DEVELOPING A MULTI WATER DROPLETS EVAPORATIVE COOLING SYSTEM

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A thesis submitted
in fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering (with Honours)

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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DECLARATION

I declare that this thesis entitled "Developing a multi water droplets evaporative cooling system" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

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

Signature : ....

Supervisor Name : Dr. Yusmady Bin Mohamed Arifin

Date : ....

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DEDICATION

To my beloved family, friends and teachers

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ABSTRACT

Climate change is becoming undeniably significant every day which is beneficial neither for human population nor the planet. This directly affect thermal comfort level in our surroundings. However, it is difficult to curb it all at once. It is important to look into possible aspects that can be explored and studied that may contribute towards the betterment of the environment. Cooling systems are closely related as they are observed to be crucial in altering indoor ambience according to human comfort level. Even though the conventional options seem to be efficient in this matter, continuous usage or mishandling results in environmental damage. Hence, it is important to explore alternative options that may serve the same purpose in a better way. The purpose of this study is to develop a evaporative cooling system using multi water droplets approach and investigate the performance of the system by testing different configurations of multi water droplets. An experimental setup was developed consisting a flow straightener, water supply system, fan and evaporation chamber. The droplet generator is fabricated using a metal plate and syringes to form water droplets. All components mentioned was fabricated and enclosed in a support frame to form a cooling system. The experiment is then conducted using plain water and cold water. Three type of configurations were tested in the evaporation chamber by altering the number of opened and closed syringes which are named as Configuration A, B, and C. Thermocouples and a data logger were used to collect the temperature readings of inlet, test section and outlet air. Performance of the system is determined based on its capability to reduce temperature of the inlet air. The research has shown that a multi water droplets evaporative cooling system is capable of reducing temperature. The findings of this study showed that the highest average temperature difference between air inlet and air outlet in Experiment 1 to be 0.74°C and 1.06°C in Experiment 2. Besides that, Configuration B as the most suitable configuration among all three configuration tested.

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ABSTRAK

Perubahan iklim sedang menjadi setiap hari adalah sesuatu yang tidak dapat dinafikan. Ianya adalah sesuatu yang tidak baik untuk populasi manusia dan planet ini. Isu ini secara langsung mempengaruhi paras keselesaan terma di persekitaran kita. Walaubagaimanapun, ia adalah sukar untuk membendungnya sekaligus. Adalah penting untuk melihat aspek-aspek yang berkemungkinan yang boleh menyumbang yang dapat diterokai dan dikaji menjuru kepada kesejahteraan alam sekitar. Sistem penyejukan berkait rapat kerana ia diperhatikan sebagai sesuatu yang sangat penting dalam penggubahan persekitaran dalaman mengikut tahap keselesaan manusia. Walaupun pilihan konvensional adalah cekap dalam perkara ini, penggunaan berterusan atau pengendalian yang salah akan berakhir dalam kerosakan kepada alam sekitar. Oleh itu, adalah penting untuk meneroka pilihan alternatif yang boleh memenuhi tujuan yang sama dengan cara yang lebih baik. Tujuan kajian ini adalah untuk membangunkan sistem penyejukan penyejatan dengan menggunakan pendekatan titisan air dan menyiasat prestasi sistem dengan menguji konfigurasi titisan air berbilang yang berlainan. Suatu persediaan eksperimen telah dibangunkan yang terdiri daripada pelurus aliran, sistem bekalan air, kipas dan kamar penyejatan. Penjana titisan air dibuat menggunakan plat logam dan picagari untuk membentuk titisan air. Semua komponen yang disebutkan disediakan dan disertakan dalam satu bingkai sokongan bagi membentuk sebuah sistem penyejukan. Eksperimen ini kemudiannya dijalankan menggunakan air biasa dan air sejuk. Tiga jenis konfigurasi telah diuji dalam bahagian rig ujian dengan menggantikan bilangan picagari yang dibuka dan tutup yang telah dinamakan konfigurasi A,B, dan C. Thermokopel dan peralatan catatan data digunakan untuk mengumpul data mengenai perbezaan suhu antara udara masuk dan keluar. Prestasi sistem ditentukan berdasarkan keupayaannya untuk mengurangkan suhu udara masuk. Penyelidikan telah menunjukkan bahawa sebuah sistem penyejukan penyejatan titisan air mempunyai keupayaan untuk mengurangkan suhu. Hasil kajian ini menunjukkan bahawa purata suhu perbezaan di udara masuk dan udara keluar yang tertinggi dalam Eksperimen 1 ialah 0.74°C dan 1.06°C dalam Eksperimen 2. Selain itu, konfigurasi yang paling sesuai di antara tiga konfigurasi yang diuji ialah Konfigurasi B.

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LIST OF ABBREVIATIONS

CFC	-	Chlorofluorocarbon
DEC	-	Direct evaporative cooler
GWP	-	Global warming potential
LDD	-	Liquid desiccant dehumidification
min	-	Minutes
ODP	-	Ozone depletion potential
PCT	-	Passive cooling techniques
PDEC	-	Passive downdraught evaporative cooling
RIEC	-	Regenerative indirect evaporative cooler

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LIST OF SYMBOLS

2D	-	2-Dimensional
$\dot{M}$	-	Flow rate
δ	-	Plate thickness
D_1	-	Distance between manifolds and heat exchanger face
D_2	-	Distance between nozzles
D_3	-	Distance between manifolds
h	-	Net channel height
L*	-	Net plate length and width
o	-	Outside air
pt	-	Plate pitch
T, t	-	Temperature
w	-	Water
wb	-	Wet-bulb

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CHAPTER 1

INTRODUCTION

1.1 Background

The world population in the year of 2017 is hitting 7.5 billion [1]. It is continues to rise every other day which results in excessive consumption of fossil fuel resources, increase in economic and environmental issues related with global warming, also, climate change [2]. These phenomenon occurs as we look forward to the betterment comfort living. Therefore, it is important for us to focus on energy and environmental conservation. This is where the conventional air conditioning system comes into question. They consume a large amount of electrical energy besides creating residue that are harmful to the environment which is why a more efficient air conditioning option is favourable. Evaporative cooling technology is well known for its potential high efficiency and cheaper production and running cost [3]. These aspects are relatable when compared with the existing air conditioning systems such as the vapour compression, absorption/adsorption and thermoelectric refrigeration systems taking into account regions with dry and hot climate as well as more temperate climates. An evaporative cooling system cools the air based on water evaporation concept. Water has considerably large enthalpy of vaporization, which is why the air temperature can be reduced by phase transition from liquid to vapour. A typical evaporative cooling system does not require any mechanical refrigeration making it in line with low energy consumption. Besides, water will be used as the medium neglecting any usage of chlorofluorocarbon (CFC) that are harmful for the environment.

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A multi water droplets approach satisfies these aspects and they work the same as an direct evaporative cooling system. A direct evaporative cooler, will take in outside air through the help of a fan and blown through a medium that is water saturated which will be cooled via evaporation. Direct evaporation cooling systems assist in moistening the air until the humidity in the surrounding region has risen to a significant level. However, traditionally they require the help of an evaporative pad which is moistened by water. This becomes the medium that stands in between outside air and indoor air. Multi water droplets approach took place as the medium in this study without the use of an evaporative pad. This study is focused on an evaporative cooling system built using multi water droplets approach which will be tested on different configurations.

1.2 Problem Statement

Commercial cooling system in the market currently is observed to be energy consuming. Constant draining of non-renewable energy sources is neither good for the climate or the environment. Therefore, it is important implement cooling system with a higher efficiency which is compatible with the energy conservation policy. Moreover, commercial cooling systems produce residues that are dangerous to the environment if there is a leakage. This is because commercial cooling system requires the usage of refrigerants. These refrigerants exhibit global warming potential (GWP) and ozone depletion potential (ODP). It is also notable that existing cooling system requires high initial cost. Hence, a alternate option that is efficient, cost effective, and environmental friendly should be considered.

Evaporative cooling system may serve as an alternative cooling system taking into account benchmarks such as low-cost, energy conserving and environmental friendly [3]. A multi water droplet approach in an evaporative cooling system can be a good option when compared to the existing air conditioning system as it requires low running cost, does not use refrigerants that are hazardous and consumes less energy due to the absence of compressor.

1.3 Objectives

The objective of this project are as follows:

1. To develop an evaporative cooling system using multi water droplets approach.
2. To determine the performance of evaporative cooling system by testing different configurations of multi water droplets.

1.4 Scope of Project

The scopes of this project are:

1. The evaporative cooling system is built based on multi water droplets approach and tested with three different configurations in the test section.
2. Temperature changes occurring to the ambient air or air inlet, air outlet and test section throughout the experiment was measured and tabulated based on type of configuration and condition of water tested which is natural running water and cold water.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A comfortable environment is what allows us human being to be able to focus and be effective in any activity that we intend to do. Aspects such as thermal comfort plays important role in bringing the best out of a desirable environment. Thermal comfort is defined as the state of comfort a person has with his or her surrounding environment. However, towards the effort of achieving high level of thermal comfort, natural resources are being exploited in a huge volume [5]. This in turn result in environmental damage and unhealthy practices that causes bad effects to climate. Therefore, it is important to study and practice an effective cooling method that does no harm to the nature and serve the purpose of achieving desired level of human comfort.

This second chapter reviews studies and researches carried out in relation to evaporative cooling technologies. It includes type of air conditioning system that comprises evaporative cooling as its core technology. Section 2.2 explains the idea of evaporative cooling and technologies involved in air conditioning application. In section 2.3, direct evaporative cooler traits and study related to it is discussed. Meanwhile, indirect evaporative coolers are reviewed in section 2.4. Combination of both direct and indirect evaporative coolers or also known as hybrid evaporative coolers are reviewed in the section 2.5. Studies focusing on the evaporation rate are presented in the section 2.6.

