EXPERIMENTAL STUDY OF THE EFFECT OF PICCOLO TUBE PIPE ON THE AIR-CONDITIONING EXPERIMENTAL RIG HUMIDITY

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JUNE 2018

This dissertation is submitted to

Universiti Sains Malaysia

As partial fulfilment of the requirement to graduate with honours degrees in

BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)

School of Mechanical Engineering

Engineering Campus

Universiti Sains Malaysia

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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ACKNOWLEDGEMENT

After going through all the countless effort, Alhamdulillah, praised to Allah S.W.T that always give me hopes and strength to complete my final year project and guided me to the right path. First and all, I would like to give a special gratitude to my final year project supervisor, Dr Mohd Azmi b Ismail who give me a lot of knowledge and guidance throughout completing my final year project. I am thankful for all the contribution from him which helped me to coordinate my project and gives me a lot of encouragement and suggestions which enables me to carry out this whole project smoothly especially in writing this report. This project would not be completed without the help of him.

Next, I would also like to acknowledge with much appreciation to my school technician who are En. Latif b Hamzah who helped me a lot in giving ideas and suggestion about the project and helping me in completing this project. Never forget En. Zaimi Mat Isa for his guidance in fabricating Perspex box and using circular saw, En. Norijas, En. Halim, and En Zhafril who really helping me in designing and machining process and make my progress run smoothly.

Furthermore I would also like to express my utmost gratitude to my parents that never forget to encourage me in completing my project and thesis, my fellow friends for their kind co-operation and moral support throughout the whole project.

Finally, special thanks to the authority of Universiti Sains Malaysia (USM) especially to School of Mechanical Engineering (SoME) for providing good facilities needed to complete this project and thesis.

Title of Thesis: **Experimental Study of the Effect of Piccolo Tube Pipe On The Air-Conditioning Experimental Rig Humidity**

Date of Submission (Academic Year): **23rd May 2017 (2017/2018)**

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LIST OF ABBREVIATION

AC	Air Conditioner; Air Conditioning
AH	Absolute Humidity
ASHRAE	American Society of Heating and Refrigeration and Air Conditioning Engineers
DP	Dew point
HVAC	Heating, Ventilation and Air Conditioning
RH	Relative Humidity (%)
T	Temperature (°C)
Tsat	Saturation Temperature

NOMENCLATURE

comp	Compressor
cond	Condenser
clo	Clothing insulation value
evap	Evaporator
exp. valve	Expansion valve
u	Air Velocity (m/s)

ABSTRAK

Sistem penyaman udara memainkan peranan penting dalam mengekalkan persekitaran yang sejuk dan nyaman serta bertindak sebagai medium untuk mencapai persekitaran yang selesa. Penghawa dingin adalah proses menghilangkan haba dan kelembapan dari ruangan dalaman yang diduduki dan menghasilkan udara yang sejuk kepada persekitaran seperti di dalam rumah, pejabat dan juga bangunan untuk meningkatkan tahap keselesaan penghuninya. Melalui proses penghawa dingin yang menyebabkan pengurangan kelembapan udara, paras kelembapan udara di ruangan dalaman juga dikurangkan secara mendadak. Kadar kelembapan di udara yg mengalami pengurangan boleh menyebabkan ketidakselesaan di kawasan kediaman. Kadar kelembapan yang rendah menjadi punca masalah utama kerana udara sejuk tidak dapat menahan lebih banyak kelembapan dibandingkan dengan udara kering. Semakin rendah suhu, semakin berkurang air terbentuk dalam keadaan wap. Masalah berlaku dalam kadar kelembapan yang rendah menyebabkan ketidakselesaan dari kulit kering, saluran hidung kering, kerengsaan mata dan juga boleh merosakkan perabot dan lantai. Cara yang paling berkesan untuk menangani kadar kelembapan yang rendah di ruangan dalaman ialah dengan menggunakan humidifier yang boleh dipasang dalam sistem HVAC. Humidifier berfungsi menambah kelembapan sehingga mencapai tahap keselesaan. Dalam kajian ini, pemasangan humidifier ke dalam sistem penghawa dingin telah dilakukan dengan menggunakan ultrasonic humidifier sebagai alat yang menghasilkan wap air, seterusnya dapat meningkatkan kadar kelembapan udara di dalam sistem HVAC. Kajian ini juga telah dijalankan untuk mengkaji tentang kesan saiz diameter lubang piccolo pada peratusan kelembapan relatif (RH) dengan kadar kelajuan aliran udara yang berbeza. Ukuran diameter lubang piccolo yang digunakan adalah 5mm, 7mm, 10mm dan 12mm. Aliran udara dihasilkan oleh kipas dengan kelajuan $1ms^{-1}$, $3ms^{-1}$ dan $5ms^{-1}$ di dalam rig eksperimen HVAC. Keputusan menunjukkan peningkatan peratusan kelembapan relative (RH) jika diameter saiz lubang piccolo yg digunakan lebih besar, pada kelajuan aliran udara yang rendah. Apabila kelajuan meningkat, aliran udara yang lebih tinggi mengurangkan dan membatalkan kesan wap air yang dihasilkan oleh ultrasonic humidifier dalam saluran HVAC kerana saiz wap air kecil dan halus yang dihasilkan oleh ultrasonic humidifier, (kira-kira sekitar 1 mikron dalam saiz), dengan itu memberi peratusan bacaan RH yang lebih rendah di dalam bahagian ujian HVAC.

ABSTRACT

Air-conditioning systems play an important role in maintaining the indoor built environment and act as a medium to achieve environment pleasant reply. Air conditioning is a process of removing heat and moisture from indoor of an occupied space and generates cool air to the environment such as in homes, offices and building to improve the occupants comfort level. Due to the process of removing moisture from air by air conditioning process, the indoor humidity level can be reduced drastically. Lack of moisture in the air can contribute to discomfort in residential areas. Low humidity acts as the main problem because cold air may not able to hold as much moisture as warm air. The lower the temperature, the less water can exist in the vapor state. Problems occurred while in low humidity which include discomforts from dry skin, dry nasal passages, irritated eyes and even damage to furniture and flooring. The most effective way to deal with low humidity level inside indoor is by using a humidifier which can be installed in the HVAC system. The humidifier adds moisture to air and provide humid climate thus achieve thermal comfort level. In this research study, installation of humidity system into air conditioning system is done, by ultrasonic humidifier as a device that produce mist or water vapor, thus increase moisture in the air in the HVAC system. This research also has been carried out to investigate the effect of piccolo hole diameter size on percentage of relative humidity (RH) with variation speed of air flow. The diameter of piccolo hole size is 5mm, 7mm, 10mm and 12mm respectively. The flow of air is produced by axial fan with speed of $1ms^{-1}$, $3ms^{-1}$ and $5ms^{-1}$ in HVAC experimental rig. Results show increasing percentage of RH as diameter of piccolo hole size increase at lower speed of air flow. As the speed increase, higher speed of air flow can reduce and cancels out the effect of water vapor produced by ultrasonic humidifier in the HVAC duct due to low size of the fine mist water particles produce by ultrasonic humidifier, (approximately around 1 micron in size), thus give lower percentage of RH reading in HVAC test section.

