SILICA GEL MULTILAYER DESICCANT HOLLOW CYLINDER BED FOR AXIAL FLOW DEHUMIDIFICATION ADSORPTION OPERATIONS

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree

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LIST OF ABBREVIATION

AC	Air Conditioner; Air Conditioning
ASHRAE	American Society of Heating and Refrigeration and Air Conditioning Engineers
DAC	Desiccant Air Conditioning
VAC	Vapour Air Conditioning
DP	Dew point
HVAC	Heating, Ventilation and Air Conditioning
RH	Relative Humidity (%)
T	Temperature (°C)
SDC	Solid Desiccant Conditioning
VOC	Volatile Organic Compound
CO2	Carbon Dioxide

ABSTRAK

Seperti yang kita semua sedia maklum penggunaan tenaga elektrik meningkat secara mendadak pada masa kini. Ini disebabkan oleh permintaan kepada keperluan penghawa dingin yang tinggi akibat tindak balas terhadap suhu pada musim panas yang lebih tinggi. Peningkatan suhu ini kesan daripada akibat perubahan iklim dan pemanasan global. Penyejukan melalui kaedah bahan pengering adalah aplikasi tenaga penyejuk yang baru, terbukti, boleh dipercayai dan bersih malah dapat meningkatkan tahap keselesaan. Teknologi ini juga menghadkan kesan terhadap alam sekitar dan menjimatkan penggunaan tenaga. Dalam kajian ini, satu lapisan dan dua lapisan balang silika berongga telah dihasilkan dan diuji. Kajian ini direka untuk mengkaji kesan halaju udara ke atas balang silika berongga, diisi dengan bijirin gel silika semasa proses penjerapan. Untuk tujuan ini, pengukuran suhu dan kelembapan di tempat masuk dan keluar dari balang ujian telah dijalankan. Dalam kajian ini, balang ujian lompang satu dan dua lapisan telah dihasilkan. Keupayaan penjerapan gel silika sebagai bahan pengering jenis pepejal juga diuji dengan pelbagai halaju udara (1.0 m/s, 1.2m/s, 1.5 m/s, 2.15 m/s, 3.7 m/s dan 4.9 m/s). Hasil eksperimen menunjukkan bahawa peningkatan nilai halaju udara menyebabkan pengurangan pada kadar penjerapan balang penegering. Trend ini boleh dilihat pada kedua-dua eksperimen balang pengering satu dan dua lapisan. Walau bagaimanapun, persediaan eksperimen memerlukan keupayaan sistem pelembab yang stabil untuk eksperimen penjerapan. Kaedah semburan telah dipilih untuk digunakan dalam sistem pelembab. Prestasi 4 dan 9 susunan nozel yang disusun dengan aliran menegak, selari dan bertentang telah dianalisis dengan halaju udara dari 1 m/s hingga 6.2 m/s, kelembapan relatif udara antara 59% dan 78% dan suhu bilik dari 28.5 ˚C hingga 30.2 ˚C. Data diperolehi menunjukkan bahawa kesan pelembapan adalah berkadar terus dengan bilangan nozel. Kelembapan relatif tertinggi dicatatkan pada 88.4% dengan penggunaan 9 nozel disusun secara aliran menegak. Kemampuan aliran menegak dan bertentang diperiksa lagi dengan susunan nozel sebanyak 2, 4, 6 dan 8. Data yang dikumpul menunjukkan bahawa hasil relatif tertinggi telah dicatakan dengan 8 nozel disusun secara menegak pada 89.8%.

