_{\mathrm{di}} - P_{\mathrm{rdi}})V_{\mathrm{d}}}{T_{\mathrm{i}}}\right) - \left(\frac{(P_{\mathrm{cd}} - P_{\mathrm{rf}})V_{\mathrm{cd}}}{T_{\mathrm{f}}}\right)\right] \quad (2.1)$$

Where M_{ads} is the mass of liquid vapour absorbed by silica gel, M_{di} is the initial mass of liquid vapour in the dosing tank, M_{cd} is the final mass of liquid vapour left in charging and dosing tank, P_{di} is the initial of the dosing tank, P_{rdi} is the initial residual pressure of argon gas, R_w is the characteristics gas constant of liquid, P_{cd} is the final pressure of charging and dosing tank, P_{rf} is the final residue pressure of argon, V_{cd} is the volume of dosing tank, T_f is the final temperature if dosing and charging tank.

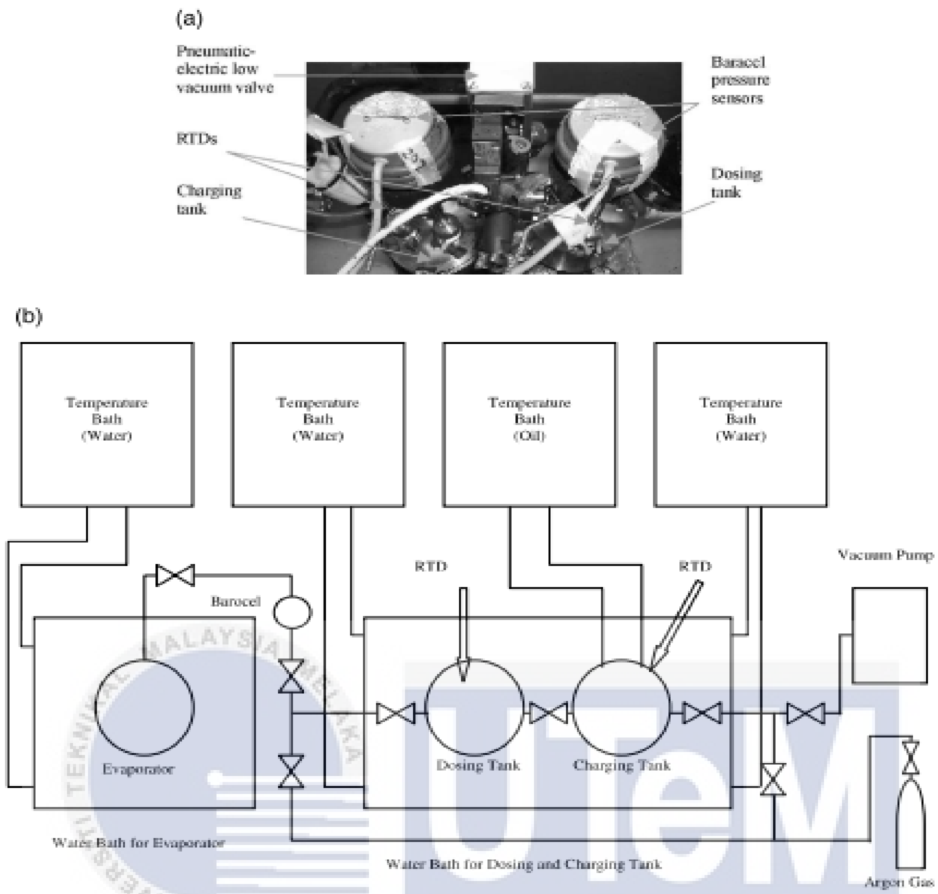


Figure 2.16 Experiment to test silica gel absorption rate

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.3.6 Moisture Content

Moisture content define as the total volume of the water molecule contained inside the products or grains. It can also be called moisture shrink, shrink factor and total shrink. Moisture shrink can be calculated by the formula 2.2 while formula 2.3 below.

$$1-\frac{(100-\text{Initial Moisture})}{(100-\text{Final Moisture})}\text{ x }100\% \tag{2.2}$$

$$\frac{100}{(100-\text{Final Moisture})} \tag{2.3}$$

2.3.6.1 Calculation method

Calculate the % moisture for each of the materials you plan to compost.

Weigh a small container.

Weigh 10 g of the material into the container.

Dry the sample for 24 hours in a 105-110-degree C oven.

Reweigh the sample, subtract the weight of the container, and determine the moisture content using the following equation:

$$M_n = ((W_w - W_d)/W_w) \times 100 \qquad (2.4)$$

in which:

M_n = moisture content (%) of material n

W_W = wet weight of the sample, and

W_d = weight of the sample after drying.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, Methodology of the study aims to explain in detail base on the three main hypothesis that have aforesaid in the objectives. Besides, all actions and activity will be listed out and arrange in this chapter in systematic ways. This is to describe in particular how the project flows and the routines used to complete the project. The procedures and steps used to complete the objectives stated are explained. The methodology of this project might be divided into four parts including design of the system drying chamber, materials to be dried, those variables affect the experiment and the process work of the system and experiment.

3.2 Flow Chart

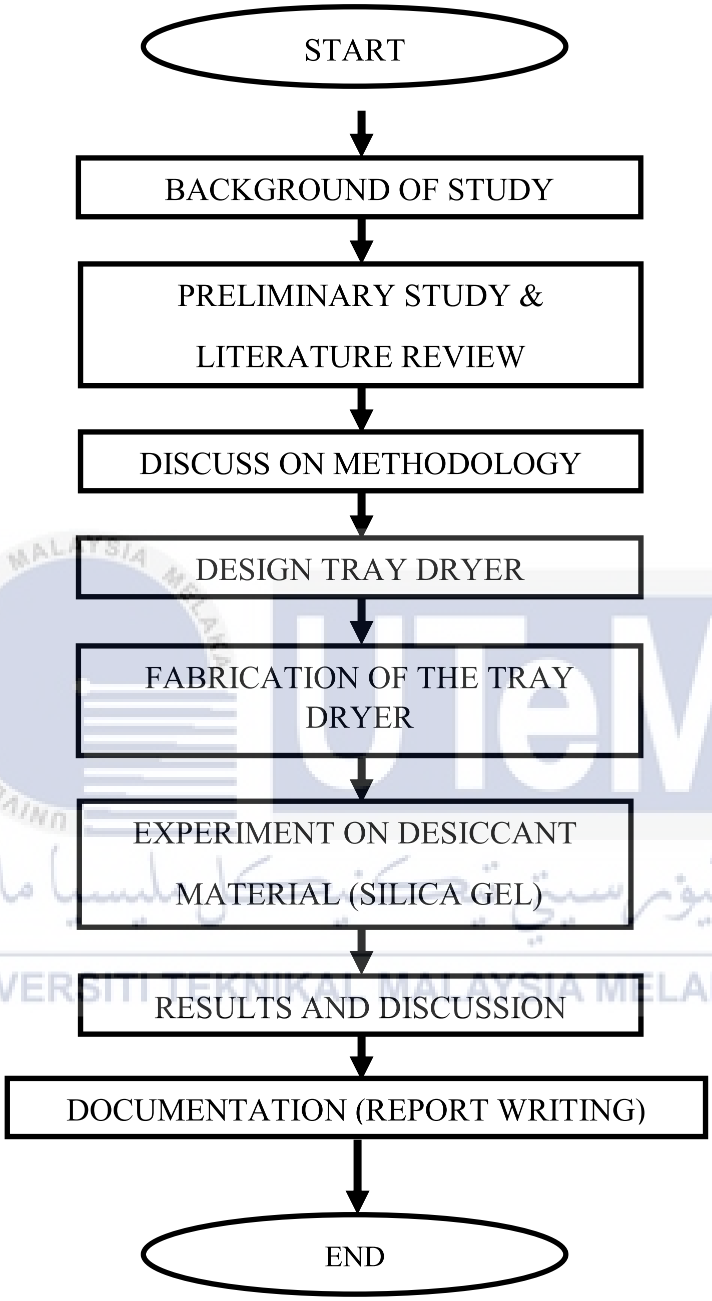


Figure 3.1 Methodology Flow Chart

3.3 Design of the system

Solid work software is the software used to design the product, this design combines all the diverse modes of drying, direct, indirect, and desiccant materials that used to absorb the moisture content during day or night time. It has diverse modifications and enhancements which makes it distinct from the previous designs. Some of these modifications are new concepts and others are inspired from the previous designs. These changes had been applied to this design to enhance the performance and help to obtain better results of drying process without damage the quality of the drying products. Furthermore, the project is mainly focus on the drying process with the solid desiccant materials which is the silica gel. So, a special merit of this design is that it has a feedback pipe linked with the exit of the chamber and return back to the bottom inlet of the chamber. This created a in and out air flow which circulate the drying chamber and secure all the air will be recycle. Moreover, there are two speeding fans are fixed under the drying chamber above the feedback pipe bottom inlet of the air to get better air flow and circulation inside the drying chamber. The configuration of this mixed mode solar desiccant dryer is presented in figure 3.2. The other new concept in this design is on the solar air cell. This new design is extra and mainly focuses on the solar energy in drying during daytime. The solar air cell consists of solar plates absorbers which is attached to the drying chamber from two side direction in order to increase the surface area and collect more solar energy. This results in increasing of the temperature achieved by chamber and therefore increasing the efficiency of the system as well.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

