Experimental drift study of a dry and adiabatic fluid cooler

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Abstract

Water drift emitted from cooling towers is objectionable for several reasons, mainly due to human health reasons. These objections raise walls to the installation of the cooling towers and penalize the COP of the cooling plants they serve. The dry and adiabatic fluid cooler works as a standard fluid dry cooler enhancing the dry cooler’s capacity with adiabatic pre-cooling of the air intake. The objectives of this work were two-fold: the first one was to review the available drift test methods usually used on cooling towers, and the second one was to carry out drift measurements on a dry and adiabatic fluid cooler and on a cooling tower of similar capacity working in real facilities. No drift was registered on the dry and adiabatic fluid cooler by using the sensitive paper drift test method, while a drift of 0.0023% was measured in the cooling tower.

Keywords: drift; cooling tower; legionella; sensitive paper

1. Introduction

Cooling towers are equipment devices commonly used to dissipate heat from water-cooled refrigeration, air conditioning and industrial processes. The principle of operation of cooling towers requires distributing or spraying water over a heat transfer surface across or through which a stream of air is passing. As a result, water droplets are incorporated in the air stream and, depending on the velocity of the air, will be carried out of the unit. This is known as drift and it is independent of water lost by evaporation.

It is common practice to fit drift eliminators to cooling towers in order to minimise the water loss from the system. All drift eliminators work by changing the direction of the airflow as it passes through the eliminator section so that most of the entrained droplets are separated from the air stream and fall back into the unit.

Cooling tower drift is objectionable for several reasons [1]. Mainly, it represents an emission of chemicals or microorganisms to the atmosphere. In addition, corrosion problems can result on equipment, piping and structural steel, and can be the source of electrical systems' failure.

In the case of cooling towers, undoubtedly the most well known pathogens are the multiple species of bacteria collectively known as legionella. These bacteria tend to thrive at the range of water temperatures frequently found in these cooling systems. Hence, workers or other persons near a cooling tower may be exposed to drift, may inhale aerosols containing the legionella bacteria, and may become infected with the illness. Several legionella outbreaks have been linked to cooling towers [2-4].

In Spain, some local Governments tend to restrict the installation of cooling towers after several severe outbreaks of legionella [5-6]. For example, local government of Murcia city has forbidden the installation of cooling tower in the metropolitan area [7]. Regional government of Valencia has published public financial aids [8] to replace cooling tower with a more safety alternative, standard dry coolers. Following this tendency, some companies, owners of commercial buildings with large air conditioning systems (thousands of kilowatts), have replaced cooling towers by dry coolers. This situation deals on human health but also on energy efficiency and sustainability.

Like cooling towers, the objective of the dry and adiabatic fluid coolers is to cool water but with a different operation principle. The dry and adiabatic fluid cooler works as a standard fluid dry cooler enhancing the dry cooler's capacity with adiabatic pre-cooling of the air intake. The ambient dry bulb temperature is reduced as the air passes through an evaporative pad especially designed to humidify and cool the air (Fig.1). Part of the water is evaporated, while the excess water leaves the adiabatic section via a gutter system to the sewer.

The COP of the cooling plants the dry and adiabatic fluid coolers serve is expected to be higher than that achieved with standard dry coolers (and lower than that reached with cooling towers). The energy efficiency gained regarding dry coolers (or energy efficiency sacrificed regarding cooling towers) is welcome so long as no drift, and therefore no legionella, comes out from these equipments. Information derived from manufactures' catalogues rather than from physical operation principles.

Several types of instruments have been described in open literature to measure cooling tower drift [9, 10]. A very detailed comparison of methods can be found in the work of Golay et al. [11]. The results indicated that the instruments tested vary widely in their capabilities and no single device is superior to the alternatives over the entire range of cases tested.

The standards of some countries specify the method to measure the drift loss from cooling towers. In the case of Spain, the standard establishes a maximum percentage of 0.05% of the circulating water mass flow rate as limit for the drift without referring to the method of measurement [12].

The method adopted by the British Standard BS 4485.2 [13] and by the Japanese Industrial Standard JIS B 8609 [14] is the Thermal Balance method. The amount of drift loss is estimated by taking the difference between the quantity of make-up water flow and the sum of the purge flow and evaporation loss. To calculate evaporation loss is necessary to include the water and ambient air conditions measured in a mass and energy balance.

The method described in the Australian Standard AS 4180.1 [15] is the Chloride Balance Method. This method, in essence, consists of the measurement of the rate of decrease in the concentration of a tracer chemical added to the circulating water. An initial dose of the tracer is added to the cooling water. When this material is uniformly mixed with the circulating water, a sample is removed and analyzed. After a period, a second sample is removed and analyzed. Using the equations that take into account evaporation, drift loss may be calculated.