CHAPTER 1

INTRODUCTION

1.1 Moisture in Air

Humidity plays an important role in our daily weather and climate [1]. Humidity is the measurement of water vapor content in air. Air has a capacity to hold water in gaseous state and this capacity changes with pressure and temperature. Water vapor is one of the many gases of the atmosphere. The amount of water vapor in a unit of air is referred as the *absolute humidity, ah* of the air, which is usually expressed as grams per cubic meter of air. The warmer the air is, the greater the capacity of water vapor it can hold compared to cooler air [2].

The maximum value of absolute humidity is expressed as *saturated humidity, sh* at the current temperature, or the maximum amount of water vapor that the air can hold [3]. This represents or 100% humidity, which is the air, reached saturated condition and it can't absorb any more water in gas state, or dew point. If additional moisture is added, it will condense into liquid water, causing clouds, mist or fog, which is called moisture. The difference between the saturated humidity and the absolute humidity is known as saturation deficit, a measure of how much additional moisture the air can hold.

In the majority of cases, the amount of moisture in air is expressed as relative humidity (RH), ϕ. By definition, RH is the ratio of the absolute humidity to the saturated humidity at a given temperature [3]. RH doesn't shows the amount of water vapor is in the air; instead it shows the percentage of the maximum vapor pressure has been reached. Correspondingly, RH can be expressed in terms of vapor pressure as the ratio of the vapor pressure and the saturated vapor 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.

1.2 Humidity and Thermal Comfort

ASHRAE (2010) defines thermal comfort as a condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation [5]. Malaysia has a yearly mean temperature of between 26°C and 27°C and relative humidity (RH) ranging from 70% to 90% throughout the year with an average of 84% [6]. The Subang Jaya meteorological station located in Kuala Lumpur recorded maximum daytime temperature between 33°C to 35.6°C and minimum night time temperature between 19.6°C to 22.9°C [7]. The yearly daily average temperature range is as low as 5°C.

This condition can also be assessed by means of objective investigations looking at the human body as a thermodynamic system exchanging heat with the surrounding physical environment [8, 9]. In physiological terms, thermal comfort is what we experience when the body functions well, with core temperature around 37°C and skin temperature of 32- 33°C.

Thermal comfort and health also depend on the composition of the air itself. For example, people feel uncomfortable when the air is odorous. Poor air quality and thermal conditions can lead to occupants' dissatisfaction and discomfort, and reduction in their performance. Poor conditions can also affect occupants' health, creating physical symptoms such as headaches, nose, throat, eye and skin irritation, nausea and drowsiness.

There are some factors that have influence on the thermal comfort of an occupant's space. It can be divided into personal and environmental factors. For personal factors, it includes clothing factor (Clo) and personal activity, while for environmental factors such as humidity, temperature, thermal radiation and air speed. Madhavi *et al*. [10] identified that thermal comfort as a six-dimensional topological solid, having at least six parameters that give dimensions to any unique thermal condition. Two of these, activity and clothing are specific to an individual while air temperature, humidity, air velocity and radiation are the properties of the environment.

Regardless other environmental factor that influences thermal comfort such as air velocity, air temperature and thermal radiation, humidity will be more focussed aspect as it'll be main topics regarding this research project. Humidity levels can be a factor in home thermal comfort and HVAC performance in both the cold and warm weather. Most people know that excessive humidity can make them feel even hotter during the summer. It has a major impact on the effectiveness of air conditioning systems. When the humidity inside home is too high or too low, achieving optimal thermal comfort is not easy to achieve. In the era of technology nowadays, most of the HVAC systems included with humidifiers and dehumidifiers to keep the relative humidity levels under control.

1.3 Humidity affects Air Conditioning and Heating

Needless to say, air conditioners cool homes by removing heat and moisture from the air. When humidity is high and levels of humidity are excessive, air conditioners need to work harder to keep the home cool, thus it makes the surroundings may end up feeling warmer than actually it is because the air is holding extra moisture which not being properly removed. If the air conditioning system doesn't have sufficient cooling capacity, it may be unable to deal with extreme humidity. As a result, the surroundings may never achieve comfort level. Some of few common signs of high humidity included moist and clammy air. In this condition, our skin may feel clammy. Other symptom of high humidity is such as foggy windows. This happened because of humidity is vaporized water in the air. Last but not least, a musty odor can occur if the surroundings have extreme humidity. This is because the excessive humidity causes dampness around the surroundings and can eventually lead to unpleasant smell.

Humidity also can affect heating [11]. Humidity levels drop drastically during the winter. In other words, relative humidity levels inside the home drop as well. Because of this the surroundings feel a lot cooler than it actually is. In the winter or cold climates, a lack of moisture in the air can contribute to discomfort in residential areas. Low humidity acts as the main problem because cold air may not able to hold as much moisture as warm air. As the temperature is lower, the less water can exist in the vapor state. The percentage of relative humidity may become higher, but the actual amount of water vapor in the air (absolute humidity) will drop as the temperature drops.

Problems occurred while in low humidity which include discomforts from dry skin, dry nasal passages, irritated eyes and even damage to furniture and flooring. The most effective way to deal with low humidity level inside indoor during the winter is by using a humidifier. It can be installed in HVAC system. The humidifier adds moisture to air and provide humid climate thus achieve thermal comfort level.

1.4 Heating, Ventilation and Air Conditioning (HVAC)

Heating Ventilating and Air Conditioning (HVAC) system is the technology of indoor and vehicular environmental comfort. Its goal is to provide and maintain good indoor air quality through adequate ventilation with filtration and provide thermal comfort. HVAC systems are designed to control the indoor environment including indoor air quality and thermal comfort for occupants. HVAC systems are used in residential and commercial buildings worldwide.

