EXPERIMENTAL INVESTIGATION ON THE PERFORMANCE OF REGENERATION FOR AXIAL FLOW MULTILAYER SILICA GEL HOLLOW CYLINDER DESICCANT BED

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DECLARATION

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS

LIST OF ABBREVIATIONS

Abbreviations	Explanation
HVAC	Heating, Ventilation, and Air Conditioning
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AC	Air-conditioner / Air-conditioning
RH	Relative Humidity (%)
Temp.	Temperature (°C)
DBT	Dry bulb temperature (°C)
WBT	Wet bulb temperature (°C)
COP	Coefficient of Performance
CFC	Chlorofluorocarbon
CEH	Constant Enthalpy Humidification
CTH	Constant Temperature Humidification
LDCS	Liquid Desiccant Evaporation Cooling Air Conditioning
SDC	Solid Desiccant Cooling
VAC	Vapor Air Conditioning
DAC	Desiccant Air Conditioning

ABSTRAK

Harga dan permintaan tenaga semakin tinggi dari semasa ke semasa. Dalam usaha untuk mengatasi perubahan iklim yang berlaku dan untuk mencapai keselesaan terma, tindakan ini akan membuat masyarakat telah meningkatkan pergantungan mereka pada penggunaan lebih banyak tenaga. Penyejukan solar adalah aplikasi tenaga yang agak baru, boleh dipercayai dan bersih. Teknologi penyejukan terbukti dapat memperbaiki keadaan yang sedia ada. Teknologi ini juga menghadkan kesan ke atas alam sekitar dan menjimatkan tenaga. Kelebihan teknik bahan pengering penyejukan ialah ia mengelakkan penggunaan penyejuk yang mempunyai kesan negatif ke atas lapisan ozon. Elemen utama dalam sistem penyejukan bahan pengering adalah bijirin gel silika itu. Dalam kajian ini, satu dan dua lapisan alat pengering berongga telah dibuat. Keupayaan penyerapan gel silika sebagai bahan pengering pepejal juga diuji di bawah keadaan operasi yang dipilih. Kajian ini direka juga untuk mengkaji kesan halaju udara pada alat pengering silinder, dipenuhi dengan bijirin gel silika semasa proses regenerasi semula. Untuk tujuan ini, pengukuran suhu dan kelembapan udara di bahagian masuk dan keluar dari bahan pengering telah dilakukan. Walau bagaimanapun, persediaan eksperimen memerlukan keupayaan kelembapan stabil untuk percubaan penyerapan. Terdapat beberapa kaedah pelembapan yang biasa digunakan seperti semburan kabus, penyejatan, semburan, dan wap. Kaedah semburan kabus dipilih untuk digunakan bagi projek ini. Kajian ini telah membawa beberapa hasil pemerhatian. Kesan kelembapan tertinggi dicatat pada susunan nozel 2x4 dalam keadaan menegak dengan 89.8% diikuti 83.7% dalam keadaan berlwanan arah dan 80.0% dalam keadaan selari. Sementara dalam aspek regenerasi, nisbah kelembapan menurun sebanyak 90% untuk satu lapisan manakala 87.6% untuk dua lapisan dan untuk kelembapan relative, penurunan sebanyak 94.6% untuk satu lapisan manakala 90.5% untuk dua lapisan. Walau bagaimanapun, dua lapisan mendapat lebih banyak tenaga disalurkan sebanyak 1.4% membuatkan ia lebih efektif daripada satu lapisan.

ABSTRACT

The price and energy demand are getting higher from time to time. In order to cope with the climate change that taking place and to achieve the thermal comfort, this action will make people increase their dependency on consuming more energy. 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. Advantage of the desiccant cooling technique is it avoids the refrigerants use that have a negative effect on the ozone layer. The main element in desiccant cooling system is the desiccator. In this study, single and double-layer hollow test bed were made. The adsorption ability of silica gels as the solid desiccant materials also tested under selected operating conditions. This research is designed also to examine the effect of air velocity effect on multilayer hollow cylindrical desiccant bed, filled with silica gel grains during regeneration process. For this purpose, measurements of temperature and humidity at the inlet and outlet of the test bed are done. However, the experimental setup requires a stable humidification capability for the adsorption experiment. There are several humidification methods are commonly used such as mist spray, evaporative, spray, and steam. Mist spray method is chosen to be applied for this project. This research brings various results related to humidification and regeneration process. The highest humidification effect is by using 2x4 vertical flow arrangement at 1 m/s with 89.8% of relative humidity followed by 83.7% in counter flow and 80.0% in parallel flow. While in regeneration view, humidity ratio is decreasing by 90% for single layer while 87.6% for double layer and for RH, it is decreasing by 94.6% for single layer while 90.5% for double layer. However, double layer gets more energy supplied by 1.4% which makes it more effective than single layer.