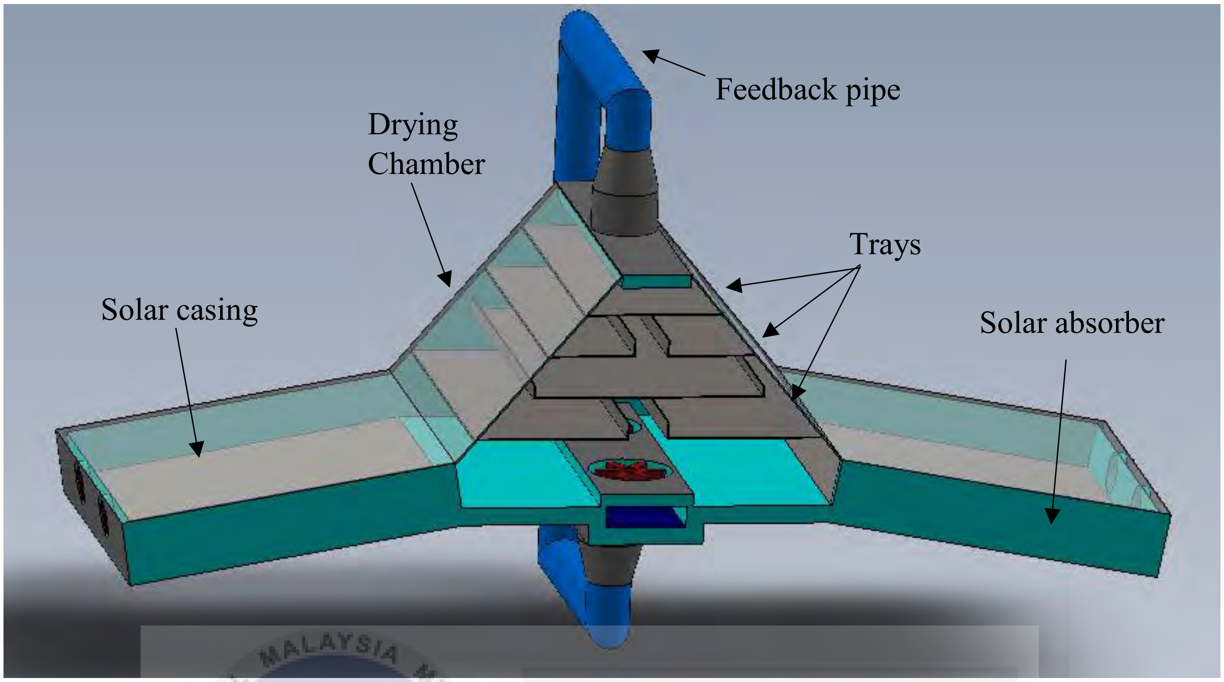


Figure 3.2 Configuration of the design system of the drying system

3.3.1 Drying chamber

The drying chamber is designed as a container where the product is placed and ready to be dried. The chamber is located between the two solar panels and it is perpendicular to the horizontal plane. This drying chamber integrates a mixed mode system to receive heat in two methods, direct and indirect method. In the first mode which is indirect mode, it receives the heated air coming out from the panel's casings and speeded up with fans. While in the second mode, which is the direct method, the radiant heat is absorbed directly through the transparent side walls of the chamber which made up from glasses. Inside the chamber, layers of stationary trays are fixed in a different format to provide better air distribution through the tray. The height of the first layer above the bottom surface is 20cm, then the remaining trays are arranged with an equal height from each other with a value of 10 cm. Figure displays all the dimensions and details of the design in three projections, front, side, and top view.

A desiccant material is aimed to be placed beneath the first lower tray during the off-sun time. On the bottom surface of the chamber, two blowing fans are installed in order to speed up the hot air entering the chamber from the solar panels. On the other hand, an exhaust fan is installed at the top to release the dehumidified air out of the drying chamber. During the day time, drying of the products is held by the high temperature air inside the chamber while during the night time, the system is supported by a desiccant material to remove the moisture in a continuous drying process. In order to assure a uniform air flow and distribution in the system, the trays are organized in an alternative shaped way. It expected that the air continues flowing throughout the trays at the same rate from bottom layer to the top one.

3.3.2 Recirculate pipe

The recirculate pipe is connected between the outlet of the air at the top of the drying chamber and the inlet window at the bottom of the drying chamber. This pipe is expected to be functioning only during night time. As it has been explained earlier, pending the sun time, the bottom inlet of the drying chamber is closed and the top outlet which attached with an exist fan is opened to enable the air has been used for drying to flow freely out of the dryer. However, during the night, the surrounding weather is very humid. The system will be in closed system and all the inlet will be closed by designed blocker at the side of the drying chamber and top chimneys. Therefore, with the help of desiccant materials the air humidity inside the chamber is reduced until it become less than atmospheric humidity. Thus, it would be more beneficial if we reuse the interior air again through the feedback pipe. The humidified air flowing out of the chamber from the top outlet hole is received by the pipe and then sent back to the bottom inlet hole so as to be dehumidified again. This process is repeated constantly during night or in rainy and cloudy days.

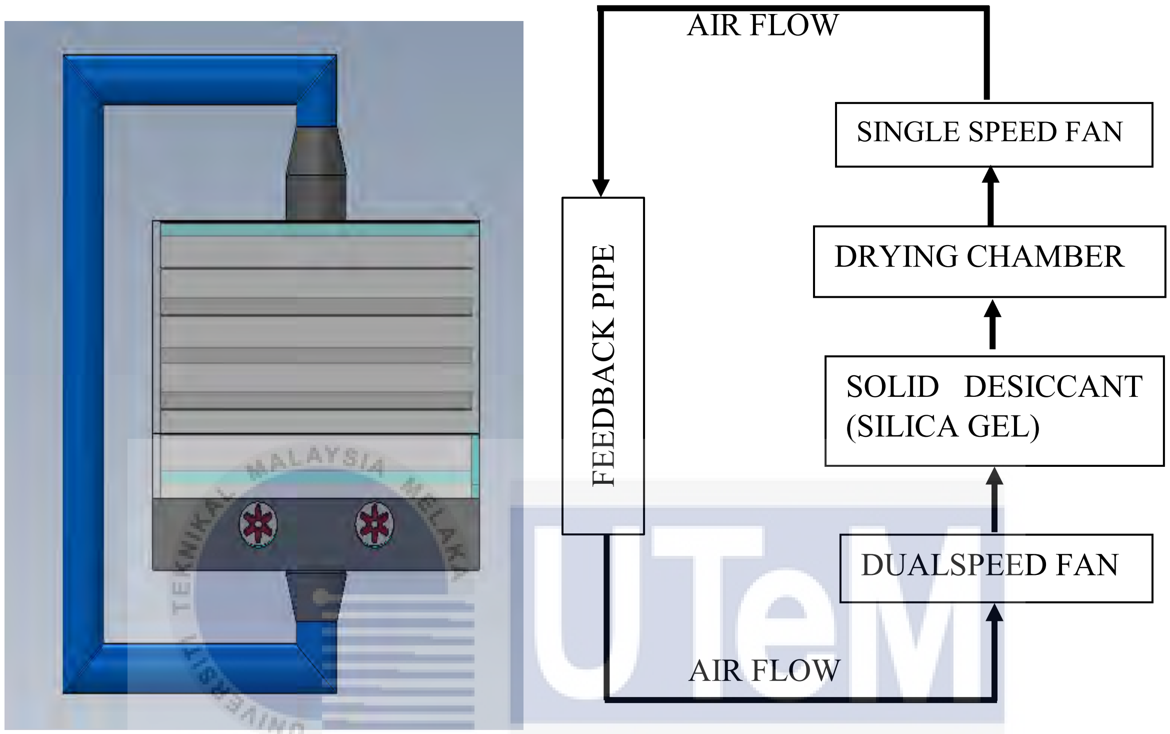


Figure 3.3 Circulation of air flow in drying chamber and flow chart of the air flow system

اونيورسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

3.4 Materials for drying

In this experiment, one of the materials to be chosen to be dried is corn seed. Handling, drying and processing of corn need high knowledge to avoid damage the seeds and to preserve germination ability. (Ear corn drying and processing, 2018) Normally, corn seeds are preserved by natural-air drying method. This method also called ambient-air drying or air drying by operating fans for removing moisture content coming primarily from the drying potential of outdoor air. After the drying, the moisture content can be dried until safe storage moisture which is 15% from the actual 50%. (Natural-air corn drying in the upper Midwest, 2018)

Figure 3.4 Dried corn seed

The other materials suitable for drying is the onion which can be found in every market. The total moisture content inside the onions is as high as 83% in weight and it is dehydrated until 5% before storing for another used. Normally dry onions are active in medical substances which it is very useful and give a lot of benefits to the human health. (John W. Lund, 2018)

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 3.5 Dehydrated Mushrooms

Other than food product, the experiment might carry up by using a sponge filled with clear water. The reason of using sponge is to test the ability of silica gel in absorption and it could save more time in the experiment process. Fixed amount of water will be added to the sponge and the total volume of water absorb by the silica gel will be calculated for the moisture content later on at the end of the whole experiment.