According to Huang *et al.* [12], 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 systems has drawn attentions of the research community.

HVAC is based on inventions and discoveries made by Nikolay Lvov, Michael Faraday, James Joule, William Rankine, Sadi Carnot is a mechanism of HVAC system based on the principles of heat transfer, thermodynamics and fluid mechanics. HVAC systems include central air conditioners, heat pumps or furnaces, boilers, rooftop units, chillers, and packaged systems. HVAC also is an important part of residential structures which cover such big area for example in a single family homes, apartment buildings and hotels, from medium to large industrial and office buildings such as skyscrapers, in marine environments such as ships and submarines, and many more. All HVAC system installed were safe and healthy building conditions are regulated with respect to temperature and humidity, using fresh air from outdoors.

Ventilation is a process that either supplies or removes air from a space by natural or mechanical means. It’s the process of exchanging or replacing air in any space to provide high indoor air quality which involves temperature control, oxygen replenishment, and removal of moisture, odors, smoke, heat, dust, airborne bacteria, carbon dioxide, and other gases. Ventilation also removes unpleasant smells and excessive moisture, keeps interior building air circulating, and prevents stagnation of the interior air.

Ventilation includes both the exchange of air to the outside as well as circulation of air within the building. All air that is exhausted from a building must be replaced by outside air. Outside air must be brought to a certain temperature by makeup air units used throughout the building. It is one of the most important factors for maintaining acceptable indoor air quality in buildings. Negative building pressure can be a problem during winter heating season and could lead to a number of other problems such as difficulty in opening doors and equipment operation.

1.5 Problem Statement

The usage of air conditioning these days are widely used and it’s very important for people as it provide better environment and achieve thermal comfort for them. Nowadays the temperature of the earth is increasing. That’s why the usage of air conditioning is very important. But, with the usage of the air conditioning, it will remove heat and moisture from the air. This encounter the human comfort level as it removes the moisture from the air, providing lower humidity level. For human thermal comfort level, the relative humidity in the surroundings should be kept between 30–60% RH, recommended by ASHRAE Standard 62-2001. Therefore, to overcome this problem, this research study will come out to prevent low humidity level produce by air conditioning system by installing a humidity system (ultrasonic humidifier) into the air conditioning system to increase the humidity level and achieve human comfort level.

1.6 Objectives

The main objective of this project is to develop humidity system into air conditioning system in the HVAC experimental rig at the Heat Transfer Lab, School of Mechanical Engineering (SoME) and to study the effect of piccolo hole size on the Relative Humidity (RH) reading at different flow rate of air.

1.7 Scope of the Project

In this project, the existing component of HVAC system experimental rig in the Heat Transfer lab is being modified to integrate a humidity system and vapourise water into it. By using Solidworks, the design of the modification is created by determine the location of the hole need to drill to integrate the humidity system into HVAC system, connected by piping.

The humidity system is produced from ultrasonic humidifier. The study being conducted in term of suitability of the type of humidifier used, price, capacity to hold water, time taken for water to completely evaporate, advantages and power consumption of the humidifier.

Compressor also involve in this scope of work to provide little pressure to push the water vapour from the humidity system into the HVAC duct because high pressure in the HVAC duct will push away and prevent the water moisture from entering the HVAC duct.

The experiment is run to test the percentage of relative humidity at the test section based on the diameter of piccolo hole size. In theory, the higher the diameter size of piccolo hole, the higher the percentage of RH reading. Last but not least, the (vapor compression cycle, which used in the air conditioning process need to be studied in order to achieved more understanding about all the processes involved in the HVAC system.

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 Introduction

This literature review is based on term on related topic that was study and has been discussed by a professional and has given a complete explanation on how the things of study work out. The topics that are related including the component or air conditioning system, vapour compression cycle, installation of humidity system by using ultrasonic humidifier, and the air flow rate that will affects the percentage of relative humidity.

2.2 Air Conditioning

Air conditioning is the process of treating air in an internal environment to establish and maintain required standards of temperature, humidity, cleanliness and motion. For temperature, the air temperature is controlled by heating or cooling the air. Air humidity, is controlled by adding or removing water vapor from the air in an air conditioner through humidification or dehumidification processes. For cleanliness factor, the removal of undesirable contaminants is by using filters or other devices or by ventilation. Often both filtration and ventilation are used in an installation of air conditioning. Lastly, the air motion refers to air velocity and to where the air is distributed.

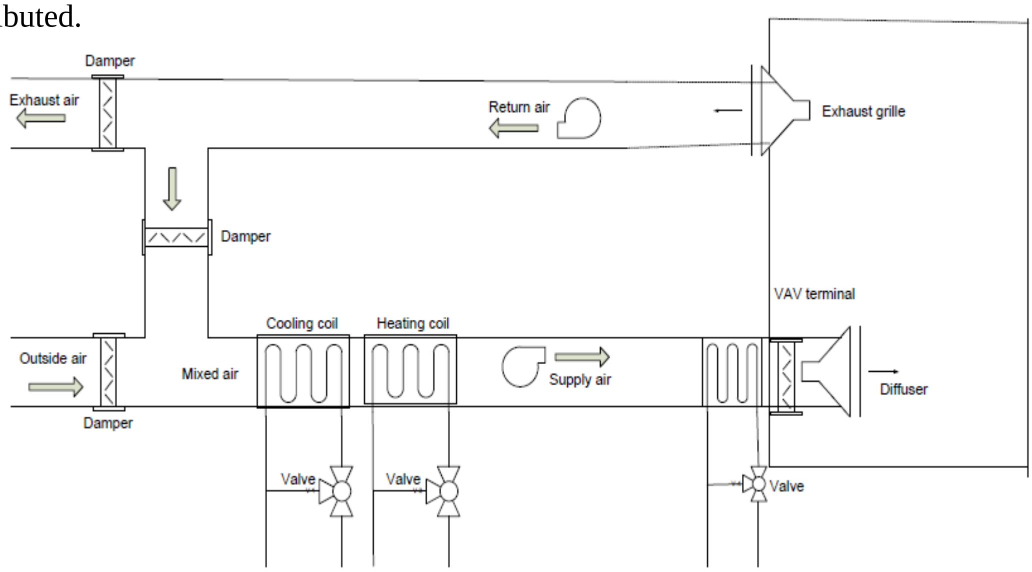

Figure 2.1 Schematic diagram of typical HVAC system

An air conditioner is an appliance, system, or machine designed to stabilise the air temperature and humidity within an area typically using a refrigeration cycle but sometimes using evaporation, commonly for comfort cooling in buildings and motor vehicles. The air conditioning system transfers heat from a cooler low-energy reservoir to a warmer high-energy reservoir [14].