ABSTRACT

Energy consumption is increasing gradually every year. It is caused by the growth of air conditioning need in response to higher summer temperature resulted from climate changes. Consequently, this causes an increase in electricity demand. Solar cooling is a relatively new, reliable and clean energy application of proven refrigeration technology that able to improve comfort conditions. This technology also limits the impact on the environment and conserves energy. The main element in desiccant cooling system is the desiccator. In this study, single and two layer hollow test bed were made. The adsorption ability of silica gels as the solid desiccant materials also tested under varied inlet air velocity (1.0 m/s, 1.2m/s, 1.5 m/s, 2.15 m/s, 3.7m/s and 4.9 m/s. The result show that increase in inlet air velocity value cause reduction in adsorption rate of the desiccant bed. This trend can be seen for both single and double layer desiccant bed experiment. However, the experimental setup requires a stable humidification capability for the adsorption experiment. Mist spray method has been selected to be used in the humidity addition system. The performance of 4 and 9 numbers of nozzles under vertical, parallel and counter flow arrangement have been analysed for air velocity from 1 m/s to 6.2 m/s, relative humidity between 59% and 78% and room temperature from 28.5 ˚C to 30.2 ˚C. The data shows that the humidification effect is directly proportional to the number of nozzle. The highest relative humidity is recorded at 88.4% in 9 numbers of nozzle use under vertical flow. The performances of vertical and counter flow are further tested with nozzle arrangement of 2, 4, 6 and 8. The data collected show that highest relative produce was by 8 nozzles under vertical flow at 89.8%.

CHAPTER 1

INTRODUCTION

1.1 Heating, Ventilation and Air Conditioning (HVAC)

A good HVAC system aims to provide thermal control and indoor comfort, and one that is designed using the principles of thermodynamics, fluid mechanics, and heat transfer. The HVAC system may also be responsible for providing fresh air to reduce interior contaminants such as odours from occupants, volatile organic compounds (VOC's) emitted from interior furnishings, chemicals used for cleaning, etc. A properly designed system will provide a comfortable indoor environment when it is properly service and maintained.

Although the HVAC system may provide us the thermal comfort that is intended, but it is also have an impact in many ways to the environment. According to Huang *et al.* [1], HVAC systems contribute over 60% of the energy consumed by buildings and this number is likely to grow in the future. From the efficiency perspective, it is crucial to maintain a healthy and a comfortable indoor environment for occupants as in modern society people spend large portion of their time in buildings [13]. Therefore, balancing the energy efficiency and effectiveness of HVAC system without sacrificing of thermal comfort has drawn attentions of the research community.

Not only is the HVAC energy consumption detrimental, but the gases emitted from air conditioners are also affecting the environment. Many of the most harmful CFC gases have been stamped out via the Montreal Protocol, which reduces the emission of pollutants, but the gases that are still being emitted have a huge impact on global warming. It has been said that 27% of all global warming will be due to the gases emitted from air conditioning by the year 2050. This shocking statistic is largely due to the expected increase of use of air conditioning as temperatures continue to rise, thus creating a cycle of damage.

Desiccant cooling technology is an alternative option to the HVAC cooling technology to reduce the amount of electricity demand and harmful gases released to the environment. Dehumidification and sensible cooling can be performed separately in desiccant cooling systems [2]. Air conditioners cool homes by removing heat and moisture from the air. Overcooling cooling is needed when humidity levels are excessive. If the equipment doesn't have sufficient cooling capacity, it may be unable to cope with extreme humidity.

1.2 Thermal Comfort and Humidity

Thermal comfort is generally regarded as a desirable or positive state of a person. It is used in relation to how warm or cold a person feels and is clearly related to the environment a person occupies [3]

Relative humidity is an important factor that could affect thermal comfort. In a warm environment, evaporation would be the main source of heat loss from the human body to its surrounding environment and the heat loss by conduction and radiation is small. Heat loss by evaporation is cause by the vapour pressure difference between the body and its surrounding air. The vapour pressure difference would become small at higher relative humidity and evaporation of water is slow. Thereby sufficient evaporation heat losses are not maintained. The temperature gradient between the body core temperature and skin temperature would become small [4].

The optimal relative humidity level for comfort and for avoiding health effects is between 35 and 60 percentage. It is increasingly likely that certain health issues will occur when spending time inside a room or space with humidity levels in excess of 60 percentage.

