A Review on Evaporative Cooler using Maisotenko Cycle

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Abstract— A maximum part of the world's energy is consumed by ventilation and air-conditioning. The process of air cooling is one of the most energy-intensive processes in the ventilation and air-conditioning. A lot of energy is consumed by traditional systems based on the compressor cycle. The compressor which contained refrigerants in circuits produced a harmful effect on environment. These factors were mainly responsible for the active development of evaporative coolers. For overcoming this difficulty the former soviet scientist Valery Maisotsenko improved evaporative cooling technology and the resulting cycle was called as Maisotsenko cycle or M-cycle. He also patented a series of devices whose working was based on the M-cycle. This study aims to improve the performance of existing indirect evaporative coolers. A new dew point indirect evaporative cooler with counter-current heat/mass exchanger was developed in this research by optimal design, proper material selection, effective experimental investigations and evaluations as well as economic, environmental, regional acceptance analysis.

Key words: Evaporative cooler, Maisotenko cycle, Counter flow heat exchanger, Dew point temperature

I. INTRODUCTION

The building sector is responsible for around 30–40% of world total energy consumption and similar proportion of global carbon emission. Heating, Ventilation and Air Conditioning (HVAC) is the major energy user in a building and consumes around 50% of the total supplied energy. Air-conditioning, representing an important function of the HVAC system, is becoming increasingly crucial for many buildings, particularly those public types e.g., office blocks, supermarkets, sport Centres , airports, factories etc., owing to recent frequent warm spells, improved building insulation and growth of in-house heat generating appliances. Over the past decades, evaporative cooling, utilizing the principle of water evaporation for heat absorbing, has gained growing popularity for use in air conditioning, owing to its simplicity in structure and good use of natural energy (i.e., latent heat of water) existing in ambient. This led to enhanced system COP in the range 15–20, which is significantly higher than that for conventional vapour compression and adsorption/absorption air conditioning systems. To enhance cooling performance of the IEC heat exchanger, a novel thermodynamic cycle, known as the M-cycle, was proposed by Professor Valeriy Maisotenko as the new approach of making and operating a heat exchanger. [1, 3, 6]

II. WORKING

A. *Indirect Evaporative Cooling:*

Indirect Evaporative Cooling (IEC) systemscan lower air temperature without adding moisture into the air, making them the more attractive option over the direct ones. In an indirect evaporative air cooling system, the primary (product) air passesover the dry side of a plate, and the secondary (working) air passes over theopposite wetside. The wet side air absorbs heat from the dry side air with aid of water evaporation on the wet surface of the plate and thus cools the dry side air; while the latent heat of the vaporized water is transmitted into the working air in the wet side. If the product air of the IEC system travels in a counter flow manner to the working air at an appropriate air-flow-ratio and across an infinite surface area, the temperature of the product air in the dry side of the plate will reach the wet-bulb temperature of the incoming working air. The temperature of the working air in the wet side of the plate will be lowered from its incoming dry- bulb temperature to the incoming wet-bulb temperature. However, the actual effect is that only 40–80% of the incoming air wet- bulb temperature can be achieved. [1]

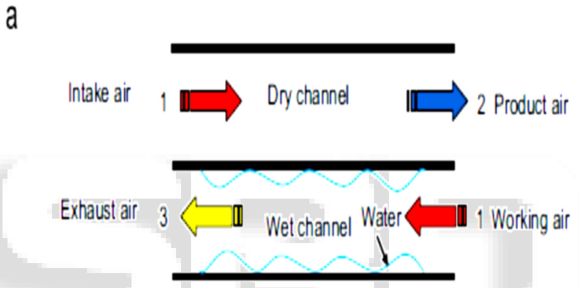

Fig. 1: Working Principle Of Indirect Evaporative Cooling [1]

