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Investigation and design of Maisotsenko Indirect Evaporative Cooling System

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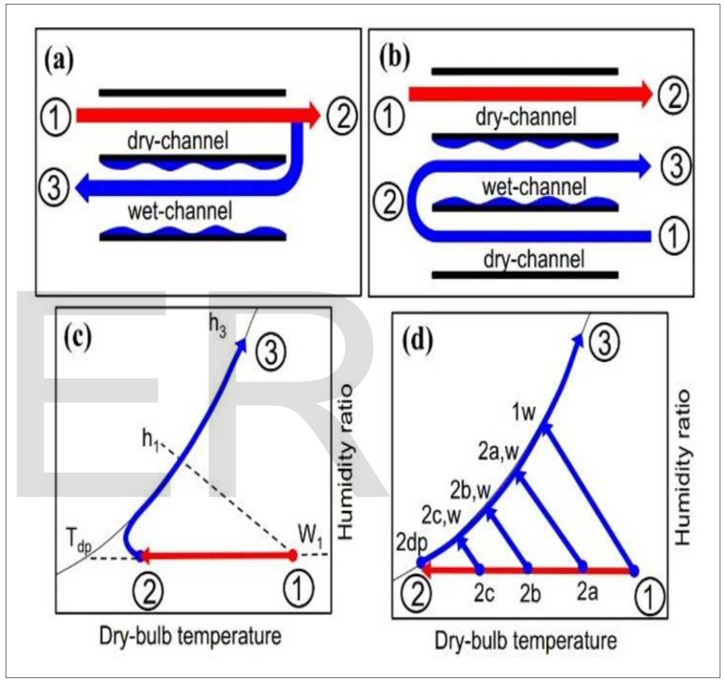
Abstract— In this paper, the Maisotsenko based Indirect Evaporative cooling system related Material considerations, performance standards, design related assumptions and dimensionless values are investigated. The physics of the Maisotsenko IEC was investigated based on a developed geometry. A CAD model of hiorizontal plate M-IEC is prepared based on the understood physics. The operational parameters observed in various papers were collectively studied. Based on the parameters the effect on performance is investigated.
Index Terms— Indirect Evaporative cooling system, Maisotsenko cycle, fundamental study, model, design formulae, performance evaluation standards, assumptions, material considerations

1 Introduction

MOST of the currently existing energy consuming and producing systems (based on Vapour Compression cycle) are inefficient and/or involved in environmentally harmful technologies. Heating, ventilation and air- conditioning (HVAC) systems; and cooling systems are the big energy consumers in today's modern society. In Direct Evaporative cooling (DEC) the cooling process of air is taking place by addition of moisture in air until it reaches the saturation point. This increase in humidity content is not favourable in many applications. In Indirect Evaporative Cooling (IEC) the air to be cooled does not come in direct contact with water. It is in contact with surface which is maintained at lower temperature. It consists of two channels one is 'dry channel' and other is 'Wet channel'. The Indirect Evaporative Cooling System is a good alternative to the conventional air conditioning systems, for protection of environment, energy saving and cost saving. Maisotsenko cycle (M-cycle) applies an improved design of indirect evaporative cooling leading it to dew point cooling.

The Maisotsenko cycle allows the product air to be cooled below the wet bulb temperature and toward the dew point temperature of the incoming working air. It utilizes the psychometric renewable energy available from the latent heat of water evaporating into the air. It can be explained from Fig.1a and Fig.1b representing the old and modified M-Cycle, respectively. The psychometric representation of old and modified M-Cycle is also shown in Fig.1c and Fig.1d respectively. It consists of two kinds of primary channels named as wet and dry channels. The product as well as working channels are devoted for air flow in case of old M-Cycle (Fig. a), whereas modified MCycle (Fig. b) gives the freedom to recover the heat from any fluid/gas by using an additional dry- channel.