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2.2 Evaporative Cooling

Heat and mass transfer process is the core of evaporative cooling that utilizes the evaporation of water for air conditioning process. In this process, high volume of heat is exchanged from air to water which simultaneously decreases the air temperature. There are three main types of evaporative coolers. First, direct evaporative coolers, indirect evaporative coolers and combination of direct and indirect evaporative coolers [8]. Evaporative cooling is known to be a efficient option in thermal management and controlling the temperature across a wide scope of natural and artificial applications [6]. Existing air conditioning technology such as thermoelectric refrigeration, vapour compression, and absorption or adsorption when compared with evaporative cooling shows that it is a better choice. Aspects such as cheaper cost and possibility of higher efficiency is what evaporative cooling technology is made of regardless of dry and hot weather or milder climate [9].

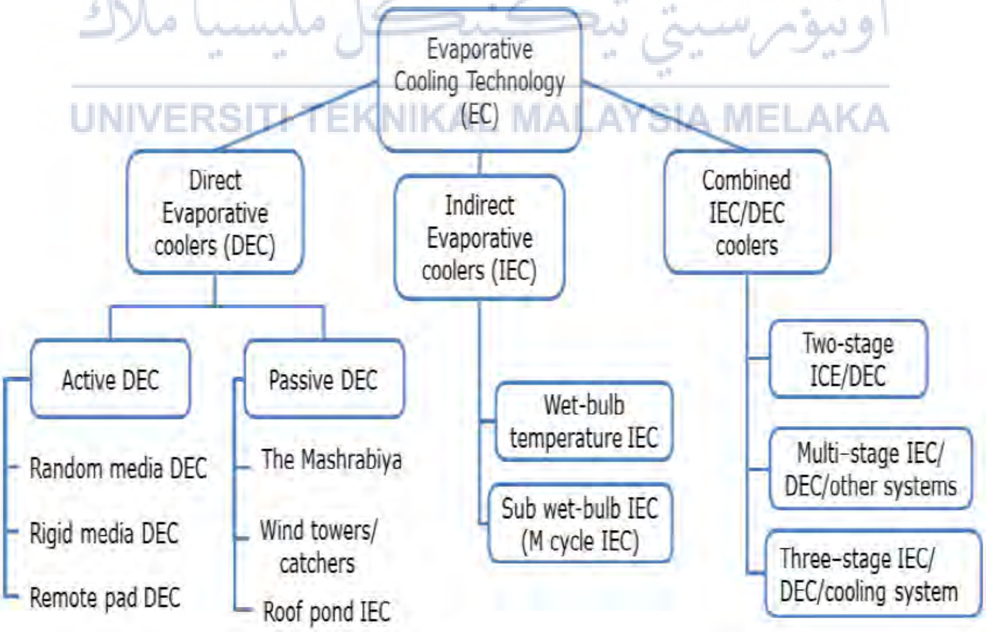

Figure 2.1 Types of evaporative cooling [9]

2.3 Direct Evaporative Coolers

Direct evaporative cooling is known to be the earliest and easiest form of evaporative cooling. This system works in a manner that ambient air flows coming into contact with water which allows the conversion of heat, mainly sensible to heat. Various ways of implementation can be observed across a lengthy timeline for air conditioning purposes such as placing pad with water holding traits as a screen through the flow of air. Direct evaporative coolers maybe classified into two different groups, namely active or passive direct evaporative coolers. They differ mostly in terms of power consumption where active direct evaporative cooler requires electricity for operation while passive direct evaporative coolers does not require power consumption [17].

Huang et al. (2014) discussed the issues in application of evaporative cooling in a subway station in their research [10]. The study is focused at Lanzhou, China subway station particularly during summer. Parameters determined for the outdoor design are dry-bulb temperature and wet-bulb temperature. Packing performance test were done with fixed face velocity of 3 m/s and varying packing thickness. Types of packing tested consist of stainless steel, aluminium foil, plant fibre, glass fibre, and polymer. It is observed that maximum direct evaporation cooling efficiency is obtained when the water spray density is at 5400 kg/(m^2h) regardless of the type of packing tested. The research concludes that stainless steel packing is suitable a direct evaporation cooler to be installed in a subway station.

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Figure 2.2 Physical prototype figure [10]

Chiesa et al. (2017) conducted a study on the integration of passive downdraught evaporative cooling (PDEC) in buildings [11]. An experimental setup is done and tested within laboratory for tabulation of data. Based on information gained in data collection of five days, system dimensioning is done. It is found that PDEC systems can be installed conveniently in existing buildings without causing any damage to the design. Also, performance of nozzles at low pressure can be obtained from low cost ones as well and water usage can be reduced significantly at the presence of recirculation pumps.

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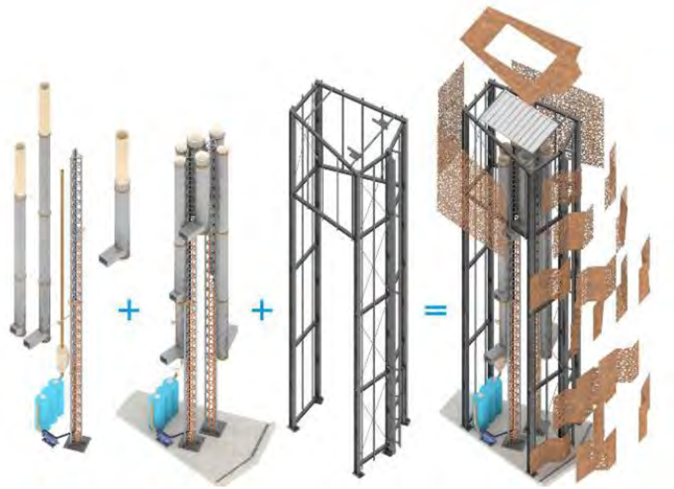

Figure 2.3 Proposed PDEC system [11]

Han et al. (2017) investigated the application and develops water retaining bricks on the roof which has air conditioning ability accordingly during summer and winter [12]. The research team experimented their test location on three different configurations; 1) roof with water retaining bricks, 2) roof with radiation shield, 3) ordinary roof. Parameters taken into account are ambient temperature, relative humidity, ordinary roof temperature, roof temperature with bricks, indoor temperature with bricks, and indoor temperature without bricks. The study revealed that maximum cooling capacity can be achieved by using roof with water retaining bricks and radiation shield. Besides, water retaining bricks may not perform up to expected standard in winter.

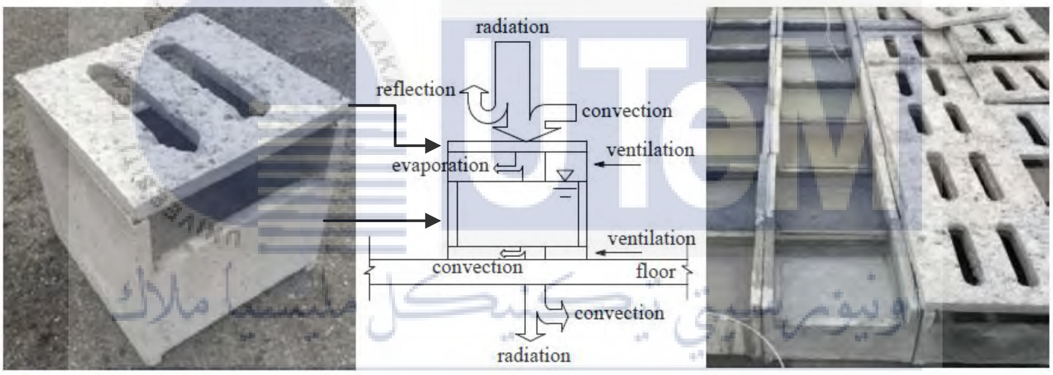

Figure 2.4 Water retaining brick structure and heat transfer mechanism [12]

2.4 Indirect Evaporative Coolers

An indirect evaporative cooler works based on the decrement of air sensible heat keeping its humidity constant. This serves as an notable advantage when compared to direct evaporative coolers. Parts that make up a typical indirect evaporative cooler include fan, water reservoir, pump, and distribution lines with plates that creates space between working fluids[18].

De Antonellis et al. (2017) conducted a study on developing an indirect evaporative cooling system model since they are seen as a efficient choice of cooling system in data center facilities [13]. The cooler being analysed is attached with a cross-flow plate heat exchanger, spray nozzles and a pump. In order to monitor the performance of the system, the temperature and humidity ratio is measured. Measurement of air conditions are done by coupling temperature and by using a relative humidity sensor. However, it is notable that measurement process was not an easy one since there less available space and constantly changing air and water conditions. The findings from the experiment concludes that indirect evaporative cooler has the capability of reducing the air temperature which is based on the air and water flow rate. When there is a higher flow rate of water, higher area for heat and mass transfer is present.