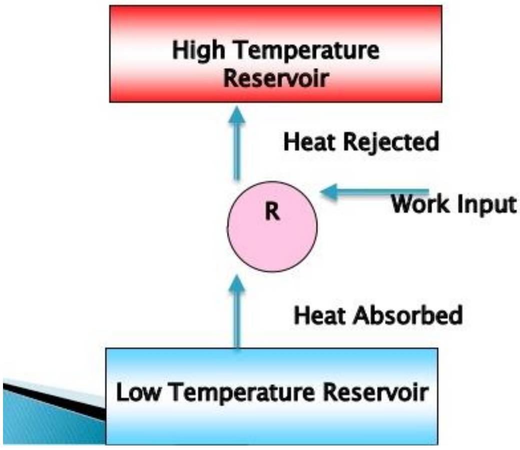

Figure 2.2 Air conditioning diagrams [14]

There are three basic types of air conditioners:

a. **Direct expansion coolers**

   Include window air conditioners, heat pumps and packaged or rooftop units. Air is cooled and dehumidified as it moves past a cold, refrigerant-filled coil.

b. **Chilled water systems**

   Use water cooled by a refrigeration machine instead of air. This cool water supplies a coil, which cools and dehumidifies the air.

c. **Evaporative coolers**

   Usually only operated in hot, dry climates and bring hot air in contact with water spray or damp surface. The result is evaporation of moisture, which lowers the temperature of the air.

2.3 Component of Air Conditioning

Basically air conditioning system has four components. The first component in the air condition cycle is the compressor. The compressor takes low temperature refrigerant gas and compresses it into a high pressure, high temperature gas. The refrigerant is then sent to the condenser which sits in front of the radiator. The condenser removes some of the heat from the refrigerant which causes the refrigerant to change phase from a hot gas to a warm liquid. In the expansion valve air condition system, the warm liquid is then passed through a receiver-drier which removes moisture from the refrigerant to maximize the efficiency of the heat exchange capability of the refrigerant. From there, the refrigerant is then passed through the expansion valve.

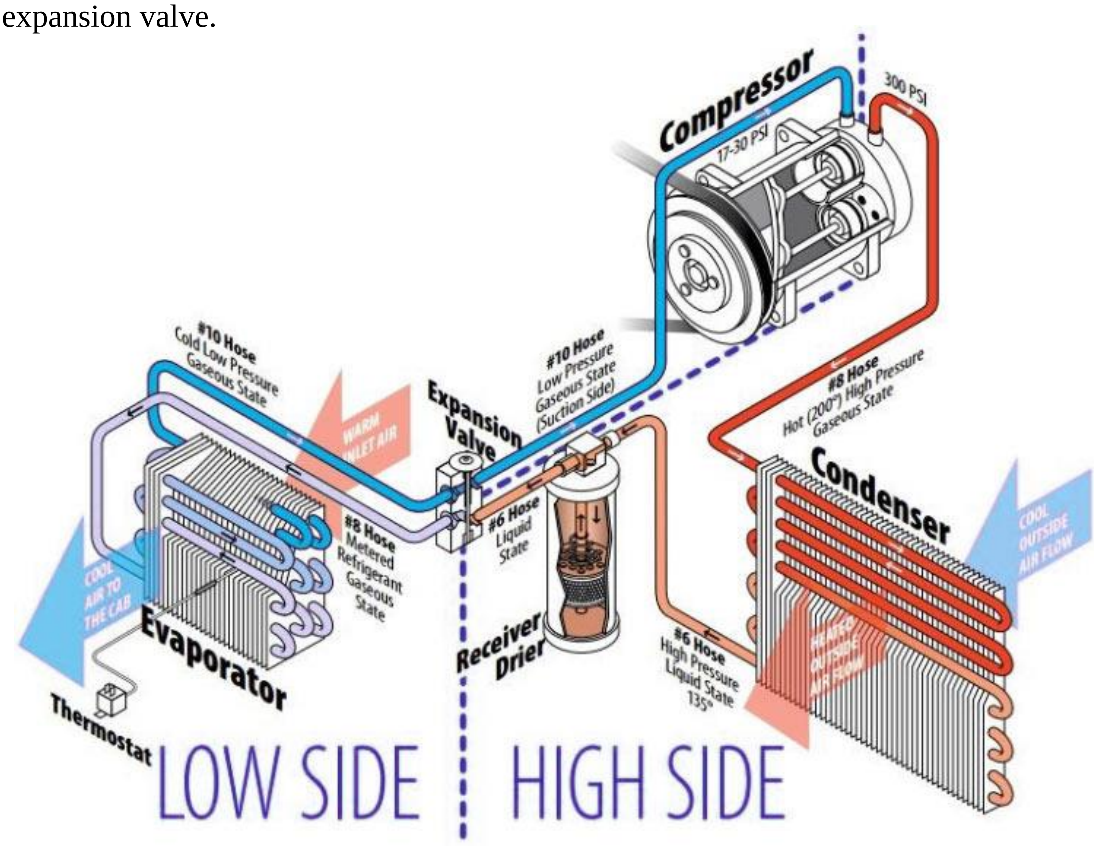

Figure 2.3 The diagram for air conditioning process

2.3.1 Compressor

The heart of the vapour compression cycle is the compressor. The four most common types of the refrigerant compressor are the reciprocating, screw, centrifugal and vane. The reciprocating compressor consists of a piston moving back and forth in a cylinder with suction and discharger valves to allow pumping to take place. The screw, centrifugal and vane compressors all use rotating elements, the screw and vane compressors are positive-displacement machine, and the centrifugal compressor operates by virtue of centrifugal force [15].

Figure 2.4 Compressor used in air conditioning system

2.3.2 Condensers

The type of a condenser is generally characterized by the cooling medium used. Thus, there are three types of condensers which is air cooled condenser, water cooled condenser and evaporative condenser.