B. *M-Cycle Based Indirect Evaporative Cooling:*

To enhance cooling performance of the IEC heat Exchanger, a novel thermodynamic cycle, known as the M-cycle, was proposed by Professor Valeriy Maisotenko as the new approach of making and operating a heat exchanger. This cycle was claimed to enable harnessing extra amount of energy from the ambient using a dedicated flat plate, cross-flow and perforated heat exchanger. [1]

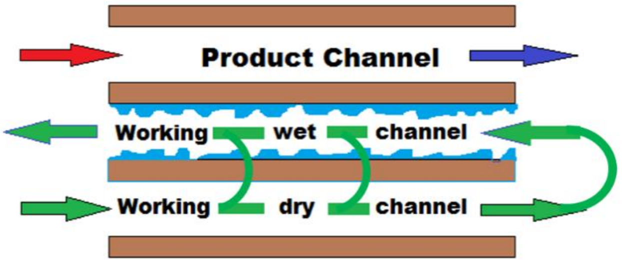

Fig. 2: Principle Of M-Cycle Based Indirect Evaporative Cooling Heat And Mass Exchanger [1]

C. *Counter-Flow Heat Exchanger:*

During operation, both the product and working air are directed into the dry channels, losing heat to the adjacent wet channels and at the end of each channel, all parts of air are cooled to a level approaching the inlet air’s dew point. At this end, part of the air (product air) is delivered to the building space and the remaining air (working air) is diverted to the adjacent wet channels, where it travels on an opposite direction to the dry channel air. After getting processed in wet channel, thermodynamically indirect evaporative air cooler passes primary or product air over the dry side of a plate and secondary or working air over the opposite wet side of a plate. The wet side absorbs heat from the dry side by evaporating water and therefore cooling the dry side with the latent heat of vaporizing water into the air. Theoretically, the working air on the wet side of the plate would increase in temperature from its incoming air wet bulb temperature to the incoming product air-dry bulb temperature and be saturated. [1]

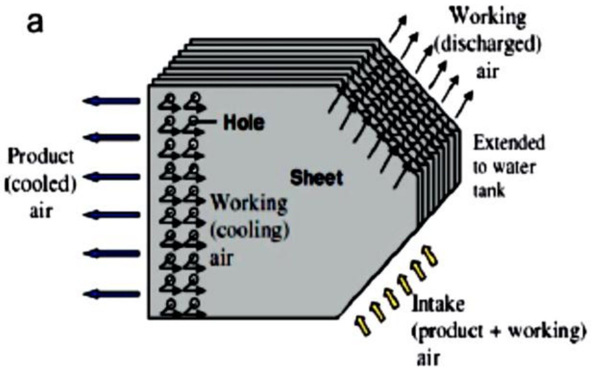

Fig. 3: Structural Representation Of Counter Flow Heat Exchanger [1]

III. LITERATURE SURVEY

Zhiyin Duan, et al.,[1] represents an overview of the Indirect Evaporative Cooling (IEC) technology, which was concluded by considering various aspects including background, history, current status, concept, standardization, system configuration, operational mode, research and industrialization, market prospect and barriers, as well as the future focuses on R&D and commercialization. This paper work represents that the IEC technology has potential to be an alternative to the conventional mechanical vapour compression refrigeration systems to take up the air conditioning system of building.

X. Cui, et al.,[2] presented the performance of a novel dew-point evaporative air cooler is theoretically investigated in this paper. The novel dew-point evaporative air cooler, based on a counter-flow closed-loop configuration, is able to cool air below the ambient wet bulb temperature and approaching dew-point temperature. A systematic computational model for the cooler has been developed. The novel dew-point evaporative air cooler was able to cool air to the temperature below its inlet wet bulb temperature and approaching dew-point temperature efficiently. Operating under variant inlet conditions (air temperature and humidity ratio), simulation results showed that the cooler could achieve wet bulb effectiveness of up to 132%, and dew-point effectiveness of up to 93%.

