Parametric Study of M-Cycle Evaporator Cooler

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Declaration

I certify that this research work titled “Parametric Study of M-Cycle Evaporator Cooler” is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Muhammad Zulfiqar

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Copyright Statement

Acknowledgements

In the name of Allah, the Magnificent, the Merciful.

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Dedicated to My Father

Without Whom I am Nothing

Abstract

Refrigeration and air conditioning systems consume a major portion of the electricity produced. A dew point evaporative cooler was constructed and analyzed on the basis of outlet air temperature and effectiveness by varying the inlet air properties i.e. humidity, temperature and velocity. The wet bulb effectiveness measured in the experiment was between 65 % and 125 %. Whereas the dew point effectiveness ranged from 30 % to 85%. The system was also operated with inlet air being treated by a liquid desiccant dehumidifier for operation in humid climates. The liquid desiccant reduced the outlet relative humidity by 4% to 8%. An improved cross flow HMX (Heat and Mass Exchanger) composed of aluminum sheets coated with felt material sheets were used and the working to product air ratio was fixed at 0.5. The experimental results obtained were compared with the available literature and improved effectiveness was observed. The system provided a viable option to replace the conventional energy intensive mechanical vapor compression system with energy efficient and an environment supportive alternate. The paper focuses on the m-cycle cooler. The M-cycle cooler was manufactured with an improved cross flow HMX (Heat and Mass Exchanger) composed of aluminum sheets with felt sheets. The working to product air ratio was fixed at 0.5. The experimental results obtained were compared with the available literature and improved effectiveness was observed. The wet bulb effectiveness measured in the experiment was between 65 % and 125 %. Whereas the dew point effectiveness ranged from 30 % to 85%. The proposed system provides better efficiency as compared to the literature, the results were discussed with the effect of different variables. Hence the proposed cooler has better effectiveness as the system can be made commercially suitable for medium load applications. An efficient dew point cooler has been developed based upon Maisotsenko cycle. The testing was conducted on different cases (temperature, humidity, Inlet air velocity and dehumidifier). Improved wet bulb and the dew point effectiveness was attained by experimentations. Better effectiveness was observed for the higher relative humidity.

Key Words: Air Conditioning, Evaporative Cooling, Dew Point Cooler, Sensible Cooling Maisotsenko Cycle.

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Chapter 1

Introduction

With the increase in world energy consumption in the recent past has caused concern worldwide and the need for alternate energy sources as well as replacement and revision of existing Energy cycles is growing alongside. As Zulfiqar pointed out during his comparative study (Zhan, Duan et al. 2011) about 20 to 40 % of the world's energy is consumed by Architecture. Among that figure, half of the energy is being consumed by Air Conditioning Applications. This means that about 20 % or $1/5^{th}$ of the total energy consumption worldwide is in the Air conditioning applications. This is a quite a large figure when compared to other energy consumption applications. With the exponential increase in the world population, rise in the world temperature, abundance of the buildings. and increased demand of comfort conditions this is figure is only going to increase.

In past the compression system consisting of condenser, evaporator and compressor was the only way of air conditioning. This system operates on reverse Carnot cycle and uses refrigerant gases (R-22, R-134a). The operation of this system is quite simple. The refrigerant of evaporator changes the state of liquid from liquid to vapor to extract heat from exchanger. The vapors are then compressed by the compressor and are supplied to the condenser which transfers the energy to convert the vapor to the liquid state. In the wake of leaving Condenser, the flow of refrigerant is from expansion valve with the large then returning into evaporator by completing cycle. As a result of its great cooling capacity, this procedure has been safeguarded and improved for quite a while. As of now, the ease, full-developed innovation and great agent and upkeep exhibitions clarify why regardless it overwhelms the ventilating market. In spite of aforementioned advantages, very high consumption of the electricity has been a major concern for this cycle. Further in order to dissipate the high energy produced during the process, other equipment is also required to be installed. The refrigerant gases used in the process are also not environment friendly. These gases are a major contributor for the depletion of ozone layer and rise in the temperature of earth in the recent past.

The idea of Evaporative cooling is old. Ancient civilizations used these phenomena predominantly in Egypt. They used porous utensils covered with liquid submerged clothes for food preservation during the extreme hot Egyptian weather. They also used wet chutes embedded into walls for cooling. This implausible technique was soon spread into the places where temperature was very high. This practice can still be seen to date at different parts of the world. As in example, Figure 1.a demonstrates the set to wet cushions joined to its working, through water is splashed by holes. The water cooling the ambient intake flow by evaporation and provides cooled humid air to the inside surroundings. This is very common equipment that is being used in deserts, dry environments and is common in developing countries where income level of people cannot afford conventional Air Conditioners. We ourselves often experience evaporative cooling in daily life. For example when we take bath and stand in front of a fan, a sense of cooling is felt due to the evaporation of water from our body.

Figure 1: Wet pads in horticulture

1.1 Explanation of Research

1.1.1 Research Concept:

An aluminum sheet with acrylic sheets is proposed to supplant the current exchanger outline. The sheets are required stacked together utilizing aides of a similar felted, as appeared in Fig. 1.2, each sheet is wetted with a felt sheet from one side to liquid infiltration.. Activity would be as per the following: The wind currents through the channels and is partitioned into two sections: One part noticeable all around stream continues moving at a similar orientation and where the main requirement was to cool, and the air stream is redirected to neighboring water ways channel.

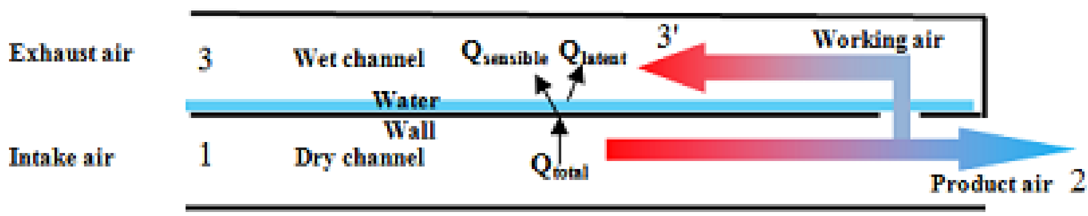


Figure 2: Air Flow in Heat Exchanger.

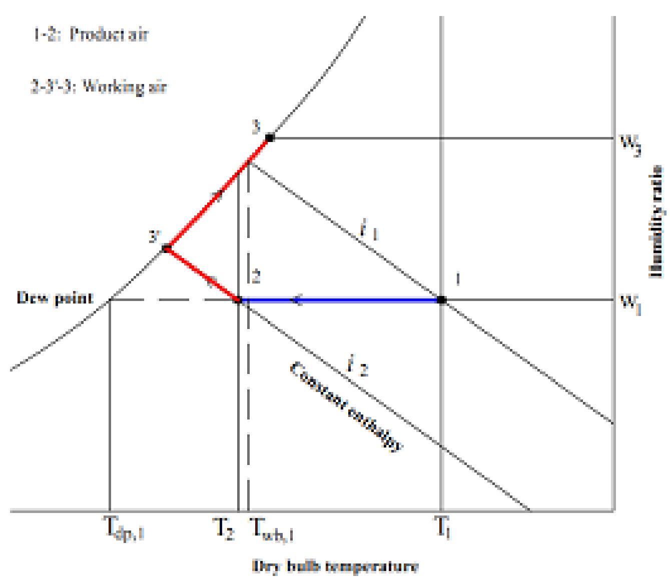


Figure 3: Air Conditioning Process on Psychometric Chart.

1.1.2 Research Objectives:

The designated inquire about design is to improve the outline of the exchanger regarding its structure, design and material selection. The new exchanger will prompt change in both wet-globule and dew-point adequacy at low speeds. The particular goals of the exploration include:

- Optimization of the exchanger configuration, as far as structure, design and material selection and cost.
- Development and research center testing of system.
- Monetary, ecological and territorial acknowledgment investigations.

1.1.3 Thesis Structure:

In the Chapter No.1 illustrates the background and motivation for the study of EC System, which normally consists of two types namely DEC and IDEC type. Both types are evaluated on the basis of past research. It is found that IDEC has a discrete advantage over DEC cooler as in the former. Hence it remedies problems pertaining to the creation of moisture, spread of bacteria and fungus. Further INDEC cooler also has the ability to operate in humid climates. main focus about research is IDEC system and in particular on the Maisotsenko Cycle.

In Chapter No.2 thoroughly surveys the writing on the backhanded EC framework. From writing audit, it is watched that regularly two kinds of arrangements are connected in the IDEC, which are plate and tubular compose. Exceptional accentuation is on Maisotsenko cycle.

In the Chapter 3, experimental arrangement used in this thesis is explained. Justification for the configuration used, the material and the mechanism of air flow has been explained in detail. The selection of desiccant, its merits and demerits are explained in detail. The construction of HMX and the reasons for the selection of the model are being explained.

In the Chapter 4, results are being presented. Discussion has been made on the obtained results. Various factors affecting the results are discussed in detail. The inlet air temperature, inlet humidity ratio, feed water intake temperature and the effects by using the liquid desiccant are discussed in detail.

In Chapter 5 conclusions are being drawn from the obtained results and are explained.

1.1.4 Brief Introduction of the Evaporation Processes

1.1.4a Direct evaporative cooling system:

This cooling system utilizes the concept of evaporation in order to extract the heat from the hot fluid (i.e. Air) through the evaporation of water vapors. According to the type of operation used, normally have two kinds:

- DEC System
- IDEC system.

The system utilizes the concept of evaporation, the water absorbs heat from the hot air, evaporates and the temperature of supply air is being lowered in the process. The cooling of hot air takes place from 1 to 2 and the saturated occurs at 1', this indicates to loss of sensible heat with increase of moisture content

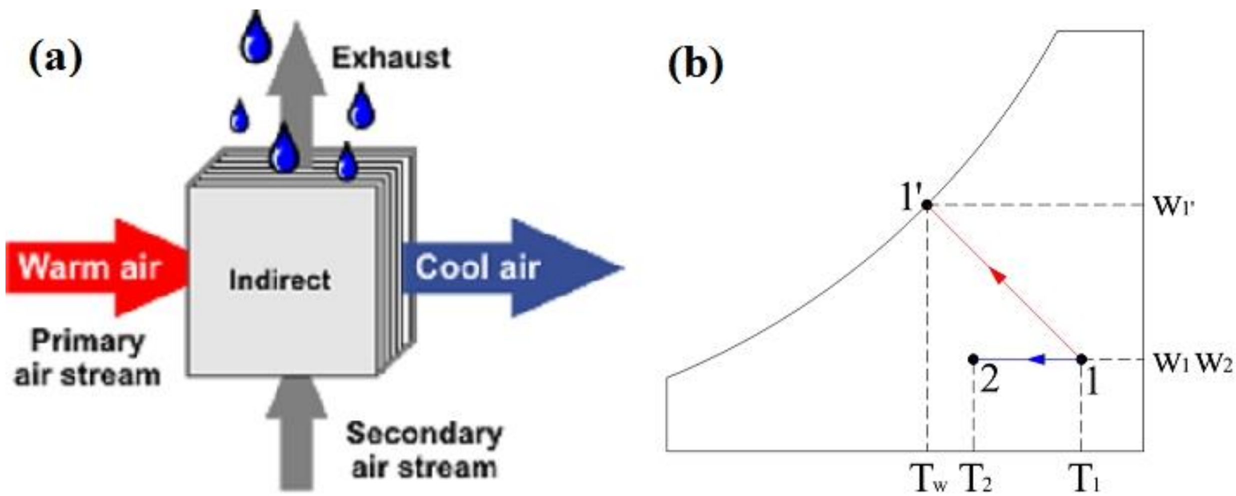


Figure 4: In Direct Evaporative Cooling (IDEC) (b) Representation on Chart

1.1.5 IDE Cooling System :

IDE cooling system differentiates intake is supplied in form of spray water by the use of wet and dry sections. Hence intake air is supplied to heat exchanger; in the meantime the working air flows across the wet portion, and directed towards the water. In this process, heat given off by the primary air transfers to gets wet by the water. The evaporated water is then flows out with the secondary air. The working of IDEC system on the chart. The state of intake air moves from the point 1 to point 2, temperatures is decreased but the humidity is unaffected which actually shows that water vapors in air. As higher humidity is related to high latent load and causes discomfort in the occupants, the no change in the humidity level makes the indirect evaporative cooling process much more effective process in hot humid conditions [4].

Contrary to this, the auxiliary air gets un-adiabatically cooled from direct 1 toward point 1' which is immersion point. The soaked states of both the streams are indistinguishable as the surrounding air is being utilized as optional air. It is to noted here that the wet globule temperature of optional air will be bring down that the leave temperature of essential air so the warmth and mass exchange can 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.

