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Research Article

Performance Study and Comparison of Three Types of Film Fill Packings in Bisotoun Power Plant of Kermanshah Province in Iran Using Merkel Model

[1]J. Khorshidi, [1]M. Baniasadi and [2]H. Davari
[1]Department of Mechanical Engineering, Hormozgan University, Bandar Abbas, Iran
[2]Department of Mechanical Engineering, Roudan Branch, Islamic Azad University, Iran

Abstract: This study deals with calculation and comparison of performance parameters of three types of horizontal, vertical and mixed corrugated film fill packing, to their actual values in cooling tower of the Bisotoun power plant. Through this, performances of cooling packing are compared with each other. Also utilization of the most appropriate cooling tower in Bisotoun power plant has been investigated. In order to rich the above mentioned goals, added to describing performance of physical mechanisms in wet mechanical counter current cooling towers and Merkel's thermal theory, thermal properties of the pre-mentioned cooling packings are presented also, moreover performance parameters of the three packing are calculated and compared, then the appropriate conclusion is made. The results show that among the three packings, because of having appropriate characteristics like higher surface to volume ratio and mass transport coefficient and so on, the mixed corrugated packing has had the best performance in comparison with the other two packings and can perform acceptable in Bisotoun power plant. As, the Values of the cold water temperatures, the temperature difference between cold water and wet point temperature of the ambient and the coolness range the mixed corrugated packing is fully consistent with those gathered from the power plant's data. However, values of these parameters show considerable difference in two other packing with their counterparts in Bisotoun power plant, the water flow rate to air flow rate ratio in the mentioned packing shows a tiny difference with the actual value in the power plant which is 2.15 (1.4% increase). If this packing was used the amount of air used to cool down the water in the cooling tower which is prepared by each fan would be 521 m^3/secs, which defers 5.4 % with that of Bisotoun, that is 551 m^3/sec.

Keywords: Wet Cooling Tower, Packing, Bisotoun Power Plant, Thermal Properties, Merkel's Model

INTRODUCTION

Due to the fact that all industrial processes are coupled with heat generation, it is a must that the generated heat be removed. Power plants, petrochemical units, refineries, air conditioning systems and so on belong to those units that require the generated heat to be removed. One typical method is to use water which gets hot when takes this extra heat. The hot water must be discharged and replaced or cooled down for performing another cooling circle. In industry it's a common solution to use cooling towers for cooling the hot water down. Cooling towers are generally divided into two groups, wet and dry, both of which have different types.Among wet towers, one of them is called wet mechanical counter current cooling tower with film fill packings. Packings are one of the most important parts of cooling tower which are heat and mass transport surfaces. Packing makes fluid flow to be laminar and steady state in cooling towers which provides the most contact surface for water drops in air leading to the minimum water film thickness in the highest surface. Moreover, increasing water passage time is another goal of packing usage in towers. Given the importance of packings in cooling towers, so study on them have been of interest to various researchers:

In Goshayshi *et al*. (1999) accomplished experimental study on packings made of PVC. Influence of distance and roughness of packings on heat and mass transfer coefficient and pressure drop was reported in their study. Stefanović *et al*. (2000) build a laboratorial cooling tower with vertical parallel surfaces made up of plexiglas and recorded temperature along the tower. Bilal and Syed (2006) proposed a model consisted of three zones: spray, packing and sprinkler. They rewrote governing equations of cooling towers using energy balance for the zone of filling materials and a new reference volume. In their study published in 2006, Mohseni *et al*. (2006) investigated heat and mass transfer in wet cooling towers of counter current type with mixed corrugated packings. Farhad *et al*. (2007) investigated two types of film fillers in mechanical cooling towers. Eskandari *et al*. (2008) published an study titled as "Obtaining characteristics of the packing of wet cooling towers of HamedanMoffateh power plant and modeling and comparison with experimental

Corresponding Author: J. Khorshidi, Department of Mechanical Engineering, Hormozgan University, Bandar Abbas, Iran

results". In that study after modeling of the cooling system using the obtained equations, water and electricity consumption in the towers were examined at an ambient archived condition of the power plant. Heydar Nejad and Karami (2008) surveyed practical properties of heat and mass transfer in the evaporating cooling towers. In their study, they have proposed a mathematical model governing a wet counter current cooling tower. Mamouri and Goshayeshi (2011) studied effect of the packing on temperature and pressure drop in cooling towers with mechanical counter current cooling towers.In this study performance of three film packings of vertical corrugated, horizontal corrugated and mixed corrugated type is examined by using Merkel's model and in design conditions of Bisotoun power plant of Kermanshah.

