Design of an agricultural nozzle:
Experimental investigation of a round jet impacting vertically a horizontal disk

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Agricultural background and goal

Emitted droplets within sprays drastically affect agricultural treatment efficiency. Decades of technical developments in the crop protection field have led to different nozzles designs: Hydraulic nozzles, which are widely used, produce a liquid sheet followed by ligaments that lead to droplets of various sizes. However, spinning discs, which were designed in 1980, use centrifigual forces to produce round liquid jets of uniform sizes at the exit of a serrated disk then the jets break in almost uniform droplets by the Rayleigh-Plateau mode (the most unstable perturbation breaks the jet in droplets of 1.89 times the jet diameter) (Strutt & Rayleigh, 1878; Dumouchel, 2008). However, the spinning disc is bulky and requires an extra power source, what may explain his commercial failure. On this basis, this study is the first step to design a hydraulic nozzle producing a narrow droplet spectrum based on the Rayleigh-Plateau break up mode.

Nozzle description

The nozzle geometry can be simplified as a pipe set perpendicularly on a horizontal disk. The disk was Plexiglas cut with laser cutter. The diameter jet is 3 mm and the gap between pipe tip and the plate is 0.5 mm.

Disk flow: flow radial expanding and liquid sheet formation

The tap water flow (σ = 72 mN m^{-1}) impact the plate center and flows radially to create a liquid sheet with specific thickness and disc according to the radial distance on the disk (De Cock et al., 2014). Then, the flow exceeds the disk edge to form a liquid sheet, which is bordered by a rim collecting the liquid (Gordillo et al., 2014) and resulting into droplets with various sizes.

The thickness of the liquid sheet is measured using a fine needle. When the needle touches the liquid surface, a droplet will be formed rapidly (initial height). Then, the liquid fed is stopped and the needle gets down until reaching the disk surface. The difference between the two positions heights corresponds to the liquid thickness. Fig.1 shows measured velocities at the disk edge as a function Re number for three disk diameters. Re, which depend only of the applied liquid flow rate, indicate higher values reflecting a turbulent regime. The velocity of the liquid is increased when the Re is increased. Also, the flow is slowed when the disk diameter is increased due to much friction.

Disk border

Different exits structures such as teeth, grooves and needles were investigated in order to split the liquid sheet into multiple jets. Only grooves were found most efficient as they guide correctly the flow on the disk border to multiple jets despite they slow down the flow velocity. Fig. 2 shows the percentage of grooves occupancies rate on the disk, which is calculated as the number of grooves multiplied by their widths and divided by the disk perimeter, as a function the flow rate. Different scenarios of the liquid sheet behavior can be observed. For both slow occupancies percentages and flow rates, main (through the groove) and secondary (between the groove) jets are obtained. These main jets are remained as the flow is increasing but the form of secondary jets is magnified until having a V shape and may also be merged. For medium grooves occupancies, main and secondary jets are formed and they may also be merged for all flow rate ranges. For higher occupancies percentages, only main jets are observed, which determine the zone of interest. The main jets can be also merged in case of higher flow rates.