Figure 3.6 Sponge added with water

3.5 Variables affect drying rate

A variable is a factor that can change in quality, quantity, or size, which you have to take focus on it during the whole experiment. Decisions could be made on the fan speed, temperature, and the amount of solid desiccant material used. Other variables will be effected are the surrounding air humidity.

3.5.1 Air flow velocity (fan speed)

The fans that are located under the drying chamber mainly to recirculate the air flow through the desiccant and absorb the moisture content and reduce the humidity inside the drying chamber as shown in Figure 3.6. For this experiment, air flow velocity is one of the factors which can affect the results of the drying process. The speed of fan can be the manipulated variable while drying rate will be the responding variable throughout the experiment. Drying chamber consists of upper fan and two lower fans. The experiment will be carried out by both of the fan. The higher the air flow velocity, the rate of change of the drying will be increased. Experiment will be going by using both fans, then record and note down the absorption rate from the air flow.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

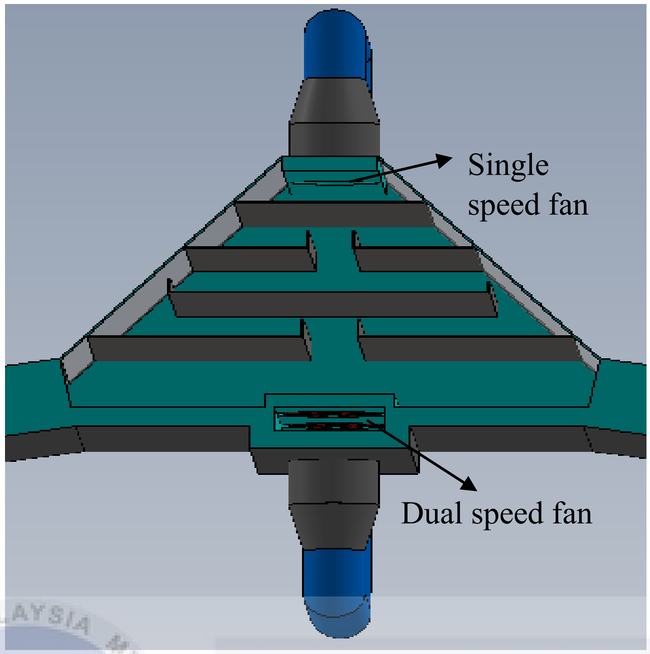


Figure 3.7 Drying chamber with speed fan installed

3.5.2 Temperature

Temperature is one of the variables which affect much on the absorption rate of the silica gel throughout the experiment. Theoretically, the higher the temperature, the easier the water vapour to be evaporate, the lower the humidity, drying rate will be more effective. Temperature plays an important role in this experiment, so the data of temperature noted is very concerned throughout the experiment. The drying experiment is carried up by 8 o'clock in the morning due to 6 hours period experiment. Although the time session sun is presence, it is for the purpose to recharge the battery by solar panel, the drying chamber will not expose direct to the sunlight. Temperature will be measured by the device called anemometer which have many functions in testing such as relative humidity, temperature, light intensity and air flow velocity.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

3.5.3 Amount of solid desiccant used

All silica gels seen in market are in granule or beads form which mean the amount of silica gel used can be easily controlled throughout the experiment. Amount of silica gel can directly affect the results. Theoretically, there are many statements requested about absorption rate of silica gel when the volume or weight is increase to a certain value. These all just the problem statement may occur before carrying up the experiment. All the possible test needs to be carried up and obtain the results to conclude that what is the best amount of silica gel to be used to achieve the highest drying rate of the product in order to save more time and dry the product effectively. In the experiment, silica gel will be placed at the design tray at the bottom of the drying chamber. The amount of silica gel is measured by the weight as shown in figure 3.7. The aim of this experiment is to test whether larger amount of silica gel will increase the absorption rate or it will block the air flow and reduce the speed through the product.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 3.8 Tray dryer for silica gel

3.6 Experimental work

In this section, we are going to setup variables for performing test on the fabricated device and try on with the system at the particular time. In this experiment, we are focusing on the absorption rate and the regeneration rate of the silica gels which are the solid desiccant material on the product chosen, wet sponge. We are recording the time, temperature, humidity, silica gel weight and amount of silica gel used during the experiment. There are some external devices used in the experimental work to measure the product. The first device is an electronic digital weight scale device for measuring the weights. The device mainly to record the results before and after the experiment for calculation purpose. The second device is stopwatch which used to record the time taken for a process of drying carrying on. Thirdly is the multipurpose device, Anemometer which has the function of detect air humidity, temperature, light intensity and air velocity.

Figure 3.9 Weight balance and stopwatch

During the experiment, some procedures will be carried on getting the results for the whole system.

1. Firstly, product will be chosen.
2. After that, product will be inserted into the drying chamber without stacking on each other. Product will be put flat on the tray dryer.
3. Next, silica gels added to the slot under the drying chamber as the drying agent to absorb the water from the air. When the gel and product is settled, the drying chamber will be close tightly without air entering.
4. Initial experiment will start by using sponge with pipe water first. The aim of this initial experiment is to test and confirm the absorption ability of the silica gel.
5. After the initial test, the next variable just can be continued. First experiment will be started by using the 1 kilogram of silica gel. Stopwatch start with 60 minutes for the drying process to be taken. The experiment continues by changing to 2 kilogram of silica gel. Data will be collected by the Anemometer and weight machine and recorded into the result table. Temperature and humidity will also be tested throughout the experiment to study the effect and their role in drying process. Time also will be set with a proper period and measure the drying rate of the product with weight scale.
6. After the absorption rate experiment, regeneration experiment will be carried on based on different method including external energy or natural energy. Moisture content also will be calculated after recording down the weight. All the data will then use for the result and discussion further on and carry up comparison.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the detail design of the of the dryer in the previous chapter. Results of the experimental work is also presented in detail. Two different method and method of the experimental work are showed and explained in this chapter. The results will be shown after carrying out detail experiment focused on three main parameters of the drying chamber which are the humidity, temperature and silica gel weight. Moreover, the measurement of the design displays these parameters through the various locations of the dryer. This chapter seeks to find the answer to these questions: i) What is the most effective weight of silica gel to be used for drying particular volume of moisture content in a closed chamber? ii) what was the change in humidity and temperature affect the absorption rate? iii) Do silica gel can regenerate easily and faster rate on certain method?

To perform the analysis and solve the questions, this chapter is divided into several section. Those section will present and explained in detail of the relationship of the amount of silica gel weight and its absorption rate and regeneration rate per min. However, the variables stated in the previous chapter that play important role also will be analyzed. Finally, the chapter's conclusion is drawn and presented as the final section.

4.2 Experimental results

As it has been mentioned in the previous chapter, the experimental work had been run under two different weight of silica gel for drying purpose. In this chapter, we are going to explain the setup of these conditions and laterally discuss the results taken by weight balance and handheld digital anemometer. Some additional experiments are added during the progress of experiment to have more understanding on the tested material.

4.3 Absorption experiment

Absorption is one of the main functions by silica gel towards wet product chosen. To ensure it can be used for continuous drying during off sunlight. Several experiments have been done by changing certain variable and results is shown below.

UTeM
اونيورسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

4.3.1 Experiment result with 1-kilogram of silica gel

In this experiment, 1kg of silica gel is used to act as the drying agent to absorb the water from the sponge. Silica gel is scattered evenly in the tray. From table 4.3, we can observe that silica gel can really absorb water as its weight is increasing over time while the weight of water with sponge decreasing. This proved that silica gel is one of the desiccant materials. The initial absorption is the highest as the difference of vapor pressure is the highest at the starting of the experiment. At the 1st hour, the total absorption by the silica is 56g, but the sponge releases 17g of water only. This is because the ambient around the chamber is humid, silica gels need to absorb the water from the ambient air first and then just the water in the sponge. The data also show that the rate of absorption will remain constant until certain rate either absorption or releasing. Table 4.4 shows the drying process rate always increase linearly at the early stage and when the silica gel is getting saturated, less spaces in the molecule will lead to low absorption rate.

