Parametric Study of Indirect Evaporative Cooler Based on Maisotsenko Cycle (M.cycle)

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MS Mechanical Engineering

Thesis Supervisor:

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Dedicated to my beloved mother

Abstract

In this thesis the performance of an indirect evaporative cooler is experimentally analyzed in terms of its thermal effectiveness. A heat and mass exchanger (HMX) using a cross-flow pattern incorporating Maisotsenko cycle (M-cycle) is designed and fabricated having a compact channel width to height ratio, proper water supply system for wet channels and more efficient moisture absorbing material on the wet channel. To provide continues supply of cooling water to wet channels, force & induced combined cooling tower is design to reduce more temperature at outlet. Experimental investigations are conducted under various operating conditions of inlet air including its humidity, temperature and velocity along with water temperature. The experimental results indicate that temperature difference is 16ºC at different air velocities and inlet temperature. The proposed framework design gives better efficiency when contrasted with the previous work, the outcomes were examined with the impact of various factors. Thus the proposed cooler has more efficient design that is commercially suitable Moreover, the overall performance of the improved design is found more compact and efficient as compared to previous system.

Key Words: Air Conditioning, Evaporative Cooling, Effectiveness, Maisotsenko Cycle.

Table contents

List of Figures

Chapter 1

Introduction

Fast expansion in world energy utilization in the ongoing past has caused concern worldwide and the requirement for substitute fuel sources just as substitution and amendment of existing Energy cycles is developing close by. As Zhan called attention to during his near investigation (Zhan, Duan et al. 2011) around 20 to 40 % of the world's energy is devoured by Architecture. Among that figure, half of the energy is being devoured via Air Conditioning Applications. This implies that around 20 % or 1/fifth of the complete energy utilization overall is in the Air molding applications. This is a significant huge figure when contrasted with other energy utilization applications. With the outstanding expansion in the total population, ascend on the planet temperature, wealth of the structures and expanded interest to get comfortable conditions increasing day by day.

Compression system is the main method of cooling which consist of condenser, evaporator and blower. The system uses refrigerant gases (R-22, R-134a) and work on principle of reverse Carnot cycle. This system working is very basic. The evaporator’s refrigerant used to change state of liquid, it take heat from exchanger to convert in to vapor. Compressor used to compress the vapors and after that it moved to condenser to convert vapor to liquid. After this the refrigerant leave the condenser and moves towards the expansion valve which will complete the cycle after return in evaporator. Because of its incredible cooling limit, this strategy has been protected and improved for a long time. Starting at now, the straightforwardness, full-created advancement and incredible specialist and upkeep displays explain why notwithstanding it overpowers the ventilating market. Despite previously mentioned focal points, maximum usage of the power has been a significant worry for this cycle. Further because of the high energy consumption during the cycle and not ecofriendly refrigerant gases, other systems are needed to be introduced.

Evaporative cooling is an old concept. In ancient societies it was used thousands of years ago, especially in Egypt. The porous pot used by Egyptians and the pool’s water to cover food in the hot Egyptian climate. To keep the interior space cool the wet embedded chutes in the walls used, as air passes result in evaporation. This unique method spread to other regions as well. This different parts of the world trend is still evident. For example, in Figure 1 it shows that nozzles are used to sprayed water on a packet of water packs attached to a structure. The water cools the dry air by evaporation and provides a cool, moist atmosphere to the environment. These are standard equipment used in deserts, dry areas and in developing countries its common where the standard of living cannot afford standard Air Conditioners. In everyday life evaporative cooling often experienced by all of us, for example when we bathe and stand in front of a fan, then because of evaporation of water from our body we feel the cooling sense.

Figure 1: In horticulture wet pad

1.1. Research Explanation

1.1.1. Research Concepts

To replace the current exchanger layout, a combination of aluminum sheet and acrylic sheet is proposed. The sheets are stacked together with the help of felt sheets which are wetted from one side with fluid penetration. The air flow follows the following path:

The air enters into the dry channel and is divided into two sections:

One section of air stream keeps moving in the same direction as the fundamental necessity was to cool, and the other section of air stream is diverted to neighboring streams channel which is the wet channel.

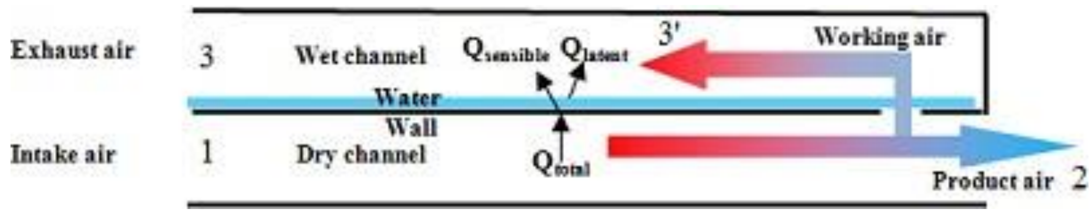

Figure 2: Flow of air in Heat Exchanger

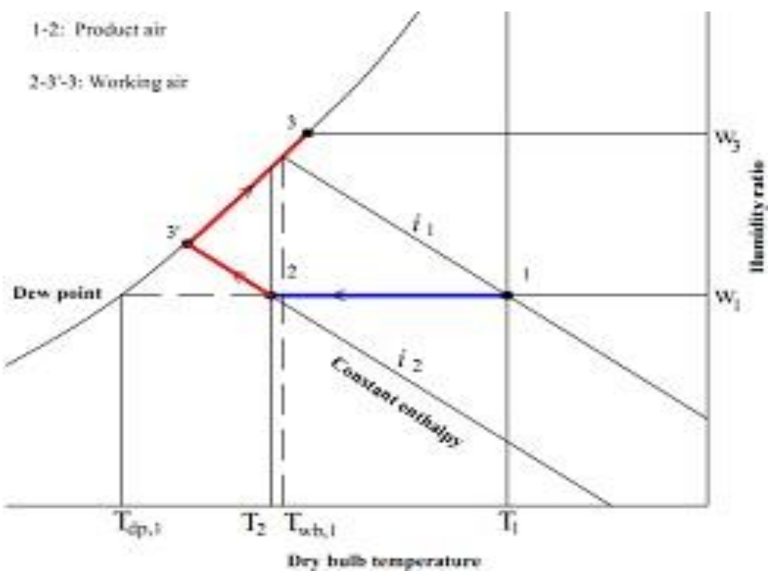

Figure 3: Psychometric chart shown Air conditioning process

1.1.2. Research Objectives

The main objective is to improve the framework of the exchanger with respect to its structure, plan and material determination. The new exchanger will incite change in both wet-globule and dew-point sufficiency at low speeds. The specific objectives of the investigation are:

- To optimize of the exchanger setup, i.e., the structure, plan, material determination and cost.
- To develop and test the framework

- To investigate and examine the framework monetarily, environmentally and regionally

1.1.3. Thesis Structure

The chapter No.1 outlines the foundation and inspiration for the investigation of EC System, which regularly comprises of two sorts to be specific i.e., DEC and IDEC type. The two kinds are assessed based on past research. It is discovered that IDEC has a discrete favorable position over DEC. Henceforth; it cures issues relating to the formation of dampness, spread and growth of microbes. Furthermore, INDEC can additionally work in humid environments. The examination will mainly concentrate the IDEC framework, specifically on the Maisotsenko Cycle.

Chapter No.2: reviews the writing of the EC system in detail. The audit shows that usually, two types of arrangements i.e., plate and tubular compose are connected in the IDEC. Exceptional accentuation is on Maisotsenko cycle.

In the Chapter 3, the experimental plan utilized in this research is described. Support for the setup utilized, the material and the instrument of wind current has been described in detail. The determination of desiccant, its benefits and faults are clarified in detail. The development of HMX and the purposes behind the determination of the model are being clarified.

In the Chapter 4, results are being introduced. Conversation has been made on the gotten results. Different elements influencing the outcomes are talked about in detail. The inlet air temperature, feed water intake temperature, inlet humidity ratio, and the impacts by utilizing the fluid desiccant are examined in detail.

In Chapter 5 deduction has been made through the obtained results and the conclusion is drawn.

1.1.4. Brief Introduction of the Evaporation Processes

The concept of extracting heat from hot fluid i.e., air through evaporation of water vapors is being used in the framework of this cooling system. There are two systems based on the operation the cooling system is based on:

- DEC System
- IDEC system.

1.1.4a. Direct Evaporative Cooling System (DEC)

The framework uses the idea of heat dissipation, the water assimilates heat from the hot air, evaporates and the temperature of the air is brought down as water absorbs the heat. The cooling of hot air happens from 1 to 2 and the saturation occurs at 3, this shows the loss of heat with the increasing moisture level.

