Investigation of the effect of packing location on performance of closed wet cooling tower based on exergy analysis

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Abstract. In this paper, the effect of packing location on thermal performance of Closed Wet Cooling Tower (CWCT) based on exergy analysis has been studied. The experimental study incorporates design, manufacture and testing of a modified counter flow forced draft CWCT prototype. The modification based on addition packing to the conventional CWCT. The variation of spray water temperature, air dry bulb temperature, air wet bulb temperature, enthalpy and relative humidity of air for different position along the tower are measured experimentally. Applying the exergy destruction method for the cooling tower; exergy destruction, exergy efficiency, exergy of water and air were calculated for two cases: CWCT with packing below the heat exchanger and CWCT with packing above the heat exchanger. It is highly important to analyze the exergy along the cooling tower height. Therefore, the exergy analysis of different elements along the height of the tower is carried out. Results show that the total exergy destruction of modified CWCT is higher when the heat exchanger is located above the packing at the highest point of the tower.

1. Introduction

Many studies have been made on the performance of cooling tower in view of exergy analysis. Qureshi and Zubair [1] presented theoretically a thermodynamic analysis of counter flow wet cooling towers and evaporative heat exchangers using both the first and second law of thermodynamics. By applying an exergy balance on each of the systems, the variation of second- law efficiency as well as exergy destruction as a function of various input parameters such as inlet AWBT & inlet water temperature has been identified. Mani and Rajagopal. (2008), [2] formed a scientific model taking into account mass and heat transfer to find the outlet conditions of air and water in counter flow open type cooling tower. Their model has been solved using iterative method. Energy and exergy analysis infers that inlet AWBT was found to be most vital parameter than inlet water temperature. Thy showed that at lower inlet AWBT, the outlet temperature decreases which leads to higher water approach temperature and exergy destruction by decreases the second law efficiency. Ramkumar and Ragupath.(2014), [3] investigated thermal performance of open type mechanical draft counter flow cooling tower with expanded wire mesh packing. Exergy analysis has been applied to study the cooling tower potential of performance using the psychometric gun technique. Abdul Hadi (2015), [4] Derivative Merkel theory for a counter flow induced draught cooling tower with a few rearrangements. The overseeing mathematical statement was settled by an iterative strategy. The tower was isolated into 100 even components. Mass, energy and exergy equalizations were assessed for every component utilizing Engineering Equation Solver (EES) programming.

2. General information

A modified CWCT was designed and constructed in which different operating parameters could be varied and tested in the laboratories of Environmental Engineering Department of Al-Mustansiriya University College of Engineering. The general arrangement of the equipment is shown in figure 1.

Figure 1.a. Photographic picture for experimental apparatus (lateral view). **Figure 1.b.** Photographic picture for experimental apparatus (front view).

The tower fabricated from galvanized steel sheet connected together by screws and nuts as a rectangular box of external dimensions (700 mm×400 mm×2300 mm). As exists in every forced cooling, the test section consists of three zones: spray, fill and rain zone. Fill zone at 1000 mm height and characterized as consisting of three places for sliding removable drawer rectangular boxes at the same dimensions, manufacturing for packing and heat exchangers to ensure change the locations and types of heat exchangers and height of packing to study the influence of all these additions on the performance of the tower. The rectangular drawer made of galvanized steel with dimensions of 420 mm in width, 760 mm in depth and 280 mm in height. Air from the atmosphere, enters the single stage centrifugal blower at a rate which is controlled by the butterfly valve. The fan discharges into the PVC pipe and the entrance duct before entering the packed column. As the air flows through the packing and heat exchanger, its moisture content increases and the water in the heat exchanger are cooled. Hot water is pumped from the load tank through the control valve and a water flow meter to the heat exchanger placed inside the test section of tower. Plain tube heat exchanger was designed and manufactured for the present work. The tubes were fixed horizontally in test section inside supported frame of rectangular drawer .Cooling water moves through the tubes while the spray water and air move over the tubes in perpendicular direction. The tubes are arrayed in staggered arrangement with tube pitch of $3D_o$ (pitch over diameter of 3).The specification of heat exchangers shows in table 1.

Table 1. Physical dimensions of heat exchanger.