X. Cui, et al.,[3] considered here gives the representation of simulation results on a novel dew-point evaporative air conditioner which was designed based on a closed-loop counter flow configuration consisting of different separated working channels and product channels. The novel evaporative air conditioner is able to cool air below the ambient wet bulb temperature and approaching dew-point temperature. To investigate and measure the performance of the evaporative air cooler under various conditions, the Eulerian–Lagrangian computational fluid dynamics (CFD) model was adopted. The researchers validated the model by comparing the temperature distributions and the conditions of outlet air against the experimental data. The performance of a novel counter-flow closed-loop dew-point evaporative air conditioner has been studied and evaluated.

Sergey Anisimov, et al.,[4] describes numerical modelling of heat and mass transfer in the Maisotsenko cycle heat and mass exchanger (HMX) used for indirect evaporative cooling. For this purpose a numerical model is developed based on the modified e-NTU method to perform thermal calculations of the indirect evaporative cooling process, thus quantifying overall heat exchanger performance. Numerical simulation reveals many unique features of considered HMX, enabling an accurate prediction of its performance. The outcomes of computer simulation showed high efficiency gains that are sensitive to various inlet conditions, and allow for estimation of optimum operating conditions, including suitable climatic zones for the proposed unit using. This study presents theoretical energy analyses of the novel plate-fin heat exchanger based on Maisotsenko cycle and used for indirect evaporative cooling in air conditioning system. The performance of the Maisotsenko HMX was investigated and parametrically evaluated by transitional simulation under various ambient and working/operating conditions in terms of cooling efficiency.

Chandrakant Wani, et al.,[5] reviews and represents the underutilized applications that the Maisotsenko Cycle could have. The use of Maisotsenko Cycle overcomes the constraints set by the conventional vapour compression system. Direct evaporative cooling is associated with the increased humidity though it gives a fair drop in temperature. On the other hand, the indirect evaporative cooling controls the humidity but the temperature drop is insufficient. Both the systems are coupled in Maisotsenko cycle to form a new system.This paper after reviewing the literature of many authors across the globe regarding the Maisotsenko Cycle, evaporative cooling, desiccant cooling, cooling pads concludes that M-cycle cools down the product air without any considerable increase in the humidity. This principle of M-cycle can find a very vital role in many applications of cooling.

Hakan Caliskan, et al.,[6] showed the study based on three various novel air coolers based on M-Cycle are evaluated using energy analyses based efficiency assessments along with their impact on environment and sustainability parameters. The M-Cycle systems are considered to cool a building room air while their inlet air parameters are same, but outlet cooled air parameters are different. The energy and energy analyses, and sustainability and environmental impact assessments are applied to the three novel air cooler systems considered to cool a building air. Energy analysis is performed for achieving the wet bulb effectiveness, cooling capacity, COP and PER of the systems.

Ala Hasan, et al.,[7] studied a method whose main objective was to achieve sub-wet bulb temperature by indirect evaporative cooling of air (without using a vapour compression machine). For this purpose, an analytical model is first developed based on the effectiveness-NTU method (e-NTU). The main idea regarding this study is to achieve the sub-wet bulb temperature by indirect evaporative cooling of air by indirectly pre-cooling the working air before it enters the wet passage. An analytical model is developed for finding the thermal performance of indirect evaporative coolers based on modifications of the e-NTU method, which is originally used for sensible heat exchangers. It is shown that the modified e-NTU method for indirect evaporative coolers can be based on that for a sensible heat exchanger when proper and suitable adjustments are made.

Hakan Caliskan, et al.,[8] presented energy analyses and sustainability assessment of the novel evaporative air cooling system based on Maisotsenko cycle which allows the product fluid to be cooled to dew point temperature of the incoming air. In the energy analysis, Maisotsenko cycle's wet-bulb and dew point effectiveness, COP and primary energy ratio rates are calculated. A comprehensive thermodynamic investigation through energy analyses and sustainability assessment is performed for the novel air cooler based on the Maisotsenko cycle. The performance and characteristics of the cycle are then evaluated and studied carefully.