The American Cooling Technology Institute uses the Isokinetic Drift Test Code ATC-140 [16]: The Heated Glass Bead Isokinetic system involves a sampler which draws in effluent air at the same velocity as is flowing at each individual sampling location. The circulating water must contain, either naturally, or by artificial salting, a usable tracer element at levels adequate to assure the ability to measure the concentration of the sample solutions. This concentration is related to the sampling duration and to the concentration in the circulating water to determine the mass flow rate. HGBIK consists of the sampler (tube and canister combined), umbilical cord (vacuum line, power cord and thermocouples leads), condensate trap and control panel. A vacuum pump is used as the air moving device. The drift sampler consists of a heated high density bead-pack and a large area five-layer felt dry air filter, the downstream layer of which is used as a removable check filter. The tower discharge air, containing drift droplets and evaporated moisture from the heat transfer process is drawn into the sampler at isokinetic velocity. As the mixture passes through the hot bead pack, the moisture in the air is vaporized and much of the salts contained in the drift droplets are plated out on the beads. The five-layer filter pack traps the particles which were too small to be caught or plated out in the bead pack. The circulating water is analyzed and the concentrations of the tracer element determined. Using the ratio of the micrograms trapped to the concentration of tracer in the circulating water, the volume of drift water sampled can be calculated.

The American Cooling Technology Institute in the Isokinetic Drift Test Code ATC-140 [16] also refers the Sensitized Surface Methods. Wilber and Vercauteren [17] describe their methodology. The air stream is forced around collection planes covered with sensitive paper, upon which droplets impact and are recorded. Water droplets impinging on this sensitive paper cause a chemical reaction in which a precipitate is formed, leaving a droplet size-dependent stain. The processing of these exposed sensitive papers consisted of measuring the stain diameters by means of a digital imaging processing procedure that groups the counts of all stains by size ranges. Once the stain sizes are counted and grouped according to size, calibration curves for specific droplet sizes are employed via computer programs to generate the original droplet sizes from which the stains were formed.

The objectives of this work were two-fold: the first one was to review the available drift measurement methods usually used on cooling towers, and the second one was to carry out drift tests on a dry and adiabatic fluid cooler and on a cooling tower working in real air conditioning systems.

2. Method

2.1 Experimental procedure

Drift measurement methods described vary widely in their operating principle and capabilities. Some comparison of methods can be found in the open literature. Missimer et al. [18] studied the relationship between Sensitive Paper and HGBIK drift measurements. They concluded that the drift rate computed for the SP test method was approximately 12% higher than the average drift rate produced by the HGBIK method. However, they pointed out the need for a second look. Whittermore et al. [19] compared two isokinetic methods HGBIK and EPA 13A, which differ only in the collection train. They found nearly identical results in the series of tests. The most detailed comparison of methods can be found in the work of Golay et al. [11]. The results indicated that no single device is superior to the alternatives over the entire range of cases tested. Devices performing best under low water loading conditions utilize sensitive surface techniques. Devices performing best under high water loading conditions include the isokinetic mass sampling and chemical balance techniques.

Following the conclusions of Golay et al. [11], the sensitive paper technique was selected as the most suitable drift measurement method due to low drift being expected to be emitted by the dry and adiabatic fluid cooler. Besides a quantitative drift value, this technique provides qualitative information of drift droplet size distribution. Useful information in the case of building dispersion and deposition drift models, Meroney [20].

Drift measurements were performed on a 666 kW dry and adiabatic fluid cooler (see Table 1) that serves the rejection heat needs of a commercial building air conditioning system in Torrevieja (Spain). Sensitive papers of 52 x 76 mm were exposed on the outlet sections of the twelve fans that circulate de airflow through the cooler. These sections were tested in randomised order using eight sensitive papers disposed as shown in Figure 2. The exposition time was of 900 seconds.

Drift measurements were also carried out in a cooling tower of similar cooling capacity (see Table 1) using the sensitive paper technique. 15 sensitive papers of 52 x 76 mm were exposed in the outlet sections of the cooling tower's as shown in Figure 3. The exposition time was of 30 seconds.

Drift results were obtained under ambient and operating stationary conditions. Standard UNE 13741 "Thermal performance acceptance testing of mechanical draught series wet cooling towers" was selected as stationary conditions reference.

Pt-100 temperature sensors registered the inlet and outlet temperatures of the equipments' primary water flow. Two ultrasonic flowmeters (Micronics, Portaflow 216) were used to measure the equipments' primary water flow and, in the case of the dry and adiabatic fluid cooler, the evaporative pad water flow. Meteorological conditions (dry bulb temperature and relative humidity) were also registered.