CHAPTER 1: INTRODUCTION

1.1 Climate change and energy demand

Climate change is a phenomenon that faced globally by every country including Malaysia. The fifth assessment report from the Intergovernmental Panel on Climate Change (IPCC) founds that from 1983 to 2012 was the warmest global land and ocean temperature for the past 800 years [1]. Related to that issue, air conditioning systems play an important role in maintaining the indoor built environment and act as a medium to achieve pleasant environment. Air conditioning systems perform mechanical process by removing heat and moisture from indoor of an occupied space and generates cool air to the environment such as in homes, office buildings to improve the occupants comfort level.

As we know the price and energy demand are getting higher from time to time. In order to cope with the climate change that taking place and to achieve the thermal comfort, this action will make people increase their dependency on consuming more energy. Related to air conditioning scope, it can contribute to the worse case where with high humidity of air at the inlet, it will literally make the evaporator load to consume more energy to do its job. This will result in reducing the system efficiency, which is measured by the parameter, coefficient of performance (COP).

1.2 Moisture control

This problem stated above can be solved by applying a moisture control concept in air conditioning system. Moisture control or dehumidification is one of the important aspects in cooling or air-conditioning system. The moisture level reduce in the ambient air could improve not only the comfortability for human, but it also makes the home less hospitable to allergens such as dust mites. The way dehumidification works in an air-conditioning system is when warm air from the indoor provide heat to the cool refrigerant in the evaporator which in turn causes moisture to condense on the cooling coil.

On the other hand, when the indoor air has high humidity, it will reduce the cooling effect of the refrigerant as more moisture condenses on the cooling coil. This will lead to a reduction in efficiency or COP of the air-conditioning system. So, in order to reduce air moisture, we could use the desiccants material that could absorb air moisture. The desiccants are placed in the air-conditioning system (air inlet) in order to reduce air moisture before the air reaches the evaporator. As a result, efficiency or COP of air-conditioning system will increase.

1.3 Project background

Higher demand in the application of air conditioning in order to adapt to global climate change especially in homes and working areas lead to a worrying issue since it will eventually consume more energy. In addition, the presence of Chlorofluorocarbon and refrigerant especially R22 can cause the depletion of the ozone layer [2]. It could be the best if we can counter or overcome the factors affecting the thinning of the ozone layer, yet it requires very strong knowledge and huge efforts to make it happen. On the other hand, we can work on the way to optimize the efficiency of an air conditioning system by reducing the energy consumption while the system is running.

High moisture content in the ambient air is the typical cause for an air conditioning system to consume more energy because it will reduce the cooling effect of the refrigerant as more moisture condenses on the cooling coil at process 2-3 (Figure 1.1). The reason being is that the water droplet condensed on cooling coil will act as a barrier that disrupts heat transfer process or an insulator between warm air and cooling coil. Correlated to that issue, in order to reduce the moisture level of ambient air, the air conditioning system requires to lower the temperature to dew point and by condensation or adsorption process through desiccant material. The study showed there are many types of desiccants can be used in air dehumidification purpose for air conditioning with proven its effectiveness such as silica gel, synthetic zeolite, activated alumina, activated carbons, bentonites clay and calcium chloride. Since silica gel famous with its effectiveness [3], it will be used as a desiccant in this project.

Once the desiccants reduce the moisture from the air by absorbing, it releases heat and directly warms the air or in the other words, latent heat which heats inside the system changes to sensible heat where heat that can be felt by human skin. The interesting part is, those desiccants can be reused after going through the regeneration process in which moisture is driven off by a form of heat. This theory is proven in the concept of rotating wheel desiccant where it contains three sections that carry different purposes which are adsorption, regeneration and cooling section. Once regeneration is accomplished, the returned air gets cooled. It shows the system can deliver supply air at a lower dew point temperature and its performance is better than other typical regeneration systems [4].

The arrangement of desiccant will affect its ability to reduce the moisture of the ambient air. In this research, multilayer silica gel is another type of arrangement that will be studied after a single layer as did in previous studies. The performance of both arrangements in adsorption-desorption capability is then observe and evaluate.

Prior adsorption arrangement is set, a humidifier system is needed to be located before the axial fan in order to supply the desired relative humidity to the system. Proper type with a high mass flow rate of humidifier is needed to increase the system relative humidity. Therefore, this experiment is essential to study the effect of humidity mix on the HVAC experimental rig (Figure 1.2), to build a regeneration system and to study the silica gels' performance based on its arrangement.