Too much humidity combined with high temperatures can cause our bodies to overheat. High level humidity impedes your body's ability to regulate body temperature and cool down. Sweating cools the body when the moisture evaporates from the skin. However, when the air is already saturated with water vapour (when humidity levels rise to 70% and higher), sweat evaporation rate is very low. Thus you will feel hotter and stickier.

At that point, the body is forced to cool off. A person may experience rapid breathing as you get increasingly hotter. Heart pumps more blood to the extremities, and less to your internal organs and your brain. That's why we feel sluggish and foggy and light-headed or even faint may begin to occur. Eventually, if body can't maintain temperature, heat exhaustion or heat stroke may happen, which can be fatal. Thus, a dehumidifier with efficient energy usage (like desiccant cooling technology) is studied to overcome this kind of setback.

1.3 Humidity

Humidity plays an important role in our daily weather and climate. Air has the ability to hold water in gaseous state and the capacity of water that can be hold changes with pressure and temperature. The water vapour content in air is referred to humidity. Absolute humidity is the mass of water vapour divided by the mass of dry air in a volume of air at a given temperature and expressed as grams of moisture per cubic meter of air (g/m3). The hotter the air is, the greater the water it can contain.

Relative humidity is the ratio of the current absolute humidity to the highest possible absolute humidity at given air temperature. RH doesn't shows the amount of water vapour is in the air; instead it shows the percentage of the maximum vapour pressure has been reached. Correspondingly, RH can be expressed in terms of vapour pressure as the ratio of the vapour pressure and the saturated vapour pressure. RH is typically expressed as a percentage so that a relative humidity of 100% corresponds to the saturated humidity at the certain temperature [4].

Another widely used approach to assessing the amount of moisture in air is by dew point (DP). By definition, DP is the temperature at which the air of a given absolute humidity saturates [3]. When the current temperature is known, absolute humidity, relative humidity and dew point can all be calculated from one another.

1.4 Humidity affects Air Conditioning and Heating

Humidity has a major impact on the effectiveness of air conditioning systems. Air conditioners cool air by removing heat and moisture. Humidity affects air conditioning negatively because it reduces the efficiency of the cooling effect. The system is required to work harder when the humidity level in the air is excessive. If an air conditioning system does not have sufficient cooling capacity, it may be unable to cope with extreme humidity. Thus, the comfort level will not be achieved.

It is crucial to buy air conditioner according the cooling load required of the room or house. If air conditioner’s capacity is much larger than needed, it won’t be able to remove moisture effectively. In turn, humidity levels will remain high. This is because larger capacity air conditioners don’t need to run as much, so the amount of moisture being removed from the air is very low.

The best way to handle excessive humidity is by having a dehumidifier installed on your HVAC system. This simple appliance will pull moisture from the air before it is forced through the ducts in your home. Dehumidifiers can be paired with air conditioning systems, which allow you to adjust the temperature and humidity level of your home simultaneously.

When humidity levels are kept in check inside a home during the summer, air conditioners are able to do their jobs much more effectively. You will notice that you feel cooler and more refreshed under these conditions. As an added bonus, you should notice a nice drop in your energy bill. That’s because your air conditioner won’t have to work as hard, but it will still be able to cool your home properly

1.5 Problem Statement

It is clear that desiccant cooling and air dehumidification is a good alternative for vapor compression air conditioning. Desiccant cooling presents the advantage of reducing consumption of fossil fuel and charcoal that going depleted. The thermal energy to regenerate the desiccant can be provided from solar radiation or waste heat. With desiccant systems, indoor air humidity and temperature are directly controlled in an open cycle and the use of CFC is minimized.

Silica gel has a large capacity for adsorbing water because of small porous and higher surface area 650m^2/g typically pore size ranging from 0.7 nm to 2-3 nm and adsorption of heat is nearly 2800kj/kg. Porous diameter of 0.7 nm (Type B) silica gels are preferred to use for dehumidification process when RH is more than 50%, especially at high vapour pressures.

