FIELD TEST OF THE SIZE AND VELOCITY DISTRIBUTION OF THE RAINDROPS IN THE RAIN ZONE OF THE COOLING TOWER

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ABSTRACT

The rain zone is one of the most important areas in the wet cooling tower. It contains about 20% of the overall heat and mass transfer of the whole wet cooling tower. The air drag in the rain zone accounts for more than 50% of that in the entire wet cooling tower. However, the study of the rain zone is always a difficulty in the cooling tower research. This is because there exist numerous raindrops in the rain zone, the size distribution and the motion mechanism of the raindrops are very complicated. Therefore to carry on the study of the rain zone, this paper conducts the field test of the raindrops measurement in the wet cooling tower for the first time. The velocity distribution and the size distribution of the droplets in the rain zone are explored and analyzed. The scattering techniques of the drop sizing measurement are used firstly in the cooling tower research. The optical disdrometer which is often used in the meteorology is employed. A stretchable jib arm with full length of 20m is designed by the author to equip the optical disdrometer. The velocity and the diameter of the raindrops are firstly investigated in different positions in the rain zone. The characteristic of the droplets size distribution is revealed, that is the raindrops have almost the same diameter distribution in different positions in the rain zone. At last, the mechanism of droplets motion and its impact on the size and velocity distribution are analyzed and discussed.

INTRODUCTION

The natural draft wet cooling tower (NDWCT) is a kind of stable and efficient cooling equipment which is widely used in the power plants. The NDWCT plays a very important role in the cooling system of power plant, and its cooling capacity can affect the total power generation capacity. The rain zone is one of the most important areas in the NDWCT. According to Kröger [1], 10 to 20% of the overall heat and mass transfer of large wet cooling towers take place in the rain zone. Moreover, the air pressure drop in the rain zone accounts for more than 50% of that in the whole NDWCT [2]. R·F·Rish [3] conducted an experiment in 1961 and then gave out the drag coefficient of the rain zone. But the coefficient is perpendicular merely and cannot represent the real drag coefficient of the rain zone. Е·А·Сухов [2] from Russia gave out the horizontal drag coefficient of the rain zone in 1984. However, in his experiment the rain zone was represented by several tiny sticks, so the results were not accurate. Zhao [4] and Wang [5] carried out the air pressure drop experiments of the rain zone in a cross-flow simulating equipment and then got the equivalent raindrop diameter of the rain zone. Scholars from South Africa investigated the size distribution based on the imaging techniques [6-9] in laboratory and developed the devices which could enhance the cooling tower performance by decreasing the average drop size in the rain zone. However, these previous works mainly focused on the laboratory experiment, field test of the rain zone are never found in any literatures. Actually, there exist countless raindrops in the rain zone. The size and velocity distribution and the motion mechanism of the raindrops are all significant for the rain zone study. However, the rain zone is huge in scale, and the complex motion of the droplets makes their size and velocity distribution rather complicated. In consequence, all these characteristics of the droplets cannot be reproduced in the laboratory experiment as it in the rain zone. Therefore field test of the rain zone is very necessary for the rain zone research. To carry on the rain zone study more accurately, this paper conducts the field test of the raindrop measurement in the rain zone for the first time. The velocity distribution and the size distribution of the droplets in the rain zone are explored and analyzed. The scattering techniques of the drop sizing measurement are used firstly in the cooling tower research. The Particle Size Velocity (Parsivel^2) disdrometer which is often used in the meteorology is employed. A stretchable jib arm with full length of 20m is designed by the author to equip the optical disdrometer. The velocity and the diameter of the raindrops are firstly investigated in different positions in the rain zone. The characteristic of the droplets size distribution is also revealed.

NOMENCLATURE

C	[-]	Non-dimensional drop size
D,d	[mm]	Diameter of the drops
G	[m/s^2]	Gravitational acceleration
S	[-]	Shape factor
V,v	[m/s]	Velocity

Special characters

ρ	[kg/m^3]	Density
σ	[N/m]	Surface tension
Δ	[-]	Differential

Subscripts

a	Air
av	Mixture of air and vapour
d	Drops
p	The primary drops

FIELD TEST OF RAINDROPS MEASUREMENT

Scattering Techniques and Disdrometer in Field Test

The size and velocity measurement for the particles is always a hotspot for scholars from many research fields. A large number of drop sizing instruments are described in literature. They can be divided into several groups, depending on the physical principle used.

