Theoretical Investigation of an Indirect Evaporative Air Cooling System

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ABSTRACT

In this paper an indirect evaporative cooler theoretically investigated. Because of its low cost and low environment pollution, the indirect evaporative coolers have great potential as an alternative to conventional air conditioning in an arid hot climates such as southern of Libya where the temperature and relative humidity reach 45°C and 20 % respectively. The present investigated system consists of cooling tower, cross unmixed heat exchanger, air blower, circulating pump, air filter, humidifier, and air duct. The main factors that affect on the temperature output of the system are presented. The affect of air conditions input to the cooling tower and air duct were clarified by solving the control equations using Matlab program. The results show that the air dry bulb temperature directly proportion to the outlet dry bulb temperature, and air input relative humidity notable proportion to the outlet dry bulb temperature. The water flow rate in the cooling tower affect on the outlet air temperature, were as it increases the outlet air temperature decreases. Also the air flow rate through the cooling tower contributes in the outlet air temperature, while the increasing in the air flow rate leads to decreasing in the outlet air temperature. Furthermore as the flow rate of the air inside the air duct increases, the outlet temperature decreases. Moreover investigation proves that the indirect evaporative cooling successfully can be used in the southern of Libya.

KEYWORDS : Indirect evaporative cooling, Cooling tower, Arid hot climates

1 Introduction

An indirect evaporative air cooler (IEC) is one of the promising solution for air conditioning specially in the arid hot climates, which encouraging the researchers to taken up different studies concerning of this subject. The analysis for theoretical and experimental works takes place over a wide world locations even in the cold weather State, such as European countries where the experimental analysis of (IEC) system studied [1]. The components of the (IEC) have factors effecting on the system performance, [2] investigated the conductivity of metal, fibers, ceramics and how they impact on the (IEC) system. The (IEC) acts as an energy recovery device in air conditioning systems which called a semi-indirect evaporative cooler [3]. The outdoor conditions have a most effect on the (IEC) availability applications that provide a comfort conditions, [4]. The review of (IEC) [5] technology was undertaken from a variety of 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 commercialization indicated that (IEC) technology has potential to take up the air conditioning duty for buildings. The (IEC) systems has been modified to increase its cooling performance one of modification is an effectiveness- number of transfer unit (Ɛ-NTU) method analysis using an indirectly pre-cooling the working air before it inters the wet passage that could be based on (Ɛ-NTU) heat exchanger by redefining the potential gradients, transfer coefficient, heat capacity rate parameters [6]. The thermodynamic characteristics of (IEC) experimentally and theoretically research works on feasibility studies, performance test and optimization as well as transfer analysis reviewed [7]. The advantages of the (IEC) is the low energy consumption and the environmental friendly and very low warming impact, the disadvantage is the water consumption [8]. For the (IEC) system, the main equipment is the cooling tower where the cold water produced. The principle of the cooling tower is the process of heat and mass transfer by direct contact between air and water in the tower packed by means of the coefficient of both heat and mass transfer. The simultaneous heat and mass transfer between water and air experimentally investigated [9] where the effect of air and water flow rates on the global heat and mass transfer coefficient clarified. In this paper the effect of the air conditions and the flow rates of both air and water on the air out of (IEC) that mainly consists of cooling tower, cross unmixed heat exchanger, air blower, circulating pump, humidifier, and air duct is investigated by solving the control equations using Matlab computer program.

2 System Description

The investigated (IEC) system is shown in Figure 1,and it can be described as following.
Air Blower: It is a centrifugal fan type that supply the air from an ambient air to the conditioning duct where the processing equipments of the system assembled.

Heat Exchanger : The heat exchanger is the equipment where heat transfer between the water from the cooling tower and the air inlet to the system is taken place. The heat exchanger type is staggered order find tube unmixed cross flow and its effectiveness is 75%.

Humidifier : The humidifier is a bank of atomizer nozzles that spry the cooled water from the cooling tower into the stream of the cooled air that is outlet from the heat exchanger.

Duct System: Duct is a passage where the ambient air flows onto the equipments of blower, filter, heat exchanger, humidifier, and eliminator. Duct cross section area, and length are 64×64 cm^2, and 1.3 m respectively.

Cooling Tower : The cooling tower is the equipment where the heat and mass transfer occurring by direct contacting between the air and to produce the cold water. The cooling tower type is the forced counterflow. The tower consists of a draft axial fan mounted at the top of the tower. The nozzles spray water on the dick for enlarging the contacting area between the air and water to maximize the heat and mass transfer rate. The bottom of the tower body is a water sump which collects the cold water. The tower height is 2 m, cross section is area, 1×1 m^2.

