EXPERIMENTAL STUDY OF DESICCANT MATERIAL PRESSURE DROP

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EXPERIMENTAL STUDY OF DESICCANT MATERIAL PRESSURE DROP

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UNIVERSITI SAINS MALAYSIA

2022

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LIST OF SYMBOLS

V	Volt
v	Volume
r	radius
D	diameter
Φ	Porosity

LIST OF ABBREVIATIONS

ANN	Artificial Neural Network (ANN)
HVAC	Heating, Ventilation and Air Conditioning
COP	Coefficient of Performance
RH	Relative Humidity
CFCs	Chlorofluorocarbons
HFCs	Hydrofluorocarbons
LCDS	Liquid Desiccant Cooling Air Conditioning System
DAC	Desiccant Air Conditioning
IAQ	Indoor Air Quality
USM	Universiti Sains Malaysia

KAJIAN EKSPERIMEN DESICCANT MENURUN TEKANAN BAHAN

ABSTRAK

Pada masa kini, permintaan tenaga semakin meningkat berikutan pertambahan penduduk dan taraf hidup. Kecekapan pemanasan, pengudaraan dan penyaman udara (HVAC) akan menggunakan kurang tenaga dan menyediakan persekitaran dalaman yang selesa. Kelembapan lembapan yang tinggi boleh menyebabkan kerosakan dalam pelayan data dan penyebaran bakteria dan virus. Bahan pengering dalam penghawa dingin boleh menyerap jumlah lembapan yang besar daripada udara dan boleh diserap dengan mudah pada suhu penjanaan semula yang rendah. Tiga jenis bahan pengering yang berbeza seperti tanah liat pengering, alumina teraktif, dan gel silika digunakan sebagai bahan pengering dalam eksperimen ini. Keliangan bahan pengering yang berbeza dihasilkan disebabkan oleh saiz bahan pengering yang berbeza. Keliangan bahan pengering ialah nisbah isipadu lompang setiap jumlah isipadu. Terdapat tiga voltan berbeza yang dibekalkan kepada blower dalam eksperimen ini iaitu 163.2V, 2176V dan 272V. Roda bahan pengering reka bentuk baharu dicadangkan untuk eksperimen penurunan tekanan bahan bahan pengering. Untuk tiga voltan berbeza yang dibekalkan kepada peniup dalam eksperimen ini, apabila keliangan bahan pengering berkurangan, penurunan tekanan meningkat sedikit. Halaju masuk maksimum dan minimum berkurangan sedikit apabila keliangan bahan pengering berkurangan, untuk semua voltan berbeza yang dibekalkan kepada peniup. Penurunan tekanan dikekalkan dalam jumlah peningkatan yang kecil apabila merentasi reka bentuk baharu roda pengering.

EXPERIMENTAL STUDY OF DESICCANT MATERIAL PRESSURE DROP

ABSTRACT

Nowadays, energy demand is increasing due to the increase population and standard of living. Efficiency of the heating, ventilation and air-conditioning (HVAC) will consuming less energy and provide comfortable indoor environment. High humidity can cause malfunction in data server and spread of bacteria and virus. Desiccant materials in desiccant air conditioning can absorb large amount moisture from air and can be desorbed easily at low regeneration temperature. Three different types of desiccant materials such as desiccant clay, activated alumina, and silica gel are used as desiccant in this experiment. Different porosity of desiccant is produced due to different sizes of different desiccants. The desiccant porosity is the ratio of void volume per total volume. There are three different voltage supplied to the blower in this experiment which is 163.2V, 2176V and 272V. A new design desiccant wheel is proposed for the desiccant material pressure drop experiment. For three different voltage supplied to the blower in this experiment, when desiccant porosity decreased, the pressure drop increased slight. Maximum and minimum inlet velocity decrease slightly when the porosity of the desiccant decrease, for all the different voltage supplied to the blower. A pressure drop maintain in small amount of increase when across new design of desiccant wheel.

CHAPTER 1
INTRODUCTION

1.1 Overview of Dehumidifier

Nowadays, human activities mainly spent in the indoor environment, thus big amount of primary energy is consumed by residential and commercial building for support occupants daily activities [1]. Energy demand will increase due to the population increase and standard of living increase and thus increase the energy consumption. The consumption of the electrical energy is expected to increase 120% from 2002 to 2030 [2]. The efficient of the heating, ventilation and air-conditioning (HVAC) will consuming less energy and provide comfortable indoor environment. Since building sector consume approximately 40% of the world's energy demand [3], increase building energy efficiency by increase the efficient of HVAC is the useful way to save energy. IEA statistics [4] claims that by the next 30 years, air conditioner system demands will triple worldwide.

For high technology industry, high humidity can cause malfunction in data servers. This happens due high relative humidity process air from de-centralized vapour compression air conditioning systems. This situation is usually occurs in Costal Asian Countries such as Thailand, Singapore and Malaysia. Thus, dehumidifiers is important to be installed in the HVAC system in high technology industry [5].

Dehumidifier is a device used to decrease the moisture of a room to ensure the comfort of the occupants. The dehumidifier is an air conditioning device which help reduces humidity level in the air. The relative humidity (RH) knowns as percentage of the amount of moisture that already retrained by the atmosphere without condensation at a given pressure and temperature. RH shows the percentage of moisture in the air and different room temperature can hold different amount of moisture. RH are the working parameters that affect the heating ventilation and air conditioning (HVAC) efficiency.

The humidity for human comfort and the indoor air temperature separate the cooling load of the building into latent heat and sensible heat. The conventional compressor based air conditioners can efficiently control building sensible load but weak in control building latent heat. Thus, to remove the moisture from the air, lot of energy is wasted to overcool the air below its dew point by condensation and reheat again to required supply temperature [6]. This overcooling process ease the growth of bacteria due to wet surface which can cause health problem and bring bad effect to indoor air quality [7].

The materials which can adsorb the moisture are called desiccant material. These materials play an important role in dehumidification systems. By using the desiccant in the cooling system, up to 5% for heating and 30% for cooling of the energy consumption can be reduced [8]. The water adsorption of desiccant used in desiccant air-conditioning is used to remove the moisture for humidity control [9].