Table 4.1 Total weight absorbed by 1 kilogram of silica gel and weight of water with sponge lost every hour

Time (min)	**Silica gel weight(g)**			**Weight of water with sponge(g)**		
	Before	**After**	**Difference**	**Before**	**After**	**Difference**
0	1028	1028	0	453	453	0
60	1028	1084	56	453	436	-17
60	1084	1126	42	436	417	-19
60	1126	1154	28	417	392	-25
60	1154	1180	26	392	366	-26
60	1180	1210	30	366	342	-24
60	1210	1235	25	342	319	-23

Table 4.2 Absorption rate of 1-kilogram silica gel per an hour

Time (min)	**Absorption rate (g/min)**
0	0.0000
60	0.9333
60	0.7000
60	0.4667
60	0.4333
60	0.5000
60	0.4167

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Data in table is calculated recorded based on the absorption rate formula stated below. All the data are taken from the previous table 4.2.

$$\text{Absorption rate (g/min)} = \frac{\text{Differences in silica gel weight(g)}}{\text{Drying time (min)}}$$

$$\text{Absorption rate (g/min)} = \frac{56\text{ (g)}}{60\text{ (min)}}$$

$$= 0.9333\text{g/min}$$

Table 4.3 Accumulative time, Accumulative total weight of water absorbed by silica gel and Accumulative weight of water released by sponge of 1 kilogram

Accumulative Time (min)	**Accumulative total Weight of water absorbed by silica gel (g)**	**Accumulative Weight of water with sponge (g)**
0	0	0
60	56	-17
120	98	-36
180	126	-61
240	152	-87
300	182	-111
360	207	-134

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

4.3.1.1 Short period absorption experiment (testing result)

The aim of this experiment is to test whether time do affect the absorption ability of the silica gel. The results of this experiment will directly affect the data in the next experiment, so it must be tested at the very first. Table 4.4 shows the total volume of water being absorb by silica gel in every 15 min of time while Table 4.5 is the accumulative of the results. This experiment is carried up for a short period which is about 15 min for the drying to carry up. The purpose of this experiment is to decide whether silica gel can absorb water in such short period and can bring big effect in drying properties. The weight of water calculated shows that silica gel can absorb less water in short period due to some factors. One of the factors is the water vapour inside the ambient air. When the door is opened for taking measurement, the air inside the chamber will expose and easily attract the high humidity air to enter the chamber again. Due to the water vapour from outside air, the data recorded will be not accurate and hypothesis is not accepted. So, to minimize the error and can get the data more accurate, we decide to take readings every one hour for the next experiment.

Table 4.4 Amount of water absorb by silica gel and total water lost by wet sponge

Time (min)	**Silica gel weight (g)**			**Weight of water with sponge (g)**		
	Before	**After**	**Difference**	**Before**	**After**	**Difference**
0	1235	1235	0	342	342	0
15	1235	1244	+9	342	340	-2
15	1244	1252	+8	340	337	-3
15	1252	1258	+6	337	334	-3
15	1258	1265	+7	334	332	-2
15	1265	1270	+5	332	330	-2
15	1270	1276	+6	330	327	-3

Table 4.5 Accumulative time, Accumulative total weight of water absorbed by silica gel and Accumulative weight of water released by sponge

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Accumulative Time (min)	**Accumulative total Weight of water absorbed by silica gel (g)**	**Accumulative Weight of water with sponge (g)**
0	0	0
15	9	-2
30	17	-5
45	23	-8
60	30	-10
75	35	-12
90	41	-15

ABSORB

RELEASE

4.3.1.2 Maximum absorption by silica gel test result

Another experiment is carried on after the 1 kg silica gel absorption process. This experiment aims to find the maximum percentage of volume to be absorb by the silica gel. During the experiment, optimum weight of water has been achieved and some phenomenon have happened. At the 3rd hour of this experiment, we can see from table 4.6, the weight of silica gel obviously drops. So, we can conclude that all of the silica gel has fully saturated. Due to the low humidity at the surrounding air, the water molecule inside the silica gel might release to the surrounding which lead to decreasing in weight. Regeneration then starts to occur during this situation.

Table 4.6 Absorption experiment of 1kg of silica gel until fully saturated

Time (min)	**Silica gel weight (g)**		
	Before	**After**	**Difference**
0	1289	1289	0
60	1289	1301	+2
60	1301	1303	+2
60	1303	1302	-1
60	1302	1297	-5
60	1297	1288	-9
60	1288	1282	-6

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 4.1 Optimum weight of water per gram absorb by 1kg of silica gels

Regeneration is one of the special abilities for the silica gel to be reuse and recycle for many drying processes. When silica gels reach the optimum absorption of water molecule. It is the time for itself to regenerate. Regenerate means that silica gels release the water molecule from itself to the atmosphere. From the figure 4.1, the optimum weight of water to be absorbed by the 1 kg silica gel is 275g after the total weight deduct the initial weight. From the moisture content calculation, it is 29.58% water of its own weight. So, the results show that silica gel can accept at least 30% water of its own weight in any drying process. Further explanation will be explained at the regeneration experiment.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

4.3.2 Experiment result with 2-kilogram of silica gel

Compared with the 1-kilogram results, it is obvious that the more the silica gel the higher the absorption rate based on the result took in table 7 and table 4.8. Thus, more silica gel is efficient and better for drying process. The highest absorption rate reaches 2.45g per min. It was observed that the higher the amount of silica gels, the more the water can absorb, so the result can conclude that 2 kg of silica gels is more efficient than 1 kg. At the initial drying process, we can see that the results are the same as 1 kg where the absorption rate is the highest. Due to the high vapour pressure inside the ambient air, the rate of water enters the molecular of the silica gel will then increase. All drying process of silica gel will have a higher absorption at the starting few hours which shown in figure 4.2. When the drying agent is ready to absorption the moisture content of itself will reach almost 0% of its own weight. By the exposure of 0% moisture content drying agent to the wet ambient, the process of absorption will quickly in progress and will significantly slowing down when the moisture content getting higher which mean it started to be saturated. Basically, the result of silica gel weight increased should be same of the weight of water lost from the sponge, but due to the ambient air from the environment, the data will not be guarantee accurate. This is because ambient air humidity is very high especially our country. Ambient air is the most first molecule to expose with the silica gel. So, silica gel will absorption the water molecule from the surrounding air first and decrease in humidity inside the drying chamber. Then, the water inside the sponge will just evaporate to increase back the humidity. The process is recycling until the silica gel is completely saturated.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Table 4.7 Amount of water absorb by silica gel and total water lost by wet sponge

Time (min)	Silica gel weight(g)			Weight of water with sponge(g)		
	Before	After	Difference	Before	After	Difference
0	2017	2017	0	747	747	0
60	2017	2164	147	747	706	-41
60	2164	2253	89	706	669	-37
60	2253	2285	32	669	635	-34
60	2285	2329	44	635	604	-31
60	2329	2357	28	604	572	-32
60	2357	2376	19	572	548	-24

Table 4.8 Absorption rate of 2-kilogram silica gel per every 60 minute

Time (min)	Absorption rate (g/min)
0	0.0000
60	2.4500
60	1.4833
60	0.5333
60	0.7333
60	0.4667
60	0.3167

Data in table is calculated recorded based on the absorption rate formula stated below. All the data are taken from the previous table.

$$\text{Absorption rate (g/min)} = \frac{\text{Differences in silica gel weight(g)}}{\text{Drying time (min)}}$$

$$\text{Absorption rate (g/min)} = \frac{147\ (g)}{60\ (min)}$$

$$= 2.45 g/min$$

Table 4.9 Accumulative time, Accumulative total weight of water absorbed by silica gel and Accumulative weight of water released by sponge of 2 kilogram

Accumulative Time (min)	Accumulative total Weight of water absorbed by silica gel (g)	Accumulative Weight of water with sponge (g)
0	0	0
60	147	-41
120	236	-78
180	268	-112
240	312	-143
300	350	-175
360	359	-199

ABSORB

RELEASE

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

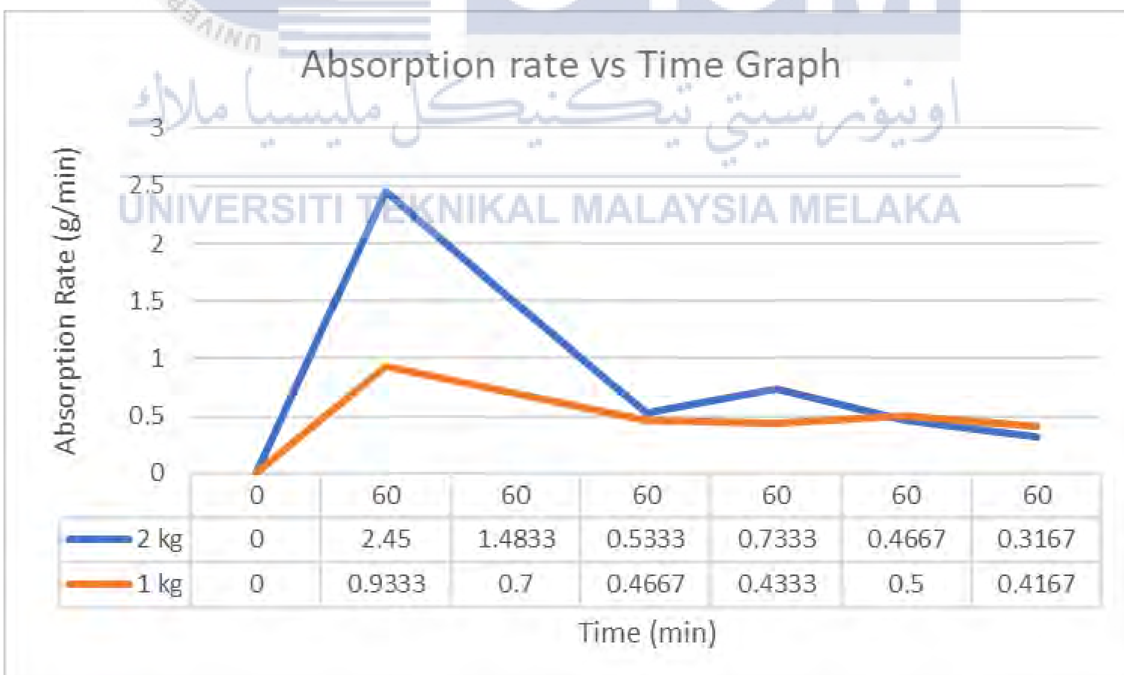


Figure 4.2 Absorption rate vs time Graph comparison among 1kg and 2kg silica gels

