Numerical Study on Cross Flow Maisotsenko Cycle Indirect Evaporative Cooling (MCIEC) Heat Exchanger

by

Yee Guo Shen

22737

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Mechanical Engineering
With Honours

FYP 2
JANUARY 2020

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CERTIFICATION OF APPROVAL

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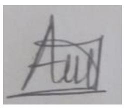

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(Dr. Aklilu Tesfamichael Baheta)

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

JANUARY 2020

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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YEE GUO SHEN

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Abstract

The Maisotsenko Cycle (M-Cycle) is a new heat exchanger model which captures energy from the ambient air by utilizing the psychrometric renewable heat transfer energy which can be obtained from the latent heat of water evaporating into the air. The cycle is well-known in the air-conditioning (AC) field due to its potential of dew-point evaporative cooling. However, its applicability has been recently expanded in several energy recovery applications. This paper provides the overview of M-Cycle and the general background of evaporative cooling system. The evaporative cooling is differentiated into direct evaporative and indirect evaporative cooling. M-cycle cooling is an indirect evaporative cooling that modified from the traditional IEC. The inventor of M-cycle is Valeriy Maisotsenko which is the founder for Coolerando company. Several research studies on M-cycle had been compared and analysed in this paper. There are several experimental studies and numerical studies on IEC did by previous researchers. These studies are mostly traditional IEC or M-cycle counter flow. The numerical analysis on cross flow M-cycle is still an unknown. Numerical study on cross flow M-cycle is proposed for the FYP 2. ANSYS FLUENT is the main tool for the numerical simulation study. A new cross flow heat exchanger model will be designed according to the author’s design dimension specification. The outcome of the FYP is to identify the optimum inlet air velocity for greatest cooling performance.

1.0 INTRODUCTION

1.1 Background of Evaporative Cooler

According to MECS, the overall energy consumption for all manufacturing industry is 10%. The energy consumption is directly affects the operating and production cost of the manufacturing industry. The efficiency of HVAC facility plays a huge role in minimizing the production cost. Therefore, IEC (Indirect Evaporative Cooling) has becoming the main trend for HVAC industry to produce low energy consumption air conditioning system. Indirect evaporative cooling, utilizing the principle of water evaporation for heat absorbing, has gained growing prestige for use in HVAC [1], due to its austerity in constitution and good use of natural water latent heat energy present in ambient. This led to improved system COP with the range from 15 to 20, which is greatly higher than the conventional vapour compression and common air conditioning systems. Evaporative cooling has been proven to save more energy than the conventional vapour compression refrigeration. It has great energy saving potential, and it is also an eco-friendly solution for air cooling systems which is able to reduce carbon emission [2].

A new kind of mass and heat exchanger utilize the benefit of the Maisotsenko cycle (M-Cycle) has captured huge attention from the HVAC field in recent years for its excellent cooling efficiency and the ability to save a lot energy [3]. The Maisotsenko cycle (M-cycle) is a proven thermodynamic process which captures energy from the air and utilizing the psychometric renewable heat transfer energy from water latent heat, the overall heat transfer process is spontaneous which required less energy and it is able to produce great cooling load. In cooling process, the M-cycle uniquely integrate thermodynamic processes of heat transfer and evaporative cooling, in order to produce air that nearly equal to the ambient dew point temperature. In addition, the heat energy captured from the latent heat of evaporation may be used in generation of electricity, advance engine technology, and distillation of water with definitely zero carbon dioxide emissions. Most popular application of the Maisotsenko cycle is the indirect evaporative cooling. It is proven that M-Cycle can reduce the energy consumption up to 90% in comparison to traditional solutions [4]. Although M-cycle is mostly used in indirect evaporative cooling but the principles of M-cycle is very beneficial in any application which requires energy. Besides the evaporative cooling systems, M-Cycle can also be used for effective water desalination, increasing the effectiveness of gas turbines and photovoltaic panels.

1.2 Problem Statement

The IEC, compared to the conventional refrigeration air conditioning system, is still relatively fresh technology and is less known to public including some of experts. New indirect evaporative cooling heat exchanger model, M-cycle (Maisotsenko Cycle) is develop by Valeriy Maisotsenko in 2004, M-cycle were no full area of study are undergoing and no clear information and research data about the M-cycle cross flow system. In the aspect of water flow method, allocation and status, the available studies are distant from excellent. Impact of the flowing water velocity along the wet channel for the cross flow heat exchanging plate on the temperature drop efficiency of the M-cycle cross flow heat exchanger was not yet studied. Furthermore, the water flow pattern along the wet channel of the heat exchanger plate was also not undergoes detailed measure [5]. Path of water channel and spray and its potential of producing good flow of water along the surface of the heat exchanger plate are also the major topics to be highlighted. Furthermore, way of handling water to maintain its cleanliness and avoid precipitation of the wet surface of the heat exchanger plate is considered as a complex issue, which is required of advanced investigation.

Due to the short history of the technology and the low market demand, the M-cycle evaporative cooling products is still relatively inconsistent compared to the current air conditioning refrigeration cycle systems. The common application for M-cycle IEC is restricted to the most favourite climatic regions. The M-cycle IEC is usually joined operation with other air conditioning devices like air conditioning refrigeration cycle systems [6]. M-cycle cross flow heat exchanger were not undergoes fully investigation and no clear knowledge and understanding in term of the numerical analysis study. Currently, there is no real numerical analysis that is able to visualise the internal operation of M-cycle cross flow heat exchanger.

1.3 Objective

- To design a 3D model of cross flow heat exchanger for M-cycle Indirect Evaporative Cooling (MCIEC)
- To conduct numerical study on the crossflow heat exchanger of M-Cycle Indirect Evaporative Cooling (MCIEC) using CFD simulation approach
- To identify the air temperature drop across primary channel respect to different inlet air velocity

1.4 Scope of Study

The general purpose of the study on the evaporative cooler is to identify the characteristic of the new indirect evaporative cooling system technology, M-cycle. Several journal and article had been studied to improve the current information about the M-cycle configuration. The factors like humidify, temperature, air flow rate and thickness of air passage that affect the effectiveness of M-cycle is identified for the further simulation process. Different type of evaporative cooler technology such as direct evaporative cooling, indirect evaporative cooling, power and unpowered evaporative cooling are studied to compare the application and to understand the working principle of the current advance evaporative cooling technology. The operational skill of the software ANSYS FLUENT is practice well to improve the accuracy of the simulation analysis.

2.1 Introduction of Literature Review on Evaporative cooler

Evaporative cooling is a natural cooling process where the evaporation of water reduced the temperature of an object. It occurs when sensible heat is converts into latent heat which decreases the temperature of the ambient due to the cooling effect by water evaporation [7]. The evaporative cooling application has been implemented for different sector from small volume cooling to heavy HVAC application. Evaporative cooling is able to provide great cooling towards the environment without using any external energy source which is the uniqueness of evaporative cooling that different from conventional air conditioning refrigeration cycle technologies that always required a compressor. The cooling effectiveness of evaporative cooler increases by increase the wetness of a surface and allowing the water to evaporate to the ambient. It is similar to the body of humans, during sweating the body is cooled and cooling effect can be felt notably when the sweat on the skin is evaporated during physical exertion. This is a form of direct evaporative cooling which is the foundation for more advance evaporative cooling systems like indirect evaporative cooling.