1.2 Overview of Desiccant Materials

Desiccant materials in desiccant air conditioning can absorb large amount water vapour and can be desorbed easily at low regeneration temperature [10]. Desiccants are the materials with a high affinity for water vapour, and generally solid, remains un-changed in the dehumidification process. Due to desiccant materials has high capability to absorb and hold the water like a sponge, desiccant has been widely applied to marine cargo, pharmaceutical, and storage. Desiccant can be classified into different ways, likes solid, liquid, physisorption, chemisorption, natural, artificial, bio, rock based, composite, and polymer based etc. Physisorption and chemisorption terms refer to the bond strength between the adsorbate and adsorbent. Physisorption is the water vapour removal due to bond strength between adsorbate and adsorbent is weak. For an efficient regeneration process in DAC system, low bond strength is kept optimally [11].

Jani et al. [12]reviewed several of studies on artificial neural network (ANN) that used to predict the performance of solid desiccant cooling system using input and output parameters such as humidity ratio, regeneration, and temperature. They concluded that, ANN has a potential to apply on evaluation of solid desiccant performance at higher precision.

Solid desiccant materials' another characteristic is it will desorb the adsorbed water vapour from the moist air by regenerating at relatively high temperature. It is classified into two main categories [13], substances that can form solid crystalline hydrate, and substance with porous structure, such as, activated alumina, silica gels, desiccant clay etc. These materials' adsorption, based on water vapour pressure between pores within the desiccant material and surrounding air, by physical process occurs in the adsorption phase. Adsorbents having special affinity with polar substances, for example water are termed `hydrophilic'.

1.3 Problem Statement

In the dehumidifier system, the desiccant materials, likes silica gel and activated alumina, are important characteristic component in determining the performance of the dehumidifier. Usually, denser desiccant material absorbs higher water vapour, but, it come together with higher pressure drop. Thus, high power consumption is needed for the blower in order to overcome the high pressure drop. Although less dense desiccant material accompany with lower pressure drop, thus lower electrical energy is needed for the blower, but desiccant performance will be affected and no be satisfied.

The problem here is how to get the satisfied desiccant performance by not increasing the electrical demand from the blower. The design of the desiccant wheel has been studied for getting this expectation. Theoretically, when the porosity of the desiccant increase pressure drop will decrease, thus affecting the desiccant performance. New design of the desiccant wheel is proposed for studying the relationship between the porosity of the desiccant and the pressure drop. The relationship of the pressure drop and the frontal air velocity is studied also for this proposed desiccant wheel.

1.4 Objectives

There are three main objectives of this study:

i. To develop an experimental setup for the proposed desiccant wheel.
ii. To determine the desiccant wheel porosity from several desiccant materials.
iii. To study the relationship between the pressure drop against air velocity and porosity.

1.5 Scope of Project

Firstly, a new design of desiccant wheel is proposed for the experiment to study the relationship between porosity of the desiccant wheel and its pressure drop and also the frontal air velocity. By doing some literature review from the design of the desiccant wheel present nowadays, the design of the desiccant wheel come out which contain square slots arrange accordingly inside it. The design is then draw by using SOLIDSWORK software. After the design come out, 3D printing process is continued for the prototype of the desiccant wheel. The desiccant wheel later is used to carry out the experiment in the experimental rig.

Next, by using the proposed design desiccant wheel, the porosity of the desiccant wheel can be determined. Several desiccant materials are used in this experiment, which is desiccant clay, activated alumina and silica gel. The different desiccant materials have its own diameter or volume. Since porosity is the ratio of void volume per total volume, different volume of the desiccant materials will produce different value of the porosity. By placing the constant amount of the desiccants in each slots in the desiccant wheel, the porosity of the desiccant wheel can be calculated by the porosity formula.

Since the porosity of the desiccant clay can be known, thus relationship between the porosity and the pressure drop can be studied for the proposed design desiccant wheel. The pressure drop results for different porosity can be taken by using the manometer. Also, for the relationship between the pressure drop and the frontal air velocity can be investigated by using the anemometer apparatus to record the inlet air velocity. Lastly, the table is tabulated and the graph is plotted to study the relationship between these parameters.

CHAPTER 2
LITERATURE REVIEW

2.1 Desiccant Cooling System

The conventional air conditioning consumed large amount of electrical energy for handling the moist air for dehumidification process. Bacteria and will easily developed for the moist air and cause health issue by affecting Indoor Air Quality (IAQ) [14]. Failed control of air humidity for air conditioning system can lead to discomfort of people livings, malfunction data servers in high technology industry and bacteria easily developed. The desiccant cooling system is preferable as it free from CFCs, and HFCs. In this system, desiccant handle the latent load efficiently and evaporate cooling directly and indirectly the sensible load [15]. Desiccant cooling system is forcing the incoming air stream pass through the desiccant material for dehumidifying. For continuous dehumidifying, moisture absorbed by the desiccant must be dragged out by heating the desiccant to its temperature of regeneration. This is for the desiccant to continue absorb water for dehumidifying process. Each desiccant has its own temperature of regeneration and depend on its nature. The desiccants are natural substances of absorbing or adsorbing water vapour. They are classified in both liquid and solid state. Liquid desiccant have low pressure drop, low regeneration temperature and feasibility in utilisation. While solid desiccant are compact and hard corrosion.

2.1.1 Liquid Desiccant Cooling System

For liquid desiccant, the liquid desiccant is brought contact with incoming air stream. Liquid desiccant is more preferable as its flexible operation and absorbing bacteria. Liquid desiccant has lower regenerated temperature compare to solid desiccant [16], thus lower airside pressure drop. The liquid desiccant in air conditioning can attain 40% energy savings by compared to conventional air conditioning [17]. For improving air quality and save energy, solar energy driven liquid desiccant cooling air conditioning system (LDCS) has been proposed. The strong desiccant solution is used to absorb the moisture of the air for dehumidification process and gets diluted by regeneration to useful level of concentration [18]. The liquid desiccant cooling system was firstly put forward by Lo ̇f [19]. A packed bag dehumidifier for solar conditioning with liquid desiccant and theoretical model for performance prediction packed bag dehumidifier is developed by Factor and Grossman [20]. By investigated both experimental and theoretical, Lazzarin used solutions $H_2O/LiBr$ and $H_2O/CaCl_2$ as liquid desiccant [21].

2.1.2 Solid Desiccant Cooling System

Adsorption of water vapor from air is the mechanism for solid desiccant cooling system and solid desiccant is hygroscopic material such as silica gel. The excess moisture of the air is removed by passed the rotary dehumidifier. By using the cooling coil, this warm and dried processed air can be cooled down. Dehumidifier need to be regenerated to remove water vapor in this system.

