WATER SAVING PERFORMANCE AND MACRO FLUID ANALYSIS OF A NEW CYCLONIC WATER COLLECTOR

by

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Power and chemical plants entail serious water loss during their operation. In order to save water by alleviating the loss of the circulating water in the cooling tower, a FLUENT simulation is performed to design and analyze a cyclonic water collector. The geometrical structure of the collector was such designed that the trajectory of the steam is optimized. The turbulence caused by the collector increases the possibility for collisions between water molecules, and the accumulation of tiny drops could be recycled. The results of the numerical simulation and the experiment verification demonstrate the ability of the proposed device to save much water. Furthermore, the mechanisms for water recycling and water saving are elucidated clearly through the gas-liquid coupling of the circulating water and cooling water. The present theory gives deep insights into the optimization of water-saving facilities and improvement of water-saving efficiency.

Key words: *cooling tower, water collector, fluent simulation, turbulence*

Introduction

Natural draft wet cooling towers are one of the most widely-used types of wet cooling towers in large-scale power plants [1]. As a major device for water saving and environmental protection, a water collector is usually installed above the water shower. The water drops, carried by the rising stream, are blocked after they touch the collector and then recycled. The air, along with the tiny drops which are not captured by the collector, continues to rise and is thus expelled into the outside environment [2]. Currently, most cooling towers adopt the ripple collector for water collection. After the steam in the tower enters the curved channel that carries the drops, the steam can continue to rise, but any drops larger than a certain diameter are unable to change their direction due to their inertia. These drops will therefore touch the wall of the collector and then be recycled. The principle of the ripple collector is illustrated in fig. 1, in which the small drops usually disappear with the steam and cannot be recycled.

In this paper, we use a rotational flow to design a novel water collector with a guide-vane cyclone structure for cooling towers, which can significantly improve water savings more effectively by recycling the tiny drops of water.

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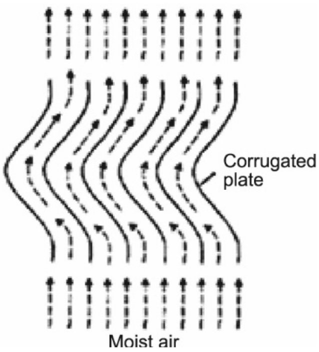

Figure 1. Water reclamation device with corrugated plates

Theory development

Drops of liquid moving upward with the steam are subject to gravity and the resistance of the steam. There are two possibilities in this scenario:

– If the force of gravity acting on the drop is less than the resistance of the steam, it will be carried upwards by the steam and expelled into the air.

– If the force of gravity acting on the drop is larger than the resistance of the steam, the drop will fall and be recycled.

The decisive factors during this process include the drop's diameter, d, and the steam's speed, v. The drop's gravity, G, can be approximately calculated:

$$G = \frac{\pi \rho_1 g d^3}{6} \tag{1}$$

where ρ_1 [kgm^{-3}] is the drop's density, and g – the local gravity acceleration (= 9.81 m/s^2 for our analysis). The resistance of the steam, F, is:

$$F = \frac{\pi d^2 \rho_g v^2 \xi}{8} + \frac{\pi \rho_g \xi d^3}{6} \tag{2}$$

where ρ_g [kgm^{-3}] is the steam's density within the tower, and ξ – the resistance coefficient which is usually set as 0.1. Equations (1) and (2) can be simplified into:

$$v = \sqrt{\frac{4g(\rho_1 - \rho_g)d}{3\rho_g \xi}} \tag{3}$$

$$d = \frac{3\xi \rho_g v^2}{4g(\rho_1 - \rho_g)} \tag{4}$$

After coming into contact with the steam, the drop will fall provided that the speed of the steam, v, is less than the calculated value of eq. (3) for a given diameter, d. Otherwise the drop will continue to move upward with the steam. Similarly, the drop will fall if the diameter of the drop is larger than the calculated value of eq. (4) for a given value of the speed of the steam, otherwise it will continue to move upward. After the drops, which are moving upward with the steam, arrive at the collector, the steam will be separated from the water to recycle some of the tiny drops of water.

The cooling tower is mainly responsible for cooling and recycling the hot water from the plant. After being processed by the distribution system, the hot water is sprayed onto the filler to reduce its temperature. Therefore the smaller the diameter of the drop that is sprayed, the more effective the tower is in cooling the water.