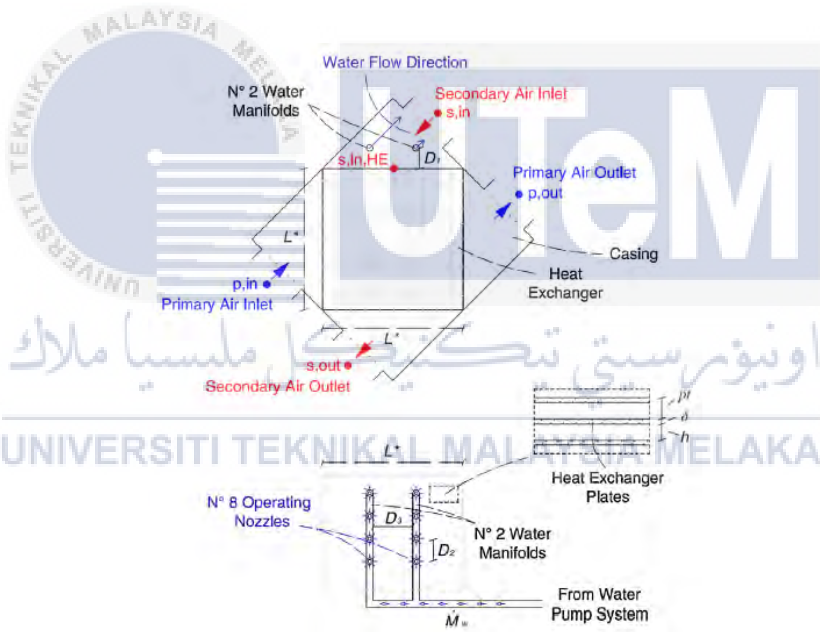

Figure 2.5 Schematic diagram of indirect evaporative cooler being studied [13]

Sosa and Gómez-Azpeitia (2014) have done a study that presents the cooling potential of indirect evaporative cooling system in arid climates [14]. The experiment was conducted in five different Passive cooling techniques (PCT) tested onto the top section of experimental apparatus in a arid climate. The aim is to figure out which system would have lowest energy and water consumption and efficiency rate equivalent to existing air conditioning system. The results of the study confirms that evaporation cooling is the best option of air conditioning in hot and dry climate. Besides, one of the techniques, exposing roof pond to the night sky, has the ability to cool down which gives them the trait of the best cooler and economical in terms of water usage. As a conclusion, the roof pond method is to be observed as a possible replacement to existing cooling system having the said traits to be applicable which gives way for it to be further studied and put into use.

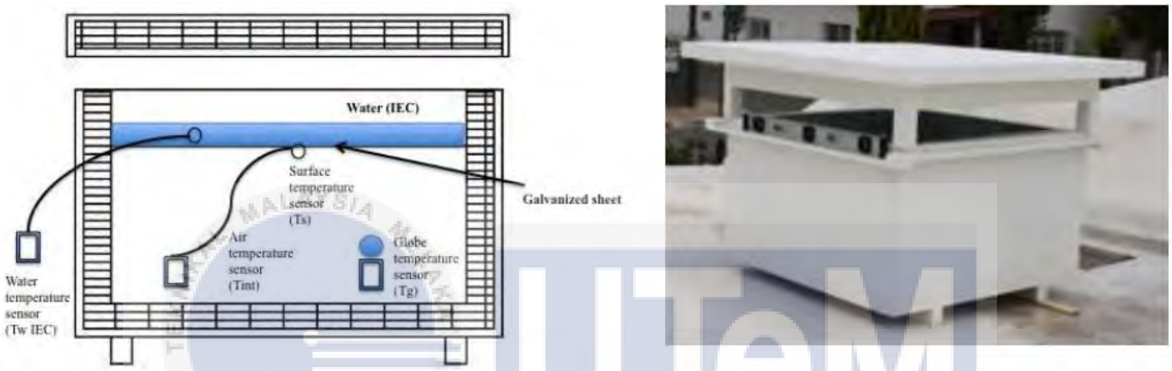

Figure 2.6 Indirect evaporative cooler with shading devices [14]

2.5 Hybrid Evaporative Cooling System

Since both direct evaporative cooling system and indirect evaporative cooling system both have their benefits and drawbacks based on application, bringing together both technologies together or even other air conditioning related systems may have greater possibility of higher performance and efficiency rate. Despite , the high possibility of potential hybrid evaporative cooling system or Direct-Indirect evaporative cooling system comes with price. They cost much higher in the commencing stages and are more complex than direct and indirect evaporative cooling system [19].

Chen et al. (2017) focused on liquid desiccant dehumidification and evaporative cooling system comprising dehumidification of ambient air in the dehumidification unit and cooling process in the evaporative cooling section [15]. The mentioned system is

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compared with existing air conditioning system. Evaporative cooling system used in this study is known as regenerative indirect evaporative cooling system. The process begins with fresh air being dehumidified, passed on to regenerative indirect evaporative cooling system twice before a portion of processed air proceed to a direct evaporative cooling system to be mixed forming the final product, supply air. The study reveal that system developed have the potential to over the place of vapour compression air conditioning system given that it is to be implemented in weather condition the study was conducted.

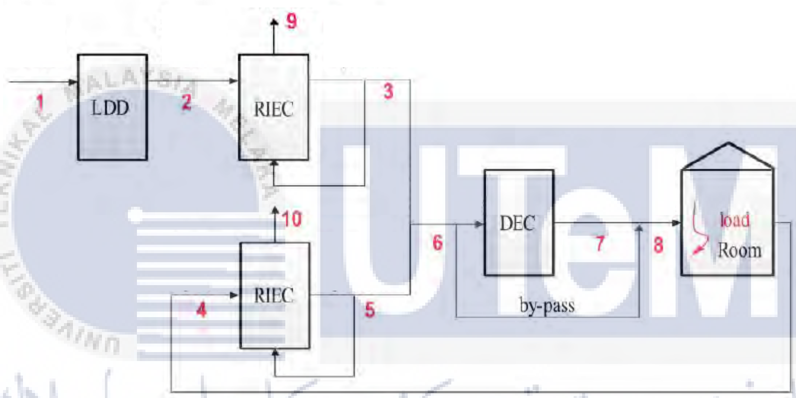

Figure 2.7 Liquid desiccant dehumidification and evaporative cooling system [15]

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Alklaibi (2015) focused on the study of an internal two-stage evaporative cooler performance. The system mentioned was compared with direct evaporative cooler by experimenting the both of them. Besides, it was also compared with two-stage and direct evaporative coolers based on theory. Both sets of experiment took place in Saudi Arabia under same temperature and humidity. It is found that air speed affect efficiency of direct evaporative cooler at a higher rate when compared to internal two-stage evaporative cooler efficiency which also has greater humidity percentage. Also, external two-stage evaporative cooler may have efficiency above than 100% when compared with direct evaporative cooler. However, it is not possible with a internal two-stage evaporative cooler. It is known that internal two-stage evaporative cooler produces final product of highly humid air which is recommended for facilities requiring high humidity [16].

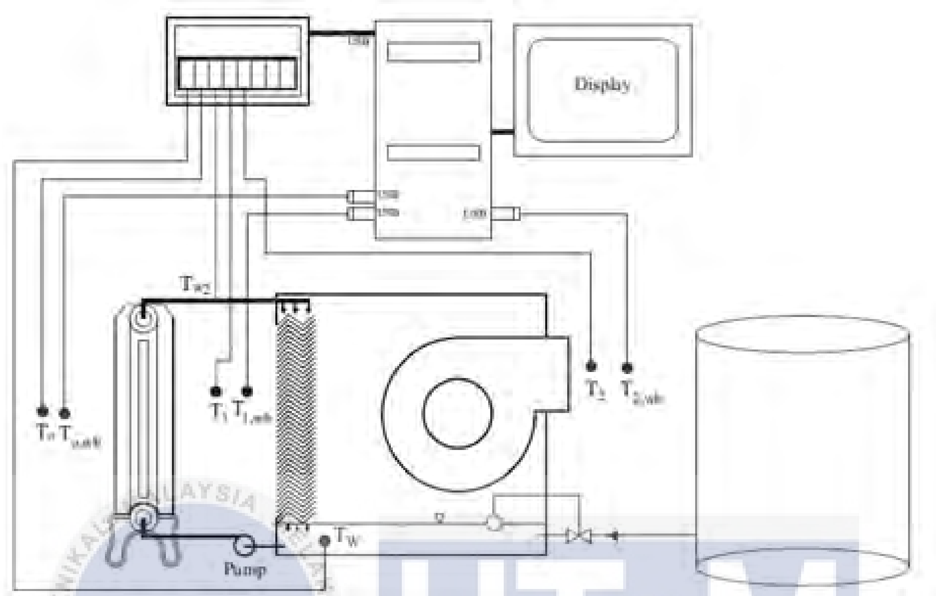

Figure 2.8 Evaporative cooler setup comprising internal two-stage evaporative cooler and direct evaporative cooler [16]

2.6 Evaporation Rate Improvement

Chakraborty et al. (2017) had done a functionality analysis to assess the effectiveness of an evaporative cooling system. This system comprises diffusion based evaporation of sessile water droplets. It is built for the cooling of microprocessors within the space requirements. Two methods were used in these study which were the analytical model and numerical model. The capability of a single layer of water droplets and the size of droplets necessary for sufficient cooling is determined using the analytical model. Parameters taken into account in the analytical model are vapour concentration, diffusion coefficient, case temperature, contact angle and atmospheric temperature. Numerical model is used to develop a three-dimensional tiered system which aims to able to match cooling capacity that can be achieved by the single layer of water droplets developed in

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analytical model. The results of the study revealed that cooling capacity of diffusion-based evaporation of sessile droplets can be achieved with a number of configuration [7].

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CHAPTER 3

METHODOLOGY

3.1 Introduction

Working towards achieving the objectives mentioned earlier requires a set of approaches which has been thoroughly observed throughout this chapter. In order to discuss the sequence of the project, this chapter begins with a overall project flowchart. Processes done towards the development of this study is briefly stated in the flowchart as an overview on how the development of an evaporative cooling system using multi water droplets approach took place.