Ventilation cycle is the first solid desiccant cooling introduced by Pennington. In this cycle, moist ambient air in stage 1 is dehumidifies by passing a rotary dehumidifier and converted to warm and dry air. Later, it sensible cooled by pass through sensible heat wheel and cooled further up by passed through evaporative cooler. Next, the room air returned is humidified and cooled by another direct evaporative cooler. The air later sensible heated by pass through sensible heat recovery wheel. The air later is heated up again to required regeneration temperature of desiccant materials by regeneration heat source. After the desiccant wheel is reactivating, the air is flow to surrounding, while small portion of return air stream bypass to heat regeneration source to decrease regeneration heat consumption [15].

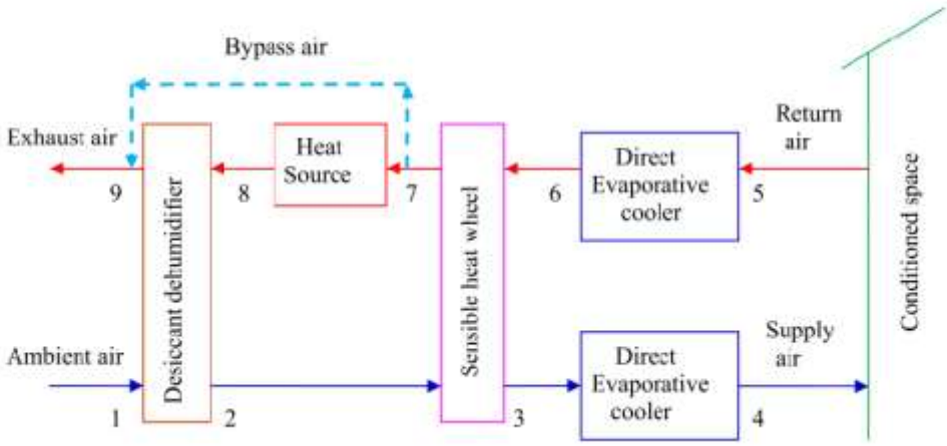

Figure 2.1 Pennington (ventilation) cycle [15]

2.2 Desiccant Materials

Desiccant is hygroscopic substance which attract moisture when different in vapour pressure. The affinity water adsorption give desiccant to remove the moisture [9]. The desiccant handle the latent load of conventional air conditioning efficiently, save the energy and increase the COP [22]. Solid desiccant which compact and hard corrosion is usually act as comparison materials to other desiccants [23]. Silica gel, activated alumina and desiccant clay are the examples of conventional solid state desiccant material. New desiccant developed which consists of composite materials, giving better results compared to conventional solid desiccant [24]. For this experiment, conventional solid desiccant material is choose as the desiccant which are silica gel, activated alumina and desiccant clay.

Figure 2.2 Activated alumina

Figure 2.3 Silica gel

Figure 2.4 Desiccant Clay

2.2.1 Silica Gel

Pure silica is a main ingredient in Silica gel or Silicon dioxide (SiO_2. xH2O) development. It is a natural occurring mineral which is later processed to granular form with amorphous micro-porous structure. Due to small porosity and higher surface area per weight, which is 650 m^2/g, it has a large capacity to absorb water. Silica gel has a typically pore size ranging from 0.7 nm to 2-3 nm and adsorption is nearly 2800 kJ/kg [25]. Type B is the silica gel with porous diameter 0.7nm, showing better performance in dehumidification process, which RH50% and above at high vapour pressure. Losing adsorption capacity will occur due to overheating, thus temperature under 200 ^oC is usually used and the regenerated temperature is 85 ^oC. Silica gel can absorb high capacity of water which lead to high latent heat of evaporation up to 40% of dry mass [26].

2.2.2 Activated Alumina

Activated alumina is come from aluminum hydroxide by dihydroxylation for bigger surface area. It has a 150–500 m^2/g surface area and it pores sizes is 1.5 to 5nm ranging. The heat adsorption of activated alumina is nearly 3000KJ/Kg [25]. Activated alumina is widely used for desiccant dehumidification in solid desiccant cooling system [27].

2.2.3 Desiccant Clay

Clay desiccant is a natural origin material. Due to its adsorption capacity, desiccant clay act as desiccant material such as reduce dew point in the packaging. It composed mainly calcium and magnesium silicate. Aristov et al [28] filled a sample of expanded vermiculite with 40% (wt) solution of calcium choride and when it dried, 57.3 contents of $CaCl_2$ left. Sorption isobars and isotherms at varying temperature and vapour pressure were then determined. Tokarev et al [29] developed a desiccant consisting of $CaCl_2$ in a matrix of MCM-41 (Mobil Composite Material). After drying MCM-41, it was filled with saturated solution of calcium chloride. It contain 37.7% (wt) of $CaCl_2$ after drying. It found that desiccant has a moisture sorption of 70-75% (db) under 70% relative humidity. The regeneration temperature for MCM-41 and calcium chloride is between 70 ^oC to 120 ^oC.

2.3 Pressure Drop

Pressure drop for liquid desiccant in a packed bag has been studied. In this paper, calcium chloride is act as liquid desiccant. Hydraulic performance effect from the random packing shape and type of structural packing has been studied. The result shows that structural packing has lower pressure drop compared to random packing which has lower capacity then structural packing. Among random packing, Intalox saddles produces the lowest pressure drop, and sheet-type Mellapak 250 Y has the lowest pressure drop for structure packing [30].

Besides structure packing, the desiccant thickness have the effects on pressure drop of desiccant material. The paper of using composite material to improve utilization of desiccant material in a packed bag has been studied [31]. From the theoretical result, composite silica gel desiccant is more utilize when compare to ordinary silica gel as desiccant. For same amount of desiccant materials and same mass flow rate, the pressure decrease about 60% when 0.2 thickness ratio is proposed. This shown that thicker desiccant material produces higher air pressure drop as velocity of the air pass through the bed is low for same mass flow rate of air. For bidispersed bed desiccant, dehumidification decrease when the pressure drop increase. This due to when increase in pressure drop, adsorption happen more quickly, thus desiccant moisture adsorption capacity decrease lead to decrease in dehumidification [32].