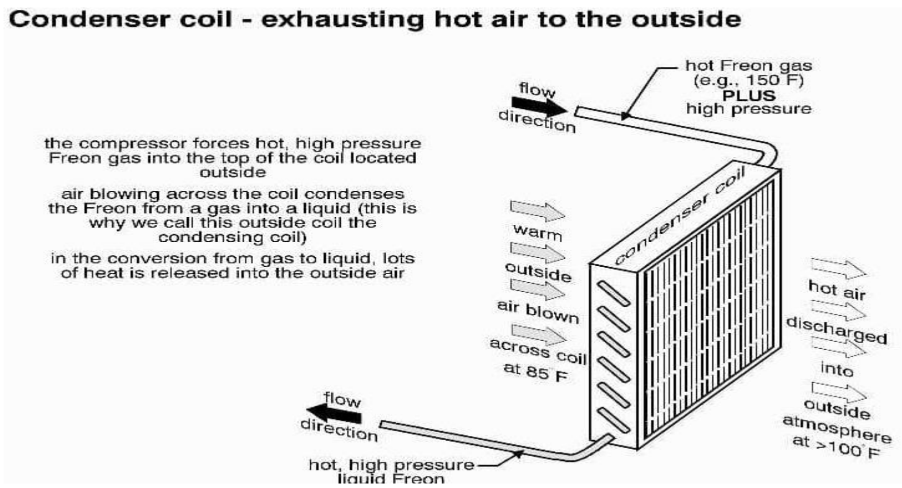

Figure 2.5 Condenser used in air conditioning system

a) Air cooled condenser

In air cooled condenser, heat is removed by air using forced circulation or by either natural. The condensers are made from steel, cooper or aluminium tubing provided with fins to improve air-side heat transfer. The refrigerant flows inside the tubes and the air outside.

b) Water cooled condensers

Water cooled condenser can be of three types, it is shell and tubes, shell and coil, and double tube. The shell and tubes type, with water flowing through passes insides tube and the refrigerant condensing in the shell is most commonly used condenser. Figure shows the arrangement for a two pass condenser.

A shell and tube condenser also serves the purpose of a receiver especially for pumping down the refrigerant, because there is sufficient space in the shell. The bottom portion of the condenser also serves the purpose of a sub cooled as the condenser liquid comes in contact with the entering water at a lower temperature [15].

c) Evaporative Condenser

The refrigerant first reject its heat to water and then water rejects its heat to air, mainly in the form of evaporator water. Air leaves with high humidity as in a cooling tower. Thus an evaporative condenser combines the functions of a condenser and cooling tower [15].

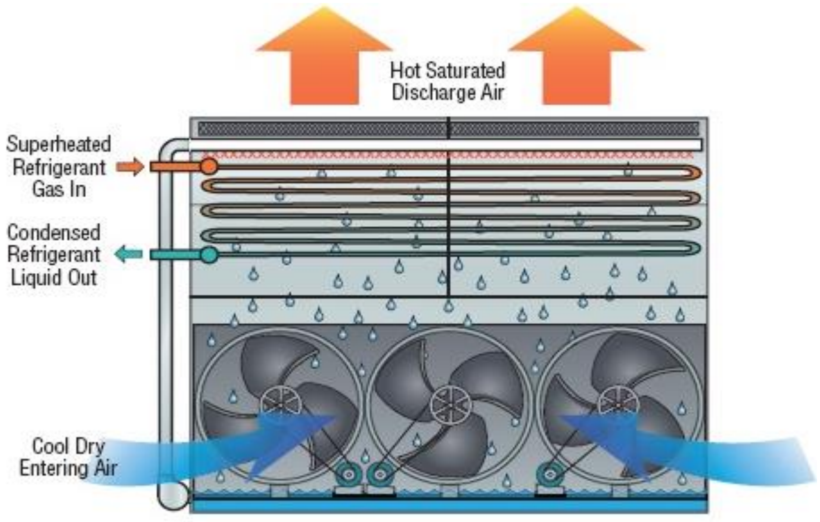

Figure 2.6 Evaporative condenser

2.3.3 Expansion Devices

The last of the basic elements in the air conditioner cycle, after the compressor, condenser and evaporator is the expansion devices. The purpose of the expansion devices is twofold: it must reduce the pressure of the liquid refrigerant, and it must regulate the flow of refrigerant to the evaporator. An expansion device is essentially a restriction offering to flow so that the pressures drop, resulting in a throttling process. Basically there are two types of expansion devices;

a) Variable-restriction type

b) Constant –restriction type

In variable restriction type, the extant of opening or area flow keeps on changing depending on the type of control. There are two common types of such control devices. It is automatic expansion valve and the thermostatic expansion valve. The constant restriction type device is the capillary tube which is merely a long tube with a narrow diameter bore [16].

Figure 2.7 Expansion device or expansion valve

2.3.4 Evaporator

The evaporator is the component of a refrigerant system in which heat is removed from air, water or any other body required to be cooled by the evaporating refrigerant. Evaporators are mainly classified as flooded or direct-expansion such dry. In flooded evaporator, the liquid refrigerant covers the entire heat-transfer surface. In dry evaporator, a part of the heat transfer surface is used for superheating the vapour [17].

Figure 2.8 Evaporator

2.4 Vapor Compression Cycle

Air conditioners and heat pumps work the same way to provide cooling and dehumidification. Both of them extract heat from indoor air and transfer it to the outside air. Both systems typically use a vapor compression cycle. This cycle circulates a refrigerant throughout the whole refrigeration cycle process. A refrigerant is substance or mixture, usually fluid that will increases its temperature significantly when compressed and cools rapidly when expanded. The characteristic of the refrigerant is that it condenses during heat rejection in the condenser and boils during heat addition in the evaporator.