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3.2 Overall Flowchart

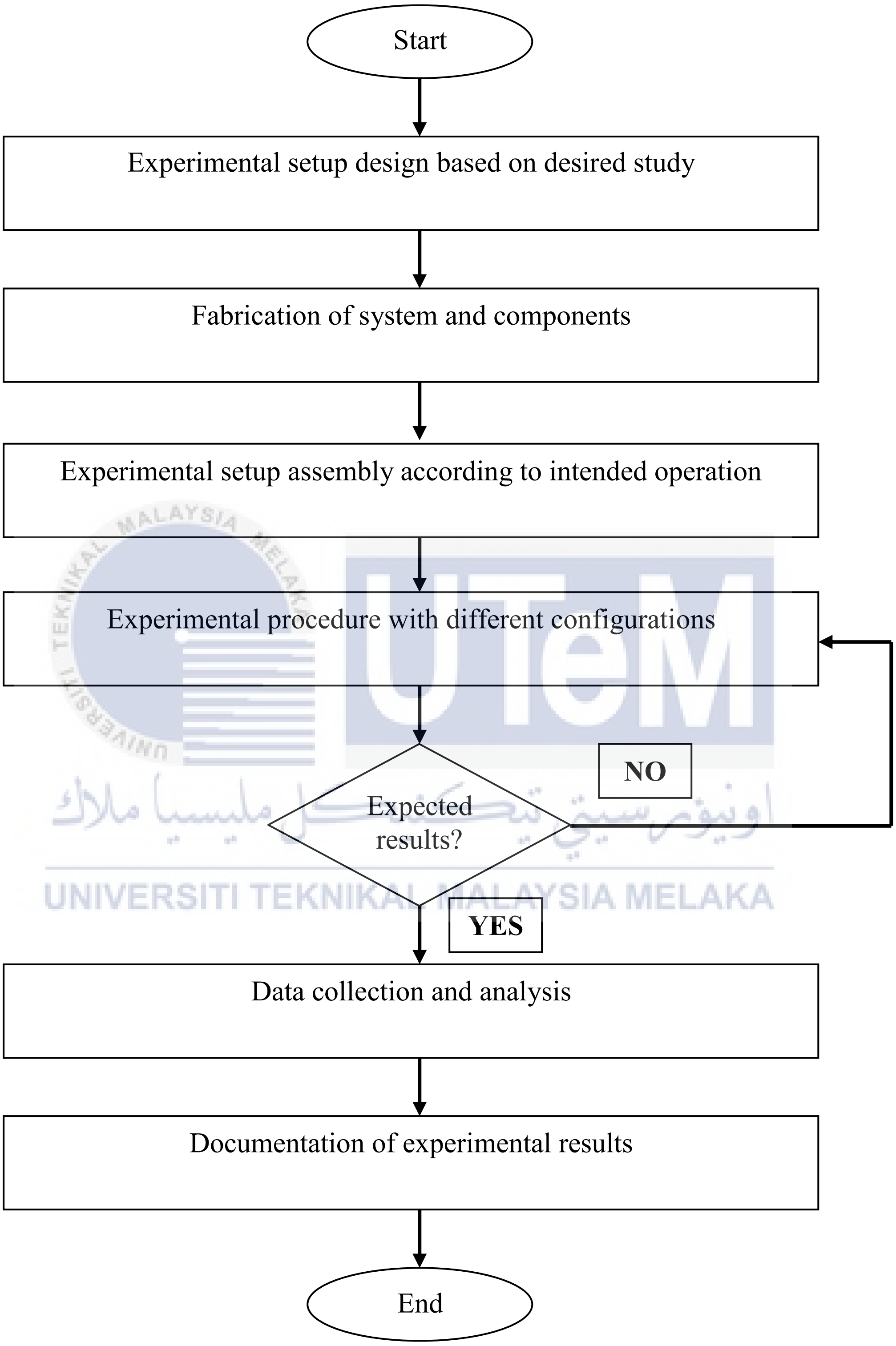

Figure 3.1 Flowchart of overall process involved in this project

3.3 Chronology of Project

The completion of this project depends on every stepping stone that has been crossed throughout the study. Important aspects such as objectives, scope and problem statement was established in order to ensure a systematic flow for this project. Objectives set for this project was to be able to develop a evaporative cooling system based on multi water droplets and to determine the performance of the system in three different configurations. However, before the commencement of the project, it is important to understand key points and detailed description on the research done before which lead to review of literature such as journal and research papers. They provide a general idea and better understanding on the research done before and future study that should be done for improved knowledge on execution and implementation besides additional information. Next, it is important to build the experimental setup in order to conduct the study. Hence, an experimental setup is designed as per the requirement of the study where fabrication of the entire system using necessary parts and components mentioned in Section 3.5 was done. Experimental setup was assembled based on initial design. Then, the droplet generator in the evaporation chamber section used to test different type of configuration was developed. Once the evaporative cooling system is built, the experiment was conducted with the first type of configuration and data collection took place. Next, after completion, the same steps was repeated with a different configuration. Configurations differs in terms of how the water droplets flow or move within the droplet generator based on the arrangement it has been built. Necessary parameters such as initial and final temperature is observed and readings were taken. Based on data collected, analysis is made by comparing it with the expected performance of the system built which is the reduction of inlet air temperature.

3.4 Fabrication Process

Fabrication works of the experimental setup begun with the building of support frame. The support frame holds the parts and components required in the system in place so it is required to be firm and steady. Therefore, the material selected was steel that is square shaped and bevelled corner with dimension of 1 x 1 inch was selected. Dimensions were set by using the fan's dimensions as a reference. The fabrication of the steel frame involved three main processes; cutting, grinding and welding. Initially, the steel was cut as per the required dimension using a measuring tape, scribber, marker and a cut-off machine. Grinding process were done at various stages of the fabrication using hand grinder. First, it was used to prepare the metal before being weld as it came with grey coatings and had rusty parts. Also, after welding in order flatten the surface that has been weld. Besides, The hand grinder was both used to grind and to trim off small chips from the edges of the metal bar. Type of welding used to join the metal pieces is the metal inert gas (MIG) welding.

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Figure 3.2 Completed metal support frame

3.5 Parts and Components

Once the support frame have been fabricated, parts and components that make up the whole system was developed. The following sub-sections highlights every participating components used to built the multi water droplets evaporative cooling system based on figure 3.6. Furthermore, their specific purpose and method of use will be described thoroughly.

3.5.1 Flow Straightener

Stream of air entering the system may contain turbulences due to its swirling motion. Therefore, to maintain a orderly entrance and decrease the swirling waves, a flow straightener was used. Outdoor air will come first in contact with the flow straightener which will induce axial flow in the air before entering the evaporation chamber. Flow straightener used in this system is fabricated using straws which was inserted through the holes of a metal net. This metal net acts as retainer that holds the straws in an orderly manner.

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3.5.2 Water Pump, Water Reservoir and Flow Line

Water supply system in this evaporative cooling system was built based on three main equipment. A water pump to ensure the movement of water from the reservoir to the droplet generator, a water reservoir to hold required volume of water, and a flow line for the water to travel. The water pump requires electricity to function.

3.5.3 Fan

An axial flow fan was used as it propels air in a parallel direction which is necessary to draw the outdoor air into the system.

3.5.4 Thermocouple

Thermocouples are used to measure the temperature difference throughout the experiment which works in conjunction with a data logger. Three temperature reading will be taken during the data collection so three thermocouples are used which are placed in the following location. The first one, right outside the flow straightener to measure temperature of air inlet, one in the test section, and the last one near the fan to measure air outlet's temperature.

3.5.5 Data Logger

Data logger used in these experiment works as a temperature monitor. Produced by Pico Technology based in the United Kingdom, this data logger is known as the TC-08 Thermocouple Data Logger. It will be connected to a personal computer through a USB cable with a data logging software called PicoLog for data analyzing and tabulation purposes. Data was collected at a predefined period time relevant to the experiment to determine changes.

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3.5.6 Support Frame Wall

Support frame, once completed, was enclosed using polystyrene foam. The polystyrene foam will act as wall to prevent interference of ambient air from surroundings during the experiment. Besides, heat loss of outlet air will reduce if air is to be drawn from all direction instead of a stream of air coming in from the flow straightener. An insulated system allows air to flow from a single inlet, cooled in the evaporation chamber and exit the system having its temperature reduced.

3.6 Droplet generator

The droplet generator in the evaporation chamber is where the different configurations was tested as mentioned in the objectives. The droplet generator is a metal tank fabricated using galvanised metal sheet. There are several process involved in the making of the metal tank. First, a 2D drawing of the metal tank is done using Autodesk CAD software. The design of the tank consist of 28 holes. These 2D drawing file is then encoded into a computer that acts a control section of a plasma cutter. The plasma cutter then cuts a much bigger metal sheet according to the dimensions in the 2D drawing.

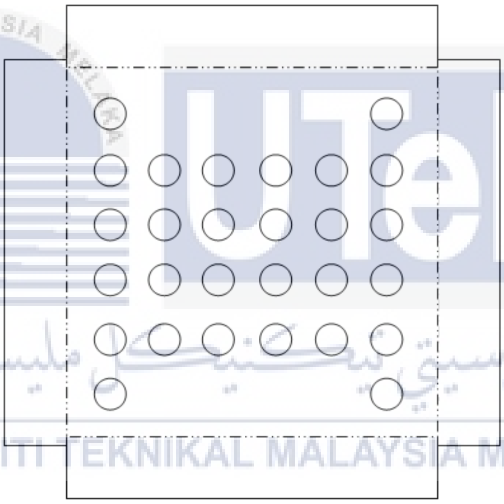

Figure 3.3 2D drawing droplet generator plate used in plasma cutter

Once these processes completed, the droplet generator, when viewed from top view will be as shown in figure 3.3. The circles shown in the drawing represents holes, which is filled by inserting syringes. The top plate was inverted and placed on top of the evaporation chamber with the syringes facing outwards by inserting it from top in this direction.

