Research and Development of Rotary Sprinkler Hydraulic Characteristics of the External Flow Field

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ABSTRACT: Sprinkler key equipment is the irrigation system in sprinkler hydraulic characteristics of the external flow field. It is also an important indicator in performance evaluation of the sprinkler. It is a literature review that the progress of the recent research in the field of hydraulic characteristics of the outflow nozzle is reviewed in this paper, including the test and numerical simulation of droplet trajectory, the distribution of water droplets based on different factors, the uniformity of water distribution and its impacts on the construction of water distribution model and dynamic simulation. The basis of analysis in this research was to analyze the problem of the hydraulic characteristics of the nozzle outflow field and look at the nozzle trends and methods of the hydraulic characteristics of the field for future outflows sprinklers.

Keywords: sprinklers; hydraulic characteristics; water distribution; droplet movement; distribution

1 INTRODUCTION

With an advanced water-saving irrigation techniques, sprinkler can improve the utilization of irrigation water to enhance crop development [1]. Sprinkler hydraulic characteristics of the external flow field including droplet trajectory and the distribution of water droplets and spray water distribution uniformity are important indicators in evaluation sprinkler effects on the yield of crops. If the sprinkler intensity is too high, the ground will be soaked with water, soil structure destroyed and soil will not be productive; however, if the sprinkler intensity is too low, it will produce water drift phenomena and reduce water efficiency. The low irrigation uniformity will not only reduce crop yields and quality, but may also lead to deep percolation of water, resulting in the loss of soil nutrients. Excessively increased uniformity in sprinkler system will increase the investment and operating costs and this will not be conducive to the future [2].

Domestic and foreign scholars who worked on the field of hydraulic characteristics of nozzle outflow came out with two main issues. One was on the establishment of water droplets movement and distribution model that provides basis for sprinkler irrigation system design and kinetic energy estimate. The other also emphasizes on spray water distribution uniformity test and simulation. In recent years, many scholars have done even further in-depth work on external hydraulic characteristics of the flow field of inquiry through a lot of research. Although much work has been done, there is no clear cut progress and summary of the current status of the rotary sprinkler hydraulic characteristics of the flow field. Therefore, it is necessary to study the hydraulic characteristics of the outflow nozzle field, especially to review for subsequent studies and also to provide more in-depth knowledge.

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2 TECHNOLOGIC ADVANCES

2.1 *Movement and distribution of water droplets*

2.1.1 *Research of droplet motion model*

An important basis for determining optimal nozzle spacing and pitch pipe is to determine the size of wet area by droplet trajectory. Chinese scholars began to study the nozzle droplet motion model both in theory and experiment in the 1980s. The formula was concluded from the results of extensive experimental investigations upon the ranges of the series PY1 sprinklers. According to Newton's second law of motion and the basic theory of hydraulics in Gan Zheming et al. [3]. Tuo Yunfei et al. [4] deduced a new theoretical formula of sprinkler range based on Newton movement law and hydraulics theories. But many factors are ignored in these two formulas with high precision, such as the impact of wind on the range. Wang Bolei et al. [5][6] analyzed the raindrops' regular exercise under downwind conditions and the establishment of a rotary sprinkler range of theoretical computing model wind conditions by mechanical methods. Also, they emphasized that the nozzle elevation LM algorithm based on artificial neural network can predict the range of predicted nozzle and the nozzle diameter and pressure mapping network model. Most of scholars use ballistic trajectory to model various droplet motion models. According to the ballistic mechanics mode, Giulio Lorenzini et al. [7] considered the evaporation of water droplets motion model. Playán et al. [8] used the ballistic trajectory model to calculate the single nozzle, combination nozzle sprinkler, sprinkler uniformity and intensity at different nozzle diameter, operating pressure, wind conditions, and the development of a simple application. In recent years, foreign scholars also have tried a new model for

the movement of water droplets; Ozgur Oguz Taskiran et al. [9] proposed a collision with a raindrop model to study the movement of raindrops.

In summary, the current models are based on the movement of water droplets to obtain the nozzle range of ballistic model formula, but this empirical formula ignores many factors that do not apply to many types of water droplets motion model jets.