Impact techniques are the basis of the first group of instruments. Early work with a filter method was dong by Diem [10]. A disadvantage of this method was the large effort needed to evaluate the measurements. Another instrument in this group is the well-known Joss-Waldvogel disdrometer [11]. It is widely used as a reference instrument for rain investigations.

The second group is based on imaging techniques. Scholars from South Africa [6-9] employed digital SLR camera in their rain zone study based on imaging techniques. Some other examples of these are the optical array probe [12], the three-dimensional holography [13], the pluviospectrometer [14] based on a video camera, and the particle spectrometer [15], to mention just a few.

The third group uses a large variety of scattering techniques. On the one hand, there are single particle counters, such as the forward scattering probe [16], phase-Droppler instruments [17], or extinction probes [18]. On the other hand, there are instruments that probe smaller or larger particle collectives by making use of Fraunhofer diffraction [19-20] or by measuring the backscatter of radar waves [21-22].

In this paper the Parsivel^2 based on scattering techniques which is often used in the meteorology is employed. The Parsivel^2 is a laser-optical disdrometer that measures the size and fall velocity of hydrometeors. It has many advantages such as easy-to-operate, robust and low-cost. More importantly, the measuring range of the Parsivel^2 in diameter and velocity is extensive. All these characteristics make the Parsivel^2 very suitable for the field test of the raindrop measurement. Some specifications of the optical disdrometer are shown in Tab.1

Tab.1 Some specifications of the Parsivel^2

Laser diode wavelength	780nm
Output power	0.5mW
Beam size	180×30mm
Measurement surface	54cm^2
Particle size range	0.2~25mm
Particle velocity range	0.2~20m/s

Size	670×600×114mm
Weight	max. 6.4kg

The functional principle of the Parsivel^2 is shown in Fig.1. The theory behind the Parsivel^2 is a laser sensor that produces a horizontal strip of light. The emitter and the receiver are integrated into a single protective housing. If there are no particles in the laser beam, the maximum voltage is output at the receiver. Particles passing through the laser beam block off a portion of the beam corresponding to their diameter, thus reducing the output voltage; this determines the particles sizes. To determine the particle speed, the duration of the signal is measured. A signal begins as soon as a particle enters the light strip and ends when it has completely left the light strip.

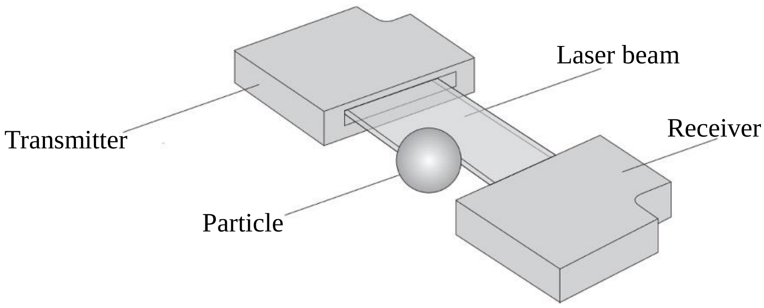

Fig.1 Functional principle of the Parsivel^2

The Jib Arm in the Field Test

The rain zone of the NDWCT is huge in scale, the test data in a fixed position cannot represent the entire rain zone. Therefore the multipoint measurement must be satisfied in the field test of the rain zone. The jib arm which is often used in the film and television production is a good choice for these requirements. The jib arm designed by the author for the field test of the raindrops measurement is shown in Fig.2. It is stretchable and installed on the four wheel dolly. It can be extended from 2m to 20m and can handle the Parsivel^2 at 10m height. The aviation aluminum-alloy is adopted to ensure enough strength and to lighten the whole construction. The mortise-tenon joints are used between two arms shown as Fig.3 to simplify the assembly process. The parallelogram mechanism is employed to ensure the perpendicularity of the Parsivel^2. The stretchable arm and the removable dolly can settle the Parsivel^2 in different positions in rain zone.