Governing equation: Physical mechanism of the wet forced (mechanical) cooling tower of the counter current flow type with film packing is as follows: air flow is produced by one or some fan (s) and then sent from base of the tower in order to cool down the hot water. Hot water is poured from top of the tower on the packings that are heat and mass transfer surfaces and is put in close contact with air flow. Accordingly the temperature of the water decreases and cooled water is collected at the bottom of the tower. Then this cooled water is forwarded to condenser or the process which needs cooling.

Merkel's thermal theory: The idea of general evaluation of wet towers was first proposed by Merkel in 1925. Merkel's thermal theory explains heat transfer from water to air in counter current evaporating cooling towers. The overall heat (enthalpy) consists of specific heats of water, air and evaporated water in addition to latent heat for water evaporation.

Merkel expanded the tower theory for mass transfer (evaporation of a small part of water) and specific heat between water and air in the cooling tower. This theory considers energy and mass transport from water to boundary and from boundary to the surrounding. The flow from these two boundaries shows resistance from itself because of temperature gradient, enthalpy and moisture ratio.

Merkel's analysis and related equations, includes sensible heat transfer and latent heat in the form of heat and mass transfer form on basis of enthalpy difference as propellant. Every surface of water is covered with a tiny film of saturated air with a temperature same as the mass water. Flowing through the tower, the air gets warm and saturated. Temperature and physical properties of the water and the air change in proportion to their relative position. Heat and mass transfer is related to enthalpy difference in any point with temperature figure.

Merkel's theory is based on the fact that water cooling in the air is restrictedly related to the wet bulb temperature and this temperature is an approximate indicator of enthalpy. The wet temperature is gain form psychometric diagram that is defined as the nodal of ambient temperature and dew point or nodal of ambient temperature and relative humidity. The wet temperature defines the probability of evaporation. Wet temperature is also known as saturated adiabatic temperature. In the tower, water cannot get cooler than the wet bulb temperature.

Assumption:

- Heat and mass transfer through tower walls to the surroundings is was ignored.
- The cross section of the tower is uniform.All over the tower heat and mass transfer coefficients are taken as constant.
- Heat and mass transfer occur simultaneously. The air temperature on the surface is the same as that of flowing water.
- The air in the contact surface is saturated.

The governing equation for cooling tower is as:

The usual method for designing wet cooling towers is done using Merkel's equation:

$$\int_{t_{L1}}^{t_{L2}} \frac{\mathrm{dt}}{(\mathrm{H_w}-\mathrm{H_a})} = \frac{KaV}{L}$$

$$\mathrm{I_M} = \mathrm{I_P}$$

The value of $\mathrm{I_M}$ depends on air and water temperatures at entrance and exit of the tower . The value of $\mathrm{I_M}$ can be determined without considering the types of packing.

The value of $\mathrm{I_p}$ depends on the properties of the packing and is independent to inlet and outlet properties of air and water.

Deign of a tower is nothing more than determination of properties and amount of water and air and properties of the packing, in a manner that the pre-mentioned relation be established.

The value of the characteristic of the packing $\mathrm{kav/L}$ is usually gain by experiment and is defined as a non-dimensional ratio of mass fluxes $(\mathrm{L/G})$.

DETERMINING THE DESIGN POINT OF THE TOWER

To calculate the design condition of tower three steps was done:

- Determination of the characteristic of the tower in different L/G
- Determination of the characteristic of the packing with different L/G s. in this stage it is adequate to choose a type of packing with specific experimental data and then the thermal characteristic for the packing versus ratio of mass flux be plotted

Fig. 1: A schematic view from the horizontal corrugated film packing type

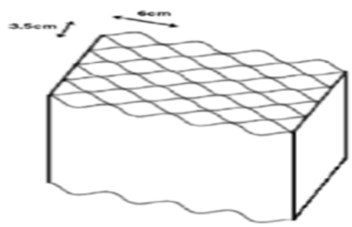

Fig. 2: A schematic view from the vertical corrugated film packing type

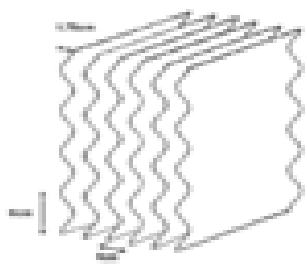

Fig. 3: Mixed corrugated film packing type

- Determination of the L/G in a manner that Merkel's equation be satisfied. Due to the aforementioned steps, when the packing and the tower characteristic plot according to the value of L/G ratio is in hand, we can then determine the design point of the tower. Two characteristic curves cross each other in a point which is the design point. Due to the design point (the point where the two characteristic curves collide) the water/air mass flux ratio is then determined and using the water flow rate, the air mass flow rate for the tower is achieved.