The same is shown in the below equation for the wet bulb effectiveness which is used as a base standard for the calculation of cooling effect in the evaporative cooling process [5]

$$\epsilon_{\mathrm{wb}} = \frac{T_{db,in} - T_{db,out}}{T_{db,in} - T_{dew,out}} \qquad \text{Equation 2-1}$$

Literature Review:

2.1 Background:

Contrasted and the prevalent regular vapor-pressure and retention refrigeration, the evaporative cooling has a couple of essential points of interest : a) huge capacity of vitality sparing and carbon dioxide outflow diminishment on the grounds that no real vitality expending blowers exist in evaporative cooling systems; b) a domain benevolent cooling innovation in light of the fact that exclusive water contribute in the cooling procedure as opposed to perilous refrigerants; c) it is straightforward as far as arrangement, produce, and control methodologies. A large portion of regular aerating and cooling systems depend on vapor-pressure and retention refrigerating cycles, that is set up innovation and has widely connecting in business structures. This shows to vapor-pressure and ingestion refrigeration systems are relentless and satisfactory to give cooling to structures. By and by, they are vitality comprehensive refrigeration advancements because of the utilization of vitality expending blowers. As no blower is introduced, the EER estimations of evaporative cooling systems are considerably larger. The vitality usage of evaporative cooling systems is normally 30-half that of vapor pressure aerating and cooling system of a similar limit. Subsequently, the EER estimation of an evaporative cooling system is that of a commonplace vapor-pressure [8].

Refrigeration cycle	Vapour-compression	Absorption	Adsorption	Desiccants	Ejector	Thermoelectric
EER(Btu/Wh)	7-17	2-3.4	0.7-2.7	1.7-5.1	0.9-2.7	1.7-3.4

Figure 5: Characteristic values

The present standard refrigerants used as a piece of vapor-weight ventilating frameworks have magnificent an unnatural climate change potential (GWP) and they can get warm more than CO2 (Wobbles) .

Working Principle of EC Cooling Systems:

2.2.1 DEC System:

This type of configuration has both speculatively, tentatively through numerous researchers as it is anything but difficult to manufacture and has high proficiency in hot and dry regions [6-9]. It has wide application and has set up to be exceptionally conservative and straightforward in task. Heidarinejad [10] completed the execution trial of a direct cooler joined it in Tehran. His examination portrayed that this system completely furnished the solace condition having more uses of effectiveness and extraordinarily decreased the cost of power. An execution examination was likewise completed by Elmetenani [11] for coordinate evaporative cooling system controlled by sun powered vitality with photovoltaic boards in Algeria. The got information about the temperature drop of air supplied was accomplished to the figure of 18.86℃ and because of the predominant hot and dry atmosphere, over 65% of the nation was profiting from Direct Evaporative system. It can be viewed as sufficient and agreeable in numerous applications. Henceforth, the electrical vitality utilization related with this kind of cooling gear is very low, bringing about expanded electrical coefficient of execution (COP). Conversely, the issue of bacterial spread related with high water vapor content likewise keeps the gigantic augmentation of DEC. This offered ascend to indirect evaporative cooling system and it gradually picked up its prevalence.

Guide EC connects dampness into product cooled air. The graph of DEC and the doing phenomenon spoke to Psychometric diagram has been appeared in Fig. 2-1a.

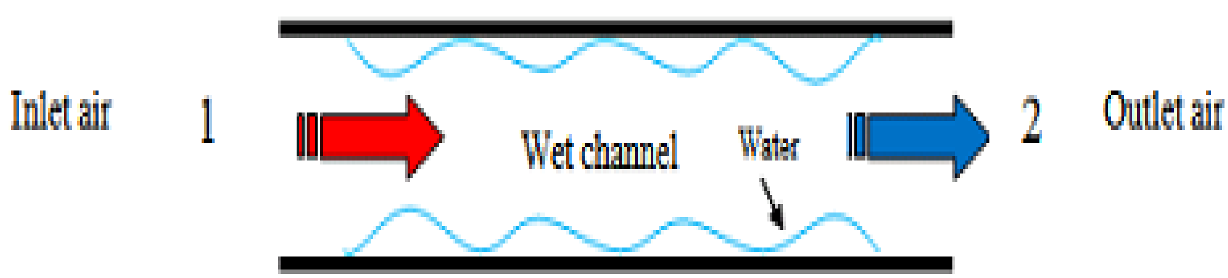


Figure 4: DEC System

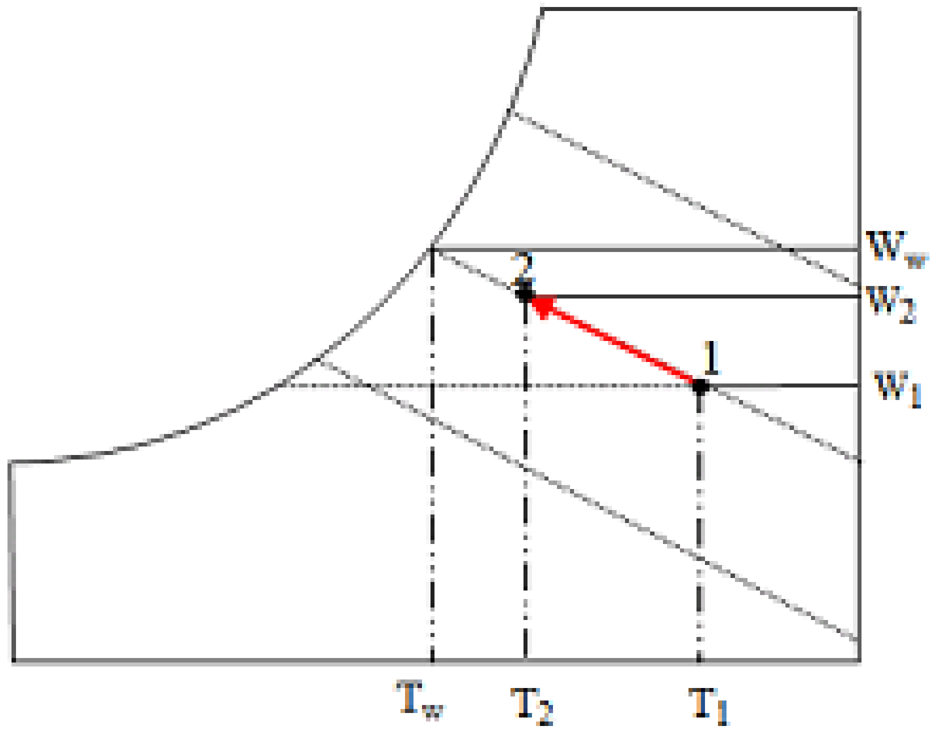


Figure 6: Process shown on Chart

Fig: 6 (a) and process shown on chart (b) DEC system

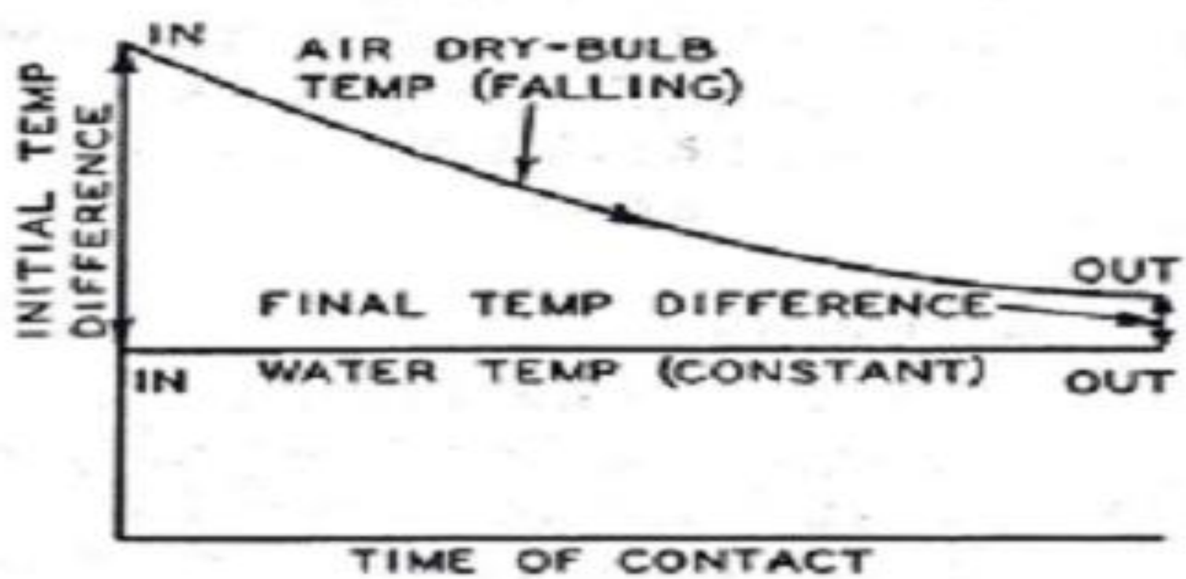


Fig 7: Process of Temperature of air in contact with water for change in DEC Process

A important term for figuring adequacy of this cooling systems is how much outlet air is drawing nearer the WB temperature of intake air, i.e that is characterized to take after:

$$\epsilon_{wb} = \frac{T_{db,in} - T_{db,out}}{T_{db,in} - T_{dew,out}}$$

2.2.2 IDEC System:

This type of indirect system has been contemplated both speculatively and tentatively by numerous researchers as it is anything but difficult to manufacture and has high proficiency in hot and dry regions [6-9]. It has wide application and has set up to be exceptionally conservative and straightforward in task. Heidarinejad [10] completed the execution trial of a direct cooler joined it in Tehran. His examination portrayed that this system completely furnished the solace condition having more uses of effectiveness and extraordinarily decreased the cost of power. An execution examination was likewise completed by Elmetenani [11] for coordinate evaporative cooling system controlled by sun powered vitality with photovoltaic boards in Algeria. The got information about the temperature drop of air supplied was accomplished to the figure of 18.86℃ and because of the predominant hot and dry atmosphere, over 65% of the nation was profiting from Direct Evaporative system. It can be viewed as sufficient and agreeable in numerous applications. Henceforth, the electrical vitality utilization related with this kind of cooling gear is very low, bringing about expanded electrical coefficient of execution (COP).. Conversely, the issue of bacterial spread related with high water vapor content likewise keeps the gigantic augmentation of indirect evaporative cooler.

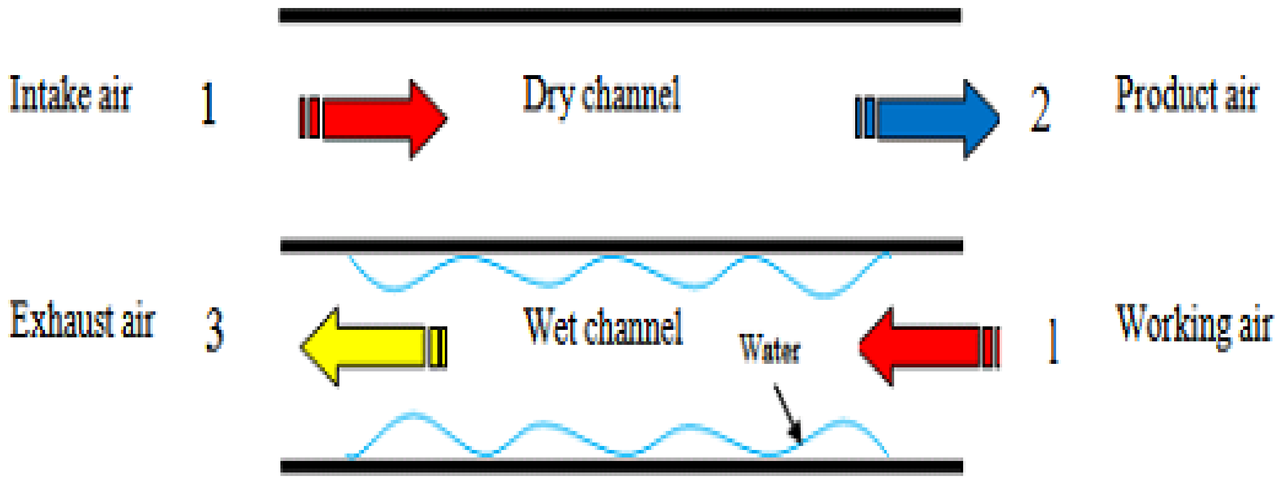


Figure 8: Flow Diagram of In DE System

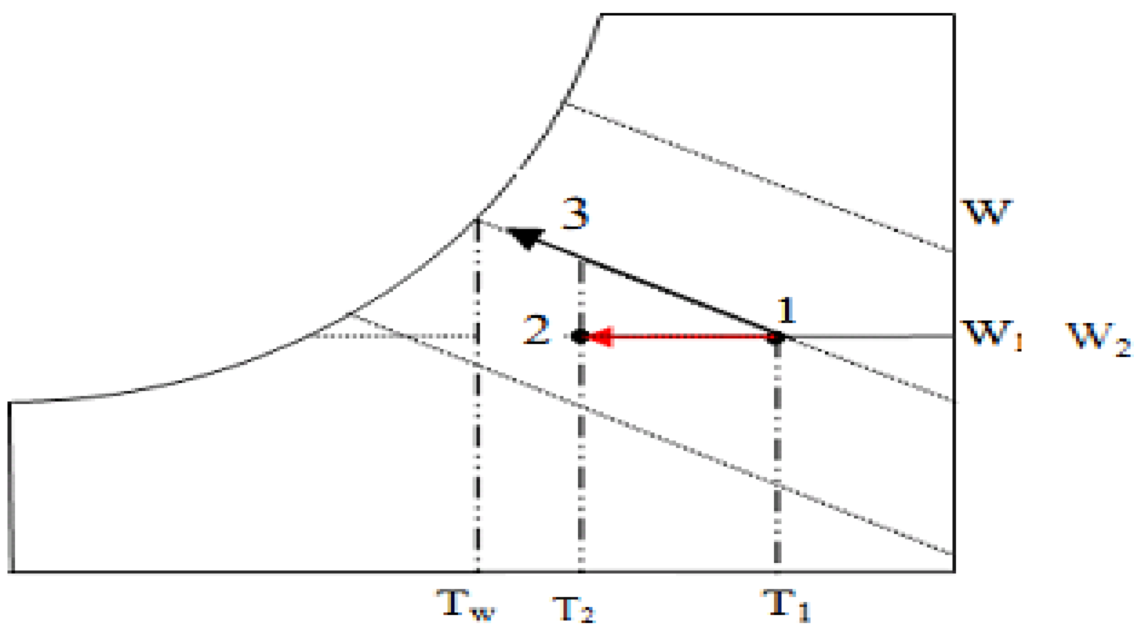


Figure 9: Working Process shown in Chart

Fig: 9Flow Diagram (1) and process shown in chart (2) of IDE system

The wet-bulb viability of current trademark this cooling systems may extend in the vicinity of 55% and 75% or greater, which is lower than that previous system. Be that as it may, because of no dampness expansion for the air supply, this don't need to give a similar cooled to the previous systems to give a similar solace feeling.