Cooling Water Circulating System : The cooling water is circulated by means of a centrifugal pump and water flow rate is controlled by three valves.

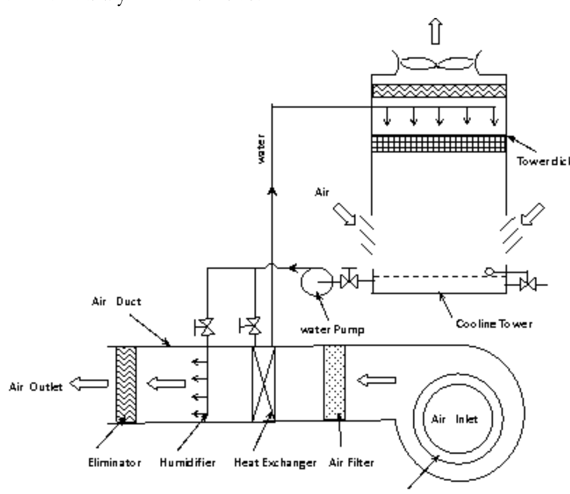

Figure 1: Indirect evaporative air cooler system.

3 Theory

The main processes are occurred first in the cooling tower where the mass and heat transfer takes place to produce the cold water, next the heat transfer between the air and cold water through the heat exchanger for air cooling, then the air humidified by the cold water. For the cooling tower, from Figure 2, ignore water loosing and heat transfer through the tower walls, the energy balance equation for the process of direct contact of heat and mass transfer in cooling tower is [10]

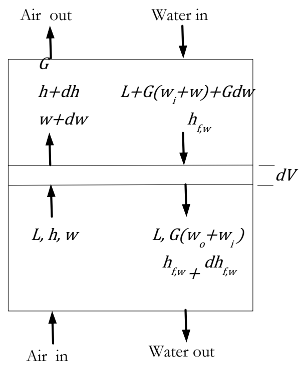

Figure 2 : Counterflow cooling tower diagram.

$$Gdh = -[L - G(w_2 - w)]dh_{f,w} + Gdwdh_{f,w} \quad (1)$$

where G is the air flow rate, (kg/s), h is the moist air enthalpy, (kJ/kg), L is the water flow rate, (kg/s), w, is humidity ratio of moist air, (kg_w/kg_a), $h_{f,w}$ is water enthalpy at its temperature, (kJ/kg).

(w_2- w) is small and it can be ignored so,

$$Gdh = -Ldh_{f,w} + Gdwdh_{f,w} \quad (2)$$

For water energy balance in terms of the heat and mass transfer coefficients, K_C(kw/m^2 ^{o}C) and, K_D(kg/s.m^2) respectively

$$-Ldh_{f,w} = K_C A_V dV(t_w - t) + K_D A_V dV(w_{s,w} - w)h_{fg,w} \quad (3)$$

where, A_V, is water surface area per unit volume, (m^2/m^3), t_w , water temperature (^{o}C), t, moist air dry-bulb temperature, (^{o}C), $w_{s,w}$, humidity ratio of saturated air at t_w, (kg_w/kg_a), $h_{fg,w} = h_{g,w} - h_{f,w}$.

$h_{g,w}$, is the enthalpy of saturated water vapor at t_w (kJ/kg).

The air side water vapor mass balance is

$$-Gdw = K_D A_V dV(w_{s,w} - w) \quad (4)$$

Introducing Lewis number $Le = \frac{K_C}{K_D c_{pa}}$ in equation (3) gives,

$$-Ldh_{f,w} = K_D A_V dV[Lec_{pa}(t_w - t) + (w_{s,w} - w)h_{fg,w}] \quad (5)$$

Combining equs. (2), (4),and (5)

$$\frac{dh}{dw} = Lec_{pa}\frac{t_w - t}{w_{s,w} - w} + h_{g,w} \quad (6)$$

The enthalpy of moist air for constant C_{pa},

$$h = c_{pa}dt + wh_g$$

$$dh = c_{pa}dt + dwh_g$$

$$h_{s,w} - h = c_{pa}(t_w - t) + h_g^o(w_{s,w} - w)$$

where $h_{s,w}$, is the enthalpy of saturated air at t_w, h_g^o is the enthalpy of saturated water vapor at 0^{o}C.