2.4 Desiccant porosity

Desiccant porosity is referring as void space remaining in the desiccant wheel. The paper of moisture adsorption in silica gel bidisperse beds has been reviewed. Bidisperse bed is bed filled with two different sizes of desiccant for void reduction. The result show that bidisperse packed in desiccant increased 22.9% for dehumidification capacity and 25% for water mass absorbed when compared to conventional monodisperse packing in this paper [32]. Santos et al. [33] described that when particle size ratio decrease, desiccant porosity decrease, thus packing density increase. Pressure drop across the wheel increase when porosity decrease. Pressure drop can be reduced by decreasing the applied air flow rate. When the desiccant more compact in the desiccant wheel, porosity will decreased. The use of bidesperse packed desiccant is to form more compact solid desiccant structure and reduce its porosity. The coefficient of performance(COP) of desiccant cooling increase due to small void spaces in the desiccant bed and increase the mass water absorbed [34].

2.5 Desiccant wheel design

Desiccant wheel is the important part in the solid desiccant cooling system. A good design of the desiccant wheel decide the efficiency of the desiccant system. A paper has been studied on two heat and mass transfer models of a counter flow desiccant wheel. Figure 2.5 show the design of the counter flow desiccant wheel. There are two sides consideration, one is gas-side resistance, the other side is both solid-side and gas-side resistances are developed. This models show good match with experimental data and used to compare the performance of different wheel design. By comparing the dehumidification rate, counter flow desiccant wheel is better than parallel flow desiccant wheel [35].

Next is the redesigned traditional honeycomb matrix structure of rotary desiccant wheel so that pressure drop value below 2Pa, for passive ventilation target. Due to redesign of the desiccant wheel, regeneration temperature was lowered. By comparing the previous traditional model which consumed large amount of energy due to high pressure drop, the redesigned model can safe more energy as it has lower regeneration temperature. By using this new design, keeping low pressure drop across it, relative humidity reduced in 55% [36].

The weakness of the conventional desiccant wheel is overheating the supply air or desiccant material during dehumidification. This will increase the partial pressure of water on desiccant and affect the desiccant performance. Thus, non-adiabatic desiccant wheel is proposed. This wheel has internal heat transfer structure with alternative channels for the dehumidification purpose and indirect cooling. Figure 2.6 show the design of the non- adiabatic desiccant wheel. The design achieving cooling simultaneously and dehumidification by the air supply and regeneration air flow in opposite way axially while the cooling air axially enter the center and radially exits [37].

This show that a design of the desiccant wheel will bring effect to the desiccant performances. From the paper, we found that the performance of the desiccant wheel, such as dehumidification rate can be known by carry out the experiment to test on it.

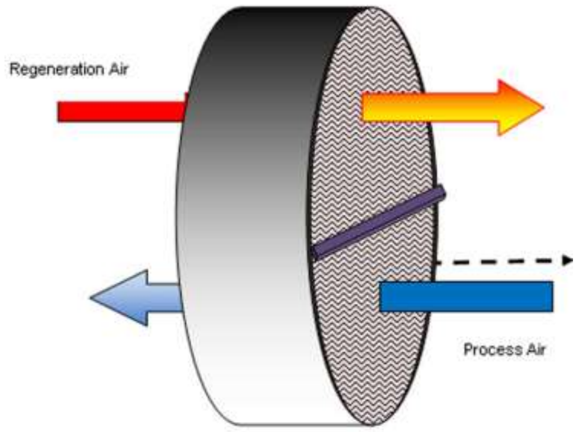

Figure 2.5 Counter flow desiccant wheel design [35]

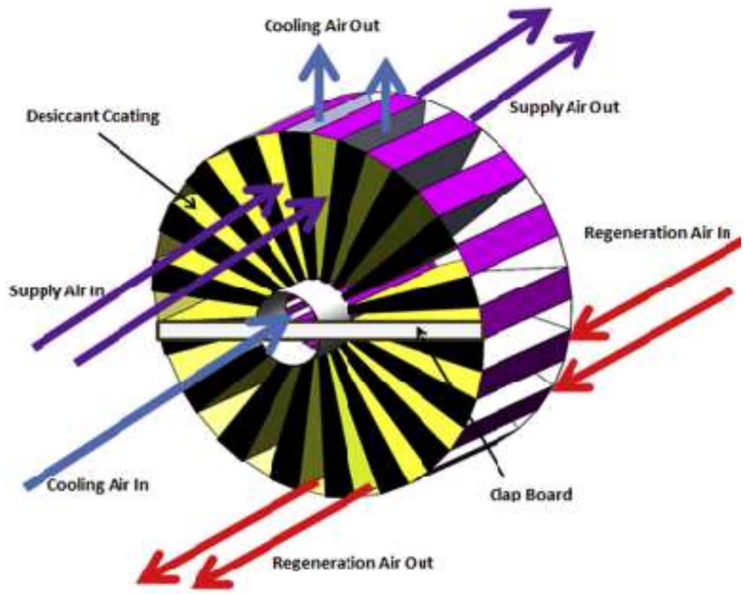

Figure 2.6 Non-adiabatic desiccant wheel design [37]

CHAPTER 3
METHODOLOGY

3.1 Design of the Desiccant Wheel

The idea for the design of the desiccant wheel come out from various literature review [35]–[37]. Since the focus of the experiment is the desiccant material pressure drop, the final design of the desiccant wheel shown in figurer 3.1 come out. Final design desiccant wheel was developed and employed to conduct the experiment. The function of this desiccant wheel design is used to control the number of desiccants inside it, thus porosity of the desiccant can be manipulated and known by placing certain number of desiccant in the wheel.

The use of this design of desiccant wheel is used to study the relationship between porosity of the desiccant and the pressure drop when air pass through it and also, the relationship between the pressure drop and the frontal air velocity. Firstly, the pipe dimension for placing the desiccant wheel is measured. After getting all the measurements, desiccant wheel is designed through SOLIDWORKS software. There are total 3 parts have been designed for the desiccant wheel which is upper cover, body and lower cover. Three part of the desiccant wheel is then compile and make sure that no interference occur in the SOLIDSWORK software, the material chosen for this desiccant wheel is PLA. After that, the file is saved as STL file for 3d printing purpose.