Figure 3.4 Luer slip type syringes

Syringes that is used in the droplet generator is a 30 ml Luer slip type syringe. The piston of the syringes was removed to make it function as a container. These syringes will later be filled with water using water pump. It was expected that the water exiting from the syringes' tip produce droplets. However, the tip of the syringe is too big for water to flow in droplet manner. Therefore, in order to manipulate the size of the tip, modelling clay was used. Modelling clay was rolled in a circular manner and pressed against the tip blocking the existing hole in the tip. A needle is then slowly inserted, through the clay and tip to form a small hole, which induces water to flow in the form of droplets.

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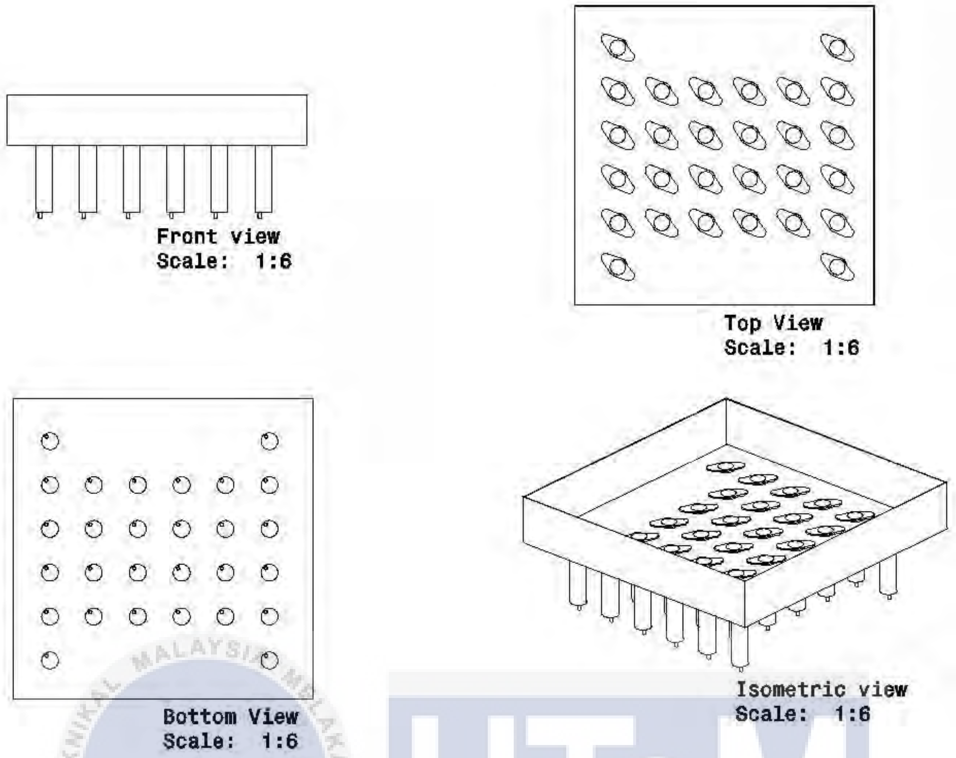


Figure 3.5 Droplet generator metal tank design

Next, the trimmed metal sheet is bent using a bending machine to form a box like shape. The corners are folded and joined using rivets. Before inserting the syringes into the holes, balloons with two open ends were rolled to form a ring. This ring served as washers which prevent water flow through the narrow gap between the holes in the plate and the barrel flange. Thus, every syringe had a balloon ring placed around them before being inserted through the holes. Besides, all four corners of the droplet generator is sealed with acetic silicone to stop water leakage.

3.7 Experimental Setup

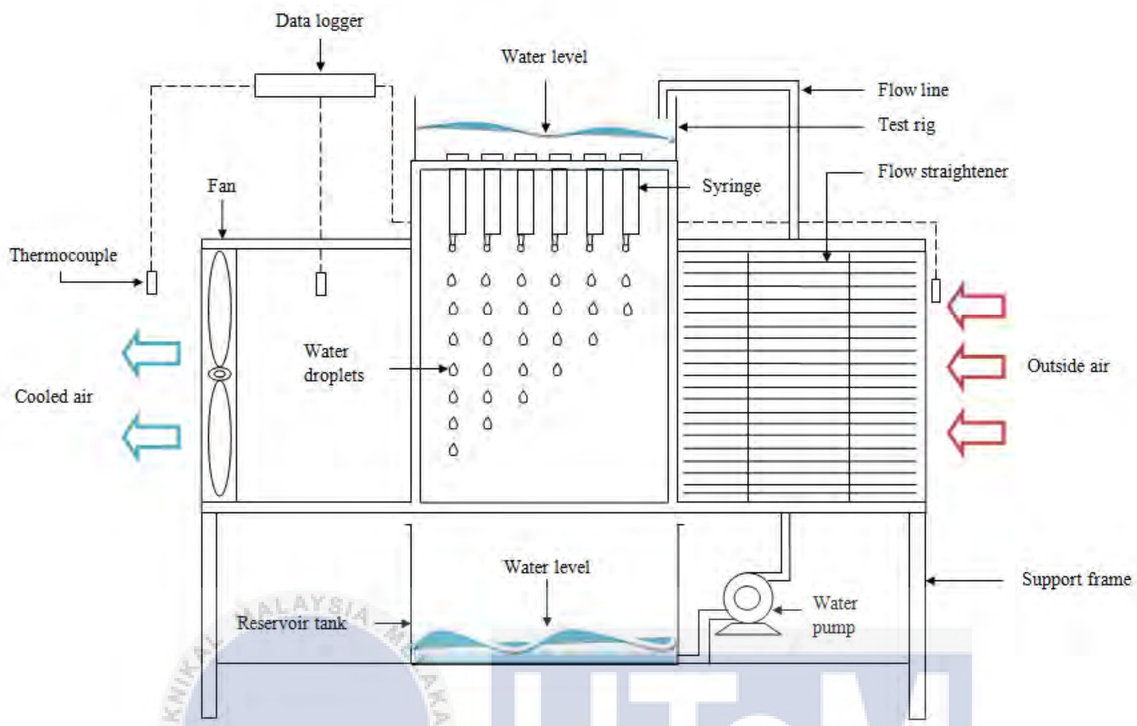
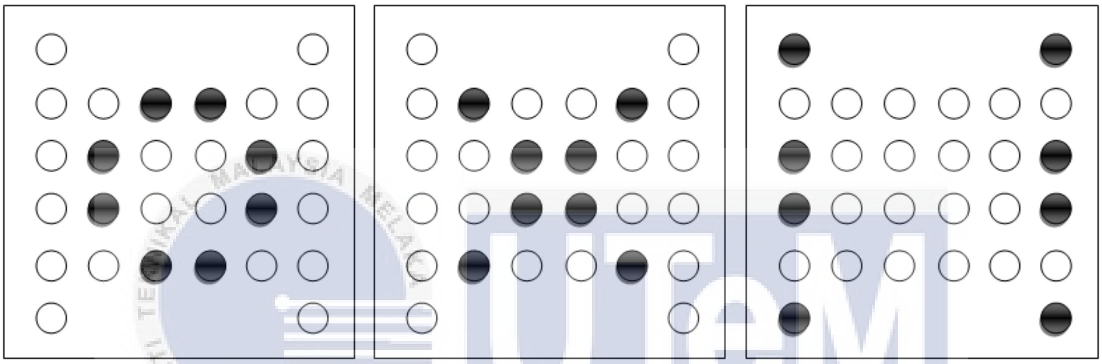


Figure 3.6 Schematic diagram of evaporative cooling system using multi water droplets approach

An experimental setup as shown in figure 3.6 is developed. This setup comprises mainly an evaporation chamber where the droplet generator is used configuration variation. This evaporative cooling system is made of flow straightener, an evaporative chamber, droplet generator, water pump, water reservoir, flow line, support frame, fan, thermocouples, and data logger.

3.8 Experimental Procedure

Water supply system is switched on to ensure smooth flow and formation of droplets. In the evaporation chamber, the droplet generator will be fixed with the first configuration. Next, the fan was switched on, where ambient air is drawn to flow through the air straightener and enter the evaporation chamber before leaving through the fan. The air velocity induced by the fan was kept constant throughout the experiment. The data logger is switched on with all the thermocouples in place. It is then connected to the computer and the PicoLog software was started. Once all the thermocouple are able to record temperature, the data collection process was started. The reading of data is set for a time period of 1 hour for each configuration. Configurations that will be tested in the experiment are as shown in Figure 3.7. The three type of configurations shown below are type A, type B, and type C respectively.



(A) (B) (C)

Figure 3.7 Three type of multi water droplets configurations

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Coloured holes are holes that are closed blocking the water flow. Since these holes contain syringes in order to close these holes, existing piston of the syringes itself is reused. The reason behind this is because the piston is designed in a manner that it creates an airtight seal between it and the barrel of the syringe. Uncoloured holes on the other hand will be open for water flow. Holes designed in the droplet generator can be observed to be higher in numbers at the center. Therefore, variation at the center was put together by creating a circular pattern at in Configuration A. Configuration B is also focused at the center however holes closed for water flow in Configuration A is opened and. Configuration C aims the outer part and corners of the droplet generator in order to optimize all holes at the center of the droplet generator. The number of closed holes in every configuration is eight. This is because a uniform number of twenty open holes was maintained in Configuration A, B and C. Every configuration will be tested for one hour. At every interval of 1 minute, temperature data will be collected and recorded by Picolog software. Each configuration will also be tested with plain water and cold water where in the first set of experiment plain water will be used followed by cold water in the second set. Cold water used is a mixture of ice cubes and natural running water. Once done, the droplet generator configuration was changed and the procedures were repeated. The experiment is complete once all configuration has been tested and relevant data has been collected.