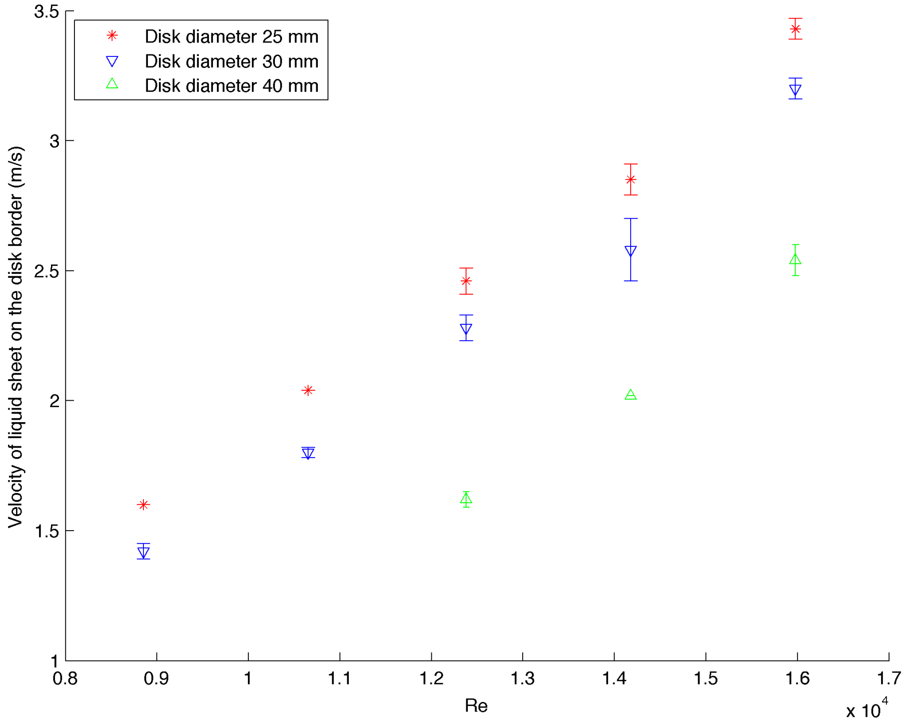

Fig. 1. Velocity of the liquid flow on the disc edge as a function of Reynolds numbers

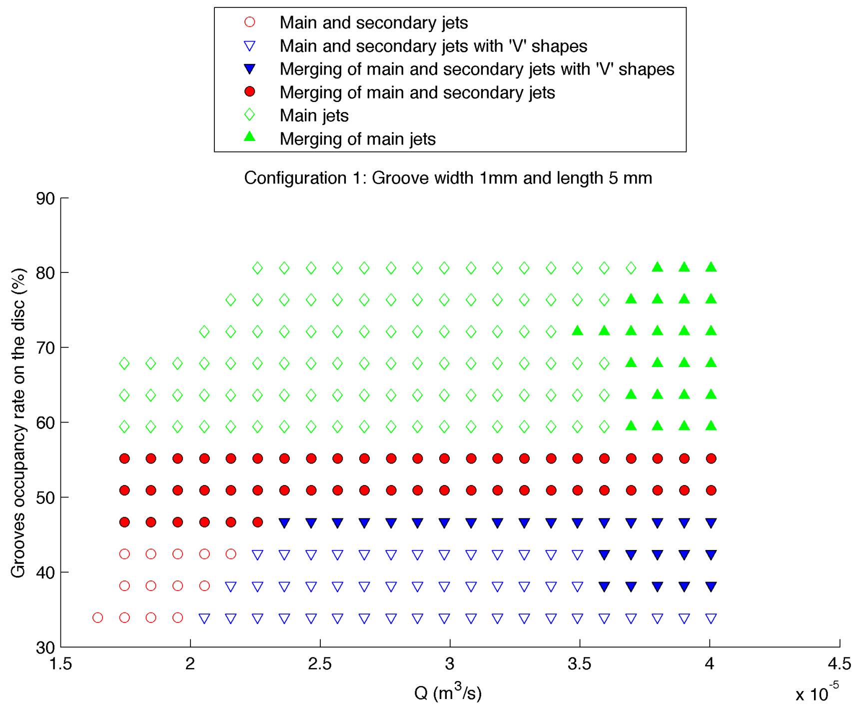

Fig. 2. Percentages of grooves occupancies on the disk as a function of the applied flow rate (Disk radius is 15 mm)

Conclusion

Measured velocities at the disk edge are too much slow as intended compared to recommended agricultural sprays (around 10 m/s). Minimizing the pipe radius or increasing flow rates may be the right alternatives to meet these previous recommendations. Also, grooves seem useful to correctly guide the flow on the disk to multiple jets. Further work is needed to influence the size of emitted droplets such as needles or flexible features.

References

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