Evaporative cooling only occurs when the air that passes over the wet surface is not overly humid. It provides greater cooling when the rate of evaporation is fast. Therefore, the efficiency or the cooling performance of an evaporative cooler relies on the ambient air humidity. When the ambient air is dry, the air tends to absorb more moisture, this produce greater cooling effect. In some of the extreme condition, when the air is saturated with water, the water inside the air is difficult to evaporate thus cooling process would not happen. Commonly, the structure of evaporative cooling is made from porous object that is constantly supplied with water. When high temperature and low humidity air passes through the porous object, the water evaporates into the hot air and increases its humidity while the dry bulb temperature of the air is drop [8].The evaporative cooling take advantages on the difference between the dry bulb temperature and wet bulb temperatures of the ambient air and evaporation rate of water to undergo the heat removal process for the ambient air. By using evaporative cooling, it cut down the usage of high power consumption electrical part like compressor and the chemical refrigerants like R410, R32. With the result to significantly reduce the total energy, at the same time reduce carbon emission, improved cooling performance. The evaporative cooling system has begun to gain growing popularity in the sector of HVAC.

2.2 Types of evaporative coolers

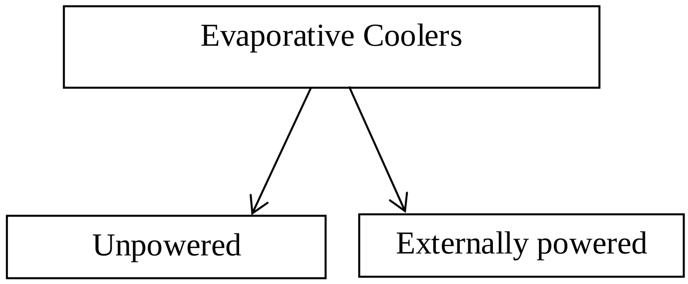


Figure 2.1: Type of evaporative coolers

The evaporative cooler designs differ according to the absorbent medium, storage chamber structure and evaporation method. Most evaporative coolers designs retain in either unpowered or in the form of externally powered. The evaporative coolers that do not require external power source are made to create the spontaneous airflow for sufficient cooling purpose through convection process. Different configurations among the unpowered and powered coolers allow the heat transfer in briefly different method. The method is either direct evaporative cooling or indirect evaporative cooling. Most evaporative coolers depend on altering the sensible heat from air into latent heat of water, the working principle for this alteration can be dissimilar. Several evaporative cooler designs are developed from porous object to let water to infiltrate from an inner container to an outside surface which evaporation takes place. For these designs, heat is removed from inner cooling chamber during evaporation of water. During evaporation, high temperature water molecules evaporate and leaved the outer surface, thus the surface temperature drop and appearance of heat gradient allow heat to transfer from the inner chamber out to the surface [9]. At the end of the process, the temperature of the inner volume drops and causing a cool space which can provide cooling effect for any object that is inserted in the cooler. There is another type of evaporative cooler process depends on speed of air over a moist pad to produce cooling. For this design, absorbent pads act as part of the boundary between cooling chamber and air. The cooling takes place either through spontaneous airflow or forced air flow from an electrical blower travels over the moist pad. The temperature of the air is drop when the water is evaporated from the moist pad into the air. Cooling effect is produce when this cool air travels over to the cooling chamber.

2.2.1. Unpowered

Pot-in pot cooler is one of the most outstanding evaporative coolers because of its austerity and performance. Mohammed Bah Abba is the first person that design the pot-in-pot evaporative cooler who is a Rolex Award receiver of this contribution. The pot-in-pot evaporative cooler consists of one large and one small concentric clay pot. The smaller pot is located inside the larger pot with compact sand medium in between. The function of sand is to provide a moist medium that contains the water as heat absorbent for evaporative cooling purpose [10]. One moist fabric lay on the upper part of the pots for better cooling effectiveness. The other name for pot-in-pot evaporative cooler is Zeer pot because of the repuatation of the pots usage at several Africa region. The Zeer pot undergoes examination for food conservation by the organization called Practical Action, it is proven to increase food storage life notably which up to five times longer for some vegetable [11]. The Zeer pot has a proximate storage volume of 12kg of vegetable. The effectiveness of the Zeer pot is restricted by the overall size of pots currently used, larger volume yield better cooling effectiveness.

There are several other unpowered cooler designs exist besides the most popular pot-in-pot design. The Janata cooler is another unpowered cooler developed by the Nutrition and Food Board of India is similar to the Zeer pot which also using pots made by ceramic. The Janata utilize one storage pot inserted in a huge water bowl which fully filled with water and it is cover with a cloth [12]. The cloth is contacted with the water bowl to absorb water for wetness which is essential to produce significant evaporative cooling.

The third example of unpowered cooler is Almirah cooler which is made from a wooden box with cloth covering the box to provide a enclose storage chamber. Cloth is immersed into a plate of water to soak up water and provide a low surface temperature for better rate of evaporation [13]. The unpowered rigid evaporative coolers give a bigger room for higher volume storage chamber. Unpowered rigid evaporative coolers are commonly constructed with a bilayer bricks material chamber. The space among the layers differs by other designs utilize an interval from 3 to 5 inches. The interval is packed fully with sand like the Zeer pot. The moisture of sand can be controlled by physically water addition it or with the usage of a drip hose binding with water tank. The foods are usually kept inside the cooling chamber and the foods are placed into different tray [14].

2.2.3. Externally Powered

Externally powered evaporative cooling system is constructed with the support from an electrical blower to increase air flow rate and a water pumping device to supply non-stop moisture into the wet channel. Externally powered system are designed dissimilarly than unpowered coolers, externally powered system using a cooling cushion as an moist medium and do not depend on water flow rate along a porous material that is undergo evaporation. Electrical fan pushes air over the moist absorbent cushion where water evaporation takes place and thus the air is cooled. The cooled air then moves through the cooling chamber to reduce the temperature of desired area. In these systems, the absorbent pad plays a important role throughout the cooling process. Several factors can affect performance of pad are the pad material, pad thickness, and size of perforations [15]. Most commercial pads are often made of acetate, plastic, or fiberglass which can be expensive and are not made from locally accessible materials by most manufacturer [16].

2.3 Factors Affecting Rate of Evaporation

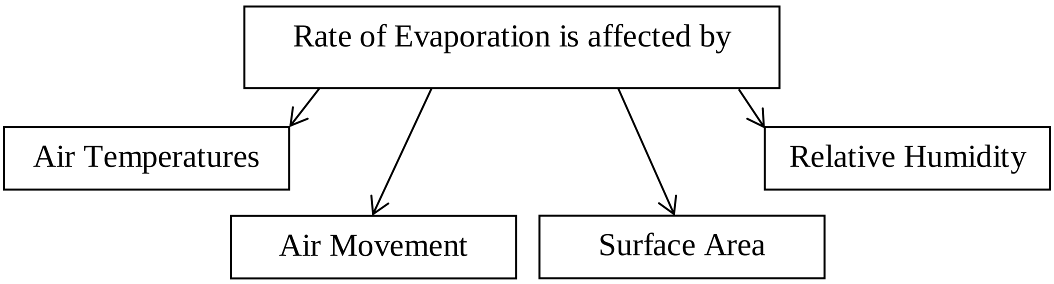


Figure 2.2: Factor of evaporation rate

According to study conducted by D. Pandelidis [17], there are 4 main factors could impact the water evaporation rate. These major factors all correlate with each other to impact the water evaporation rate for the overall cooling system, and the cooling capacity. The factors discussed by [17] consist:

(1) Air Temperatures: Water evaporation takes place when water molecule is draws adequate heat energy to transform state from liquid to vapour form. High temperature hot air is able to boost the water evaporation rate and the air able to hold large amount of water molecule in vapour state. Thus, object surface with higher temperatures yield higher water evaporation

rate and causes bigger temperature drop. If air temperature is low, less water molecule can be kept by the air and less water evaporation rate yield lower cooling load.

