International Journal of
Mechanical Engineering and Futuristic Technology
A Peer-reviewed journal

ISSN : 2456-1266 (O)
Impact Factor : 1.485 (Calculated by I2OR)
IJESFT 03 (2016) 001-010

M-Cycle based Indirect Evaporating Cooling System: A Literature review

Meet Shah[1*], Digbijoy Sarkar[2], Bharat Kumar[3], Meet Patel[4], Nikunj Shah[5], Vivek Sitapara[6]

[1, 2, 3, 4, 5, 6]Mechanical Engineering Department, Institute of Technology and Management Universe, India

A B S T R A C T : The requirement of energy and its usage has been increasing drastically nowadays. Moreover, the human race is also facing various global challenges like global warming and climate change and increase in temperature of earth. So, need of refrigeration and air- conditioning has been increased. But older methods are not sufficient. Hence it is required to develop a new system of cooling which is more sufficient and efficient too. This review paper describes the study, working, construction and application of one of such cycles called Maisotsenko Cycle (M- cycle).

© 2016 A D Publication. All rights reserved

Keywords: M-cycle, Indirect evaporative cooling, heat and mass exchanger, Maisotsenko.

1. Introduction

With the beginning of the Industrial revolution, development of the human Society began. The progress of the world began from this Industrial Revolution with an excess speed and extreme usage of energy resources. But along with that, we have open doors to many challenges and problems. These lead to the discovery of a new word ‘Energy Crisis’, which is related to the increase in the demand of the energy consumption.

Excessive and haphazard uses of these resources lead the world to problems like Global Warming. Due to these, there is increase in temperature of the Earth’s atmosphere. In such condition, human comfort becomes a major concern. And hence, development of cooling and air-conditioning equipment took place. Requirement and necessity for Cooling and refrigeration has been continuously increasing nowadays. It is estimated that current demand estimation of energy is between 40 to 50 % of the total energy consumption. Out of which, about 70 % energy is consumed in refrigeration and air-conditioning. Hence it is necessary to develop a system of cooling which is effective and reliable [1].

2. Methods of Cooling

The process of decreasing the higher initial temperature to some desired lower temperature is called Cooling. It is also known as Air-Conditioning. It is a thermodynamic process in which some heat is removed by performing some external work on the system.

The process of cooling is classified into following types, based on cooling method of air.

[*] Corresponding author e-mail: mrshah2295@gmail.com
Tel.: +91 9427538719

© 2016 A D Publication. All rights reserved

Nomenclature

Greek symbol	
γ	ratio of mass of product air to mass of working air
Abbreviations	
DEC	direct evaporative cooler
IEC	indirect evaporative cooler
IDEC	indirect direct evaporative cooler
HMX	heat and mass exchanger
DBT	dry bulb temperature
COP	co-efficient of performance
VCR	vapour compression refrigeration
VAR	vapour absorption refrigeration
NTU	number of transfer units
Special character	
ε	thermal effectiveness

2.1. Direct Evaporative Cooling

In DEC system, there is direct contact between air and water droplets. Due to this, the heat from the air gets transferred to droplets, due to which it evaporates and the air gets cooled. This cooled air is then supplied to the required system [2]. This system has such a simple working and construction and also is economical. But the main drawback of this system is the humidity content present in air is higher, which sometimes can be the reason for discomfortability in dry seasons. Moreover, the temperature drop is also lesser. The wet-bulb effectiveness of this system reaches between 70-95% [1]. Hence, for dry and arid lands like India, this system of cooling is not so suitable. Following fig. 1 shows the schematic diagram and psychometric chart of a DEC system [2].Whereas Fig. 2 shows a typical construction of direct evaporating cooling system.

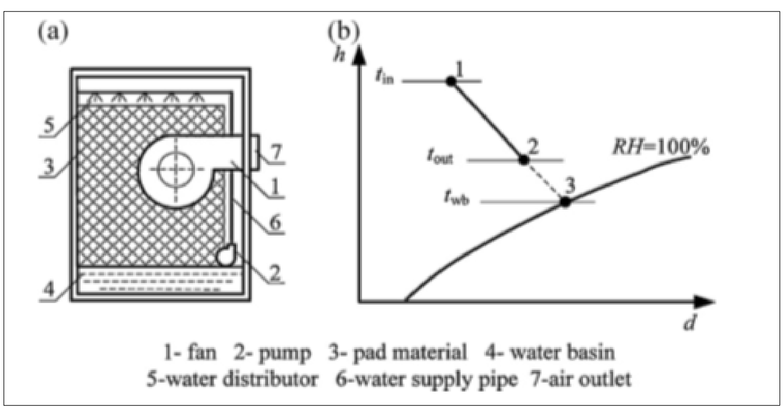

Fig. 1.Schematic diagram and psychometric Chart of DEC System [2]