In direct evaporative cooling system has been used in many configurations. Some of them are explained below.

2.2.3. Single stage IDECS:

Jaber [14] studied an IDEC system which was done in Jordan and also is depiction of weather of Mediterranean. Apart from satisfying the comfort conditions, the system greatly reduces the omission of Carbon Dioxide. The data also shows that if conventional air conditioning systems installed in 500,000 buildings I in the Mediterranean are converted to indirect evaporative cooling system, Kruger [13] also studied an IDEC system in response of its thermal energy removal capacity to longer durations. This appeared the system meet the needs of indoor comfort conditions and can decrease the temperature closer to wet bulb temperature. Another study was also carried out by A.Joudi [15] to examine the capability of an Indirect evaporative cooler to get rid of the variable cooling load of Iraq. It was noted that indirect evaporative cooling system could give the residents with comfortable conditions round the clock with high efficiency as only mechanical parts are fan and pump which consume majority of the Energy. Another possible realistic application of Indirect evaporative cooler is that it can be used as a unit to Pre – Cool the ambient air before it is being fed to the conventional air conditioning system. The indirect evaporative cooler saved nearly 75% load and 55 percent of consumption electricity.

2.2.4. IECS connected with desiccant dehumidifier:

In this a desiccant dehumidifier was connected with the system which comprises of two portions: the dehumidification and cooling system, which makes indirect evaporative cooler pertinent in hot and moist condition.

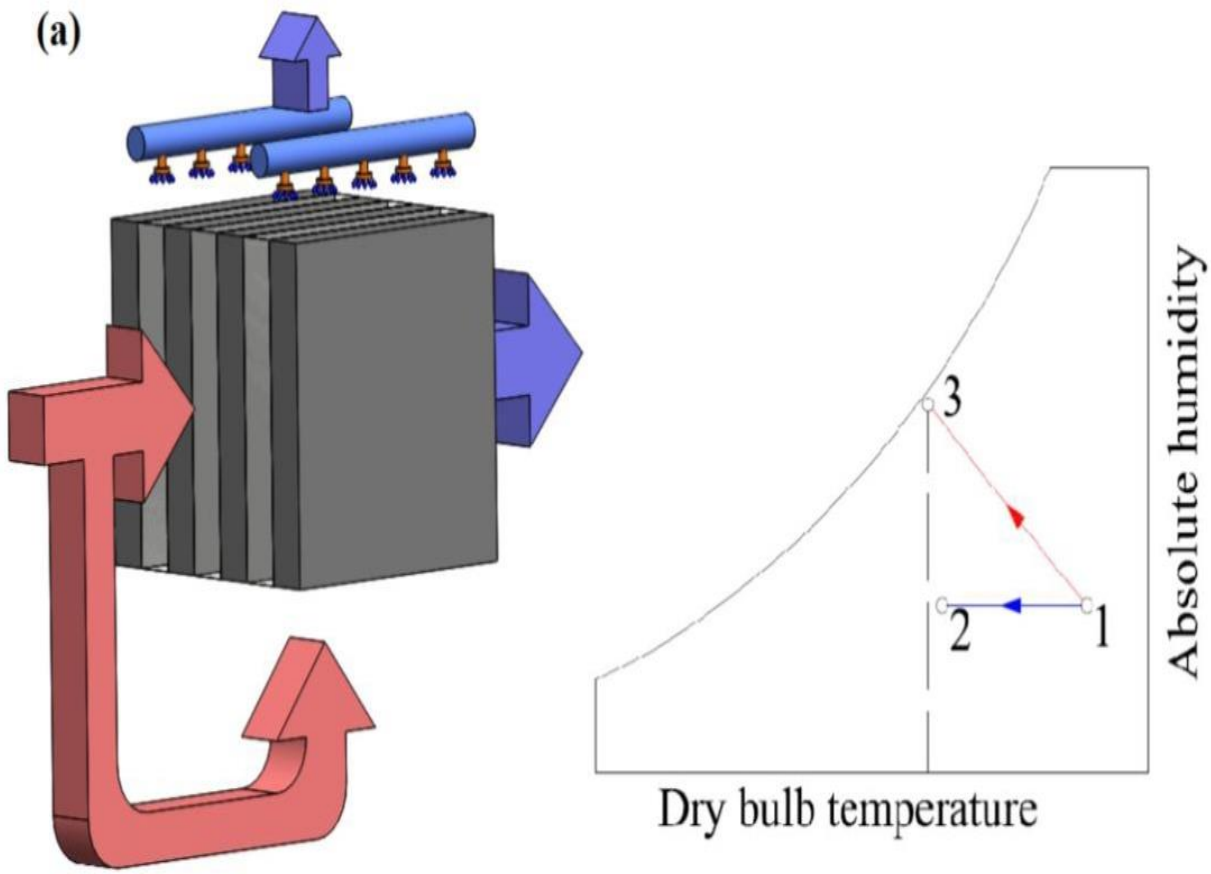


Figure 10: a IDEC System

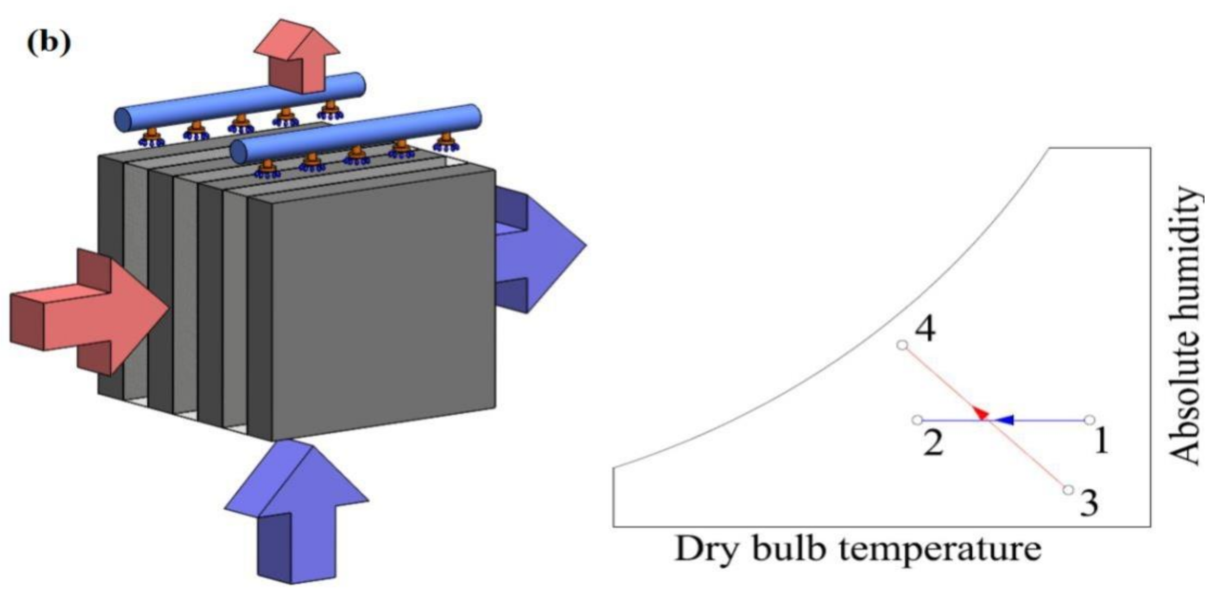


Figure 10:b IDEC System.

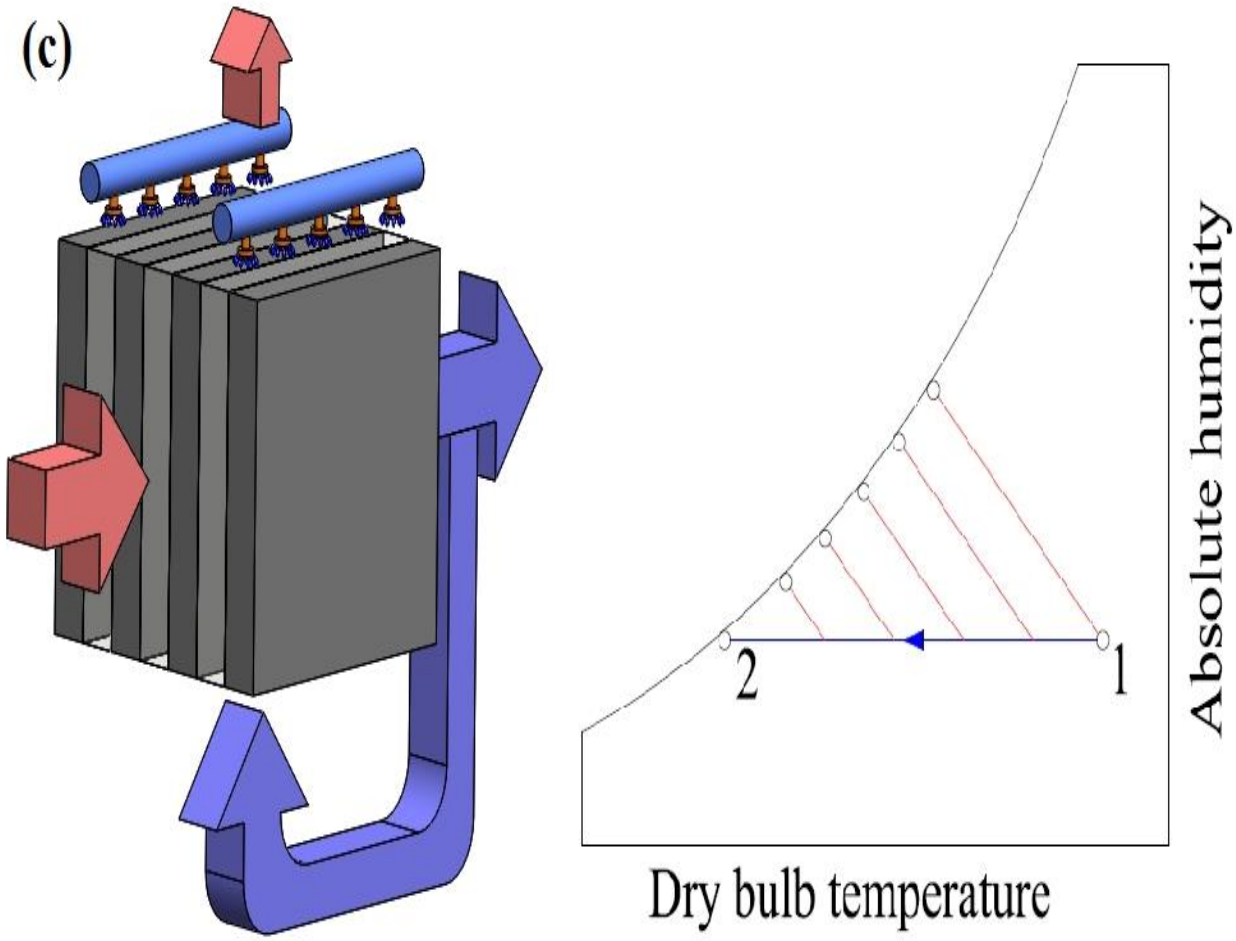


Figure 10: c IDEC System

2.2.5. Flow arrangements:

In practice, all about IDEC system has been shown in above figures .This theory has been founded on the procedure appeared in the figure 2.1 (c). The previously mentioned process is the most productive of all giving the base conceivable temperatures at the outlet. This procedure is known as Maisotsenko cycle (M-Cycle) subsequent to being found by soviet researcher Valery Maisotsenko. All indirect or direct evaporative cooling forms are just ready to bring down the temperature to the wet bulb temperature of the encompassing air. Be that as it may, the M-Cycle process can bring down the temperature of the surrounding air to the dew point temperature. That is the reason it has been region of awesome enthusiasm for the ongoing past.