Changhong Zhan, et al.,[9] elaborates the numerical analyses of the thermal performance of an indirect evaporative air cooler incorporating M-cycle cross-flow heat exchanger has been carried out. The numerical model was established from solving the coupled governing equations for heat and mass transfer between the products and working air, using the finite-element method. The model was developed using the EES (Engineering Equation Solver) environment and validated by published experimental data. The research has established a computer model able to simulate the thermal performance of an M-cycle cross-flow heat exchanger.

B. Riangvilaikul, et al.,[10] shows that the dew point evaporative cooling system is an alternative to vapour compression air conditioning system for sensible cooling of ventilation air. This paper presents the theoretical performance of a novel dew point evaporative cooling system operating under various conditions of inlet air (covering dry, moderate and humid climate) and influence of major operating parameters (namely, velocity, system dimension and the ratio of working air to intake air).A model of the dew point evaporative cooling system has been developed to simulate the heat and mass transfer processes.

Ghassem Heidarinejad, et al.,[11] studiedCooling function of two-stage indirect/direct evaporative cooling system is experimentally investigated in the different conditions. For this purpose, a two-stage evaporative Cooling experimental setup consisting of an indirect evaporative cooling stage (IEC) followed by a direct evaporative cooling stage (DEC) was designed, constructed and tested. In different outdoor conditions, the effectiveness of IEC stage varies over a range of 55–61% and the effectiveness of IEC/DEC unit varies over a range of 108–111%. Considering the evaporative comfort zone, this system can provide comfort condition in a huge region in Iran where direct evaporative alone is can't provide summer comfort condition

B. Riangvilaikul, et al.,[12] analyzed the experimental datas of evaporative cooling system for sensible cooling of the ventilation air for airconditioning application was built and experiments were carried out to investigate the outlet air conditions and the system effectiveness at different inlet air conditions covering dry, temperate and humid climates. Effectiveness ranged between 92 and 114% and the dew point effectiveness between 58 and 84%.In day of summer in a hot and humid climate showed that wet bulb and dew point effectiveness constant at about 102 and 76%, respectively. This give better performance at various operating state, covering dry, moderate and humid climate. The wet bulb effectiveness ranged between 92 and 114%, whereas the dew point effectiveness lies between 58 and 84% for different inlet conditions. At inlet air temperature greater than 30 ^{o}C, the velocity of inlate air should be kept below 2.5 m/s to obtain wet bulb effectiveness greater than 100%

B. Naticchia, et al.,[13] undertook the experimental studies based on high summer conditioning consumption which is becoming a tough and critical issue and consequently there is a need to provide buildings with new technologies for energy saving. A new technology which is capable of canceling conduction gains through walls: "water-evaporative walls", which are not only able to prevent the entrance of energy fluxes from the exterior to the interior, but also to reduce wall temperatures to below the values found indoors. This solution basically suggests equipping standard ventilated facades with a proper water-evaporative system, which exploits the latent heat of water evaporation, in order to absorb summer cooling loads. A prototype of a wall stratification including an active spraying system which cools the air layer of ventilated facades was built and then evaluated in relation to the corresponding benchmark, both tested within an outdoor experimental campaign.

Joohyun Lee, et al.,[14] showed thatthe regenerative evaporative cooler is the indirect evaporative cooler comprised of multiple pairs of dry and wet channels. The air flowing through the dry channels is cooled without any change in the humidity and at the outlet of the dry channel a part of air is redirected to the wet channel where the evaporative cooling takes place. This type f cooler consist of the multiple pairs of finned channels in counter flow arrangement. The regenerative evaporative cooler was placed in a climate chamber and tested at various operation state. To improve the cooling performance, the evaporative water flow rate needs to be minimized as far as the even distribution of the evaporative water is secured. At the inlet condition of 32 ^{o}C and 50% RH, the outlet temperature was measured at 22 ^{o}C which is well below the inlet wet-bulb temperature of 23.7 ^{o}C.