DESIGN CONDITION OF COOLING TOWER OF BISOTOUN POWER PLANT

Three types of packings was applied to operating condition of bisotoun power plant:

Horizontal corrugated type: This packing is made of PVC and has a height of 64 cm from the horizontal corrugated film type and is like Fig. 1. The relation between the packing characteristic and water to air flow rate ratio is $\mathrm{Kav/L} = 0.224(\mathrm{L/G})^\wedge(-0.295)$ (Farhad *et al*., 2007).

Vertical corrugated type: This packing is made of PVC and has a height of 64 cm from the vertical corrugated film type and is like Fig. 2. The relation between the packing characteristic and water to air flow rate ratio is $\mathrm{Kav/L} = 0.342(\mathrm{L/G})^\wedge(-0.253)$ (Farhad *et al*., 2007).

Table 1: properties of the cooling tower of Bisotoun power plant

1-Type of the cooling tower	Mechanical wet counter current
2-Type of the packing	Film fill made up of, PVC
3- Information about temperature, volume flow rate used in calculations and designing of the tower	1- Ambient wet temperature, 23˚C 2- Ambient dry temperature, 44˚C 3- Tower inlet hot water temperature, 39˚C 4- Tower outlet cold water temperature, 31˚C 5- Cycling water flow rate, 47000 cubic meter per hours
4-Information about fans	1- Number of all fans, 10 fans 2- Air flow rate for each fan, 551 cubic meter per seconds 3-Required power for each fan, 160 kilowatts 4- Overall required power for air supply, 1600 kilowatts
Temperature difference between cold water and wet temperature	8˚C
5- Coolness range	8˚C
Ratio of water to air flow rate	$\frac{L}{G} = 2.15$

Mixed corrugated type: This packing is made of PVC and is in 1220×1220×300 dimensions (Fig. 3). The relation between the packing characteristic and water to air flow rate ratio is $\mathrm{Kav/L} = 2.2389(\mathrm{L/G})^\wedge(-0.608)$ (Eskandari *et al*., 2008).

DISCUSSION ABOUT PERFORMANCE OF THE THREE PACKING TYPES IN THE COOLING TOWER OF THE BISOTOUN POWER PLANT

Table 1 and also the relation between packing characteristic and water to air volume flow rate ratio in each packing, performance parameters consisting of cold water temperature, proximity temperature, cooling range, L/G and $\mathrm{Kav/L}$ for each packing was calculated and the results are presented in Table 2 and 3.

In order to discuss the results originated from the Merkel's Model for each of the three corrugated packings, horizontal, vertical and mixed in the design conditions of the Bisotoun power plant of Kermanshah, each parameter brought to Table 2 and 3 are discussed as follows, then performance of each packing in proportion to each other and in the power plant is examined and conclusions are made.

The first parameter that is investigated in relation to packings is L/G, which is the ratio of liquid to gas. Here the liquid is water and the gas is air. This scalar determines heat transfer between water and air. Water to air mass flux ratio is one of the important parameters of wet cooling towers that affect all performing qualities. Qualities like outlet cold water temperature, cooling range, proximity temperature of the water, performance of the cooling tower (ratio of actual transferred energy to the maximum possible value of energy transfer) and also thermal ratio (the ratio of range to the ideal range).

Table 2: values of $\frac{L}{G}$ and $\frac{Kav}{L}$, calculated for all of the studied packings

Row	Parameter	Unit	Calculated values in the three types of packings Packing number 1 (Horizontal corrugated) value	Packing number 2 (Vertical corrugated) value	Packing number 3 (Mixed corrugated) value
1	L/G	Non-dimensional	-	0.11	2.18
2	Kav/L	Non-dimensional	-	0.58	1.44

Table 3: Cold water temperature, proximity temperature and cooling range for the three packings examined for Bisotoun power plant at design condition with actual water to air flow rate ratio ($\frac{L}{G}$)

Row	Parameter	Unit	Calculated values in the three types of packings Packing number 1 (Horizontal corrugated) value	Packing number 2 (Vertical corrugated) value	Packing number 3 (Mixed corrugated) value
1	Cold water temperature	°C	36.1	35.1	31
2	Proximity temperature	°C	13.1	12.1	8
3	Cooling range	°C	2.9	3.9	8

According to Table 2, the value for L/G in the packing number 3 (mixed corrugated) and packing number 2 are 2.18 and 0.11 respectively and for the packing number 1 (horizontal corrugated) no value was possible to read (because the curves had no intersection). According to the values that were mentioned previously, the third packing, due to its higher L/G in proportion to the second packing, caused lower water temperature in Bisotoun power plant, leading to lower approach temperature and also more coolness rang in the cooling tower of the power plant. On the other hand having higher L/G this packing increases the performance of the cooling tower of the power plant and decreases the thermal ratio.