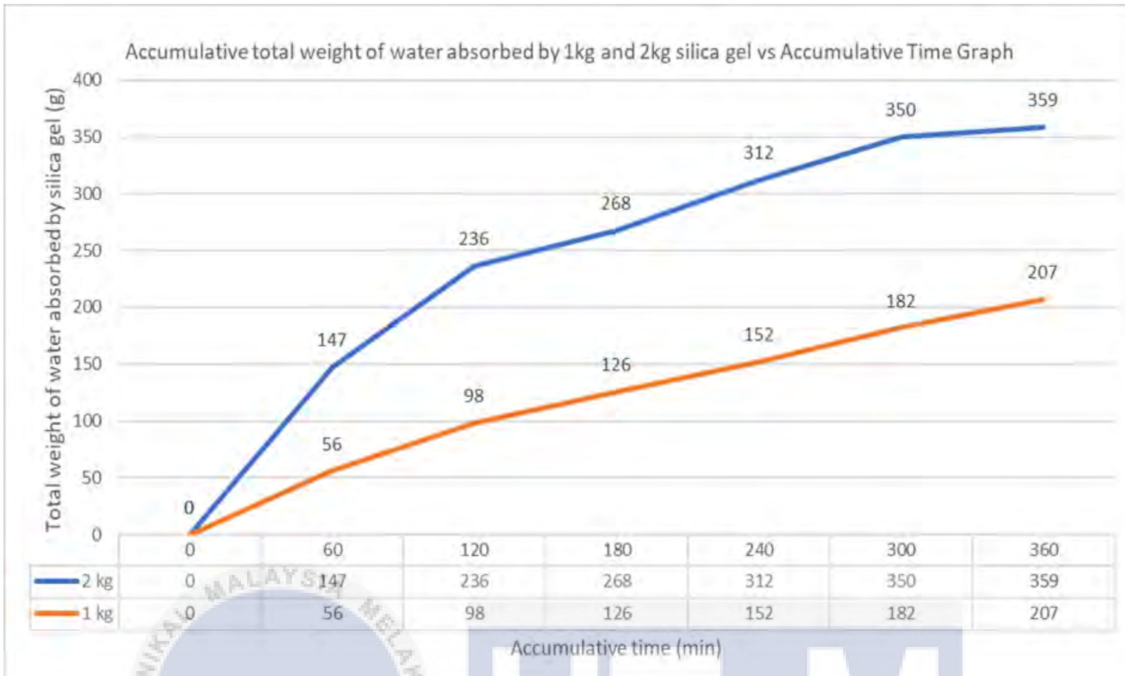


Figure 4.3 The relationship between accumulative total weight of water absorbed by silica gel with accumulative time of 1 and 2-kilogram of silica gel

The graph in Figure 4.3 shows almost the same trend for both 1 and 2 kilogram of silica gels. Overall, we can see the upward trend in the total weight if water absorbed starting from staring first hour until the end. However, although the total weight if water is increased through the time, but the gradient of the graph is getting smaller compared to the first two hour for both 1 and 2 kilogram of silica gels. It can be explained that the silica gels are going saturated over time. There is a limit of around 30-40% of its own weight is occupied by the water molecule based on the research.

4.4 Humidity test result

Relative humidity is the total volume percentage of water vapour that accumulate in the surrounding or ambient air. When the humidity is high means that surrounding air contains lots of water molecule. Air will always contain water vapour. At any given temperature there will be a saturation point at which no more moisture can be retained (any excess will condense). The Relative Humidity of air is the actual moisture content expressed as a percentage of this saturation content. The aim of using silica gel is to keep the Relative Humidity at levels below 50% of the saturation capacity. At these levels, corrosion and mould growth will not be promoted. Figure 1.2 shows the relative humidity vs time graph among 1 kilogram and 2-kilogram silica gels. Based on the research, drying process will lead to decrease in humidity in a close area as the desiccant material absorb the water vapor from the surround air. The result also proved that silica gel very sensitive to the water vapor which lead the relative humidity to be dropped time to time. The lower the humidity, the drier the air inside the chamber.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

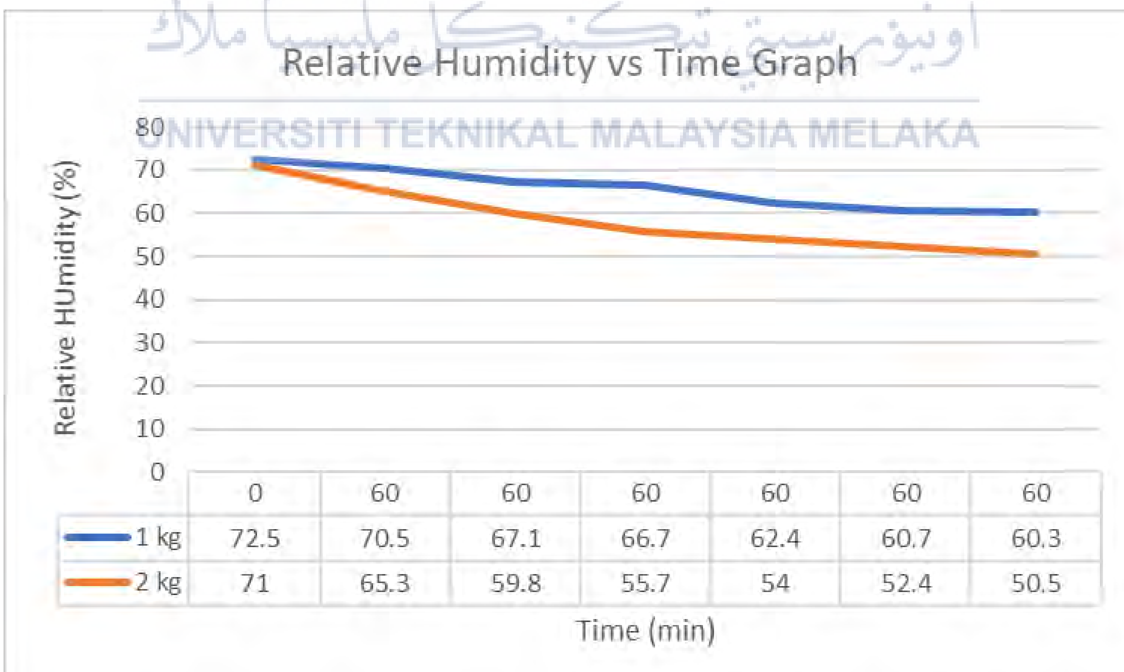


Figure 4.4 Relative humidity of surrounding air vs time Graph

4.5 Temperature test result

Figure 4.5 shows the increase of temperature throughout the experiment during the drying process. The experiment is carried up in the morning from 9 morning until 3pm in the evening. Although there is sunlight, the whole experiment is carried up under shade which does not expose to sunlight to prevent solar energy to interrupt the experiment and causes the data recorded not accurate. However, experiment which done is the afternoon will slightly effect by the temperature surrounding due to the hot sun. Another factor is the silica gel absorb the water inside the chamber also effect the relative humidity to be decreased. When the lesser the water vapour, the drier the air, the easier the temperature to be increased.

