Structural design and performance characteristics of the fluidic sprinkler application technology for saving irrigation water: a review

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Abstract

The fluidic sprinkler was designed to have the prospect of a simple design, ease of construction, low energy consumption, and water saving. The present review focused on the fluidic sprinkler, compared the performance parameters of the fluidic sprinkler with the impact sprinkler, and highlighted the main challenges associated with the fluidic sprinkler. Even though the fluidic sprinkler compares quite well with the impact sprinkler, the review highlighted that the fluidic sprinkler appears to have more variability in application rate (0-1.5 mm/h) than the impact sprinkler (0-0.8 mm/h). The wetted radii were, on average, less than the impact sprinkler by 9.7, 9.3, 11.0, and 9.9% at 200, 250, 300, and 350 kPa operating pressures, respectively. Experiments on the fluidic sprinkler have mainly concentrated on the structural design of the fluidic component, water distribution profile, coefficient of uniformity, droplet size characterisation, and rotation uniformity, as well as the effect of different nozzle sizes on hydraulic performance under varying discharge and pressure conditions ranging from 100-500 kPa under indoor conditions. However, experimental studies on its performance in the field remain scanty. Statistical analysis of research papers published on the fluidic sprinkler indicates that less than 10% of the studies focused on the performance of the fluidic sprinkler on the field, and more than 90% on the design, structural and hydraulic performance under indoor conditions. Rotation stability of the fluidic sprinkler and testing with different sizes of the nozzle under low-pressure conditions on the field require further research to achieve energy and water saving through optimisation of the operating conditions.

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Introduction

Climate change is increasingly resulting in unpredictable water availability and high temperatures. A world bank report has indicated that the combined effects of climate change and the growing population will lead to an exponential rise in the demand and cost of water and energy (Kijne, 2006; Shah and Wu, 2020; Wang *et al*., 2022). These adverse effects have made most farmers increasingly water and energy-saving conscious, with a focus on the uniform and efficient application of water at low operating pressures during irrigation. However, in most parts of the world, the lack of efficient irrigation methods leads to wastage or excessive use of irrigation water. Furthermore, research shows that many irrigation systems in use are inefficient (Hoogenboom *et al*., 2019; Obaideen *et al*., 2022).

Sprinkler irrigation remains one of the most versatile irrigation methods that apply water uniformly and efficiently to the field (Zhang *et al*., 2018; Li and Liu, 2020). It can be defined as an irrigation system that distributes water onto the field by projecting water from the nozzle of a sprinkler into the air, subsequently falling as discrete droplets of different diameters (Kincaid, 1996; Kincaid *et al*., 1996; Tang *et al*., 2022). The practicality of its use on various soils, climates, and crop types and in difficult topographic conditions is an attribute that makes sprinkler irrigation attractive (Waller and Yitayew, 2016). Sprinkler systems are used for crop and soil cooling, frost protection, delaying fruit and bud from developing, providing water for germinating seeds, application of agricultural chemicals, and land application of wastewater (Jensen, 2007). Water-saving sprinkler irrigation requires water to be distributed uniformly and efficiently with very minimal losses (Zhang *et al*., 2018; Jin and Wu, 2022).

The sprinkler head is seen as a key component of any sprinkler irrigation system in ensuring water-saving is achieved (Uygan *et al*., 2021). The function of the sprinkler head is to distribute water over the field under irrigation at a specified operating pressure (Yan *et al*., 2009; Li *et al*., 2021). Several different types of sprinklers are available and in use worldwide to perform this function. Two main types are currently commercially available: rotating and fixed-head sprinklers (Faci *et al*., 2001; Sourell *et al*., 2003). Rotating sprinklers include impact, gear-driven, reaction, and fluidic sprinklers. Fixed-head sprinklers include most of the spray-type sprinklers currently available (Kincaid *et al*., 1996). The impact sprinkler was created by Rainbird and Nelson Companies in America in 1933 (Rogers and Cone, 1980), and in the middle of the 1990s, the new series of innovative rotating spray plate sprinklers called rotators were developed (Zhu *et al*., 2012a). Low-pressure sprinklers, such as the R33 rotator from Nelson Irrigation Company, are reported to be innovative and water-saving sprinklers (Phocaides, 2007). The impact sprinkler is currently by far, one of the most popular worldwide. Komet in Italy launched a sprinkler whose irrigated angle can be adjusted by distance control.

