TEST Engineering & Management

July –August 2020
ISSN: 0193-4120 Page No. 6575-6584

Computational Performance Analysis of an Indirect Evaporative Cooler (IDEC) Unit

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Article Info Volume 83
Page Number: 6575-6584
Publication Issue:
July - August 2020

Article History
Article Received: *25 April 2020*
Revised: *29 May 2020*
Accepted: *20 June 2020*
Publication: *10 August 2020*

Abstract:
Nowadays the usage of conventional air conditioners is becoming a problem for environmental aspects point of view due to the release of chlorofluorocarbons (CFCs) and ozone depletion. To overcome this problem, it is proposed to go with Indirect Evaporative Cooler (IDEC) because in this the refrigerant is replaced with water. This work deals with the simulation and performance of an Indirect Evaporative Cooler (IDEC) of flat plate size of 40 mm x 60 mm is analyzed by placing a countercurrent sensible plate heat exchanger. Computational techniques of CFD analysis have been carried out on IDEC flat plate heat exchanger. The effect of parameters such as the velocity of primary air stream and inlet water temperature is investigated on the performance of IDEC. Thermal effectiveness, Cooling Capacity and Thermal Conductance are the output parameters are analyzed and compared the results both from simulation and theoretical aspects of view. For the better performance of IDEC, some of experiments is also executed with different volume flow rates and with different inlet temperatures of air at 40, 35, 30, and 25^{0}C. After evaluation of the results, it has shown the output parameters of thermal effectiveness, cooling capacity, and thermal conductance have shown better values at a 175 m^3/hr volume flow rate of air.

Keywords: *Indirect Evaporative air Cooler (IDEC), Thermal Effectiveness, Cooling Capacity, Sensible Plate Heat Exchanger, Thermal Conductance*

I. INTRODUCTION

Demand for global cooling is on the rise surprisingly in recent decades. This has created a great deal of concern that, in some countries, additional resources are also available and therefore additional provision should have been considered to increase the general cost of equipment. On the other hand, increased power consumption has negative environmental effects related to increasing CO_2 release and Chlorofluorocarbons (CFCs) deplete the ozone layer in the atmosphere conditioners. Kyoto protocol bonds are demanding for advanced countries to reduce the combined issuance of six keys greenhouse gases - among them CO_2 at least 5% per 2008-2012. This protocol encourages the governments to improve energy efficiency and motivation of renewable energy (EU, 2003) resources. Therefore, the argument on natural energy and energy for air conditioning is a strong demand for the future. Recently, research has been directed at low-energy methods, one of which is adopting evaporative cooling technology in air conditioning types of equipment.

1.1 History of the indirect evaporative cooling (IEC) technology

Appearance of evaporative cooling happened at around 2500 B.C., during which the antiquated Egyptians utilized water-containing permeable dirt containers for motivation behind air cooling. This system was additionally applied to antiquated Egypt structures and further spread over the Middle East districts where the atmospheres are consistently at a hot and parched state. For example, permeable water pots, water lakes, pools, and flimsy water chutes showed up the structure developments to make the structures cooling impacts. The advanced evaporative cooling gadgets were started in the USA. In the mid-1900s, air washers were designed at New England and Southern Coastline and utilized for cleaning and cooling air in material plants and industrial facilities. During that period, a few air cooling gadgets including the immediate and