1.6 Objectives

The main objectives of this project is to redesign and modify the adsorption system in HVAC experimental rig and conduct experiment at the Heat Transfer Lab, School of Mechanical Engineering (SoME) and to study the silica gels' adsorption ability in operating conditions of temperature and relative humidity.

1.7 Scope of the Project

In this project, several part or components of HVAC experimental rig system in the Heat Transfer lab need to be modified to integrate a humidity addition system by using low pressure misting system. Humidity addition system is studied and tests to increase the RH of the ambient air. This act is needed to supply high percentage RH of air to the multilayer hollow cylindrical desiccant bed dehumidifier.

The quality of mist produce from the misting system depends on several parameters. The parameters are water pressure, size of nozzle opening, number of nozzle used, water temperature, air velocity and configuration of mist flow. Because of some limiting factor in this only three parameters is tested (air velocity, number of nozzle used and configuration of mist flow).

Then, adsorption ability of silica gel is compared in single and two layer hollow cylindrical desiccant bed dehumidifier. Effect of air velocity on the adsorption system is tested and analysed for both single and two layer beds. For every air velocity, the adsorption process was let to run for two hours. Inlet and exit air parameters are monitored and recorded along the adsorption process. Exit humidity ratio difference between during initial and final of the adsorption process is use to evaluate the adsorption ability.

1.8 Thesis Structure

The thesis is divided into chapters. There are total of 5 chapters including this chapter. Chapter 1 cover the general introduction, background of the study, problem statement, research objectives, scope of the research, and thesis organization.

Chapter 2 represent the comprehensive literature review, journal, article and research work that related to the topic. The literature reviews including the fundamental knowledge HVAC system, vapour compression cycle, portable ultrasonic humidifier, and the effect of air flow rate on different size of piccolo hole has been studied.

Chapter 3 will explain about the methodology used in the present of the research work. In this chapter, the experimental setup is being discussed on how to install the humidity system and integrate it into the air conditioning system. All the fabrication processes and experimental setup being approached in this chapter.

Chapter 4 presents the result and discussion part of the project. This chapter will include the result and discussion of the project. The data obtained from this experimental will be analysed.

Chapter 5 summarize the conclusion of the project. The objectives made in the beginning are discussed and the whole thesis is concluded. Some future work and improvement are suggested.

CHAPTER 2

LITERATURE REVIEW

2.1 Open-cycle solid desiccant systems

Pennington (1995) patented the first ever desiccant cooling cycle which is commonly known as the ventilation cycle (Pennington cycle) [5]. A rotary heat exchanger was saturated with a solid desiccant, converting the heat exchanger into an adiabatic regenerative dehumidifier, which takes in ambient air and adsorbs the moisture in it. Then, this air is sensibly and evaporatively cooled before being introduced into the conditioned space. The return air is first evaporatively cooled and allowed to pass through a sensible heat exchanger to recover the heat of adsorption from the supply air. It is then heated with a low grade thermal energy source and used to regenerate the desiccant [6]. Coefficient of performance (COP) values of about 0.8-1.0 are commonly predicted for this cycle [7].

Desiccant dehumidification and air conditioning system have gained great attention in recent years as the substitute to the conventional dehumidification system. Moisture in air can be dehumidified without water condensation using desiccant dehumidification as there is direct contact between humid air and dry desiccant. Desiccant can be reactivate or regenerate by using low grade regeneration heat source such as thermal solar energy and waste heat from a cogeneration of other source.

Desiccative and evaporative cooling systems are based on the principle of adiabatic evaporative cooling. The maximum allowed water content of the supply air limits the extent to which the supply air can be cooled through humidification. In hot and humid climate, the atmospheric air contains large amount of water and thus demanding high dehumidification rates. For continuous dehumidification, the water adsorbed by desiccant material need to be driven out. This is done by permitting hot air to flow through the desiccant material [8].