Heat exchanger configuration	Value	Unit
Length (L_1)	690	mm
Height (L_2)	166	mm
Width (L_3)	381	mm
Number of tubes for coil	30	-
Vertical tube spacing (X_L)	24	mm
Horizontal tube spacing (X_T)	80	mm
Tube per row	5	-
Outside tube diameter	15.88	mm
Total heat transfer area	1032691.77	mm^2

Thermocouples type K inserted before and after the cooler coil to measured cooling water temperature. To measure the spray water temperatures at intermediate locations inside test section, especially channels have been manufacturing to insert thermocouples through holes. These holes are closed by rubber stoppers through which thermocouples are inserted to measure the temperature profile. The variations of air dry bulb temperature and relative humidity along the test section as well as the inlet and outlet of the tower were measured by humidity meter, which combined temperature/humidity sensor. The humidity meter model TH-305 has a (main faction) temperature and relative humidity measurement range from 0 to 60℃ and 20 to 95% respectively. The sensor probe handle is placed directly in the air stream and connected to display.

3. Exergy Analysis

In this study, the exergy analysis of the CWCT based on the Exergy Destruction Method (EDM) was carried out in the simplified system shown in figure 2. For steady state conditions, neglecting the effect of kinetic and potential energy, an exergy balance is formulated for all components of the CWCT were presented in figure 2.

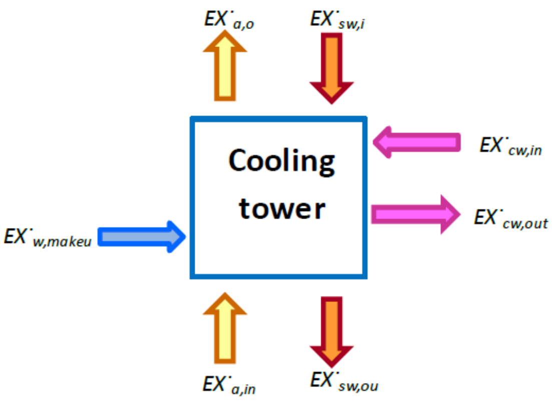

Figure 2. Exergy balance of the cooling tower.

Exergy of water can be obtained by Bejan as flows [5]:

$$EX_w^o = m_w^o\left[\left(h_{fw} - h_{fo}\right) + T_o\left(S_{fw} - S_{go}\right) - R_v T_o \ln Ø_o\right] \quad (1)$$

Neglected the mechanical exergy of water comparing with chemical exergy, so the exergy of water for ideal gas law, equation (6) becomes [6]:

$$EX_w^o = m_w^o\left[C_{Pw}\left(T - T_o\right) - T_o C_{Pw} \ln\frac{T}{T_o} - R_v T_o \ln Ø_o\right] \quad (2)$$

The total exergy in the psychometric process –such as in the cooling tower operating mechanism, on the bases of dray air and water vapour as an ideal gas when neglecting the change of pressure through the cooling tower can thus be generally represented presented in Bejan [5]:

$$EX_a^o = \left[\left(C_{Pa} + \omega C_{Pv}\right)\left(T - T_o - T_o \ln\frac{T}{T_o}\right) + R_a T_o\left(\left(1 + 1.608\omega\right)\ln\frac{1 + 1.608\omega_o}{1 + 1.608\omega} + 1.608\omega \ln\frac{\omega}{\omega_o}\right)\right] \quad (3)$$

Exergy destruction represents by the difference between exergy change of water and of air.

$$\sum EX_{in}^o - \sum EX_{out}^o - EX_D^o = 0 \quad (4)$$

The exergy destruction can be determined by:

$$EX_d^o = \left(EX_{a,in}^o + EX_{sw,in}^o + EX_{cw,in}^o + EX_{w,makeup}^o\right) - \left(EX_{a,out}^o + EX_{sw,out}^o + EX_{cw,out}^o\right) \tag{5}$$

The exergy efficiency (second low efficiency), which is measured of irreversibility losses in a given process is define as [1]:

$$\eta_{Ex} = 1 - \frac{EX_d^o}{\sum EX_{in}^o} \Delta \overset{o}{EX}_{air} \tag{6}$$