Maisotsenko IEC system combines thermodynamic processes of heat transfer and evaporative cooling to facilitate product temperature to reach the dew-point temperature of the ambient air. It consists of *2 types of dry channels.* 1st Dry channel is dedicated for the primary product air (also called supply air) to be supplied into the room. 2nd Dry channel is dedicated for continuous pre-cooling of woring air and supplying th pre-cooled working air into the Wet channel through the perforated holes for further operation. The wet bulb temperature of secondary woring air is reduced repeatedly, due to continuous addition of cold air from working dry channel passages, which are dedicated for wet channel. In the *wet channels*, the air travels in normal direction to the dry channel air, taking the evaporated water from the saturated wet pad over the surface of the wet channel 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 into the surroundings. Refer to Fig.2 for flow understanding.

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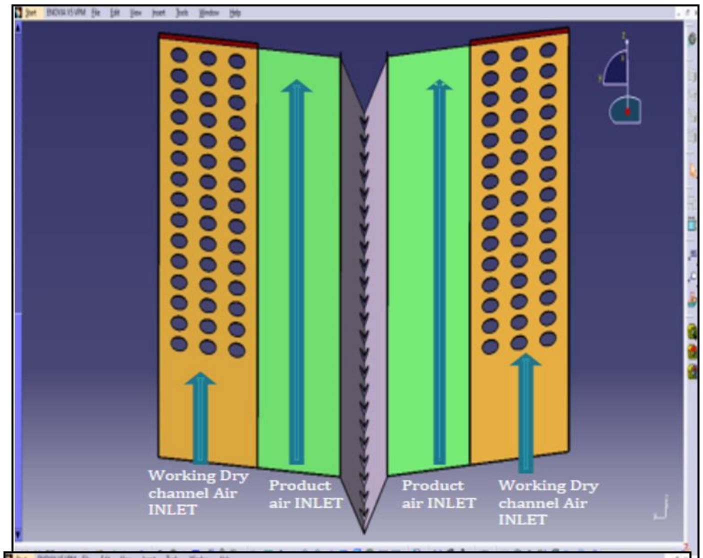
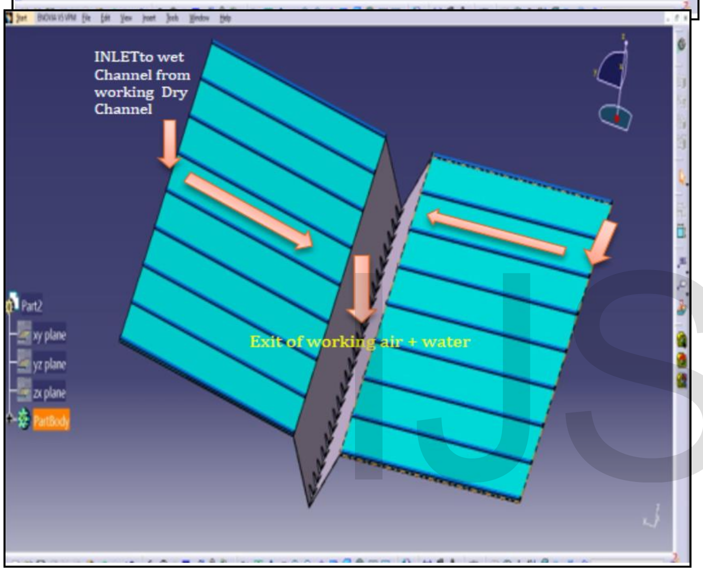




2 Objective

a) To understand the Physics (mechanics) involved in M-cycle Cross Flow Heat and Mass Exchanger, through our geometry.
b) To create CAD model of M-IEC
c) To study the variation of operational parameters on the performance of the M-IEC.