2.1.2 Study of droplet distribution model

Water droplets distribution which directly determines the sprinkler irrigation uniformity has important implications on the growth of crops. However, domestic scholars began late on the droplet distribution model. Huang Xiuqiao et al. [10] used the spraying droplet ballistic trajectory equations and combined with the measured radial water distribution through linear interpolation into the grid point of water distribution and concluded on using a superposition principle to simulate windy conditions. Yan Haijun et al. [11] theoretically researched the combination with the equations of water droplets motion, and the density of water droplet probability was emphasized on the research into sprinkler irrigation water evaporation loss under windless conditions. They also used the flour method to analyze the diameter distribution of R3000 and A3000 low damping nozzle droplet diameter and the water droplets, droplet size and speed, nozzle diameter and nozzle working pressure. Xu Hong et al. [12] used the same flour method to study the rocker rotary nozzle droplet diameter trends ZY-1 and ZY-2 along the range direction and explore the relationship among droplet diameter, operating pressure and nozzle distance. Many scholars used traditional methods of sprinkler droplet diameter measurement to test, but this traditional method is more complicated and tedious. In response to these shortcomings, some scholars combine the technological development with the introduction of new technology research. Wang Bolei et al. [13] proposed a new method of water droplet diameter measurement based on the Adobe7.0 software to obtain the relationship between water droplets and the droplet diameter nozzle distance of cumulative volume percentage. A two-dimensional video disdrometer (2DVD) was used to measure drop sizes, drop velocity and drop angles from Nelson D3000 spray-plate sprinklers with a 4.78 mm nozzle and operating pressure of 50, 100, 150 and 200 kPa. The relationships among drop sizes, drop velocity and drop angles were analyzed in Gong Xinghui [14].

Foreign scholars have studied the water drop distribution model by using sophisticated instruments. Bautista-Capetillo.C et al. [15] used low speed photography to study the impact sprinkler raindrops hit kinetics in three pressure and studied raindrop diameter, velocity and the fight against the distribution of angles by the particle tracking technology (PTV). Li. J et al. [16] concluded that spray the entire area of the droplets hit, the intensity wound is varied with the change of the end of the jet's droplet diameter by regression analysis. Many scholars obtained the droplet distribu-

tion result through mode and used the ballistic trajectory model fitting. M.J. Monnens et al. [17] estimated the average droplet diameter and droplet kinetic energy for a single nozzle for hydraulic test through using trajectory model; Carrión et al. [18] simulated the sprayed water distribution based on wind conditions according to ballistic theories and air drag coefficient model. Meanwhile, they improved SIRIAS simulation models.

The droplet distribution model proposed by domestic and foreign scholars are now based on sprinkler and other single-phase jet nozzles without considering the height and other factors affecting the shape of the nozzle and the smaller scope.

2.2 Sprayed water distribution uniformity

The sprayed water distribution is an important factor affecting the uniformity of water which is distributed on a crop field, mainly including: nozzle flow, working pressure, nozzle rotation uniformity, spraying time, wind speed and direction, and a nozzle structure. Taking the sprinkler head of 30PSH as an example, the method of perpendicularity is used to analyze the influence of combination distance, work pressure and layout form on uniformity coefficient in irrigation by YU Liming et al. [19]. The average sprinkler intensity and the combined uniformity which is changed with the pressure of sprinkler ZY-1 and sprinkler ZY-2 were examined in Jia Ruiqing [20] under the conditions of altered pressure in the constant-pressure sprinkler irrigation system. The combined uniformity and the average sprinkler intensity are linearly represented under different pressure. Under the influence of pressure on sprinkler uniformity, five different water nozzles at 23 different pressure distributions are analyzed in Zhu Xingye et al. [21]. Rotational fluidic sprinkler type 10 was chosen as an object to explore the relationships between geometrical parameters and the spraying uniformity. Nine kinds of different offset length H, working area length L and contraction angle θ were specially fabricated and experiments were carried out under the operating pressure of 300 kPa and the radial water distributions for the nine different nozzles were tested out. MATLAB program was used to draw the three-dimensional water distribution and to calculate out the combined uniformity coefficient. The lightweight lateral move irrigation system was developed in the house and variations in water distribution and its uniformity were analyzed in terms of time. The relationship between the Distribution Uniformity (DU) and the Christiansen Uniformity Coefficient (CU) was established from the test results of the overlapping sprinkler water distributions in Li Jiusheng et al. [22]. Uniformity improvement of varied spray nozzles was done by Yuan Shouqi et al. [23] through using the improved shaped nozzle test of water distribution. Liu Junping et al. [24] designed a new type of sub-nozzle structure, namely a combination of improved sprinkler spray uniformity. Current studies are mostly from a single factor in the distribution uni-

formity of water and it has not provided much study on the combined effects of several factors under conditions of water distribution uniformity and there is a lack of univariate empirical formulas and theoretical formulas.