2.2 Hybrid desiccant cooling systems

Moisture removal is achieved in a conventional vapor-compression system by condensation. In high humidity regions like the Southeast of the United States, this method could be very inefficient since it usually involves reheating the air after dehumidification. Vapor compression systems are efficient in sensible cooling, whereas desiccant dehumidifiers are efficient in handling latent loads. Hybrid systems, which integrate desiccant dehumidifiers with conventional cooling systems are proven to provide substantial energy savings.

Maclaine-Cross (1988) found that energy costs were cut in half by using his hybrid system. His system consisted of a regenerative dehumidifier, a heat exchanger, an evaporative cooler and heating coils and fans, to provide the latent and part of the sensible load, as well as a gas engine-driven chiller which is also used to take up the remaining sensible load. This also suggests that desiccant cooling systems may prove to be competitive with conventional systems when the desiccant units are commercially available [9].

2.3 Performance indices to evaluate solid desiccant materials

In a solid desiccant cooling (SDC) system, the process air is dehumidified in an adsorption process by a solid desiccant material, and then cooled to desired temperature. Adsorption and regeneration performance of the desiccant material can greatly affect dehumidification of the SDC system. In order to improve the performance of the system, the desiccant is expected to have large water adsorption capacity and can be easily-regenerated at a relatively low regeneration temperature. Desiccant material can be classified into two main categories:

1) Substances with porous structure, such as activated alumina, silica gels, zeolites and so on. These materials realize the adsorption based on water vapor pressure differences between pores within the desiccant material and surrounding air. A physical process occurs in the adsorption phase.

2) Substances that can form solid crystalline hydrate, such as LiCl, $CaCl_2$, LiBr and etc. A hydration reaction always occurs within these materials

The optimal desiccant material for a solid desiccant cooling system should meet the following requirements;

I. for adsorption process, saturated water adsorption is expected at medium relative pressure ($0.45 < P/Po < 0.5$);
II. for regeneration process, water adsorbed is expected to be fully regenerate at relatively higher P/Po (>0.6) [10].

Po is the saturated vapor pressure at adsorption temperature and P is the vapor pressure.

2.4 Desiccant cycle design

The design of the air conditioning system is controlled by several operating conditions. The following parameters may be used as a basis for designing the system: ambient conditions, regeneration air temperature before the dehumidifier, supply air and return air flow rates [6].

2.5 Energy conservation

As in the vapour air conditioning (VAC) system humidity is controlled by ensuring temperature is less than supply air dew point. Thus, more energy is required to obtain the desired conditions of temperature and humidity. It is unnecessary to overcool the air and reheating while driving desiccant air conditioning (DAC) cycle as compared to VAC cycle. Energy conservation is also the name of environment conservation because most of the energy is produced from fossil fuels. A recent study on wet markets of Hong Kong reported that the DAC system enabled 1–13% reduction in carbon dioxide (CO2) emission as compared to VAC system. Furthermore, a DAC system obtained electricity saving of 24% in hot and humid climate of Thailand [9].

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter will explain the Heating Ventilation and Air Conditioning (HVAC) Experimental Rig in Heat Transfer Laboratory, the selection of most suitable humidifier, measuring equipment used, setup and fabrication process for both humidifier and regeneration experiments.

3.2 Heating and Ventilation Air Conditioning (HVAC) Experimental Rig

The HVAC experimental rig consists of cooling coil, axial fan, heater and testing section. HVAC experimental rig are modified for enable to insert humidity addition system by using misting system since the ambient air relative humidity need to be elevated. The desiccant bed is placed at the testing section to observe the effect of air velocity on the adsorption ability of desiccant bed. The air velocity in the HVAC duct is controlled by the voltage regulator of the fan.

