S2 The Relationship of Nozzle Parameters, Droplet Characteristics and Relative Spray Drift of the Air Inclusion Nozzle Using in Japan

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Abstract

Compared with conventional nozzles, drift reduction nozzles with larger droplet diameters have been proven to significantly reduce the amount of spray drift. However, a study of how the droplet size characteristics and nozzle parameters such as nozzle height, pressure, and size, influence the drift reduction performance of high-pressure nozzles used in Japan has not been carried out. Therefore, KIRINASHI ES nozzles were investigated by measuring their droplet size characteristics and relative spray drift. The relative spray drift was measured by the wind tunnel test and a laser analyzer was used to obtain the droplet size characteristics. The results indicated that nozzle height had the strongest influence on the drift potential index, followed by nozzle size and nozzle pressure, whereas the droplet size characteristics were found to have little influence. Additionally, a nozzle classification table based on relative spray drift was established.

Key words: spray drift, nozzle height, nozzle size, nozzle pressure, droplet size

1. Introduction

Recently, the demand for air inclusion nozzles has been increasing in the market. KIRINASHI ES nozzles have been widely used as drift reduction nozzles in Japan, especially in the Hokkaido region (Miyahara, 2012). However, the working and design parameters for the nozzles (henceforth referred to as nozzle parameters) being used on boom sprayers in Japan are different from those being used in the Europe and America. The most obvious difference is the nozzle pressure. The ranges of nozzle pressure on boom sprayers in Japan are usually between 1.0 and 1.50MPa. Therefore, the nozzles used in Japan are called as high-pressure nozzle and the nozzles used in Europe and America are called as low-pressure nozzles in the study. The relationship among nozzle parameters, droplet characteristics and the drift reduction performance of high-pressure nozzles might differ from that for low-pressure nozzles.

Measurement of droplet size characteristics, wind tunnel tests to determine the relative spray drift, and field tests of actual spray drift are the main approaches for evaluating the drift reduction performance of nozzles or the overall spray system. Measurement of the droplet characteristics is the fastest of the three and the droplet size distribution has proven to be one of the most important factors influencing the spray drift associated with certain some kinds of nozzles (Nuyttens et al., 2010). However, this method cannot be used to investigate the influence of the nozzle height on the drift reduction performance. Additionally, the influence of droplet characteristics on drift reduction performance of the high-pressure air inclusion nozzles (KIRINASHI ES nozzles) has not been confirmed. Although field tests can be used to evaluate the drift reduction performance of the overall spray system, variable weather conditions can lead to large differences among repetitions and the cost of such tests is relatively high. Additionally, it may be difficult to convince farmers to allow researchers to use liquids other than water, such as the soluble tracers that are often needed for quantitative measurements. Wind tunnel measurements have proven to be a reliable way of evaluating the influence of different nozzle parameters on the drift reduction performance of nozzles (Nuyttens et al., 2010).

Therefore, the goals of the present study are to (1) carry out laser-based droplet size measurements and determine the relative drift potential by wind tunnel tests; (2) evaluate the influence of the nozzle size, nozzle pressure, nozzle height, and droplet size characteristics on drift reduction performance.

2. Materials and methods

2.1 Droplet size measurements

A laser diffraction analyzer, LDSA-1400A (Nikkiso), was used in this study to measure the droplet size characteristics. Using the accessory software, the volume distribution of droplet sizes can be determined, in addition to parameters such as the volume median diameter (VMD) and the volume percentage of droplets smaller than a certain diameter. The VMD and the volume percentage of droplet smaller than a certain diameter were evaluated for different nozzle size and pressure combinations in order to evaluate the influence of the droplet size characteristics on the drift reduction index.

Measurements were carried out on the entire series of KIRINASHI ES nozzles, with nozzle sizes from #05 to #11 with nozzle pressures of 1.0 and 1.5MPa. When measuring the droplet size characteristics, the vertical distance between the nozzle and the laser beam was 0.3 m. For each nozzle size and pressure combination, the measurement was repeated five times.

2.2 Measurement of relative spray drift and index calculation

A schematic diagram of the wind tunnel used in this study is shown in Fig. 1. The dimensions of the wind tunnel and the layout of the drift collector are also shown in the figure. The measuring protocol and other information have been previously reported (Bai et al., 2013).

The nozzle size and pressure combinations used in the wind tunnel tests were the same as those for the measurement of droplet size characteristics. As a measure of the amount of reduction in the drift potential index (DIX), the drift potential index reduction percentage (DIXRP) index was used in this study. The method of calculating the DIXRP has been previously reported (Bai et al., 2013). After determining the DIXRP for each condition, the influence of the nozzle size, nozzle pressure, nozzle height, and droplet size characteristics on the DIXRP was investigated.