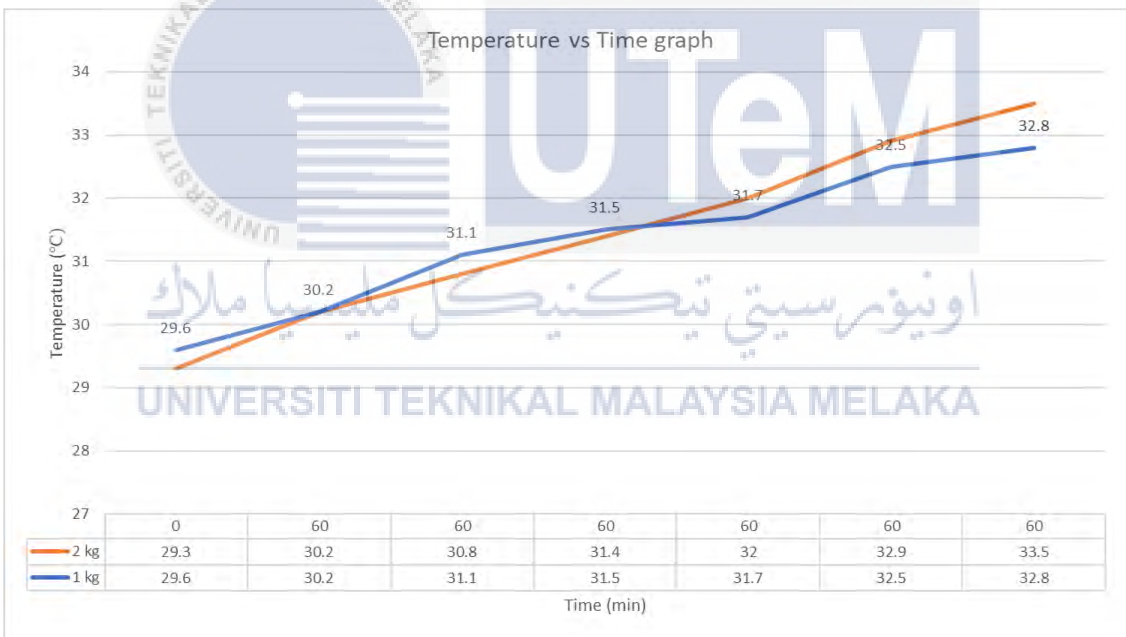


Figure 4.5 Temperature of surrounding air vs time Graph

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

4.6 Color indicator test result

Silica gel that’s used in the experiment is the orange indicator mixed with white silica gel. The function of the orange indicator silica gel is to detect when the silica gel is saturated or not. Color indicator silica gel do contain chemical substances inside the molecular. The main reason there is color indicator is to detect whether the silica gel is getting saturated or not. The figure below will show the color change by absorb the moisture content from the sponge by time. From the results, we can see that orange color will slowly saturated and change into dark green color when it reaches the optimum moisture content which is around 30% of its own weight.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 4.6 Initial Silica gel that absorb water around 5% of its own weight

Figure 4.7 Silica gel that absorb water around 30% of its own weight

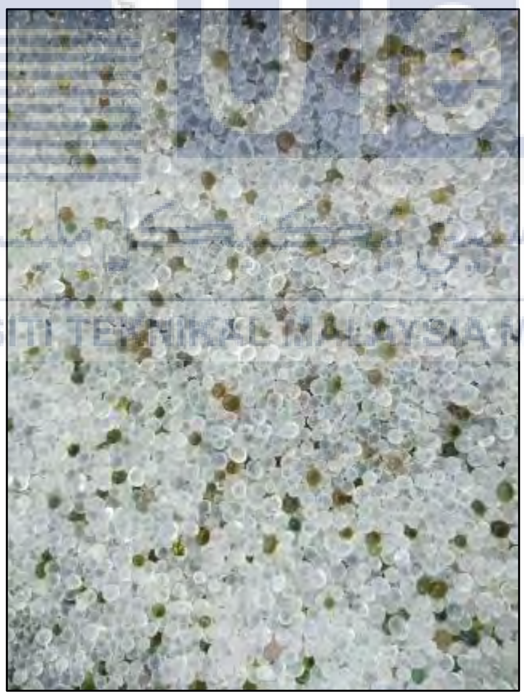


Figure 4.8 Silica gel that absorb water around 80% of its own weight

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 4.9 Silica gel that absorb water around 100% of its own weight

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

4.7 Regeneration method analysis

Regeneration is the process which need high temperature to heat up the silica gel and force the water inside the poles of the silica gel molecule to evaporate and regenerate to its initial weight. However, many problems had faced throughout the experiment which bring a big impact to the result. First of all is the weather, due to saving the environment, the regeneration aims to use the renewable energy such as solar heat energy to heat up the silica gel. Unfortunately, inconsistent of the weather had created problem to the experiment result. For example, regeneration took a long period to completely dry up the silica gel, normally it may used up to 5-6 hours. Moreover, the unstable change in temperature also affect the regeneration rate and the data will be big difference at certain point during the raining season. Due to the weather change in sudden from big hot sun to shady, the regeneration will be interrupt while absorption start to occur. The weight of silica gel will increase linearly but not reducing. This phenomenon lead to the next experiment will be delayed.

Many types of possible regeneration method had been tested to find out the best method for regeneration no matter including renewable energy or non-renewable energy. Silica gel is very attractive to moisture, it only regenerate when the temperature is high enough to force the water molecule to evaporate. The method will be experimented and record the data. Among all the possible method, we had chosen natural direct convection by hot sun, mixed mode solar dryer and universal oven to obtain the result. Regeneration is one of the specialties of silica gel to let it being use for many times. Once the rate of regeneration can be handled and understood, we can reuse at the perfect timing.

4.7.1 Natural convection by Hot sun test result

Hot sun produces heat energy which may called solar energy and it is efficient and renewable energy mainly useful in drying purpose. There will a reaction happen between the silica gel and the ambient through convection. Solar energy would release heat which the temperature can increase up to around 40 °C. So, experiment is carried up by using solar energy to regenerate silica gel. The goal of this experiment is to test that by using renewable energy which is the natural heat from the sun can regenerate the silica gel effectively. This experiment had been running at 11.30 in the morning and it was run for three hours. The setup up of the silica gel and the testing meter is shown in the figure 4.10.

Figure 4.10 Regenerating silica gel under hot sun and record result using anemometer

The readings are taken manually by Anemometer. The readings are recorded for three hours. Table 4.1 shows the resulted weight of water lost from the silica gel at certain temperature and different humidity level.

Table 4.10 Weight of water lost by silica gel in the period of 1 hour after regeneration under hot sun.

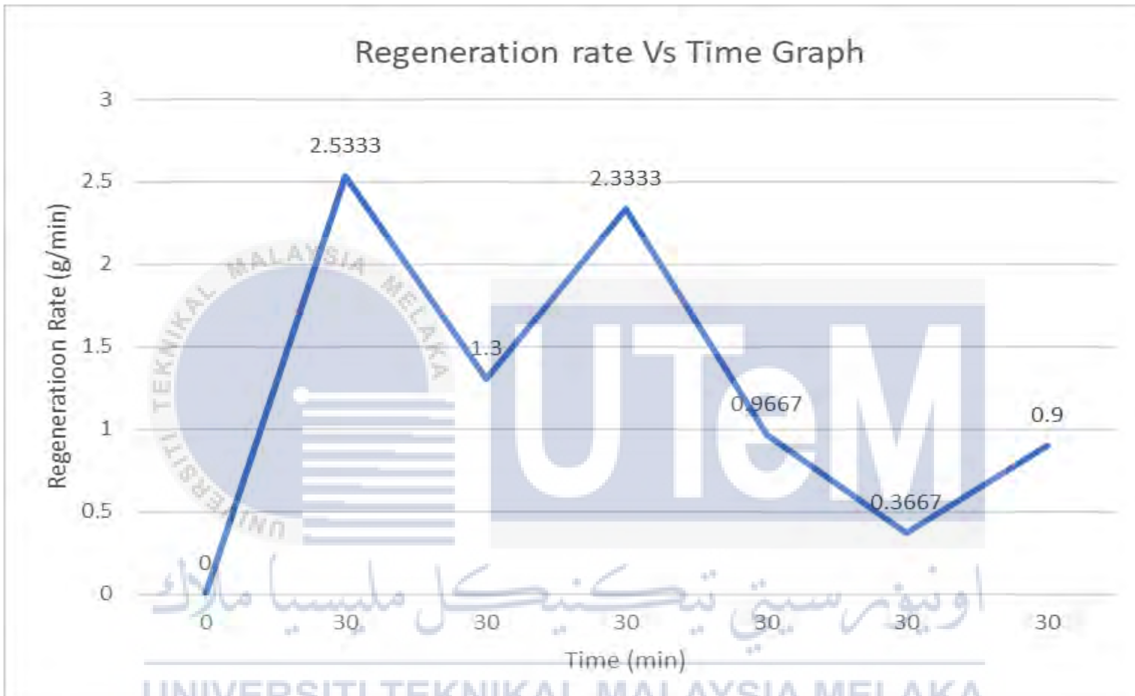
Time (min)	**Weight of silica gel (g)**			**Temp (°C)**	**Humidity (%)**	**Regeneration Rate (g/min)**
	Before	**After**	**Difference**			
0	2483	2483	0	32.2	60.5	0
30	2483	2407	-76	33.6	56.0	2.5333
30	2407	2368	-39	34.5	63.4	1.3000
30	2368	2299	-69	35.5	57.1	2.3333
30	2299	2270	-29	36.1	61.2	0.9667
30	2270	2259	-11	33.7	62.5	0.3667
30	2259	2234	-27	33.3	60.1	0.9000

Table 4.11 Accumulative time and Accumulative ttal weight of water released by silica gel

Accumulative Time (min)	**Accumulative total weight of water released by silica gel (g)**
0	0
30	-76
60	-115
90	-134
120	-163
150	-174
180	-201

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

From the table 4.10 it can be seen that the highest regeneration rate among all the time was 2.5333g/min. The ambient temperature at the commencement of the experiment was recorded as 33.6°C and the humidity is 56.0% For the second highest which is the 3rd timing of the experiment, the ambient temperature reached around 35.5°C and humidity is 57.1%. Both of these results have a literally lower relative humidity compare to others and achieve quite high regeneration rate. This can be assumed said that there is very wind flow during the period of time, due to lower air flow, the air molecule inside the ambient air will evaporate faster at that particular region and force the water molecule inside the silica gel to leave from it. All these readings are plotted in a graph as shown in the figure 4.11



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 4.11 Graph of regeneration rate over time

The graph illustrates one lines for the regeneration rate. It can be seen from the figure that the trend is going upside down. The rate is not accurate among all the period of time. It is noticeable that at the 1st period the rate is very high and suddenly drop about half of it then increased to almost double of the rate. After the first one and half hour, the regeneration rate is obviously drop below 1 gram per min. The results is assumed that the silica gel is getting non saturated and absorption rate is going to start over again.