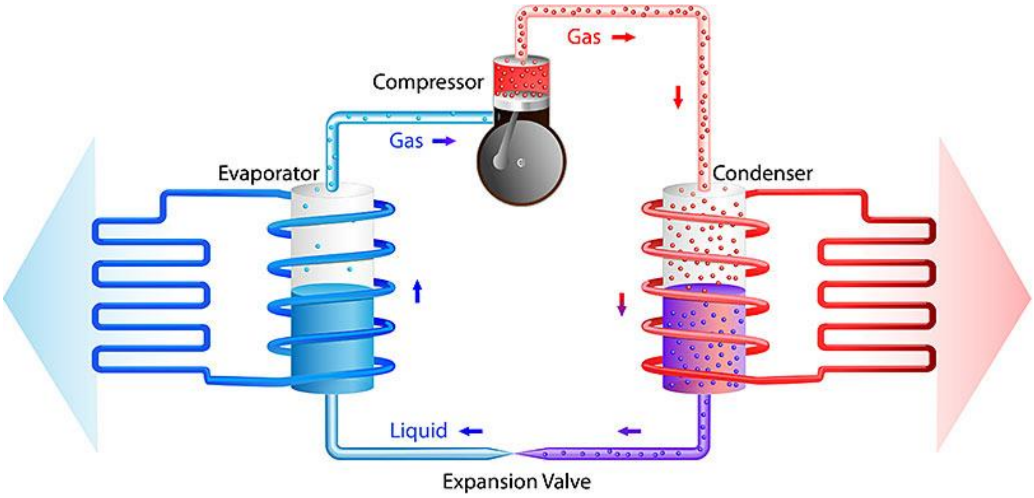

Figure 2.9 Vapor compression cycle

2.4.1 Working Principle of Vapor Compression Cycle

1) The compressor which located in the outside unit of air conditioning system pressurizes refrigerant to become in gaseous state. The refrigerant heats up during this process and appear in high temperature and pressure condition.
2) Condenser in the outdoor unit blow air across the heated and pressurized gas of refrigerant in the condensing coil and makes the refrigerant gas cool down and condenses into a liquid, and gives off its heat to the outside air.
3) The pressurized liquid then moves to the expansion valve under high pressure. This valve restricts the flow of the fluid, and lowers its pressure as it leaves the expansion valve. The refrigerant enters a throttling or expansion valve, where it expands and cools.
4) The low-pressure liquid (cooled liquid) then moves to the evaporator, where inside air is blown across the coiling coils and cooled while the refrigerant warms and evaporates. The heat from the inside air is absorbed and changes the refrigerant from a liquid to a gas. The refrigerant, now a low pressure gas, returns to the compressor where the process repeats.

2.5 Development of Humidity System using Ultrasonic Humidifier

Feng *et al*. [18] stated that human exposed to low level of humidity will tend to have dryness for their skin, eyes and respiratory symptoms, which are closely related with indoor thermal comfort and air quality. To increase indoor humidity level, portable humidification device such as ultrasonic humidifiers are widely used in residential buildings due to their economy and convenience.

Based on [19], most people spend almost 90% of their time in indoor environment. The indoor environmental parameters such as temperature, relative humidity (RH), and air quality are strongly associated with human comfort and health [20, 21]. Indoor humidity is important aspect to human thermal comfort [22, 23]. In conclusion, being in situation with low indoor RH caused human discomfort and health issues.

For example, in some cities in north China which has RH value below 20%, most of their residences there equipped with indoor heating system in winter season [24-27]. Therefore, the indoor air humidity should be controlled by air humidification. Ultrasonic humidifier becomes more popular in indoor application due to safety, economy and convenience, compared to traditional steam humidification system [28-31]. In steam humidification system, the mechanism is only injecting water vapor, while for ultrasonic humidifier; it generated water vapour and droplet simultaneously.

Ultrasonic humidifier was widely applied and assembled in the air-conditioning systems [28, 29], or indoor environment directly as portable humidification system [30]. In air-conditioning system, dry air was humidified in ventilation ducts before being force to supply into indoor space [28]. Differently, portable humidifier placed in indoor environment could humidify air directly and create local humidity comfort [31].

Pu *et al*. conducted numerical simulations to study the steady air temperature and relative humidity distributions in a ventilated room with ultrasonic humidification system installed in ventilation ducts [29]. During the indoor humidification process, water droplets and water vapor were generated by ultrasonic humidifier simultaneously [31], resulting in complex and non-uniform thermal environment (temperature and humidity). This study was to investigate the influences of indoor portable ultrasonic humidification system (continuous humidification process induced by water droplet and vapor) on air temperature, relative humidity, thermal comfort and air quality.

2.6 Flow Rate over Diameter Size of Perforated Pipe

Air flow distribution has become one of the most important components that contribute to Heating, Ventilation and Air Conditioning (HVAC) system. Recently, perforated pipe has been chosen to be included into the air flow distribution system due to its effectiveness in distributing air through perforated holes. Air flow characteristics through perforated pipe depends on many parameters such as pipe materials, size of hole, pipe diameter and fan speed which could lead to the variation of air flow characteristics [32].

Perforated fluid distribution pipes have been widely used in agriculture, water supply and drainage, ventilation, the chemical industry, and other sectors. It's a typical type of dispensing equipment that can ensure that the main stream flows uniformly from the sidewall keyhole along the axial channel.

In practical projects, the outlet of the lateral pipe might be a pipeline, spray nozzle or microspores. Because the total flow consists of separated multi-flows, the flow in the perforated pipe is also referred to as embranchment flow, in which the discharge, head loss and pressure distribution of the perforated pipes differ from those of non-perforated pipes. The flow characteristics of the perforated pipe are highly important for the pipeline design of sprinklers and drip irrigation projects and for applications in the chemical, dynamic, ventilation and environmental fields.

Flow distribution in a perforated fluid distribution pipe has been studied by a number of authors using the energy equation method. Wang *et al.*[33] introduced a general theoretical model to calculate the flow distribution and pressure drop in a channel with porous walls. Based on research study made by professional, it can be conclude that the higher the diameter size of the perforated hole, the higher the flow rate can pass through it.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter will present the principle operation of ultrasonic humidifier, the function and component of the ultrasonic humidifier parts, the experimental setup on how to integrate humidity system into HVAC system. Several steps have been approach within research period. Finally, the last step which used piccolo hole PVC pipe as a medium to increase the humidity in experimental rig seems suitable toward the objective.

3.2 Principle Operation of Ultrasonic Humidifier

The humidifier added up moisture to the air by humidification process and uses very little energy. The operation of the humidifier is instantaneous (no waiting for start-up) and produces no noise. The basic component ultrasonic humidifier is consisting of a piezoelectric ceramic disc which is provided with current through two nickel electrodes. This piezoelectric transducer is immersed in water in the ultrasonic humidifier. The ceramic disc which is piezoelectric oscillates in the presence of electric current at ultrasonic frequency, converts a high frequency, electronic signal into a high frequency mechanical oscillation.