The second examined parameter is the amount of cold water that each of the packings would produce in the design conditions of the power plant. As the table shows, the value for the outlet temperature of the packings number 1, 2 and 3 are 36.1, 35.1 and 31 centigrade degrees respectively. Whereas in power plants cooling down the cycling water into lower degrees, causes lower pressure in the condenser which results in a rise in the thermal efficiency of the power plant. So it can be inferred that, respectively packings number 1, 2 and 3 have the best to worst performances on the basis of outlet cool water temperature in the Bisotoun power plant.

The third parameter that is examined in relation with the three packings is approach temperature that is the difference between cold water temperatures at the outlet of cooling tower to the wet bulb temperature from the ambient. The value of this parameter is related to capabilities of the tower. In an ideal tower this value is zero. This means that water at the outlet is cooled to the wet bulb temperature of the ambient (Faezian *et al*., 2008). As Table 3 indicates, the approach temperature for packings number 3, 2 and 1 is respectively, 13.1, 12.1 and 8. Obviously the packing number three has the best performance in this part for the power plant.

The forth parameter is range of cooling, which is gain by subtracting the inlet temperature to that of outlet. Its magnitude has direct relation to the amount of heat transfer in the cooling tower as multiplying it by specific heat and flow rate of water would give the total amount of heat that the water loses (Faezian *et al*., 2008).

According to Table 3 the packing number 3 causes the highest and numbers 1 causes the lowest water heat transfer in Bisotoun power plant. Thus it can be inferred that the packing number 3 has the best performance among the three packings. Another important parameter which must be supervised in this survey, is the value of KAV/L. This parameter expresses heat transfer properties in the tower and includes other parameters like dimensions and the also filling material and it shows the ability of the tower to remove heat from water. It also is the one that it is used to compare towers performances. Higher KAV/L value for a power plant shows higher ability of it to cool down.

Investigation of KAV/L value in Table 2 for packings of this study, shows that the mixed corrugated packing (number 3) has higher ability in cooling the water down in the cooling tower on the other hand the vertical corrugated packing (number 2) has the lowest ability in doing so. That's because of higher mass transfer coefficient and effective surface in the mixed corrugated packing and lower values of them in packing number 2.

In economical view, the packing with better performance and lower output temperature of water would bring out higher power plant efficiency, as it was expressed and accordingly higher energy sale.

Comparison of the cold water, approach temperatures and coolness range, calculated by Merkel's model for the three packings (Table 3) with their actual values of them gain from Bisotoun power plant data (Table 1), shows that values of the mentioned parameters for the packing number 3 is in good agreement with their counterparts of the power plant, but the other two packings have significant difference with those of the power plant.

The last discussed matter would be comparison of the values gain from Merkel's model for L/G of the three packings, with their actual values from Bisotoun. As Table 2 shows, L/G values calculated for packings number 3 and 2 are 2.188 and 0.11. Among these two values the one related to packing 3, has a negligible difference with its actual value from the power plant which is 2.15 (1.4 % error), but L/G for the packing number 2 (0.11) has a significant difference with the power plant value. This value means that using this package we need more air to cool the water down. Thus usage of this packing is more energy consuming and is not recommended.

In case of using packing number 3, with L/G = 2.18, the required amount of air for each fan is 521 (m^3/sec). This value is very close to its actual value (521 m^3/sec) and differs only -5.4% with that. Whereas in industry for safety and performance related reasons, it's usual to increase design values.

CONCLUSION

Performance of three packings in types of vertical corrugated, horizontal corrugated and mixed corrugated were investigated in this study using Merkel's model and in design condition of the Bisotoun power plant of Kermanshah. To do so, some parameters related to performance of the cooling tower like water to air ratio L/G, temperature of the cold water, approach temperature, cooling range and KAV/L were calculated for each packing in the design condition of Bisotoun power plant using Merkel's model. The results are presented in Table 2 and 3. Using these parameters all the three packings were compared with each other. The results show that the third packing (mixed corrugated) has better performance, efficiency and thermal ratio in proportion to the other two packings. After that the vertical corrugated packing stands which is better than the horizontal corrugated packing. Between the three examined packings, mixed corrugated packing suits the calculated thermal needs for the Bisotoun power plant and the L/G value calculated for this packing by Merkel's model had negligible difference with the actual value of the power plant.

Also, the required amount of air for cooling purposes of the tower calculated for the three packings has little difference with their actual values. In general the accomplished studies assesses the use of mixed corrugated packing in Bisotoun power plant as proper but refuses to do o for the other two types of packing. The results show that during a year, Merkel's model can be used to estimate the amount of air needed for the cooling system to be prepared by the fans. Based on design conditions of the power plants, Merkel's model is a good choice to examine thermal performance of the packings with each other and select the best one.

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