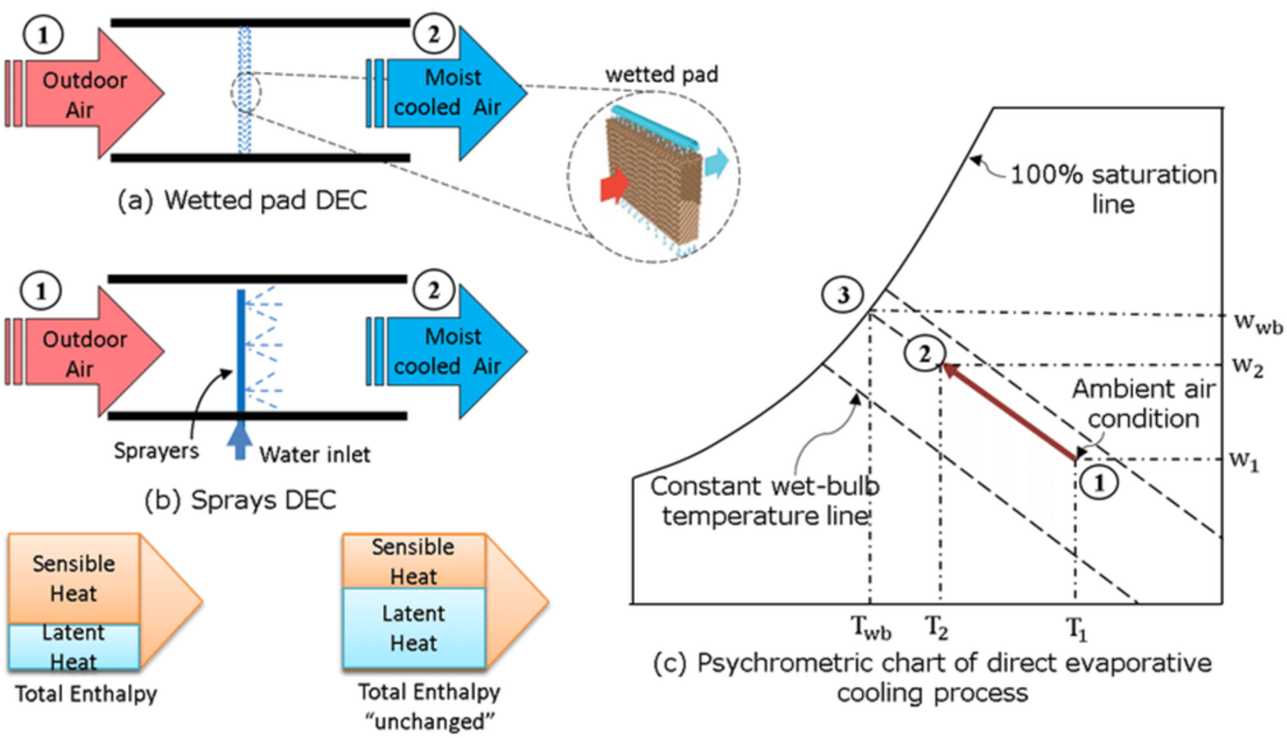

Figure 4: Direct evaporative cooler working principle and Psychrometric chart

1.1.4b. Indirect Evaporating Cooling System (IDEC)

IDE cooling system is different from DEC as at the intake water is sprayed on the wet and dry sections. Then intake air is added to the heat exchanger; meanwhile the working air travels across the wet portion, moves towards the water. In this system, heat from the hot intake air is absorbed by the water. The water absorbs heat and evaporated and travels out of the exchanger with the secondary air. Figure 5 shows the working of IDEC system. From point 1 to 2, temperature as shown decreases but the level of humidity is constant as there is water spray still present in the system. As high humidity refers to high latent load, the indirect evaporative cooling process becomes more effective with no change in the humidity level but the presence of hot humid air. [5]

On the other hand, the secondary air gets cooled un-adiabatically from 1 toward the immersion point which is point 1'. The wet states of both the streams cannot be distinguished as the air surrounding them is optional. It is to focus here that the wet globule temperature of this air will decrease the outlet temperature in order to for the mass exchange to be done proficiently. Another purpose behind it is that the distinction of temperatures on air the wet globule, temperature of intake air mean primary base for this cooling procedure. The perfect most minimal temperature, which the essential air can get, is the wet globule temperature of the auxiliary air.

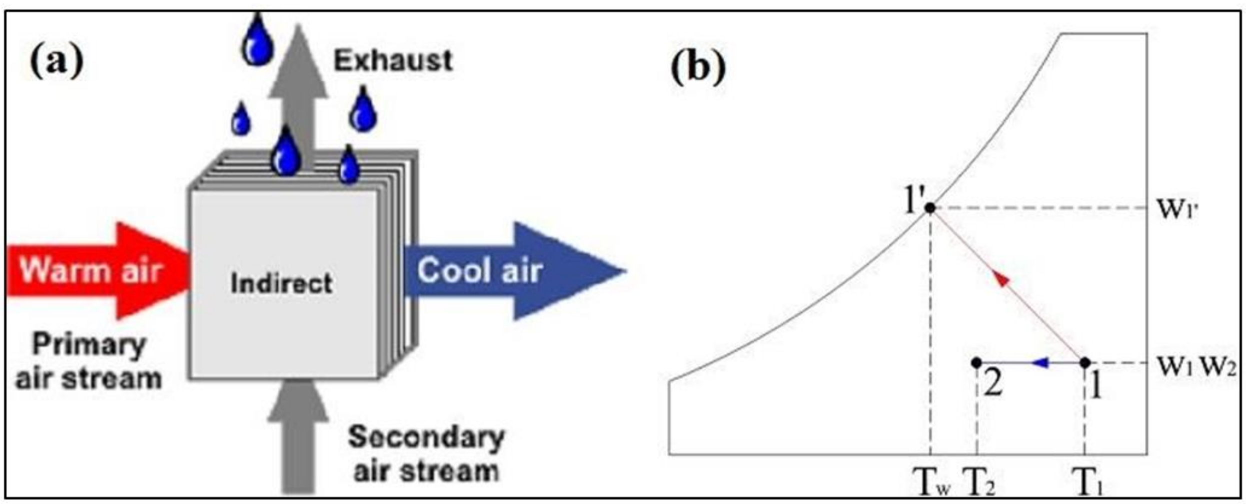

Figure 5: Indirect evaporating cooler

Chapter 2:

2. Literature Review

2.1. Background

As compared to conventional vapour compression cooling system that is widely used on domestic and commercial level, evaporative cooling system has remarkable characteristics that are distinct and make this ecological system an area of interest for many researchers. Some of the key benefits of evaporative cooling system are as follows: a) It uses water as refrigerant. There is no emission of Chlorofluorocarbons or any other harmful refrigerants that damage the ozone layer; b) the evaporative cooling is a technique naturally available on this planet and is environmental friendly; c) The evaporative cooling system has very large value of Energy Efficiency Ratio (EER) [4] as compared to conventional compression refrigeration system which implies that evaporative cooling system consumes very less energy as compared to conventional refrigeration system to achieve the desired temperature; d) The maintenance and operational cost of the evaporative cooling system is very low. The system only need water and requires electric supply to power a low energy consumption fan and small pumps. There is no compressor, so the system requires the maintenance of filters and water distributors. So the system is both economical and fulfils the modern era requirements where energy is the driving force of economy and the environment is of utmost concerned for the whole world [10]

2.1.1. Direct Evaporative Cooling System:

The direct evaporating cooling had a topic of interest for many researchers for a long time and numerous experiments had been performed by many researchers to check the effectiveness of the system [6]. The system is highly effective in hot and dry regions and can be used in buildings and applications where adding moisture to the air can be tolerated. Heidarinejad [7] carried out many trial experiments on a direct evaporative cooling system in Tehran and revealed that the system has the capacity to meet completely the solace conditions while consuming very less amount of energy. His research depicts the extraordinary potential and high effectiveness of the direct evaporative cooling system. Elmetenani [8] had also performed an execution trial for coordinate evaporative cooling system power by sunlight through photovoltaic cell boards in Algeria. His results shows that the temperature of primary or inlet air was dropped to 18.86℃ which is a really incredible figure for comfort. Due to this significant temperature drop and low energy consumption characteristics of the system, about 65% of the nation is utilizing this system. However, due to water addition in the air, the system cannot be used where the moisture can cause bacterial spread. The increase of humidity in air due to water in direct evaporative cooling emphasize the need of an indirect evaporative cooling system which lowers the temperature of the air without the increase of moisture content of the air [10].

A schematic diagram of the direct evaporative cooler is shown in figure 6.