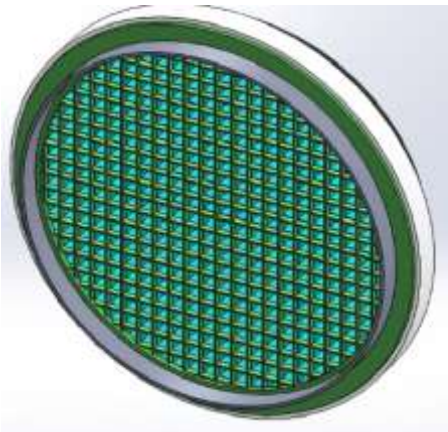

Figure 3.1 Final assembly desiccant wheel

3.1.1 Lower Cover Desiccant Wheel

The lower cover of the desiccant wheel is designed to cover the lower part of the desiccant wheel body. This is due to small freely movable desiccant materials in desiccant wheel body. The lower cover with netting can make sure that the desiccant materials fixed in its slot when running the experiment.

The front view for the lower cover is likes waffle type, made up by many square slots with dimension 8mm x 8mm and distances between them is 1mm. The design of the lower cover is shown in figure 3.2. This design is due to prevent the blockage of air flow and not affect the porosity value and also the pressure drop result, thus same design in front view of the desiccant wheel body.

Furthermore, the design for the lower cower is improved by adding the extension for outlet pipe to grab the desiccant wheel. This is to make sure that percentage of air leaking to the surroundings is negligible. After that, the design is saved as STL file for 3d printing purpose. The material choose for this lower cover is PLA.

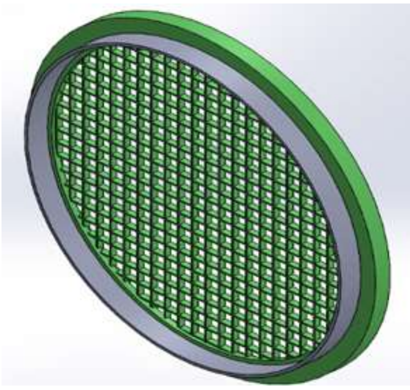

Figure 3.2 Lower cover desiccant wheel

3.1.2 Upper Cover Desiccant Wheel

The upper cover of the desiccant wheel is designed to cover the desiccant wheel in upper part. This is due to small freely movable desiccant materials in desiccant bed body. The upper cover with netting can make sure that the desiccant materials fixed in its slot in upper side of the desiccant wheel when running the experiment.

The front view for the upper cover is also looked likes waffle type, made up by many square slots with dimension 8mm x 8mm and distances between them is 1mm, which same as lower cover design also. The design of the upper cover of the desiccant wheel in SOLIDWORK software is shown in figure 3.3. This design is due to prevent the blockage of air flow and not affect the porosity value and also the pressure drop result.

Apart from that, the design for the upper cower is improved by adding extension for experiment rig inlet pipe to hold the desiccant wheel tightly. This is to make sure that percentage of air leaking to the surroundings is negligible. After that, the design is saved as STL file for 3d printing purpose. The material choose for this upper cover is PLA.

Figure 3.3 Upper cover desiccant wheel

3.1.3 Desiccant Wheel Body

The function of the desiccant wheel body is used to place the desiccant materials and determined the porosity of the desiccant. This square slot design of the desiccant wheel body is to make sure that when less amount of desiccant is used for lower porosity purpose, the desiccants is distribute equally in every parts of the desiccant wheel. When there is no square slots in the desiccant wheel body, all the small freely movable desiccant will be accumulate at the lower part of the desiccant wheel for lower porosity purpose when experiment ongoing, this will decrease the accuracy for the pressure drop and frontal air velocity result. The square slot design in the desiccant wheel bed is to make sure that air velocity and pressure drop results taken is based on the real porosity of the desiccant.

The design of the desiccant wheel bed is design in waffle type, which consists of many square slots with dimension 8mm x 8mm and distance between them is 1mm. The design of the desiccant wheel body is shown in figure 3.4. Total width of the desiccant wheel body is 8mm. The design later is saved as STL file for 3d printing purpose. The material choose for this desiccant wheel body is PLA.

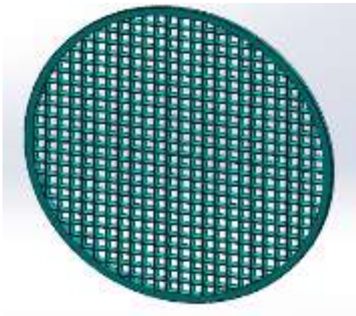

Figure 3.4 Desiccant wheel body

3.1.4 3D Printing Process

After the desiccant wheel design is completed, 3d printing process is required for the desiccant wheel design prototype. 3D printing software, Ultimaker Cura software is used in this 3D printing process shown in figure 3.5. SOLIDWORK file have to save as stl file for the purpose to import the desiccant wheel design to Ultimaker Cura application for 3D printing process. After imported the file and set up the 3D printer with PLA material, 3D printing process can start. Print setting in the Ultimaker Cura application can act as a review and control for the printing process. Figure 3.6 show the desiccant wheel design is being printed by using 3D printer. Figure 3.7 show the 3D printer used for the prototype printing for the desiccant wheel design by PLA material.