However, the importance of sprinkler systems in irrigation was recognised in China in 1954, and subsequently, sprinklers from Russia were recommended for usage in China (Zhu *et al*., 2009). Since then, research institutions in China have been trying to develop new and improved sprinkler models of existing sprinklers. In 1980, Jiangsu University developed the self-controlled step-by-step complete fluidic-type PX sprinkler. Subsequently, in 1981, Fuzhou University came up with another completely different fluidic sprinkler that controlled itself by feedback (Zhu *et al*., 2012b). In 1990, Hang and others invented the double-strike synchronism complete fluidic sprinkler. Jiangsu University later invented the gap-controlled complete fluidic-type PXH sprinkler in 2005 (Zhu *et al*., 2012b; Liu *et al*., 2022) and has since then conducted extensive research on the fluidic sprinkler. The fluidic sprinkler was envisaged to have a simple design, easy to assemble, low cost, ease of usage, and energy and water saving as targeted qualities. Therefore, it was proposed to become a competitive alternative to other sprinklers on the market, which are widely used but considered quite expensive and complicated (Zhu *et al*., 2009). However, the available literature does not show the realisation of the intended prospects of the fluidic sprinkler, especially in irrigated fields, even though extensive studies have been carried out to improve the structural and hydraulic capabilities of the fluidic sprinkler (Yuan, 2006; Zhu *et al*., 2009; Zhu *et al*., 2012b; Jiang *et al*., 2022; Zhang *et al*., 2022). Therefore, this paper considered a review of the structural design and performance characteristics of the fluidic sprinkler. This review aimed to highlight and analyse the numerous research on the fluidic sprinkler, identify limitations of its design performance compared to other rotating sprinklers, and recommend possible areas of its design and operation for future research considerations for improvement.

Working principle and structural design of fluidic sprinkler

The fluidic sprinkler, shown schematically (Figure 1A) and pictorially (Figure 1B), is a rotating sprinkler with its working principle based on the theory of the Coanda effect (Cîrciu and Dinea, 2010; Yun *et al*., 2018) to perform the function of rotation of the sprinkler. The working principle has been detailed by several authors (Li *et al*., 2008; Liu *et al*., 2008; Yuan *et al*., 2005; Zhu *et al*., 2012b; Jiang and Zhu, 2022). The fluidic component is the main distinguishing feature of the fluidic sprinkler. The working principle of the fluidic sprinkler is such that as water is ejected from the nozzle of the main tube into the fluidic component, a region of low-pressure develops on both sides at the entry into the fluidic component. Water then flows from the reversing plastic tube into the right side, forcing the jet to deflect towards the right and eventually attaching itself to the boundary of the fluidic element. Subsequently, the jet flow bends to the right boundary such that the signal nozzle cannot receive any flow and later becomes straight as it exits the fluidic component. Alternate air movement from the signal nozzles and the plate cover account for the stepwise rotation of the fluidic sprinkler automatically (Zhu *et al*., 2012a). On the other hand, the impact sprinkler is a type of rotating sprinkler that is driven in a circular motion by a spring-loaded arm and pushed back each time it comes into contact with the water stream. This breaks up the water stream, thus enabling a uniform watering area around the sprinkler (Brouwer *et al*., 1988; Issaka *et al*., 2018).