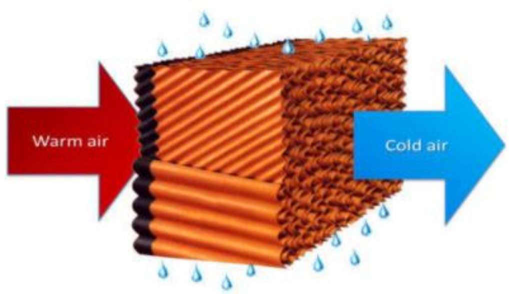

Figure 6: Schematic Diagram of Direct Evaporative Cooling

The hot outside air is blown to an evaporative wet pad. The pad is supplied with water from a sump through a pump. The water falls under the action of gravity and wets the pad. As the ambient air flows over the porous evaporative pad, heat is absorbed by the water as it evaporated from the surface as a result the temperature of the air is dropped. The thermodynamic process involves both the heat and mass transfer. The process follows the constant enthalpy line on Psychrometric chart as shown in figure 7. The minimum temperature that can be achieved this way is limited to the wet bulb temperature of ambient air.

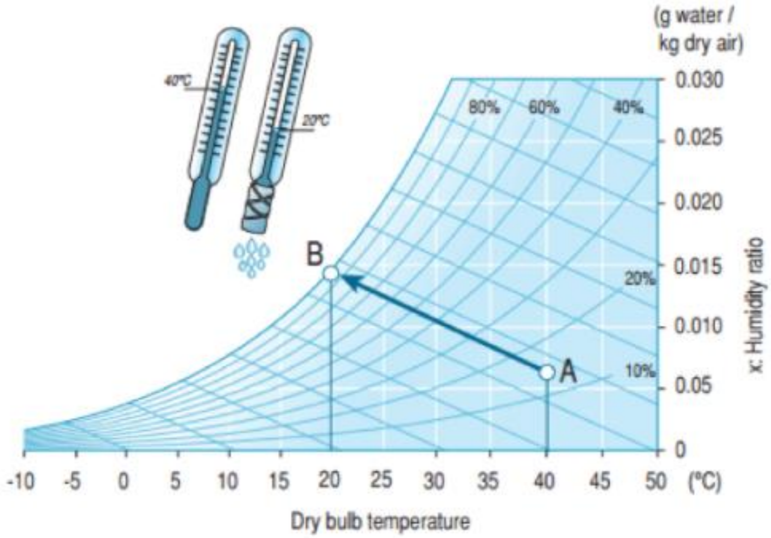

Figure 7: Direct Evaporative Cooling Process on Psychrometric Chart

2.1.2. Indirect Evaporative Cooling System

The working principle of the indirect evaporative cooler can be illustrated with the help of diagram figure 8.

The cooling system consists of two channels. The primary air flows through the dry channel transferring heat to the air in the wet channel. The produced air (product air) at the outlet has lower temperature without increase in the moisture content i.e. absolute humidity of the air in the dry channel remains same. The wet channel has the flow of both secondary air and water. This contact between water and air is approximately the same as in direct evaporative cooling system. The water temperature in the wet channel is approximately the same as the wet bulb temperature of secondary air. Heat transfers from the primary air in the wet channel to the water in wet channel through a thin metal plate. The water by absorbing heat diffuses into the secondary air as water vapours thus increasing the humidity and reducing the temperature of the secondary air. If the air in secondary channel gets saturated with vapour, then part of the heat the primary air is absorbed by the water as latent heat and part of is absorbed by the secondary air as sensible heat thus increasing the temperature of the secondary air.

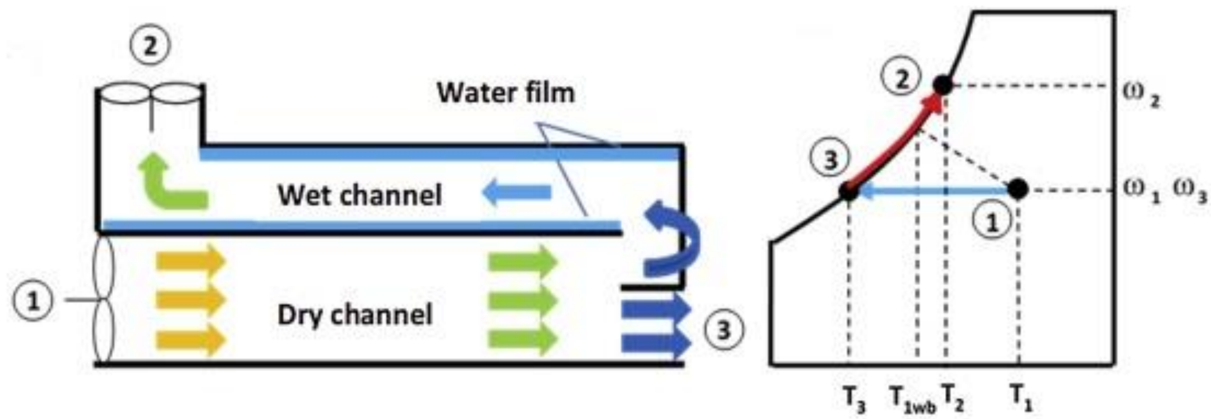

Figure 8: Schematic Diagram of Indirect evaporative Cooling system

The main advantage of this type of cooling system is that the air is cooled without increasing its humidity. While the disadvantage of the system is that at limit, the cooling process of the primary air could be continue until the wet bulb temperature of the secondary air at the inlet is achieved.

2.1.3. Single Stage Indirect Evaporative Cooler

According to a research carried out by Jaber in Jordan, it revealed that the use of indirect evaporative cooling reduces greatly the emission of CO_2 gas. The emission of CO_2 causes the greenhouse effect which results in climate change and increase in temperature. The emission of CO_2 gas emission is a main concern for many countries. According to 2011 edition of "Spain greenhouse gas stock list", the emission of CO_2 gas has increased drastically which is shown in figure 9.

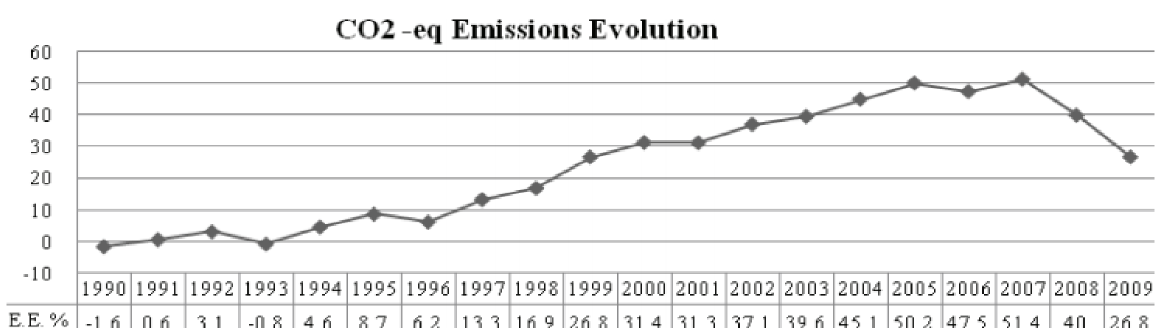

Figure 9: Carbon Dioxide Emission Evolution in Spain from 1990-2009

Jaber [11] study depicts the climate conditions of Mediterranean. The results of the study shows that if 500,000 buildings in Mediterranean were switched from the conventional air conditioning system to the indirect evaporative cooling system, the country can save about 1084GWh energy and the emission of carbon dioxide gas can be reduced by 637,873 ton.

Kruger [10] also performed a similar study on an indirect evaporative cooling system. The data obtained shows that indirect evaporative cooler has huge potential and can fulfill the comfort requirement of indoor air conditioning. He also showed that the indirect cooling system has the capacity to reduce the temperature of the ambient air close to the wet bulb temperature.

A.Joudi [12] examined the indirect evaporative cooler to meet the variable load requirement of Iraq. He also suggested the use of indirect evaporative cooler in combination of the conventional air conditioning unit to save energy. The results show that the indirect evaporative cooler can meet the air conditioning requirement with high efficiency. The system has only two mechanical parts, fan and pump which consume the energy in the system. While for other application, using indirect evaporative cooler as Pre-cooler with conventional air conditioning system can reduce 75% of load and 55% consumption of electric energy.

2.1.4. Indirect evaporative cooling system connected with desiccant dehumidifier system

A new proposed deign of the air conditioning system is the combination of the indirect evaporative cooler with a liquid desiccant dehumidifier is of high interest. It consists of two stages; each stage consists of stack of channels separated from the exhaust channel through a thin plastic strip. In the first stage the supply air is passed through a channel that is lined with a liquid desiccant film. The liquid desiccant has the capability to reduce the moisture content of the air to 20% of relative humidity. The liquid removes the moisture content from the air through a hydrophobic membrane reducing the humidity of the air. The heat from the desiccant is absorbed by the water in the exhaust channel and transferring it to the exhaust air, thus cooling the desiccant. The second stage of the design is an indirect evaporative cooler in which the product air from stage 1 is used in dry channel, getting cool by the heat transfer to the water in the wet channel (panelJasonWoods). The model can be used to measure the state of the airstream during each stage.