4.7.2 Universal Oven test result

To compare the efficiency of non-renewable energy versus renewable energy, a simple heat up process had carried up by leave the silica gel inside universal oven with a constant temperature. Universal oven used is the Memmert model UM200 which heat up material under natural air circulation (convection) without any help of fan (Swadaya, 2018). Universal oven mainly functions to heat up silica gel at a constant heat up to 120°C and force the water molecule inside the silica gel to be evaporated. Different silica gel has different kind of porous size on the surface. The narrow the porous size the higher the temperature needed to heat up. (Giebel-adsorber.de., 2018) But there is a disadvantage of this universal chamber is that the evaporate water molecule still inside the chamber as it is closed system. There is no air ventilation inside the oven if using natural air convection. However drying cabinet is a machine that maintain the internal humidity at a certain percentage is used for the experiment to prevent the hot silica gel to absorb back the moisture from the surrounding. The setup of the test is shown in the Figure 4.12.

اونيورسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 4.12 Silica gel is regnerate inside universal oen and cooling by drying cabinet

The recording of the experiment had done for total of 6 hours and each of the experiment result was recorded by one hour and total weight of 1 kilogram of silica gel was tested due to universal oven size. Table 4.12 has recorded the data of regeneration taken from universal oven.

Table 4.12 Total moisture content lost through regeneration by universal oven

Time (min)	Weight of silica gel (g)			Temp (°C)	Regeneration Rate (g/min)
	Before	After	Difference		
0	1247	1247	0	0.0	0.0000
60	1247	1216	-31	120	0.5167
60	1216	1195	-21	120	0.3500
60	1195	1172	-23	120	0.3833
60	1172	1152	-20	120	0.3333
60	1152	1129	-23	120	0.3833
60	1129	1110	-19	120	0.3167

اونيۏرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

From the table 4.12 it can be seen that the highest regeneration rate among all the time was 0.5167g/min. The temperature will be constant the whole experiment as it was set manually at 120°C. Due to temperature constant and no air ventilation, the results shown in the table in more consistent compare to that regenerate under hot sun. On the other hand, universal oven does not perform well in regeneration if compared to hot sun. We can assume that no air ventilation inside the closed chamber is the problem. The water evaporated will be trapped inside the chamber and might transfer back into the silica gel. The initial regeneration is the highest is because of the low humidity inside the oven chamber. There were more spaces for the water molecule to enter compared to saturated ambient air inside the chamber. The results are plotted in a line graph presented in the graph as shown in figure 4.13

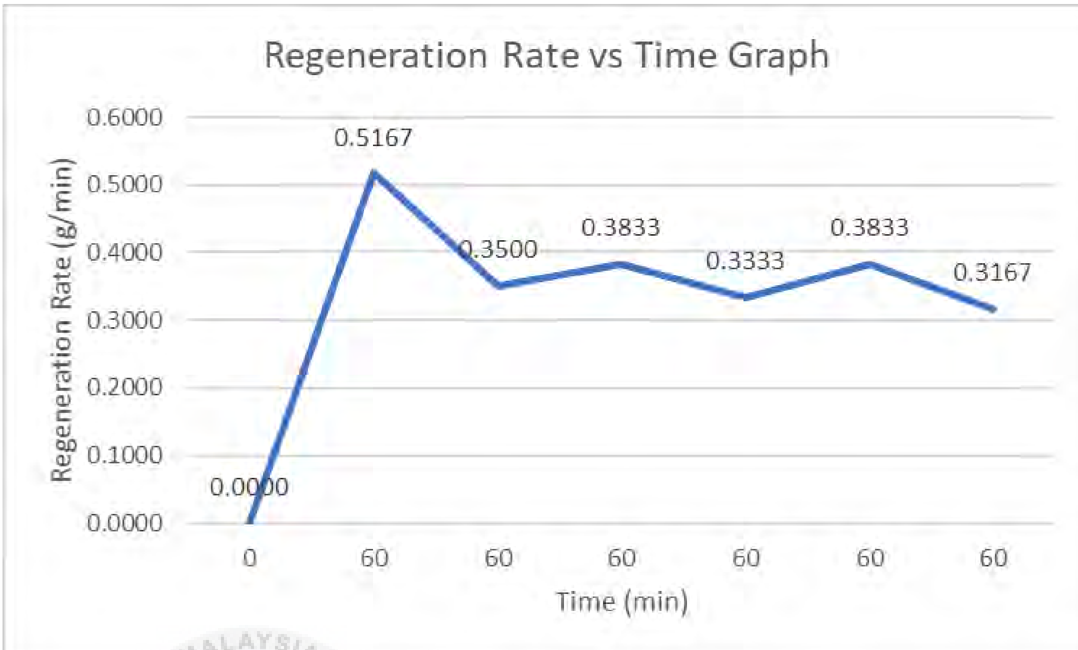


Figure 4.13 Regeneration rate vs time graph using universal oven

The graph shows the shape of the changing in regeneration rate of 1kg silica gel. Overall, we can see a consistent trend of regeneration rate start from the first hour. However, during the first hour, a sudden raise up. The main reason of this sudden increment is the low humidity in the ambient space inside the drying chamber. Initially, the oven had a low volume of water molecule inside. It is noticeable, after the first hour there are a fluctuating trend and the regeneration rate keep constant with a slight variation over the time. We can said that when power supply exists a constant temperature will achieve and result in constant regeneration rate.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

4.8 Calculations

In this part we are going to make some calculations to determine the percentage moisture content, absorption rate and regeneration rate based on the results provided by the testing work. In our calculation, we are going to evaluate the results for wet sponge as a sample of the agricultural products. The steps needed for the calculation in order to get out the rate of absorption and regeneration of silica gels are explained down.

4.8.1 Moisture content

We have been discussing the moisture content of the silica gel for the whole absorption process. The total percentage of moisture content are generally determined by the total amount of weight increased after absorbing the water from the surrounding air and the wet sponge inside the drying chamber.

As an example, in percentage of the moisture content is given by:

$M_n = ((W_w - W_d)/W_w) \times 100$

where M_n is the moisture content (%) of material, W_W is the wet weight of the sample, W_d is the weight of the sample after drying.

Total moisture content absorbs by silica gel

<u>1 kilogram of silica gel</u>

Total weight of water absorbs by silica gel = Final weight – initial weight

= 1235 g – 1028 g

= 207 g

Total weight of water absorbs by silica gel = Final weight – initial weight

(Maximum absorption) = 1303 g – 1028 g

= 275 g

Ww = 1235 g Wd = 1028 g

Mn = ((1235 g-1028 g)/1028) x 100 = 16.76%

Total moisture content that been absorbed by 1 kilogram of silica gels is total up to **16.76%.**

Ww = 1303 g Wd = 1028 g

Mn = ((1303 g-1028 g)/1028) x 100 = 26.75%

Maximum moisture content can be absorbed be 1 kilogram of silica gels is **26.75%.**

Total water lost from the sponge = Final weight – Initial weight

= 453 g – 319 g

= 134 g

اونيۈرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Ww = 453 g Wd = 319 g

Mn = ((453 g-319 g)/453) x 100 = 29.58%

Total moisture content exit from wet sponge is **29.58%.**

2 kilogram of silica gel

Total weight of water absorbs by silica gel = Final weight – initial weight

= 2376 g – 2017 g

= 359 g

Ww = 2376 g Wd = 2017 g

Mn = ((2376 g-2017 g)/2017) x 100 = 17.80%

Total moisture content that been absorbed by 2 kilogram of silica gels is total up to **17.80%.**

Total water lost from the sponge = Final weight – Initial weight

= 747 g – 548 g

= 199 g

Ww = 747 g   Wd = 548 g

Mn = ((747 g-548 g)/747) x 100 = 26.63%

Total moisture content exit from wet sponge is **26.63%.**

4.8.2 Absorption Rate

$$\text{Absorption rate (g/min)} = \frac{\text{Differences in silica gel weight(g)}}{\text{Drying time (min)}}$$

4.8.3 Regeneration rate

$$\text{Regeneration rate (g/min)} = \frac{\text{Differences in silica gel weight(g)}}{\text{Drying time (min)}}$$

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 5

CONCLUSION

5.1 Summary

The goal of this project is to conduct the experiment on the performance of desiccant material in continuous drying of agriculture product when the solar energy is absence. The main aim of the experiment is to test on the desiccant material chosen which are the silica gels towards water. The reason of choosing silica gel is because of it is in solid form and widely used in the market. Based on the analysis of the result, silica gel is very attractive to the water molecule and it can absorb up to 30% of water of its own weight. This prove that silica gel is one of the best desiccant material to be used for any drying process including food product. White silica gel is non-toxic if compared to others color indicator silica gel which contain chemical substances. Although there is some orange indicator silica gel mixed with white gel is applied, it is for the purpose to detect whether the silica gel is saturated or not. It is easy to carry up experiment and does not waste a lot of time.