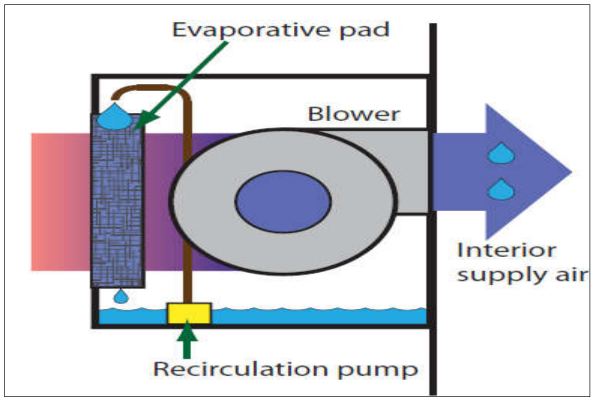

Fig. 2. Direct Evaporative Cooling System

2.2. Indirect Evaporative Cooling

In IEC, the cooling takes place in two stages. In the first stage, some part of air gets cooled by direct contact of water, that is, by DEC method. It is called Secondary air. Now the atmospheric air or main air, also called primary air is cooled down in an exchanger with the help of the secondary air discussed above. Hence the air gets cooled down without any type of contact with water. This method gives a required temperature drop and avails controlled humidity. The wet-bulb effectiveness of this system is in the range of 40–80%, which is lower than that of the DEC systems [1]. But the economy of this cooling system is much higher. Also it has a complex structure. Moreover, the coolants used in this system sometimes are useful to humans as well as to Earth's atmosphere. Following fig. 3 shows the working mechanism, configuration and psychometric chart of a typical IEC system [3].

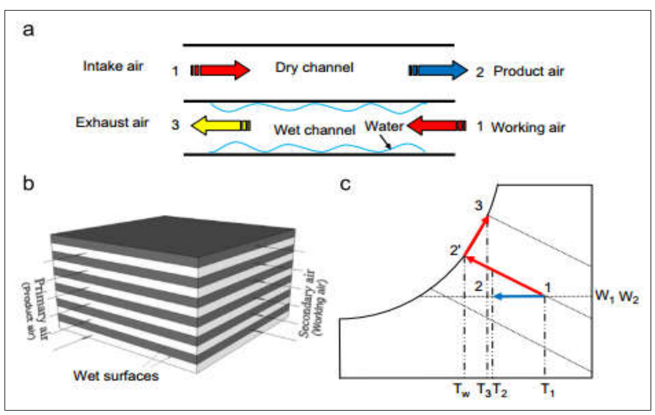

Fig. 3 a) Working principle, b) configuration of heat and mass exchanger c) psychrometric chart of an Indirect Evaporative Cooling system[3]

2.3. Indirect-Direct Evaporative Cooling

The third system, IDEC, is the combination of both the above system. In this system, initially, air is cooled with IEC method and then is again cooled down by keeping it in direct contact with water that is by DEC method. It has the same drawback as that of DEC, except the temperature drop is little higher than DEC method of cooling.

To overcome these drawbacks of the different cooling methods, a Soviet Scientist named Valeriy

Maisotsenko developed a new system after a lot of research work and experiments. This method is named as M-cycle or Maisotsenko Cycle, after him.

3. Maisotsenko Cycle (M-Cycle)

3.1. Overview

M-cycle is an indirect evaporative cooling based cycle, which utilizes a smart geometrical configuration for the air distribution. The achievement of this geometry is the high efficiency of the cycle, as it produces cold air of temperature lower than the wet-bulb ambient air temperature. M-cycle has been designed to optimize the effectiveness of both stages of evaporation (direct evaporation of working stream and heat exchange between streams). Instead of one-stage evaporating, M-cycle is based on a multi-evaporating approach, which allows to it to achieve high values of effectiveness, higher than 105%. The usage of M-cycle–based coolers leads to significant energy saving, more than 80% in terms of electricity [4].