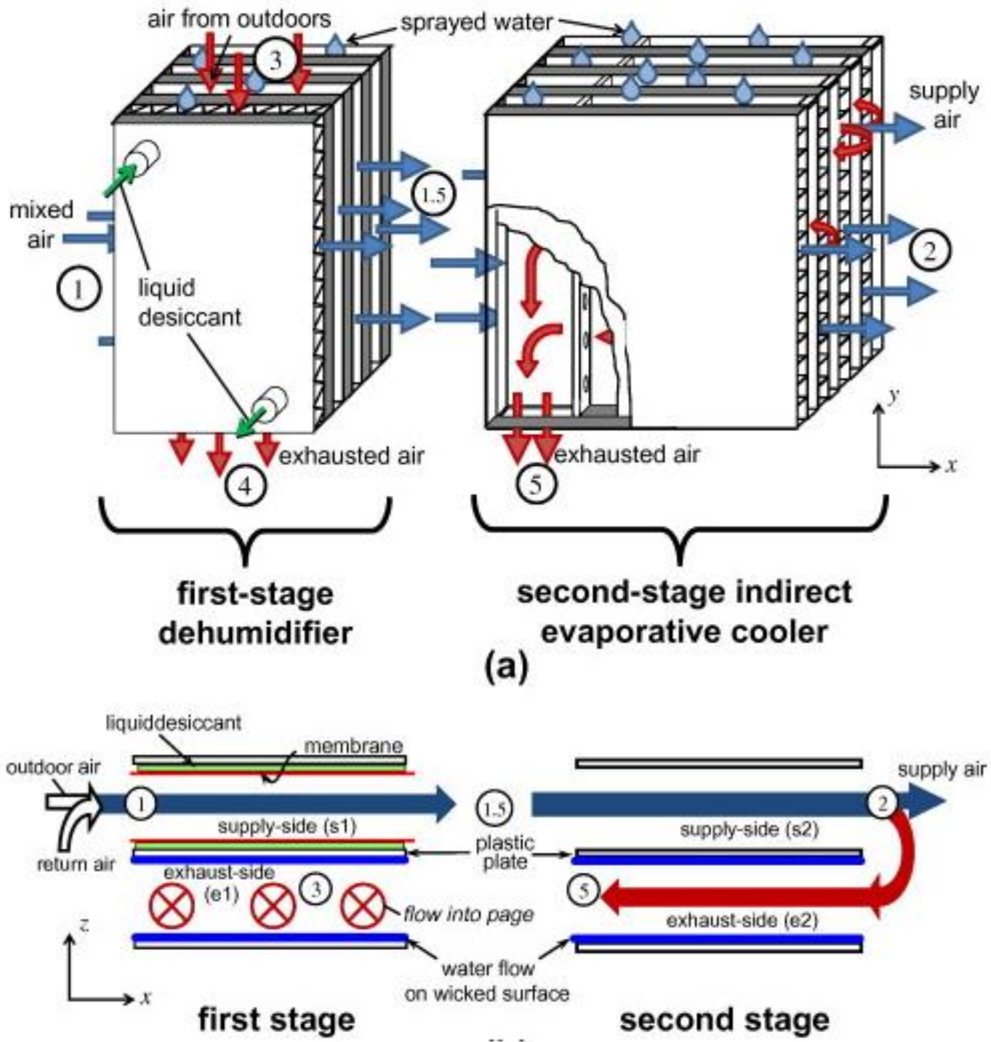

Figure 10: Schematic of the design. (a) Four stacked channel pairs (b) top view, one channel pair.

2.1.5. Flow arrangements

There are many designs of the indirect evaporative cooling system. From all, the one for which the experiments has been performed is shown in figure 11. This design has been considered to be the most effective in terms of temperature at the outlet and is known as Maisotsenko Cycle or simply M-Cycle and is proposed by soviet researcher Valery Maisotsenko. The cycle has the potential to bring the temperature of ambient air down to the dew point temperature. That's why cycle has been an interest for many researchers due to its future and present aspects.

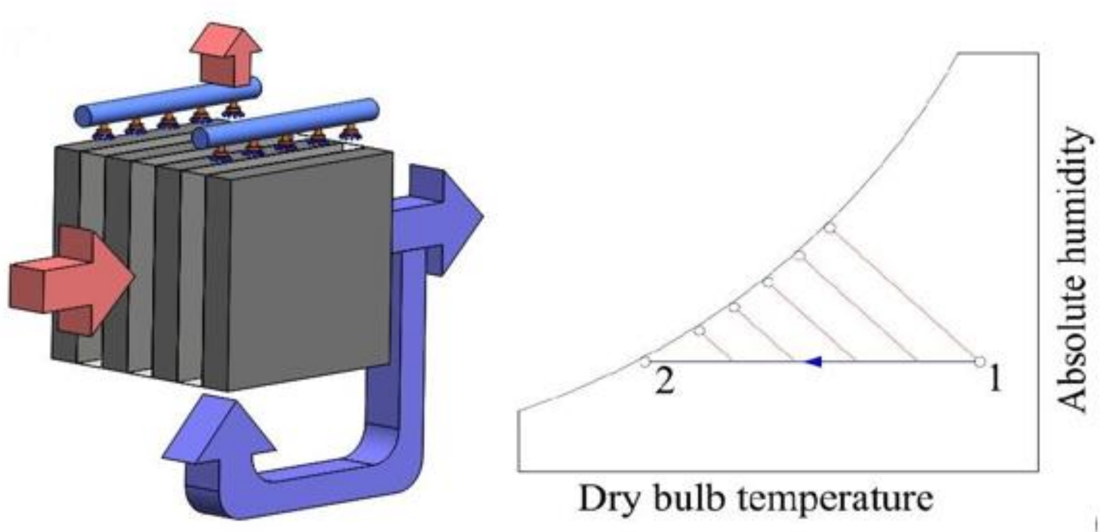

Figure 11: Maisotsenko Cycle

2.1.6. Dew Point Evaporative Cooler (M-Cycle)

Maisotsenko Cycle is based on indirect evaporative cooling. This method was proposed by Valery S. Maisotsenko and Alexandr N. Gershuni in 1987 in Soviet Union and was later patented in the United States of America in 1990s as “Method for indirect evaporative cooling”.[2] The process is considered to be adiabatic cooling because no heat is exchanged with the environment. In this process, the primary heat moves in the dry channel, gets cold and part of it is then sent back into the wet channel as working air. This working air absorbs water in the wet channel and then released into the atmosphere.

Chapter 3:

3. Construction and Experiment

In this chapter the overall structural design of M-cycle and cooling tower describe here. The results of experiments performed on it also describe in detail in this chapter.

3.1. Structural design of M-cycle and cooling tower

The structural design of M.cycle consist of following parts

- Heat exchanger
- Water distribution nozzles
- Inlet air blower
- Exhaust air fans
- Water pumps
- Blower speed controller

The structural design of cooling tower consist of following parts

- Inlet air fan
- Outlet air fan
- Water distribution shower
- Water pumps

3.1.1. Heat Exchanger

Heat exchanger made from felt material coated aluminum sheet which coated which can absorb large amount of water. The heat exchanger consists of 10 dry channels and 10 wet channels. To avoid contact of air with water acrylic sheets are installed for proper separation.

3.1.2. Air Fan

Fans are mounted at inlet and outlet of system for supply of air. They all are provided by potentiometer and characterized by the ability to provide a high coefficient of pressure; an axial fan is placed in the ventilation system of the system to provide air flow. Inlet and exhaust fan having different speed range of fan and by changing speed inlet air flow is provided for heat exchanger.

3.1.3. Casing

The whole setups of this experiment are made up of Acrylic sheets casing.

3.1.4. Felt material on aluminium sheets:

Felt material on aluminium sheet water absorbing material, used to keep the surface of aluminium sheet wet. The heat transfer efficiency increase after attaching felt material with aluminium sheet.

3.1.5. Acrylic Sheets:

Acrylic sheet used to separate dry channel and wet channel in heat exchanger and the whole structure of M-cycle made from this material. Reason behind using acrylic sheet for manufacturing of M-cycle is to make the whole process visible and the reason behind using acrylic sheet in between channels is to separate wet channel from dry one.

3.1.6. Water Cooler Material:

Initially, cooling towers were made primarily of wood, including frame, cable, spaces, overflow and cold water. Sometimes the basin of cold water was made of concrete. Today, manufacturers use a variety of materials to build cooling towers. The building materials are selected to improve corrosion resistance, reduce retention, and promote reliability and longevity. Combined steel, various grades of stainless steel, fiber glass, and concrete are widely used in tower construction, as well as aluminum and plastics in some parts.

3.1.7. Water Cooler Nozzle:

Plastic is also widely used for microphones. Most pipes are made of PVC, ABS, polypropylene, and nylon filled glass.

