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Experimental determination of drift and PM_{10} cooling tower emissions: Influence of components and operating conditions☆

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A B S T R A C T

Cooling tower emissions have become an increasingly common hazard to the environment (air polluting, ice formation and salts deposition) and to the health (Legionella disease) in the last decades. Several environmental policies have emerged in recent years limiting cooling tower emissions but they have not prevented an increasing intensity of outbreaks.

Since the level of emissions depends mainly on cooling tower component design and the operating conditions, this paper deals with an experimental investigation of the amount of emissions, drift and PM_{10}, emitted by a cooling tower with different configurations (drift eliminators and distribution systems) and working under several operating conditions. This objective is met by the measurement of cooling tower source emission parameters by means of the sensitive paper technique. Secondary objectives were to contextualize the observed emission rates according to international regulations.

Our measurements showed that the drift rates included in the relevant international standards are significantly higher than the obtained results (an average of 100 times higher) and hence, the environmental problems may occur. Therefore, a revision of the standards is recommended with the aim of reducing the environmental and human health impact. By changing the operating conditions and the distribution system, emissions can be reduced by 52.03% and 82% on average. In the case of drift eliminators, the difference ranges from 18.18% to 98.43% on average. As the emissions level is clearly influenced by operating conditions and components, regulation tests should be referred to default conditions. Finally, guidelines to perform emission tests and a selection criterion of components and conditions for the tested cooling tower are proposed.

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1. Introduction

Cooling towers are evaporative heat transfer devices. They have traditionally been used in applications where heat rejection is needed such as power cycles, refrigeration and heat pump cycles or industrial processes. This type of evaporative water-cooled device is energy-efficient compared to air-cooled heat exchangers because it offers lower energy consumption. Wet cooling towers work by dissipating waste heat to the atmosphere mainly through water evaporation. Because of their operation principle, they may emit water droplets into the atmosphere. This is usually referred as drift.

Drift emissions from cooling towers are harmful to the environment for many reasons. Hanna and Pell (1976) and Talbot (1979) reported some ecological effects of cooling tower emissions. Among them, the authors listed corrosion, downwind deposition salts and ice formation during winter. Concerning human health, drift emissions contain the same chemicals and micro-organisms contained in the cooling tower. Hence, water droplets taken away from the tower by the air stream may become carriers of hazardous pathogens such as *Legionella pneumophila*, Mouchtouri et al. (2010). The chain of transmission of Legionella from water sources indicates that this bacterium may be dispersed from cooling towers if contaminated aerosols are discharged. Hence, if Legionella is present in the tower basin (due to inappropriate maintenance) the bacterium will be spread as cooling towers discharge aerosols in their exhaust air stream. Inhaled airborne particles can cause the well-known Legionnaires disease.

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Cooling tower emissions are not limited to drift. When the water from the drops evaporates, the chemicals present in the water remain in the air and may deposit on the ground. This source of pollution is termed as Particulate Matter (PM) and may be classified as an emission according to the EPA (1995) AP-42 report. McCune (1991) referred to this type of emissions as an anthropogenic air pollutant because of the ecological effect of salt particles on vegetation.

Ashrae (2000) states that the risk of bioaerosols inhalation strongly depends on the size of the drops. In spite of this, drift measurement methods must be capable of providing both, the amount of drift and the drop size distribution data at the cooling tower exit surface. Several methods to measure drift have been reported in the literature. Lucas et al. (2012) provided a complete description of several techniques. Some of these methods have been adopted by developed countries as the reference method to measure drift in cooling towers (see Table 1). In some cases, the amount of water drift escaping the tower is also limited as a strategy to prevent and control Legionella outbreaks. In Australia, Australian Standard AS/NZS 3666 (AS/NZS, 2011), limits cooling tower drift to 0.02% of the circulating water. In Spain, cooling tower emissions are limited to 0.05% of the circulating water by Royal Decree RD 865/2003 (BOE, 2003). The Spanish Standard does not refer to any particular measuring method.