3.2. Working of M-Cycle

There are two types of channels (Dry channel and Wet channel) alternatively used in M-Cycle to get the desired effect. As shown in fig. 4. During operation, all part of air is initially brought into the dry channels of the heat exchanger, and cooled when moving along the flow path owing to the established temperature difference between the dry and wet side of the exchanger plates. When passing across the perforated holes, part of the air, and known as the working (or secondary) air is diverted into the adjacent wet channels. Within the wet channels, the air travels in normal direction to the dry channel air, taking away the evaporated water from the saturated wet surface of the plate and receiving the sensible heat transferred across the plate. As a result, the working (secondary) air is gradually saturated and heated when travelling across the flow paths, and finally discharged to ambient, leading to the state change from point3´, 3´´ to 3. Meanwhile, the remaining air in the dry channel continues to move forward and at the end of its flow path, is cooled to a state below its relative wet bulb and close to its dew point [5].

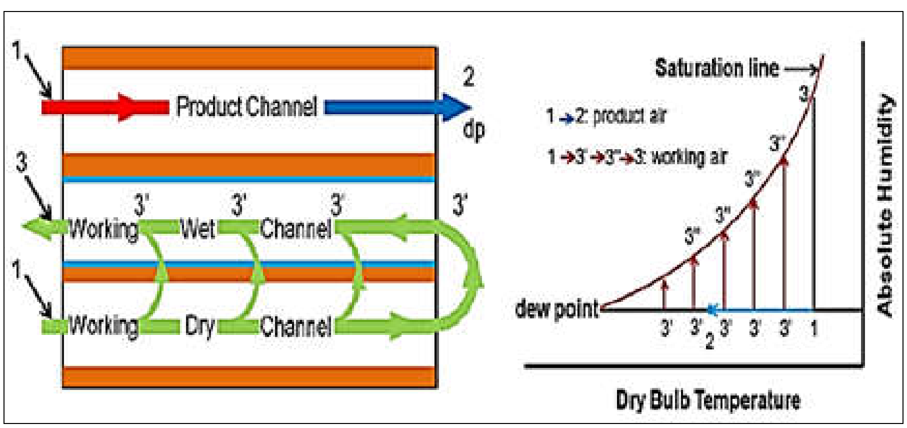

Fig. 4. Principle of the heat and mass exchanger based on M- cycle and its representation on psychometry chart [5]

In M-Cycle based heat and mass exchanger atmospheric air first cooled in dry channel and supplied to wet channel, so that this pre-cooled air gets cool in wet channel and achieve wet bulb temperature. Further it is supplied to dry channel and so on, so that one can achieve product air below wet bulb temperature. Compared to the conventional IEC heat exchanger, this M-cycle exchanger will produce a much colder air flow to be delivered to the room space, thus generating the increased cooling output. Due to its potential in reaching the dew point of the product air, the approach is also known as dew point (M-cycle) cooling. A test indicated that the M-cycle based heat exchanger could obtain a wet bulb effectiveness of 81–91% and dew point effectiveness of 50–60%, which is 10–30% higher than that of the conventional IEC heat exchangers [5].

Leland Gillan, a senior R&D engineer at Idalex states, “the ability to add moisture using waste heat allows the Maisotsenko cycle to run at high efficiency at any load from 50% to 100%”. The M-Cycle claims that it can overcome the practical limitations of the “humid air turbine”. The main practical limitation of the Humid Air Turbine cycle is its humidification process [6].

In the above the figure, main air stream is taken up from the room-1 and is passed through dry duct-1. After passing through the dry duct-1, some portion of air is separated out of main stream as cooled air stream which is returned back to room-1 and rest of the air is directed to moist duct-2 as auxiliary air stream-1. The auxiliary air stream-2 which is taken from atmosphere is passed through dry duct-2 which is in heat exchange relation with moist duct-2. After passing through dry duct-2, it passes through moist duct-1 which is in heat exchange relation with dry duct-1. Since the auxiliary air stream-2 is precooled and then passed through moist duct-1, it cools down to dew point temperature of surrounding air. Thus, the main stream and auxiliary air stream-2 which is precooled are in heat exchange relation which causes the main stream to cool down to dew point temperature of surrounding air without changing its moisture content [7]. The purpose of the method and apparatus for dew point indirect evaporative cooling is to provide the product fluid for example air, water, oil, etc., which is cooled by passing multiple product streams through the invention apparatus to a user [8]