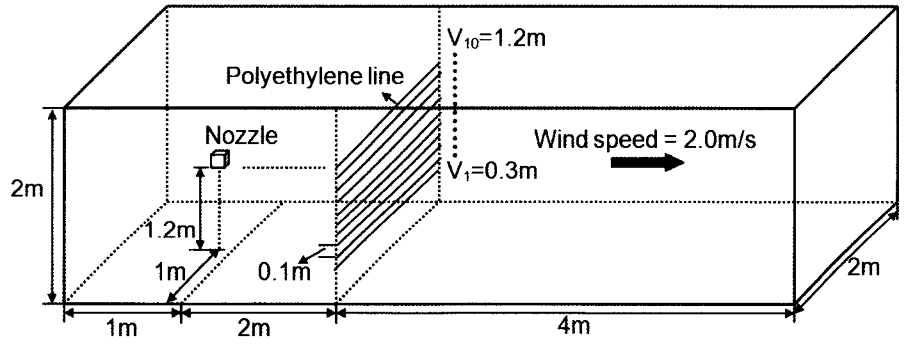

Fig. 1 Sketch of the wind tunnel and the layout of the drift collectors

3. Results and discussion

3.1 Influence of nozzle parameters on DIXRP

Table 1 shows the influence of nozzle height on the DIXRP for different nozzle size and pressure combinations. First order linear regression was carried out to determine the relationship between the DIXRP and the nozzle height for nozzle heights in the range 0.3 to 0.9 m. It was found that nozzle height was inversely proportional to the DIXRP, with high coefficients of determination. It should also be noted that for the single set of nozzle size and pressure combination of ES05-1.50, the regression line exhibited the largest absolute slope, so that the DIXRP decreased most rapidly with increasing nozzle height. This indicates that the nozzle height should be strictly controlled to be as low as possible when the ES05-1.50 condition is applied. The columns to the right of the R^2 values show the threshold value of the nozzle height for which the DIXRP becomes 50%. Based on the Julius Kühn Institut (JKI) classification method, a nozzle is considered to be a drift reduction nozzle if it reduces the drift by more than 50% (Herbst, 2001). Therefore, in the present study, when the nozzle height is smaller than the threshold value for that particular condition, the nozzle can be considered a drift reduction nozzle.

Tables 2 and 3 show the regression equations describing the relationship between the DIXRP and the nozzle size for different nozzle heights, and nozzle pressures of 1.0 and 1.5 MPa, respectively. For a fixed nozzle height, increasing the nozzle size caused a sharp increase in the DIXRP, followed by a slower increase, and the curve could be fit using a log function. Since for pressures of 1.0 and 1.5 MPa, the VMD was found to be about 350 and 300 μm, respectively, regardless of the nozzle height, the increase in the DIXRP with nozzle size is not due to an increase in droplet size. Instead, it may be caused by an increase in the flow rate due to the larger nozzle size. This larger flow rate may produce a thicker spray liquid sheet, which may decrease the effects of wind disturbance on the droplets and lead to a decrease in the amount of spray drift.

Table 3 shows that the coefficients of determination of the regression equations for a nozzle pressure of 1.5 MPa are not very high. A possible reason for this may be that the effect of the flow rate on the DIXRP does not increase when the flow rate becomes relatively high. Polynomial regression was also carried out to achieve higher coefficients of determination. The influence of nozzle size on the DIXRP was statistically significant in a one-way analysis of variance (**P<0.01).

Table 1 Regression equations of the relationship between the nozzle height and the DIXRP values under different nozzle size-pressure combinations where x represents the nozzle height (m) and y represents the DIXRP values (%).

Condition	Regression equation	R^2	x y=50	Condition	Regression equation	R^2	x y=50
ES05-1.0	y=-441.3x+220.1	0.96	0.39	ES08-1.5	y=-239.8x+176.3	0.96	0.53
ES05-1.5	y=-1557.1x+534.7	0.97	0.31	ES09-1.0	y=-164.0x+150.9	0.96	0.61
ES06-1.0	y=-289.0x+189.3	0.95	0.48	ES09-1.5	y=-157.0x+149.9	0.96	0.64
ES06-1.5	y=-389.8x+222.4	0.95	0.44	ES10-1.0	y=-131.5x+143.4	0.95	0.71
ES07-1.0	y=-301.1x+192.4	0.96	0.47	ES10-1.5	y=-174.0x+157.2	0.96	0.62
ES07-1.5	y=-170.1x+152.1	0.96	0.60	ES11-1.00	y=-126.7x+141.1	0.96	0.72
ES08-1.0	y=-170.7x+150.8	0.96	0.59	ES11-1.50	y=-212.9x+174.8	0.95	0.59

Table 2 Regression equations of the relationship between the nozzle size and the DIXRP values under 1.0MPa nozzle pressure at different nozzle height where x represents the nozzle size (diameter, mm) and y represents the DIXRP values (%).