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backhanded coolers were additionally found in Southwest (Arizona and California) locale [1]. In late, The 1930s, numerous houses and business spaces at Southwest were outfitted with separately made water dribbling air coolers which, when going into the mid-1950s. Eloy Velasco Gómez et. al., [2] worked on two working modes. i.e in the first mode, exhaust air from the atmosphere chamber, in comfort conditions, experiences one side of the heat exchanger, creating heat to move from the open air stream through the plastic dividers of the framework. In the subsequent case, an evaporative cooling mode is executed by providing water to the fumes airstream. Results were shown by them in such a way that warmth air move through the warmth exchanger polycarbonate divider improves in the evaporative cooling mode. At long last, higher outside air temperatures infer better cooling limits and warm viability. J.F. San Jose Alonso et. al., [3] done work on heat and mass exchange model dependent on essential standards has been produced for warm computations of a backhanded evaporative cooler exhibition. A few rearrangements have been joined to make the model more easy to use. It is all inclusive and can be utilized to investigate different circuitous evaporative cooler plans and conditions. This suggests a unique commitment that no other model has been considered up to now. Trilok Singh Bisoniya et. al., [5] conducted the experiment on evaporative cooler gives best execution in dry summer climate conditions in blistering and moist atmosphere like in Mumbai, Chennai and so forth the altered evaporative cooler with just reasonable cooling and without distribution of return exhaust damp air is appropriate. It is prescribed that to improve the presentation of altered circuitous evaporative cooler, warm conductivity between gracefully air and warmth exchanger plates ought to be expanded. Erens and Dreyer [8] demonstrated the backhanded evaporative air coolers and three count models are portrayed. Test estimations showed that the ideal state of the cooler unit would bring about an essential to auxiliary air speed proportion of about 1.4, accepting that the essential and the optional air mass stream rates are equivalent and that a similar plate spacing are utilized on the essential and optional sides. Dipak ashok warke and samir deshmukh [9] studied on humidity variety, pressure drop, and effectiveness for a few inlet air velocities. The outcomes show that general pressure drop and measure of dissipated water increments by expanding the inlet air speed and thickness in the two kinds of cooling pads. Then again, effectiveness and humidity variety diminishes by expanding inlet air speed. shahram Delfani et. al., [10] planned two air test systems and used to recreate indoor heating load and outdoor air configuration conditions. The outcomes show that IEC can diminish cooling load up to 75% during cooling seasons. Additionally, 55% decrease in electrical energy utilization of PUA can be chosen. Zhiyin et. al., [11] done IEC frameworks on fundamentally upgraded cooling execution over those the decade back, with the wet-bulb effectiveness of more noteworthy than 90% and energy efficiency ratio (EER) up to 80. Structure of the IEC heat and mass exchanger fluctuated from flat plate-stack, tube, heat pipe and conceivably wave-structure. Bogdan porumb et. al., [12] gone through the IEC hardware and innovation in various cooling applications like business, mechanical, private or server farms. The IEC innovation is totally natural amicable and has exceptionally low global warming impact. The single detriment of IEC is the water utilization. Yi chen et. al., [13] investigated the indirect evaporative cooler (IEC), on a low-carbon cooling effect, was proposed as natural air pre-cooling and heat recovery device noticeable all around molding the framework to break the district restriction of use in hot and humid zones. In this mixture of framework, the depleted air with low temperature and stickiness from cooled space is utilized as optional air to cool the channel natural air. As the dew point temperature of the outside air is high, condensation may happen in the dry channels. Luis perez Lombard et. al., [14] highlighted the worldwide commitment from structures towards energy utilization, both private and business, has consistently expanded arriving at figures somewhere in the range of 20% and 40% in created nations, and has surpassed the other significant areas: modern and transportation. C harpham and V.I.hanby et. al., [15] investigated the atmosphere projections of an expansion in wet-bulb depression giving a decent sign of the cooling capability of an evaporative cooler. The move is more prominent for London than for Glasgow with a separate 71.6% and 3.3% expansion in the middle yearly cooling load.

Despite available huge research on various evaporative coolers, but some more work on Indirect

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Evaporative Cooler (IDEC) with a countercurrent sensible plate heat exchanger to be carried out yet.

ε: Effectiveness
T_{ai} : Inlet temperature of air (°C)
T_{ao}: Outlet temperature of air (supply air) (°C)
T_{wi} : Inlet water temperature (°C)
T_{wo}: Outlet water temperature (°C)
E_{CC}: Cooling capacity (W)
m: Dry air mass flow (kg/s)
C_{pa} : Air specific heat capacity (J/kg)
U : Global heat transfer coefficient (W/m^2 K)
A: Heat exchange area (m^2)
ΔT_{LM}: Log mean temperature difference (°C)
ΔT outdoor air temperature drop (K)

II: INDIRECT EVAPORATIVE COOLER (IDEC) MODEL GOVERNING EQUATIONS

A schematic chart of the counter flow type IDEC is appeared in the fig 1. From the energy and mass conservation law, a bunch of differential conditions are to be considered alongside the length of IDEC as follows, as indicated by the schematic outline of heat and mass exchange in an IDEC.