3 Literature Survey

3.1 Literature Review

J.K. Jain et.al. [1]: This paper objected to do Analytical evaluation of energy saving potential of an indirect evaporative cooler for summer months in Indian climates. Three climates likely to be suitable for indirect evaporative cooling, namely composite, hot and dry and moderate. **Bogdan Porumba et.al. [2]:** The review is presenting in details: theory, working principles, flow and construction. The IEC equipment and technology is suitable in different air conditioning applications: commercial, industrial, residential or data centres. The IEC technology is completely environmental friendly and has *very low global warming impact.* The single disadvantage of IEC is the water consumption. **Changhong Zhan et.al. [3]:** Numerical analyses of the thermal performance of an indirect evaporative air cooler incorporating the M-cycle cross-flow heat exchanger. It is found that *lower channel air velocity, lower inlet air relative humidity, and higher working-to- product air ratio yielded higher cooling effectiveness.* **Omar Khalid et.al. [4]:** Experimental investigations are conducted under various operating conditions of inlet air including its humidity, temperature and velocity along with water temperature. *The outlet air temperature depends linearly on the entering air temperature. Inlet velocity has important role in the performance of the considered system*. The outlet air conditions when the intake air velocity was varied while keeping the humidity ratio fixed. Air at humidity ratio of 11.2 g/kg at the inlet gives larger decrease in the outlet air temperature if the inlet air velocity is decreased. One possible explanation is the fact that at higher inlet velocities, the contact duration of air with wet side of channel is reduced. *Dew point effectiveness and the wet bulb effectiveness vary in the range of 62–85% and 92–120%, respectively with inlet air temperature variation from 25 to 45 °C.* **Qilong Liu et.al. [5]:** A plate cross-flow indirect evaporative cooling experimental system is constructed. A new efficiency evaluation index called enthalpy efficiency is proposed. A plate cross-flow indirect evaporative cooling experimental system was set up, and the inadaptability of the existing evaluation indexes was analyzed by applying the experimental data. In extreme weather where fresh air temperature is higher than 40 °C and humidity is still 90%, IEC has higher heat exchange efficiency and enthalpy efficiency is greater than 1. However, *such extreme weather conditions rarely occur, so the enthalpy efficiency varies between 0 and 1. The ideal condition is 1.* The temperature distribution range of the primary air passage in the indirect evaporative cooling process is usually from 20 to 30 °C. In hot and humid regions, IEC channels will be a fertile bed for the growth of legionella bacteria and other organisms due to condensation. **Stefano De Antonellis et.al. [6]:** In this work an indirect evaporative cooling system based on a cross flow heat exchanger has been widely tested. The system has been designed in order to minimize water consumption, with water mass flow rate between 0.4% and 4% of the secondary air. It is shown in many operating conditions a high fraction of evaporated water is achieved $\dot{M}eva$ / $\dot{M}w,in$> 40% : in those cases such system can be manufactured without a pump for water recirculation, leading to a compact apparatus and minimizing risks of bacterial contamination. In all tests the water temperature supplied to nozzles was around 20◦C. In all experiments the difference between total heat exchanged by primary and secondary air streams was within 5%. In a few tests it has been verified the correctness of the water mass balance by measuring the amount of water at the bottom of the heat exchanger in a determined period. *Higher the water mass flow rate, the higher the wet bulb effectiveness*. **Stefano De Antonellis et.al. [7]:** A phenomenological model of the indirect evaporative cooler has been developed: the model takes into account the effects of the adiabatic cooling of the secondary air stream in the inlet plenum and the actual wettability of the heat exchanger surface. The two air handling units are designed to control temperature, humidity and mass flow rate of primary and secondary air streams. Air conditions are controlled through heating coils, cooling coils, evaporative coolers and an electrical heater. The following assumptions have been adopted in this study: 1. Steady-state conditions. 2. No heat losses to the surroundings. 3. Negligible axial heat conduction and water diffusion in the air streams. 4. Negligible heat conduction in the heat exchanger plates. 5. Uniform air inlet conditions. 6. Interface plate temperature is equal to bulk water temperature. 7. Constant Lewis number. **Hossein Lotfizadeh et.al. [8]:** This investigation aims to evaluate the performance of a very small cooler with minimum energy consumption (10 W). In order to evaluate the performance of the cooler, the air temperatures at different locations in the room was measured and compared during five consecutive days. The results have shown that performance of the cooler is relatively reasonable during the summer. *The cooler with three wet pads was more efficient than single wet pad or dual wet pad.* **Khalid A. Joudi et.al. [9]:** The concept of variable air volume (VAV) was employed as a control strategy over the day by changing the supply air flow rate through a variable speed fan according to the variation in the cooling load. The simulation of the system included variation in the effectiveness of the plate heat exchanger employed for the indirect evaporative cooling stage and its effect upon the variation in the air flow rate. *The cooling load of a space depends on both the magnitude and nature of the heat gains. Because of the thermal inertia of the space construction, the instantaneous cooling load does not coincide with the instantaneous heat gain.* Hence, each component of the heat gain gives rise to a distinct component of the cooling load. This behaviour was simulated using the transfer function concept. The IEC effect in the present work was considered to be provided by using a cross flow plate heat exchanger (PHE). **Hakan Caliskan et.al. [10]:** This study presents energy and exergy analyses and sustainability assessment of the novel evaporative air cooling system based on Maisotsenko cycle which allows the product fluid to be cooled in to a 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. Exergy analysis of the system is then carried out for six reference temperatures ranging from 0^0C to 23.88^0C as the incoming air (surrounding) temperature. The specific flow exergy, exergy input, exergy output, exergy destruction, exergy loss, exergy efficiency, exergetic COP, primary exergy ratio and entropy generation rates are determined for various cases. Energetic COP of the cycle is higher than exergetic COP. *Energetic COP of the cycle is calculated to be 2.30.* **Qilong Liu et.al. [11]:** Indirect evaporative cooler is applied as a device of the combined air conditioning system to precool the fresh air in hot and humid regions, which may cause condensation in the primary air channels. For this case, the trend of the existing evaluation indexes used to express the heat exchange efficiency is inconsistent with that of the total heat transfer. In this paper, a plate cross-flow indirect evaporative cooling experimental system was set up, and the inadaptability of the existing evaluation indexes was analyzed by applying the experimental data. The comparative analysis showed that the existing heat transfer evaluation indexes could not evaluate the total heat transfer capacity of the IEC when there is primary side condensation. *Among all the evaluation indexes, COP seems to be the one that is consistent with the variation of total heat transfer, but it was used to evaluate the energy recovery benefit of IEC, thus it could not be used to evaluate the heat exchange capacity of IEC.* In hot and humid regions, IEC channels will be a fertile bed for the growth of legionella bacteria and other organisms due to condensation. Therefore, regular cleaning, ultraviolet sterilization, ozone sterilization or other treatment methods should be done in the primary channel to prevent the polluted air from entering air conditioning room and being harmful to human health.