Several authors have systematically studied the structural design of the fluidic sprinkler over the years. (Liu *et al*., 2008; Zhu *et al*., 2009) performed extensive analysis and experiments on relationships between geometrical parameters such as the offset length, working area length, pipe length, contraction angle, the inner wall attachment jet structure, as well as the frequency of completion and working pressure in relation to spraying uniformity, rotation speed, range of throw of the fluidic sprinkler. The wall-attaching offset of the fluidic sprinkler, including turbulent offset jet, and mean flow characteristics were also studied. The afore-

A) ***Schematic view***

B) ***Pictorial view***

Figure 1. The fluidic sprinkler. *1. Swivel connection block; 2. Hollow shaft; 3. Limiting ring; 4. Reverse mechanism; 5. Signals water into faucets; 6. Sprinkler tubing; 7. Reversing plastic tube; 8. Fluidic element.*

mentioned parameters used by previous authors were relatively smaller and could not generate enough pressure to rotate the sprinkler efficiently. Other studies further worked on the design parameters, such as the shape, size, and angle of signal air hole, to improve the working performance of fluidic sprinkler (Wang *et al*., 2012; Liu *et al*., 2013; Chen *et al*., 2022; Xu *et al*., 2022).

Table 1 presents nozzle sizes and corresponding pressures of different sizes of the fluidic sprinkler. As the sprinkle size increased, the nozzle size and the operating pressure also increased (Liu *et al*., 2016c; Zhu *et al*., 2018). According to Uygan *et al*. (2021) and Tarjuelo *et al*. (2015), low-pressure sprinklers ensure energy saving. Therefore, it is imperative, as recommended by Fordjour *et al*. (2020a), that the fluidic sprinkler type 10PXH could be redesigned and tested with the different types of nozzle sizes and operating pressures to get the best combination that can produce the desired spray characteristics to overcome wind interference and evaporation under low-pressure conditions. Optimisation of the spraying parameters is, therefore, necessary to enhance the efficiency of the application.

Comparative analysis of the performance characteristics of the fluidic sprinkler with other sprinklers

Uniformity of water application

For the first time, Dwomoh *et al*. (2013) and Liu *et al*. (2021) studied the performance of the fluidic sprinkler, specifically PXH20 and PXH10, on the field using single leg and solid set experimental arrangement. All tests were performed according to the ASAE standard (Standard, 1985a) and ASAE standard (Standard, 1985b) at operating pressures of 200, 250, 300, and 350 kPa. Tarjuelo *et al*. (1999) used the Rain Bird 4611 sprinkler, a registered trademark by Rain Bird Inc, fitted with 4.4 and 2.4 mm nozzles and jet-straightening vane, following the methodology of (Merriam and Keller, 1978) and ASAE standard (Standard, 1985a) as well as ASAE standard (Standard, 1985b) and conducted field evaluation under the solid set experimental arrangement. The field tests conducted by Tarjuelo *et al*. (1999) were categorised under three wind speed regimes such as 0-2, 2-4, and 4-4.6 m/s, subjected to three categories of operation pressures [210-300, 300-400, and 400-480 (kPa)] which were quite similar to the operating pressures of Dwomoh *et al*. (2013). Tarjuelo *et al*. (1999) obtained a mean CU value of 84.6% for the entire set of experiments for the Rain Bird 4611 sprinkler. The findings established that under wind speeds of 2 m/s, the mean CU value was 87.4% and for wind speeds ranging from 2 to 4 m/s, the average CU value was 85.3%. However, CU value of 77.2% was registered for wind speeds higher than 4 m/s.

On the other hand, the findings of Dwomoh *et al*. (2013), indicated that with the fluidic sprinkler at low to moderate wind speed regime (U<1.5 m/s), the average CU value recorded was at 84%, which, according to Keller and Bliesner (1990) is acceptable and also comparable to the findings of Tarjuelo *et al*. (1999) with the Rain Bird 46 sprinkler (Merriam and Keller, 1978).

However, at high wind speeds (U>3.5), CU values were generally low for the fluidic sprinkler, estimated below 75%. According to Dwomoh *et al*. (2013), under high wind conditions, a decrease in spacing could not offset the effect of the wind for all the operating pressures with the fluidic sprinkler. The recorded coefficient of uniformity values ranged from 73.2% at 16×16 m and 59.8% at 16×18 m.