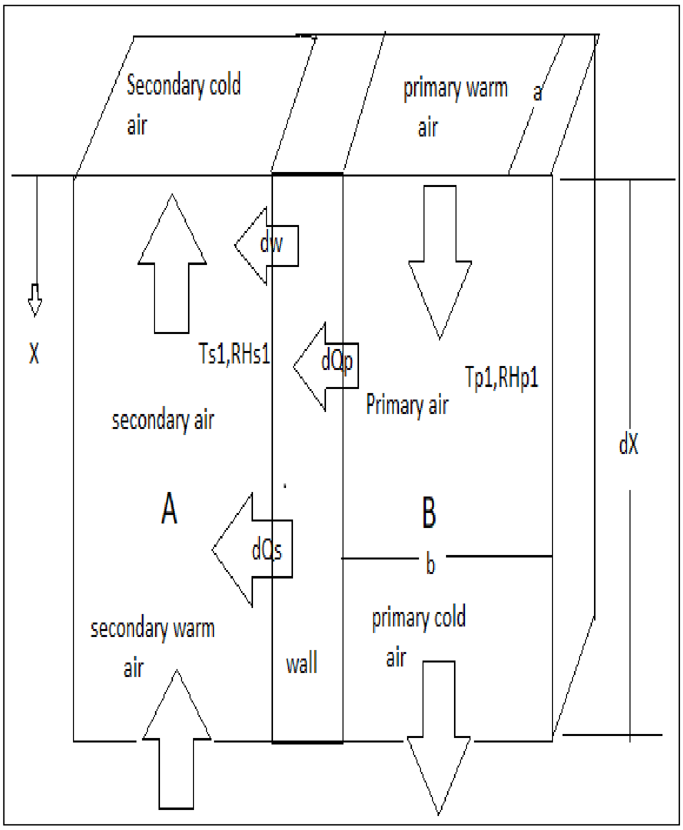

Fig. 1(a) Schematic model diagram of heat exchanger

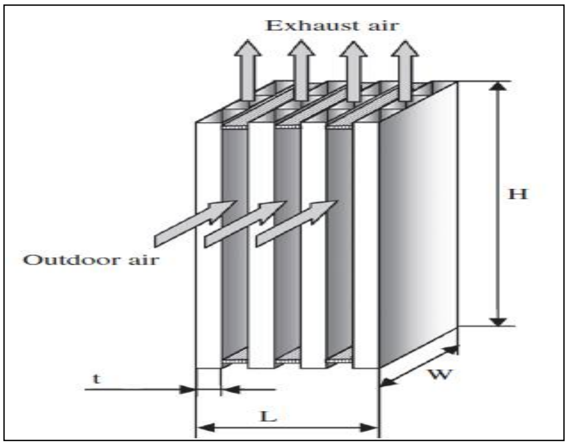

Fig. 1(b) Flat plate Counter Flow Heat Exchanger

The heat transfer from the water into the secondary air flow:

$$dQs = \Delta s\ (Tw - Ts)\ dA \quad (1)$$

The mass flow of water that is evaporated into the secondary air:

$$dW = \Delta m\ ((Tw) - \omega) \quad (2)$$

The heat transfer from the primary air into the water:

$$dQ_p = U_z\ (Tp - Tw)\ D_a \quad (3.a)$$

$$dQ_p = -msdE_p \quad (3.b)$$

The water mass balance (refer to Fig.1a) yields:

$$dm_w = dW \quad (4)$$

The overall heat transfer coefficient is:

$$U_z = \frac{1}{\frac{1}{hp} + \frac{\delta wall}{kwall} + \frac{1}{hW}} \quad (5)$$

The water and air mass balance (refer to Fig.6), yields

$m_s dw = dm_w$

The overall energy balance on the process for the A and B control surface can be expressed as:

$$m_s dH_s + dQ_p = m_W dH_W + H_w dm_W \quad (7.b)$$

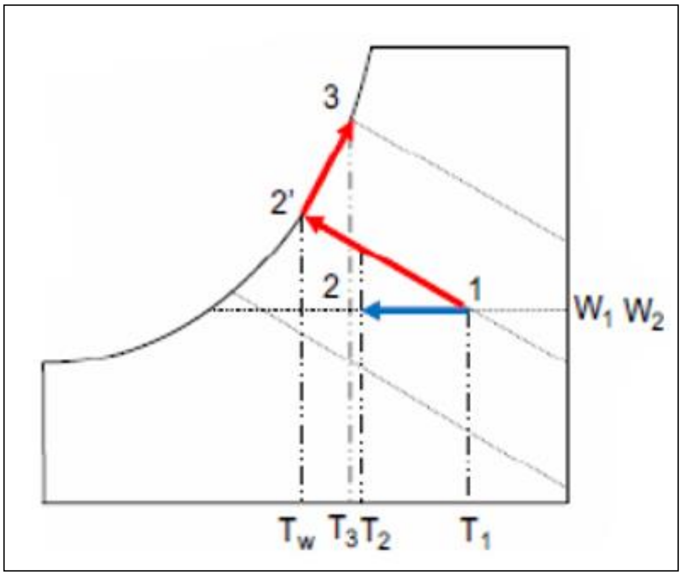

Fig. 2. Psychometric chart of IDEC

Psychometric chart of IDEC is shown in figure 2. The enthalpy of humid air rises to the amount of the enthalpies of the dry air and water fume. The particular enthalpy of moist air is additionally characterized per unit mass of dry air. For lower pressure, the particular enthalpy of water fume is just about a direct capacity of temperature. Thusly, the enthalpy of moist air can be communicated as:

$$H(T) = CpT + (2.501 + 1.805 \times 10^{-3} T) \quad (8)$$

By using equations (1) - (3) and rearrangement of equations (5) - (8), a set of ordinary differential equations are described below:

$$dT\text{p}/dx = -Uz(T\text{pi}-T\text{w})/(m\text{p}C\text{p}) \quad (9)$$

On solving the above differential equation, we obtain the following relation:

$$T\text{p} = (T\text{p}i - T\text{w})\exp(Ax) + Tw; \quad \text{Where, } A = -(Uz \times a \times n)/(mp \times Cp) \quad (10)$$

Subsequently, the essential air (state1) is cooled at the steady dampness substance and moves towards the wet-bulb temperature of the delta optional air; though the optional demeanor of state 1 is continuously immersed and changed in to state 2 at its previous stream way, at that point warmed while moving along the stream way lastly released to environment in the soaked state 3. It should be noticed that to empower heat move between the dry side air to wet side air, the state 3 ought to have a lower temperature than the state 2 and hypothetically, the enthalpy decline of the air inside the dry side channel is equivalent to the enthalpy increment of the air inside the wet side channel i.e., h_1-h_2=h_3-h_1. Due to higher thermal conductivity of Aluminum, low thickness of plates and higher convective warmth move coefficient on the wet side, is diminished as follows: $Uz = \Delta\text{p}$

The following governing IDEC output parameters are outlined below.