2.3 Dew Point Evaporative Cooler (Maisotsenko Cycle) :

Regularly distribution water is utilized as a part of evaporative cooler. This isn't totally protected. In systems with water distribution there are dependably odds of dormant water. In this manner, there is high possibility of development and collection of microorganisms. This requires standard cleaning with disinfectants, in any event month to month and consistent depleting every day to anticipate issues related with these microorganisms. It might likewise require utilization of hostile to bacterial or against germ answers for cleaning of the evaporative cooler. All these indicate the running expense of the evaporative cooler.

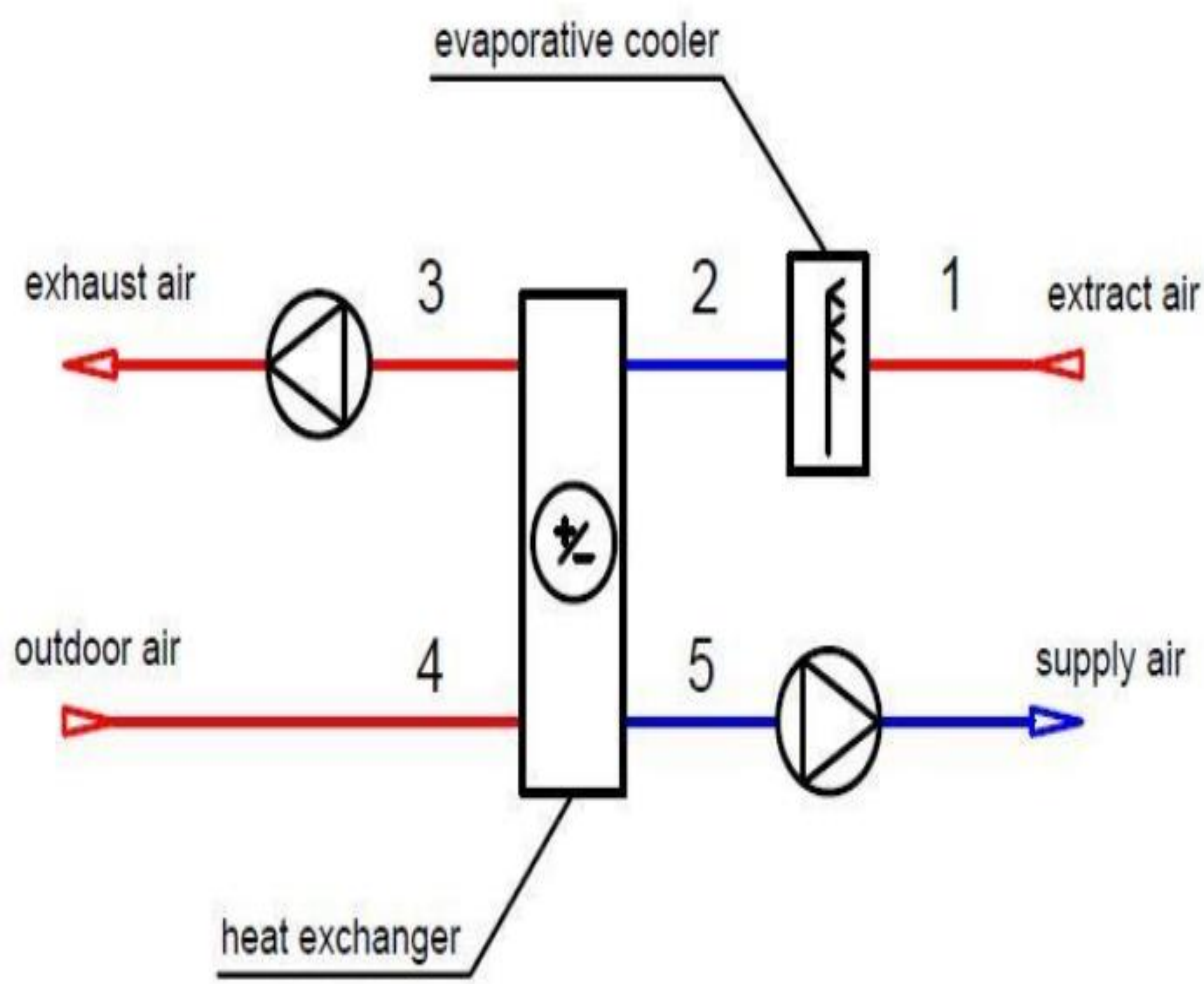


Figure 2: Schemetic Diagram.

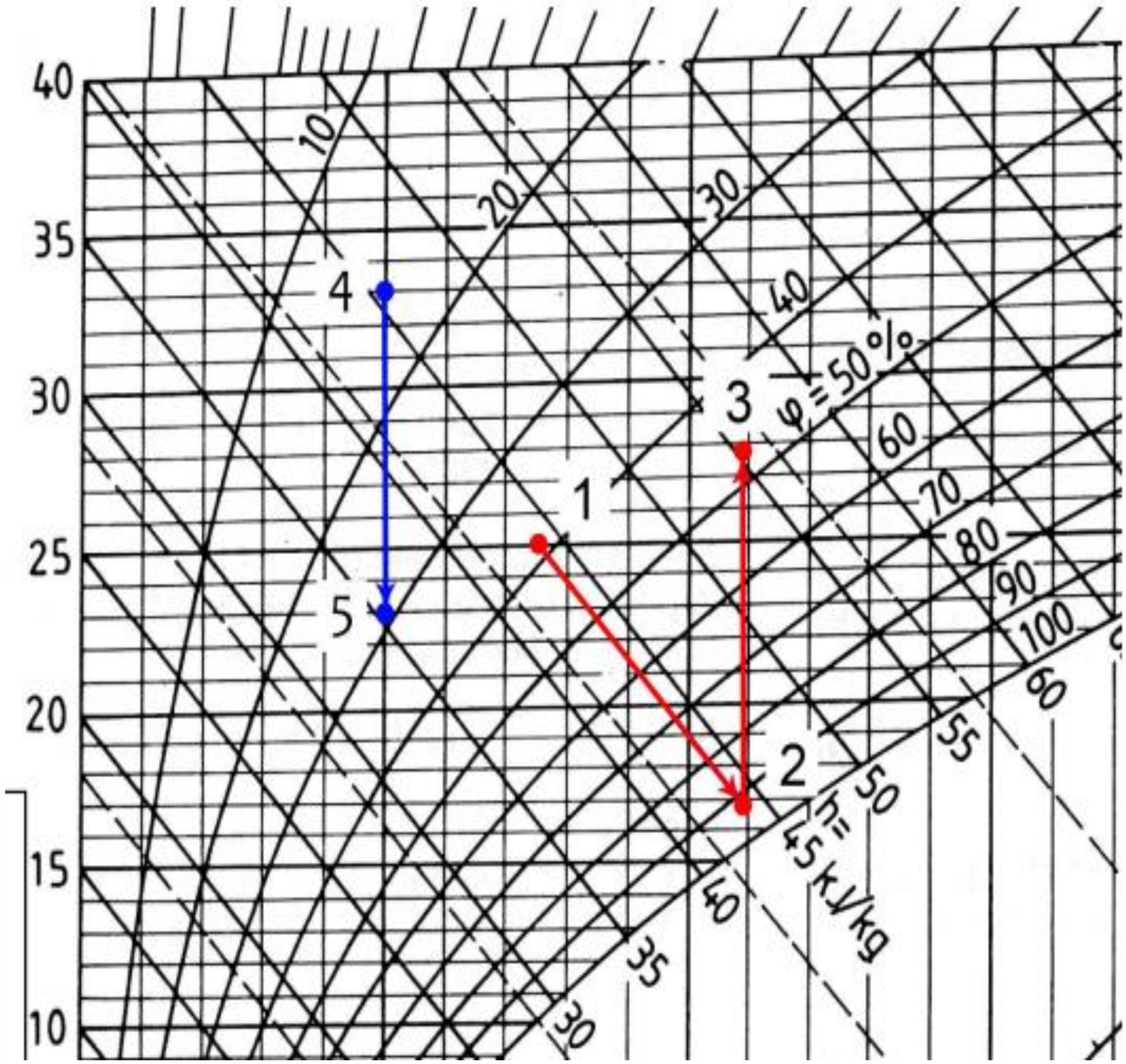


Figure 11: Indirect Adiabatic Cooling Process, a. Line Diagram, b. Psychometric

2.3.3 Systems Based On Maisotsenko Cycle:

This Cycle was effectively connected in the field of ventilation and Air Conditioning. Further, its utilization isn't restricted just to ventilation and aerating and cooling systems. Substantial thickness contrast between the adapted and heated air is the prospect, which can be utilized as a main impetus vitality and heat transfer advancements. The real temperance's of system in light of the M-cycle is more secure to condition, high productivity, low unit cost (no perplexing design) and low running expenses.

2.3.4 Operation Principle of Maisotsenko Cycle

It is clarified over that the customary adiabatic cooling can't give outlet temperatures beneath the wet bulb temperature. By the by, the utilization of the M-cycle enables cooling air to bring down Temperatures. On account of that the M-cycle, was presented. To comprehend the working design of this cycle, we think about basic adiabatic model.

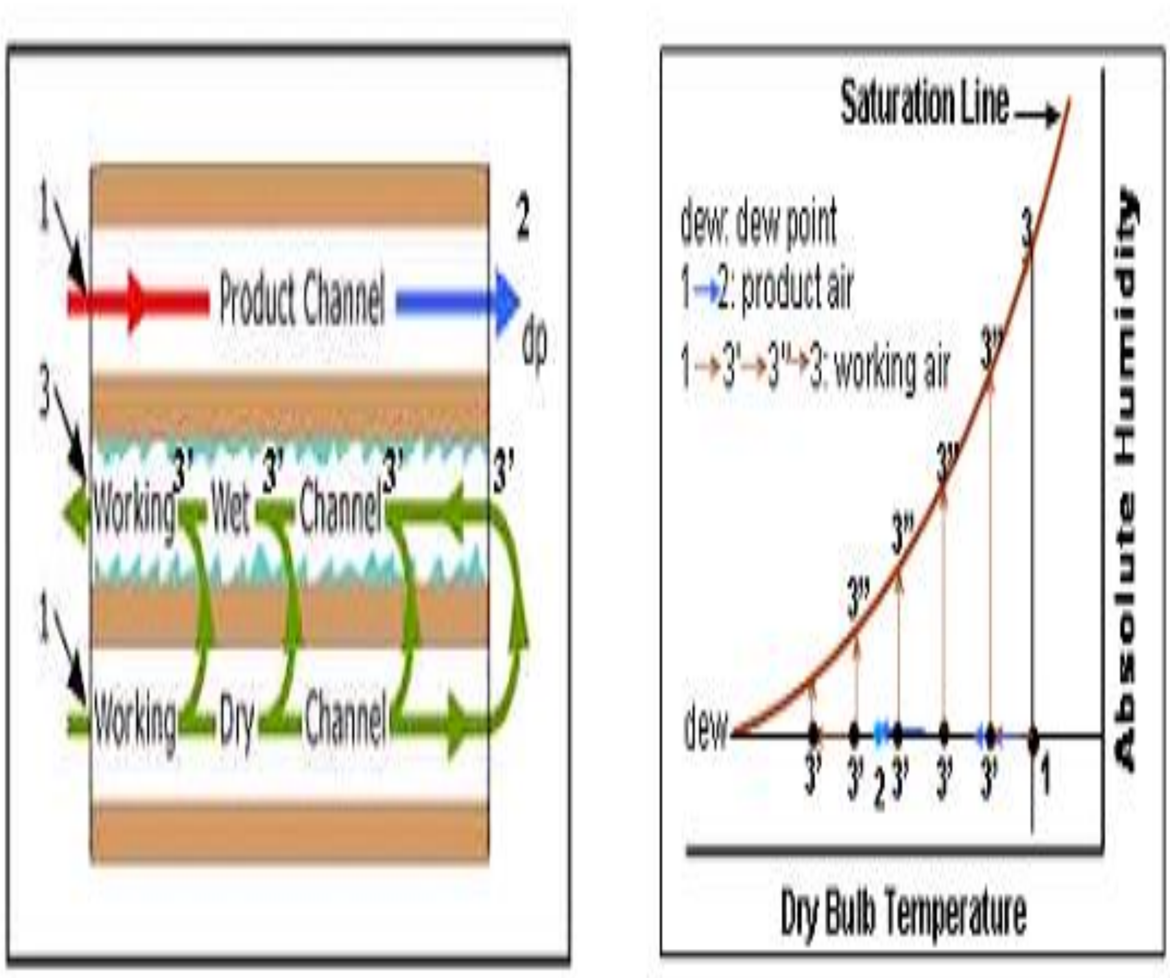


Figure 12: Basic Schematic of Dew Point Evaporative Cooler.