Aftab Ahmad, et al.,[15] undertook the study of a 5-ton capacity indirect evaporative cooler under controlled environmental conditions but for different air flow rates. The experimental results showed that the inlet air energy efficiency ratio of the cooler lies between 7.1 to 55.1 depending on test conditions and air flow rate. The power consumption of indirect evaporative cooler was found to lies between 68.3 to 746 watts. Water consumption was found to lies between 0.0160 and 0.0598 m3/h. At full fan speed, an average of 58.7% of the total water consumed by indirect evaporative cooler was evaporated. The results indicated that intake air energy efficiency ratio was directly proportional to the wet-bulb depression. The indirect evaporative cooling system can achieve wet bulb effectiveness more than 100% because theoretically the limiting value of supply air temperature to the conditioned space is the dew point temperature of the intake air.

IV. FINDING FROM LITERATURE SURVEY

Maisotsenko cycle eliminated the major issues concerned with the set of constraints of the vapour compression system. The conventional direct evaporative cooling system obtained a fair temperature drop but the main problem related to it was humidity which was later avoided by the indirect evaporative cooling system but resulted in the less and insufficient temperature drop. But later on both the systems are coupled in the Maisotsenko cycle to form a main new coupled system.

A significantly enhanced cooling performance has been obtained form over a decade. The wet bulb effectiveness obtained is more than 90% and the energy efficiency ratio of about 80. Structure of the IEC heat and mass exchanger varied from flat-plate-stack, tube, heat pipe and potentially wave-form. Materials used for making the exchanger elements (plate/tube) included fiber sheet with the single side water proofing, Aluminium plate/tube with single side wicked setting (grooved, meshed, toughed etc.), and ceramic plate/tube with single side water proofing. Counter-current water flow relevant to the primary air is considered the favorite choice; good distribution of the water stream across the wet surface of the exchanger plate (tube) and adequate (matching up the evaporation) control of the water flow rate are critical to achieving the expected system performance.

It was noticed that the IEC devices were always in combined operation with other cooling measures and the commonly available IEC related operational modes are (1) IEC/DEC system; (2) IEC/DEC/mechanical vapour compression system; (3) IEC/desiccant system; (4) IEC/chilled water system; and (5) IEC/heat pipe system. The future potential operational modes may also cover the IEC-inclusive fan coil units, air handle units, cooling towers, solar driven desiccant cycle, and Rankine cycle based power generation system etc. Future works on the IEC technology may focus on (1) heat exchanger structure and material; (2) water flowing, distribution and treatment; (3) incorporation of the IEC components into conventional air conditioning products to enable combined operation between the IEC and other cooling devices; (4) economic, environment and social impacts; (5) standardization and legislation; (6) public awareness and other dissemination measures; and (7) manufacturing and commercialization.

	X. Cui, et al.,[3]	Zhan et al. [1]	B.Riangvilaikul et al. [10,21]
Study method	Simulation	Simulation	Simulation, Experiment
Type of the cooler	Plate heat exchanger	Plate heat exchanger	Plate heat exchanger
Flow arrangement	Counter flow; product air and working air are separated	Cross flow; one inlet for both the product air and the working air	Counter flow; working air is part of the product air
Product channel height	3–20 mm	5 mm	5 mm
Working channel height	1.5–10 mm	5 mm	5 mm
Channel length	300–1500 mm	1000 mm	1200 mm
Inlet air temperature	25–35 °C	28 °C	25–45 °C
Inlet air humidity ratio	8–12 g/kg	11.35 g/kg	7–26 g/kg
Inlet air velocity	0.3–4.0 m/s	1 m/s	2.4 m/s
Wet bulb effectiveness	1.22 - 1.32	1.16	0.92 - 1.14
Dew point effectiveness	0.81 - 0.93	0.81	0.58 - 0.84

Table 1: Finding From Literature Survey

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