The results contradicted the general recommendation that decreasing sprinkler spacing under wind conditions would typically improve uniformity. The above finding indicates the need for further detailed study to ascertain the contradiction of the general recommendations for improvement as stated by Dwomoh *et al*. (2013).

Wetted radius

The wetted radius indicates how far the sprinkler can throw water from the nozzle. Coupled with the distribution profile, the wetted radius has implications on sprinkler and lateral spacing, ultimately influencing design and operational cost. Zhu *et al*. (2015b), Liu *et al*. (2021) and (Zhu *et al*., 2021), in comparing the hydraulic performance of the outside signal sprinkler, a fluidic sprinkler, and an impact sprinkler at 200, 250, 300, and 350 kPa operating pressures, concluded that the impact sprinkler had the largest measured wetted radius of the three sprinklers. The wetted radius for the outside signal sprinkler was 10.4, 10.6, 10.8, and 11.1 m at 200, 250, 300, and 350 kPa, respectively. These radii were, on average, less than the impact sprinkler by 8.7, 10.4, 12.0, and 9.9%, respectively. For the fluidic sprinkler, the wetted radii were 10.3, 10.7, 10.9, and 11.1 m at 200, 250, 300, and 350 kPa, respectively. These radii were, on average, less than the impact sprinkler by 9.7, 9.3, 11.0, and 9.9%, respectively (Zhu *et al*., 2015b). The wetted radius for the outside signal sprinkler was not significantly different from that of the fluidic sprinkler and was 8.7-12% less than the wetted radius of the impact sprinkler. The reduction in the wetted radius in the outside signal sprinkler and the fluidic sprinkler was attributed to the two-phase fluidic working theory (Zhu *et al*., 2015b).

Uniformity of rotation speed

Variations in the rotation speed of the sprinkler may have a negative effect on the range of water application intensity and efficiency of the sprinkler (Strong, 1966; Solomon, 1987; Dogan *et al*., 2008; Shi *et al*., 2021). Dwomoh *et al*. (2014a) compared the rotation speed variation of the PXH20 fluidic sprinkler and the PY20 impact sprinkler, considering the effect of water application intensity and uniformity of application at 250, 300, and 350 kPa operating pressures. An inverse linear relation was observed between the rotation time in the quadrants of rotation and application intensity. For the impact sprinkler at 300 kPa and radial distances of 8, 10 and 16 m, ranges of standard deviation were 0.31-0.40, 0.12-0.25, and 0.26-0.55 mm/h, respectively. In the case of the fluidic sprinkler at 300 kPa, standard deviation ranges were 0.47-1.29, 0.36-0.64, and 0.12-0.71 mm/h at radial distances of 8 m, 10 m, and 16 m, respectively. They indicate that variations in water application rate are pretty significant, and the fluidic sprinkler appears to have more variability in application rate (0-1.5 mm/h) than the impact sprinkler (0-0.8 mm/h).

Table 1. Sprinkler type with different nozzle sizes and pressures.

Sprinkler type	Nozzle diameter (mm)	Pressure/kPa
10PXH	4	250
15PXH	6	300
20PXH	8	350
30PXH	10	400
40PXH	14	450
50PXH	18	500

Even though non-uniformity in rotation speed may be linked to the stability of operating pressure, it is also closely related to the design features and efficiency in manufacturing (Dwomoh *et al*., 2014a). This is because the fluidic component is the main feature responsible for the stepwise rotation of the fluidic sprinkler. On the other hand, the impact sprinkler rotates by the impact of a swinging arm which repeatedly strikes the body of the sprinkler. Further optimisation of the design features of the fluidic component will therefore be necessary to minimise variability in water application rate by improving the rotation stability of the fluidic sprinkler. Using metallic material in the fluidic sprinkler was recommended to improve upon rotation stability under wind conditions (Zhu *et al*., 2015a).