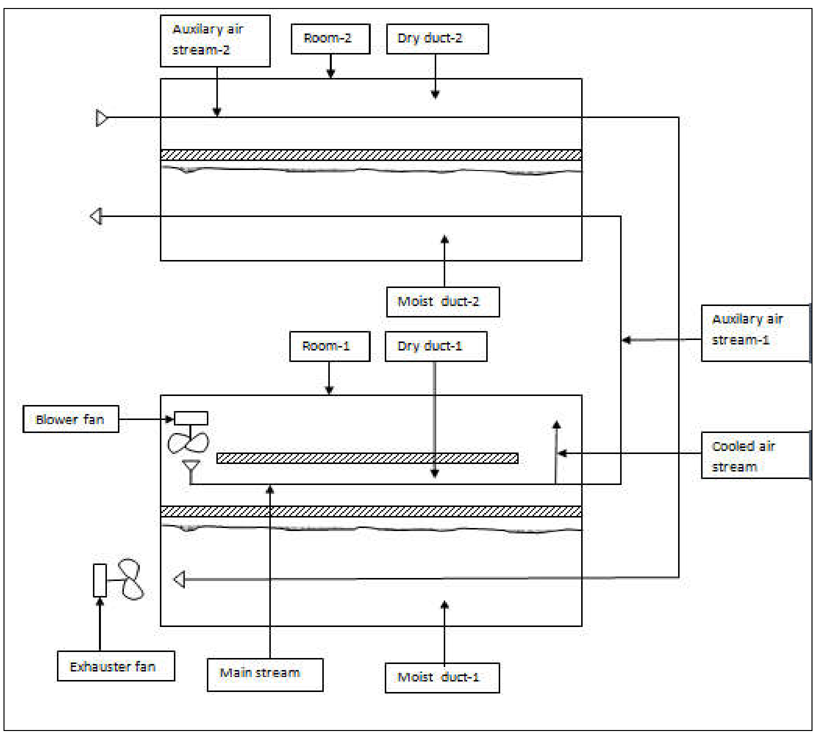

Fig. 5 Basic flow diagram of M-Cycle [7]

3.3. Psychometry Chart

In conventional cooling technique humidity increases and Dry bulb temperature decreases, so that Wet bulb temperature remains constant. Whereas in M-Cycle based indirect evaporative Cooling system humidity remains Constant and dry bulb temperature decreases, so that we can achieve temperature upto due point temperature in this system. Above concept is explained with respect to below Psychometry chart.

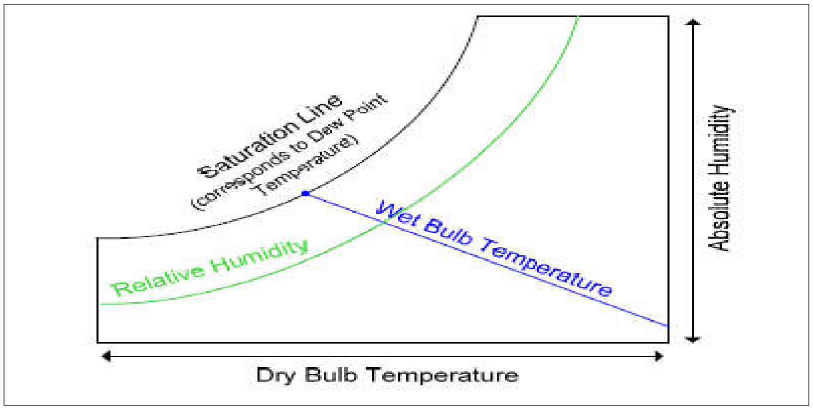

Fig. 6. Psychometric Chart [9]

Dew point evaporative cooling processes, including the M-Cycle, can be used to remove undesired heat from industrial, commercial, and residential facilities, including electrical power plants, oil refineries, chemical production plants, and air conditioning systems. Dew point evaporative cooling processes take advantage of the fact that when a parcel of air is sensibly cooled, the saturated water vapor pressure decreases, reducing its wet bulb temperature, thus increasing its evaporative cooling potential. Consequently, as the working fluid is humidified, the temperature of the evaporative cooling liquid that it is in contact with is also cooled to theoretically as low as the incoming air dew point temperature. This is accomplished in Fig. 7 through the sensible pre-cooling of the air at Point 1, lowering its wet bulb temperature. This wet bulb depression is limited to the incoming air dew point temperature [9].