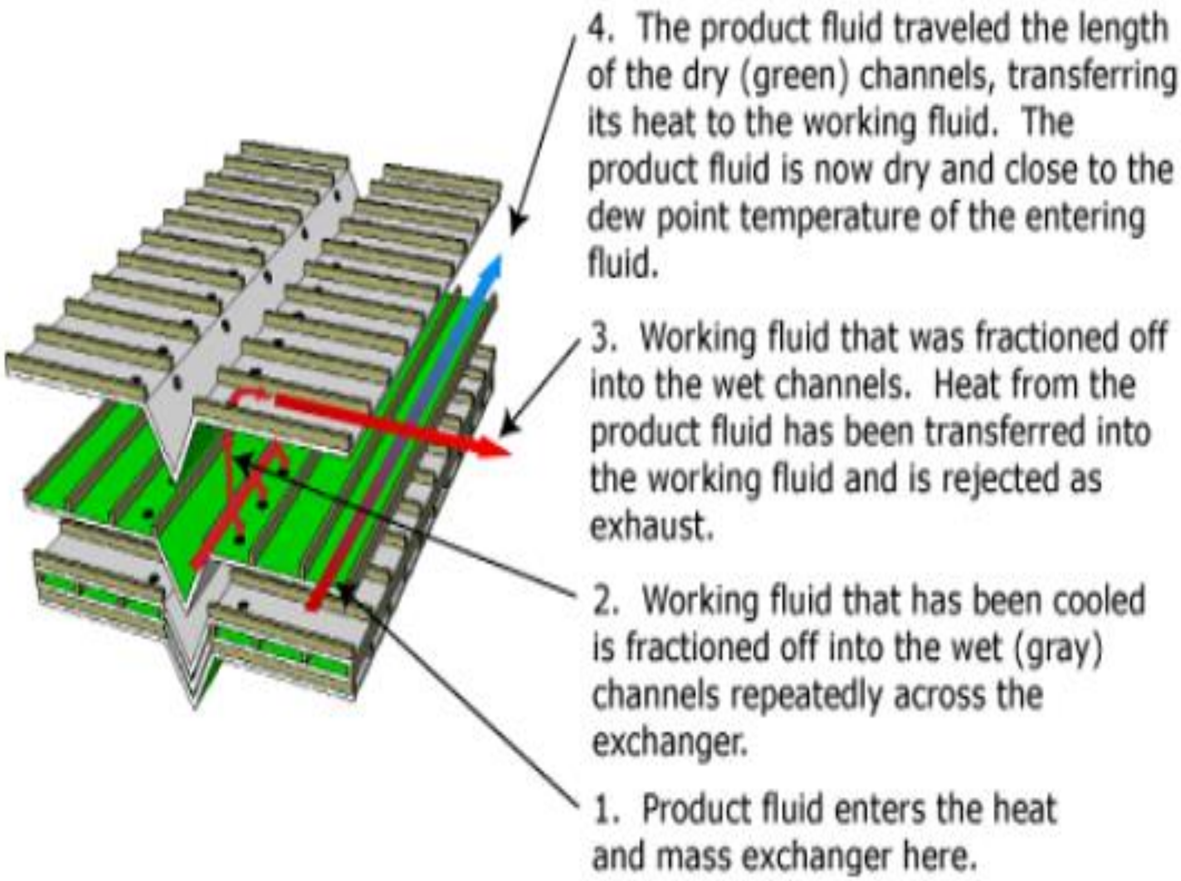


Figure 13: Perforated Dew Point Evaporative Cooler.

2-4 Working Standard Indirect evaporative cooling:

These systems have generally assessed from accompanying variables like intake air and humidity,cooling limit, control utilization, vitality proficiency and water utilization. The meanings of the fundamental parameters are indicated beneath.

2.4.1 WB and DP effectiveness:

Temperature distinction admission to intake air partitioned temperature contrast of both wet and dry of admission intake air, that communicated to accompanying condition:

$$\epsilon_{wb} = \frac{T_{db,in} - T_{db,out}}{T_{db,in} - T_{wb,out}} \qquad \text{Equation 2-1}$$

Where,

ϵ_{wb} = Wet-bulb effectiveness,

$t_{db,1}$ = Inlet Dry Bulb temperature,

$t_{db,2}$ = Leaving Dry Bulb temperature,

$t_{wb,1}$ = Inlet Wet Bulb temperature

Dew point viability characterized as the accompanying recipe can be utilized to rate the coolers.

$$\epsilon_{dew} = \frac{T_{db,in} - T_{db,out}}{T_{db,in} - T_{dew,out}}$$

Chapter 3

Constructions and Experiments

3.1 Structural Model:

- Intake air fan.
- Heat Exchanger
- Exhaust fan
- Supply air VCD.
- Water pump

3.1.1 Heat Exchanger:

Heat exchanger was designed with aluminum sheets coated with felt material which has a large water absorbed into it. The dry and wet channels were made, in the dry and wet channels the acrylic sheets were constructed to be not in contact of air with water. The dry channels were 25 and wet channels also 25.

3.1.2 Air Fans:

Depicted by littleness and limit of giving substantial stream of air, Air was sent from delta to the warmth exchanger. fan can give extent of wind current which is proper to sketched out wind streams of the warmth exchanger. Vapor center point air fan portrayed by little weight drop and broad wind current volume, a center fan is set up at the outlet of the framework to blows incapacitate air to exhaust. The fan is in like manner given a potentiometer.

3.1.3. Casing:

The Galvanized Iron casing is being used for this experiment.

3.1.4 Aluminum sheets with Felt material:

The flying warmth and mass exchanger of this contains warm exchange sheets, mass exchange sheets and air guiders. The surface of exchanger engages thing air experience without gets. In any case, the hydrophilic surface engages working air get inundated while experiencing. For the air guider material, plastic channels are being used. Differentiated and the air, the warm and properties of evaporative material accept more imperative parts on the warmth exchange and mass exchange of the exchanger.

3.3 Heat transfer and Mass Transfer Sheets:

A warmth exchanger includes warm exchange sheets, mass exchange sheets and air guiders. These sheets are molded by covering a wet material on the material. In any case, the hydrophilic surface engages working air get inundated while experiencing. For the air guider material, plastic funnels are being used. Differentiated and the air , the warm and properties of evaporative material accept more critical parts on the warmth exchange and mass exchange of the exchanger.

3.4 Acrylic Sheets:

The materials of the channels which divide exchanger into two dry and wet, acrylic sheets were utilized for the qualities of simple get together and light weight, as appeared . The sheets go about as the channel, guides airflow to go through the channels of exchanger.

3.5 Experiments of Model:

The cooling unit was developed in lab. As the primary piece of the cooling system, the heat exchanger has been shaped by aluminum sheets and acrylic sheets. See Fig 4-2a. The fiber and layered sheets were connected into channels (Fig. 4-2 (b). Every one of the segments of cooling system were introduced to the correct states. The segments incorporate heat exchanger, and authority, inlet pivotal fans, channels, velocity controllers, water pumping as appeared in fig. 4-1.

Potentiometers have been used to control the speed of inlet and exhaust fans. Water is sprayed in a water tray placed directly above the heat exchanger. The water flows in the vertical channels that is also circuit of the outlet flow of air while thesupply air flows in to the horizontal channels which are isolated from the water and undergo cooling via indirect evaporation.

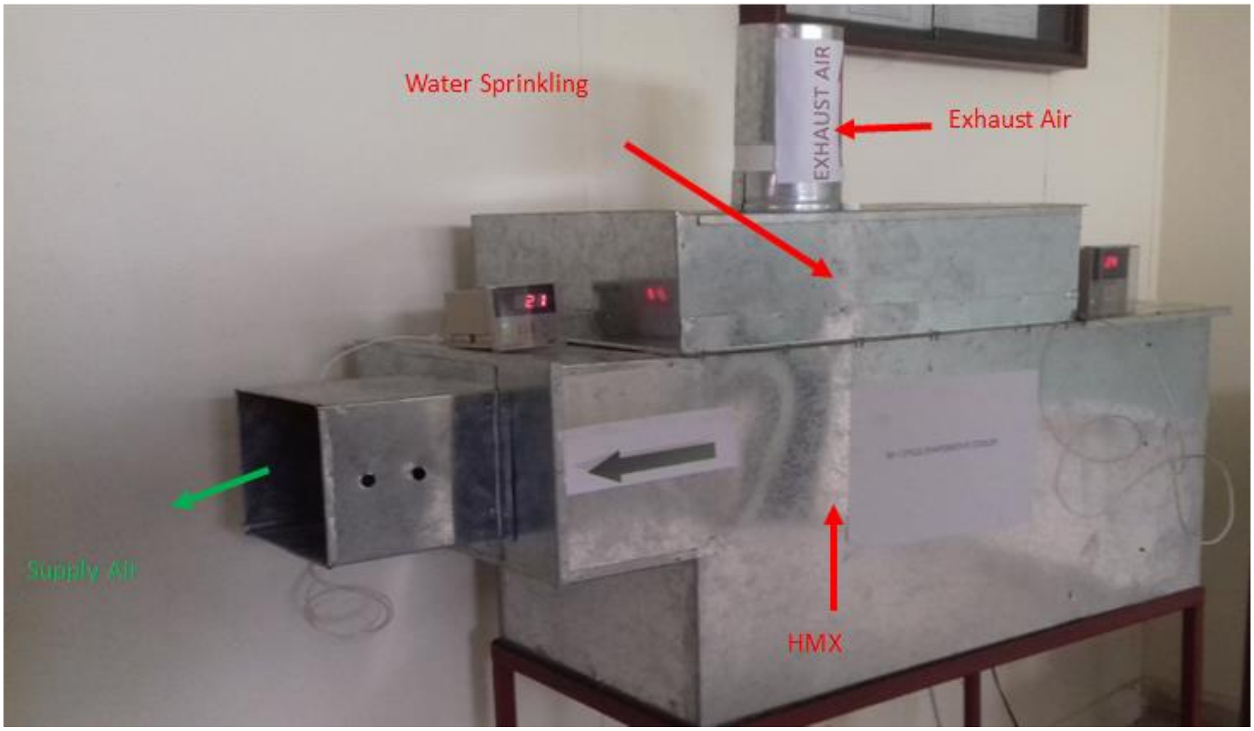
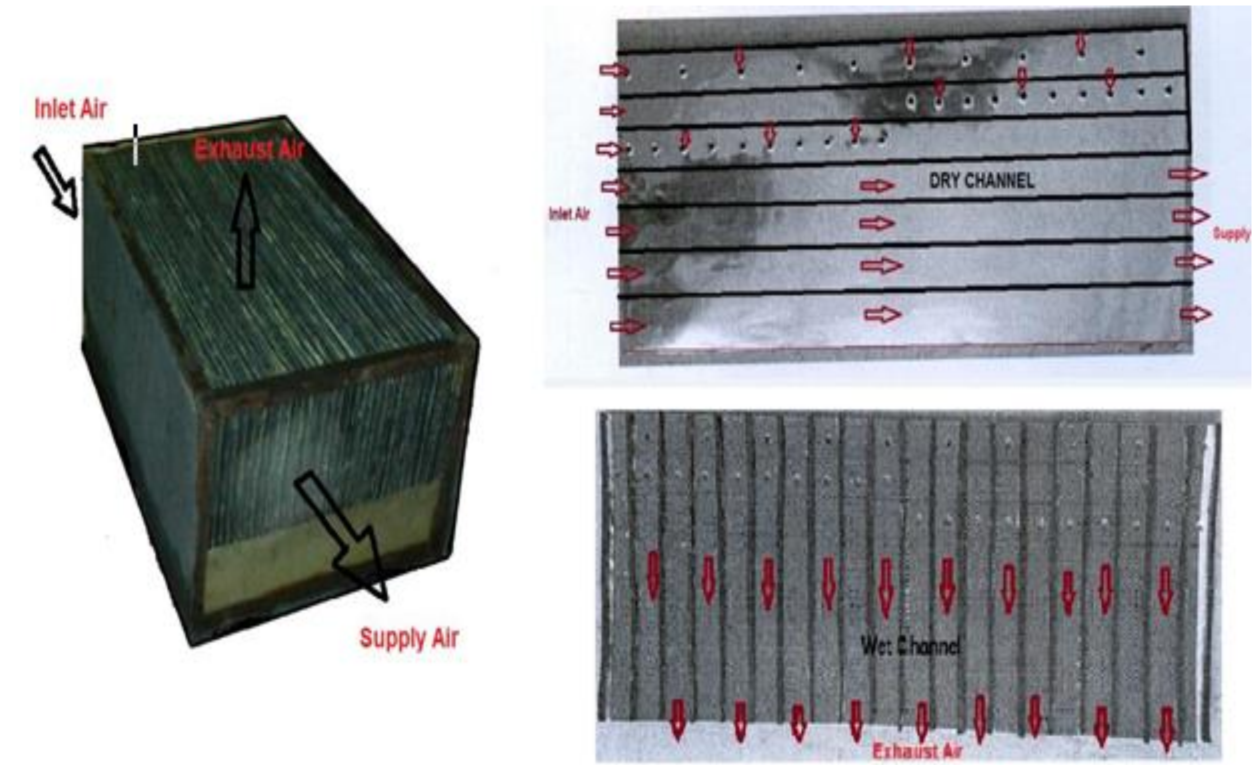


Fig 14: a Experimental Arrangement of IEC

Figure 14: b Inlet Fan.