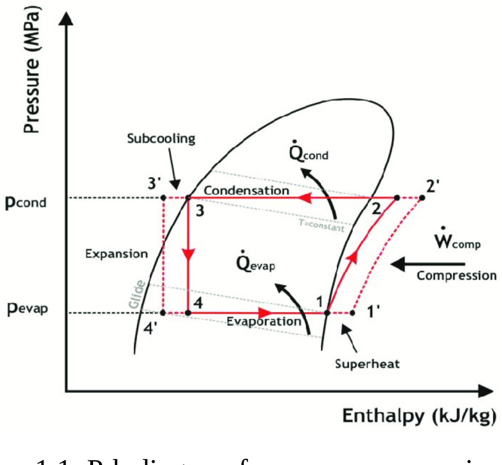

Figure 1.1: P-h diagram for vapor compression cycle

Figure 1.2: HVAC Experimental Rig in USM Heat Transfer Laboratory

1.4 Problem Statement

Desiccant cooling and air dehumidification are 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.

1.5 Objectives of Project

i) To study the effect of humidity mix on the HVAC experimental rig

ii) To study silica gels' regenerating performance with different bed layer, operating velocity, and relative humidity.

1.6 Scope of Work

This project aims to develop an air desorption system by removing moisture through regeneration process with the multilayer silica gel hollow cylinder desiccant bed. However, before conducting the main experiment, there are some set up and experiments that need to be carried out such as placing a humidifier in the air-conditioning system, experiment to determine the inlet and outlet condition when humidifier is placed to get the highest humidity supply and redesign regeneration system in experimental rig. Once those stages are successfully achieved, then the experiment on silica gels' regeneration performance with different bed layer, operating velocity, and relative humidity can take part.

1.7 Thesis Structure

The thesis is divided into 5 chapters. 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, misting system humidifier, and the effect of number of layers of desiccant bed on the adsorption – desorption process.

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 and placing multilayer silica gel bed. All the fabrication processes and experimental setup being explained 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 General information of adsorption – desorption process

Biodiversity, water resources, public health, agriculture, and energy are aspects that particularly affected by the spike of climate change in Malaysia [1]. However, energy aspect is one of the most worrying issues if to compare with other aspects since the demanding of energy in alarming rate and it keeps increasing day by day in order to cope with the outstanding climate change. Morna Isaac et al. [5] had stated that air conditioning demand is expected to rise rapidly over the period from the year 2000 to 2100 due to the associated of CO_2 emission (from 0.8 Gt C in 2000 to 2.2 Gt C in 2100) that yields simultaneously in increasing the number of human growths. Therefore, one action that possible to carry out to reduce the impact of the stated problem is by achieving better energy-efficient of air conditioning which is being studied by K.J Chua et al.

K.J Chua et al. [6] revealed that air produced from air conditioning will get cooled and dehumidified if the inlet air with low humidity is allowed to flow through a finned cooling coil which its surface is kept at below the inlet dew point temperature. This will make the room possible to achieve the thermal comfort for human skin with needed of lesser energy consumed. Moreover, the cooling energy further can be reduced if the moisture removal of inlet air is handled by implementing the desiccant type of dehumidifier. He also emphasizes that dehumidifier only can works well if enough moisture is being supplied inside the air conditioning system, therefore, development of humidity system is essentially needed in order to meet the requirement for energy-efficient air conditioning.

Humidifiers have been used in various applications and fields such as medical, food preservative, pharmaceutical and in many engineering fields like an air-conditioning system, aerospace etc. It brings different performance for the different application, therefore there are various types of humidifiers that can be used such as steam, impeller, ultrasonic, central and evaporative humidifiers [7]. All types of humidifiers essentially bring the same function as to increase the relative humidity (RH), where it will be placed. Meanwhile, M. Ghazikhani et al. [8] had studied about exergy analysis of two humidification process methods in air-conditioning systems which are Constant Enthalpy Humidification (CEH) and Constant Temperature Humidification (CTH).

In the scope of HVAC, commercial humidity system being installed is from an ultrasonic and water misting type of humidifier. Identifying the essential behavior of mist produced by the humidifiers play an important role since it will eventually affect the performance of air conditioning system such as its droplet size that can help to specify the intensity of moisture being supplied. A previous study from A. E. Sain et al. [7] about the size and mineral composition of airborne particles generated by an ultrasonic humidifier revealed that 3-L capacity of an ultrasonic humidifier can produce approximately 1.22×1010 - 2.50×1010 airborne particles per milliliter with droplet diameter range between 109-322 nm. Meanwhile, from C. Rodes et al. [9] study, droplets with a median diameter of 110 nm can be produced from 1.6 MHz transducers. Even though the mist size fulfills the experiment requirement but at low-cost ultrasonic humidifier, it cannot supply high capacity of mass flow rate compared to water misting humidifier which is needed to supply high humidity of supplied air. Therefore, water misting humidifier will be used in this study.