Nozzle height, m	Regression equation	R^2
0.9	y = 271.31ln(x) + 18.215	0.9027
0.7	y = 147.01ln(x) + 57.913	0.8906
0.5	y = 76.998ln(x) + 83.388	0.8539
0.4	y = 52.274ln(x) + 91.406	0.8311
0.3	y = 33.847ln(x) + 96.854	0.8333

The influence of the nozzle pressure on the DIXRP for a nozzle height of 0.3 m is shown in Fig. 2; similar results were found for other nozzle heights, and are not shown here. A one-way analysis of variance on the data shown in Fig. 2 for nozzle sizes of #05 and #07 showed that the influence of nozzle pressure was statistically significant (**P < 0.01). The reason why the nozzle pressure had no significant influence on the DIXRP for other nozzle sizes may be that the droplet size decreased, the flow rate increased and the droplet velocity increased with increasing nozzle pressure. These factors may have interacted with each other, leading to no significant influence of the nozzle pressure on the DIXRP. For the ES05 condition, the DIXRP abruptly decreased with increasing nozzle pressure, possibly because this condition produces the thinnest droplet sheet which could easily be affected by the wind. Thus, the influence of the flow rate and the droplet velocity on the DIXRP could not counteract that of the decrease in droplet size when the nozzle pressure increased.

Table 3 Regression equations of the relationship between the nozzle size and the DIXRP values under 1.5MPa nozzle pressure at different nozzle height where x represents the nozzle size (diameter, mm) and y represents the DIXRP values (%).

Nozzle height, m	Regression equation 1	R^2	Regression equation 2	R^2
0.9	$y=903.9\ln(x)+63.2$	0.56	$y=-5435.4x^2+9770.5x-4288.7$	0.82
0.7	$y=521.5\ln(x)+87.1$	0.55	$y=-3123.7x^2+5617.5x-2416.4$	0.81
0.5	$y=253.5\ln(x)+99.1$	0.56	$y=-1482.6x^2+2673.9x-1096.8$	0.80
0.4	$y=166.4\ln(x)+103.5$	0.58	$y=-919.3x^2+1670.1x-650.0$	0.79
0.3	$y=99.1\ln(x)+104.5$	0.58	$y=-542.7x^2+987.0x-341.4$	0.79

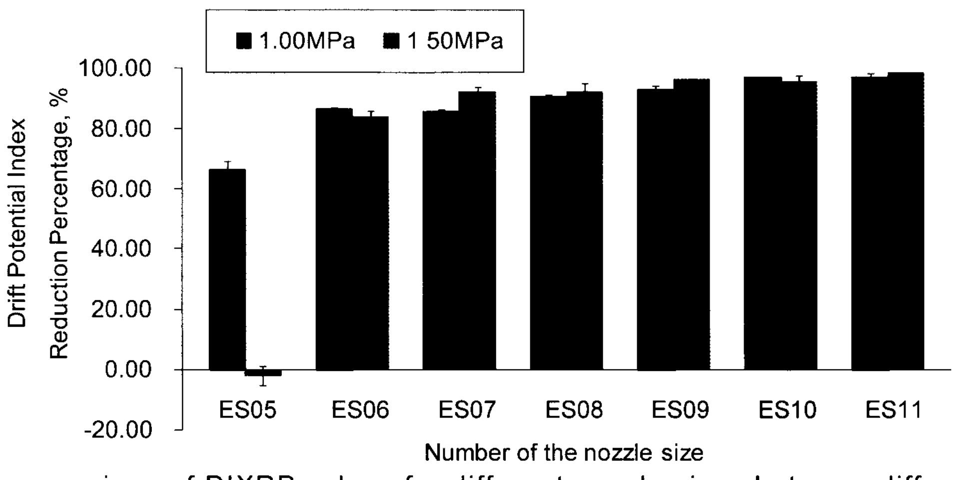

Fig. 2 The comparison of DIXRP values for different nozzle sizes between different nozzle pressures at 0.3m nozzle height

3.2 Influence of droplet size characteristics on DIXRP

For two nozzle pressures, the droplet size characteristics under different nozzle sizes are shown in Fig. 3 and 4, respectively. The droplet size characteristics include VMD and the volume percentage of droplets smaller than a certain diameter (V80, V100, V120, V150, and V200). Because the VMD shows a strong linear relationship with V200 (R^2=0.95), V150 (R^2=0.91), V120 (R^2=0.86), V100 (R^2=0.82) and V80 (R^2=0.77), the VMD could be used as a droplet size indicator for analyzing the relationship between the droplet size characteristics and the DIXRP.