3.1.8. Water cooler Fan:

Aluminum, fiberglass and hot metal are the most widely used building materials. Centrifugal fans are usually made of composite steel. Propeller fans are made of composite steel, aluminum, or reinforced plastic glass.

3.2. Experimental Model:

The experimental setup developed in lab. This whole setup made up from acrylic sheet and consists of inlet fan, exhaust fans, heat exchanger, water pump and water distribution nozzles. Inlet fan used to throw air with different velocities in heat exchanger. To control speed of both inlet and exhaust fans potentiometer have been used. Water pump are used to circulate water through water distribution nozzles which sprayed water on heat exchanger. The flow of water in vertical direction while the air flow in horizontal direction but both channels are separated from each other completely

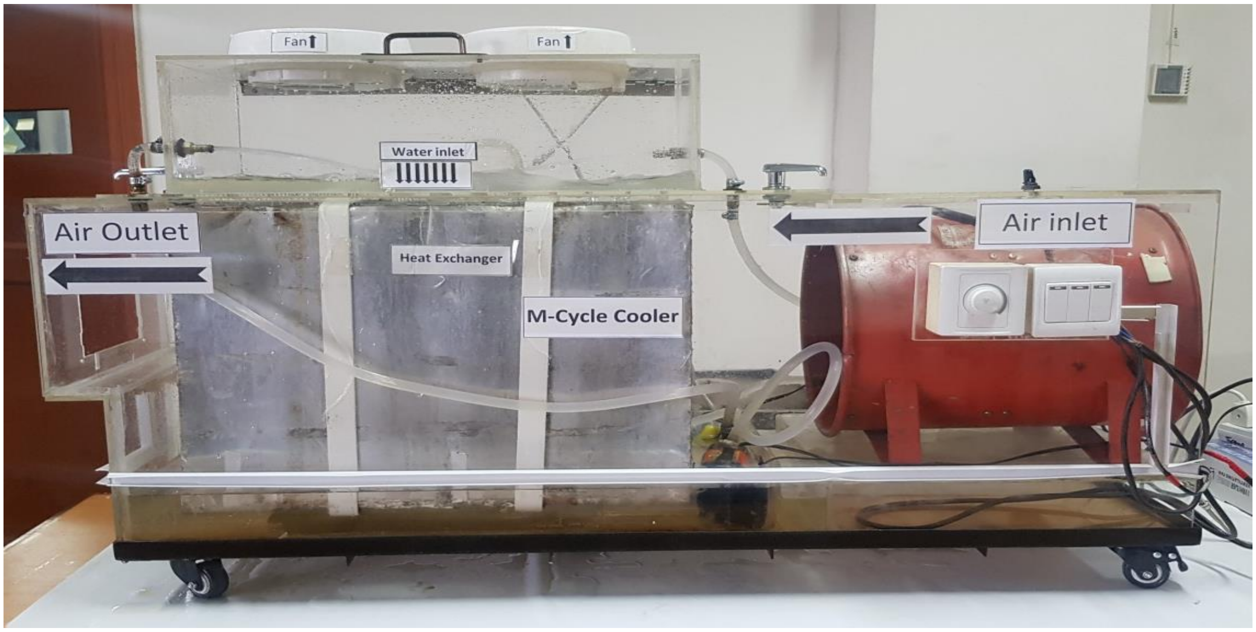

Figure 12: M-cycler Experimental Arrangement

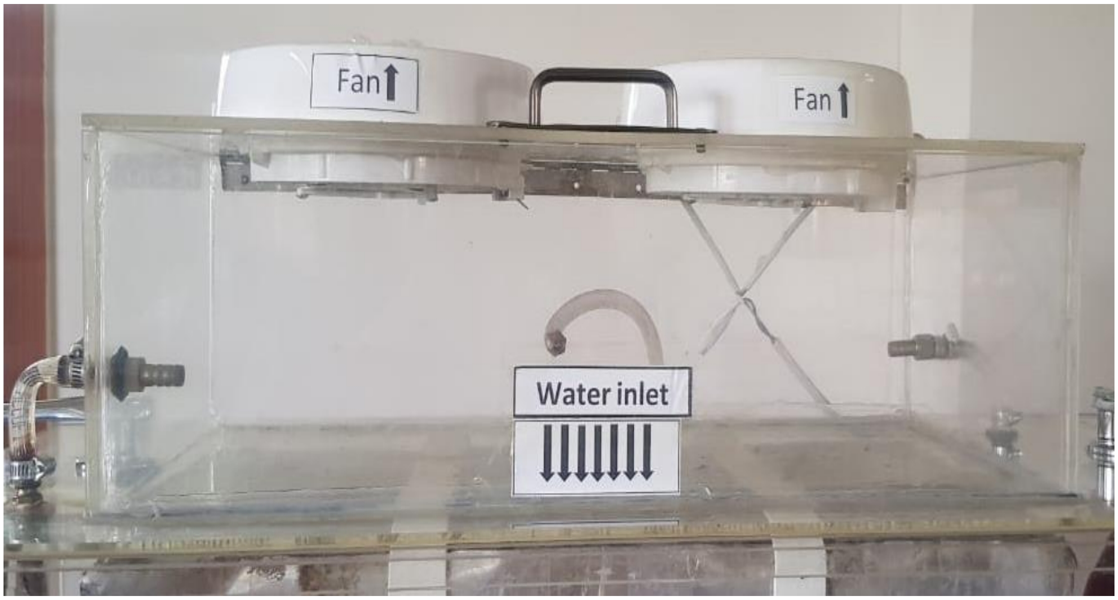

Figure 13: Water sprinkling arrangement

Figure 14: Cooling tower Experimental setup

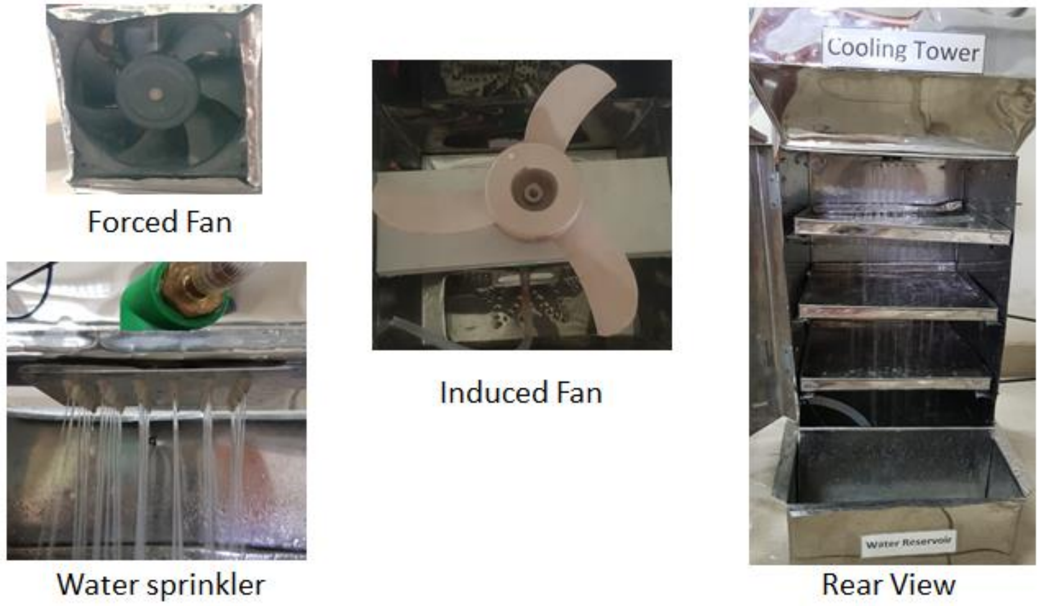

Figure 15: Cooling tower Experiment Arrangement

3.3. Specifications of Equipment:

Details of the specifications of the cooling equipment used in the experiment are shown below. Various parameters such as thickness details and details of the dry and wet channels are also entered below.

Table 3.1: Specifications of Equipment

Sr. No	Parameter	Dimensions
1	Wall Material	Aluminum
2	Wall thickness	0.5 mm
3	Length of dry channel	550mm
4	Length of wet channel	280mm
5	Width of Channel	400mm
6	Channel Gap	12mm
7	Number of wet channels	10
8	Number of dry channels	10

3.4. Cooling Tower

- **Cooling Tower Approach**

Approach = Cold water temperature – Wet bulb temperature

$$\text{Approach} = T_{w2} - T_{wb1}$$

- **Cooling Tower Range:**

Range = Hot water temperature – Cold water temperature

Range = $T_{w1} - T_{w2}$

- **Effectiveness** = ε = $\frac{Range}{Range + Approach}$

$$\varepsilon = \frac{T_{w1} - T_{w2}}{T_{w1} - T_{wb1}}$$

Chapter 4

4. Calculations and Experimental results discussions

From the results obtained from experimentation, on heat transfer the lowest effect is generated by induced fan. Air flow it is very weak on the other side of the tower. Therefore, inefficient cooling is detected. Level of minimum evaporation loss compared to other cases. Therefore, it is necessary HVAC engineers and technicians continue to investigate the weakness of having only fans in cooling towers. From result it’s shown that highest efficiency can be obtained from combined case.