2.2 Drift Measurement method

As stated above, the sensitive paper technique relies on droplet collection by inertial impaction on water-sensitive paper. The paper is chemically treated so that a droplet impinging on it will generate a well-defined dark blue stain on the pale yellow background of the paper. The relationship between the stain and the droplet size was obtained by calibrating the sensitive paper with a monodisperse water droplet generator over a range of droplet sizes.

The processing of the exposed sensitive papers consisted of measuring the stain diameters by means of a digital imaging processing procedure. Sensitive paper was scanned to a resolution of 4800 ppp. The digital imaging software Image Pro Plus was used to implement the stain detection procedure. A Sobel filter [21] was used to emphasized edges, and Canny edge detector [22] to identify the stains. The software grouped the counts of all stains by size ranges.

Once the stain sizes were counted and grouped according to size, calibration curves for specific droplet sizes were employed via computer programs to generate the original droplet sizes from which the stains were formed. In addition, a correction factor [23] was applied to compensate for the collection efficiency of each droplet size range. The sensitive paper measures the droplet number flux directly, that is the number of droplets that cross a unit area per unit time. Drift per unit of area was obtained by:

$$g_p = \frac{\pi}{6}\frac{\rho}{A_p t}\sum_{i=1}^{N} d_i^3 \qquad (1)$$

Outlet section integrated drift value was calculated by:

$$G_s = A_s \sum_{i=1}^{N} g_{p,i} \qquad (2)$$

Finally, drift was calculated as a relation between the water mass flow that escapes as drift and the circulating water mass flow rate in the cooler:

$$G(\%) = \frac{G_s}{m} \cdot 100 \qquad (3)$$

3. Results

Figure 4 shows one of the sensitive papers exposed on the dry and adiabatic fluid cooler during 900 seconds. Like this one, none of the 96 papers exposed registered droplet stains on their surfaces.

This result was expected because of the physical configuration of the equipment. Adiabatic pad water distribution system is based on the slide of water over the fill, whereas in cooling tower the water is sprayed. Besides, as can be seen in Figure 1, the dry coil acts as drift eliminator due to the change in the direction of the flow and the possibility of inertial impaction of the entrained droplets over the tubes.

Fig. 5 shows one of the sensitive papers exposed on the cooling tower during 30 seconds. After being processed by means of the above-mentioned digital imaging procedure, a drift value of 0.0023% was obtained.

This percentage, related to the circulating water mass flow rate through the cooling tower is lower than the maximum of 0.05% imposed by the Spanish normative.However although lower than the limit imposed by the normative, the drift exists and associated to the drift the risk of a legionella outbreak. Local Governments and the owners of commercial buildings rely better on equipments with zero drift and therefore zero legionella risk.

The cooling capacity of the tested equipments is nearly the same. This cooling capacity is given by the primary water mass flow rate and the difference between its inlet and outlet temperature. However, the outlet water temperature from the dry and adiabatic fluid cooler is higher than the outlet water temperature from the cooling tower. This difference can not be explained only in terms of the meteorological conditions registered during the test (as they are similar), but they are produced by the physical operating principles of the tested equipments.

This means that the COP of the chiller the dry and adiabatic fluid cooler serves will be lower than the COP of the chiller served by the cooling tower. Moreover, it would be even lower if the chiller would be served by a standard dry cooler, whose outlet water temperature could be calculated by adding approximately 15 ºC to the registered dry bulb air temperature.

4. Conclusions

The objectives of this work were to review the available drift measurement methods usually used on cooling towers, and to carry out drift tests on two equipments with the same goal but with different operating principle: a dry and adiabatic fluid cooler and a cooling tower.

The sensitive paper technique was selected as the most suitable drift measurement method. This choice was encouraged because this method is recommended by the American Cooling Technology Institute and, according to Golay et al. [8], because of the low drift being expected to be emitted by the dry and adiabatic fluid cooler. Besides a quantitative drift value, this technique provides qualitative information of drift droplet size distribution.

The sensitive papers exposed on the dry and adiabatic fluid cooler during 900 seconds registered no drift. The papers exposed on the cooling tower, after being digitalized and analysed by means of the above described digital imaging process, provided a drift value of 0.0023%.

Nowadays, energy sacrifices are welcome in order to avoid legionella risk. According to the drift and energy measurements of this study, the dry and adiabatic fluid cooler allow us to achieve a higher energy efficiency than the one obtained with standard dry coolers keeping a zero legionella risk.