Several studies can be found in the reviewed bibliography regarding drift measuring techniques comparison. Roffman and Van Vleck (1974) and Chen and Hanna (1978) carried out a state of the art review and compared measuring techniques for drift emissions. Golay et al. (1986) described numerous techniques and devices and compared them. They concluded that no single device was superior to the alternatives over the entire range of cases tested and recommended sensitive surface techniques for low emission levels and isokinetic mass sampling and chemical balance techniques for high emission levels. This work constitutes the most detailed method comparison concerning drift measuring methods. Missimer et al. (1998) compared the Sensitive Paper (SP) and HGBIK drift methods. They reported differences of approximately 12% between methods being the drift rate calculated by the SP method higher than the rate predicted by the HGBIK method. Following the conclusions of Golay et al. (1986) the sensitive paper technique has been adopted for this study (low water loadings). The method is also capable of providing drop size distribution data. Additionally, it has been referred as one of the most suitable methods for conducting on-site field measurements by Cizek and Novakova (2011) due to its portability and reasonable price.

Concerning the solid emissions calculation procedure, the studies of EPA (1995) and Reisman and Frisbie (2002) were found to be the most relevant related to cooling towers. AP-42 (EPA, 1995) method calculates the emissions of particulate matter considering that all chemicals (mainly salts) present in drift are PM_{10}. This assumption means that all solid particles diameters are below 10 μm, which may be not realistic. Reisman and Frisbie (2002) considered that the AP-42 (EPA, 1995) procedure unrealistically modelled the PM_{10} calculation and proposed a more realistic method taking into account the droplet size distribution data of the water escaping from the tower. This method was taken as a reference for the present work.

In cooling towers, the generation of the drift mainly depends upon the water distribution system, which spreads warm water over the fill located underneath. Water is sprayed (or just distributed, see Mohiuddin and Kant (1996)) across or through the airstream and, as a result, water droplets are incorporated into the air. To minimize the amount of potentially hazardous material escaping with the exhaust air, drift eliminators are installed at the cooling tower exit surface. This element removes water droplets from air stream by changing the direction of the airflow. Consequently, water droplets are collected by inertial impact.

In the reviewed literature, several studies focusing on determining cooling tower emissions can be found. However, just a few papers study the influence of components on cooling tower emissions, and they mainly investigate the eliminators' influence. Chan and Golay (1977) studied the drift emissions of three typologies of drift eliminator using laser techniques. They justified the election of the method according to its capability of providing drop size information and detecting very small diameters. Verlaan (1991) carried out experiments for different drift eliminators using diverse methods for spraying the warm water beneath the eliminators. The amount of water trapped by each eliminator was calculated by means of mass balances (for which the presence of drainage channels on the separator itself were required) while the size distribution was calculated using diffraction techniques. Mohiuddin (2005) experimentally calculated the drift losses, pressure drop and flow pattern of three commercial drift eliminators as a function of the number of the stages of the eliminator and discharge angle. They concluded that the percentage drift emissions increased as the discharge angle approached 90° and decreased when the number of stages increased. Nonetheless, the literature shows a lack of information regarding the effect of the water distribution system on cooling tower emissions.

So far, the reviewed bibliography has highlighted that for minimizing the cooling tower environmental and human health impact (emissions), the design of its components is crucial. In this sense, the main objective of this work is to experimentally investigate the influence of the cooling tower components, water distribution system and drift eliminator, on cooling tower emissions, drift and PM_{10}, of a forced draft counterflow wet cooling tower with the aim of reducing the environmental and human health impact. Secondary objectives were to contextualize the observed emission rates according to the relevant international standards. As the emission levels are clearly influenced by operating conditions and components, general guidelines for testing cooling tower emissions are proposed. Ultimately, and taking advantage of the information available in the literature regarding the influence of cooling tower components on the thermal efficiency of the device, selection criteria for use in components and operating conditions selection have been proposed.

Table 1
International standards regarding drift measurements.

Country	Reference method	Standard
Australia	Chloride Balance Method	AS 4180.1
United Kingdom	Thermal Balance Method	BS 4485.2
U.S.	Isokinetic method HGBIK Sensitized Surface Methods	CTI ATC-140
Japan	Thermal Balance Method	JIS B 8609
Germany	Sensitized Surface Methods	VDI 3679
Spain	Any	RD 865/2003

2. Material and methods

2.1. Experimental setup

Drift tests were performed in the experimental facility located on the roof of Torrepinet building, Miguel Hernández University in Spain. The facility consists of a 30 kW forced draft cooling counter flow tower. The tower cross-sectional area is rectangular shaped (0.7 × 0.48 m) and the fill consists of a honeycomb structure (height 1.13 m).

The distribution systems and drift eliminators used in the

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