(2) Air Movement (Velocity): The movement of air can be natural (wind) or artificial (fan), the air flow rate is an major factor could changes the water evaporation rate. When water molecule evaporates from moist medium, it causes humidity of air that is nearest to the moist medium to increase. The water evaporation rate will drop if the humid air keeps in environment. Because as the humidity increases the evaporation rate decrease. Besides that, if the humid air near the water medium is constantly being forced away and substituted with dry air, the water evaporation rate has the potential to rise or maintain the same.

(3) Surface Area: The third factor that can impact the water evaporation rate is the area of the evaporating surface. The larger surface evaporating area causes greater amount of water exposed to the ambient air, the greater possibility for the water to evaporate and yield higher evaporating rate.

(4) Relative Humidity of the Air: The RH of the air is the measurement of the water vapour contain in the air as a fraction of the maximum amount that the air is able to hold at a particular temperature. The definition of low relative humidity of the air is when there is only a small portion of the total amount of water which the air is capable to hold is being held. When the relative humidity of air is low, the air has the ability to take more moisture, thus with all other preferable conditions, the rate of water evaporation will increase, and thus the higher efficiency of the evaporative cooling system can be obtained.

2.4 Methods of evaporative cooling

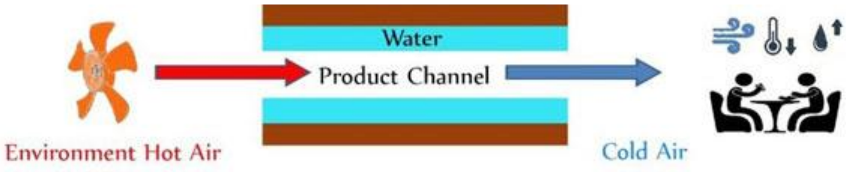


Figure 2.3: Direct Evaporative Cooling System

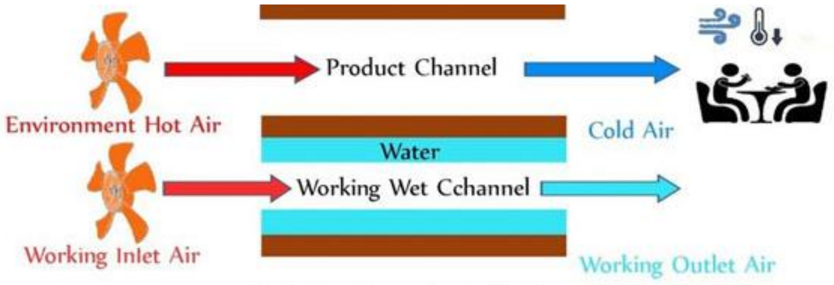


Figure 2.4: Indirect Evaporative Cooling System

Rusten[18], classified that there are two major methods of evaporative cooling which is Direct evaporative cooling (DEC) and Indirect evaporative cooling (IEC).

2.4.1 Direct evaporative cooler

Direct Evaporative Cooling is a method by which the ambient air is passed over a porous media that is saturated with water. The latent heat correlated with the evaporation of the water deceases temperature and increases humidity the air streams which then allows the wet and cool air to flow to its desired direction. [18]. [19]. Direct evaporative cooling has the three main restrictions:

1) The increments of humidity in product air may not be the desired condition.

2) The wet-bulb temperature of outside air is the lowest obtainable temperature.

3) The large quantity of precipitation or mineral in water deposit on the cushion and the heat exchanger part can lead to retardation, and corrosion, and need a lot cleaning, restoration, and maintenance.

2.4.2 Indirect evaporative cooler

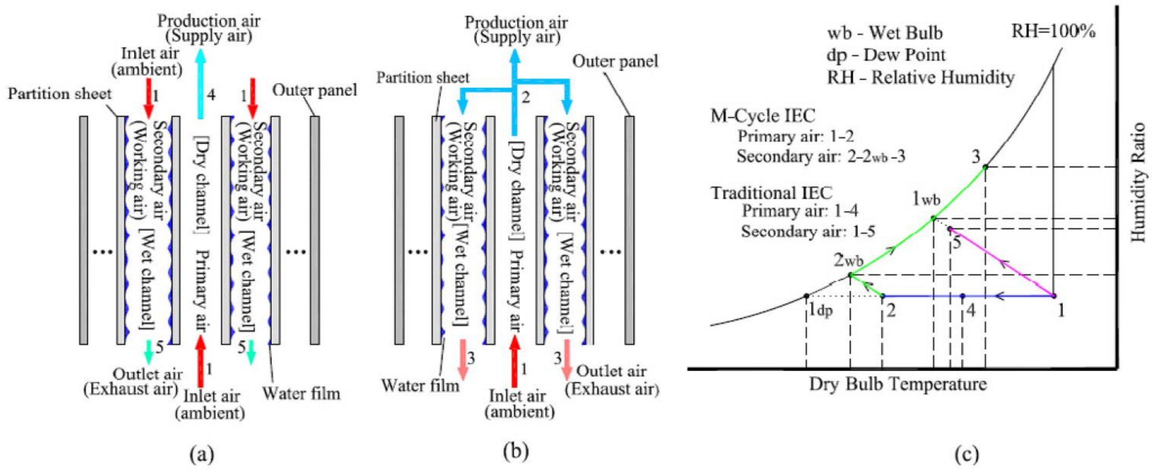


Figure 2.4 (a): Air flow pattern and psychrometric process of traditional IEC and dew point IEC with M-Cycle: (a) traditional IEC (b) M-Cycle IEC (c) psychrometric process.

For the Indirect Evaporative Cooling (IEC), an evaporative air conditioner is aggregate with a heat exchanger. The implementation of passes or return air through evaporative cooling process and air to air heat exchanger are the common heat transfer method to reduce the air temperature in IEC system. A more advance method is by implement cooling tower to evaporative cool the water circuit over a coil to low temperature air stream [18-19]. The only difference between indirect evaporative coolers and direct evaporative coolers is for indirect coolers, the process air is cooled by water evaporation in wet channel. The interaction between the product air and water is zero. The function of wet channel is to provide space for water evaporation. Therefore, the humidity of the product air is the same as the inlet.

Indirect evaporative cooler (IEC) is an Eco-friendly cooling system in contrast with the expansion for air conditioning systems. IEC utilizes the water fluid to substitute the usage of chemical refrigerant partially. IEC can be used as an energy recovery ventilation system or single cooling system. Driven by the concern about the sustainability, IEC has been demanded to lower the operating power of cooling system. Designer tends to improve its capacity in order to lower the energy usage and raise the overall efficiency of the cooling system. The water flow over the heat exchanger plate walls in the cooler is a major factor impacting the efficiency and performance of IEC. The dew points Indirect Evaporative Cooling (IEC) obtained through Maisotsenko cycle (M-Cycle) is a complex heat transfer process.