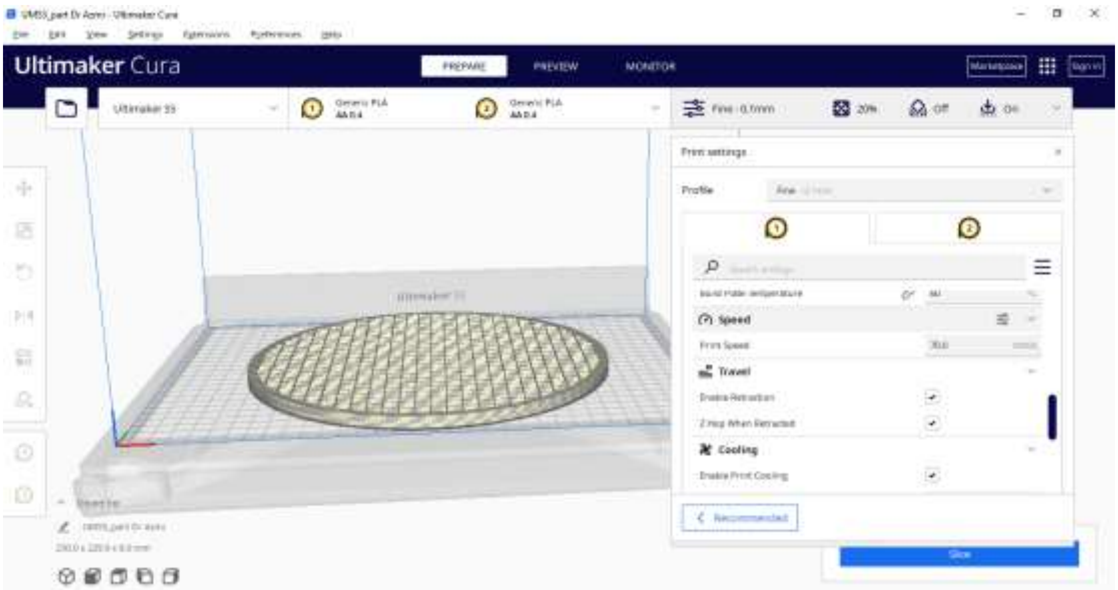

Figure 3.5 Ultimaker Cura 3D printing application for desiccant wheel design printing

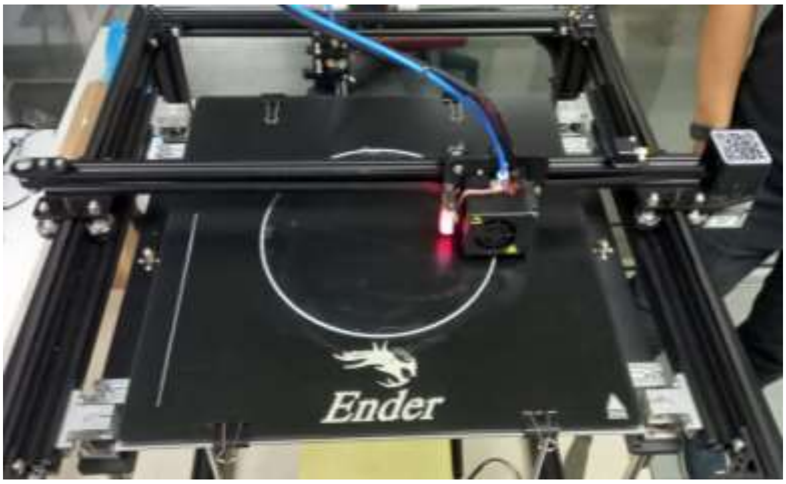

Figure 3.6 Desiccant wheel printing by 3D printer

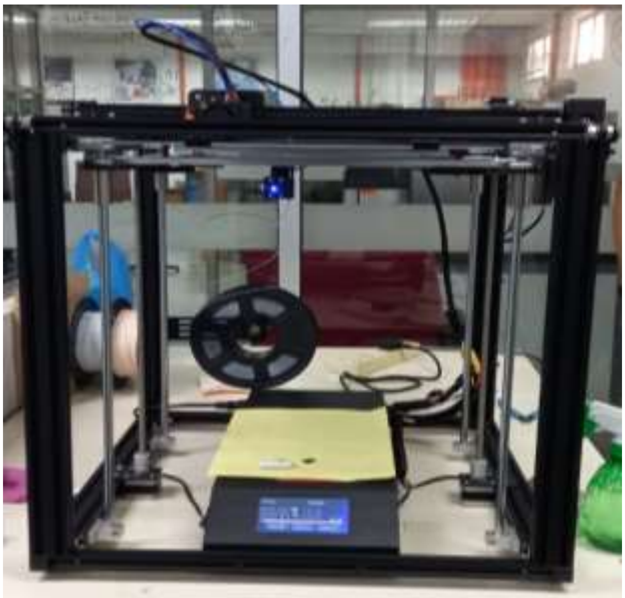

Figure 3.7 3D printer with PLA material

3.1.5 Tolerance

Tolerance is used when designing this desiccant wheel design. The tolerance is to fix the allowable deviation from the assigned dimension. The use of tolerance make sure that the final product come out can be readily be used. As the desiccant wheel totally have three parts and need to assemble it thus tolerance is used. Also the extension for grabbing purpose for the upper cover and lower cover of the desiccant wheel need to suit inside the piping in the test section part, tolerance need to use on it as every fabrication method like 3D printing comes with a certain level of inaccuracy.

3.2 Experimental setup

Experimental rig in Figure 3.8 previously purpose for the organic materials drying process in school of mechanical engineering, Universiti Sains Malaysia. Now, this experimental rig has been converted to Heating, Ventilation and Air Conditioning (HVAC) experimental rig for desiccant materials' dehumidification and regeneration study. This experimental rig consists total four important parts as shown in the Figure 3.8. First part is the air conditioning part which consist cooling coil. The function of the cooling coil in this part is to decrease the inlet temperature. Humidifier compartment section is the second part which act as controller for the relative humidity (RH) of the air. Third part is regeneration part equipped with heating, which function to dry desiccant material. Last part is test section for placing the desiccant bed when running the experiment.

Since the experiment focused on the desiccant material pressure drop and also the frontal air velocity, thus we no use the conditioning compartment, humidifier compartment, and regeneration part in the experimental rig.

High pressure drop due to desiccant friction is solved by using blower in this experiment. The axial frontal velocity is control by the voltage regulator, by adjusting the voltage to the blower. For my part, it only consists blower part and test section part, as my concentration is on the relationship between porosity of the desiccant materials in the desiccant bed and the pressure drop, also the axial frontal velocity for different variation of voltage.

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Figure 3.8 Experimental rig

Figure 3.9 show the schematic diagram of the experimental rig. The schematic diagram show that air flow in the experimental rig in simple way. Firstly, the air is flow into the air conditioning part, then later flow into the humidifier part. Then the air continue flow to the regeneration part then lastly test section part before to the surrounding. The function of the blower here is determine the direction of air flow. Blower here is to drag the air from the inlet air part to the outlet part.

Since our experiment is only focus on the desiccant material pressure drop and also the relationship between the frontal air velocity and the pressure drop, thus for air conditioning, humidifier part and heating part in the experimental rig no need on. The part only act as air flow channel in this experiment.

The focus for our experiment in this experimental rig is text section part and the blower part. Test section part is the place where the desiccant wheel located. Different porosity of the desiccant wheel is being tested in this test section part. While for blower part, since different voltage is supplied to the blower to view the relationship between the pressure drop and the frontal air velocity. The voltage supplied to the blower is verified by the voltage regulator.