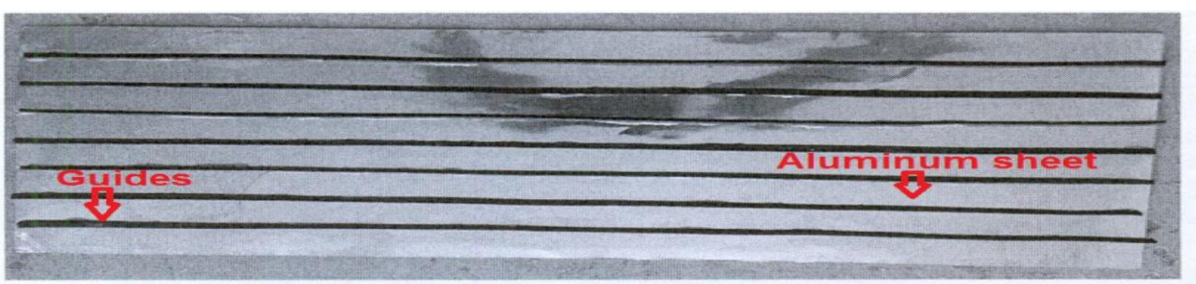
Figure 14: c Water Sprinkling arrangement

The detail of the IEC cooler is shown above. The arrangement of the supply air fan is so that it draws ambient air from the outside and blows through it. Configuration of the exchanger is shown in Fig 3.2.



a b

Figure 15: a Heat Exchanger



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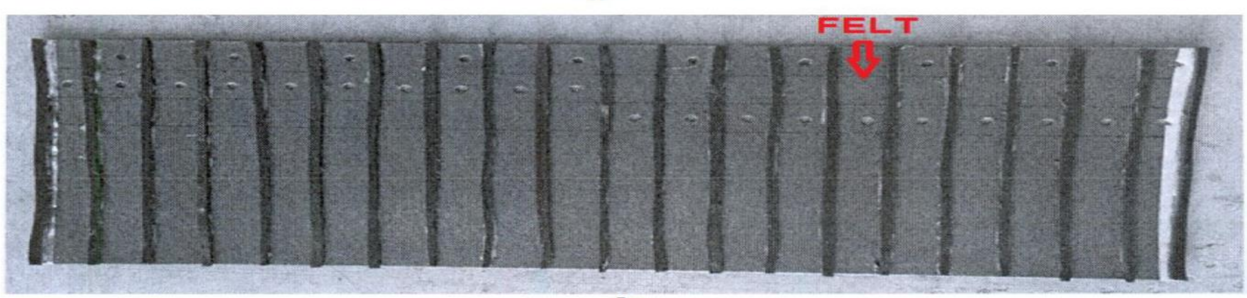

b

Figure 15: b HMX Construction

3.6 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	Material of sheet	Aluminum
2	Thickness of sheet	0.5 mm
3	Dry channel length	550mm
4	wet channel length	400mm
5	Channel width	300mm
6	Gap between Channels	12mm
7	Number of wet channels	25
8	Number of dry channels	25

3.7 Measurements and Instruments

Temperature: Fluke 971

- Range (-20 °C to 60 °C)
- Accuracy ± 1 °C
- Resolution ± 0.1 °C

Humidity: Fluke 971

- Range 5 %to 90 % RH
- Accuracy ± 2.5 % RH

Chapter 4

Discussions of Experiment Results

4.1. Effect of Changing Inlet air Temperature

In this by changing the intake air temperature and also humidity ratio while keeping velocity constant at 1.1 m/s.

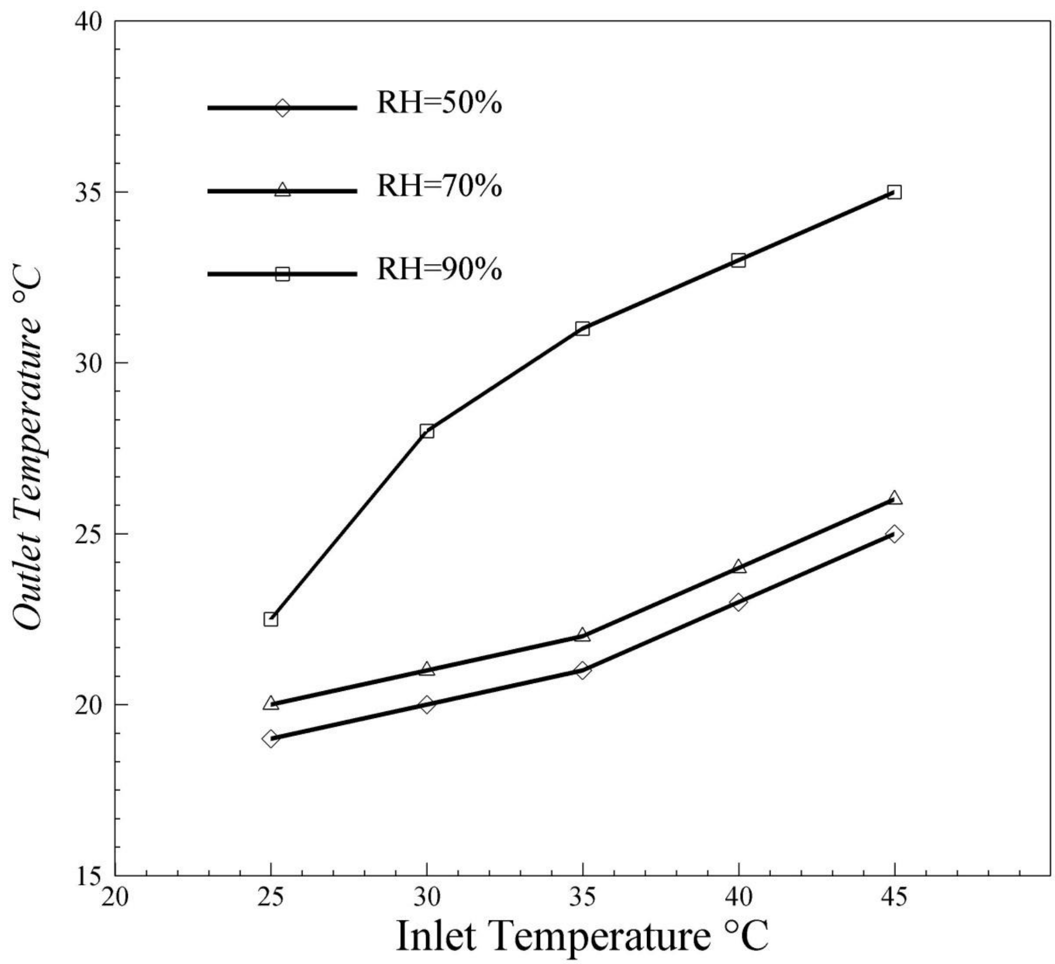

Figure 4-1: Outlet Temperature vs. Inlet Temperature at different relative humidity

The results show that at lower temperature and humidity levels, lower supply air temperature can be achieved. For the same temperature but higher value of the relative humidity, outlet temperature is relatively higher. This is understandable as the increase in relative humidity increases the latent heat in the air at constant temperature. As a result lower temperatures are achieved for higher relative humidity. Further, it also evident from the figure that temperature at outlet is varying linearly with the inlet temperature. Slope of the line ranges from 0.22 to 0.6 for the unit rise in temperature. Further, it is also shown that the outlet temperature is below 25 °C for Relative Humidity values of up to 75%. This means that the indirect evaporative cooler can perform efficiently in hot and humid localities of Pakistan.

A comparison of the obtained results with already publish experimental results is shown in Fig 4-2 under similar inlet conditions, by (Zhao, Li et al. 2008) and O. Khalid et al.2016. The air velocity of the equipment used in (Zhao, Li et al. 2008)is slightly higher (1.77 instead of 1.1 m/s). However, the test conditions used by O. Khalid et al.2016 [28] are very much similar the configuration used in this experiment.

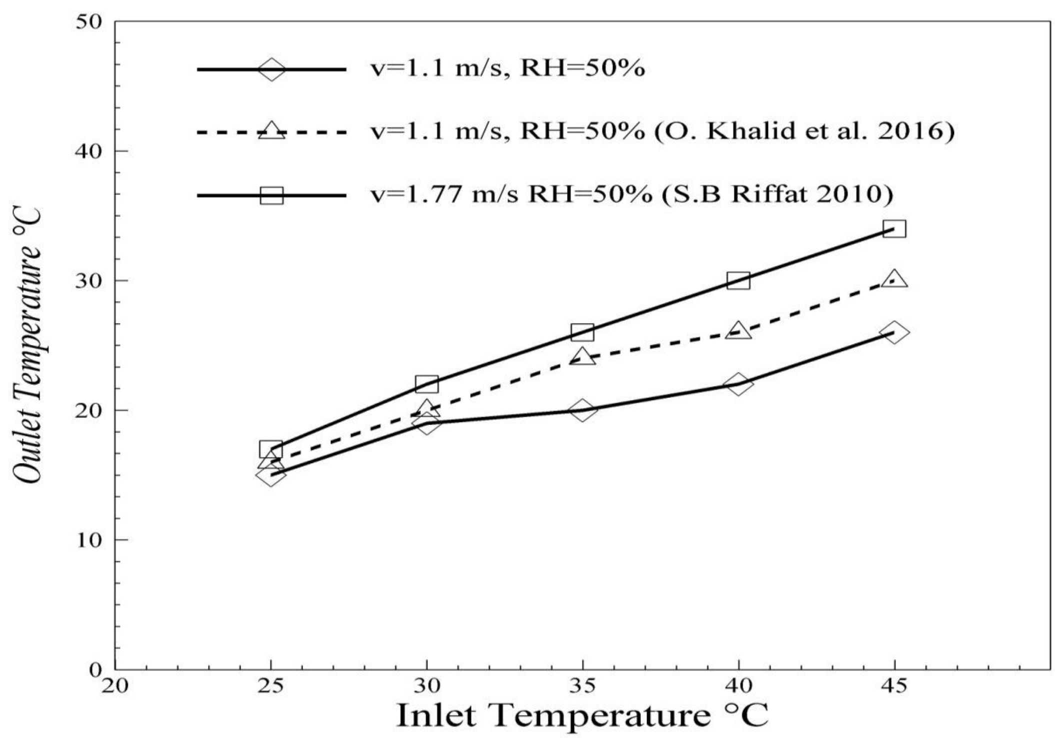

Figure 4-2: Comparison between Published and Current study

Similar trends are observed with same humidity levels of ambient air, however here inlet velocity is considerably low. Lower velocities of the air give lower outlet temperature as the time for heat exchange increases. Further, the results shown in the fig for two same inlet velocities are also influenced by the product to working air ratio. The product to working air ratio is kept at 0.5 for this experiment.

Another comparison has been made for the current experiment with Published result O. Khalid et al.2016 [28] for different values of humidity ratio of ambient air for similar air properties conditions.