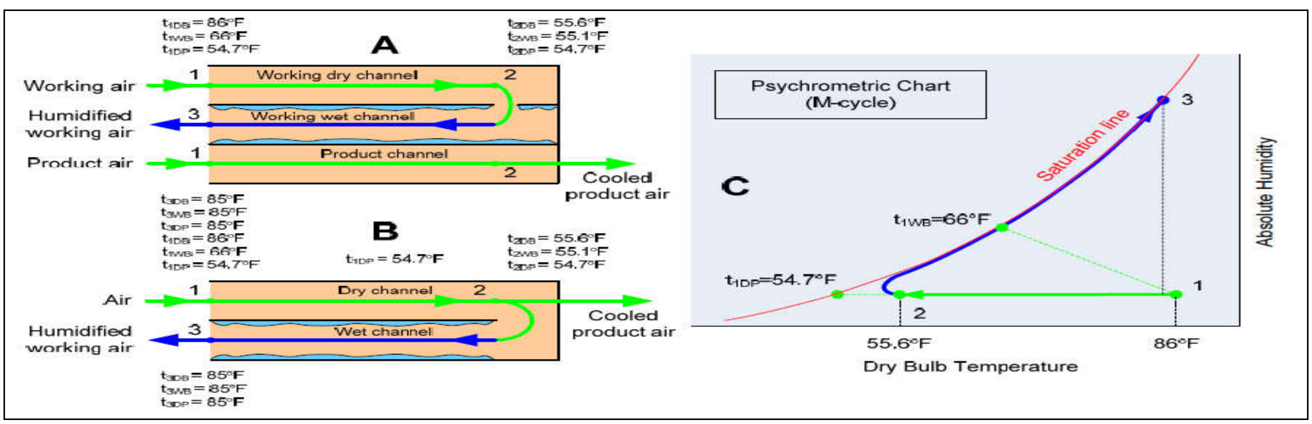

Fig. 7. M-cycle open cooling tower: (a) flow diagram and (*b*) psychometric chart [9]

4. Heat and Mass Exchanger

Heat And Mass Exchanger (HMX) is the heart of M-Cycle based Indirect Evaporative Cooler (IEC). It is a cross flow heat exchanger consisting of a number of heat transfer plates which are parallely arranged. Each plate has two sides i.e., dry side and wet side. The dry sides of adjacent plates face each other. Similarly, the wet sides of adjacent plates also face each

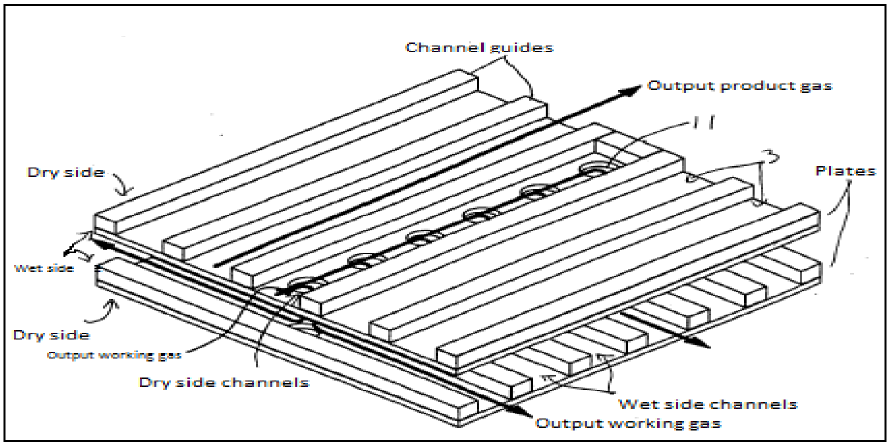

Fig. 8. Schematic representation of combination of a dry and wet plate [10]

air flows over the dry sides of plates from input end to output end. A part of the input air becomes the product air and is supplied to the space to be cooled. The rest of the air passes through the perforations made in the plates to the wet side of the plate to become working air. The wet side of the plate is wet by an evaporative liquid, usually water. The working air flowing over the wet sides evaporates the evaporative liquid which cools the evaporative liquid, the plate and finally the product gas by heat transfer. The perforations are formed in the plate

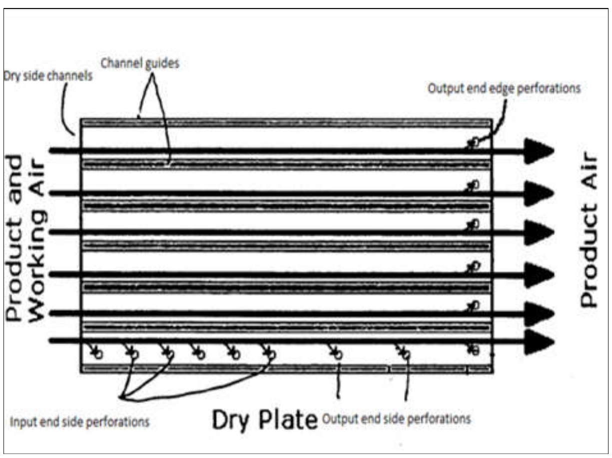

Fig. 9. Dry Channel [10]