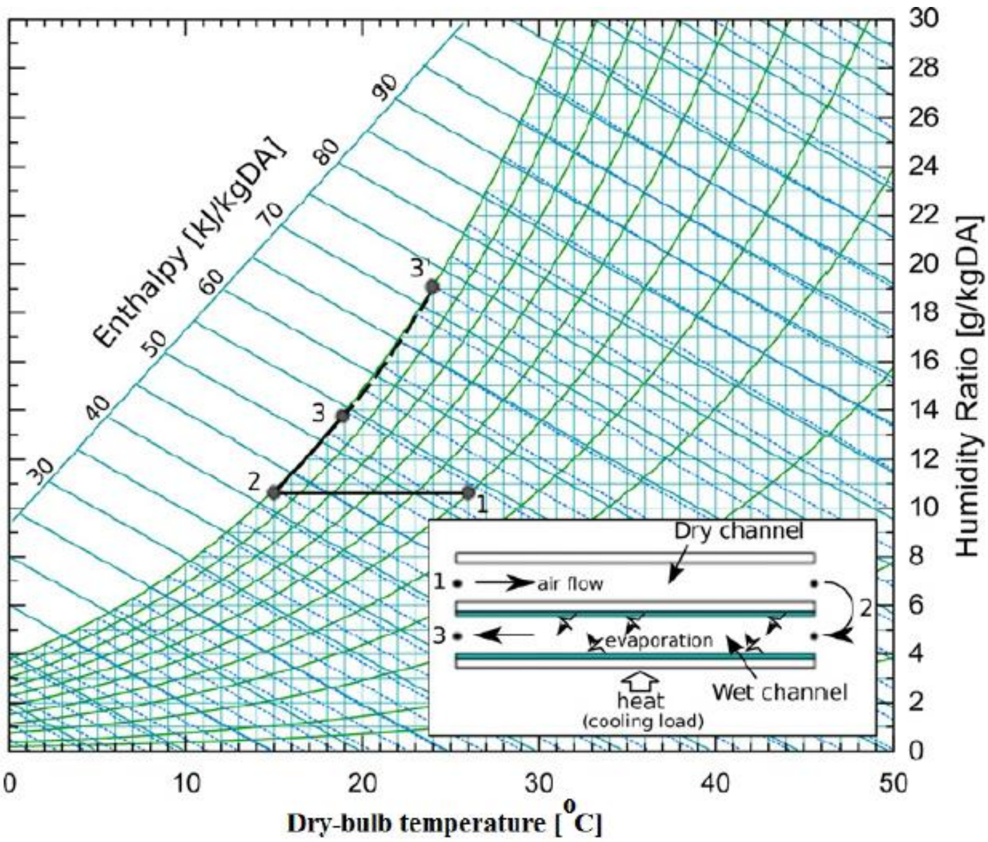


Figure 2.5: Detailed psychrometric flow of M-cycle

According to Lei Wang[3] IEC research paper, the M-Cycle makes use of the dry channel and wet channel of to exchange heat like the traditional heat exchangers of indirect evaporative cooling system, but with a another airflow method which able to produce an excellent thermal exchange. Based on schematic diagram in Fig. 2.4(b), the primary product air is separated into 2 streams. First stream (product air) is channel into places for cooling operation while second air stream channel down to the wet channels. When the process start, the primary air flows into the dry channel and a portion of the product air flow is engaged as the secondary air, it moves into nearby wet channel in opposite path. The wetness of wet channel heat exchanger surface is increased due to water addition. Thus, the temperature difference causes the sensible heat transfer in the wet channel. While pressure difference of water vapour between the wet channel surface and secondary air stream create mass transfer of water at the wet channel inlet. The temperature of primary air is dropped without interacting with water physically, the humidity ratio of primary air at entrance and exit are same. M-cycle utilises the hot water saturated air and the enthalpy difference of air during dew point temperature to remove heat from ambient air [20].

M-cycle coolers have the capability to decrease temperature of air close to dew point temperature with lesser energy consumption compare with mechanical compress air conditioner [14]. M-cycle coolers able to maintain moisture content along the product air stream even thou the cooling medium of M-cycle coolers is water fluid. Furthermore, among all coolers with similar cooling power, M-cycle cooler consumes lower amount of water compare to traditional IEC or DEC. Mechanical compress coolers maintain moisture to the air because it uses CFC as a cooling mechanism in order to achieve the cooling. By comparing to DEC coolers, the probability of getting health problems due to the water contamination in M-cycle coolers is zero because of zero interaction between water fluid from wet channel and product air from dry channel. The cooling capacity of M-cycle coolers improves by increasing inlet air temperature [14]. Due to the absence usage of high energy consumption component like evaporator, condenser, refrigerant, compressor in M-cycle coolers, this make M-cycle cooler to has greater market and lower affordable cooling expenses compare to mechanical compress air conditioner [14]. The M-cycle coolers offer health issues free enclosed environment air with comprising 100% fresh air.

2.5 Application of IEC

There are over 200 patents globally for Maisotsenko cycle [15]. The first practical apperception of the M-cycle cooler technology is developed by Coolerado cooperation [17] for many purposes including residential, commercial, hybrid and solar M-cycle air coolers. Based on testing which conducted by National Renewable Energy Laboratory (NREL), Coolerado's H-80 air cooler used 4 times lesser electrical energy than mechanical compress air conditioner in dry and hot climate country [17]. The Coolerado air conditioners are able available in HVAC markets over the world. The Coolerado coolers are separated into 3 major classes which are HMX, M50 and C60. Below is the figure of their products.

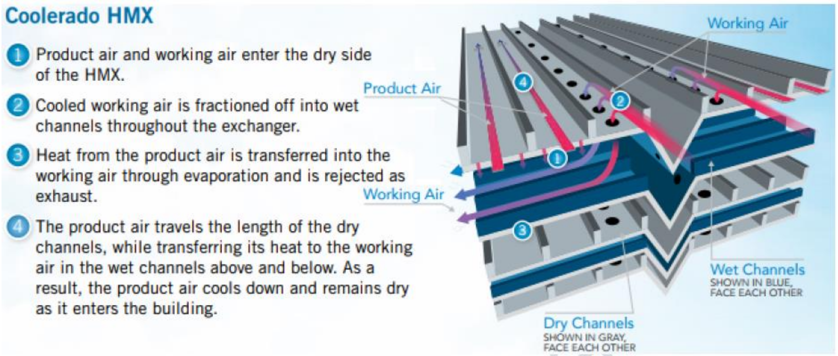


Figure 2.6: HMX Coolerado air cooler [from brochure]

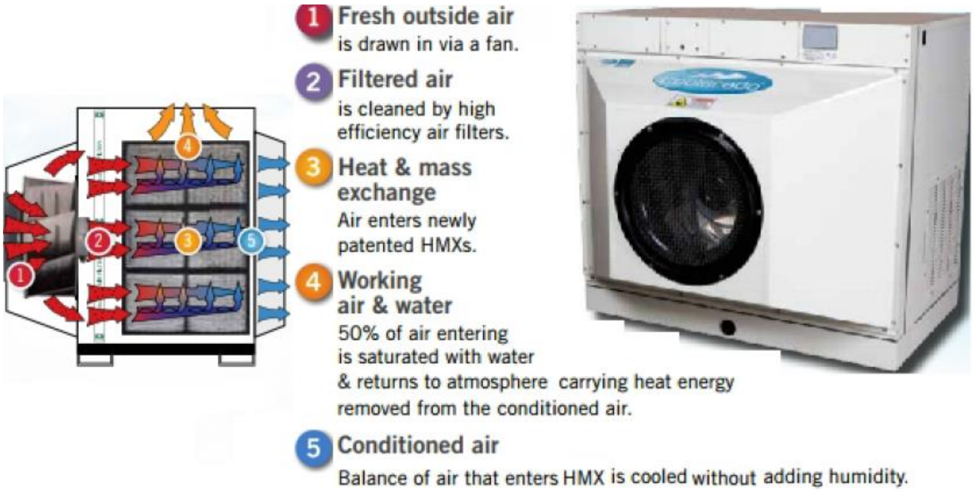


Figure 2.7: C60 Coolerado air cooler [from brochure]

Figure 2.8: Coolerado air cooler [from brochure]

2.6 Recent Research Study for IEC

In order to reduce the gap of modelling and measurement results, a 1-D numerical model of the IEC flat plate counter flow heat exchanger is developed by Kettleborough and Hsieh [20] with the support basis made by Maclaine-corss and Banks [21]. All the factors like poor wetting and alteration of the distributed water temperature along the heat exchanger plate surface is took into consideration for this one dimensional numerical model. As the final result, the percentage error between the experimental efficiency and modelling of this study had lowered down to 14%.