However, as can be seen from the water collection principles previously mentioned, the small drops are susceptible to being lost along with the steam. After the moist air enters the water collector, the large drops collide with the plate, and water drops will adhere to the plate and then move along the plate, where water drops can be recycled. It should be noted that the collision with the plate causes some large drops to break into smaller ones, which can then be carried away by the steam. In other words, tiny drops are likely to be expelled into the air, resulting in water losses. Therefore, a considerable water saving can be achieved by aggregating these tiny drops into large ones which can then be recycled.

Combining many tiny drops into large ones is impossible without both collision and aggregation. Whether the drops collide with one another in the moist air mainly depends on the inter-drop distance. The shorter the distance between the water drops, the higher the possibility there is for collision. Taking these considerations into account, a novel physical structure for the water collector is proposed in this paper. The distance between the steam molecules and the fluidity of the steam can be adjusted to influence the aggregation process of the tiny-drops, thus leading to an improvement in the water collection. Due to the tiny drops having a higher possibility of collision and aggregation under turbulent conditions, the proposed water collector is required to change the steam into a cyclonic formation by the vortex method so that the steam moves upward in a spiral way. In this way, aggregation of the tiny drops is facilitated to improve the water collection [3].

A novel cyclonic water collector is designed based on the relevant principles and rules discussed in [4]. As shown in fig. 2, the collector has a diameter of 400 mm and a height of 200 mm, with four oblique guide vanes, each of which is 150 mm wide. Due to the large cost of experimental platforms, CFD simulation and the numerical method have become effective tools to predicting the needed results for industrial and laboratory applications [5]. In this research, FLUENT is used to simulate the track and the speed of drops inside the corrugated plate and the collector, as shown in fig. 2.

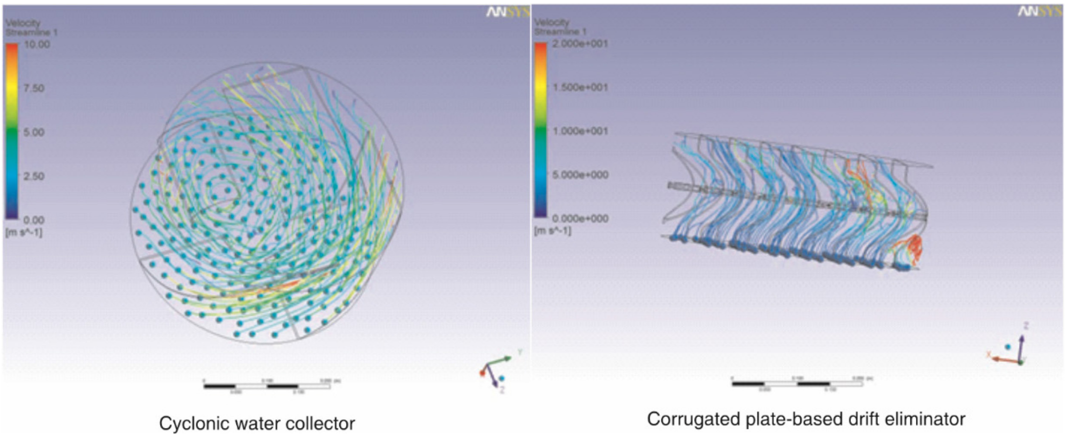

Figure 2. Trajectory of the droplet particles in the corrugated collector and cyclonic collector
(*for color image see journal web site*)

After passing through the corrugated plate-based drift eliminator, the saturated moist air moves in a straight line. After passing through the cyclonic water collector, the guide vanes funnel the steam into a rotating turbulent flow. The steam vortex does not instantly cease after it exits the drift eliminator. The four whirling guide vanes change the state of the moist air from the water collector from laminar flow to turbulent flow. The laminar flow was also used to control the motion of macromolecules in a moving jet in the macromolecular electrospinning process [6-8], while a turbulent flow is more effective to control small drops of water due to collision. When a steam reaches a certain height, it travels much longer for a rotating case than that for a straight line. The turbulent state of the moist air also increases the possibility of collisions between the steam molecules and therefore provides a favorable environment for tiny drops to combine into large ones which can then be collected.

Experiment verification

The experiments were performed under the same conditions [9]. The conditions included the external environment (indoor temperature, outdoor temperature, air humidity and atmospheric pressure), spray density in the cooling tower, blower speed and hot water temperature. The wind speed was set to 2 m/s in the experiment. A performance comparison was made between the proposed cyclonic water collector and the corrugated water collector.