1. COOLIG CAPACITY:

The cooling capacity will determining the amount of energy involved in the process, and thus quantifying the cooling achieved in the outdoor airstream used for ventilation and that is aimed to be pre-conditioned

$$E_{CC} = \dot{m}.(h_{01} - h_{02}) \quad \text{Watts} \quad (11)$$

Where, m dry air mass flow (kg/s)

h_{01} and h_{02} are outdoor air specific enthalpy at the inlet and outlet (kJ/kg)

However, as the outdoor airstream does not have its humidity rate modified, this parameter can be calculated as follows:

$$E_{CC} = \dot{m}.Cp_a.(T_{01} - T_{02}) \quad (12)$$

Where Cpa is the air specific heat capacity (J/kg C)

2. GLOBAL HEAT TRANSFER COEFFICIENT :

The global heat transfer coefficient determines the heat transfer performance of the total heat exchanger area is defined as:

$$U = \frac{E_{CC}}{A\Delta T_{LM}} \quad \frac{W}{m^2 k} \quad (13)$$

Where

$$\Delta T_{LM} = \frac{(T_{01} - T_{e2}) - (T_{02} - T_{e1})}{\ln(\frac{(T_{01} - T_{e2})}{(T_{02} - T_{e1})})} \quad (14)$$

The product of the global heat transfer coefficient and the Heat exchanger area will be called thermal conductance.

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3. EFFECTIVENESS: (Check this equation)

Effectiveness will determine the ratio between the actual heat transfer rates to maximum possible heat transfer rate

$$\varepsilon = 1 - \exp\left(\left(\exp\left(-NC*n\right)-1\right)/C*n\right) \quad (15)$$

Here $n=N^{-0.22}$ and C=1 for counter flow

III. GEOMETRIC MODEL SETUP AND CFD ANALYSIS

The indirect evaporative cooling has a high potential for meeting cooling needs at low energy costs. A backhanded evaporative cooling measure has two particular air sections, one named the ‘primary’ and the other the ‘secondary’ air entry which is shown in figure 3. The primary air is generally open air that is provided to the room after it has been cooled via air in the secondary air entries through warmth move. The primary air can be either outside air or room exhaust air. The outside of the secondary air entry is wetted by flowing water, so that heat and mass exchange happens between the wet surface and the primary air.

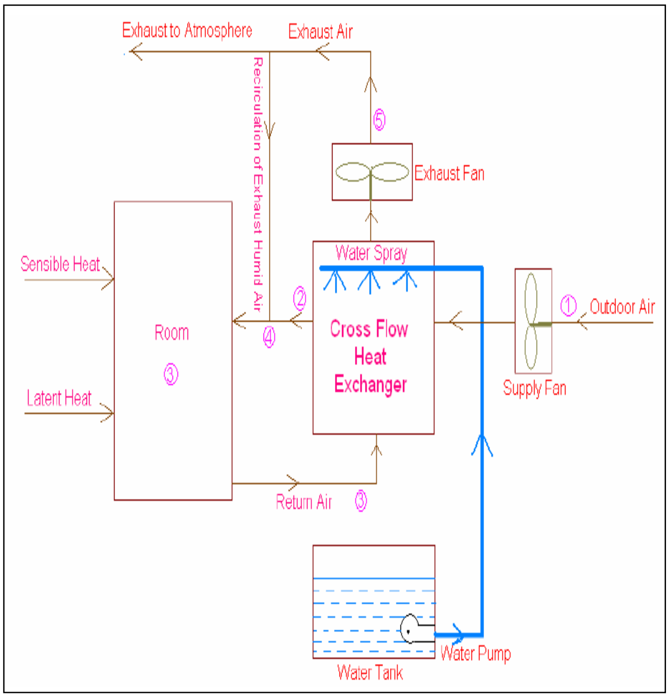

Fig. 3.Schematic diagram of modified indirect evaporative cooler

Variation of inlet temperature of primary air against supply air temperature and the specifications of wet surface plate heat exchanger (or) sensible heat exchanger are shown in table 1 and table 2.

