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Research Paper

Droplet characterisation of a complete fluidic sprinkler with different nozzle dimensions

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The complete fluidic sprinkler (CFS) has the advantages of a simple structure and the ability to work well at a lower nozzle pressures. CFS is a gas–liquid fluidic sprinkler, whose driving moment is achieved by a flow reaction as a result its droplet characteristics differ from those of conventional sprinklers. To study the droplet characteristics of the CFS, droplet diameter and velocity were measured using a Thies Clima laser precipitation monitor (TCLPM). Statistical analysis was conducted on the droplet size distribution using a volume-weighted method and droplet velocity was analysed using a number-weighted method. The results showed that volume mean droplet diameter and volume medium diameter increased with the distance from the nozzle and decreased with the nozzle size. The frequency of droplets with a diameter <3 mm increased with the working pressure. The number of larger droplets decreased with pressure and increased with the nozzle size when the pressure was 0.25, 0.30, or 0.35 MPa. A lognormal distribution model was used to evaluate the drop diameter distribution for each observed distance. With increasing pressure, the slope of the cumulative volume frequency droplet size curve at different distances from the nozzle decreased, and the distribution followed the trend of a Boltzmann function distribution. Droplet velocity increased with the droplet diameter but was not significantly influenced by the nozzle pressure. The results may provide a basis for further systematic research on the CFS.

1. Introduction

Sprinkler irrigation is popular in agricultural production worldwide. Designing and optimising sprinkler irrigation systems is mainly based on achieving adequate hydraulic performance, which is significantly related to the droplet size and velocity distributions (Chen & Wallender, 1985; Li & Kawano, 1996; Li, Kawano, & Yu, 1994; Playán et al., 2010). Droplet characterisation is necessary to evaluate the quality and efficiency of a sprinkler irrigation system, including evaporation losses and the influence of the droplet kinetic energy on the soil and crop growth. When droplets travel through the air, the effect of the wind speed on the evaporation loss is greater with fine rather than coarse droplets (Edling, 1985; DeBoer, 2002; Sadeghi et al.,2015). The evaporation of a sprinkler irrigation system has been investigated using a modified droplet dynamics model (Yan et al., 2010), and droplet characterisation has been used to analyse the effect of the droplet kinetic energy on the soil and

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Nomenclature

CFS	Complete fluidic sprinkler
LPM	Laser precipitation monitor
$\bar{d}$	Arithmetic mean diameter (mm)
D_V	Volumetric mean diameter (mm)
D_{50}	Volume median diameter (mm)
SD	Standard deviation
CV	Coefficient of variation
F	Frequency (%)
R_v	Ratio between D_v and D_{50} (%)
$\bar{v}$	Arithmetic mean velocity (m s^{-1})
E_{sdi}	Kinetic energy (J)
i	Serial number diameter
j	Serial number velocity
M	Number of droplets in one velocity class
N	Number of droplets in one diameter class
d	Droplet diameter (mm)
v	Droplet velocity (m s^{-1})
ρ_w	Water density (kg m^{-3})
D	Nozzle diameter (mm)
H	Working pressure (MPa)
x	Distance from the sprinkler (m)
y_0	Minimum value of the frequency (%)
x_c	Droplet diameter corresponding to the maximum cumulative frequency (mm)
w and A	Model parameters
L	Length value – replaced by D_{50} (mm)
α and n	Dimensionless exponents
A_1	Starting point line value
A_2	Finish line value
x_0	Centre point of the diameter values (mm)
dx	Droplet diameter constant (mm)
a and b	Regression coefficients

crops, particularly the kinetic energy of large droplets (Kincaid, 1996; DeBoer & Monnens, 2001).