R. Sureshkumar et al. [10] were conducted heat and mass transfer experiments in two phases characterized by different ambient conditions in India. Experiments conducted during April–June have been listed as hot-dry climate as during these months the ambient temperature is high (35–45°C DBT) with low humidity (10–35%). Experiments conducted during July–September are listed as hot-humid because the monsoon produces humidity from 30% to 80% (occasionally as high as 90%), and ambient DBT between 25 and 40°C. Unfortunately, Malaysia ambient condition is hot and humid with a small deviation in ambient condition (dry bulb temperature and relative humidity) throughout the year. Thus, this experiment will be conducted in a single phase by considering the constant climate condition of Malaysia every year.

The first efforts in producing experimental data under well-controlled conditions were done by Kachhwaha et al. [11] where they introduced a hollow cone sheet water spray into a wind tunnel with air flowing in parallel and counter flow configurations. Changes in air dry bulb temperature (DBT) and humidity between inlet and outlet planes were measured. The parametric study covered two commercial nozzles (3 and 5.5 mm diameter), three air velocities (1, 2 and 3 m/s) at three water pressures (1, 2 and 3 bar(g)). For each nozzle, dry bulb temperature (DBT) and humidity ratio change from inlet to exit for different water pressure.

It is seen that for constant air velocity, the air DBT change increases and simultaneously the mean water mist diameter decreases. Both these changes increase the area of contact between the water mist and air thereby increasing both heat and mass transfer between air and water. Due to several limitations of the experimental set-up, there was large variability in the data.

The desiccant is widely used in the commercial air dehumidification especially in the HVAC system. Desiccant evaporative cooling can be classified into two methods which are adsorption and absorption. Both methods carry the same function as to remove latent heat in the predetermined cycle, but adsorption is referring to solid desiccant while absorption is for liquid desiccant as being studied by Yonggao Yin et al. [12] where the liquid desiccant evaporation cooling air conditioning system (LDCS) is introduced. Meanwhile, for adsorption perspective, silica gel is the most widely used as working desiccant due to its low regeneration temperature and low cost [13]. Recent progress of this study reveals that capacity of dehumidification and regeneration had been improved by proper selection of immersed salt and host matrix [14]. M. M. Awad et al. [15] found that dehumidification period for efficient operation of hollow cylinder bed is limited to 15 minutes with 7.2 diameter ratio. The increase in diameter ratio will cause a high-pressure drop within the bed.

Once the adsorption phase is done, the working desiccant (silica gel) needs to be regenerated which means it must be dried by supplying heat to the desiccant in order to re-use it back. The regeneration process begins from hot air is ventilated over the silica gel that results in increasing of silica gel temperature thus causing evaporation. Therefore, the water content in the silica gel is reduced. The heated air crossing silica gel carries vapor that yields in increasing of exhausted air humidity with decreasing in temperature simultaneously. Eventually, silica gel is dried with humidity and air outlet temperature become similar to the initial state [16]. From A.E Kabeel [17] study, eight layers of silica gel packed bed is used to show a better illustration for the results of the regeneration process. The relation of inlet air temperature with the adsorption rate for a different layer of bed packed is studied by setting an inlet temperature of 70 ^{0}C, air velocity of 3.9 m/s and conduct the experiment for 60 minutes. The result shows that both parameters behave directly proportional.

2.2 Open-cycle solid desiccant systems

Pennington patented the first ever desiccant cooling cycle which is commonly known as the ventilation. 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. This air is then sensibly and again 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 [18]. Coefficient of performance (COP) values of about 0.8-1.0 are commonly predicted for this cycle [19].

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 cause high dehumidification rates required. For continuous dehumidification of the supplied air, the water adsorbed on the desiccant material need to be driven out. This is done by permitting hot air to flow through the desiccant material [20].

2.3 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 halved 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 [21].

2.4 Performance indices to evaluate solid desiccant materials

In a solid desiccant cooling system (SDC), 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, CaCl2, 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) [22]. Po is the saturated vapor pressure at adsorption temperature and P is the vapor pressure.

2.5 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 [18].

2.6 Energy conservation

As in the vapor 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 CO_2 emission as compared to VAC system. Furthermore, a DAC system obtained electricity saving of 24% in hot and humid climate of Thailand [21].

2.7 Renewable energy

Unlike vapor compression system, thermal heat is the main stream energy required to run a DAC system which gives an opportunity to utilize low grade waste heat and renewable energy. Utilization of solar energy in the DAC system can increase the COP from 50– 120% [23]. A solar operated DAC was feasible for United Kingdom (UK) and southern Europe where the latent heat gains are not so high.