Building a model for water distribution and dynamic simulation experiments can simplify the process and address issues related to water distribution offers a variety of methods. Li Xiaoping et al. [25] proposed superimposed triangles combination calculations of single sprinkler water distribution uniformity. Zhang Zhiyu et al. [26] studied the use of sprinkler uniformity Radial Basis model-based RBF neural network calculation methods, and finally obtained the desired genetic optimization by optimal combination of nozzle spacing. With the development of computer technology, the use of dynamic simulation software to calculate the amount of water distribution is also gradually widespread. Wang Bolei et al. [27] proposed a method based on drawing sprinkler water distribution map by the software Surfer. Yuan Shouqi et al. [28] used the MATLAB language to process the sprinkler water distribution data obtained by interpolation overlay in each grid point of total rainfall depth, uniformity coefficient, and calculated combination nozzle spacing factor based on different combinations to achieve a three-dimensional visualization. It is a good solution that some scholars develop a processed water distribution in new environment and new computing software based on some original software. And Han Wenting et al. [29] used Visual C ++ and MATLAB language research to develop a new computing software, that is round in shape with spray nozzle combination evenness domain analysis system SIUEW1.0. Lao Dongqing et al. [30] developed a new nozzle water distribution combination of simulation and optimization software system by integrating MATLAB and VC ++ development environment. Zhang Yang et al. [31] have developed a system for evaluating the water sprinkler nozzles at different slope and pressure, and working under different wind conditions based on C# and OpenGL that have also been developed. Li Yongchong et al. [32] put forward a spray droplet motion and sprinkler water distribution simulation method of wind conditions, and used Visual Basic 6 to develop the new software with considering the sprinkler water distribution of droplet motion evaporation, which can be obtained by different uniformity combinations of sprinkler spacing simulation value.

3 PROBLEMS

Although the hydraulic characteristics of the rotary nozzle outflow field at home and abroad have been studied and the results are obtained, there are still some difficulties in the theoretical point of view.

Movement and distribution of water droplets: Researches about the nozzle droplet distribution characteristics did not consider the mounting height, the Reynolds number, the nozzle shape factor and other factors on the movement of water droplets, empirical formula and actual situation outside a larger scope.

Water distribution uniformity of nozzle spray:

1) Although domestic and foreign factors on water distribution are clear, various factors that affect the strength of the order are not yet clear. The main factors that affecting the sprinklers spray water distribution include nozzle flow, operating pressure, nozzle rotation uniformity, spraying time, wind speed and direction, the nozzle structure and so on [33]. These scholars have reached a consensus, but various factors that affect the strength of the order are lack of research, and more researches are only factors affecting the situation.

2) Lack of experience of individual factors formulas and theoretical formulas. A large number of documents elaborated on the single factor affecting spray uniformity, such as the pressure and wind effects on sprinkler water distribution, a combination of factors nozzle, working pressure, arrangement in the form of impact sprinkler uniformity and so on [34]. However, there is a lack of empirical formulas and theoretical formula, which is not conducive to a more in-depth study of water distribution.

3) The combined effects of various factors on the distribution of water are with no theoretical basis and formulas. In fact, the sprayed water distribution uniformity is affected by many factors, and theoretical studies of these factors are together according to the current lack of water distribution which helps deal with practical problems in the lack of operability.

4) At present, the software calculation can improve the efficiency of the test data, but the measurement is not accurate, and it cannot be widely used in reality.

4 DEVELOPMENT TRENDS

The sprinkler nozzle affects the quality of key equipment, and the world's major developed countries have been committed to the improvement and development of the nozzle. Development trend towards multi-purpose nozzle is to save low voltage and enhance the precision of irrigation, spraying and other comprehensive direction variables [35]. For instances, Israel, the United States and other countries have developed different forms of rocker based on different elevations and different multifunctional nozzles that can be low-voltage operational and energy-efficient [36].

Outflow nozzle hydraulic characteristics are important indicators of field sprinklers evaluation. With the sprinkler irrigation development, continuous improvement and the development of sprinklers, the sprinkler drain field research on the hydraulic characteristics will certainly be more in-depth [37]. More advanced technologies such as the particle tracking and the 3D video technology will be used for nozzle research. The raindrop trajectories research of new numerical simulation method for non-grid, CFD, ANALYS simulation software and other applications will be more complex situations and simulated oper-

ating conditions.

5 CONCLUSIONS

In this paper, two aspects of rotary nozzle flow field hydraulic characteristics are summarized. Research status, namely the movement and distribution of water droplets and the spray evenly distributed model of research are presented with the current challenge. Droplets movement and empirical formulas of distribution model are greatly varied with the actual situation. Water distribution strength ranking factors are not yet clear, and individual factors lack empirical and theoretical formula. There is no theoretical basis on the combined effects of various factors on the distribution of water and the formula to calculate the uniformity of the current software which is not enough for estimation accuracy. Hence this research has provided a platform, looking at the development trend of the nozzle and nozzle outflow field hydraulic characteristics, thereby laying foundations for the future.

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