The following numerical analysis is completed by Guo and Zhao [22]. The thermal performance of the cross flow indirect evaporative cooler (IEC) had been analysed dedicatedly by them. This numerical analysis mainly concentrate on the properties of numerous parameters, these parameters includes primary and secondary air flow rate ratio, channel dimension, relative humidity of inlet air and wet-ability of the wet channel corresponding to the cooling performance for the IEC system. The research concluded that the smaller width of the channel, the relative humidity of secondary air inlet will be lower. This increases the wet-ability of the heat exchanger plate and at the same time it yielded a greater ratio of the secondary to primary air. With the condition above, higher cooling effectiveness of IEC can be obtained.

Ren and Yang [23] constructed an improved mathematical model which capable to imitate the coupled mass and heat transfer processes in counter flow and parallel indirect evaporative cooling heat exchanger according to several working state. In contradistinction with the 1-D model above, this mathematical model resolved the coupled mass transfer and heat equations by including several Lewis factor such as plate surface moisture, water evaporation, velocity, enthalpy and temperature of the injected water. By comparing with solutions obtained from the 1-D mathematical models, lower errors were obtained by implementing this improved mathematical model. The errors lowered by 0.17% to the 0.64% to the product air temperature of second channel, air supply temperature, and 0.24% to the product air humidity ratio at second channel respectively. This research rated that during counter current flow, most efficient operation can be obtained in constant heat exchanger parameter inside the flat-plate heat exchanger. The parameter such as the primary air flowing in the counter-current orientation to the secondary air and water membrane yield a better cooling result because no heat conduction was identified along the air flow longitudinal direction within the boundary of heat exchanger.

Hettiarachchi et al. [24] uses NTU method to investigate the impact of 2D longitudinal heat transfers in the plate wall among a tight cross flow flat plate heat exchanger. A group of governing equations is applied in this study to consider the important parameters like the mass transfer inside the wet channels and the heat transfer parameters of convection inside the dry channel and wet channel. This research concluded that the depravation in cooling effectiveness of the indirect evaporative cooling by the longitudinal heat conduction was nearly 10% or above during normal working state while below 5% was identified under several extreme states.

The table 2.6 below showed the important experimental study for traditional IEC and numerical study on M-cycle counter flow. The numerical data from Cui X [25] is validated by the experimental study by Riangvilaikul B [26]. The validation graph is showed in Figure 2.6. The error between two study is within 10%.

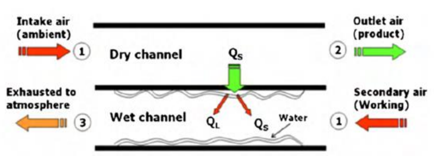
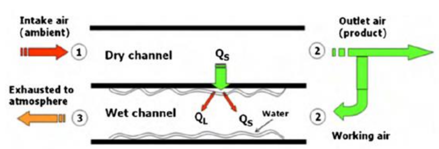
Type of Evaporative Cooling System	Analysis Method	Study Detail (Heat exchanger dimension)
Traditional IEC  	Experimental	**Riangvilaikul B [26]** Parameters — Experimental data Riangvilaikul Wall thickness, mm — 0.5 Channel length, m — 1.2 Channel width, m — 0.08 Channel height, m — 0.005 Working to intake air ratio — 0.33 Range of tested intake air temperature — 25, 30, 35, 40, 45 °C Range of tested intake air humidity — 6.9, 11.2, 20, 26.4 g/kg
MCIEC – Counter flow  	Numerical Simulation	**Cui X [25]** Parameters — Numerical results Cui Wall thickness, mm — 0.3 Channel length, m — 0.5 Channel width, m — 0.5 Channel height, m — 0.005 Working to intake air ratio — 1 Range of tested intake air temperature — 30, 32.5, 35, 37.5 °C Range of tested intake air humidity — 70, 80, 90%