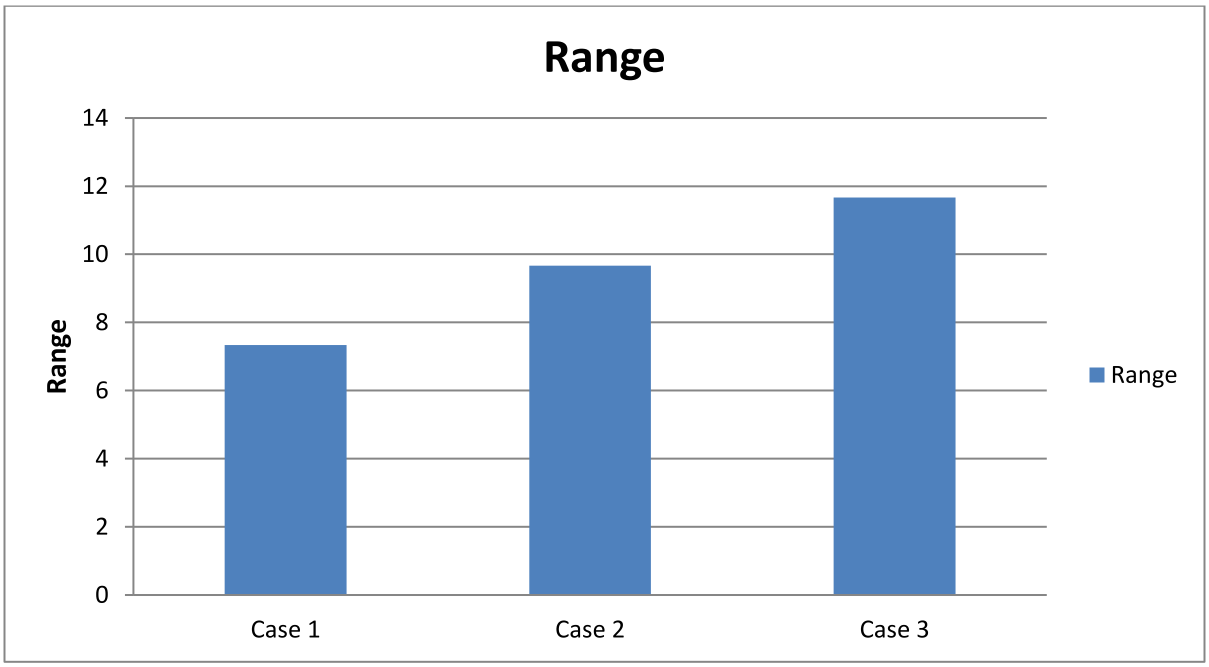

Figure 16: Comparison of range of all three cases

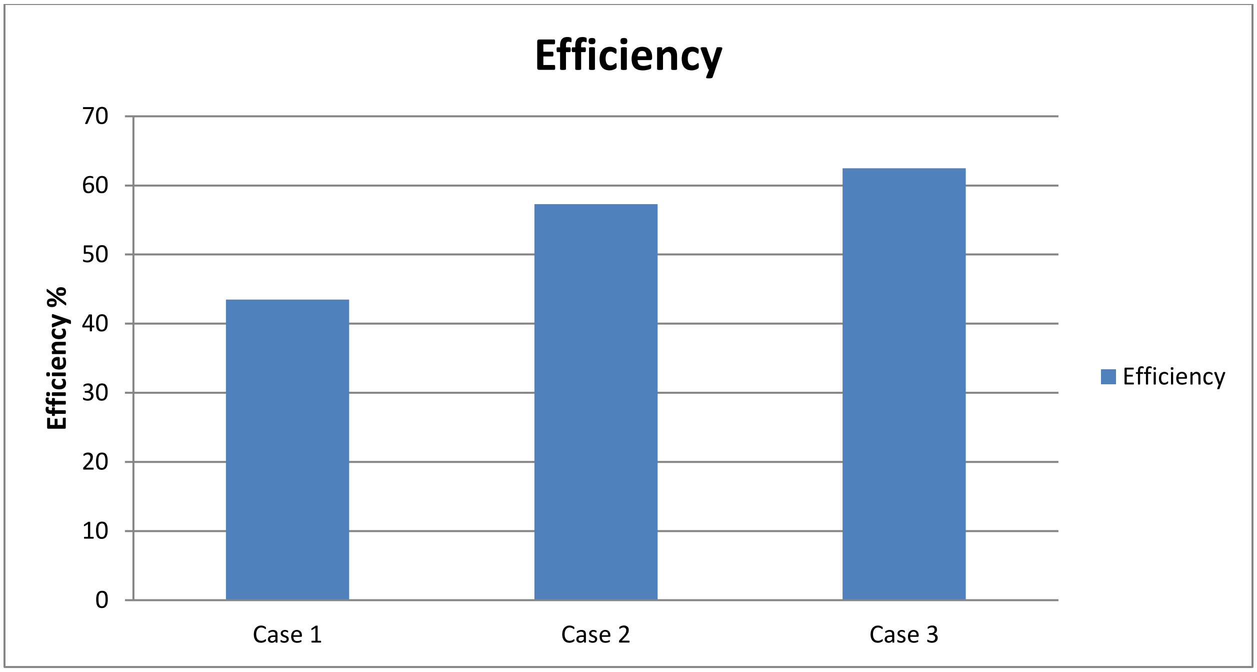

Figure 17: Comparison of efficiency of all three cases

- Without fans & extra water nozzles

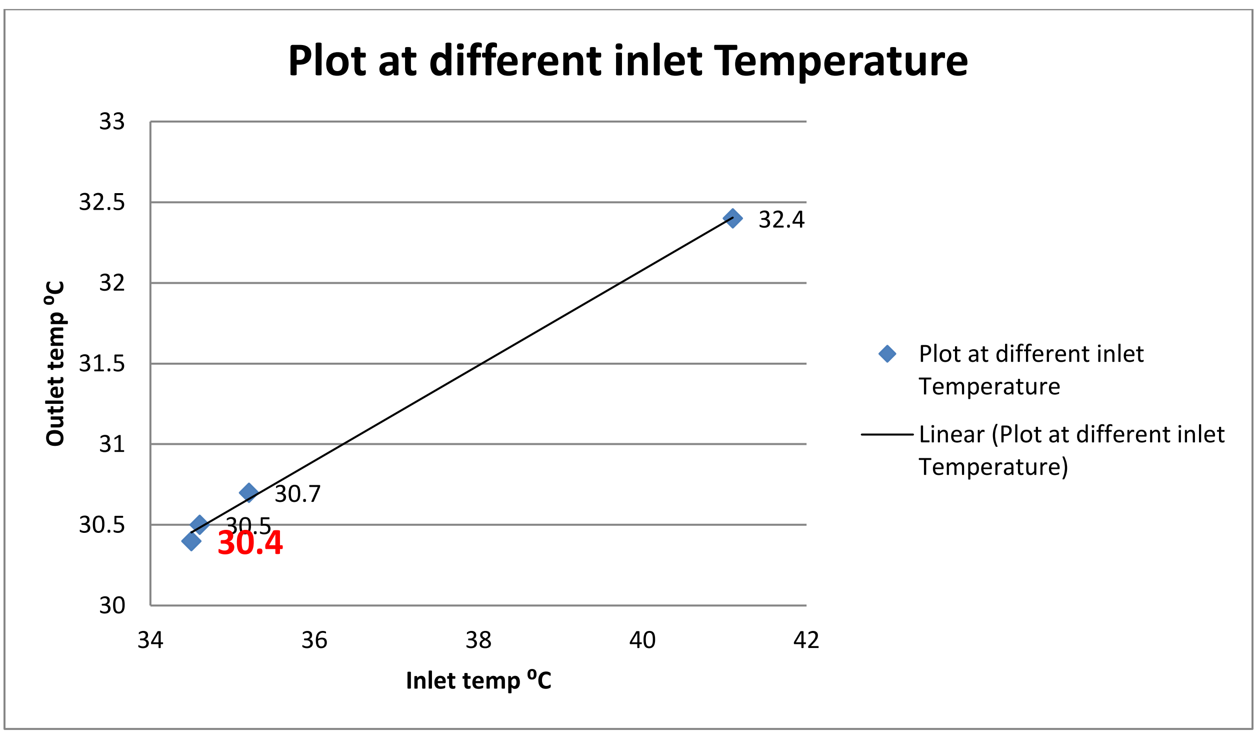

Figure 18: Effect of changing Inlet temperature (v = 2 m/s) at constant humidity

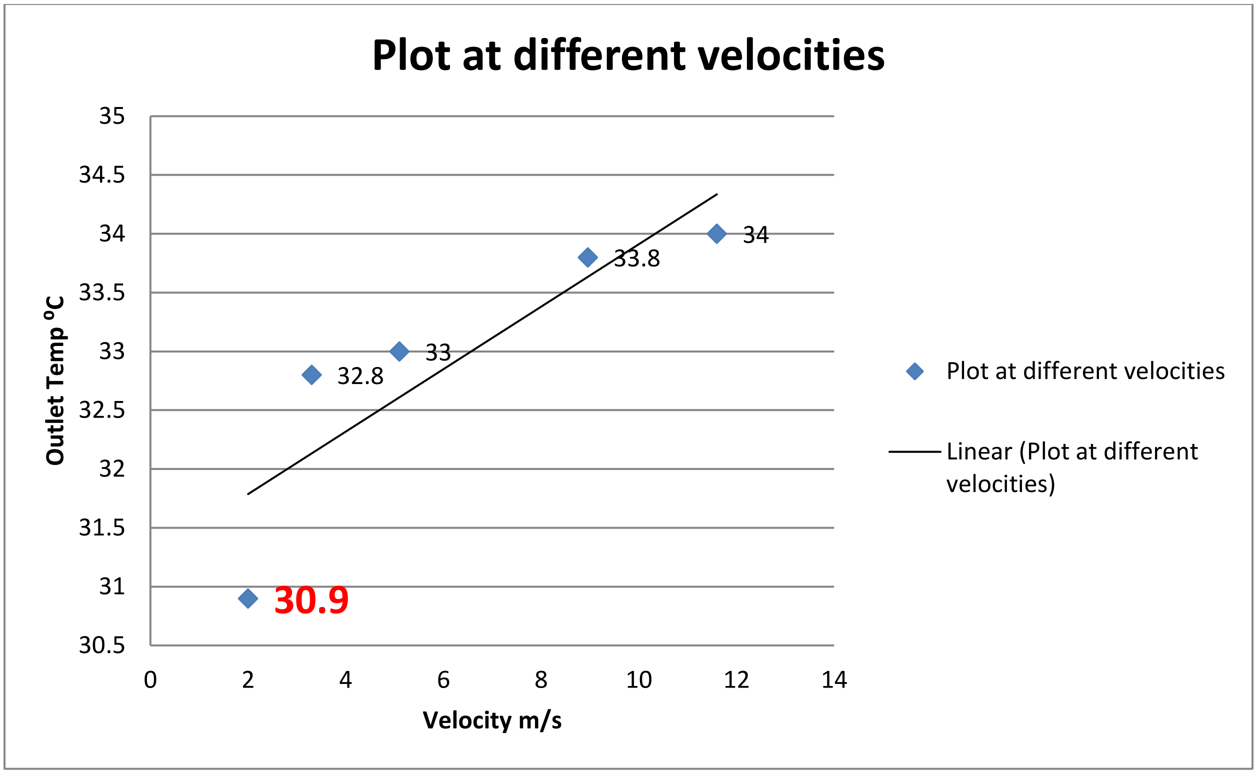

Figure 19: Effect of changing velocities at constant humidity and inlet temperature