So basically this study brings a different approach from the previous study in evaluating the performance of multilayer silica gel hollow cylinder desiccant bed. We are focusing to vary the inlet air condition in a range between 1 – 4.9 m/s of fan speed. Furthermore, the temperature range that will be set is between 100 – 120^{0}C which is much lower than the previous study and in terms of multilayer, the previous study did for 8 layers with same bed length but this study is the first study that conducting for 1 and 2 layers for same area of bed lengths using silica gel.

CHAPTER 3: RESEARCH 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 Ventilation and Air Conditioning (HVAC) Experimental Rig

HVAC experimental rig that available is modified by inserting humidifying system by using misting system since the ambient air relative humidity need to be elevated. The HVAC experimental rig consists of cooling coil, axial fan, heater and testing section. The desiccant bed is placed at the testing section to observe the effect of air velocity controlled by the voltage regulator by channelled the humidified air through it.

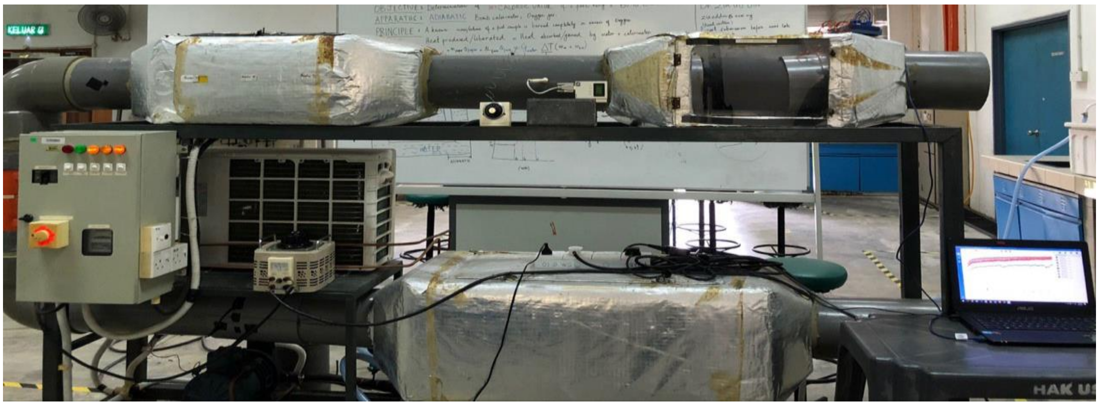

Figure 3.1: Modified HVAC Experimental Rig in USM Heat Transfer Laboratory

3.2.1 Fan speed regulator selection

Axial fan speed is one of the important parameters to control during conducting the experiment. Initially, the HVAC system use a resistance fan speed regulator (Figure 3.2) to control the axial fan speed. It operates by adjusting the amount of resistance to generate the power input to the axial fan. Due to outworn issue at the knob, it seems difficult to control the fan speed and sometime the fan speed will increase or decrease while experiment is running which obviously may affect the experimental data.

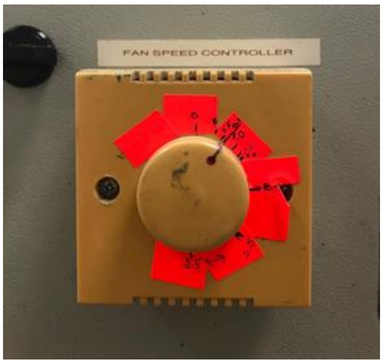

Figure 3.2: Resistance fan speed regulator

As an alternative, a TDGC2 voltage regulator (Figure 3.3) is used to replace the current fan speed regulator. It works by controlling the amount of voltage instead of resistance to be supplied to axial fan. It works much better than the current one in terms of controlling the desired speed.

Figure 3.3: TDGC2 voltage regulator

3.3 Measuring instrument

3.3.1 Water flow meter

Water mass flow rate is an important parameter in designing a humidification system. It can be determined as simple as conducting an experiment by measuring amount of water flow with respect to the time. However, the result will not so accurate since various errors will be formed while conducting the experiment. Therefore, a rotary water flow meter (Figure 3.4) is chosen to measure the water mass flow rate. It can measure as low as 0.0001 m^3 which considered as very accurate measurement.

Figure 3.4: Rotary water flow meter

3.3.2 Thermocouple data logger

Since 8 thermocouples are going to be used, it will give tedious actions if we want to take the reading on one by one thermocouple. Therefore, TC-08 thermocouple data logger (Figure 3.5) is used to record all the readings through Picolog software while running the experiment. In fact, it will give a better reading because all the data and graph can immediately be recorded through the Microsoft Excel with time increment as low as 1 second per reading.