Table 2.1: Highlighted research study for FYP

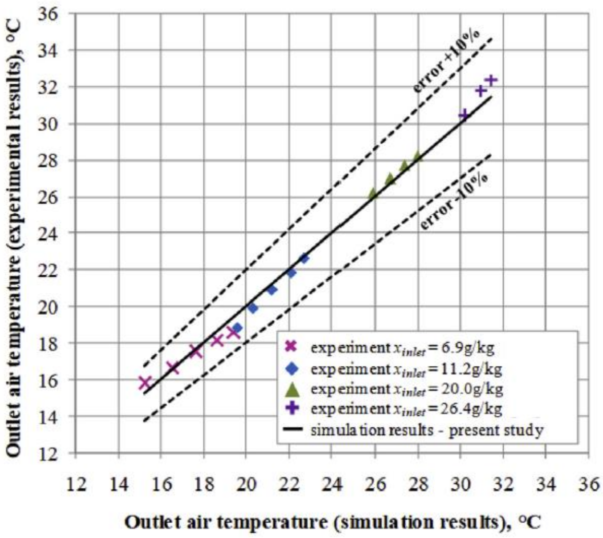


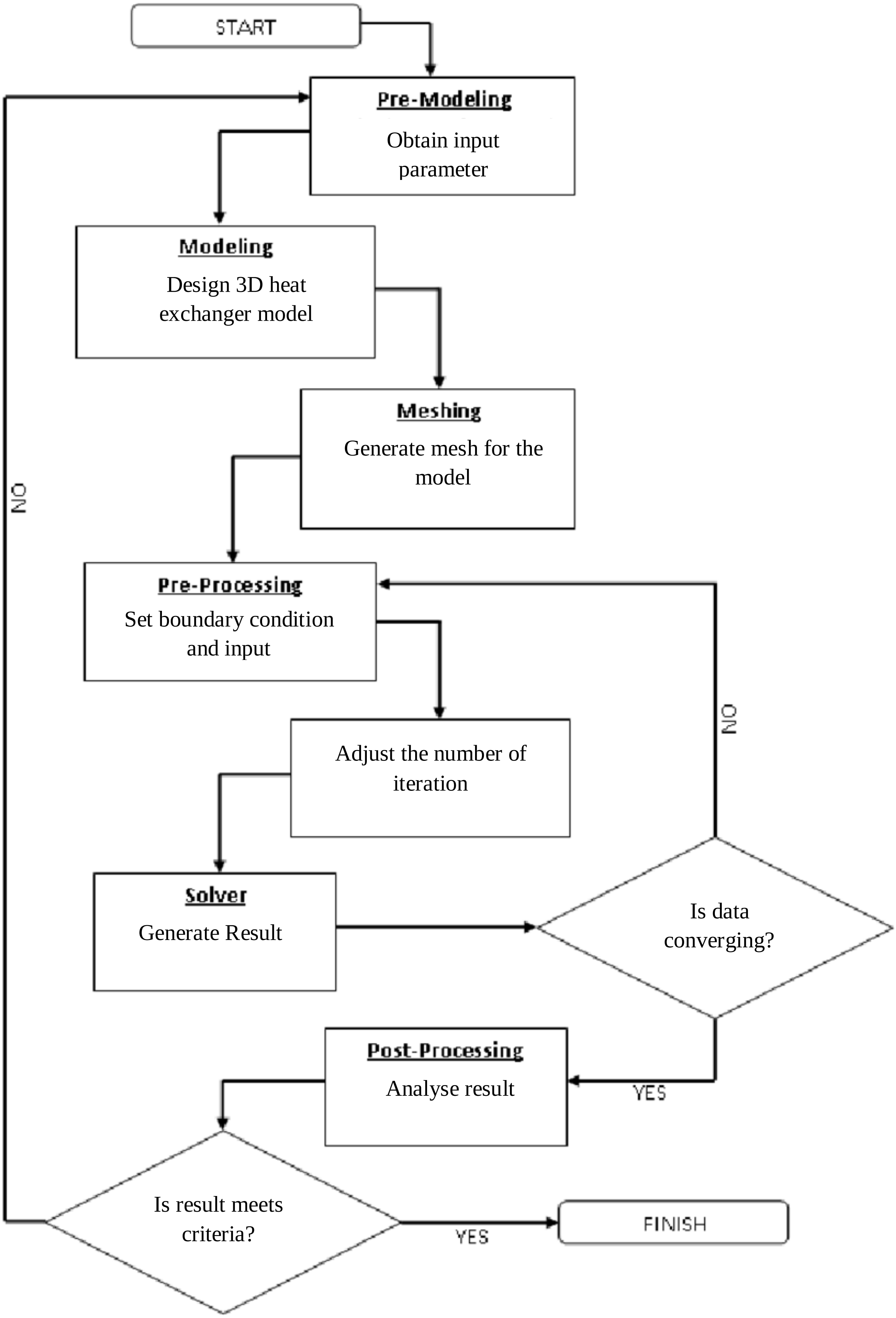
Figure 2.9: Comparison between outlet air temperature based on mathematical model and experimental data

2.7 Conclusion of Literature Review

The main evaporative cooling system is Direct Evaporative Cooling (DEC) and Indirect Evaporative Cooling (IEC). The most common application is the water spraying system with the support of ventilating fan. DEC decrease the ambient temperature by increasing the humidity of the environment. While the IEC system uses two different channel which is dry channel and wet channel. The wet channel absorbs the heat from the dry channel. The product of the dry channel is cool air with the same humidity as the entrance. The application of IEC is not popular due to lack of research data and lesser cooling load compare to air conditioner. A new IEC heat exchanger model, M-cycle is develop by Valeriy Maisotsenko in 2004. This heat exchanger model is proved to have better cooling performance than the traditional IEC model.

3.0 Methodology

3.1 Project process flow chart



Step 1: Design optimum cross flow MCIEC heat exchanger by trial and error method

The initial design dimension parameters for the 3D model are compiled in table form below. Then a 3D model is constructed in Ansys Space Claim following the value of the table. Trial and error in Ansys CFD are conducted by manipulating the dimension of the 3D model and fixed the boundary condition (inlet air temperature and velocity) to obtain suitable dimension for the 3D model.

Table 3.1: Design Parameter

Trial	1	2	3 (Best)
Height	109mm	69mm	29mm
Width	268mm	168mm	68mm
Length	321mm	201mm	81mm
Steel Thickness	3mm	3mm	3mm
Channel Size	50mm x 50mm	30mm x 30mm	10mm x 10mm
Hole Diameter	60mm	18mm	6mm
Material	Steel	Steel	Steel
Inlet Air Temperature	333K	333K	333K
Inlet Air Velocity	1 m/s	1 m/s	1 m/s

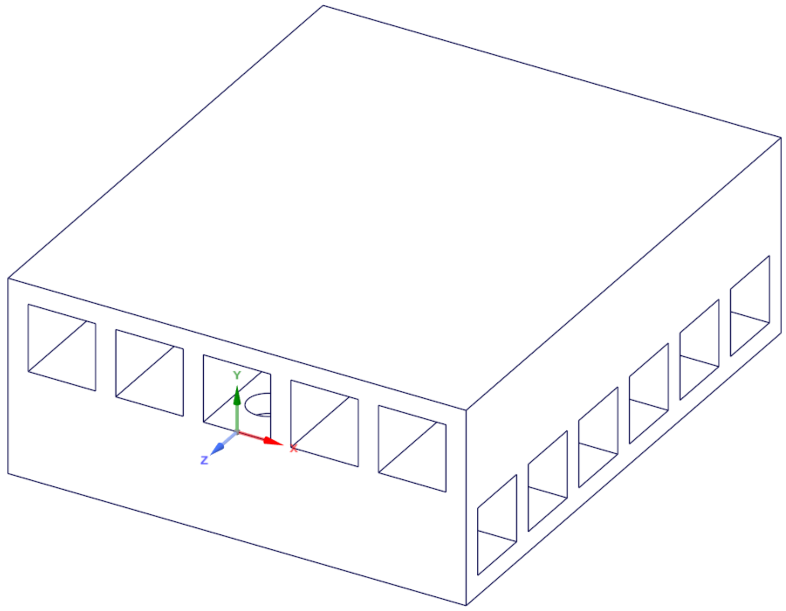


Figure 3.1: Cross Flow MCIEC 3D model

Step 2: CFD simulation for best 3D model

The best 3D model from previous design is inserted into Ansys Fluent to conduct CFD simulation. Meshing is generated accordingly before CFD simulation. The fixed boundary conditions are inlet air temperature and secondary channel surface temperature while the manipulated boundary condition is the inlet air velocity (0.5m/s, 1.0m/s, 1.5m/s, 2.0m/s,). The number iterations for 1000 times is being assigned the 3D model. The temperature drop is recorded respect to the different inlet air velocity. And the optimum inlet air velocity can be obtained by identify the temperature drop across primary channel.

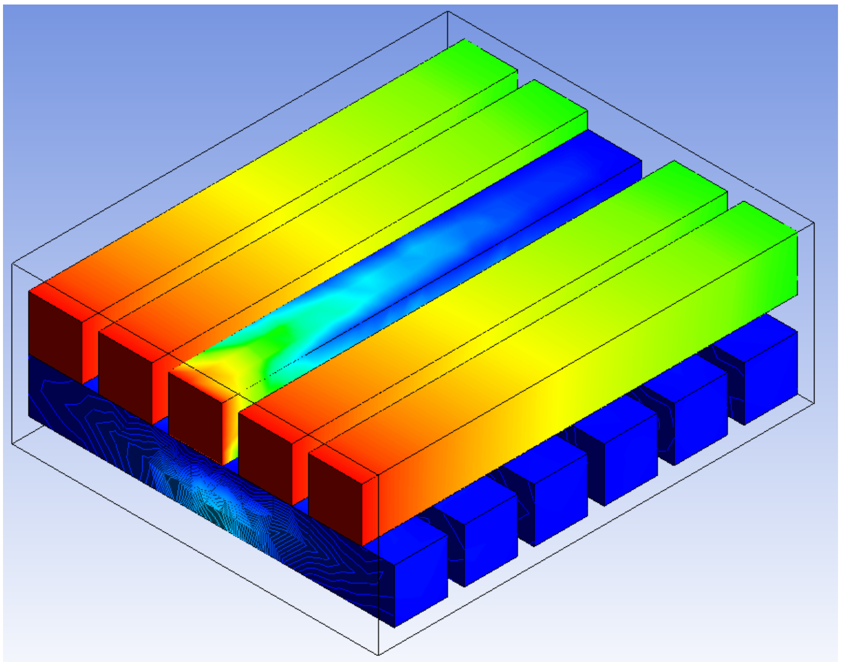


Figure 3.2: Cross Flow MCIEC 3D Temperature Contour

3.2 Gant Chart and Key Milestone

Final Year Project 1 Gantt Chart

No.	Task	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Understanding Project Background														
2	Literature Review														
3	Design Methodology														
4	Learn ANSYS Fluent														
5	Interim Report Drafting														