Table 1: Variation of inlet temperature of primary air against supply air temperature

S.No	Inlet Temperature of Primary Air (℃)	Supply Air Temperature (℃)
1	40	22.0
2	35	20.4
3	30	19.2
4	25	17.7

Table 2: Specifications of wet surface plate heat exchanger (or) sensible heat exchanger

Heat exchanger specification	Unit	Dimension
Height * Width	cm * cm	60 * 40
Plates spacing	mm	4
Plates thickness	mm	0.4

ANSYS Fluent gives thorough demonstrating capacities to a wide scope of incompressible and compressible flows. For all streams, ANSYS Fluent explains protection conditions for mass and energy. For this work it is proposed to design the sensible heat exchanger to analyze the indirect evaporative cooler with geometry and the problem involves the following five steps to solve Geometry, Meshing, Pre processing, Post processing and Results

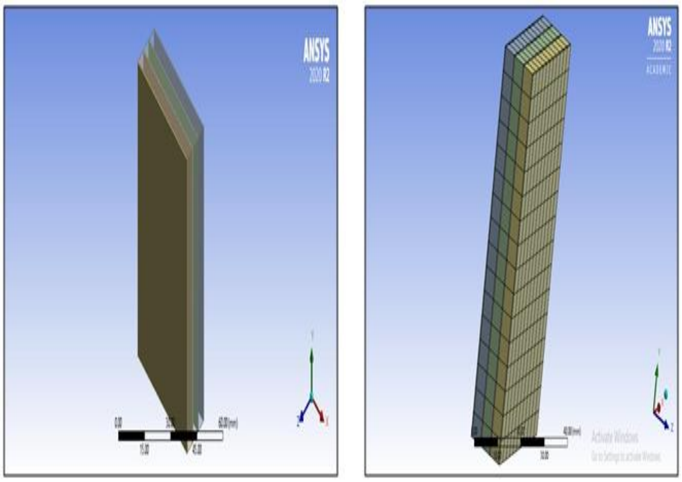

Fig. 4. Geometric modeling and meshing of indirect evaporative air cooler model

After obtaining the geometry model it needs to integral the whole geometry with meshing to be given as number of nodes is 2856, and number of elements is1232. In this problem after meshing, preprocessing is required. It contains air domain and water domain are the two fluids interaction analysis and it is not possible directly to solve in CFD. For this conjugate heat transfer (CHT) analysis is

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introduced to solve the IDEC problem. This is utilized to solve the issue include varieties of temperature inside solids and liquids, because of warm collaboration between the solids and liquids. It permits the recreation of warm association among solids and liquid space by heat trading. Furthermore it requires multi-region work to have clear definition to the interfaces in the computational area. Such work is made a hex dominant parametric activity in the mesh creator.

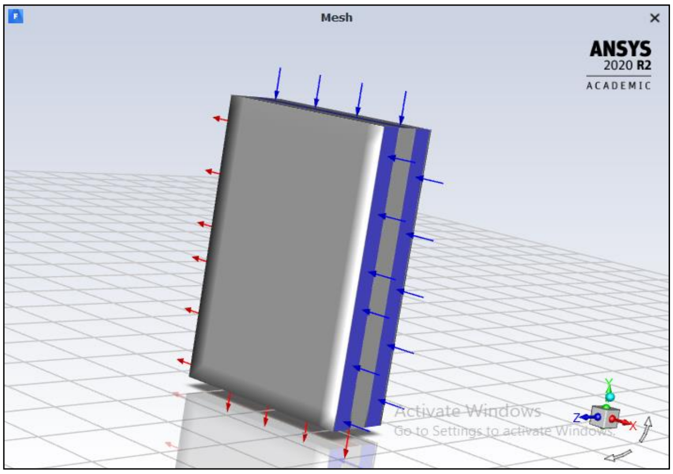

Fig. 5.Preprocessing result of IDEC

Figure 5 shows the input values were given for IDEC unit and the results were obtained by giving the energy equation is on, k-ε pressure based solver, and the considered material is Aluminum. The applied boundary conditions on IDEC are the inlet velocity of air is considered 0.001m/s and temperature of 313K, outlet pressure is 1 atmosphere. The fluids are water and air is considered. Computations have been carried out from inlet to give 100 iterations to get the converging solution and solve it. Then go to post processing and select reports, then go to surface integrals and select facet average and select zone and get temperature output of both outlet air and water. Design of experimental values under varied conditions has been tabulated in table3.

Table: 3 Varieties of Experiments of IDEC

Operation modes – Indirect Evaporative Cooling	Outdoor air volume flow, V (m^3/h)	Outdoor air dry bulb temperature, T (^0C)
1	V_1 – 175	T_1 – 40,35,30,25
2	V_2 – 250	T_2 – 40,35,30,25
3	V_3 – 300	T_3 – 40,35,30,25

OBSERVATIONS AND CALCULATIONS

The above table 4 indicated to determine the better volume flow rate is at 175m^3/hr because of the temperature drop is more at that volume flow rate and we conclude that we go past processing with that volume flow rate and also create the temperature contours on that flow rate

Table 4: Experimental data observations at inlet water temperature of T_{wi} =23^{0}C

S. No	Outdoor air volume flow rate V (m^3/hr)	Tai = 40^0 C T_{ao} ^{0}C	Tai = 40^0 C T_{wo} ^{0}C	Tai = 35^0 C T_{ao} ^{0}C	Tai = 35^0 C T_{wo} ^{0}C	Tai = 30^0 C T_{ao} ^{0}C	Tai = 30^0 C T_{wo} ^{0}C	Tai = 25^0 C T_{ao} ^{0}C	Tai = 25 ℃ T_{wo} ℃
1	300	35.6	29	32.1	28.2	28.6	27.3	28.1	23.4
2	250	24.8	24.4	24.4	24.3	23.7	23.5	23.2	23.1
3	175	23.8	23.2	23.5	23.1	23.3	23.1	23.1	23.06

V RESULTS AND DISCUSSION

The effect of parameters such as the velocity of primary air stream and inlet water temperature is investigated on the performance of IDEC. Thermal effectiveness, Cooling Capacity and Thermal Conductance are the output parameters are analyzed and compared the results both from simulation and theoretical aspects of view. For the better performance of IDEC, some design of experiments is also executed with different volume flow rates and with different inlet temperatures of air at 40, 35, 30, and 25^{0}C. After post processing, the results at volume flow rate of 175 m^3/hr. At inlet temperature Tai =40 ^{0}C.