Figure 3. 1 HVAC experimental rig

3.2.1 Fan voltage regulator

Air velocity is one the variables that affect the humidifying process [11]. Air stream velocity effects both the humidification and adsorption process. The air velocity of experimental rig is control by the rotor speed of the axial fan. Initially, the HVAC system uses a resistance-type regulator (Figure 3.2) to control the fan speed as well as the air stream velocity. It operates by adjusting the amount of resistance to generate the power input to the axial fan. Outworn is one of the factor that made the process to control the rotor speed according to the speed knob is difficult and unstable throughout the time.

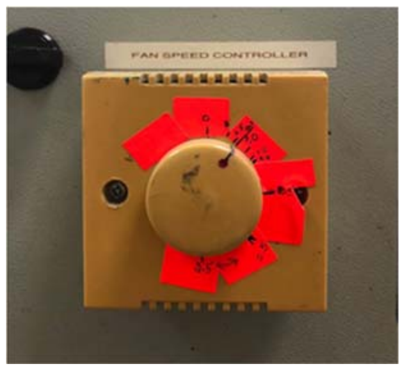

Figure 3. 2 Fan resistance-type regulator

As the solution, TDGC2 adjustable manual voltage regulator was bought to control the axial pump voltage and as the result the air stream velocity produced is more stable when adjusted

Figure 3. 3 TDGC2 voltage regulator

3.3 Humidification setup

3.3.1 Humidifier selection

A humidifier that can provide high mass flow rate is required in this project to give more significant control to relative humidity (RH) of approach air velocity. Therefore, an experiment is carried out to determine the maximum mass flow rate that can be supplied by the first option humidifier which is Deerma F430 Ultrasonic Humidifier (Table 1).

- Humidifier weight = 870.5g
- Weight of water at t = 0 is 2767.4g

Time, t(sec)	Water weight (g)	Difference in weight (g)	Mass flow rate, $\dot{m}$(g/s)
30	2765.4	2.0	0.066666667
60	2763.8	3.6	0.060000000
90	2761.3	6.1	0.067777778
120	2759.6	7.8	0.065000000
150	2757.3	10.1	0.067333333
180	2755.3	12.1	0.067222222
210	2753.1	14.3	0.068095238
240	2751.4	16.0	0.066666667
270	2749.2	18.2	0.067407407
300	2747.3	20.1	0.067000000
330	2744.8	22.6	0.068484848
360	2742.3	25.1	0.069722222
390	2740.6	26.8	0.068717949
420	2738.6	28.8	0.068571429
450	2735.7	31.7	0.070444444
480	2732.4	35.0	0.072916667
510	2731.2	36.2	0.070980392
540	2729.1	38.3	0.070925926
570	2727.3	40.1	0.070350877
600	2724	43.4	0.072333333

Table 3. 1 Mass flow rate test of Deerma F430 Ultrasonic Humidifier

From Table 1, maximum mass flow rate can be produced by Deerma F430 Ultrasonic Humidifier is 0.07 g/s and it seems that the humidifier is not be able to produce the optimum mass flow rate as desired, in fact it is too low. Since to find ultrasonic humidifier with higher capacity at low cost in current market is difficult, the water misting system (Figure 3.4) is considered as the alternative option to the ultrasonic humidifier because the chosen model can produce high mass flow rate which is up to 1.94 g/s (7L/hr) with 70 µm mist size according to the manual. Water from the tap is supplied directly to the misting system and mist is produced by forcing fluid through the small orifice at high pressure until sufficient turbulence is created to atomize the spray into a fine fog.

Figure 3. 4 Water misting humidifier

3.3.2 Conceptual design

The misting system is placed after the coil compartment (evaporator) as shown in Figure 3.5. The setup area (Figure 3.6) is divided into 4 sections;

I. Settling section: To let the ambient air passing through evaporator to be settle down and form steady temperature and relative humidity.

II. Air inlet condition: Position where inlet temperature and relative humidity are measured using a stationary RH meter.

III. Humidifying section: Position where misting humidifier is located in 2 arrangements which are both pointing upwards and combination of parallel and counter flow.