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CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will cover the result and discussion of the experiment on the workability of an evaporative cooling system based on multi water droplets approach configuration. This result in terms of temperature reading shows the performance of evaporative cooling system using multi water droplet approach. All the discussions and results related to this study are explained in the upcoming sections.

4.2 Cooling System Performance

The three thermocouples placed in the experimental setup measures temperature which exhibits the temperature changes throughout the cooling process of ambient air. Therefore, it is important to place them at significant locations for measurement purposes. Performance of this evaporative cooling system will be evaluated based on data recorded in accordance to the position. The overall performance of the system is satisfying as temperature difference of air between ambient and exit position can be observed in the results. Two experiments were carried out on all three configuration with plain water and cold water to observe the difference they are capable of. Running water is used for plain water experiment while for cold water experiment, ice cubes were mixed with plain water. The following tabulations is based on data obtained from PicoLog software. In order to differentiate the performance of each configuration in either one of the experiments, the average value of temperature difference will be compared.

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4.3 Experiment 1

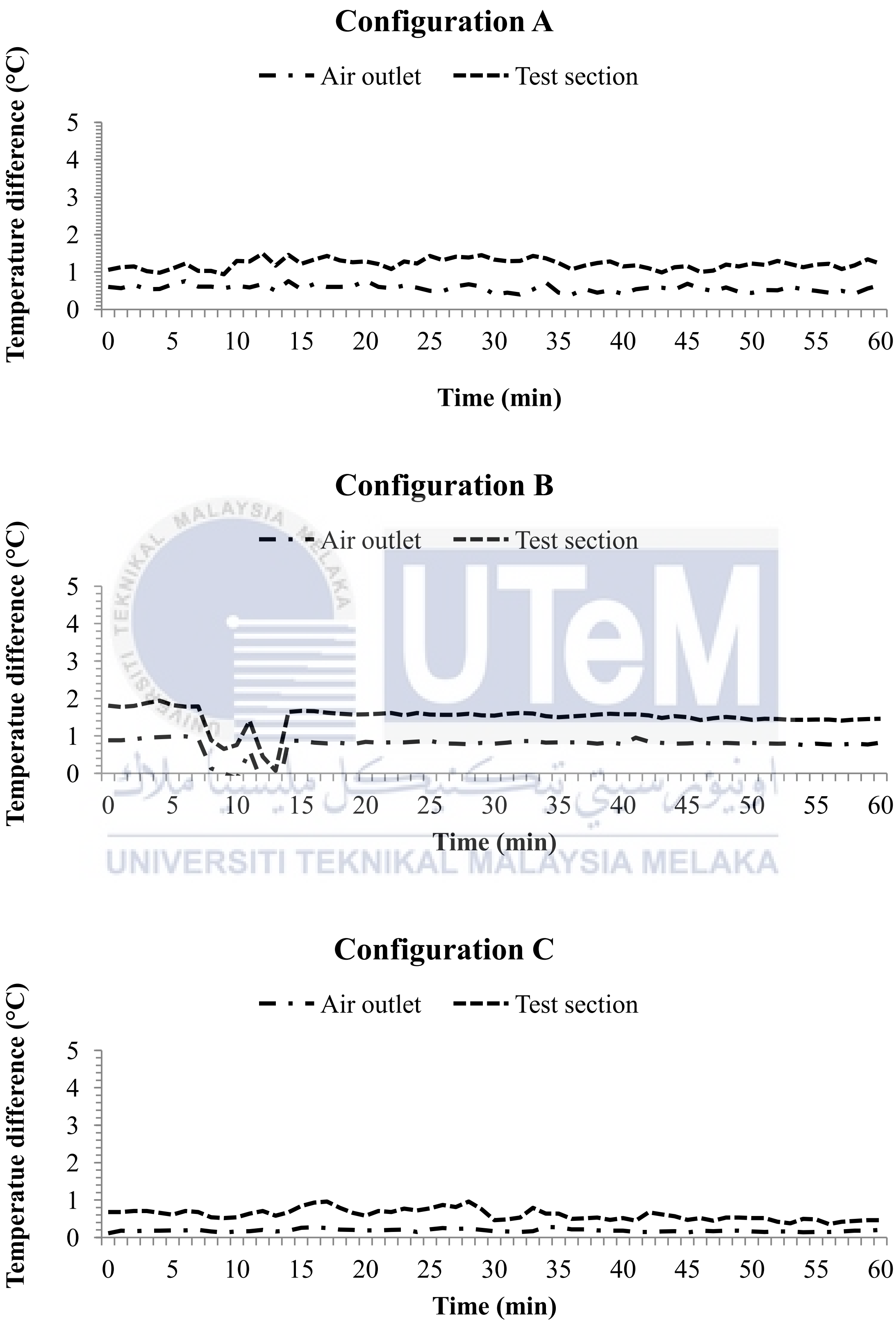

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Figure 4.1 Temperature difference results for natural running water experiment

All three type of configurations were tested with plain water in experiment 1. The figure 4.1 describes the temperature difference of air outlet, and test section with respect to air inlet temperature.

In configuration A, temperature difference between air inlet and air outlet can observed ranging from 0.77°C to 0.39°C. The average value is determined to be 0.56°C. All three trend lines in Configuration A are closely related as they in the same pattern. Configuration B on the other hand has a average of 0.74°C. Based on Figure 4.1, the time period from fifth to the fifteenth minute fluctuations can be observed. This is a result sudden change in ambient wind conditions. It shows that such system may be affected by its surroundings. However, all three temperature difference does shows similar behaviour such as Configuration A after the fifteenth minute. Next, in configuration C the average is recorded at 0.18°C. Since running water or tap water is used for this experiment, variation in terms of temperature. are circumstances that travel along due to their alternating exposure to warm or cold bodies. In experiment 1, air inlet temperature ranges from 30 to 33 signifying the common ambient temperature relevant to current daytime climate. Configuration B showed the most promising result in Experiment 1 leaving behind Configuration A slightly lower in number and Configuration C with the least value.

4.4 Experiment 2

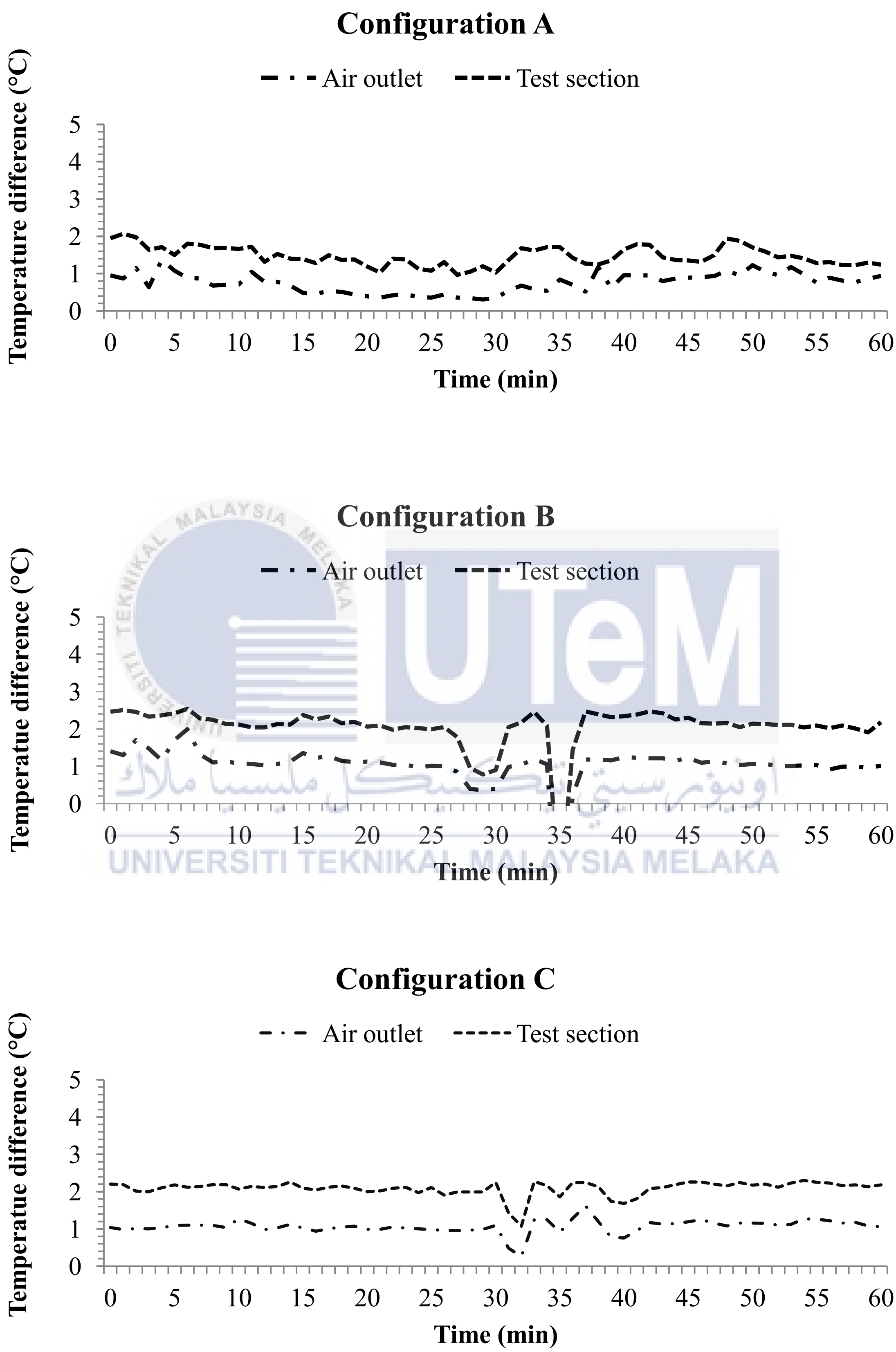

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Figure 4.2: Temperature difference results for cold water experiment

In experiment 2, cold water was used as the medium instead of plain water. All three multi water droplets configuration are tested once again with the same procedures. The result of this experiment are discussed in the upcoming section where the graphs describes the temperature differences of air outlet, test section, when compared to air inlet.