Milestone:

- Compute methodology flow chart (Week 8)
- Learn CFD 3D modeling (Week 9~12)

Final Year Project 2 Gantt Chart

No.	Task	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Develop 3D model														
2	Simulation of the developed model														
3	Obtain result														
4	Validation Process														
5	Analysis Data														
6	Final report Preparation														

Milestone:

- Obtain result (Week 5)
- Data Validation (Week 8)
- Preparation for Report (Before Week 12)

4.0 Results and Discussion

4.1 Construct 3D Model

The crossflow heat exchanger model is designed by the author because there is no any design parameters and study conducted by other researchers. All the channels width and height are 1 cm. The third primary and all the secondary channel are wet channel. There are 6 holes along the third primary channel. The diameter of the hole is 6mm. The hole allows the inlet air to move downward to the secondary channel. The thickness of the heat exchanger body is 3mm apart between each channel. Below is the specification of the heat exchanger body. The figure below is constructed using ANSYS FLUENT software.

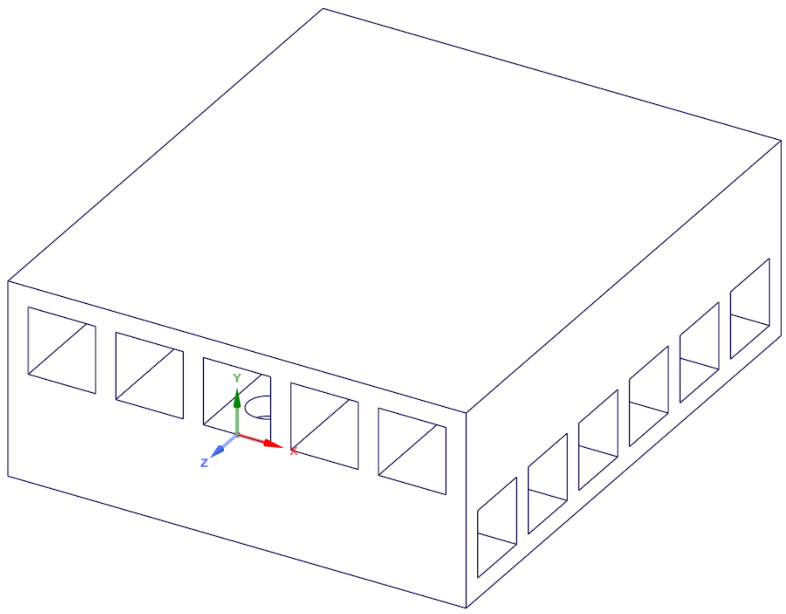


Figure 4.1: 3D Modelling of M-cycle Cross Flow Heat Exchanger (Body)

Table 4.1: Specification of heat exchanger

Height	29mm
Width	68mm
Length	81mm
Steel Thickness	3mm
Channel Size	10mm x 10mm
Hole Diameter	6mm
Material	Steel

4.2 Working Principle of cross flow MCIEC

4 Primary square channels (all top except middle), 1 secondary inlet channel (top middle) and 6 secondary square channels (bottom) were used for the 3D CFD simulations. The main cooling process take place in primary channels while secondary channels act as cooling medium. *Figure 4.1.1* shown the air flow of primary channel from inlet to the outlet. The hot air is move across the 4 primary channels and heat is absorbed by secondary channel. Cooled air is produced at the outlet of primary channel. *Figure 4.1.2* shown the air flow of secondary channel, the inlets for secondary channels is located at the top middle. There are 6 holes along the top middle channel. Hot air is forced to move from top to bottom through the holes. Then the air moves perpendicularly into 2 different direction towards the outlets. The surface of the secondary channel is surrounded by wet surface.