Although the DIXRP increased with nozzle size, the VMD did not (Figs. 3 and 4). The VMD even exhibited a gradual decrease when the nozzle size was increased from #06 to #11. This suggests that the droplet size characteristics have little effect on the DIXRP for the conditions used in the present study. Thus, for KIRINASHI ES nozzles, nozzle height and nozzle size may be the most important parameters determining the DIXRP. The reason why the droplet size characteristics did not obviously influence the DIXRP may be that the droplet size did not vary much among the different nozzle sizes (Figs. 3 and 4). The VMD for all nozzle sizes was in the range 300 to 400 μm and 250 to 350 μm for nozzle pressures of 1.0 and 1.5 MPa, respectively. However, as mentioned above, the larger flow rate may lead to a thicker droplet sheet that could suppress the drift phenomenon. It should be mentioned that the VMD has often been found to increase with nozzle size for other air inclusion nozzles (Nuyytens et al., 2007). This may be due to differences in nozzle design and the corresponding working parameters.

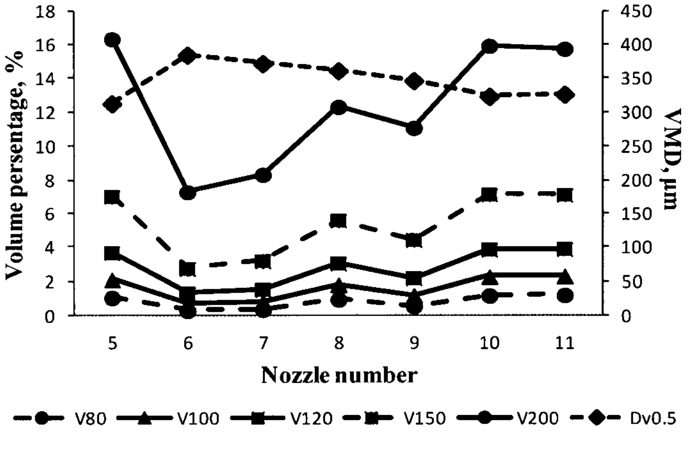

Fig. 3 Droplet size characteristics data under different nozzle sizes at 1.0MPa nozzle pressure

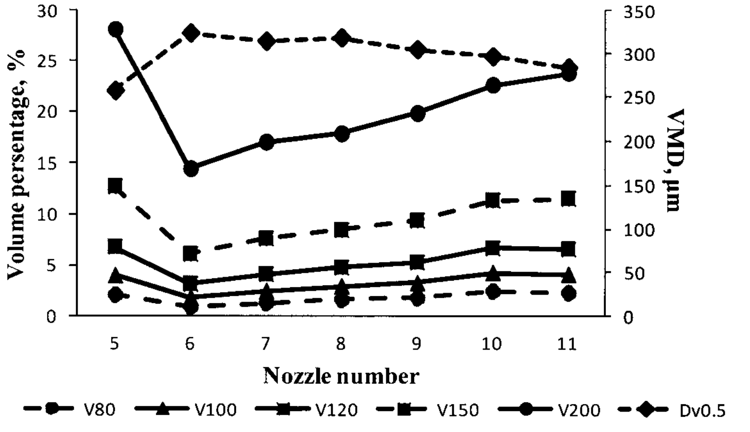

Fig. 4 Droplet size characteristics data under different nozzle sizes at 1.5MPa nozzle pressure

4. Conclusions

For KIRINASHI ES nozzles, the influence of the nozzle parameters (nozzle height, size and pressure) and droplet size characteristics on the drift reduction index (DIXRP) was evaluated in a wind tunnel test. Nozzle height was found to have the strongest effect on the DIXRP, followed by nozzle size and nozzle pressure. The droplet size characteristics had little influence on DIXRP because droplet size was relative independent of nozzle size. The increase in the flow rate, which may lead to a thicker droplet sheet, might be the dominant factor causing an increase in the DIXRP for the investigated conditions. Linear and log functions were used to express the relationship between the nozzle parameters and the DIXRP. Future works will focus on a deeper investigation of nozzle design to get a better understanding of high-pressure air inclusion nozzles and also a comparison of the spray performance between low-pressure and high-pressure nozzles to investigate the possibility of cost and energy saving if low-pressure nozzles could be used instead of high-pressure nozzles.

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