The droplet characterisation primarily involves determining the diameter, velocity, and kinetic energy of droplets. In terms of the sprinkler equipment it mainly depends on (1) the type of sprinkler, (2) nozzle size, and (3) working pressure. Much research has been carried out to assess the droplet distribution characteristics. Droplets have been characterised for many years using stain, flour, and oil immersion methods, as well as other techniques (Kincaid, Solomon, & Bezdek, 1985; Kohl & DeBoer, 1984; Magarvey, 1956; Montero, Tarjuelo, & Carrión, 2003; Sudheer and Panda., 2000). Optical particle tracking velocimetry, low-speed photography, and other modern techniques have been applied to estimate the diameter, velocity, and angle of droplets directly from single isolated sprinklers (Bautista-Capetillo et al., 2014; King, Winward, & Bjorneberg, 2010; Salvador et al., 2009). The upper limit lognormal distribution model has been used to fit droplet size data and correlate it with nozzle parameters and that ballistic models have been used to estimate the initial droplet size produced by the sprinkler (Kincaid, Solomon, & Oliphant, 1996; Montero et al., 2003; Solomon, Kincaid, & Bezdek, 1985; Von & Gilley, 1984). The kinetic energy of droplets is the key parameter in determining the effects of sprinkler irrigation on soil properties (Basahi 1998; Bautista, Zavala, & Playán, 2012). The kinetic energy contained in the water droplets significantly affects the soil erosion and infiltration processes in the soil surface (Kincaid, 1996). Crust formation attributed to droplet impact is also a problem in the seedling emergence of crops such as sugar beets (Thompson, Gilley, & Norman, 1993). When the droplet kinetic energy increases, the hydraulic resistance of the surface seal formed on a silt loam soil by the increased impact of the water droplets also increases and reduces the infiltration rates (Mohammed & Kohl, 1987; Thompson & James, 1985). Adequate information on droplet diameter and velocity is required to calculate the kinetic energy of a sprinkler irrigation system and estimate the performance of irrigation hardware under working conditions (Kincaid, 1996; King et al., 2010; Yan et al., 2011). The kinetic energy per unit droplet volume model and the kinetic energy model from common sprinkler types as a function of the nozzle size and operating pressure have been developed to assist in selecting centre–pivot sprinklers (Kincaid, 1996; DeBoer & Monnens, 2001; DeBoer, 2002).

The complete fluidic sprinkler (CFS) (Fig. 1) is a new type of sprinkler with a simple structure (Zhu et al., 2009, 2015). The working principle of the CFS is different from that of conventional sprinkler nozzles because it uses two-phases of inlet fluid (air–water) instead of the more usual one (water only). The process of sprinkler operation includes stationary, rotated step-by-step, and reverse rotation. Firstly, the main flow is straight because the pressures are equal on all sides, and thus the sprinkler jet remains stationary, as shown in Fig. 1a. With time, the signal flow forms a low-pressure eddy, shown above as the right side. The main flow jet is directed towards the wall and it is eventually attached to it, as shown in Fig. 1b. The sprinkler then achieves a stepwise rotation in sequence by self-control. The reversing blowdown nozzle is filled when the sprinkler step is confined. The main flow jet is then attached to the what is shown in Fig. 1 as the left side, and the sprinkler then rotates in the opposite direction, as shown in Fig. 1c. When the sprinkler rotates towards the other side, the reverse blowdown nozzle opens, and air enters into the left side to equalise the pressure again. The CFS achieves its stepwise rotation in sequence and reversal by self-control (Zhu et al., 2012; Li et al., 2011). The working principle of the CFS is therefore different to other types of sprinklers and it has, therefore, different droplet characteristics. Information on the droplet size and velocity distributions of the CFS sprinkler remains limited, and the results of the few studies are incomplete (Dwomoh, Yuan, & Li, 2014). This study focuses on investigating the mean and median droplet diameters of the CFS; the droplet size distribution changes with distance from the sprinkler under different working pressures and nozzle diameters and proposes a droplet distribution model for the CFS. The droplet velocity distribution characteristics of the CFS and the droplet kinetic energy distribution law of the CFS are also investigated.

2. Materials and methods

2.1. *Experimental system*

The experiments were performed in an indoor laboratory of the Research Centre of Fluid Machinery Engineering and