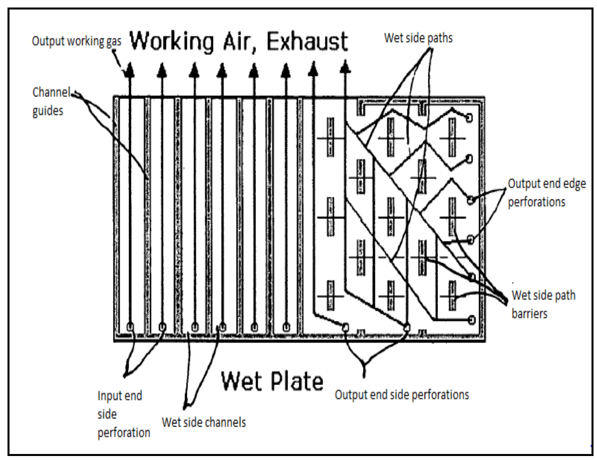

Fig. 10. Wet Channel [10]

both toward the input end of the plate and toward the output end of the plate to allow a portion of the liquid fluid to pass from the dry side to the wet side [10].

Maisotsenko et al. [11] presented Method and plate apparatus for dew point evaporative cooler using trough wetting system. He provided a method and apparatus for indirect evaporative cooling of a fluid stream to its dew point temperature. The Indirect Evaporative Cooler is having cross flowing wet and dry channels on opposite sides of a heat exchanger plate. This plate allows heat transfer through the plate due to thin plastic construction or other suitable material. The plate also has perforations between the dry side and wet side of the plate in defined areas which provides flow from the dry working channels to the working wet channels in which direct evaporative cooling takes place. In this method, the working gas flow is separated from the product fluid flow, both flowing through dry product channels and dry working channels on the same side of the heat exchanger plate. The working gas flow first enters the dry working channel and then through perforations, to the wet side and thence into the wet working channels where evaporation of liquid on the wet channels surface, cools this plate. The dry product channels are on the dry side of this plate. The plate is made of a thin material to allow easy heat transfer across the plate, from the dry product channel to the wet working channel.

Gillan et al. [12] presented plate heat and mass exchanger with edge extension. This invention provides method for drawing excess liquid and minerals away from the heat exchanging portion of the plate and removing them from the plate. To achieve this, edge extensions are added to the plates of indirect evaporative coolers to allow excess evaporative liquid to migrate to the edges of the plate and drip off which also takes away dissolved minerals with it.

Gillan et al. [13] presented Fabrication materials and techniques for plate heat and mass exchangers for Indirect Evaporative Coolers. This process for fabricating a Dew Point Evaporative Air Cooler uses the thermo forming properties of a plastic polymer to create a seal edge on the inlet and outlet faces of a heat and mass exchanger plate and around the air passageways between the dry side of the plate and a wet side. The plastic polymer material allows the edges to be sealed by melting the fiber material such as epoxy. In addition, this material uses a hydrophobic plastic polymer such as polypropylene or a combination of plastic polymer hydrophobic material such as a polypropylene spun bond intermingled or on top of a nylon naturally wicking material, with the hydrophobic material on the evaporative surface to improve wicking and evaporation, and retard mold. Also, a surfactant is used to start the wicking on the hydrophobic layer. An automated die stamper may be used to accomplish the sealing process that heats the sealed area to the effective temperature and also cuts the sheets to desired configuration. ε–NTU method is developed to analyze the performance of two M-Cycle HMXs [14].

The flow becomes counterflow at 180 degrees and parallel at 0 degrees. A substantially perpendicular flow may occur at an angle between these two extremes, provided the angle allows the streams on opposite sides of the plate to cross each other [15].The liquid desiccants can be placed in the dry channel increasing the heat transfer rate from air to desiccants and desiccants to the heat transfer surface by five to ten times [16]. Heat transfer surface or heat exchange surface has many configurations. All are encompassed within the subject of this disclosed invention with appropriate adjustment to the wetting and flows as are well known in the industry [17].

5. Analysis and experimental results

This system is suitable for hot and humid climate condition. This system influence major operating parameters such as velocity, system dimensions and ratio of working air to inlet air [18].The fan used for through the air having 80W/120W of power and 800 m^3/hr at speed 2000 rpm or 1100 m^3/hr at 2500 rpm which is maximum speed for the invention. For constant DBT and relative humidity data are as shown in below table1 [19].