3.2 Problem Statements

Conventional IEC systems can cool the product air only up to WBT of working air. IEC systems have a tendency to give lower efficiency at higher Relative humidity of air (Humid climatic conditions). In hot and humid regions, IEC channels will be a fertile bed for the growth of legionella bacteria and other organisms due to condensation. Water consumption may vary. Complex design due to horizontal plate arrangement of M-IEC.

4 METHODOLOGY

4.1 IEC system with plate heat exchanger system Components

1. Heat and mass exchange plate
2. Water sprayer
3. Water circulation pump
4. Reservoir for collecting unevaporated water
5. Fans
6. Air Filters

4.2 Material Consideration for IEC

1. *Heat exchange surface*: Should be made of good thermal conducting material with least amount of thickness such as Aluminium Alloy 1100 (K_{Al} = 236 W/mK) sheets [16].
2. *Wicking materials on wet side of plate*: Wet side are usually made by using wicking materials to reduce surface tension and hold the sprayed water over the surface for evaporation by working air. These material are hygroscopic in nature. Cellulose Blended fibre, Cotton can be used as wicking materials.
3. *Hydrophobic materials on dry side of the plate*: Dry side of the plate is usualy covered by using hydrophobic material to prevent water penetrating from wet side [13]. Polyethylene sheets
4. *Wall material*: Wall material are considered for separation of product and working channels. Acrylic strips having good strength to weight ratio.

4.3 Performance Evaluation standards of M-IEC

Following standards were studied referring to [13]
A) *Wet Bulb Effectiveness and Dew Point Effectiveness*:

The performance of the Maisotsenko cycle can be explained with the wet-bulb effectiveness ($\in wb$) which is the ratio of temperature depression of the device to the potential wet bulb depression as follows:

$$\varepsilon_{WB} = (T_{SI} - T_{SO})/(T_{SI} - T_{wb,SI}) \quad (1.1)$$

Where "T_{SI}" is the supply inlet DBT of air, "T_{SO}" is the supply outlet DBT of air and "Twb,SI" is the WBT of supply inlet air.