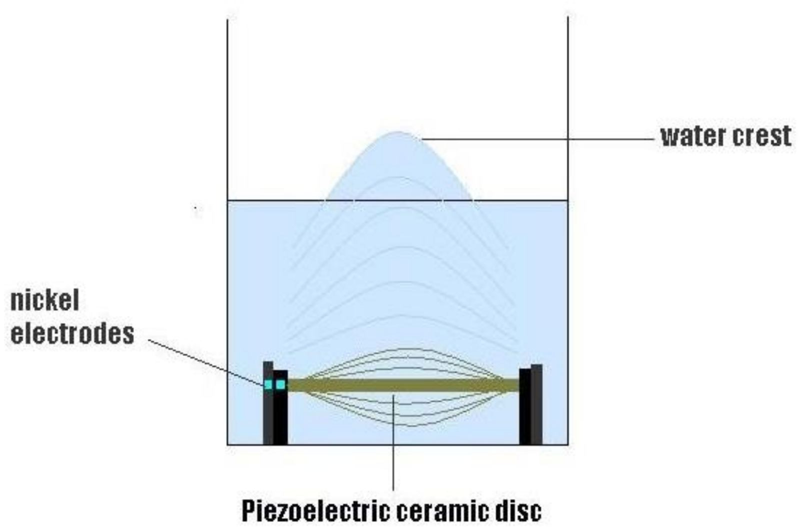

Figure 3.1 Component of Ultrasonic Humidifier contain piezoelectric disc

As the frequency of oscillation of the plate increases, the oscillation speed is increased as well. Water tries to follow the frequency oscillating with the plate but water fails to match the frequency due to its inertia and weight and causes water hammers. So as the water wave lags behind the wave of the disc where the water particles can no longer follow the oscillating surface, an area of low pressure is created between them.

A momentary vacuum and strong compression occur, leading to the explosive formation of air bubbles, which termed as cavitation. At cavitation, the broken capillary waves are generated, and tiny droplets which has 1 micron diameter, break the surface tension of the water and it quickly dissipated into the air, taking vapor form and absorbed into the air stream. The cavity can be filled with air since there is air dissolved in water and with the formation of low pressure, air moves into the cavity.

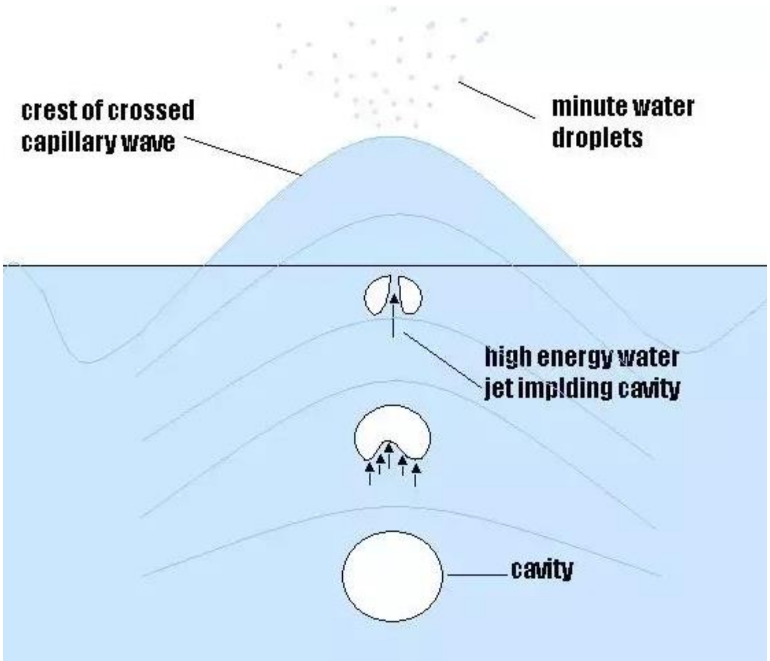

Figure 3.2 Cavitation occurred and breaks surface tension of water

When this cavity implodes, lot of energy is created and at the imploding jet area has a lot of energy. The vibrating disc also causes capillary waves at the surface of water (ripples). The capillary wave keeps oscillating up and down due to surface tension and gravity and produce crest of crossed capillary wave. As a result, the molecules of water droplets have enough energy to break off the surface tension of water.

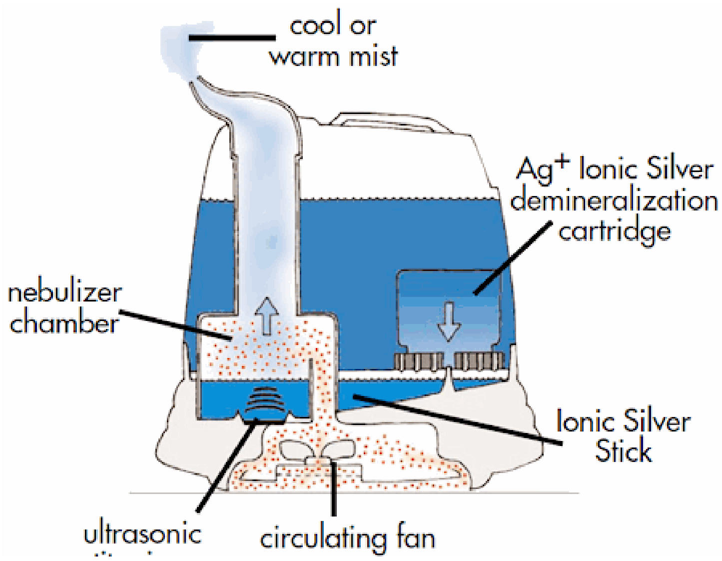

Figure 3.3 Working principle of an ultrasonic humidifier

These droplets of water were absorbed into the stream of air which being blown by a fan and leave the humidifier as mist or fog. The size of this mist would be smaller with increasing the frequency. Normally, the fine mist of water particles produce by ultrasonic humidifier is around of 1 micron in size.

3.3 Component of Ultrasonic Humidifier

The component of an ultrasonic humidifier all work together in order to help the appliance operate properly. If the part broken or not functioning, replacing the part is inexpensive and can save a lot of money compared to buy a new humidifier.

Figure 3.4 Component of Ultrasonic Humidifier

3.3.1 Water Container

The container is the place where water being stored. Most containers are equipped with sensors that inform you when the water level is too low and needs to be refilled. This is the part that will require maintenance and regularly cleaning.

3.3.2 Control Panel

The control panel allows controlling the amount of mist produce by the humidifier. This also functions to switch on or off the humidifier by rotating the control panel itself. Some of the control panel include with temperature settings and automatic shut off timers.