From equ. (6)

$$\frac{dh}{dw} = Le\frac{h_{s,w}-h}{w_{s,w}-w} + \left(h_{g,w} - h_g^o Le\right) \tag{7}$$

For $Ldh_{f,w} = LC_w dt_w$ so by equs. (5) and (7), we have

$$-\frac{dt_w}{h_{s,w}-h} = \frac{G}{LC_w}\left[Le + \frac{h_{fg,w}-h_g^o Le}{(h_{s,w}-h)/(w_{s,w}-w)}\right]\frac{dw}{(w_{s,w}-w)} \tag{8}$$

For the Heat exchanger the effectiveness is $\varepsilon = \frac{\acute{t}_o-t_i}{t_i-t_{w,i}}$ (9)

The humidifier control equations are.

$$h_{ih} = \acute{t}_o + w_i(2501 - 1.805t_{ih}) \tag{10}$$

$$h_{f,w} = 0.204266 + 4.18609t_w \tag{11}$$

$$l = g(w_o - w_i) \tag{12}$$

$$h_o = \frac{l}{g+l}\times h_{f,w} + \frac{g}{g+l}\times h_{ih} \tag{13}$$

$$t_o = \frac{h_o-2501w_o}{1+1.805w_o} \tag{14}$$

h_{ih}, t_{ih}, w_i, enthalpy, temperature, and humidity ratio of air input to the humidifier respectively, $\acute{t}_o$, is the air temperature out of the heat exchanger, *l*, g, water, and air flow rates through the humidifier respectively (kg/s), t_o, w_o , temperature, and humidity ratio of the air output.

4 Results and Discussion

The above control equations (8) through (14) solved using Matlab computer program for steady state and assuming no heat and water loss from the cooling tower and air duct. Input the system specifications, and G, L, input t_w, for Le =1, the solution is starting with the initial conditions and applying trial and error procedure to get the air outlet conditions. The process bath of the air through the air duct is shown in Figure 3 where, the air sensible temperature dropping in heat exchanger by the cold water from the cooling tower. The temperature dropping takes place as a result of the operation conditions. Finally the cold air is humidified by the humidifier which increases the air humidity as well as slightly deceases its temperature.

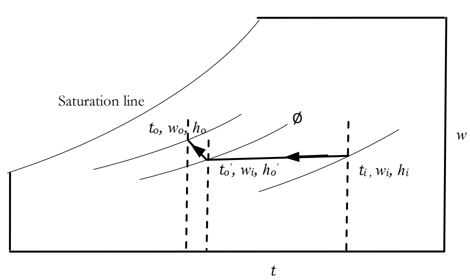

Figure 3 : Processes bath of the air through the air duct.

The effect of the conditions of the inlet air to the system for a constant air relative humidity(RH) Ø, and water, air flow rates in the cooling tower are L= 0.65 kg/s, G= 2.6, respectively, and air flow in condition duct g=1.5 kg/s is shown in Figure 4 which reveals that as inlet dry bulb air temperature t

increases, its outlet temperature increases t_o. But as (RH) decreases for constant air dry bulb temperature, the outlet air temperature deceases, that because, for the low (RH) which means low wet bulb temperature more amount of water evaporated in the cooling tower due to the high mass an heat transfer coefficient and as a result the water heat capacity between inlet and out let lowered hence, the water temperature from the cooling tower that flow to the heat exchanger and the humidifier causing air temperature drop.

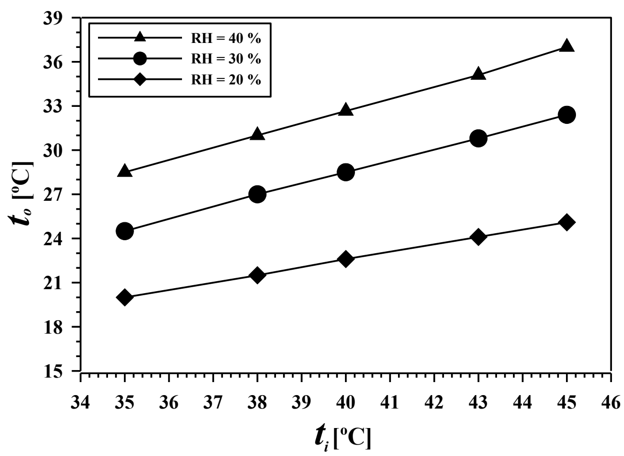

Figure 4 : Effect of inlet air conditions on the outlet air at *L*= 0.65 kg/s, G= 2.6 kg/s, and *g* =1.5 kg/s.

The water flow rate plays noticeable effect on the water temperature outlet from the cooling tower which then supplied to the heat exchanger. The effect of cold water flow rate from the cooling tower on the air temperature exit from the duct is shown in Figure 5 which illustrates that as the flow rate of water increases, the exit temperature from the duct decreases that because higher water flow rate enables heat and mass transfer between the air and water to increase as well as the increasing of the water flow rate into the heat exchanger, increases the heat transfer rate.