Fig. 2 The jib arm in the field test

Fig.3 The mortise-tenon joints between two arms

The Field Test Descriptions

The field test is conducted in a cooling tower which is under operation in Shandong Province in China. The fill of the tower is film fill with 1.25m thick. The total water drenching area is 9000m^2. The Parsivel^2 is stretched into the rain zone by the jib arm depicted in Fig.4. Five different positions (represented as Pos.A to Pos.E) in the rain zone are selected randomly. The measured raindrops are subdivided into diameter (D) and velocity (V) in a two-dimensional field, wherein there are 32 different D and V classes so that there are a total of 32×32=1024 classes. The classifications of D are shown in Tab.2.

Tab.2 The classification of diameter

Class	Diameter[mm]	Class	Diameter[mm]
1	0.062	17	3.250
2	0.187	18	3.750
3	0.312	19	4.250
4	0.437	20	4.750
5	0.562	21	5.500
6	0.687	22	6.500

7	0.812	23	7.500
8	0.937	24	8.500
9	1.062	25	9.500
10	1.187	26	11.000
11	1.375	27	13.000
12	1.625	28	15.000
13	1.875	29	17.000
14	2.125	30	19.000
15	2.375	31	21.500
16	2.750	32	24.500

The Parsivel^2 is connected to the computer through RS-485. The Parsivel^2 ASDO software is used to configure the Parsivel^2, read out data and display it. The software interface is shown in Fig.5. The data is recorded every 15s. The measuring time of each position is 120s. So there are eight sets of data in one position. The hydrophobic agent is smeared on the protective glass of the Parsivel^2 to keep it from being blurred by the raindrops and ensure the light pathway open during the experiment.

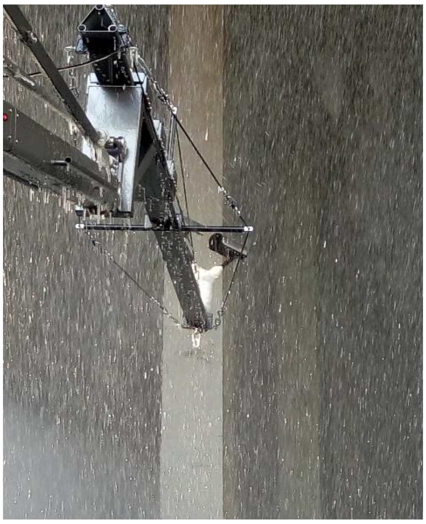

Fig. 4 Field test of the raindrops measurement

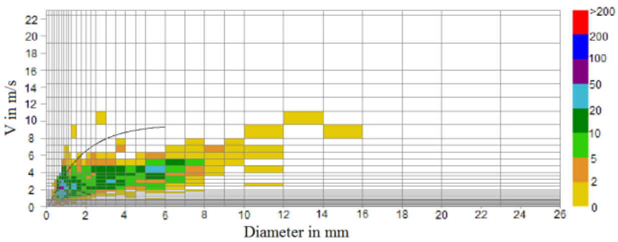

Fig. 5 The software interface of the ASDO

RESULTS AND DISCUSSION

There are forty sets of data in the field test in all positions, which are too much to be all presented in this paper. So two sets of data of each positon are selected randomly to be shown in the paper. The raindrops size distribution of all positions are shown in Fig.6. It can be seen from Fig.6 that for the same position at different times there always exists little difference in the raindrops size distribution. It can be also concluded from Fig.6 that the raindrops in different positions at different times share the similar size distribution. Actually, not only these ten sets of data shown in this paper, all forty sets of data in the field test share the similar size distribution as well.