- With fans & extra water nozzles

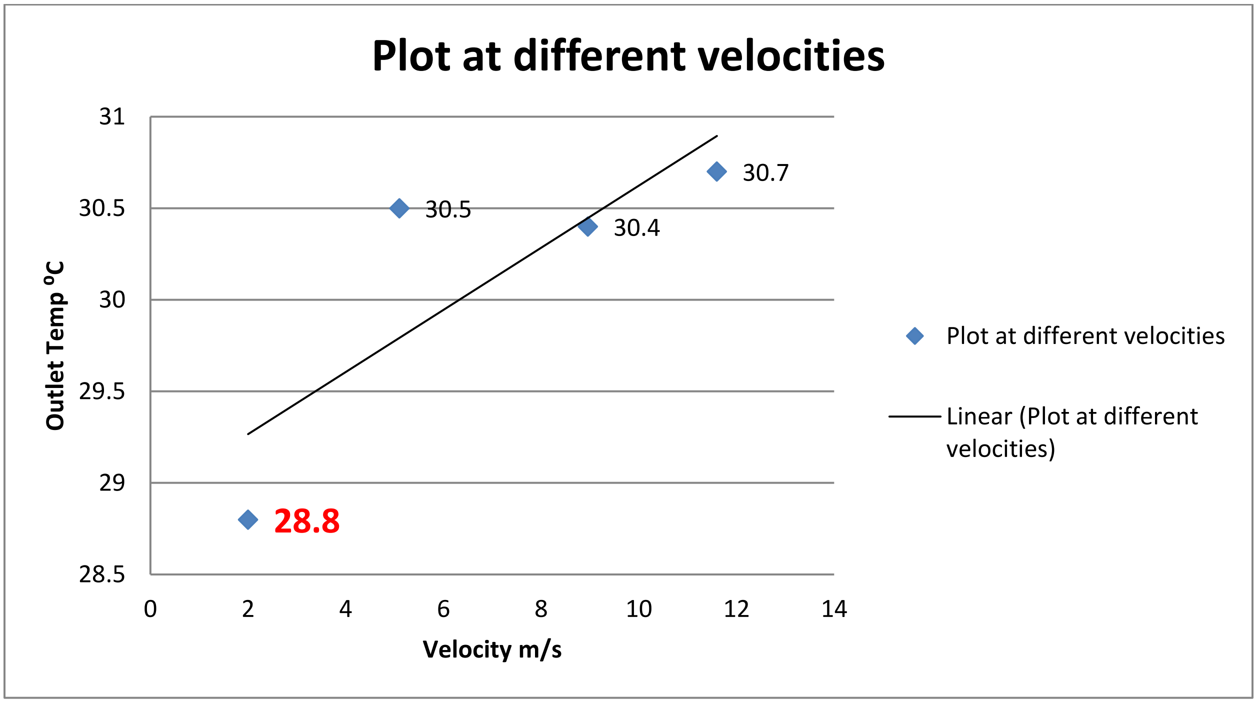

Figure 20: Effect of changing velocities at constant inlet temperature

- With fans, water nozzles & cooling tower

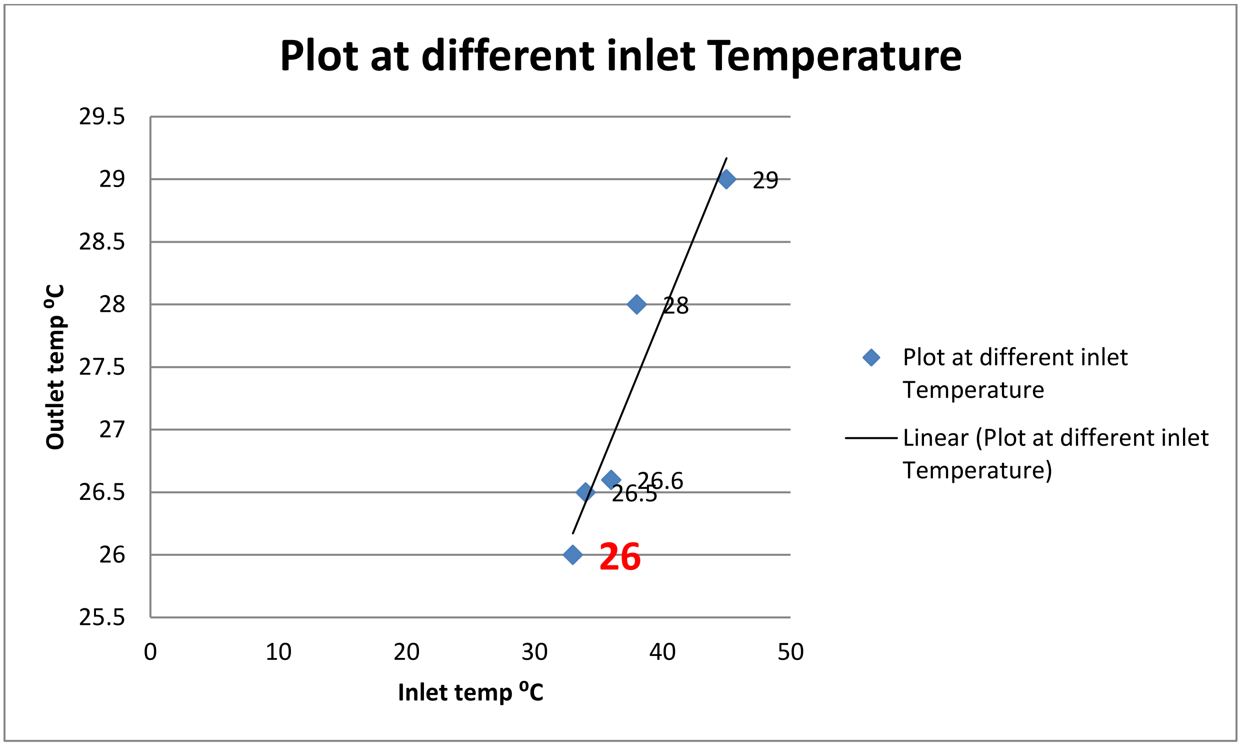

Figure 21: Effect of changing Inlet temperature (v = 2 m/s) at constant humidity

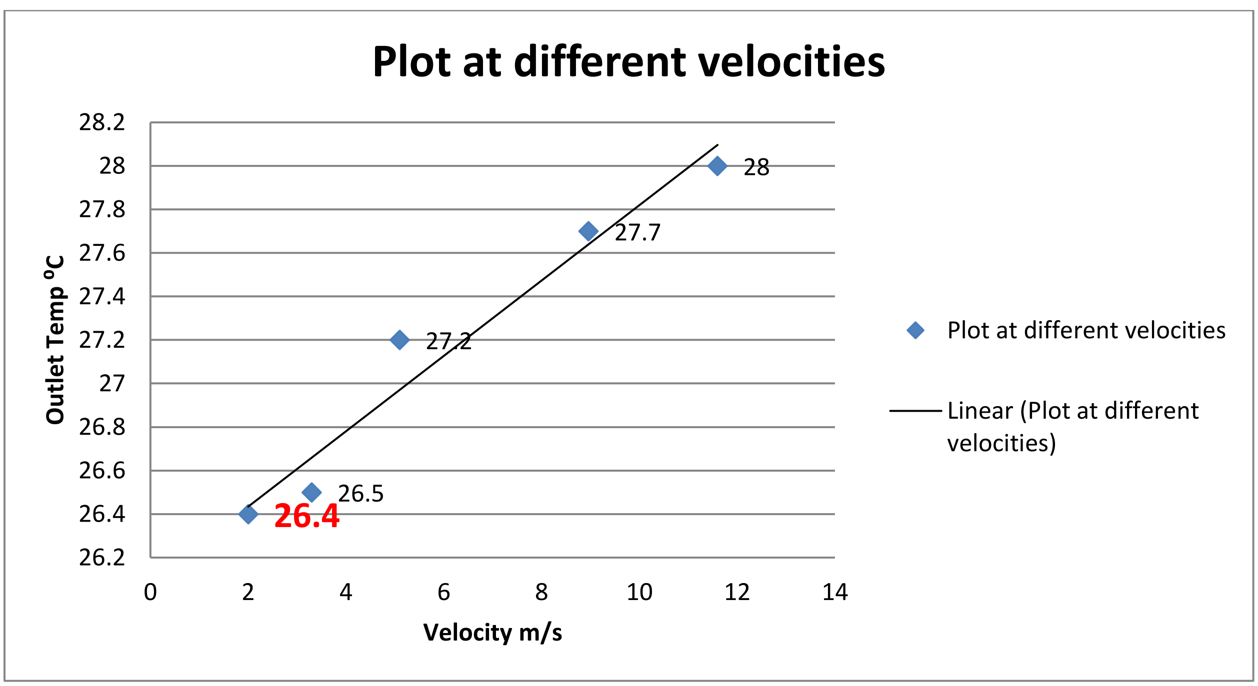

Figure 22: Effect of changing velocities at constant inlet temperature

4.1. M-Cycle Calculations

The heat from the hot air is removed by two sources:

(1) Water evaporating in wet channel (latent heat)

(2) Sensible heating of air coming back from outlet

4.1.1. Air Parameters:

Temperature of hot air at inlet = $T_1 = 45℃$

Relative humidity of inlet air = 35%

Temperature of hot air at outlet [Product Air to room] $=$ T_2= $26℃$

Temperature of cold inlet air [50% air back] =T_3= $25℃$

Temperature of fully saturated air at outlet [exit air to atmosphere] =$T_4 = 29℃$

4.1.2. Cooling Tower Effectiveness

For the efficiency of cooling tower, two terms are of primary importance:

a) Approach = Cold Water temperature (outlet) - Ambient Air Wet Bulb Temperature
b) Range = Hot Water Temperature (inlet) - Cold Water Temperature (outlet)

Then

$$\mathbf{Effectiveness} = \mathbf{Range} / (\mathbf{Range} + \mathbf{Approach})$$

$$\mathbf{Evaporation\ Loss}\left(\frac{\mathbf{m^3}}{\mathbf{hr}}\right) = \mathbf{0.00085\ x\ Range\ x\ 1.8\ x\ Circulating\ Cooling\ Water}(\mathbf{m^3/hr})$$

$$\text{Circulating Cooling Water} = 1300 \text{ liters/hr} = 1.3\text{m}^3/\text{hr}$$

Case-1: Forced fan Analysis (Base)		
Temperature of inlet air	33	C
Relative Humidity	35	%
wet bulb temperature of inlet air	21.802	C
water inlet temperature	38.67	C

Water outlet temperature	31.33	C
Range	38.67-31.33 = 7.34	C
Approach	31.33-21.802= 9.528	C
Effectiveness	7.34/(7.34+9.528) =0.43514	
Evaporation loss	0.014599	m^3/hr

Case-2: Induced Fan Analysis (Roof)		
Temperature of inlet air	32.33	C
Relative Humidity	35	%
wet bulb temperature of inlet air	21.276	C
water inlet temperature	38.67	C
Water outlet temperature	29	C
Range	9.67	C
Approach	7.724	C
Effectiveness	0.555939	
Evaporation loss	0.0192336	m^3/hr

Case-3: Both Fans Analysis (Base)		
Temperature of inlet air	32.67	C
Relative Humidity	35	%
wet bulb temperature of inlet air	21.543	C
water inlet temperature	38.67	C
Water outlet temperature	27	C
Range	11.67	C
Approach	5.457	C
Effectiveness	0.68138	
Evaporation loss	0.0232116	m^3/hr

4.1.3. Load Calculation for the Prototype

Submersible Pumps Specifications		
Total Pumps	3	units identical