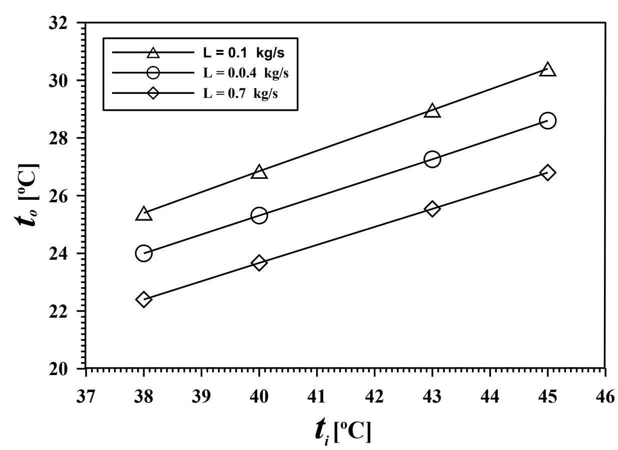

Figure 5 : Effect of the water flow rate in the cooling tower on the outlet air at G= 2.6 kg/s, *g* =1.5 kg/s, and Ø=25%.

From Figure 6, it's clear that when the air flow rate increases into the cooling tower the air out let of the duct decreases due to water temperature drop in the tower and consequently in the heat exchanger as a result of enlargement of heat and mass transfer area between air and water that gives big chance of the transferring process to take place.

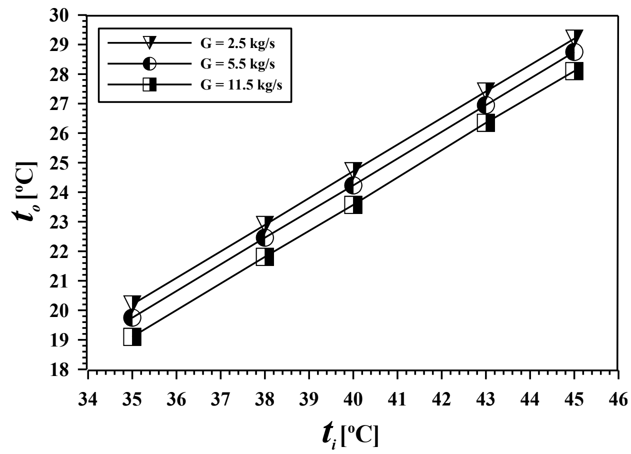

Figure 6 : Effect of the air flow rate in the cooling tower on the outlet air at L= 0.65 kg/s, g =1.5 kg/s, and Ø=25%.

The air velocity in the air duct has a manifest effect on the outlet air temperature as shown in Figure 7, from which it can be deduced that as the air velocity increases the air temperature outlet decreases due to the increasing in the NTU of the air-water heat exchanger.

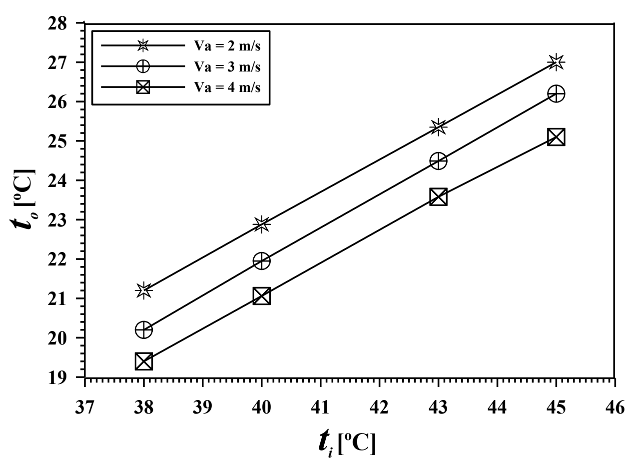

Figure 7 Effect of the air velocity in the air duct on the outlet air at L= 0.65 kg/s, G= 2.6 kg/s, and Ø=25%.

4 Conclusion

The (IEC) system have been investigated which reveals that the main principles of the (IEC) system depends on the direct contact between the air and water where both heat and mass transfer between the air and water takes place in the cooling tower. The factors that effect on the performance of the (IEC) system are the inlet air conditions mainly inlet air wet bulb temperature or (air relative humidity) as its decreases the air temperature outlet decreases for constant water and air flow rates, also the flow rates of both the air and water in the cooling tower have highly impact on the (IEC) system and whenever these flows increases the air temperature out of the system decreases due the simultaneous of heat and mass transfer raising up. Likewise as air velocity in the duct increases the outlet of air temperature decreases due the heat exchanger effectiveness improvement. The (IEC) systems may successfully used as air cold conditioners at the arid climates such as Libya particularly southern regions. more studies on the (IEC) systems required to be done to improve their performance.

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