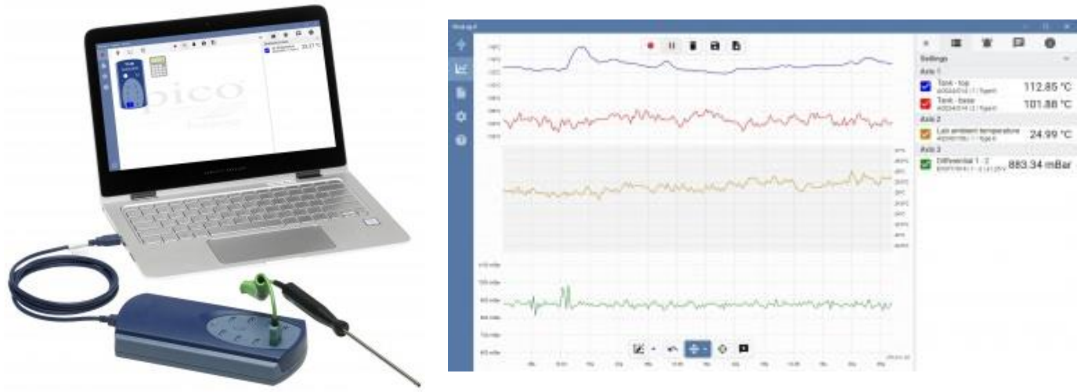

Figure 3.5: TC-08 thermocouple data logger

3.3.3 Relative humidity data logger

Relative humidity is a very sensitive reading since it can be affected even a small change happen in air. It would be better if the RH meter is attached to the system without need to take out to take the reading because once it is taking out, it might be affected with ambient relative humidity. Therefore, iTHX-SD RH data logger (Figure 3.6) is used.

Figure 3.6: iTHX-SD RH data logger

3.4 Humidification setup

3.4.1 Humidifier selection

This experiment needs a humidifier that can supply high mass flow rate which is more than 1 g/s to give more significant effect to the measured variable. Therefore, an experiment is carried out to determine the maximum mass flow rate that can be achieved for our first-choice humidifier which is Deerma F430 Ultrasonic Humidifier (Table 3.1).

- Humidifier weight = (870.6 + 870.2 + 870.6)/3 = 870.5g
- Weight of water at t = 0 is 2767.4g

Table 3.1: Maximum mass flow rate of Deerma F430 Ultrasonic Humidifier

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

By referring to Table 3.1, maximum mass flow rate can be produced is 0.07 g/s and it seems that the chosen ultrasonic humidifier is not be able to produce the mass flow rate as desired, in fact it is too low. Since to find higher capacity of ultrasonic humidifier with low cost in current market also difficult, the water misting system type humidifier (Figure 3.7) is considered as the best choice after 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. 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 flow is created to atomize the spray into a fine fog.

Figure 3.7: Water misting humidifier

3.4.2 Conceptual design

The misting system is placed after the coil compartment (evaporator) as shown in Figure 3.8 by using SolidWorks. The setup area (Figure 3.9) is divided into 4 sections,

- Settling section: To let the ambient air passing through evaporator to be settle down and form steady temperature and relative humidity.
- Air inlet condition: Position where inlet temperature and relative humidity are measured using a stationary RH meter.
- Humidifying section: Position where misting humidifier is located in 3 arrangements which are vertical, parallel and counter flow.
- Air outlet condition: Position where mist is transferred to the axial fan and supply to the system.