Droplet size characterisation

Characterisation of the droplets of sprinklers is important for the following two reasons. First, smaller droplets are easily drifted by wind and distort the application profile (Topak *et al*., 2005; Moazed *et al*., 2010). Secondly, larger droplets possess greater kinetic energy transferred to the soil surface causing particle dislodgement and ponding that may result in surface crusting and runoff (Moazed *et al*., 2010). Therefore, such information can be of practical importance in selecting, designing, and operating sprinkler irrigation systems for different types of crops. Zhu *et al*. (2015c) compared the droplet distribution of the fluidic, outside signal, and impact sprinklers and concluded that fluidic and the outside signal sprinklers had droplet sizes and velocities similar but not identical because both are gas-liquid fluidic sprinklers. On the other hand, the impact sprinkler tends to give a 0.5 mm larger droplet diameter and 0.5 m/s greater velocity than the outside signal and fluidic sprinkler. Dwomoh *et al*. (2020) in analysing the cumulative numeric frequency and cumulative volumetric frequency of the impact sprinkler and that of the fluidic sprinkler stated that both sprinklers had a relatively higher frequency of smaller (fine) drops near the sprinkler and an increasing frequency of larger drops away from the sprinkler. The shapes of the profiles are quite similar, however, the diameter of the drops obtained with the fluidic sprinkler are much smaller which confirms the conclusion of Zhu *et al*. (2015c). Specifically, at 250 kPa at radial distances of 2, 6, 10, and 12 m from the sprinkler nozzle, diameters of 0.465, 1.423, 1.670, and 2.051 mm, respectively, were obtained with the 20PXH fluidic sprinkler compared to diameters of 1.05, 1.40, 1.92, and 3.59 mm, at radial distances of 2, 6, 10, and 12 m, respectively, at 250 kPa with the impact sprinkler (VYRSA with a straightening vane, 4.8 mm nozzle). According to Okasha and Sabreen (2016), that means susceptibility to particle dislodgement and ponding will be higher with the impact sprinkler compared with the fluidic sprinkler. On the other hand, droplets from the fluidic sprinkler will be more prone to wind drift and evaporation, which has negative implications on the water-saving potential of the fluidic sprinkler.

Overview of research on the fluidic sprinkler

Quite a lot of research has been performed on the fluidic sprinkler, as seen by the high number of research papers published in various journals (Table 2) on the fluidic sprinkler. Table 2 summarises published research work on the fluidic sprinkler from 2007 to 2021. Statistical analysis of the research papers published on the fluidic sprinkler indicates more than 90% focused on the design, structural and hydraulic performance under indoor conditions at the indoor Sprinkler Laboratory of Jiangsu University and less than 10% focused on the performance of the fluidic sprinkler on the field (Dwomoh *et al*., 2014a).

Of the indoor studies, there has been much concentration on the structural design of the fluidic component of the fluidic sprinkler, water distribution profile, coefficient of uniformity, droplet size characterisation as well as the effect of different nozzle sizes on hydraulic performance under varying discharge and operating pressure conditions ranging from 100-500 kPa. According to Zhu *et al*. (2009), performing sprinkler experiments under indoor conditions eliminates the influence of wind to improve the design features for optimum performance.

After fine-tuning the design features under indoor conditions, there is the need for an extensive field test to optimise its performance by benchmarking with acceptable standards for comparison, which from the statistics, very little has been done. There is, therefore, the need for further research on the performance of the fluidic sprinkler on the field under the impact of environmental factors, especially wind (speed and direction) and evaporation, to optimise its operation conditions to ascertain its' readiness for the field. In addition, there has been a comparative analysis of the performance of the fluidic sprinkler with other sprinklers, especially the impact sprinkler, albeit under no wind conditions. Therefore, comparative research on the field performance of the fluidic sprinkler and other sprinklers is necessary to identify areas or features for improvement in the field.