4. Results and discussions

The effect of packing location (for CWCT with packing) on the exergy analysis will be discussed. figures 3 to 6 illustrated variation in: exergy destruction, exergy efficiency, water exergy change and air exergy change with cooling water flow rate for two cases: CWCT with packing under heat exchanger and CWCT with packing above the heat exchanger for 560 mm packing height for heat exchanger. The impact of cooling water flow rate on exergy destruction for different packing locations is illustrated in figure 3. From this figure, it is stated that the exergy destruction increments with the increment of cooling water flow rate for both cases. In comparison to location of packing added to CWCT, it was observed that adding packing to CWCT displays higher exergy destruction when located the heat exchanger at the highest point of the tower than the lower location. This is generally expected as a result of increasing cooling range for this case. In other words, the exergy destruction increases due to the increasing contrast between inlet and outlet temperatures of cooling water. Exergy efficiency as a function of cooling water flow rate for various packing locations is illustrated in figure 4. From this figure, it can be watched that the exergy efficiency diminishes when cooling water flow rate was expanded for both cases of added packing. On the other hand, it was observed that the exergy efficiency of CWCT with packing under heat exchanger obtained higher values than the CWCT with packing above the heat exchanger.

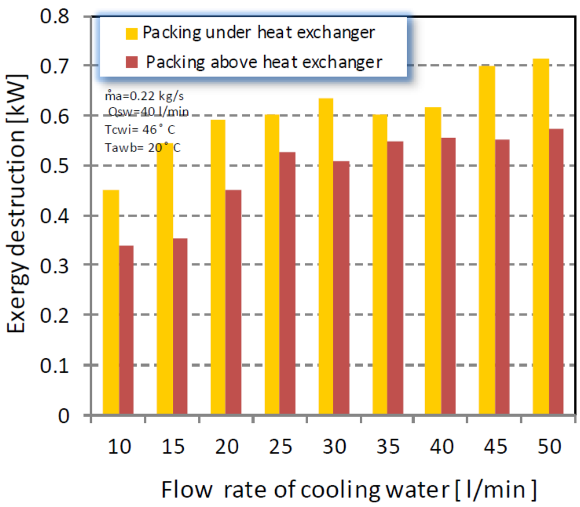

Figure 3. Mesh Variation of exergy destruction with cooling water flow rate for different locations of packing.

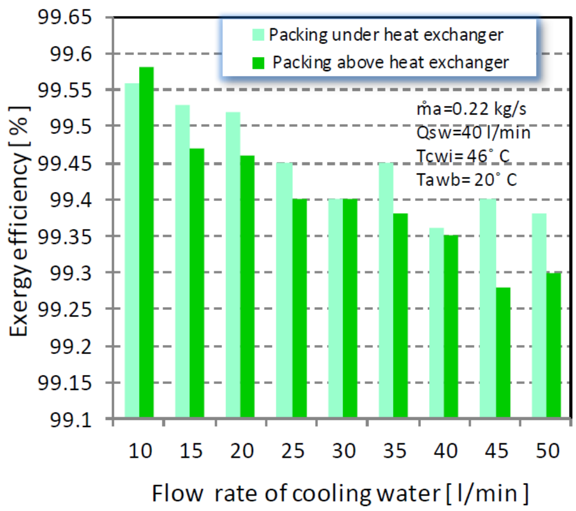

Figure 4. Variation of exergy efficiency with cooling water flow rate for different locations of packing.

The relationship between the total exergy changes of water with cooling water flow rate for different packing positions is illustrated in figure 5. It is indicated that the total exergy change of water is proportional to the cooling water flow rate. Also, it could be seen that the total exergy change of water for CWCT with packing under the heat exchanger higher than the total exergy change of CWCT with packing above the heat exchanger. Figure 6 demonstrates the relationship between the total exergy change of air and cooling water flow rate for different packing positions. It could be clearly seen that the total exergy change of air increments slightly with the increment of cooling water flow rate for both packing positions. Therefore, it is noticed that the total exergy change of air for CWCT with packing under the heat exchanger higher than that for CWCT with packing above the heat exchanger.

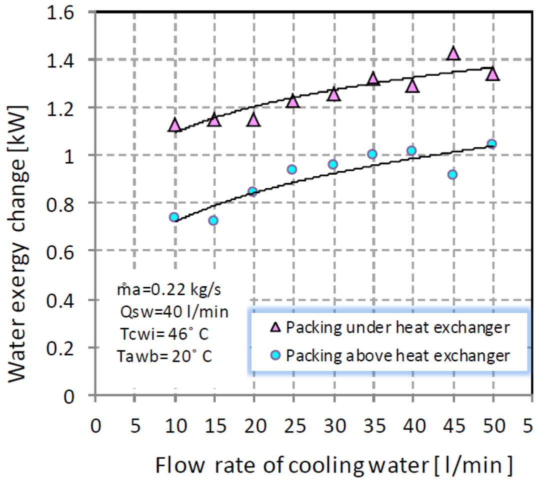

Figure 5. Variation of exergy change of water with cooling water flow rate for different locations of packing.