In configuration A, the highest temperature difference recorded is 1.37, while the lowest difference is 0.31, with average being 0.75.Configuration B, recorded a 1.01 average temperature difference. Configuration C, on the other hand produces a 1.06 average value. All three experiment 2 graphs shows significant change at the 30th minute due to the addition of water and ice cubes to the droplet generator. At the initial state of the experiment, the droplet generator was filled with ice cubes until it reaches half of the total height of droplet generator plate. The same amount is maintained during a refill as well. When compared to Experiment 1, in temperature of water inlet in Experiment 2 shows a higher margin of difference due to the presence of ice cubes. Subsequently, the averages produced in Experiment 2 are higher than those in Experiment 1 when compared with their configurations respectively. In this experiment, due to higher temperature difference between air inlet and air outlet, configuration C can be said to be most effective having configuration B closely following behind.

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CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

The thorough research is based on an evaporative cooling system using multi water droplets being developed. The first objective of the report which is to develop a evaporative cooling system using multi water droplets approach has been achieved as the entire structure have been fabricated and experimented. Furthermore, the second objective of the study which is to test multiple configurations of multi water droplets on the droplet generator was completed by testing three configurations. Such configurations were tested in two different experiments using plain water or also known as running water and cold water. Comparison of results is based on the average temperature difference between air inlet and air outlet. Experiment 1 resulted in Configuration B producing the best result which is 0.74ºC. Meanwhile in Experiment 2, Configuration B did negligibly small at 1.01°C behind Configuration C 1.06ºC. Taking knowledge from previous experiment, Experiment 1, water used to mix with ice cubes in Experiment 2, namely during the test of Configuration B and Configuration C is at different temperatures. Thus, exist such contrast in their average temperature difference between air inlet and air outlet values. Configuration B is observed to be exposing most open holes (more droplets) in the direction of the fan giving it a better chance to cool the ambient air or inlet air.

Evaporative cooling serves as the best alternative against conventional cooling system such as vapour compression air conditioning system since it is proven to be less power consuming and has a low cost of production and operation. Therefore, it was expected the system to be able to create a significant temperature difference which lead to the study of multi water droplets approach. Exploring such approach may lead to further improvement of evaporative cooling efficiency and serve towards green technology implementation. Wide scope on clean and renewable energy based human comfort related technologies must be further explored in order to reduce the harm caused towards the environment. Even though evaporative cooling system is believed to be existing since centuries ago, it is has room for improvement. Today's advancement in technology should be brought together and implemented in this system to further its abilities and effectiveness.

5.2 Recommendations

Completion of this study resulted in various potential areas for development. First, the number of water droplets. Current study utilizes 30 ml syringes for droplet generation purposes. The similar droplet generator should be altered by inserting more syringes for more water droplets to dispense. Syringes with smaller diameter can be used as well as possibilities are there for more evaporation to occur and the further cooling of ambient air to take place. Tip of the syringe can modified by attaching a custom made nozzle that produce water droplets which can be controlled. The manipulation of droplets flow can be explored for optimization of the droplet generator.

Moreover, improvisation can be made in the existing system design by considering material used. Insulation is important for a cooling system. The effect of polystyrene foam on the system can be studied. Better insulation can be installed by choosing a suitable material to fabricate the support frame wall. Entire weight of the system can be reduced replacing the steel frame used in the current study for light weight applications.

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Experimental setup developed for this study is built based on the fan dimension. Alteration can be made by choosing a different fan with smaller dimension. Size of the entire system can be reconsidered by shrinking spaces that are negligible for future study. This improvement may possible give room for the cooling system to be portable and have better aesthetic quality also commercialization prospects.

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APPENDICES

APPENDIX A: Configuration A Experiment 1 Result

Time (min)	Temperature (°C)		
	Air inlet	Air outlet	Test section
0	33.20	32.60	32.14
1	33.25	32.68	32.12
2	33.26	32.60	32.11
3	33.14	32.60	32.12
4	33.13	32.58	32.00
5	33.22	32.55	32.00
6	33.36	32.60	32.00
7	33.18	32.57	32.00
8	33.15	32.54	32.00
9	33.08	32.51	32.14
10	33.43	32.80	32.13
11	33.45	32.86	32.17
12	33.37	32.69	31.88
13	33.28	32.78	32.11
14	33.27	32.51	31.81
15	33.06	32.52	31.84
16	33.09	32.41	31.76
17	33.16	32.56	31.73
18	33.21	32.61	31.90
19	33.26	32.64	32.00
20	33.04	32.27	31.76
21	33.20	32.60	31.99
22	33.30	32.73	32.22
23	33.15	32.51	31.87
24	33.02	32.44	31.79
25	33.40	32.90	31.97
26	33.55	33.06	32.23
27	33.58	32.96	32.17
28	33.27	32.60	31.88
29	33.26	32.65	31.81
30	33.35	32.95	32.02
31	33.39	32.94	32.10
32	33.44	33.04	32.14
33	33.49	32.96	32.06
34	33.17	32.45	31.80
35	33.20	32.75	31.96
36	33.35	32.96	32.28
37	33.37	32.82	32.20
38	33.47	33.02	32.23
39	33.40	32.89	32.12
40	33.26	32.85	32.11
41	33.12	32.58	31.94
42	32.82	32.24	31.72
43	32.87	32.29	31.88
44	33.15	32.62	32.02
45	33.12	32.43	31.96
46	33.11	32.55	32.11
47	33.06	32.57	32.02
48	33.06	32.47	31.86
49	33.19	32.72	32.04
50	33.41	32.97	32.18
51	33.33	32.81	32.14
52	33.29	32.78	31.99
53	33.30	32.70	32.09
54	33.16	32.62	32.03
55	33.25	32.75	32.05
56	33.20	32.75	31.98
57	33.29	32.79	32.21
58	33.40	32.98	32.22
59	33.37	32.81	32.03
60	33.15	32.50	31.93

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APPENDIX B: Configuration B Experiment 1 Result

Time (min)	Temperature (°C)		
	Air inlet	Air outlet	Test section
0	29.91	29.03	28.10
1	29.97	29.09	28.20
2	29.97	29.06	28.17
3	29.92	28.97	28.04
4	30.14	29.17	28.20
5	29.69	28.71	27.87
6	29.57	28.58	27.79
7	29.83	28.90	28.04
8	28.84	28.71	27.95
9	27.72	27.72	27.07
10	28.90	29.04	28.14
11	29.55	28.94	28.15
12	28.51	28.81	28.06
13	28.23	28.97	28.16
14	29.58	28.71	27.94
15	29.57	28.70	27.90
16	29.62	28.80	27.96
17	29.59	28.79	27.97
18	29.50	28.69	27.91
19	29.44	28.66	27.87
20	29.51	28.67	27.93
21	29.56	28.74	27.97
22	29.61	28.78	28.00
23	29.57	28.74	28.02
24	29.59	28.74	27.98
25	29.52	28.65	27.95
26	29.47	28.67	27.91
27	29.48	28.69	27.92
28	29.50	28.72	27.91
29	29.45	28.64	27.90
30	29.44	28.65	27.90
31	29.47	28.65	27.88
32	29.47	28.61	27.86
33	29.49	28.63	27.89
34	29.42	28.60	27.89
35	29.40	28.57	27.90
36	29.40	28.57	27.88
37	29.42	28.59	27.88
38	29.48	28.69	27.91
39	29.54	28.71	27.95
40	29.54	28.76	27.96
41	29.51	28.56	27.93
42	29.37	28.52	27.82
43	29.31	28.50	27.83
44	29.27	28.48	27.74
45	29.23	28.43	27.73
46	29.22	28.40	27.80
47	29.20	28.41	27.73
48	29.25	28.44	27.74
49	29.25	28.45	27.77
50	29.27	28.46	27.84
51	29.28	28.48	27.82
52	29.23	28.44	27.78
53	29.23	28.43	27.80
54	29.24	28.48	27.81
55	29.21	28.42	27.77
56	29.17	28.40	27.73
57	29.16	28.39	27.75
58	29.22	28.43	27.78
59	29.27	28.50	27.82
60	29.26	28.44	27.80