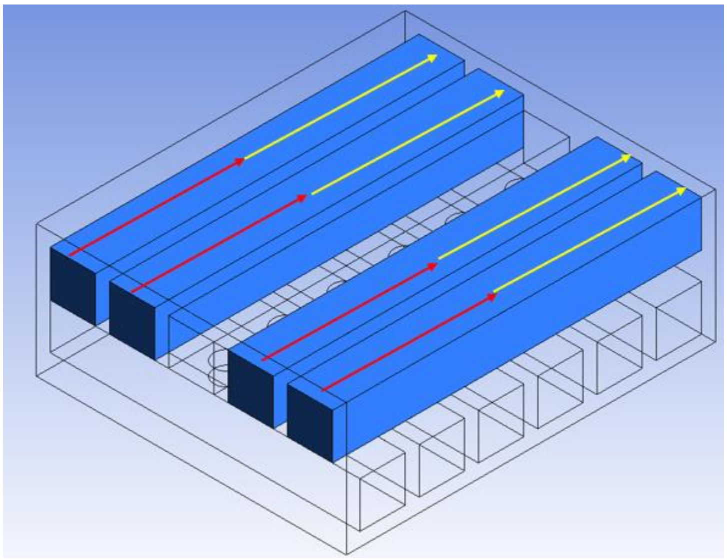


Figure 4.2.1: Air Flow Path Across Primary Channel

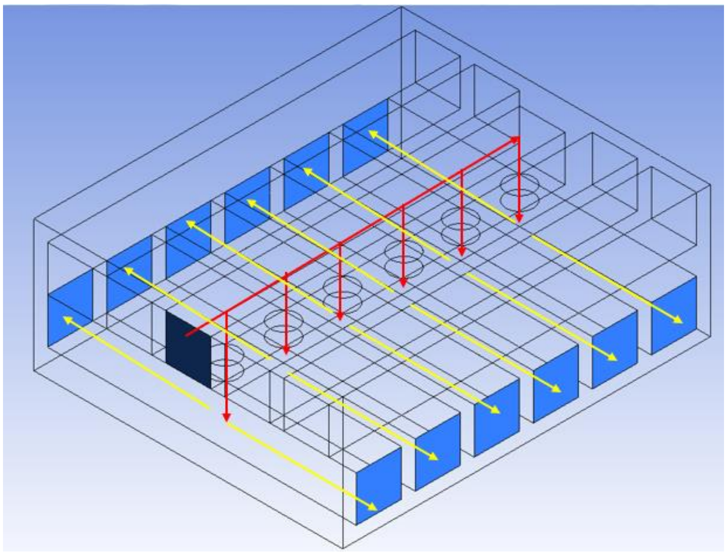
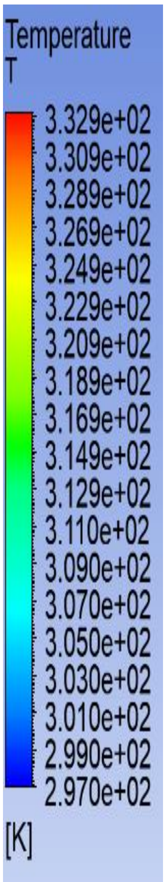
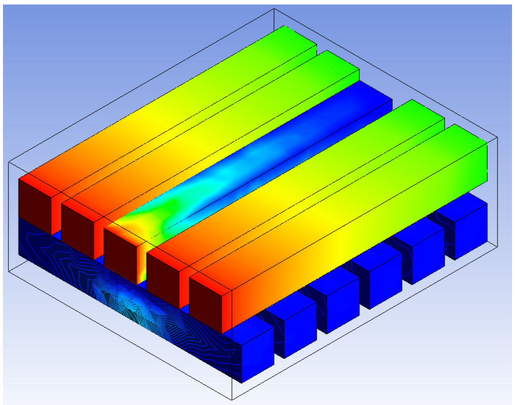
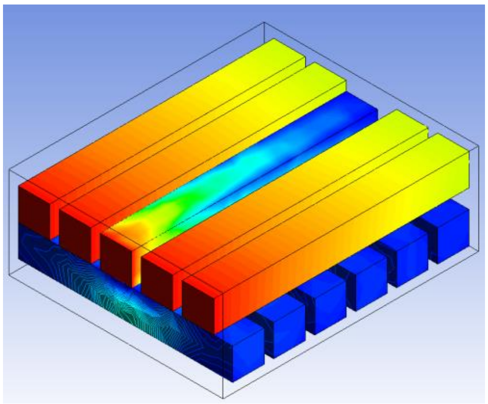
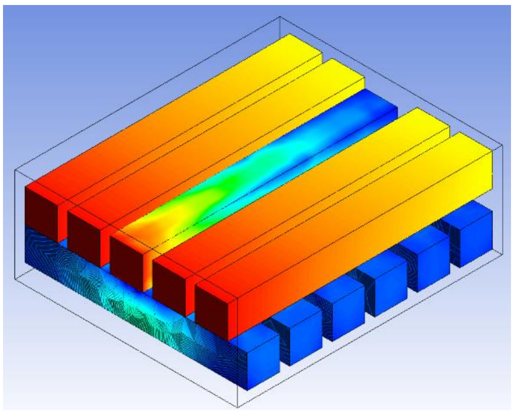
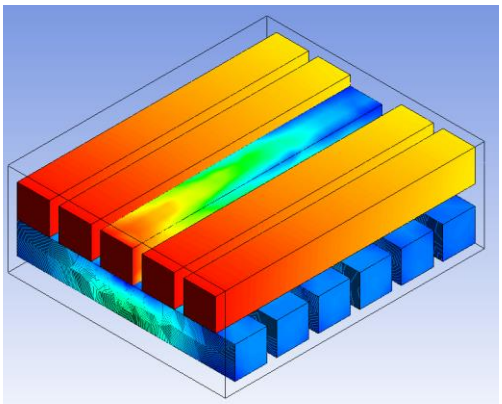


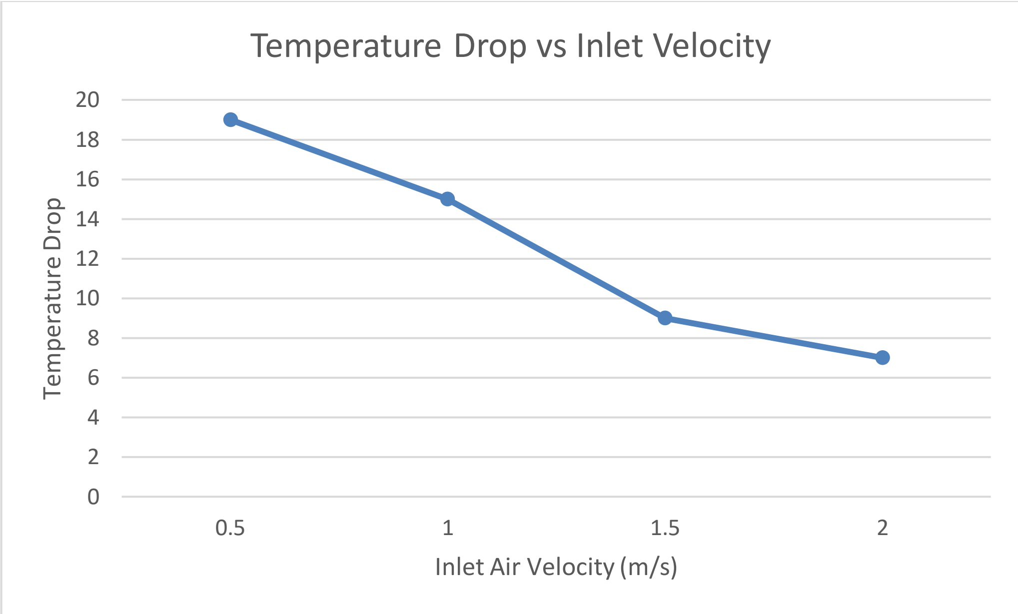
Figure 4.2.2: Air Flow Path Across Secondary Channel

4.3 CFD Simulation Results

There are 2 fixed boundary conditions for the simulation which are the inlet air temperature (333K) and the surface temperature of secondary channels (297K). The manipulated boundary condition is the initial air inlet velocity at primary channel. The inlet air velocity varies from 0.5m/s, 1m/s, 1.5m/s and 2m/s. At the end of the simulation, the outcome is to identify the temperature drop across the primary channel respect to its inlet air velocity. *Table 4.3* shown the result of CFD simulation for 4 different inlet air velocity. While the graph 4.3 shown the temperature drop against the inlet air velocity.

Table 4.3: CFD Analysis Results

Reading:	Inlet Air Velocity: 0.5 m/s	Inlet Air Velocity: 1.0 m/s
	 Reynolds Number: 10557 Temperature Drop: 19 K	 Reynolds Number: 21115 Temperature Drop: 15 K
	Inlet Air Velocity: 1.5 m/s	Inlet Air Velocity: 2.0 m/s
	 Reynolds Number: 31672 Temperature Drop: 9 K	 Reynolds Number: 42229 Temperature Drop: 7 K



Graph 4.3: Temperature Drop vs Inlet Air Velocity

The highest temperature drop 19K is obtained when the inlet air is 0.5m/s. All conditions are in turbulent flow because Reynolds Numbers are greater than 4000. As the inlet air velocity increases, the temperature drop across the primary channel reduces. This is because more heat is being absorbed by secondary channels when the duration of air remain in the primary channels is longer. Therefore, greater cooling effect can be achieved when slow air movement is applied in the primary channel. The result of this CFD simulation are successfully computed and the results are reasonable.

5.0 Conclusion and Recommendation

Evaporative cooling system is still a relatively new era for the field of HVAC. Indirect Evaporative cooling system can provide comfort cooling without changing the humidity of the environment. Cost of production is directly affected by the energy consumption during the cooling operation. IEC is the best solution for the investors in term of cost saving. IEC consume lesser electrical energy because evaporative cooling is a spontaneous process. Among all the IEC, M-cycle is the most potential heat exchanger model to replace the current air conditioner. According to previous study on M-cycle, it can generate cool air efficiently using only single air supply without changing the environment humidity. However, the numerical study data for crossflow is absent. Numerical simulation is completed in this semester using ANSYS FLUENT software. In the future, experimental prototype will be developed to future study the actual behaviour of the M-cycle cross flow heat changer model. The numerical data will be validated by previous experimental study and numerical study of counter flow M-cycle heat exchanger model. This numerical study on cross flow model is a starting point for M-cycle future development. The study is very beneficial to the HVAC field to develop less energy consumption cooling system for coming years. In the future, detail study like varying the inlet air temperature can be conducted. To be more advance, an experimental prototype of the crossflow 3D model can be fabricated, and the actual data can use to validate with the CFD simulation data of this study.

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