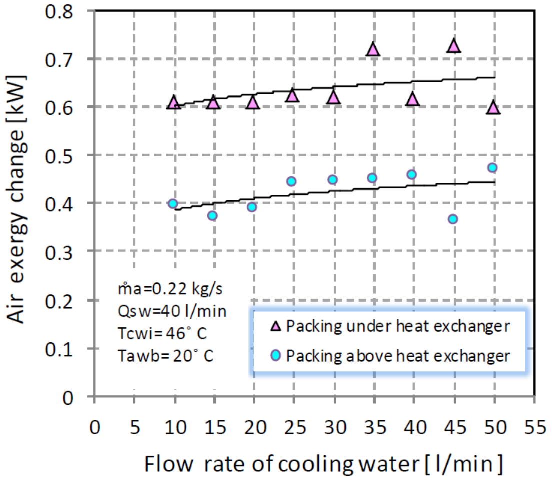

Figure 6. Variation of exergy change of air with cooling water flow rate for different locations of packing.

The exergy analyses of the different components along the height of the tower are carried out and the distribution of exergy along the tower height from up to down demonstrated in table 2. It is indicated that in both cases the exergy destruction is higher in the base area and bit by bit diminishes towards the highest point of the tower; consequently least exergy destruction is seen at the highest point of the tower. As indicated from this table, since the system generates entropy, water absorbs more exergy than of the air; the exergy of water decreases from the upper part to its lower part, while the exergy of air increases from the lower part to its upper part. This can be clarified by the way that water temperature diminishes from highest point to base of the tower as a consequence of supplying is exergy to the air.

Table 2. Exergy distribution along the tower height.

Component from upper	$\overset{o}{EX}_D$ (kW)	$\Delta \overset{o}{EX}\ water$ (kW)	$\Delta \overset{o}{EX}\ air$ (kW)	$\Delta \overset{o}{EX}\ air(conv)$ (kW)	$\Delta \overset{o}{EX}\ air(evap)$ (kW)
CWCT with packing under the heat exchanger					
1	132.0737	265.3732	133.2995	0.7992	132.5003
2	146.776	332.57	185.794	-4.0178	189.8118
3	167.242	195.5013	28.2593	2.3233	26.0035
CWCT with packing above the heat exchanger					
1	40.9153	160.9044	119.989	2.0651	117.924
2	63.6694	171.2916	107.6222	1.4786	106.1437
3	257.4054	330.702	73.2966	-1.1035	74.4001

5. Conclusions

In the present paper, experiments were conducted to determine the effect of packing location on thermal performance of CWCT based on exergy analysis. It is concluded that the exergy destruction of CWCT with packing under the heat exchanger higher is than that for the CWCT with packing above the heat exchanger. Therefore, for both cases, maximum exergy destruction inside the tower occurs at the bottom of the tower. Exergy efficiency behaviour is inversely proportional with the behaviour of the exergy destruction. Exergy change of the water is more than twice the exergy change of the air. Also, exergy of air due to evaporation more dominated function in the air exergy due to convection. Exergy of air due to an evaporation more dominated function in the air exergy due to a convection. This is because the exergy of air due to convection depends on the dry bulb temp and exergy of air due to evaporation depends of humidity ratio of wet air.

References

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Nomenclature
A=total heat transfer area, m2
Cp=specific heat at constant pressure, kJ/kg oC
D=tube diameter, m
EX_d^o =exergy destruction, kW
Eloss=rate of evaporation losses, kg/s
$\dot{m}$ =mass flow rate, kg/s
Q=volume flow rate, l/min
T=temperature, oC

Greek Symbols
ρ=density,kg/m3
Φ=relative humidity, %
ω= humidity ratio, kg/kgdry air
η_{Ex} =exergy efficiency, %

Subscripts
a=air
cw=cooling water
in=inlet
out=outlet
sw=spray water