Challenges with fluidic sprinklers

According to Faria *et al*. (2015), Dwomoh *et al*. (2014a), and Li and Kawano (1996), uniformity of rotation is an indicator of the good performance of a sprinkler. Speed fluctuations of rotating parts result from the effect of the design, technology, and operational factors, which can have a wide range of variations. A study conducted by Zhu *et al*. (2015a) acknowledged sprinkler rotation speed variation as the major factor influencing the overall uniformity of water distribution of the fluidic sprinkler. Similarly Dwomoh *et al*. (2013) suggested the optimization of the fluidic components in sprinkler applications. Junping *et al*. (2007) confirmed that there were pressure variations in the fluidic structure caused by alignment of signal nozzles and the flow through the signal pipes in the fluidic component. Hong and Xingye (2013) reported that the air entrance hole distance needs to be changed to reduce the maximum dynamic pressure and the attachment distance. Dwomoh *et al*. (2014a) confirmed the need to improve the design features of the fluidic component to maximise sprinkler efficiency. A study conducted by Liu *et al*. (2013) reported that the fluidic sprinkler rotates faster, which can affect the hydraulic performance and the sprinkler efficiency. Uniformity of rotation speed is necessary even though proper overlap of sprinklers could minimise the non-uniformity of rotation. The variations in the rotation speed of the sprinkler may have a negative effect on the range of water application intensity and efficiency of the sprinkler (Strong, 1966; Solomon, 1987; Dogan *et al*., 2008).

With the fluidic sprinkler, the rotation speed is proportional to geometrical parameters for any given inner contraction angle (Zhu *et al*., 2012b). Yuan *et al*. (2005) simulated the flow in a fluidic sprinkler and concluded that the structure of the fluidic component needs to be optimised to get the best offset ratio. The aforementioned confirms the pressing need to redesign the fluidic structure by considering the contraction angle, the shape, and the surface of the curvature, to efficiently rotate the sprinkler and improve water distribution uniformity and water-saving on irrigated filed.

Table 2. Summary of literature on the fluidic sprinkler from 2007 to 2021.