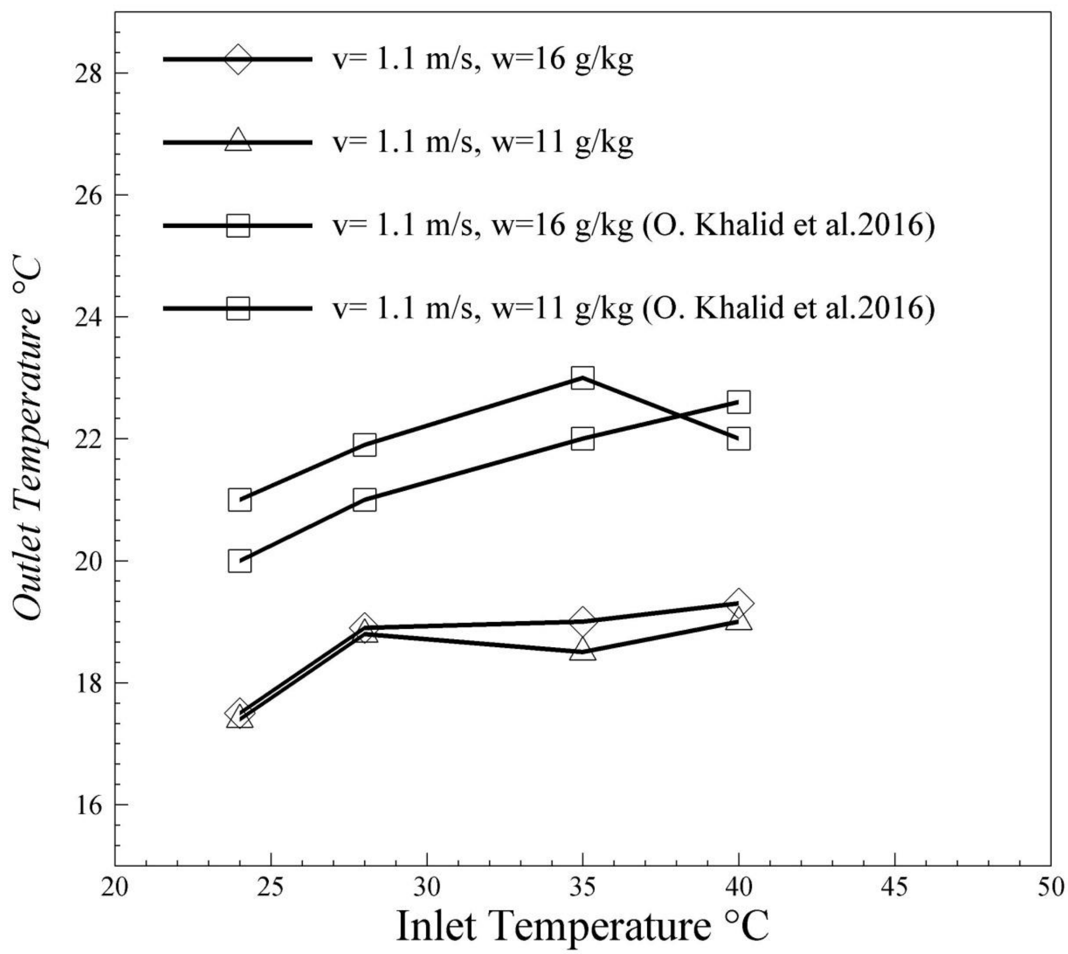

Figure 4-3: Comparison between Published and Current study

The trial arrangement on account of Khalid et al.2016 [28] is like the present design. Fig. 4-3 demonstrates the correlation for a similar estimation of inlet speed. It is again watched that lower outlet temperatures are acquired for the present investigation. Examination additionally proposes that separated from bring down inlet speed, proportion of item to working air likewise has critical impact on the outlet temperatures. The execution of the dew point cooler is estimated as far as its wet bulb and dew point viability. Fig 4-4 demonstrates the wet bulb viability of the examination at various estimations of relative humidity. Wet bulb adequacy extended in the vicinity of 60% and 125% for the inlet temperatures between 20° C and 40° C. As obvious, the outlet temperatures have been lessened beneath the WB temperature of the inlet . It has been observed that WB adequacy increments with the increments in relative humidity. This is because of the way that with the expansion in the relative humidity, the contrast between the inlet dry and wet bulb temperatures diminishes. The misery of the temperatures at outlet achieves the inlet wet bulb temperature which is higher for higher relative humidity esteems.

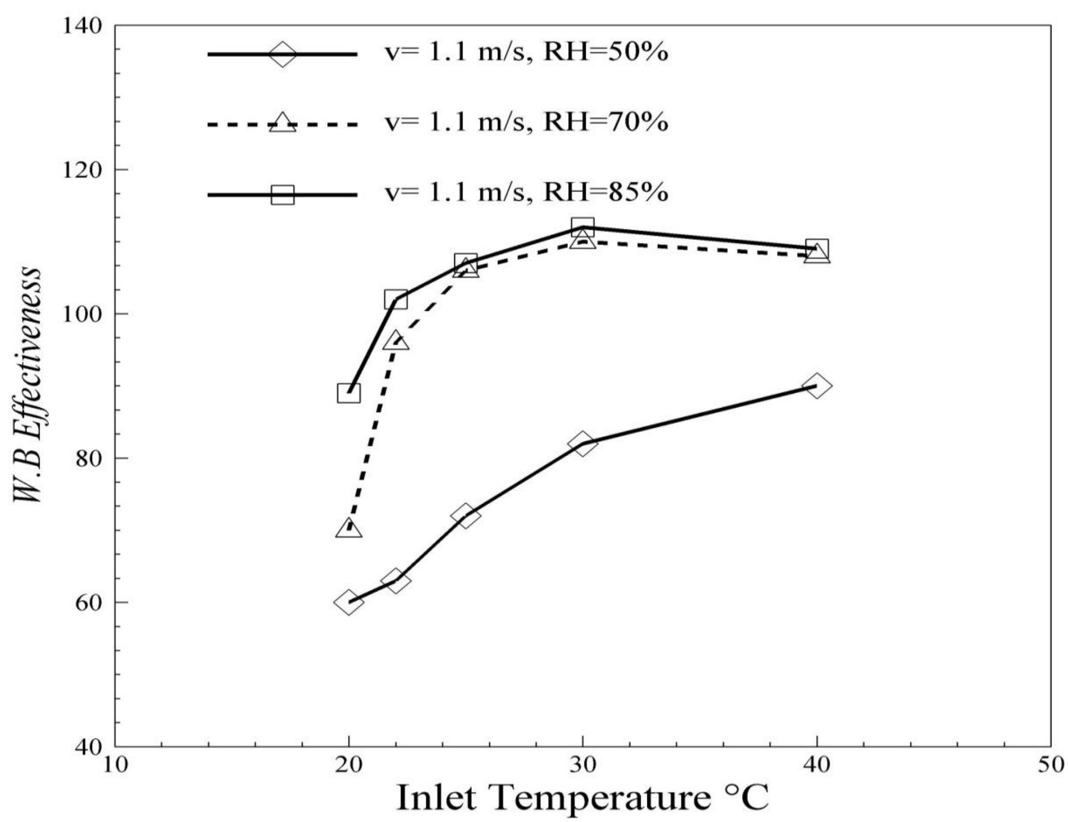

Figure 4-4: Wet Bulb Effectiveness.

This shows that the system can perform efficiently for humid conditions. However, it can also be noted that for higher values of relative humidity, relatively higher outlet temperatures are obtained. This again is understandable as the increase in the relative humidity increases the latent heat content in the air. Removal of latent heat requires greater amount of heat transfer.

Figure 4-5 shows the dew point effectiveness of the experiment for different inlet relative humidity values. The velocity has been kept constant.

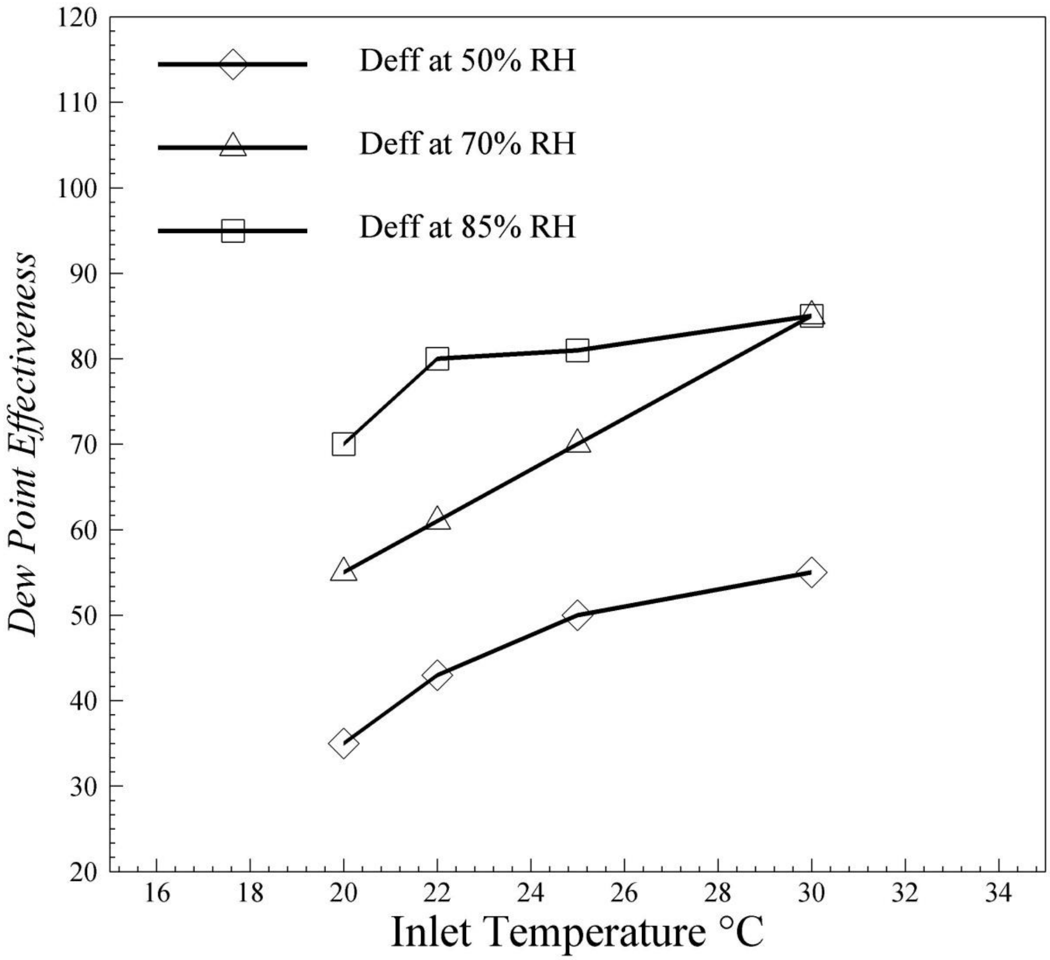

Figure 4-5: Dew Point Effectiveness

Dew point adequacy differed from 34% to 90% for inlet temperature scope of 20 °C to 40 ºC. Again it is very apparent from the assume that high dew point adequacy is acquired for high inlet temperature. Further, the dew point viability increments with increment in the relative humidity of the inlet as the dew point bulb temperature of the inlet air additionally increment at high relative humidity. Be that as it may, again the outlet temperature is bring down for high estimations of relative humidity. Subsequently, closer the dew point temperature of inlet air is to the dry bulb temperature, higher will be the dew point viability. Lower outlet temperatures are acquired for low relative humidity esteems. The aftereffects of the wet bulb and dew point adequacy acquired in this examination are superior to O. Khalid et al.2016 [28] for about indistinguishable inlet conditions.

4.2. Effect of Air Velocity

Figure 4-6 shows that the inlet velocity has effect on the outlet temperatures of the dew point cooler. The effect of inlet velocity is adequate on the cooling capacity similar to the conventional air conditioning system where face velocity of the cooling coil plays a significant role in determining the cooling capacity. The humidity ratio is kept constant in this experiment (11 g/kg) while velocity is varied.

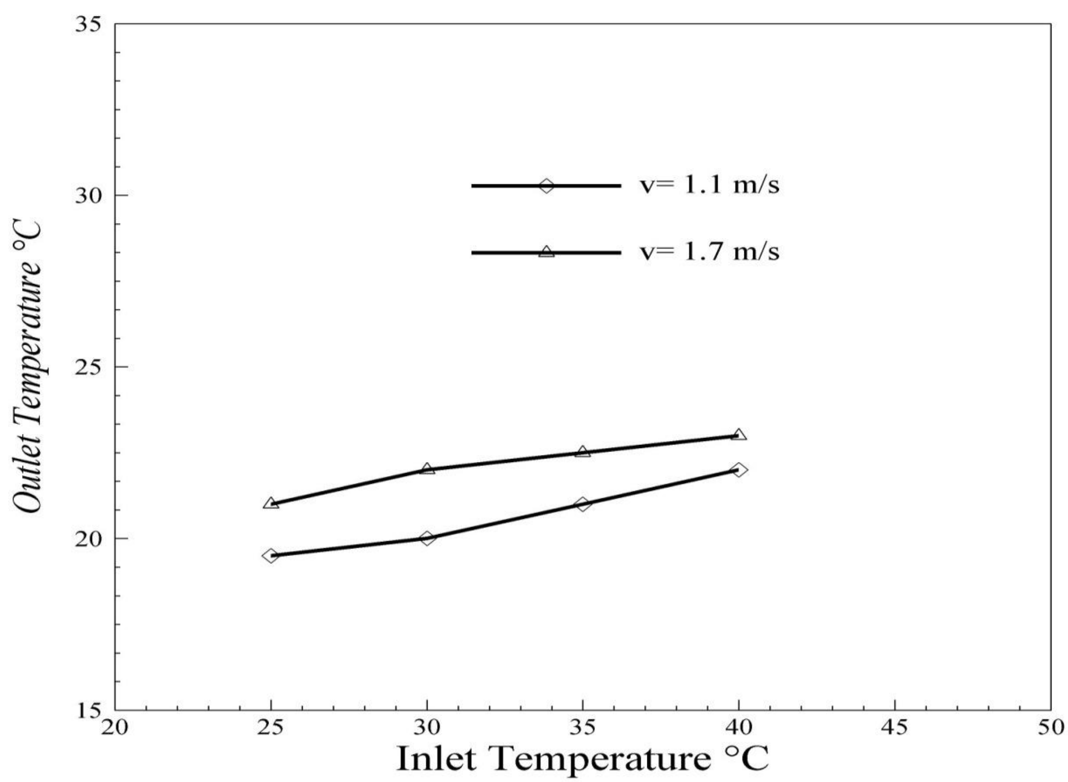

Figure 4-6: Outlet Temperatures at different inlet temperature and constant humidity ratio.

Lower outlet temperatures are obtained for lower velocities which can be explained with the reason that the contact duration of the air with the heat exchanger increases for lower velocities thus resulting in lower temperatures.

The effect of inlet velocities on the dew point effectiveness is shown in figure 4-7. Again the dew point effectiveness also increases for lower velocities.