The dew point effectiveness ($\in dp$) can be calculated to measure the performance of the cycle due to the ability of this device to cool the air below the wet-bulb temperature of the inlet air.

$$\varepsilon_{DP} = (T_{SI} - T_{SO})/(T_{SI} - T_{dp,SI}) \quad (1.2)$$

Where "Tdp,SI " is the DPT of supply inlet of air

B) *Secondary to primary airflow ratio*:
It is the ratio of Secondary air flow rate in wet channel to Primary airy flow rate in dry chanel. It is also known as 'Working to intake air flow ratio'

$$\text{secondary to primary ratio} = (\text{secondary air flow rate})/(\text{primary air flow rate}) \quad (1.3)$$

It is measured in m^3/s or m^3/hr

C) *Cooling Capacity*:
The cooling capacity refers to the enthalpy change of the product air when travelling across the dry channels of the IEC heat exchanger. Since the air is cooled at the constant moisture content during the dry channels of the IEC exchanger, the enthalpy change of the air could be represented by the temperature reduction of the air during its dry channel flow path [14].

$$Q = C_{air}.\rho_{air}.V_{SO}.(T_{SI} - T_{SO}) \quad (1.4)$$

Where C_{air} is the specific heat of air in kJ/kg-K,
ρ_{air} is the density of air in kg/m^3
V_{SO} is the volumetric flow rate of outlet air in m^3/s

D) *Energy Efficiency*:
Energy efficiency, known as 'coefficient of performance (COP), is the ratio of the cooling capacity of the IEC to the power consumption of the system.

$$\text{Energy Efficiency} = Q/W \quad (1.5)$$

Where Q is cooling capacity of M-IEC and W is the amount of electrical power consumed by the system. If this figure is multiplied by a unit conversion factor of 3.413, the COP is then converted into the energy efficiency ratio (EER).[14]

E) Water Evaporation rate:
the water evaporation rate is equal to the volume of the moisture increase in the working air in wet channel, during its operation.

$$V_{Water} = [V_{WO}.\rho_{air}.(w_{WO} - w_{WI})]/\rho_{water} \quad (1.6)$$

Where V_{water} is water evaporation rate in m^3/s
V_{WO} is air flow rate of working air at wet channel outlet, m^3/s
w_{WO} is the humidity ratio of working air at outlet, kg/kg of dry air.
w_{WI} is the humidity ratio of working air at inlet, kg/kg of dry air
ρ_{water} is the density of water in kg/m^3

4.4 Design Related Calculation Considerations

Following assumptions are considered for designing of Heat and mass exchanger [12], [13], [14], [15]:

1. The heat and mass transfer process is considered as steady state. The exchanger enclosure is considered as the system boundary.
2. The heat and mass transfer process is adiabatic. No heat transfer to the surroundings.
3. Within the air streams, the convective heat transfer is considered the dominant mechanism for heat transfer. The channel walls are impervious to mass transfer.
4. Water film on the wet surface is assumed in non flow condition. The temperature of spraying water is constant. The wet surface of the heat transfer sheet is completely saturated. The water film is distributed uniformly across the wet channel.
5. Each control volume has a uniform wall surface temperature. The temperature difference between dry and wet sides of the wall can therefore be ignored.
6. Air is treated as an incompressible gas. The velocity and properties of all air streams are considered to be uniform.
7. Air flow is laminar in nature.

Dimensionless numbers required in design,

Reynold's Number for flow of air: [17, page no-366]
It is taken as an important criterion of kinematic and dynamic similarities in forced convection heat transfer.

$$R_E = (v.L.\rho)/\mu \quad (2.1)$$

v is velocity of fluid over the surface, in m/s; L is length of channel, in m; ρ is density of fluid, in kg/m^3; μ is dynamic viscosity of fluid, in kg/m-sec

Nusselt's Number: [17, page no-367]
It is the ratio of characteristic length L to the thickness of a stationary fluid layer conducting the heat at the same rate under the same temperature difference as in the case of convection process.

$$Nu = (h_{air}.L)/k \quad (2.2)$$

Where h_{air} is Convective heat transfer coefficient of air, W/m^2K; k is thermal conductivity of heat exchange surface, W/mK.