After all the experiments, the absorption and regeneration rate have been achieved and can be concluded that silica gel have a higher absorption rate compared to regeneration rate. It can absorb up to 2.45g of water in one minute. Moreover, the larger the weight of silica gel use for drying, the higher the absorption rate as there are many spaces for the water molecule to

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

enter. This proven that silica gel is very attractive to the water and can be used for food product in the future experiments. On the other hand, from those method of regeneration been tried, although universal oven has a constant regeneration rate compared to natural air convection, but it consumed much energy in term of electric. Our experiments promote continuous drying in green way so we focus on direct sunlight. Natural air convection is good but many conditions have to reach such as weather, wind, area of exposed and many more. If any of the conditions is lack or absence, the regeneration rate will be varied and might even take over by absorption rate. If temperature does not maintain at certain high level, silica gel will choose to absorb water from the ambient air rather than regenerate. It must be kept in a closed container to prevent the water molecule inside the ambient air enter it. Regeneration for silica gel is the most challenging in this project, any conditions must be concerned in order to regenerate the silica gel completely.

All of the experiments results were recorded from the reading given by Anemometer. From the testing results it can be concluded the following:

The larger the weight of silica gel, the higher the absorption rate per minute of time inside the closed drying chamber. However, the air velocity and hence air uniformity inside the chamber was not perfect when space for the silica gel is limited, expose area is small, there will be a limit for drying process.

Regeneration can occur when temperature of the surrounding is high. The higher the temperature, the lower the air humidity, the higher the rate of regeneration. Among all the method, regenerate under hot sun is the best method because it does not consume any external energy and it achieve the aim of this project which is go green and naturally.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

At the end of this thesis, some calculations were made based on the testing results to find out the approximate moisture content lost from the wet sponge and amount of moisture content absorb by the silica gel. The calculation as well provides absorption rate, regeneration rate, moisture content and maximum absorption. The resulted calculations proved that the 2 kilogram of silica gel was the most efficient compared to 1 kilogram and possess the highest absorption rate. Furthermore, the maximum absorption calculated for 1 kilogram were 26.75% which is almost to theoretical of 40% maximum of its own weight. The moisture content release from the wet sponge can be said that when wet sponge released the moisture content about 29.58%, the 1 kilogram of silica gel has absorbed 16.76% of moisture content, the remaining moisture is left inside the surrounding air.

5.2 Suggestions for Future works

As an extension to the work carried out in this thesis, following future work will be interesting:

اونيورسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

1. It would be more preferable and affordable if we would be able to control the temperature and velocity of the dryer by using some sensors and external devices.
2. It would be more convenient if we use controlling speed fans so that we can control the speed of the fans and hence the air velocity which influence the temperature in the dryer.
3. It would be more efficient if we would design a closed system with control fan chamber for the regeneration happen effectively during on-sunshine which will influence the absorption rate during off-sunshine or at night.
4. An experimental drying if the agricultural products are required to be carried out and calculate the drying time for each product practically with the consideration of the quality of product.

REFERENCES

(2018, March 11). Retrieved from Drying - IRRI Rice Knowledge Bank. : http://www.knowledgebank.irri.org/step-by-step-production/postharvest/drying

Ahlberg, J. (1939). Rates of Water Vapor Adsorption from Air by Silica Gel. Industrial & Engineering Chemistry, 31(8), 988-992.

Alqadhi, A. A. (2018). Design and develpment of an optimizd mixed mode solar dryer. Renewable energy.

C.L. Hii, C. L. (2009). Thin layer drying kinetics of cocoa and dried product quality. Biosyst. Eng, vol.102, no. 2, pp. 153-161.

Chramsa-Ard, W. J. (2013). Performance evaluation of the desiccant bed solar dryer. Energy Procedia, 34, 189–197.

Desiccant Chart Comparisons. (2018). Retrieved from SorbentSystems.com: https://www.sorbentsystems.com/desiccants_charts.html

Dina, S. F. (2015). Study on effectiveness of continuous solar dryer integrated with desiccant thermal storage for drying cocoa beans. Case Studies in Thermal Engineering, 5,32-40.

Ear corn drying and processing. (2018). Retrieved from Cimbria.com. : http://www.cimbria.com/process/ear-corn-drying-and-processing

Ekechukwu, O. &. (1999). Review of solar-energy drying systems II. An overview of solar drying technology. Energy Conversion And Management.

Giebel-adsorber.de. (2018). Retrieved from Fundamentals for the regeneration of silica gel: http://www.giebel-adsorber.de/images/unternehmen/neue-produkte/GIEBEL_Regeneration%20of%20silica%20gel_EN.pdf

Giebel-adsorber.de. (2018, 12 2). Retrieved from https://www.giebel-adsorber.de/images/unternehmen/neue-produkte/GIEBEL_Regeneration%20of%20silica%20gel_EN.pd

Hazeeb Halib, A. H. (2016). Experimental Analysis of Solid Desiccant wheel Dehumidifier.

India, S. (2018). Blue Indicating Type Silica Gel in Bulk. Retrieved from Sorbeadindia.com: http://www.sorbeadindia.com/products/Silica-Gel-Blue

Indicating Silica Gel: Orange vs. Blue . (2017). Retrieved from AGM Container Controls: https://www.agmcontainer.com/blog/desiccant/indicating-silica-gel/

Jeong Jongsoo, Y. S. (2011). Performance analysis of desiccant dehumidification systems driven by low-grade heat source. International Journal of Refrigeration.

John W. Lund, P. J. (2018). Onion Dehydration. Retrieved from https://www.oit.edu/docs/default-source/geoheat-center-documents/publications/industrial/tp86.pdf?sfvrsn=2

Liu, X. G. (2004). Combined cogeneration and liquid-desiccant system applied in a demonstration building. Energy And Buildings.

Misha, S. M. (2012). Review of solid/liquid desiccant in the drying applications and its regeneration methods. Renewable and Sustainable Energy Reviews.

Misha, S. M. (2015). Performance of a solar assisted solid desiccant dryer for kenaf core fiber drying under low solar radiation. Solar Energy.

Natural-air corn drying in the upper Midwest. (2018). Retrieved from Harvest : Corn : University of Minnesota Extension: https://www.extension.umn.edu/agriculture/corn/harvest/natural-air-corn-drying/

Ng, K. C. (2001). Experimental investigation of the silica gel–water adsorption isotherm characteristics. Applied Thermal Engineering, 21(16), 1631-1642.

R.L.Earle. (2018, March 11). Retrieved from Unit Operations in Food Processing: http://www.nzifst.org.nz/unitoperations/drying2.htm

Rane, M. V. (2005). Energy efficient liquid desiccant-based dryer. Applied Thermal Engineering, 25(5–6), 769–781.

Shanmugam, V. &. (2006). Experimental investigation of forced convection and desiccant integrated solar dryer. Renewable Energy.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Shukla, D. &. (2017). A technical review on regeneration of liquid desiccant using solar energy. Renewable And Sustainable Energy Reviews.

Swadaya, P. (2018, December 2). Universal Oven - Memmert Universal Ovens . Retrieved from PT. Prolabmas | Jakarta | Indonesia. Prolabmas.com.: http://prolabmas.com/wmview.php?ArtID=844

Thoruwa, T. F. (1996). Developments in solar drying using forced ventilation and solar regenerated desiccant materials. Renewable Energy, 686–689.

User.S. (2018, March 11). Retrieved from What is drying?: http://www.knowledgebank.irri.org/postproductioncourse/index.php/drying/what-is-drying

What does desiccant mean? (2001). Retrieved from DEFINITIONS: https://www.definitions.net/definition/desiccant

What is the difference between white, blue and orange silica gel? . (2018). Retrieved from Deltaadsorbents.com : https://www.deltaadsorbents.com/Blog/Post/15/what-is-the-difference-between-white-blue-and

Yao, Y. L. (2009). Regeneration of Silica Gel Using High-intensity Ultrasonic under Low Temperatures. Energy & Fuels, 23(1), 457-463.

Yin YG, Z. X. (2008). Experimental study on a new internally cooled/heated dehumidifier/regenerator of liquid desiccant systems. International Journal Of Refrigeration.

Yin, Y. Q. (2014). Recent advancements in liquid desiccant dehumidification technology. Renewable and Sustainable Energy Reviews, 31, 38–52.

Yin, Y. Z. (2016). Investigation on coupled heat and mass transfer coefficients between compressed air and liquid desiccant in a packed dryer. International Journal of Heat and Mass Transfer, 93, 1218–1226. .

UNIVERSITI TEKNIKAL MALAYSIA MELAKA