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Nomenclature

A	*area* (m^2)
d	*droplet diameter*
g	*drift* ($kg \cdot s^{-1} \cdot m^{-2}$)
G	*drift* ($kg \cdot s^{-1}$)
m	*circulating water mass flow rate* ($kg \cdot s^{-1}$)
t	*paper exposition time* (s)

Greek

ρ	water density (kg/m^3)

Subscripts

p	paper
s	section (area related to each exposed paper)

Table 1

Nominal operating conditions of tested dry and adiabatic fluid cooler and cooling tower

	Dry and adiabatic fluid cooler	Cooling tower
Cooling capacity (kW)	666	620
Cooling water temperature inlet-outlet (ºC)	40-35	36.4-29
Circulating water mass flow rate ($kg \cdot s^{-1}$)	31.86	20.04
Nominal dry/wet bulb ambient temperature (ºC)	25	30/27
Electrical energy consumption (kW)	6.3	5.5

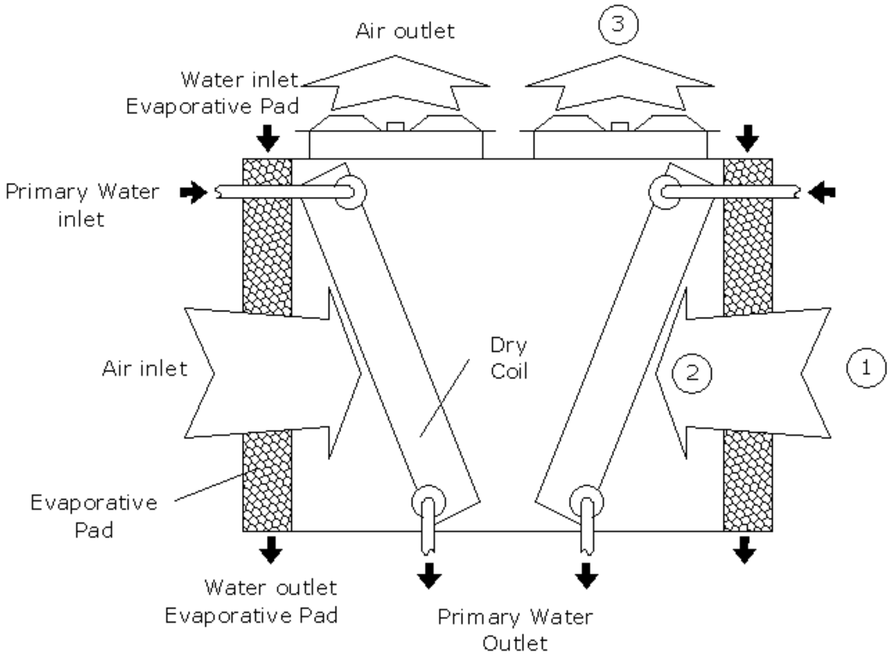
Figure 1. Schematic diagram of the dry and adiabatic fluid cooler

Figure 2. Sensitive paper distribution on the dry and adiabatic fluid cooler

Figure 3. Sensitive paper distribution on the cooling tower

Figure 4. Sensitive paper exposed on the dry and adiabatic fluid cooler

Figure 5. Sensitive paper exposed on the cooling tower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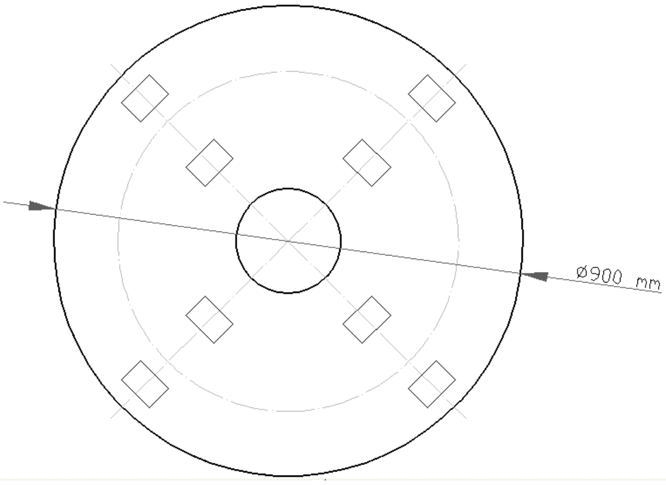
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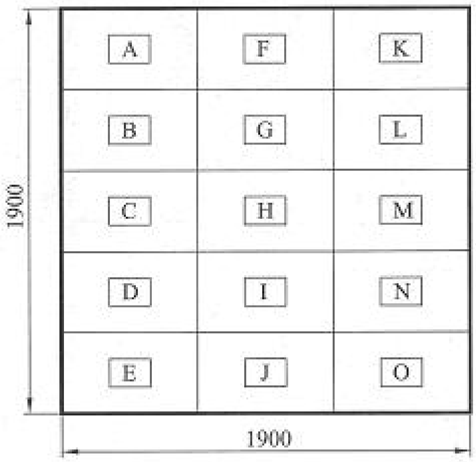

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