For laminar flow of fluid over surface of channel and Prandtl number (Pr)>0.6 [17, page no-406]

$$Nu = (0.664).\mathrm{Re}_L^{0.5}.\mathrm{Pr}^{0.33} \quad (2.3)$$

Prandtl Number: [17, page no-366]
Prandtl number is a connecting link between the velocity field and its value strongly influences relative growth of velocity and thermal boundary layers.
For Laminar flow of fluids, [17, page no-465]

$$\mathrm{Pr} \geq 0.6$$

5 Result and Discussion

Our first objective was to understand the Physics (mechanics) involved in M-IEC, through our geometry.

The Fudamental physics (mechanics) of M-Cycle Heat and mass exchanger we developed was as follows:

1. The inlet air entering into working Dry Channel gets precooled and enters into wet channel through holes.
2. The inlet air into dry channel gets cooled by passing the sensible heat through the heat exchange surface into wet channel & then sent into the surrounding as product air.
3. Water is sent from the tank to the master pipeline, which distributes the water to the PVC pipes on the wet channel which spray water over the wet channel surface. The sprayed water is holded by a wicking material. The excess water exists from the holes present in the V-notch. Along with water, the secondary working air also exits, causing a cooling effect in the water which is to be reused.
4. The water sprayed through PVC pipes is being hold by wicking surface (cotton cloth) placed on wet channel plate. The working air passes over the wicking material causing evaporation of water which causes a temperature drop of the wet

channel plate.

5. The inlet air in product dry channel passes its sensible heat to the wet channel due to the temperature difference (of product air and heat exchange surface temperature). The sensible heat transfered to wet channel is dissipated as sensible + latent heat.

Our Second objective was to create a CAD model of dry channel and wet channel based on the physics:

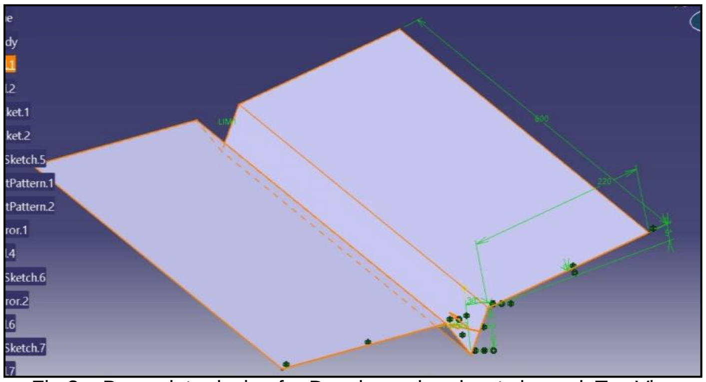


Fig.3a: Base plate design for Dry channel and wet channel; Top View

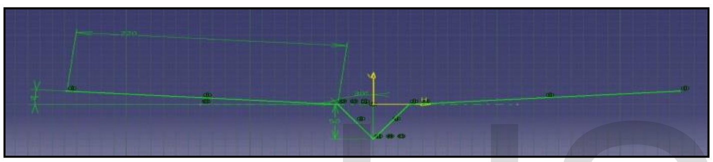


Fig.3b: Base plate design for Dry channel and wet channel; Front view

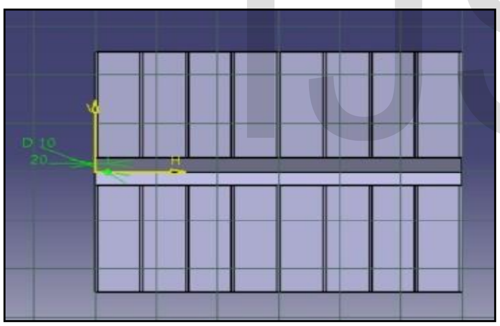


Fig.3c: Secondary air and water exit holes position

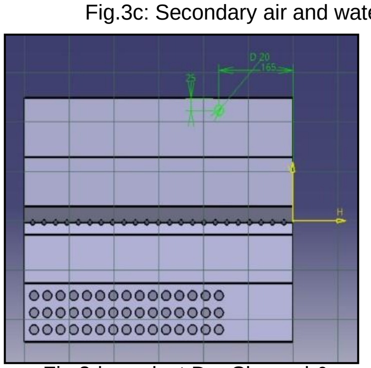


Fig.3d: product Dry Channel & Holes grid in working Dry channel part and hole dimensions

