

# Sprinkler Irrigation Hydraulic Performance and Jet Characteristics

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中国水利水电出版社  
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Author: Yue Jiang

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## SYNOPSIS

Water saving and energy saving are the theme of realizing social sustainable development. The shortage of water resources is a difficult problem in China. The development of water saving irrigation is an important means to effectively alleviate the contradiction between supply and demand of water resources, vigorously develop agricultural production and ensure food security. Sprinkler irrigation is a kind of effective agricultural water saving irrigation method, the existing research of the sprinkler irrigation technology mainly concentrated in saving water and reducing energy consumption. However, little study has been done on the non-circular jet under low-intermediate pressure as knowledge on jet breakup morphologies in the air is still limited. Therefore, the hydraulic performance and jet breakup characteristics of the sprinkler with non-circular nozzles are studied from the view of macrocosm and microcosm. The movement and dispersion mechanisms of the jets are understood, and the problem of uneven water distribution of the sprinkler under low pressure conditions is solved. The expected results would be useful in academia and of practical significance to the design and optimization of low-pressure sprinklers.

This book can be used as a reference for engineers and technicians engaged in the research of the sprinkler irrigation and micro-irrigation technologies and the water-saving irrigation project, as well as the teachers and students who major in agricultural engineering fields in colleges and universities.



# PREFACE

With the sustainable development of society, people depend on the water more and more, resulting in a constant shortage of water resources. The phenomena of large agricultural water consumption, low efficiency of water used, and serious water waste are especially common in China. Therefore, the development of water-saving irrigation technology is considered as one of the important ways to effectively alleviate the increasingly acute contradiction between supply and demand of the water resources in China, which is also an important means to guarantee the food security, the effective supply of important agricultural products, and the sustainable development of agriculture. Many scientists focused their research on saving water and reducing energy input of sprinkler irrigation system but maintained an acceptable sprinkler irrigation quality.

Dr. Yue Jiang has conducted extensive researches on sprinkler hydraulic performance and jet breakup characteristics for many years. In particular, the jet breakup characteristics of the sprinkler with circular and non-circular nozzles were studied under the low – intermediate working pressures. Obviously, these results are good contributions to the optimal design of the sprinkler, leading to the improvement of the hydraulic performance of the sprinkler under low working pressures. In recent years, Dr. Jiang has published many articles related to the jet breakup characteristics of the sprinkler with different nozzle types in international and national authoritative journals, such as *Biosystems Engineering*, *Journal of irrigation and drainage engineering*, *Irrigation and Drainage*, et al. These articles have caused the interests of many peer experts around the world.

The publication of this book will be able to demonstrate the current achievements related to irrigation science in China and abroad. Furthermore, the book is beneficial to understand the jet breakup mechanism of the sprinkler under the low-intermediate working pressures. With the shortage of water resources all over the world, there is no shirking of the responsibility for the agricultural researchers to study the new water and energy saving technologies. I am very pleased to see that young scientists have also obtained extensive achievements in the field of theoretical and experimental study of new irrigation technologies. It is

my great pleasure to write the preface and to congratulate the publication of this book.

**Hong Li**

**Professor**

**Dean of the Graduate School**

**Jiangsu University**

May, 2020

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A part of the experiments concerning sprinkler irrigation hydraulic performances and jet characteristics were conducted when I was a doctoral candidate at the Research Center of Fluid Machinery Engineering and Technology, Jiangsu University, China. I was assisted by Dr. Chao Chen, assistant research fellow, Mrs. Xiaoyin Zhou and Mrs. Lin Hua, postgraduate students, Research Center of Fluid Machinery Engineering and Technology, Jiangsu University, for the indoor experiments conducted in China. The Research Center of Fluid Machinery Engineering and Technology of Jiangsu University provided the experimental sites and sprinkler irrigation installations for the indoor experiments conducted in this study. All of the people who contributed to the experiments are gratefully acknowledged.