Study no.	Title of research paper	Authors and year of publication	Study focus	Indoors or field
1.	Analysis and experiment on influencing factors of range and spraying uniformity for complete fluidic sprinkler	Liu *et al*., 2008	The range of throw of inlet pressure, sprinkler elevation, sectional area, rotate speed, step frequency, pipe length, and signal junction depth	Indoors
2.	Compared experiments between complete fluidic sprinkler and impact sprinkler	Zhu *et al*., 2008	The relationship between angle and frequency of complete fluidic sprinkler pipe length and working pressure	Indoors
3.	Method for achieving irregular boundary area for complete fluidic sprinkler	Liu *et al*., 2008	Relationship between throw radius, pressure, rectangular and triangular spraying pattern	Indoors
4.	Wall attachment frequency of complete fluidic sprinkler's fluidic element	Xiang, 2009	Factors that affect the frequency of wall attachment offset jet, the differential pressures on both sides of fluidic element	Indoors
5.	Irrigation uniformity with complete fluidic sprinkler in no-wind conditions	Zhu *et al*., 2008	Radial water application of PXH 10 fluidic sprinkler, sprinkler spacing using MATLAB, combined uniformity coefficient	Indoors
6.	Feasibility analysis on complete fluidic sprinkler for achieving irregular boundary area	Junping *et al*., 2007	The sprinkler's altitude angle, entrance pressure, entrance sectional area, and the irrigation range	Indoors
7.	Problems and improvements in batching process of complete fluidic sprinkler	Zhu *et al*., 2006	Design and structural changes to improve the performance	Indoors
8.	A numerical simulation of pressure-adjusting devices of complete fluidic sprinklers	Liu *et al*., 2013	Numerical simulation of pressure variations in the fluidic sprinkler	Indoors
9.	Orthogonal test and precipitation estimate for the outside signal fluidic sprinkler	Zhu *et al*., 2009	Water distribution, CU for different spacing size and spacing types	Indoors
10.	Theoretical and experimental study on water off set flow in fluidic component of fluidic sprinkler	Li *et al*., 2011	Fluidic component, CFD analysis	Indoors
11.	Numerical simulation and experimental study on a new type of variable rate fluidic sprinkler	Liu *et al*., 2013	Wetted radius sprinkler rotation	Indoors
12.	Field performance characteristics of fluidic sprinkler	Dwomoh *et al*., 2013	Wind effect on CU, application intensity, and spacing	Field
13.	Sprinkler rotation and water application rate for the new type complete fluidic sprinkler ad impact sprinkler	Dwomoh *et al*., 2014a	Rotation time, uniformity in quadrants on CU at different pressure	Indoors
14.	Droplet size characteristics of the new type complete fluidic sprinkler	Dwomoh *et al*., 2014b	Cumulative numeric and volumetric frequency with pressure variation	Indoors
15.	Comparison of droplet distributions from fluidic sprinkler and impact sprinklers	Zhu *et al*., 2015c	Droplet diameter, velocity with pressure variation	Indoors
16.	Comparison of fluidic and impact sprinklers based on hydraulic performance	Zhu *et al*., 2015b	Fluidic sprinkler compared with impact and outside signal sprinkler focusing on wetted radius, application profile, and combined uniformity	Indoors
17.	Droplet characterization of a complete fluidic sprinkler with different nozzle dimensions	Liu *et al*., 2016a	Application pattern, discharge coefficient, wetted radius and droplet diameter, velocity and frequency with pressure and nozzle variation	Indoors
18.	Characteristics of water droplet size distribution from fluidic sprinkler	Liu *et al*., 2016b	Nozzle diameter, hydraulic characteristics, wetted radius drop diameter, K.E with pressure variation	Indoors
19.	Experimental and combined calculation of variable fluidic sprinkler in agricultural irrigation	Liu *et al*., 2016c	Hydraulic performance, CU, application pattern	Indoors
20.	Droplet motion model and simulation of a complete fluidic sprinkler	Junping *et al*., 2018	Droplet trajectory, diameter distribution, and kinetic energy analysis	Indoors
21.	Evaluation of hydraulic performance characteristics of a newly designed dynamic fluidic	Zhu *et al*., 2018	Droplet size, different nozzles, water distribution profiles, comparative analysis	Indoors
22.	Analysis of water droplet distribution in wind for the fluidic sprinkler	Dwomoh *et al*., 2020	Distribution profile, droplet size with pressure variation	Indoors and field
23.	Numerical simulation and experimental study on internal flow characteristics in the dynamic fluidic sprinkler	Fordjour *et al*., 2020b	Sprinkler nozzle diameter, length of tube, inner flow	Indoors
24.	Effect of riser height on rotation uniformity and application rate of the dynamic fluidic sprinkler	Fordjour *et al*., 2020a	Application uniformity, spacing, different nozzle diameters, and riser heights.	Indoors
25.	Performance optimization of a newly designed dynamic fluidic sprinkler	Zhu *et al*., 2021	Rotational speed, pressure variation, structural parameters	Indoors

Conclusion and future work

A review of the structural design and performance characteristics of fluidic sprinkler application technology has been done. The fluidic sprinkler compares quite well with the impact sprinkler. However, the review highlighted some key issues associated with the fluidic sprinkler, which needs improvement to enhance its performance. The fluidic component has been identified as critical for redesigning and optimising to ensure rotation stability, spray droplets characteristics and operate under low-pressure conditions to enhance its water-saving and energy-saving prospects.

The review highlighted that the fluidic sprinkler appears to have more variability in application rate (0-1.5 mm/h) than the impact sprinkler (0-0.8 mm/h). The wetted radii were, on average, less than the impact sprinkler by 9.7, 9.3, 11.0, and 9.9% at 200, 250, 300, and 350 kPa operating pressure, respectively.

It was observed that experiments on the fluidic sprinkler have mainly been under indoor conditions (more than 90%) and outdoor experiments less than 10%. Of the indoor experiments, concentration has been on the structural design of the fluidic component, water distribution profile, coefficient of uniformity, droplet size characterisation, rotation uniformity, and the effect of different nozzle sizes on hydraulic performance under varying discharge and operating pressure conditions. It is necessary for further research to be performed on the field under wind influence after redesigning and optimisation of the fluidic component and comparison with other sprinklers for benchmarking.

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