Table 1 Speed and discharge at constant DBT and relative humidity

Sr. No.	Speed	Discharge (m^3/hr)
1	Low speed	0.017
2	Medium speed	0.032
3	High speed	0.04

In this system, Composite sheets are used for dry and wet channels. The material of wet channel is cellulose (has a good wicking capabilities). Polyester and other similar type of material are also used for that channel. The two channels are separated by laminated plastic layer. Space between two plates is 1.57 mm to 1.83 mm, 2.17 mm to 2.33 mm, 2.16 mm to 2.87 mm. due to that spacing, pressure reduce from 1% up to 15% experimentally. The ratio of mass of product air to mass of working air is given by γ, in which $\gamma<1$ for stronger evaporation of water and produce air temperature is low and $\gamma>1$ for weaker evaporation of water and produce air temperature is high [20]. The COP for VCR system is 2-3, for VAR system is 0.4-1.2 [21] and for this evaporating system is increase upto 8-20 [22]. For the best comfort condition blowing is from bottom side at low velocity and suction is from top side at high velocity. Thermal comfort substantially disturbed by high temperature, velocity [23].

Changhong et al. [24] presented Numerical study of an M-cycle cross-flow heat exchanger for indirect evaporative cooling. In this study, a model was developed using the EES (Engineering Equation Solver) environment and validated by published experimental data, by solving the coupled governing equations for heat and mass transfer between the products and working air, using the finite-element method. Also, a correlation between the wet-bulb effectiveness, system COP and a number of air flow/exchanger parameters was developed. It has been derived that lower channel air velocity, lower inlet air relative humidity and higher working to product air ratio yielded higher cooling effectiveness. The preferred average air velocities in the dry and wet channels should not exceed 1.77 m/s and 0.7 m/s respectively. The optimum flow ratio of working to product air for this cooler is 50%. The recommended channel height is 4 mm and the ratio of channel length to height should be in the range 100 to 300.Thus study results showed that this new type of heat and mass exchanger can achieve 16.7% higher cooling effectiveness compared to the conventional cross-flow heat and mass exchanger for the indirect evaporative cooler.

Riangvilaikul et al. [25] presented Numerical study of a novel dew point evaporative cooling system. In this study, a counterflow arrangement for heat and mass transfer of all flowing fluids has been considered in design and construction of the dew point evaporative cooler. Operating under different climate, the simulations performed in the study indicated that the dew point effectiveness varies from 65 to 86% and wet bulb effectiveness varies from 106 to 109% when the inlet air humidity changes from 6.9 to 26.4 g/kg at constant inlet temperature as 35°C. To obtain wet bulb effectiveness greater than 100% in all typical inlet air conditions, the system should be designed and operated at intake air velocity below 2.5 m/s, channels gap less than 5 mm, channel height greater than 1 mm and ratio of working air to intake around 35-60%. So, indirect evaporative cooling systems increase efficiency, economy and productivity by the additions of the novel structures [26].

Conclusion

For the termination of the drawbacks of DEC system and IEC system, a new system is developed which works on M-cycle. This system has a specially designed Heat and mass exchanger. It is designed such that wet channel and dry channel are always having a counter flow direction and these channels are kept in parallel to each other. Due to such a special design, the air can cool down to a temperature below wet bulb temperature and upto dew point temperature along with controlled humidity.

Reference

[1] O. Amer, R. Boukhanouf, H. G. Ibrahim, " A Review of Evaporative Cooling Technologies ", International Journal of Environmental Science and Development, Vol. 6, No. 2, 2015.

[2] Y.M. Xuan, F. Xiao, X.F. Niu, X. Huan, S.W. Wang, “Research and application of evaporative cooling in China: A review (I) – Research”, Renewable and Sustainable Energy Reviews, 16, 3535-3546, 2012.

[3] Z. Duan, C. Zhan, X. Zhang, M. Mustafa, X. Zhao, B. Alimohammadisagv, A. Hasan, “Indirect evaporative cooling: Past, present and future potentials”, Renewable and Sustainable Energy Reviews 16 (2012) 6823–6850.

[4]E. D. Rogdakis, D. N. Tertipis, “Maisotsenko cycle: technology overview and energy-saving potential in cooling systems” Energy and Emission Control Technologies 3 (2015) 15–22.

[5] D. S. Patel, H. M. Patel, “A Detail Review of an Indirect Evaporative Cooling System Using M –Cycle”, International Journal for Scientific Research & Development| Vol. 2, Issue 10, 407-412, 2014.