The measuring equipment used here is anemometer and manometer. Anemometer is placed between the heating part and test section part in the experimental rig for recording the air inlet velocity while manometer is placed in the test section part for measuring the desiccant pressure drop.

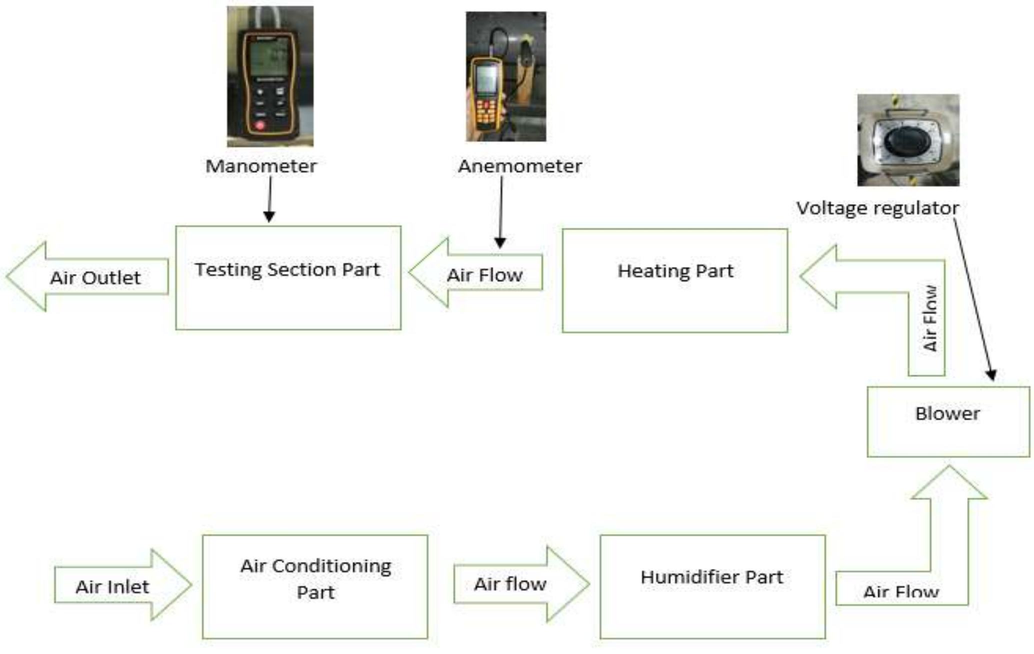

Figure 3.9 Schematic diagram of the experimental rig

3.2.1 Blower

Blower shown in figure 3.10 is used in the experiment to drag the air from the inlet of the experimental rig to the outlet of the experimental rig and overcome the high pressure drop due to the desiccant friction. By adjusting the voltage through voltage regulator, the speed of the blower can be controlled. Due to the experimental objectives need to study the relationship between pressure drop and the frontal velocity between the porosity of the desiccant. Three sets of different blower speed is used in this experiment which control by voltage regulator with voltage 163.2V, 217.6V, and 272V.

Figure 3.10 Blower

3.2.2 Test Section Part

The desiccant wheel is installed inside the test section as illustrated in Figure 3.11. Test section part is the section where the desiccant wheel design placed. The desiccant wheel design is fixed in the pipe in test section by adding the grabber. Firstly, no desiccant material is placed in the desiccant bed which act as a control set in the experiment. Three sets of different blower speed is used in this experiment which control by voltage regulator with voltage 163.2V, 217.6V, and 272V. Then, each slot in the desiccant bed is firstly placed by one silica gel and study the pressure drop against air velocity and porosity by running the experiment. Later follow by two silica gels fill in every slots in desiccant bed. Follow by three silica gels until each slot can’t place any silica gel. Each experiments need to record the pressure drop and the minimum and maximum frontal air velocity. After completed, silica gel is replaced by activated alumina and desiccant clay.

Figure 3.11 Test section part

3.2.3 Description on Measuring Equipment

There are three types of measuring equipment used in this experiment which is anemometer and manometer and also Vernier callipers. The anemometer was used to measure the frontal air velocity. The anemometer is placed between the heating part and the testing section part for measurement the frontal air velocity. For every set of experiment, there are two data need to be measured by anemometer, which is minimum inlet velocity and the maximum inlet velocity.

Figure 3.12 Anemometer position in experimental rig

The manometer is employed to calculate the pressure drop. The manometer is placed in the test section part, measuring the pressure drop for different porosity of the desiccant materials in the desiccant bed. The unit recorded for pressure drop in manometer is psi, 1 psi equal to 6894.76 Pa. There are two hose connected in the manometer, when a single hose is connected to the (+) port and pressure is applied, the manometer will read positive pressure. If a single hose is connected to the (-) port and pressure is applied, the manometer will read a negative pressure. If both ports are connected to a pressure, the manometer will read the difference (P1 - P2) between the two.

Figure 3.13 Manometer position in experimental rig

Vernier calliper is used to calculate the diameter of the desiccant materials. Main jaws in the Vernier calliper is used to calculate the diameter of the desiccant material. The sensitivity of the Vernier calliper is 0.02mm. This diameter taken is purposely used to calculate the porosity of the desiccant materials in the desiccant bed. Since every desiccant materials have different diameters thus total 10 measurements is taken and average values is recorded as the diameter of the desiccant material.