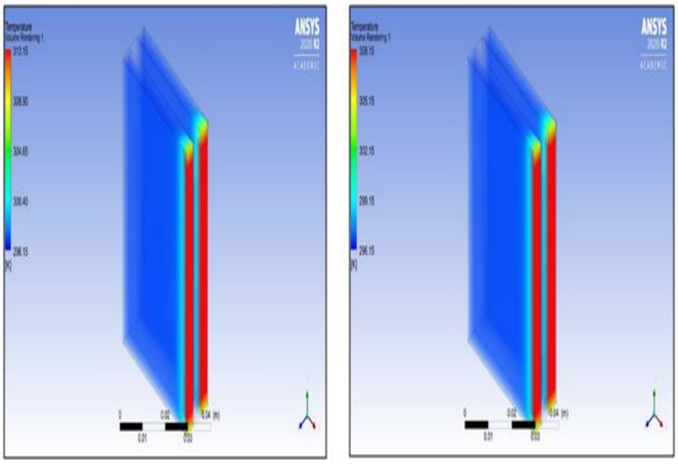

Fig. 6.Temperature contours plots along length of the plate at temperatures of 40 ^{0}C and 35 ^{0}C

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Figure 6 shows the temperature contour plots at inlet temperature of air is maintained at 40^0C and 35^0C and inlet water temperature of water is 23^0C after fluid is interaction with Aluminum solid the outlet temperature of air is 23.8^0C. In the above temperature contour inlet temperature of air is 35^0C and inlet water temperature of water is 23^0C after fluid is interaction with Aluminium solid the outlet temperature of air is 23.5^0C

Figure 7 shows the temperature contour plots at inlet temperature of air is 30^0C and inlet water temperature of 23^0C after fluid is interacted with Aluminium solid, heat transfer is done with fluid and solid the outlet temperature of air is 23.3^0C.

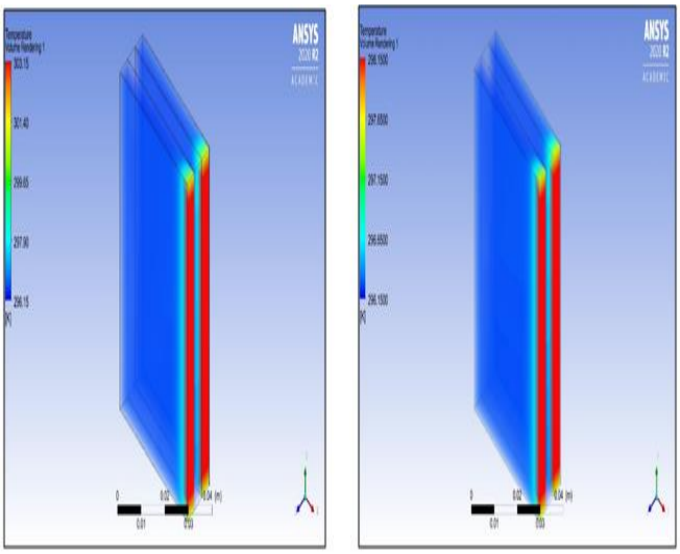

Fig. 7. Temperature contours along length of the plate at temperatures of 30 ^{0}C and 25 ^{0}C

In the above temperature contour inlet temperature of air is 25^0C and inlet water temperature of water is 23^0C after fluid is interaction with Aluminium solid the outlet temperature of air is 23.1^0C

Table: 5 IDEC Model Data calculations at air inlet and water temperature of 40^0C and 23^0C

S.No	Outdoor air volume flow rate V (m^3/min)	UA Thermal conductance (W/m^2K)	E_{CC} Cooling capacity (W)	LMTD ΔT_{LM} (^{0}C)	Effectiveness (ε)
1	175	171	900	5.255	0.75
2	250	130	836	6.390	0.70
3	300	20	242	11.78	0.26

Table: 6 IDEC Model Data Calculations at air inlet and water temperature of 35^0C and 23^0C

S.No	Outdoor air volume flow rate V (m^3/min)	UA Thermal conductance (W/m^2K)	E_{CC} Cooling capacity (W)	LMTD ΔT_{LM} (^{0}C)	Effectiveness (ε)
1	175	175	630	3.59	0.74
2	250	128	583	4.527	0.69
3	300	20	159	7.89	0.26