[6] C. Wani, S. Ghodke, C. Shrivastava, “A Review on Potential of Maisotsenko Cycle in Energy Saving Applications Using Evaporative Cooling” International Journal of Advance Research in Science, Engineering and Technology, Vol.01, Issue 01, pp.15-20, 2012.

[7] V. S. Maisotsenko, A. N. Gershuni, “Method for indirect-evaporative air cooling”, United States Patent 4977753, Dec. 18, 1990.

[8] V. S. Maisotsenko, L. E. Gillan, T. L. Heaton, A. D. Gillan, “Method and apparatus for dew point evaporative product cooling”, World Intellectual Property Organization 2001057459 A1, Aug. 9, 2001.

[9] “Maisotsenko-cycle Enhanced Cooling Towers” IDALEX Technologies, GTI.

[10] L. E. Gillan, V. S. Maisotsenko, A. Gillan, R. Gillan, “Indirect evaporating cooling of a gas using common product and working gas in a partial counterflow configuration”, United States Patent 20050210907 A1, Sep. 29, 2005.

[11] V. S. Maisotsenko, T. L. Heaton, A. D. Gillan, L. E. Gillan, “Method and plate apparatus for dew point evaporative cooler using a trough wetting system”, United States Patent 6705096 B2, Mar. 16,2004.

[12] L. E. Gillan, V. S. Maisotsenko, T. L. Heaton, A. Gillan, R. Gillan, “Plate heat and mass exchanger with edge extension”, United States Patent 7,228,699 B2, Jun. 12, 2007.

[13] L. E. Gillan, V. S. Maisotsenko, A. Gillan, R. Gillan, “Fabrication materials and techniques for plate heat and mass exchangers for indirect evaporative coolers”, United States Patent 20100018234 A1, Jan. 28, 2010.

[14] D. Pandelidis, S. Anisimov, W. M. Worek, “Performance study of the Maisotsenko Cycle heat exchangers in different air-conditioning applications”, International Journal of Heat and Mass Transfer 81 (2015) 207–221.

[15] V. S. Maisotsenko, L. E. Gillan, T. L. Heaton, A. D. Gillan, “Method and plate apparatus for dew point evaporative cooler”, United States Patent 7197887 B2, Apr. 3, 2007.

[16] V. S. Maisotsenko, L. E. Gillan, T. L. Heaton, A. D. Gillan, “Method and apparatus of indirect-evaporation cooling”, United States Patent 6497107 B2, Dec. 24, 2002.

[17] V. S. Maisotsenko, L. E. Gillan, T. L. Heaton, A. D. Gillan, “Method and plate apparatus for dew point evaporative cooler”, United States Patent 6581402 B2, Jun. 24, 2003.

[18] B. Riangvilaikul, S. Kumar, Numerical study of a novel dew point evaporative cooling system, Energy and Buildings, 42, 2241–2250, 2010.

[19] A. Ahmad, S. Rehman, I. Al-Hadhrami, “Performance evaluation of an indirect evaporative cooler under controlled environmental conditions”, Energy and Buildings, 62, 278–285, 2013.

[20] V. Maisotsenko, L. Gillan, T. Heaton, A. Gillan “Indirect Evaporative Cooling Mechanism”, United States Patent 20040061245A1, Apr. 1, 2004.

[21] C. Zhan, Z. Duan, X. Zhao, S. Smith, H. Jin, S. Riffat, “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, 6790–6805, 2011.

[22] C. Qun, Y. Kangding, W. Moran, P. Ning, G. Zeng-Yuan, “A new approach to analysis and optimization of evaporative cooling system”, Theory, Energy, 35 (6), 2448–2454, 2010.

[23] S. Çalışkan, M. Zeki Yılmazoğlu, İ. Atılgan, Ş. Başkaya, “Experimental Investigation of Thermal Comfort Inside an Office Room”, Gazi University Faculty of Engineering Department of Mechanical Engineering Maltepe Ankara/TURKEY.

[24] C. Zhan, X. Zhao, S. Smith, S.B. Riffat, “Numerical study of an M-cycle cross-flow heat exchanger for indirect evaporative cooling”, Building and Environment, 46, 657-668, 2011.

[25] B. Riangvilaikul, S. Kumar. Numerical study of a novel dew point evaporative cooling system. Building and Environment, 42, 2241-2250, 2010.

[26] V. Maisotsenko, L. Gillan, T. Heaton, A. Gillan, “Indirect evaporative cooling mechanism”, United States Patent 20050218535 A1, Oct. 6, 2005.