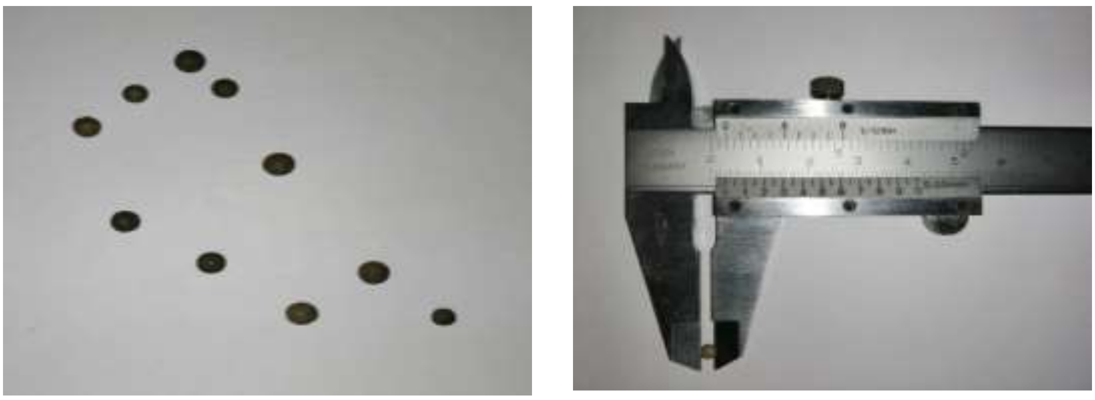

Figure 3.14 Clay desiccant

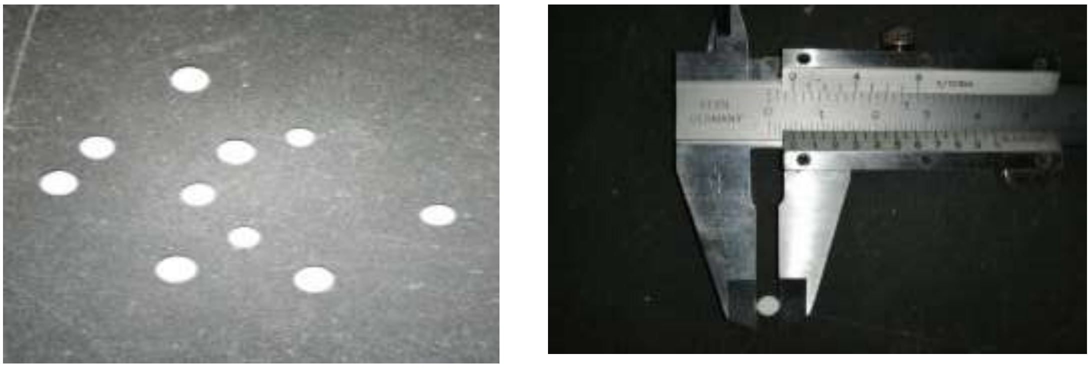

Figure 3.15 Activated alumina desiccant

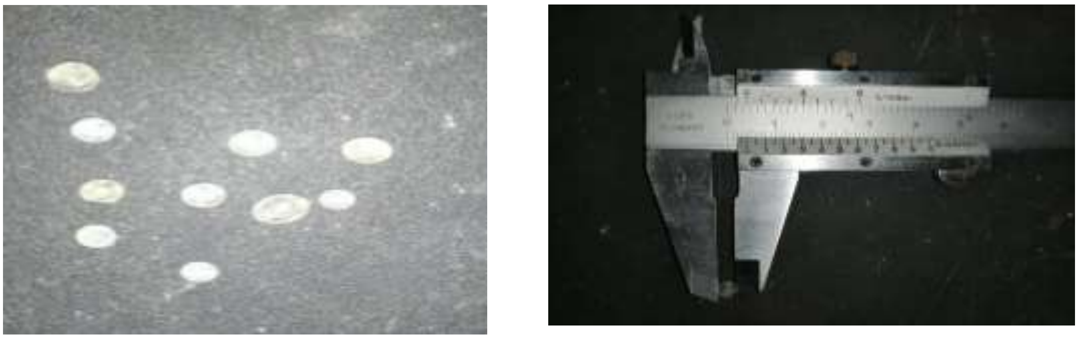

Figure 3.16 Silica gel desiccant

3.3 Experimental Procedure

In this part, experimental procedure for the experiment is describe in step by step. Firstly, measured the inner and outer diameter of the piping for the placing desiccant wheel design. This is for the design purpose of the desiccant bed, which decide the final dimension of the desiccant bed that can suit in the piping of experimental rig. For this measurement, since diameter of the piping is quite large thus Vernier calliper cant used for this measurement. Compass is used in this measurement. Firstly, the inner diameter is drew in the A3 paper, then compass is used to find the centreline of the circle, by using the ruler to measure the centerline, the inner diameter of the pipe can be known. The procedure is then repeated by drawing the outer diameter.

Next, the dimeter of the desiccant materials is measured by the Vernier callipers to calculate the porosity. Since every desiccant materials likes desiccant clay have different diameter thus 10 desiccant clays is chosen and mean diameter is calculated as the diameter of desiccant clay. This procedure is then repeated by using activated alumina and silica gel.

After complete printing the desiccant wheel design, the experiment can continue by equipped the desiccant wheel with netting for both side of the desiccant wheel. This is to prevent freely movable desiccant materials come out from the desiccant wheel when experiment is ongoing.

After that,

1. Employed the desiccant wheel in the test section with no any desiccant materials inside it. Set the voltage regulator at 163.2 V.
2. The manometer is used to record the air pressure drop result in test section part.
3. The anemometer is used to record the maximum and minimum frontal air velocity.
4. Step 1 to step 3 is then repeated by changing the voltage to 217.6 V and 272 V.
5. Step 1 to step 4 is repeated by replacing one desiccant clay in each slot in the desiccant bed.
6. Step 5 is repeated by filling 2, 3, 4, 5, 6, 7, and 8 desiccant clay in each slots in the desiccant bed.
7. Step 5 and step 6 is then repeated by changing the desiccant material to activated alumina and silica gel.
8. All the results taken is then tabulated in the table.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Porosity of desiccant materials

Porosity is a measure of the void spaces in a material. For different desiccant materials such as desiccant clay, activated alumina and silica gel, each of them have different sizes thus produced different porosity value. Also, the different arrangement of the desiccant materials in each slots in the desiccant wheel also affect the porosity value. For porosity is also known as void fraction, equal to void volume per total volume.

4.1.1 Desiccant Clay

Table 4.1 Diameter of clay

3.60mm	3.55mm
4.05mm	3.50mm
3.20mm	3.50mm
4.20mm	3.90mm
3.05mm	3.15mm

Average diameter of clay, D = $\frac{3.6+4.05+3.2+4.2+3.05+3.55+3.5+3.5+3.9+3.15}{10}$

= 3.57mm

Radius of clay, r = 3.57/2

= 1.785mm

Volume of clay, v = $\frac{4}{3}\pi r^3$

= 23.8234 mm^3

Porosity, $\Phi = \frac{Void\ volume}{Total\ Volume}$

Total volume (volume in desiccant wheel) = 233 578 mm^3

Total slots in the desiccant wheel = 468