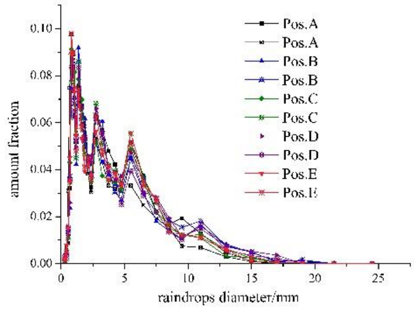

Fig.6 The raindrops size distribution

This might because the raindrops in the rain zone drip down from the fill due to gravity. The size distribution of the drops which form because of dripping is influenced by the geometry of the things where the drops drip [6]. Every primary drop that drips from a fixed point is followed by a number of smaller, satellite drops. Dreyer[23] established the correlation between the primary drop diameter d_p and the shape factor S for the specific geometry and can be expressed as,

$$d_p = C\sqrt{\frac{\sigma}{g\left(\rho_d - \rho_{av}\right)}} \tag{1}$$

$$C = 2.206 + \left(\frac{0.0597}{1.1 - S}\right) \tag{2}$$

where the σ is the surface tension, ρ_d is the drop density, ρ_{av} is the density of the mixture of air and vapour, the shape factor S is a constant value for the film fill. For every primary drop there are about five satellite of which the sizes vary linearly between $0.24d_p$ and $0.46d_p$. In this paper, the surface tension of the cooling tower, the drop density and the mixture density are almost the same at different positions of the rain zone. That is to say the sizes of the primary drops and the satellite drops dripped from the fill are almost the same at different positions in the rain zone. So the initial raindrop distributions at different positions in the rain zone are similar.

After the raindrops drip down from the fill their motions are very complicated. Deformation, breakup and collision of the raindrops are happened nearly at the same time. It is very difficult to analyze all these motions. The drop breakup is the typical characteristic in the process of falling. It directly affect the final size and dispersion distribution of the raindrops [24]. So this paper only analyzes the drop breakup, the other motions of the raindrops are neglected. According to literature [25], as the relative velocity Δv between drops and air increases, the bag, shear, and catastrophic breakup regimes are encountered respectively. The Weber number *We* is the scaling parameter for drop breakup mechanism, which can be given by,

$$We = \frac{\rho_a d_d \Delta v^2}{\sigma} \quad (3)$$

where ρ_a is the air density, d_d is the drop diameter. In this paper, the air density in the rain zone of the cooling tower is nearly the same in different positions. Despite of the deformation the collision and the coalescence, the drop diameter in this paper can be seen as the initial diameter of the raindrops dripping down from the fill. The velocity distributions of the ten sets of data are shown in Fig.7.

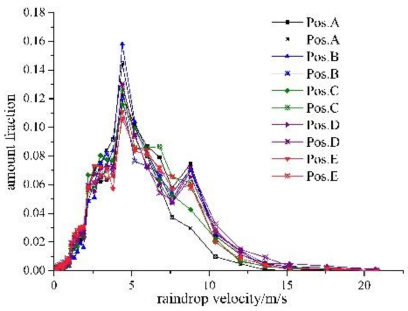

Fig.7 The raindrops velocity distribution

It can be seen from Fig.7 that the velocity distributions in all positions are also similar. That is to say the relative velocities in different positions have the similar distributions. Therefore the *We* numbers in different positions are distributed similarly. In consequence, the raindrop breakup mechanism in different positions in the rain zone is similar, resulting in the parallel size distribution in different position in the rain zone.

According to the analysis above, the raindrops in the rain zone may have parallel size distribution. That is to say an optimal size distribution could be chosen, the heat and mass transfer and the air pressure drop in the rain zone could be analyzed precisely. That is extraordinarily important and significant for the future study of the cooling tower.

CONCLUSIONS

The size and velocity distributions of the raindrops are analyzed. The initial drop distributions, at different positions of the rain zone, are nearly the same. The drop breakup mechanism in different positions is parallel. The raindrops in different positions have the similar distributions because of the parallel initial drop distribution and the similar breakup mechanism.

In summary, the field test of the raindrops measurement in the rain zone is conducted for the first time, laying a significant foundation for the future research on the cooling tower, making the accurate analysis on the rain zone feasible.

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