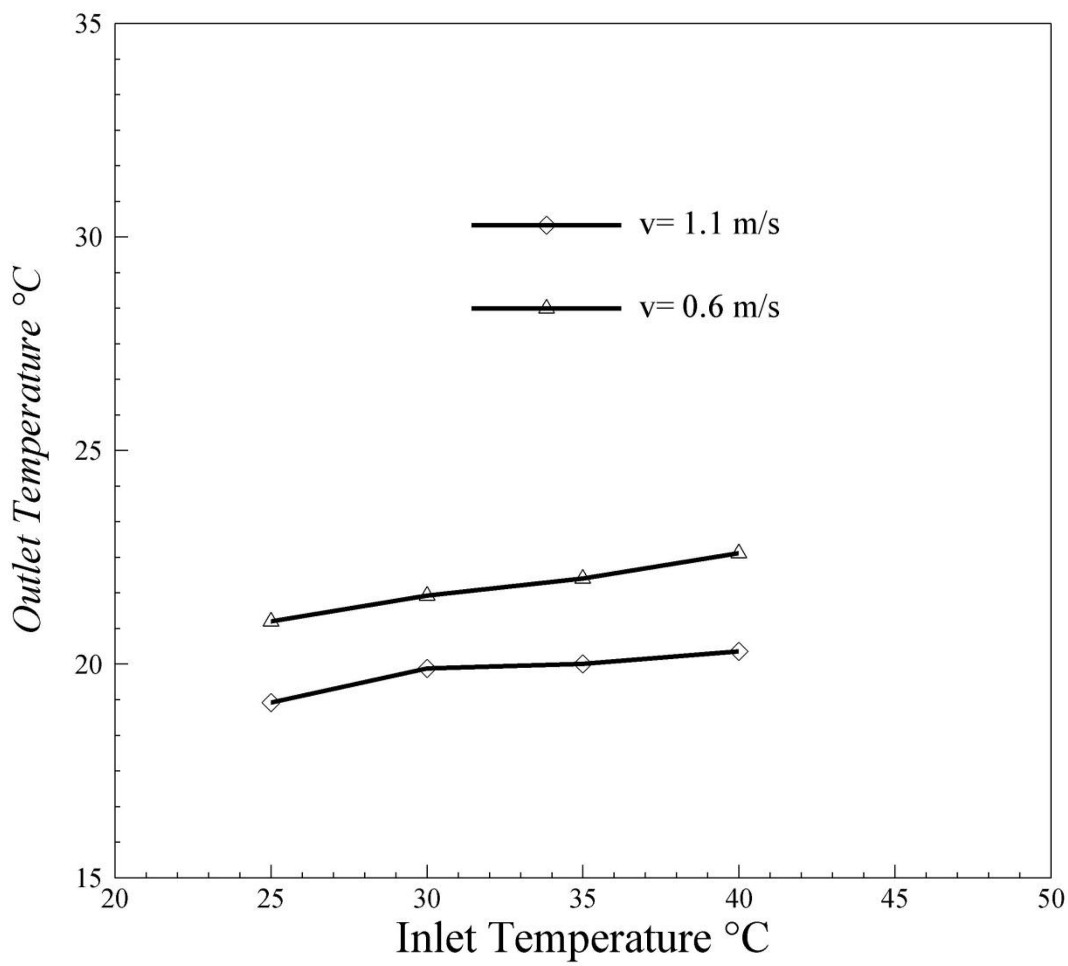

Figure 4-7: Effect of Inlet Velocities on the Dew Point Effectiveness

With the increase of velocity the impact of values decrease as similar to the outlet air temperature. The results for the experiment are found better than the results of obtained for different velocities in similar experiment by O. Khalid et al.2016 [28].

4.3 Effect of Feed Water Temperature:

The temperature of feed water was changed from 25 °C to 32 °C; however, no significant effect in the readings occurred. Maximum deviation occurred was 4%. Hence it is concluded that the change in supply of water temperature does not affect the performance of the equipment.

4.4 Effect of Liquid Desiccant:

Liquid Calcium Chloride ($CaCl_2$) was used as a desiccant dehumidifier. The temperature change due to the use of liquid desiccant was not more than 1.5 °C. The relative humidity of the air at outlet decreased by 4 to 10% with the use of liquid desiccant, as shown in the figure 4-8.

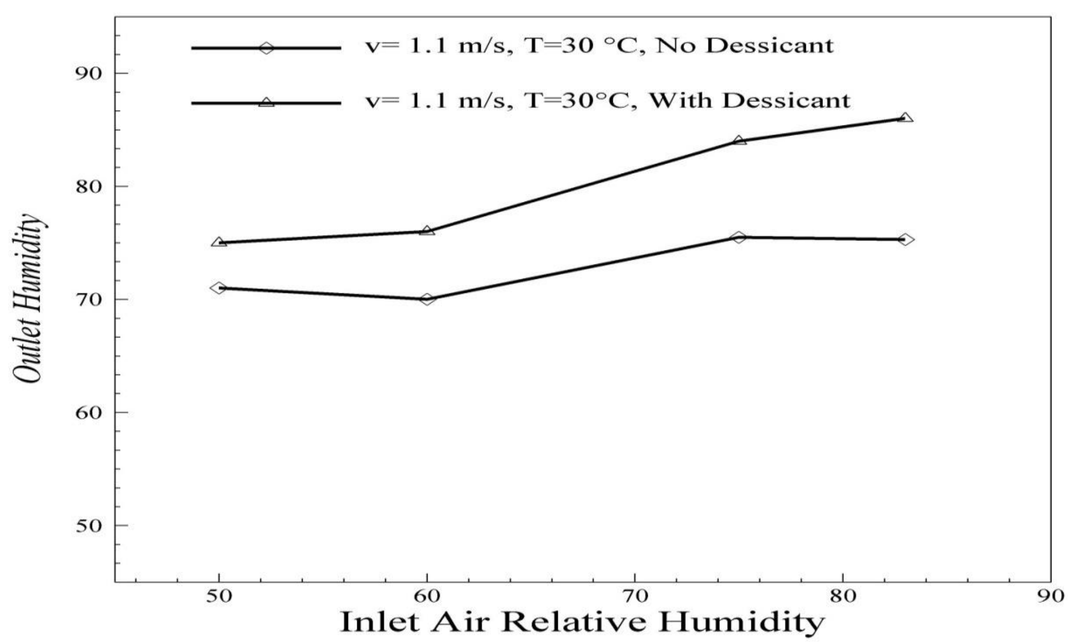

Fig 4.8: Effect of Liquid Desiccant on the Relative humidity of outlet air.

Future Work and Concluding Remarks

5.1 Conclusion :

- Dew point cooler based upon M-cycle has been prepared and analyzed for the different air inlet properties and the effect of the change in these properties have been analyzed and explained.
- The effectiveness of wet bulb is ranged between between 60% and 125% while the dew point is ranged between 34% and 90%.
- It is quite evident from the above results that the low outlet temperature are obtained for relative humidity of 50 % and less and temperature range of 25 ⁰C to 40 ⁰C. However, outlet temperatures in the range of 25 ⁰C are also obtained for relative humidity of 70%.
- This suggests that the system is viable for commercial use on small scale. Higher wet bulb and dew point values are obtained for high relative humidity and high inlet temperature.
- The efficiency of the system also increases with the decrease in the inlet air velocity.
- The use of liquid desiccant de humidifier did not significantly affected the result out comes.

5.2 Future Work:

In order to make the system commercially suitable for high load applications, the velocity of the system shall be increased and the heat exchanger designed will required to be modified to cater the pressure loss due to high velocities. Further, of the system is to be operated with desiccant dehumidifier, a suitable regeneration technique which commercially viable is also required to be worked out.

References:

[1] Zhan, C., et al. (2011). "Comparative study of the performance of the M-cycle counter-flow and cross-flow heat exchangers for indirect evaporative cooling – Paving the path toward sustainable cooling of buildings." Energy **36**(12): 6790-6805.

[2] J. R. Watt and W. K. Brown, Evaporative Air Conditioning Handbook: Prentice Hall, 1997.

[3] http://www.gothicarchgreenhouses.com/greenhouse_cooling.htm.

[4] http://www.wescorhvac.com/Evaporative%20cooling%20white%20paper.htm.

[5] A. Handbook, "HVAC systems and equipment," American Society of Heating, Refrigerating, and Air Conditioning Engineers, 2008.

[6] J. R. Camargo, C. D. Ebinuma, and J. L. Silveira, "Experimental performance of a direct evaporative cooler operating during summer in a Brazilian city," International Journal of Refrigeration, vol. 28, pp. 1124-1132, 2005.

[7] Afonso, C. F. A. (2006), recent advances in building air conditioning systems, Applied Thermal Engineering, vol. 26, pp. 1961-1971.

[8] Maisotsenko, V. and I. Reyzin (2005), The Maisotsenko cycle for electronics cooling, Proceedings of the ASME/Pacific Rim Technical Conference and Exhibition on Integration and Packaging of MEMS, NEMS, and Electronic Systems: Advances in Electronic Packaging, San Francisco, CA, U.S., pp. 415–424.

[9] J. M. Wu, X. Huang, and H. Zhang, "Numerical investigation on the heat and mass transfer in a direct evaporative cooler," Applied Thermal Engineering, vol. 29, pp. 195-201, 2009.

[10]G. Heidarinejad, V. Khalajzadeh, and S. Delfani, "Performance analysis of a ground-assisted direct evaporative cooling air conditioner," Building and Environment, vol. 45, pp. 2421-2429, 2010.

[11] S. Elmetenani, M. L. Yousfi, L. Merabeti, Z. Belgroun, and A. Chikouche, "Investigation of an evaporative air cooler using solar energy under Algerian climate," Energy Procedia, vol. 6, pp. 573-582, 2011.

[12] P. Finocchiaro, M. Beccali, and B. Nocke, "Advanced solar assisted desiccant and evaporative cooling system equipped with wet heat exchangers," Solar Energy, vol. 86, pp. 608-618, 2012.

[13] E. Krüger, E. González Cruz, and B. Givoni, "Effectiveness of indirect evaporative cooling and thermal mass in a hot arid climate," Building and Environment, vol. 45,

[14] S. Jaber and S. Ajib, "Evaporative cooling as an efficient system in Mediterranean region," *Applied Thermal Engineering,* vol. 31, pp. 2590-2596, 2011.

[15]K. A. Joudi and S. M. Mehdi, "Application of indirect evaporative cooling to variable domestic cooling load," *Energy Conversion and Management,* vol. 41, pp. 1931-1951, 11/1/ 2000.

[16] S. Delfani, J. Esmaeelian, H. Pasdarshahri, and M. Karami, "Energy saving potential of an indirect evaporative cooler as a pre-cooling unit for mechanical cooling systems in Iran," *Energy and Buildings,* vol. 42, pp. 2169-2176, 2010.

[17] B. Givoni, "Comfort, climate analysis and building design guidelines," *Energy and buildings,* vol. 18, pp. 11-23, 1992.

[18]G. Heidarinejad, M. Bozorgmehr, S. Delfani, and J. Esmaeelian, "Experimental investigation of two-stage indirect/direct evaporative cooling system in various climatic conditions," *Building and Environment,* vol. 44, pp. 2073-2079, 2009.

[19]M.-H. Kim, A.-S. Choi, and J.-W. Jeong, "Energy performance of an evaporative cooler assisted 100% outdoor air system in the heating season operation," *Energy*

and Buildings, vol. 49, pp. 402-409, 2012.

[20] J. Woods and E. Kozubal, "A desiccant-enhanced evaporative air conditioner: Numerical model and experiments," *Energy Conversion and Management,* vol. 65, pp. 208-220, 2013.

[21]Maisotsenko, V., L. E. Gillan, et al. (2004), Method and apparatus for dew point evaporative product cooling. U. S. Patent. United States, Idalex Technologies, Inc., 6776001.

[22] Вишневский Е.П., Малков Г.В. Косвенное адиабатическое охлаждение объектов. СОК. www-document. www.c-o-k.com.ua/content/view/2618/. Updated 12.02.2012. Referred 02.11.2012.

[23] D2 National Building Code of Finland: Indoor Climate and Ventilation of Buildings. Regulations and Guidelines. Ministry of the Environment Housing and Building Department. 2003.

[24] Robi Robichaud. Coolerado Cooler Helps to Save Cooling Energy and Dollars. U. S. Department of Energy, Energy Efficiency and Renewable Energy. http://www1.eere.energy.gov/femp/pdfs/tir_coolerado.pdf. March 2007.

[25] Elberling, L. (2006), Laboratory evaluation of the Coolerado cooler-indirect evaporative cooling unit, Pacific Gas and Electric Company.

[26] A Technical Description of the Maisotsenko cycle. Idalex Company. WWW-document. http://www.idalex.com/technology/how_it_works_-_technological_perspective.htm. No update information available. Referred 14.11.2012.

[27] X. Zhao, J.M. Li, S.B. Riffat, Numerical study of a novel counter-flow heat and mass exchanger for dew point evaporative cooling, Appl. Therm. Eng. 28 (2008) 1942–1951.

[28] Khalid, O., et al. (2016). "Experimental analysis of an improved Maisotsenko cycle design under low velocity conditions." Applied Thermal Engineering **95**: 288-295.