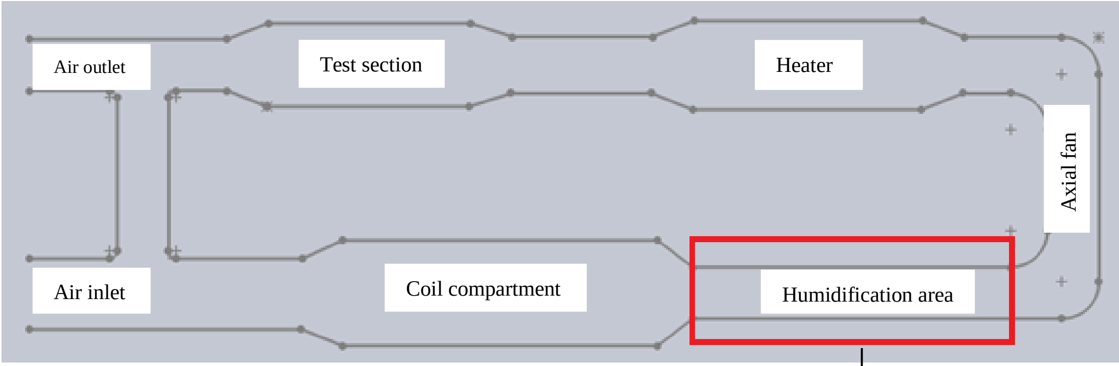

Figure 3.8: 2D of HVAC system

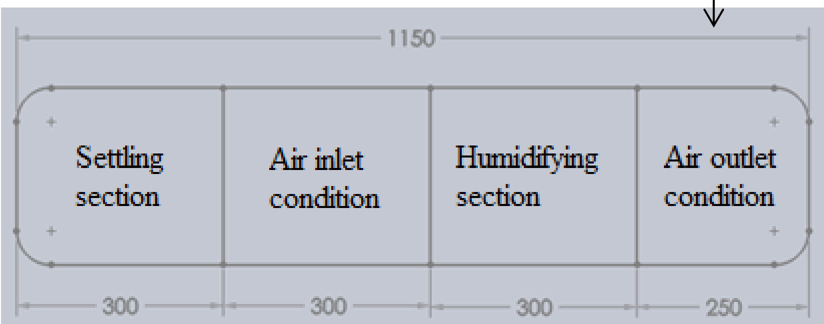

Figure 3.9: Setup area

In humidifying section, a sample of vertical with 2 lines containing 4 nozzles in each line that shown below is attached to the experiment rig using either two types of U-connector (Figure 3.12) which are for vertical and counter flow direction with 9.5cm and 5cm width respectively.

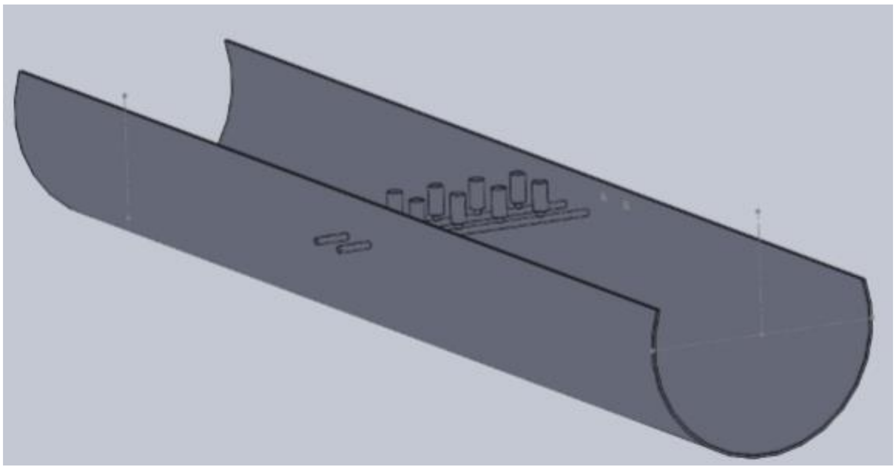

Figure 3.10: Nozzles arrangement in humidifying section

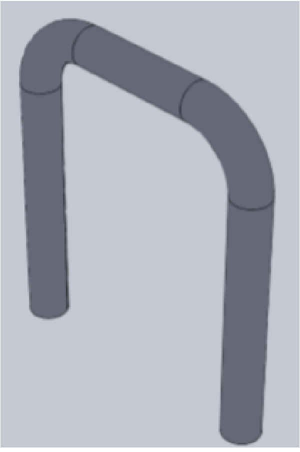

Figure 3.11: U-Connector

Both connectors and water stopper to attain a pressure in the nozzle (Figure 3.12) are fabricated using 3d printing. Figure 3.13 shows the complete humidifying section with a connector.