Results and discussion

The efficiency of water conservation of the two water collectors for droplets of various diameters is presented in fig. 3.

It can be observed from the figure that the difference in the water saving rate between the two collectors was small when the droplet diameter exceeded 50 μm. When the droplet diameter was smaller than 50 μm, the collection rate of the proposed collector was much higher than that of the corrugated device. These results indicate that droplets larger than 50 μm were able to be recycled in both devices. The small droplets had a small momentum when the wind speed was slow and moved together with the steam. Therefore, they were prone to being expelled from the corrugated device with the flow of the steam. The flow field of the moist air in the corrugated device was very uniform and the water molecules inside had a low possibility of colliding with each other. Due to these reasons, the droplets collected by the corrugated device were usually larger than 50 μm in diameter. In contrast, the moist air in the cyclonic device was turbulent and the possibility of water molecule collision was very high. As a result, the droplets were more likely to be combined into large ones and then recycled. The water collection rate peaked at a droplet diameter of 20 μm.

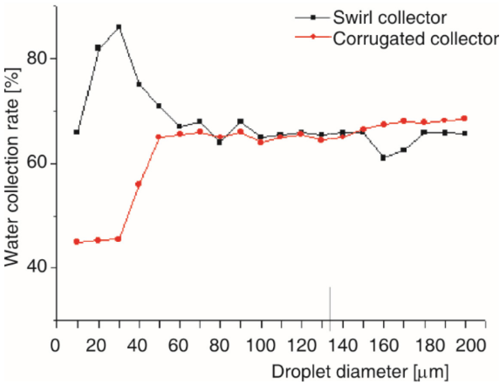

Figure 3. Comparison of the water collection rate for the cyclonic water separator and the corrugated plate water separator for a wind speed of 2 m/s

Physical experiments were performed on the two devices for the same external environment. Based on the results of the numerical simulation and the physical experiment, the following figure presented the variation of the water collection rate of the two devices.

The droplet diameters could be divided into five ranges. The droplets in the range 0-5 μm were mostly lost to the atmosphere with the steam and few were recycled by the cyclonic water collector, as they could not be combined effectively into large ones. For the droplets in the range 5-20 μm, the droplets could be combined into large ones that could be recycled more quickly and effectively. For the droplets in the range 20-50 μm, the cyclonic water collector was able to collect the droplets that were larger than 50 μm. For the droplets in the range 50-*d* μm, the two devices had the same collection rate, because the droplets were collected after they had come into contact with the walls of the devices. For the droplets larger than d μm, they were recycled due to the effect of gravity acting on them. From eq. (4), it can be seen that the value of *d* was dependent on the density of the steam inside the tower ρ_g, the resistance coefficient, ξ, the droplet density and speed. Therefore, the inflection points in the figure can change to a varying degree with the wind speed and other parameters, but the variation in the curves was still consistent with the results in fig. 4.

The physical tests have indicated that for a given wind speed of 2 m/s, the water collection rate of the proposed cyclonic device was 14% higher than that of the corrugated device. The performance gain has been mainly attributed to the small droplets of less than 50 μm combining with each other. The results have demonstrated the feasibility of the proposed water collection device based on the cyclonic theory.

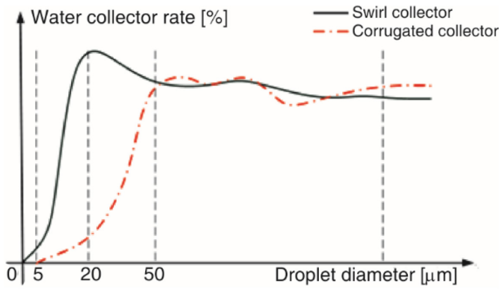

Figure 4. Relationship between the droplet diameter and water collection rate

Conclusion

This paper has proposed a novel cyclonic water collector, where the guide vanes change the path of the ascending steam. The probability of droplet collision in the proposed collector increases so that the small droplets could be combined into larger ones which could be more easily recycled. The simulation and physical experiments indicate that the water collection rate of the proposed cyclonic device is much higher than that of the corrugated device, especially for droplets in the range 5-50 μm. The work carried out in this paper has given a deep insight into the design of a more efficient water collector.

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