Flow rate	1300	litre/hr
Voltage	220	V

Maximum Head	2.5	m
Supply frequency	50	Hz
Power for 1 pump	25	W
Power for 3 Pumps	**75**	**W**

Exhaust Fans Specifications		
Two identical upper fans		
Diameter	6	inches
Voltage	220	V
Supply Frequency	50	Hz
Power for 1 fan	15	W
Power for 2 fans	**30**	**W**

Main Inlet Fan Specifications		
Voltage of Supply	12	V
Supply current	19	A
Power for fan	**228**	**W**

Total Load of M-cycle Cooler	**75+30+228 = 333**	**W**

It means half of the power is required for heat transfer rate for the given system. So we can say roughly 0.666 kW Power would be required for 1 ton cooling

- **Electricity Cost for Prototype:**

Power of the system	0.333	kW
Time	1	hr
No of units (kWh) consumed = Power (kW)* time (hr)	0.333	kWh
Cost for 1kWH in Pakistan [for first 100 units]	5.79	PKR
Total Operating cost for 1 hr No of units * Cost for 1 unit	**0.333*5.79=1.92807**	**PKR**

- **Electricity Cost for 1 ton of M-Cycle Cooler:**

Power of the system	0.666	kW
Time	1	hr
No of units (kWh) consumed =	0.666	kWh

Power (kW)* time (hr)		
Cost for 1kWH in Pakistan [for first 100 units]	5.79	PKR
Total Operating cost for 1 hr No of units * Cost for 1 unit	**0.666*5.79= 3.856**	**PKR**

- **Comparison with 1 Ton Supreme DC Inverter AC Gold Fin:**

Cooling Capacity	1	ton
Rated Power Consumption	1100	Watt
Power of the system	1.1	kW
Time	1	hr
No of units (kWh) for one hour	1.1	kWh
Cost for 1kWH in Pakistan	5.79	PKR
Total Operating cost for 1 hr No of units * Cost for 1 unit	**6.369**	**PKR**

Chapter 5:

5.1. Conclusion:

The system is viable for summer season with high relative humidity. The effectiveness of the system decreased only slightly for higher velocities. This indicates that system is suitable for small commercial scale for air conditioning applications. The results were not affected to a greater degree with the use of liquid desiccant de humidifier. This indicates the system alone can serve the cooling with de humidification. From results conclude that the electricity cost of M.cycle is half than any other commercial air condition.

5.2. Future Work:

The experiment has been conducted on limited range of velocities. The use of high speed blower for high air flow is required for use of this cycle at large commercial scale. The use of viable regeneration technique for desiccant dehumidifier is required to be established for use of desiccant with commercial scale model. HMX configuration can be improved by using latest material with high water absorbing capacities.

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