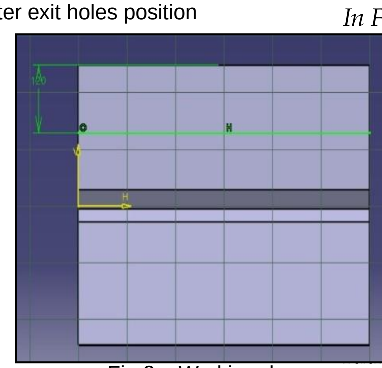
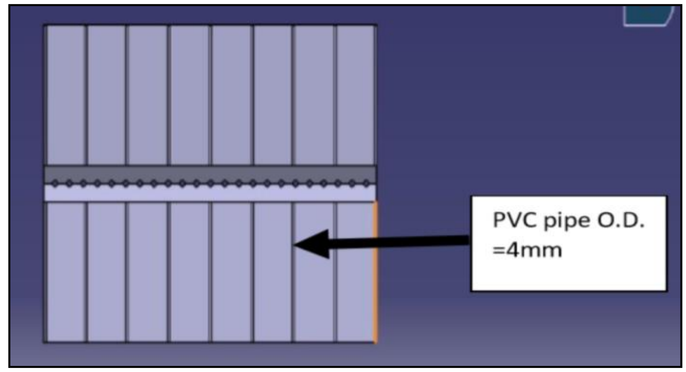


Fig.3e: Working dry width



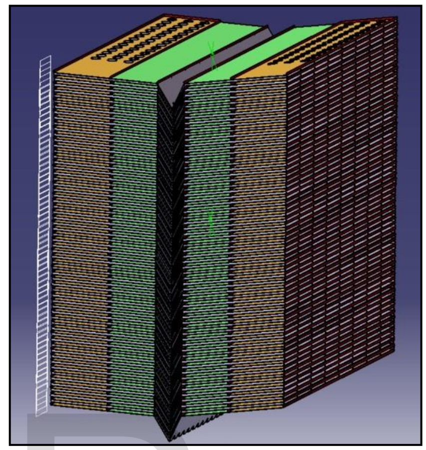


Fig.3g: Wet channel and Dry channel assembly in isometric view

Dimensions:
In Fig.3a, Length of plate=600mm, Width of plate=220mm, Thickness of plate=0.5mm, angle of V-notch= 60°, height of v-notch= 50mm;
In Fig.3b, plate inclination angle from horizontal plane = 5^0;
In Fig.3c, V-notch holes diameter= 10mm, centre to centre distance = 29.5 mm;
In Fig.3d, product dry channel width= 100mm,
working dry channel holes diameter= 20mm
In Fig.3e, Working dry channel width= 120mm
In Fig.3f, PVC pipe diameter=4mm, Center to center= 75mm
ig.3g, No. of Dry plates=61, No. of wet plates= 60, Total ght= 610mm, Width= 226mm, Length=600mm
owing operational parameter values were found and their varia- based on the performance of the M-IEC was understood from the ences [2], [12], [13], [14] *as per the third objective.*

nlet velocity of product air should be between 2m/s and 5 s in order to effectively transfer the sensible heat to heat sfer surface.

nlet velocity of working air is greater than product air ch interns provide greater Secondary to primary air flow o and higher Water evaporation rate.

Relative humidity of inlet air is supposed to be between 30% to 50% range in order to obtain lower WBT of working air amd ultimately a greater temperature drop in product air temperature.

Water evaporation rate in wet channel is supposed to be as high as possible (0.18 L/hr to 0.40 L/hr) in order to obtain higher cooling effectiveness.

Working air to Product air ratio varies from 0.3 to 1 in order to achieve higher cooling effectiveness. However, increase in value will also lead to reduced supply air volume and thus the overall cooling capacity of the system may fall.