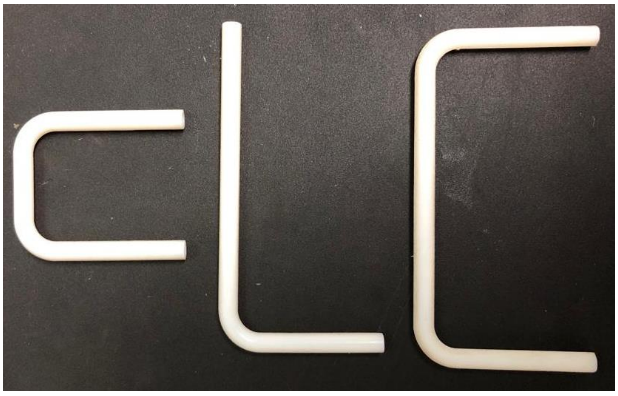

Figure 3.12: Connectors and water stopper

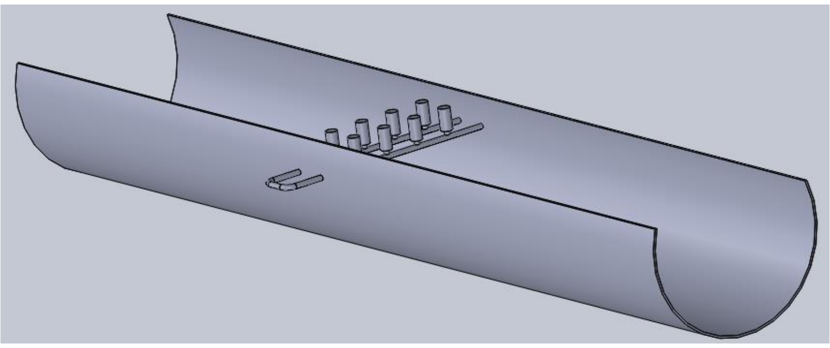

Figure 3.13: Complete humidification setup with connector

Some amount of water from mist humidifier will be accumulated at the bottom in humidifying section. Therefore, initially, a slant plastic plate with 1 mm thickness is planned to be placed at the bottom with a hole in front of it between humidifying and air outlet condition section (Figure 3.14) to allow the excess water to flow out from the HVAC system, however after we attached all the setup, we figured out that along the humidification setup is slightly higher at right hand side instead of left hand side. Due to that issue, we planned to just let the water to pass through left-hand side by making a small hole at the joint between settling section and coil compartment to allow the water to pass through. Water is then collected using a container before discharge to drain.

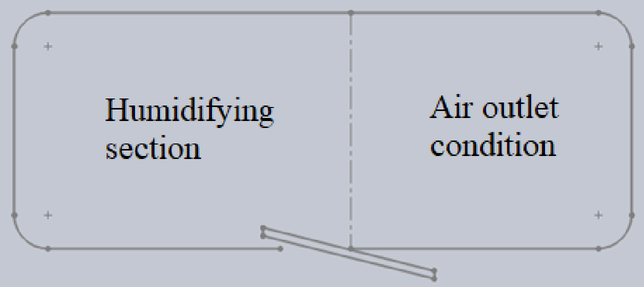

Figure 3.14 Position of 1 mm plastic plate

Figure 3.15: 1 mm plastic plate and hole for water to pass through

Figure 3.16: Location of small hole at the bottom of silicon paste

3.4.3 Fabrication

The process is started by removing all unwanted parts from air-conditioning system especially flange at both exit, PVC pipe using jigsaw (Figure 3.17) and the perspex container that used by previous project. Figure 3.18 shows the experimental rig after all unwanted parts been removed.

Figure 3.17: PVC pipe is removed using jigsaw

Figure 3.18: Experimental rig after all unwanted parts been removed

Next, for humidification part, 50cm PVC pipe is cut (Figure 3.19) to fit with connector where water misting system is placed.

Figure 3.19: 50cm PVC pipe

Setting up the humidifying part is started by developing the middle line of the connector (Figure 3.20) to ensure that the distance between each point is exactly same as planned. 2 sets pair of holes are drilled for vertical and counter mist arrangement with 9.5cm and 5cm gap respectively. An arrow is drawn as indication for the direction to insert the part in the experimental rig (Figure 3.21).

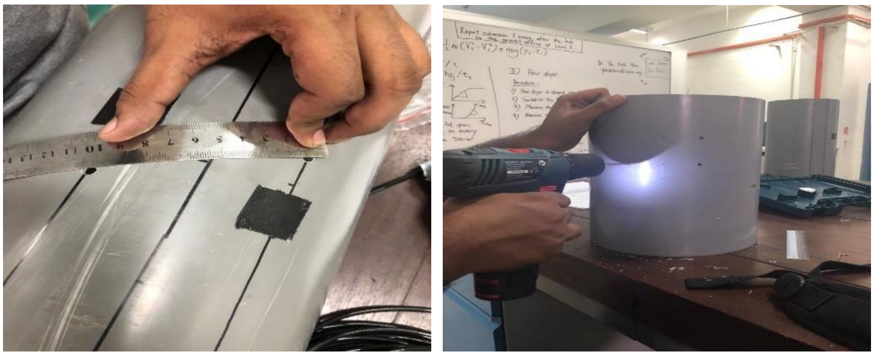

Figure 3.20: Construction of middle line and hole making using hand drill

Figure 3.21: An arrow is drawn for assembly purpose

Next, setup of water flow meter. A water flow meter is connected with 1.8cm pipe diameter at left hand side which is directly from the valve that used to control the amount of water supplied, while the valve is connected to the main water supply. The presence of valve is to control amount of water to pass through since it is quite difficult to control directly from water supply. At right hand side of water flow meter is connected to the water misting part which will be used to connect with the connector.

Figure 3.22: Setup of water flow meter