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May, 2020

# NOMENCLATURE

## 1. Symbols

|                                      |                                                            |            |                                                                                      |
|--------------------------------------|------------------------------------------------------------|------------|--------------------------------------------------------------------------------------|
| $\boldsymbol{\tau}$                  | Viscous stress tensor                                      | $C_{s0}$   | Van Driest constant                                                                  |
| $\tau_{ij}$                          | Trace-Free tensor component of the sub-grid stress         | $d_a$      | Single projected area diameter, mm                                                   |
| $\sigma$                             | Surface tension coefficient, N/m                           | $d_1$      | Outlet diameter of the jet, mm                                                       |
| $\alpha$                             | Angle between the jet boundary line and the jet axis, °    | $D_h$      | Equivalent diameter of non-circular orifice, mm                                      |
| $\alpha_0$                           | Elevation angle of the sprinkler, °                        | $g$        | Gravitational acceleration, m/s <sup>2</sup>                                         |
| $\rho_g$                             | Gas density, kg/m <sup>3</sup>                             | $h$        | Mesh size, mm                                                                        |
| $\rho_l$                             | Water density, kg/m <sup>3</sup>                           | $h_w$      | Water depth, mm                                                                      |
| $\rho_i$                             | Point water application rate, mm/h                         | $h_0$      | Outlet width of the jet, mm                                                          |
| $\bar{\rho}$                         | Average water application rate, mm/h                       | $h_1$      | Physical length between two wave crests on both sides of the jet surface, mm         |
| $\mu$                                | Water viscosity, kg/(m • s)                                | $H_0$      | Nozzle pressure, m                                                                   |
| $\eta_0$                             | Initial amplitude of the surface wave, mm                  | $H$        | Working pressure head of the sprinkler, m                                            |
| $\Delta$                             | Representative grid spacing, mm                            | $I_m$      | $m$ -Bessel function of the first kind                                               |
| $\Delta t$                           | Time step, s                                               | $k$        | Complex wave number                                                                  |
| $\Delta x_1, \Delta x_2, \Delta x_3$ | Grid dimensions in the three coordinate directions         | $K_m$      | $m$ -Bessel function of the second kind                                              |
| $\theta$                             | Cone angle of nozzle, °                                    | $L$        | Wetted perimeter of the non-circular orifice, mm                                     |
| $\phi$                               | Level set function                                         | $L_b$      | Jet breakup length, mm                                                               |
| $\mu(\phi)$                          | Viscosity, kg/(m • s)                                      | $L_c$      | Jet initial length, mm                                                               |
| $\rho(\phi)$                         | Density, kg/m <sup>3</sup>                                 | $L'_b$     | Relative error between the jet breakup lengths of the RANS simulation and experiment |
| $\kappa(\phi)$                       | Curvature                                                  | $L''_b$    | Relative error between the jet breakup lengths of the LES method and experiment      |
| $H(\phi)$                            | Heaviside function                                         | $n$        | Number of points and collectors                                                      |
| $a$                                  | Radius of the jet, mm                                      | $p$        | Working pressure, kPa                                                                |
| $A$                                  | Discharge area of the nozzle, mm <sup>2</sup>              | $p_d$      | Atomization index                                                                    |
| $A_a$                                | Projected area, mm <sup>3</sup>                            | $p_\sigma$ | Additional pressure due to surface tension                                           |
| $A_2$                                | Discharge area of the non-circular nozzle, mm <sup>2</sup> | $P_\infty$ | Static pressure, Pa                                                                  |
| $A^+$                                | Semi-empirical constant                                    | $Q$        | Flow rate of the sprinkler, m <sup>3</sup> /h                                        |
| $b_{1/2}$                            | Half width of the jet                                      |            |                                                                                      |
| $C_s$                                | Smagorinsky constant                                       |            |                                                                                      |

|              |                                                                        |                  |                                                    |
|--------------|------------------------------------------------------------------------|------------------|----------------------------------------------------|
| $R$          | Sprinkler wetted radius, m                                             | $\overline{X}_i$ | Average water depth collected in every             |
| $R_{PY1}$    | Wetted radius of the PY <sub>1</sub> impact sprinkler, m               |                  | collector, mm                                      |
| $R_{PYS}$    | Wetted radius of the PYS plastic impact sprinkler, m                   | $x -$            | $x$ -axis                                          |
| $R_{PS}$     | Wetted radius of the PSH and PSBZ progressive fluidic sprinkler, m     | $y -$            | $y$ -axis                                          |
|              |                                                                        | $z -$            | $z$ -axis                                          |
| $Re$         | Reynolds number                                                        | 2. Abbreviations |                                                    |
| $s$          | Complex growth rate                                                    | CLSVOF           | Coupled level set-volume of fluid                  |
| $\mathbf{S}$ | Strain rate tensor                                                     | DPIV             | Digital PIV                                        |
| $S_i$        | Area of the point, m <sup>2</sup>                                      | EDM              | Electric discharge machining                       |
| $s_{\max}$   | Maximum perturbation growth rate                                       | HRIC             | High resolution interface capturing                |
| $T_{\infty}$ | Static temperature, K                                                  | HSP              | High-Speed photography                             |
| $\mathbf{u}$ | Velocity vector, m/s                                                   | LED              | Light-Emitting diode                               |
| $u$          | Velocity at different sections of the free jet from the axis $y$ , m/s | LES              | Large eddy simulation                              |
| $u_0$        | Jet outlet velocity, m/s                                               | LIF              | Laser-Induced fluorescence                         |
| $u_m$        | Velocity along the axis of the jet, m/s                                | PDA              | Phase doppler anemometry                           |
| $U_{\infty}$ | Velocity of the quiescent air, m/s                                     | PISO             | Pressure-Implicit with splitting of operators      |
| $V_t$        | Instantaneous inlet velocity of the jet, m/s                           | PIV              | Particle image velocimetry                         |
| $V_{ave}$    | Average velocity, m/s                                                  | PRESTO           | Pressure staggering option                         |
| $V_{rand}$   | Velocity disturbance, m/s                                              | RANS             | Reynolds-Averaged Navier-Stokes                    |
| $We$         | Weber number                                                           | RSM              | Reynolds stress model                              |
| $X_i$        | Water depth collected by collector No. $i$ , mm                        | UDF              | User-Defined function                              |
|              |                                                                        | UCC              | Christiansen's uniformity coefficient, %           |
|              |                                                                        | VOF              | Volume of fluid                                    |
|              |                                                                        | SIMPLE           | Semi-implicit method for pressure linked equations |

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## PREFACE

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