APPENDIX C: Configuration C Experiment 1 Result

Time (min)	Temperature (°C)		
	Air inlet	Air outlet	Test section
0	30.11	30.00	29.43
1	30.12	29.94	29.44
2	30.12	29.95	29.41
3	30.12	29.94	29.41
4	30.14	29.96	29.48
5	30.19	30.00	29.58
6	30.18	29.99	29.47
7	30.13	29.93	29.45
8	29.89	29.73	29.35
9	29.77	29.64	29.25
10	29.70	29.54	29.16
11	29.71	29.54	29.07
12	29.80	29.60	29.09
13	29.78	29.62	29.20
14	29.88	29.70	29.21
15	30.04	29.78	29.20
16	30.07	29.80	29.14
17	29.91	29.66	28.95
18	29.72	29.51	28.93
19	29.72	29.52	29.06
20	29.79	29.60	29.21
21	29.84	29.65	29.13
22	29.83	29.63	29.15
23	29.75	29.54	28.98
24	29.70	29.55	28.98
25	29.79	29.57	29.01
26	29.83	29.58	28.96
27	29.82	29.59	29.01
28	29.86	29.62	28.90
29	29.85	29.65	29.09
30	29.88	29.71	29.42
31	29.88	29.72	29.40
32	29.86	29.71	29.33
33	29.96	29.79	29.17
34	30.00	29.72	29.36
35	29.97	29.70	29.33
36	29.90	29.68	29.40
37	29.87	29.65	29.36
38	29.81	29.62	29.28
39	29.83	29.65	29.36
40	29.85	29.67	29.33
41	29.87	29.72	29.42
42	29.94	29.79	29.27
43	29.98	29.82	29.36
44	29.98	29.81	29.41
45	29.93	29.80	29.46
46	29.96	29.78	29.44
47	29.91	29.74	29.46
48	29.90	29.72	29.37
49	29.84	29.66	29.31
50	29.89	29.73	29.37
51	29.89	29.74	29.37
52	29.89	29.73	29.47
53	29.82	29.66	29.44
54	29.81	29.67	29.31
55	29.81	29.66	29.33
56	29.80	29.65	29.44
57	29.81	29.65	29.39
58	29.76	29.58	29.32
59	29.75	29.57	29.29
60	29.71	29.51	29.25

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APPENDIX D: Configuration A Experiment 2 Result

Time (min)	Temperature (°C)		
	Air inlet	Air outlet	Test section
0	31.93	30.98	29.98
1	31.97	31.10	29.90
2	31.91	30.76	29.93
3	31.89	31.25	30.25
4	31.94	30.57	30.23
5	31.94	30.86	30.44
6	31.99	31.11	30.19
7	32.04	31.17	30.27
8	32.12	31.44	30.44
9	32.11	31.41	30.42
10	32.10	31.39	30.44
11	32.05	31.00	30.33
12	32.06	31.28	30.74
13	32.17	31.39	30.64
14	32.03	31.35	30.63
15	32.08	31.60	30.69
16	32.13	31.67	30.85
17	32.08	31.55	30.59
18	32.10	31.59	30.73
19	32.11	31.67	30.73
20	32.13	31.74	30.94
21	32.10	31.74	31.07
22	32.05	31.63	30.65
23	32.04	31.60	30.66
24	32.09	31.71	30.96
25	31.99	31.63	30.91
26	31.83	31.39	30.52
27	31.68	31.32	30.71
28	31.68	31.34	30.63
29	31.70	31.39	30.50
30	31.78	31.44	30.75
31	31.97	31.42	30.61
32	32.02	31.34	30.34
33	31.93	31.35	30.31
34	31.87	31.33	30.16
35	31.73	30.89	30.02
36	31.56	30.86	30.14
37	31.55	31.03	30.28
38	31.81	30.63	30.56
39	31.78	31.16	30.43
40	31.79	30.83	30.14
41	31.84	30.89	30.05
42	31.82	30.87	30.05
43	31.75	30.95	30.31
44	31.75	30.88	30.38
45	31.81	30.92	30.46
46	31.83	30.92	30.51
47	31.82	30.89	30.33
48	32.06	30.98	30.12
49	31.94	30.99	30.06
50	31.90	30.67	30.20
51	31.87	30.82	30.28
52	31.90	30.94	30.46
53	31.89	30.71	30.41
54	31.81	30.83	30.40
55	31.78	31.02	30.50
56	31.85	30.96	30.54
57	31.77	30.96	30.54
58	31.77	31.00	30.54
59	31.76	30.90	30.46
60	31.66	30.72	30.42

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APPENDIX E: Configuration B Experiment 2 Result

Time (min)	Temperature (°C)		
	Air inlet	Air outlet	Test section
0	26.85	25.45	24.39
1	26.88	25.58	24.38
2	26.93	25.23	24.48
3	26.37	24.90	24.04
4	26.19	25.03	23.83
5	26.26	24.56	23.84
6	26.45	24.46	23.91
7	26.41	25.10	24.13
8	26.41	25.31	24.17
9	26.99	25.87	24.86
10	27.34	26.26	25.22
11	27.63	26.57	25.59
12	27.86	26.84	25.82
13	27.94	26.88	25.81
14	27.96	26.84	25.84
15	27.86	26.51	25.49
16	26.97	25.75	24.71
17	27.20	25.93	24.87
18	27.32	26.18	25.17
19	27.35	26.24	25.16
20	27.27	26.15	25.21
21	27.47	26.37	25.38
22	28.30	27.26	26.32
23	27.99	26.95	25.94
24	27.95	26.98	25.93
25	27.90	26.89	25.91
26	27.93	26.93	25.88
27	29.06	28.21	27.28
28	31.72	31.33	30.77
29	31.74	31.38	30.96
30	31.46	31.07	30.56
31	26.14	25.16	24.09
32	26.51	25.47	24.34
33	26.53	25.34	24.08
34	26.48	25.43	24.40
35	22.79	26.84	25.17
36	27.12	26.91	25.69
37	27.52	26.34	25.05
38	27.37	26.19	24.98
39	27.25	26.09	24.94
40	27.29	26.05	24.95
41	27.27	26.04	24.89
42	27.29	26.08	24.82
43	27.42	26.21	25.00
44	27.46	26.31	25.21
45	27.37	26.15	25.07
46	27.44	26.35	25.29
47	27.67	26.55	25.53
48	27.79	26.71	25.63
49	27.86	26.83	25.81
50	28.01	26.95	25.87
51	28.13	27.07	26.00
52	28.20	27.19	26.10
53	28.31	27.31	26.20
54	28.66	27.64	26.62
55	28.68	27.65	26.59
56	28.65	27.74	26.63
57	28.65	27.66	26.56
58	28.79	27.80	26.78
59	28.89	27.93	26.98
60	28.87	27.86	26.69

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APPENDIX F: Configuration C Experiment 2 Result

Time (min)	Temperature (°C)		
	Air inlet	Air outlet	Test section
0	26.53	25.49	24.33
1	26.44	25.46	24.25
2	26.34	25.33	24.33
3	26.70	25.70	24.70
4	26.82	25.79	24.72
5	26.94	25.85	24.76
6	26.91	25.81	24.79
7	26.79	25.69	24.65
8	26.79	25.70	24.60
9	26.71	25.67	24.52
10	26.79	25.52	24.72
11	27.20	26.05	25.06
12	26.92	25.94	24.81
13	26.72	25.69	24.58
14	26.62	25.50	24.36
15	26.56	25.54	24.47
16	26.50	25.56	24.45
17	26.33	25.33	24.21
18	26.18	25.13	24.03
19	26.20	25.13	24.11
20	26.30	25.31	24.30
21	26.29	25.30	24.27
22	26.27	25.22	24.18
23	26.33	25.31	24.21
24	26.33	25.33	24.36
25	26.73	25.75	24.62
26	27.29	26.33	25.38
27	27.68	26.73	25.69
28	27.95	26.98	25.96
29	27.97	26.98	25.98
30	27.08	25.99	24.83
31	25.31	24.83	23.88
32	26.20	25.94	25.13
33	27.33	26.09	25.06
34	27.13	25.88	24.97
35	26.96	26.05	25.10
36	27.22	25.94	24.98
37	27.26	25.64	25.02
38	26.88	25.68	24.75
39	26.56	25.78	24.82
40	26.43	25.67	24.75
41	26.33	25.38	24.52
42	26.44	25.27	24.36
43	26.58	25.45	24.47
44	26.63	25.49	24.44
45	26.73	25.54	24.47
46	26.67	25.42	24.41
47	26.25	25.09	24.05
48	26.20	25.12	24.05
49	26.26	25.10	24.02
50	26.37	25.21	24.20
51	26.30	25.15	24.10
52	26.30	25.20	24.18
53	26.29	25.17	24.06
54	26.54	25.27	24.24
55	27.13	25.87	24.88
56	27.34	26.12	25.11
57	27.42	26.26	25.26
58	27.59	26.41	25.41
59	27.68	26.60	25.55
60	27.91	26.85	25.73

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APPENDIX G: Complete Experimental Setup

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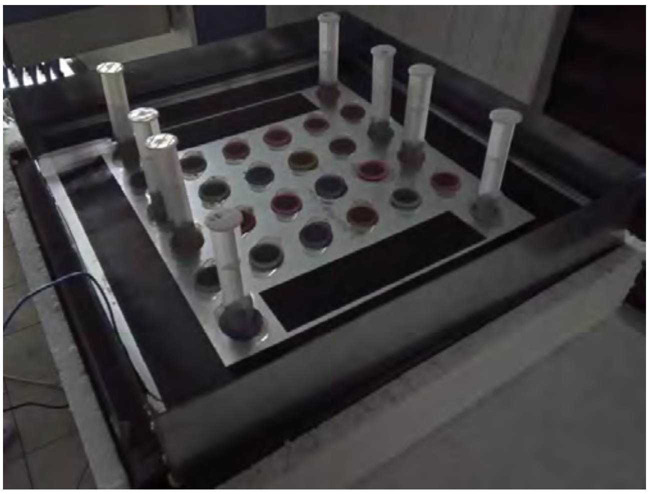
APPENDIX H: Configurations of Droplet Generator



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