Figure 3.5 Ultrasonic humidifier control panel

3.3.3 Piezoelectric Transducer

This transducer provides the high-frequency vibration oscillation and causes the water to transform into a vapor mist. This advanced piece of technology is what makes the ultrasonic humidifier easy to use and maintain.

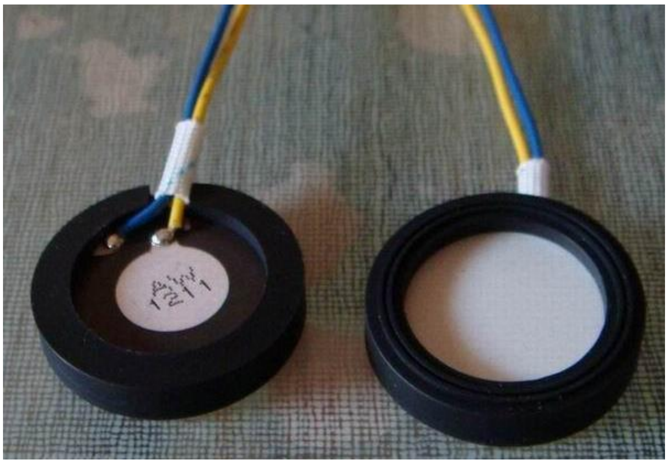

Figure 3.6 Piezoelectric transducer used in ultrasonic humidifier

3.3.4 Ultrasonic Generator

The ultrasonic generator is what the transducer feeds power from. It provides power to the transducer to create vibrations. It connects the transducer and input together. Without operation of the generator, the piezoelectric transducer will not functioning.

3.4 Installation of Humidity System into HVAC System

3.4.1 First approach

Several steps have been approach in order to install humidity system into HVAC system to increase the humidity level in the HVAC experimental rig. Firstly, ultrasonic humidifier is used as a device to increase humidity as it main function is to add moisture to the air through a mist or vapor.

Figure 3.7 Water vapor or mist produce by ultrasonic humidifier

The vapor or mist produced by ultrasonic humidifier is then need to be channelled into HVAC system. The first step is to connect between the top part of the humidifier and the section at the experimental rig by using a rubber piping. To make the top part of the humidifier fit with the piping, it needs to be modified by using 3D printing.

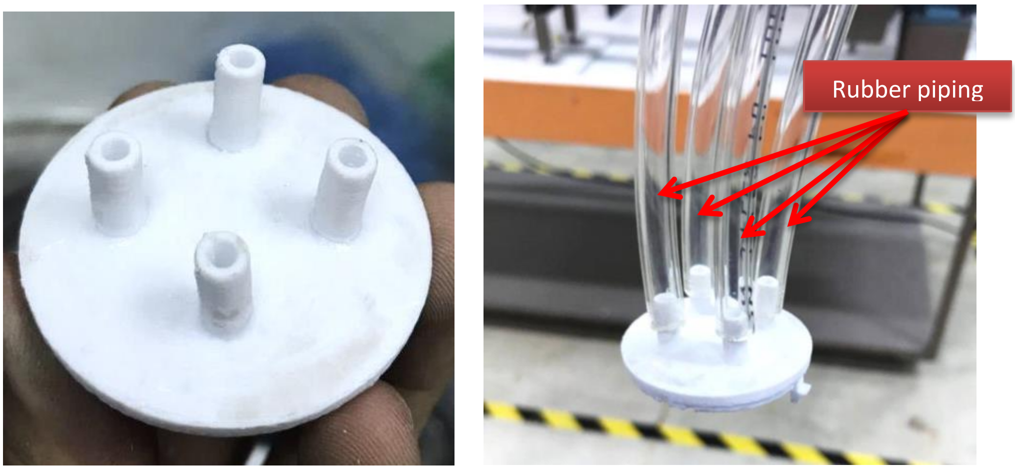

Figure 3.8 Shape of end cap of ultrasonic humidifier after being modified by 3D printing connected with rubber piping

At the HVAC section, 4 holes were drilled at the section between the axial fan and heating section of the experimental rig to connect with the piping from the humidifier. Finally, the setup has been done and the experiment is running. But, this approach seems not come out into solution as it's not increases the humidity level after being tested by humidity sensor in the experimental rig.

The reason due to this problem is because the hole at 3D printing cap at the end of the humidifier is too small in diameter. When it's small in size, the drilled hole at experimental rig and the rubber piping used is small too, to fit with the 3D printing hole size.

The smaller size of diameter of hole at 3D printing cap cause the water vapour produced from humidifier cannot pass through it and cause accumulation of water vapour in the small area. Thus it blocks the way of water vapor path and water vapour cannot go through and stuck in the smaller diameter of the cap.

3.9 HVAC experimental rig in Heat Transfer Lab

3.4.2 Second approach

With previous step seem not achieved objective of this study, another step is approach. In this step, the size of the rubber piping is increase from 8mm to 12mm. The rubber piping is connected from the top part of the humidifier to the modified section in HVAC system.

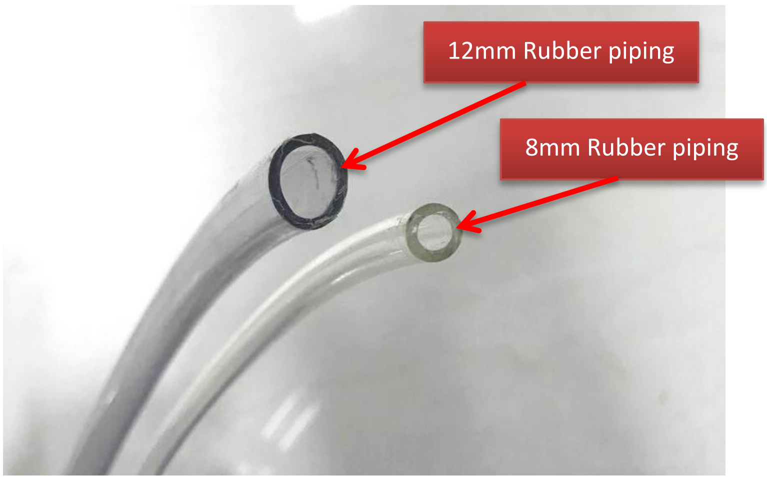

Figure 3.10 Smaller diameter tube (8mm) and higher diameter tube (12mm)