Table: 7 IDEC Model Data Calculations at air inlet and water temperature of 30^0C and 23^0C

S.No	Outdoor air volume flow rate V (m^3/min)	UA Thermal conductance (W/m^2K)	E_{CC} Cooling capacity (W)	LMTD ΔT_{LM} (^{0}C)	Effectiveness (ε)
1	175	171	360	2.11	0.75
2	250	132	346	2.62	0.70
3	300	19	77	3.97	0.25

Table: 8 IDEC Model Data Calculations at air inlet and water temperature of 25^0C and 23^0C

S.No	Outdoor air volume flow rate V (m^3/min)	UA Thermal conductance (W/m^2K)	E_{CC} Cooling capacity (W)	LMTD ΔT_{LM} (^{0}C)	Effectiveness (ε)
1	175	161	100	0.62	0.74
2	250	121	99	0.178	0.68
3	300	2	5	1.79	0.28

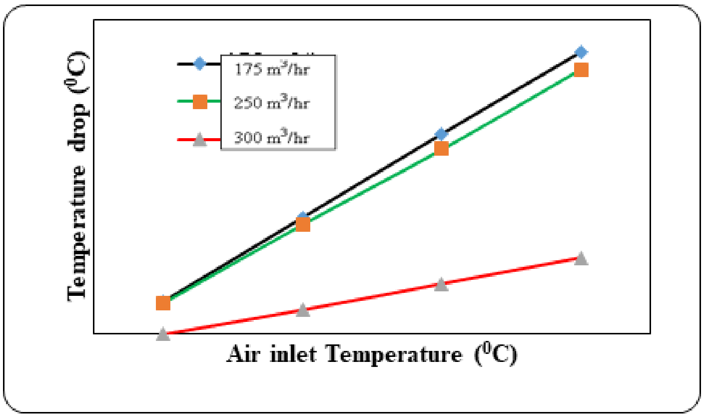

Fig. 12 Plot of variation of temperature drop vs air inlet temperature for varied volume flow rates of air

Figure 12 shows the variation of temperature drop against the air inlet temperature for varied volume flow rates of air. It is found that the temperature drop is maximum at a volume flow rate of 175 m^3/hr and high temperature drop is obtained at higher values of the inlet temperature of air because of the habitant time is longer and it is more time while air is treated with solid plates and fluid at lower volume flow rates.

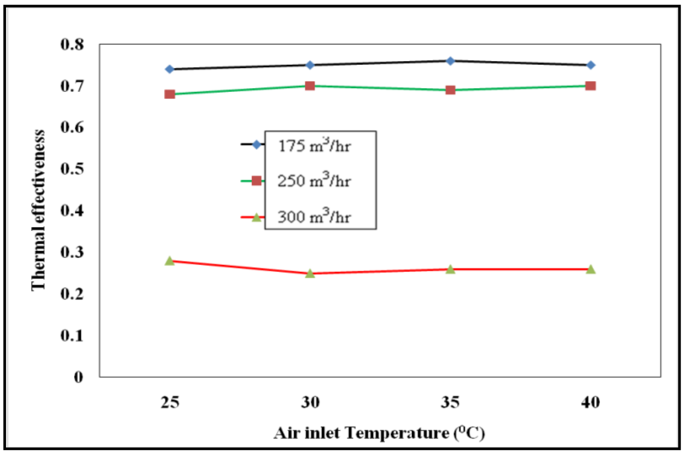

Fig. 13 Effectiveness of IDEC at varied air inlet temperature for varied volume flow rates of air

Figure 13 shows the Effectiveness of IDEC at varied air inlet temperature for varied volume flow rates of air and it is found that the effectiveness is maximum at the volume flow rate of 175 m^3/hr and irrespective of the inlet the temperature of air because of the number of transfer units (NTU) is more in lower flow rates and once the operation is run, some heat transfer rate is constant with inlet water temperature, and also irrespective of the air inlet temperatures, effectiveness is nearly the same, and it is only higher in lower flow rates because of more time spent than remaining higher volume flow rates.

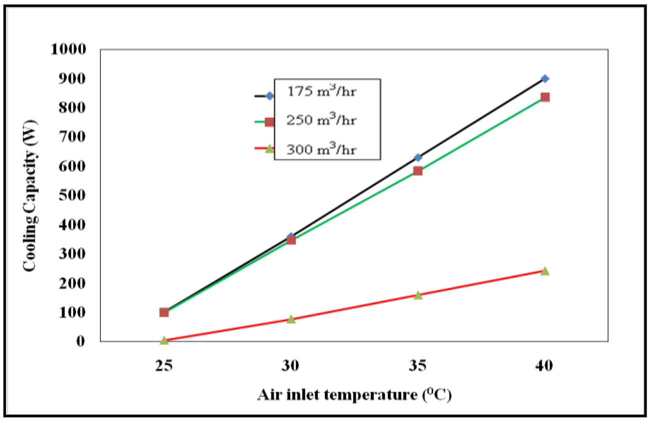

Fig. 14. Cooling capacity of IDEC at varied air inlet temperature for varied volume flow rates of air