In a typical heat exchanger for indirect evaporative cooling, the static pressure drops of the air in dry and wet channels is found to be in the range 60–185 Pa and 100– 500 Pa, respectively.

Channel height should range from 4mm to 6mm for increased convective Heat transfer rate.

Thickness of HX should be 0.5mm to 0.85 mm in order to obtain higher heat conduction rate through the channels.

Optimum length of channel 0.6m to 1.5m in order to achieve high cooling effectiveness.

6 CONCLUSION

The fundamental study of Maisotsenko cycle based Indirect Evaorative cooling System was studied successfully. In this research, the problems regarding the current stage of Indirect Evaporative cooling system was highlighted with the help of the literature [1], [2], [4], [5], [6], [11]. The flow of the air in the horizontally place Maisotsenko cooling system was also looked into. The Comonents, materials and the criterion was investigated briefly. The performance evaluation standards for M-IEC were explored for the purpose of understanding the operational parameters effects. The Dimensionless quantities required in the calculations for design of M-IEC were surveyed alongwith the assumptions required to be made in case of indirect evaporative cooling system. As per our objectives, the fundamental physics(mechanics) of a horizontal plate M-IEC based developed design was investigated and a CAD model is made using CATIA V5R21. The operational parameters affecting various performance evaluation standards were also investigated from [6], [7], [11], [12], [13], [14].

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REFERENCES

[1] Energy saving potential of indirect evaporative cooler under Indian climates by J.K.Jain andD.A.Hindoliya

[2] A review of indirect evaporative cooling technology by Bogdan Porumba, Paula Ungureşa

[3] Numerical study of a M-cycle cross-flow heat exchanger for indirect evaporative Cooling. By Changhong Zhan, Xudong Zhao, Stefan Smith, S.B. Riffat

[4] Experimental analysis of an improved Maisotsenko cycle design under low velocity conditions. By Omar Khalid, Muzaffar Ali, Nadeem Ahmed Sheikh, Hafiz M. Ali, M. Shehryar

[5] Experimental study on total heat transfer efficiency evaluation of an indirect evaporative coolerByQilong Liu, ChunmeiGuo, Xuelian Ma, Yuwen You, Yan Li

[6] Experimental analysis of a cross flow indirect evaporative cooling system. By Stefano De Antonellis, Cesare Maria Joppolo, Paolo Liberati, Samanta Milani

[7] Modeling and experimental study of an indirect evaporative cooler by Stefano De Antonellis, Cesare Maria Joppoloa, Paolo Liberati, Samanta Milani

[8] Design and performance analysis of a small solarevaporative cooler. By Hossein Lotfizadeh & Mohammad Layeghi

[9] Application of indirect evaporative cooling to variable domestic cooling load. By Khalid A. Joudi*, Salah M. Mehdi

[10] Thermodynamic performance assessment of a novel air cooling cycle: Maisotsenko cycle. By Hakan Caliskan, Arif Hepbasli, Ibrahim Dincer, Valeriy Maisotsenko

[11] Experimental study on total heat transfer efficiency evaluation of an indirect evaporative cooler. By Qilong Liu, Chunmei Guo, Xuelian Ma, Yuwen You, Yan Li

[12] Fabrication Materials and Techniques for Plate heat and mass exchangers for Indirect Evaporative Coolers. Inventors: Leland E. Gillan, Denver, CO (US); Valeriy Maisotsenko, Aurora, CO (US); Alan D. Gillan, Denver, CO (U S); Rick J. Gillan, Golden, CO (U S). US 2010/0018234 A1

[13] Investigation of a novel dew point indirect evaporative air conditioning system for buildings. By Duan, Zhiyin

[14] Indirect evaporative cooling: Past, present and future potentials. By Zhiyin Duan, Changhong Zhan, Xingxing Zhang, Mahmud Mustafa, Xudong Zhao, Behrang Ali mohammadisagvand, Ala Hasan

[15] Heat Transfer and Fluid Flow Data Books. GENIUM PUBLISHING CORPORATION

[16] https://www.metalsupermarkets.com

[17] Heat and Mass Transfer by R. K. Rajput. S. CHAND AND COMPANY LIMITED