The most interesting parameter in this operation is cooling capacity of IDEC. In the above figure 14, cooling capacity is maximum at a volume flow rate of 175 m^3/hr and higher inlet temperature of air as like of temperature drop because of the temperature drop is more in lower flow rates, and heat transfer rate is more in lower volume flow rates because the interaction between fluid and solid is more with lower flow rates. For this reason cooling capacity is more with lower volume flow rates

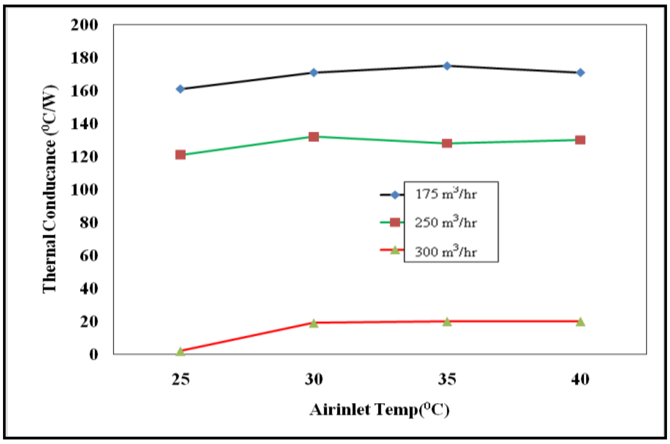

Fig. 15 Thermal conductance of IDEC at varied air inlet temperature for varied volume flow rates of air

Thermal conductance is a product of the global heat transfer coefficient and area of the heat exchanger, in which the global heat transfer coefficient is determined by the heat transfer performance of the heat exchanger. Figure 15 shows, the thermal conductance against the varied air inlet temperature maximum value at 175 m^3/hr volume flow rate and irrespective of inlet temperature of air and cooling capacity is also included in it and also it is related to both cooling capacity and log mean temperature difference. The principle the advantage is that supported playing out the evaporative cooling inside the framework rather than upstream was the way that the presence of fluid improves the film convection coefficient in the heat exchange. This could be normal on the grounds that higher volume rates cause better convection film coefficients, and consequently, heat move is improved. This is because the heat transfer coefficient becomes unstable if this temperature moves toward exhaust air at the inlet.

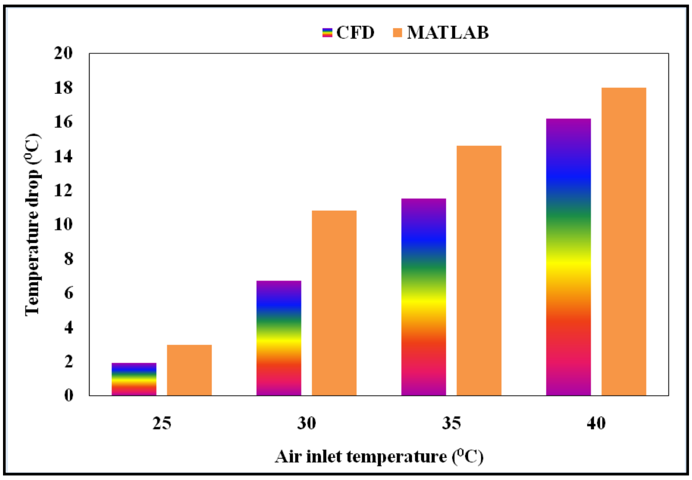

Fig. 16 Comparative evaluation of output parameters between MATLAB and CFD analysis

Figure 16 explains the comparison between the temperature drop of both MATLAB and CFD code result at the same volume flow rate of 175 m^3/hr. From the above figure, MATLAB code results have better temperature values compared to CFD analysis for the same input parameters. Because in theoretical calculations, solid and fluid interaction is very less and almost an adiabatic condition is considered, but in reality, there is some losses in the fluid domain and interaction with a loss of 10 to 20 %. . For this reason the above graph explains theoretically calculated results are more compared to the simulation results .

CONCLUSIONS

The performance of an Indirect Evaporative Cooler (IDEC) of the flat plate 40 mm x 60 mm is analyzed by placing a countercurrent sensible plate heat exchanger using computational methods of CFD analysis and the obtained results are compared with MATLAB code. CFD analysis has been carried out on IDEC flat plate heat exchanger with conjugate heat transfer (CHT) technique on fluid and solid interaction and better multi-layer meshing hex dominant for preprocessing. The effect of parameters such as the variation of volume flow rates of 175, 250, and 300 m^3/hr and the inlet temperature of water has been investigated. For the better performance of IDEC, some design of experiments is also executed with different volume flow rates and with different inlet temperatures of air at 40, 35, 30, and 25^{0}C. From the evaluated three-volume flow rates better performance at lower volume flow rate of 175m^3/hr. The output parameters of thermal effectiveness, cooling capacity, and thermal conductance are obtained maximum at 175 m^3/hr volume flow rate of air. Finally, MATLAB values are compared with CFD analysis values, and the obtained results are in good agreement with theoretical calculations.

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