Assessment of nozzle flow rate measurement methods for the inspection of sprayers in use

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Introduction

According to the directive 2009/128/EC by the end of 2016 all the sprayers in use working in the EU member states shall be inspected at least once. After that date, inspections shall be repeated at regular intervals, not longer than 3 years after 2020. The inspection protocol in most countries is based on the EN 13790:2003 standard for field crop and air-assisted sprayers, which now is under revision to be harmonized with the above-mentioned directive. This standard establishes the measurement of the nozzle flow rate as the only way to assess the liquid distribution uniformity in air-assisted sprayers. For field crop sprayers, there is also the possibility of determining the spray distribution uniformity of the sprayer booms by means of spray scan devices.

Nozzle flow rate measurements can be made detaching the nozzles from the sprayer and measuring the flow rate of each single nozzle on a measuring bench or with the nozzles mounted on the sprayer using, if required, different kinds of nozzle adaptors to convey the liquid flow to the measuring device (Fig. 1). In order to make the nozzle flow rate measurements on the sprayer easier, air-tight adaptors are often used in several manual and electronic benches. This kind of adaptors are said to cause inaccuracies in the flow rate measurement of spray nozzles. Osteroth (2007) showed that the nozzle air flow rate measured with air-tight adaptors is higher than the real value in the case of air injection nozzles working at less than 10 bar. Besides, the measured error is higher with flat fan nozzles than with hollow cone nozzles. The author advices the use of nozzle air-tight adaptors just for comparison purposes.

Fig. 1. Nozzle flow rate measurement in an air assisted sprayer.

Vanella *et al*. (2011) tested many flat fan and some hollow cone nozzle models with several nozzle flow rate measurement, air-tight adaptors and showed that the use of this kind of adaptors increased the flow rates of air induction and extended range flat fan nozzles. In the case of air induction nozzles, plugging the air holes increased the flow rate. The increase in flow rate decreased with nozzle pressure. The increase of the nozzle flow rate depended on the nozzle type but it was not affected by the nozzle size. The use of funnel shaped adaptors instead of the air-tight adaptors increased the liquid flow measurement accuracy but it requires holding a graduated cylinder under each nozzle.

In a previous work in our Institute (Camp, 2008), several nozzle flow rate measurement benches using air-tight adaptors were compared with other measuring systems. In that case, Albuz® ATR nozzles at 7 bar mounted on an air-assisted sprayer were used. Results showed a small variation among the measurement values obtained with the same bench and also a small deviation (less than 2%) between the average values obtained with the different benches. It has to be taken into account, though, that only

a single nozzle model working at the same pressure was used in the test.
In this paper, the flow rate measurements on different nozzle models working at different pressures and using several measuring systems are presented and their accuracy is compared using a statistical analysis.

Methodology

Three methods for measuring nozzle flow rate in the sprayer inspection were assessed:

a. volume measurement with a graduated cylinder and a stopwatch, using a hose for liquid collection at the nozzle outlet. The hose connection with the nozzle is not air tight, so it is necessary to hold a graduated cylinder below the nozzle outlet level to avoid any leaks. It is a methodology that is often used for the measurement of nozzle flow rate on air-assisted sprayers (Fig. 2, left).
b. electronic bench with an air-tight adaptor at the sprayer nozzle outlet. The bench performs an electronic measurement of each single nozzle flow rate based on the time taken for each nozzle to fill a cylindrical container. Air-tight adaptors are required to convey the liquid from the nozzles to the containers so that the nozzle output can be locatred below the container level. In this case, the flow rate measurement is also made with the nozzles mounted on the sprayer (Fig. 2, centre).
c. nozzle flow rate bench for detached spray nozzles. The nozzles have to be dismounted from the nozzle holders and placed on the bench board. The bench is equipped with a pressure gauge and a flowmeter (Fig. 2, right).

Fig. 2. Three methods for nozzle airflow measurement, graduated cylinder and stopwatch (left), air-tight nozzle adaptor (centre) and nozzle flow rate bench (right).

Eleven nozzle models were chosen from four manufacturers (tab. 1), in order to determine the effect of the nozzle type (flat fan or hollow cone) and the air injection technology on the accuracy of the liquid flow rate measurements.
Three different nozzle sizes were selected from each nozzle model, randomly selecting four nozzle units for the combination of nozzle model and size. The flow rate for each single nozzle was measured at three different pressures in a two replication basis. The working pressures for each nozzle model were selected within the pressure range advised by the sprayer manufacturer.
A general lineal model was used for the analysis of the variance of the flow rate measurement results. The following main classes were considered in the model: measurement method, nozzle type, nozzle size and working pressure. The interaction between nozzle type, nozzle size and pressure were also taken into account in the model. The calculations were made using the SAS 9.0 software.

Tab. 1. Nozzle models and working pressure used in the tests. Air injection nozzles are depicted in italics

Manufacturer	Nozzle models and size	Pressure (bar)
Albuz®	API 110 02, 03, 04(1)	2, 3, 4
	AVI 110 02, 03, 04(1)	3, 5, 7
	ATR yellow, orange, red(2)	5, 8, 10
	TVI 80 015, 02, 03(2)	5, 8, 10
Teejet®	XR 110 02, 03, 04 VS(1)	2, 3, 4
	TXA 80 015 VK, TXB 80 02, 03 VK(2)	5, 8, 10
Hardi®	F 110 02, 03, 04(1)	2, 3, 4
	INJET 02, 03, 04(1)	3, 6, 8
Lechler®	*IDK 120 02, 03, 04*(1)	2, 4, 6
	TR 80 015, 02, 03(2)	5, 8, 10
	ITR(3) 80 015, 02(2)	5, 8, 10

(1) Flat fan; (2) hollow cone; (3) only two nozzles sizes were selected for this model

Results

No significant differences were found between flow rate measurements of the nozzles mounted on the nozzle holder, using a hose to collect the spray, and measurements of the same detached nozzles in the nozzle bench. However, when the air-tight adaptors where attached to the nozzle outlet, in most of the cases the flow rate values deviated from those measured using the hose. Positive deviations were measured when all flat fan and air injection hollow cone nozzles were used (Fig. 3), whereas they were negative for hollow-cone standard nozzles (Fig. 4).
Tab. 2 clearly shows that deviations for flat-fan nozzles –especially air injection- working at a lower pressure are significantly higher than those obtained at higher pressure. This trend was also noticed when air injection hollow cone nozzles were used, but not for the standard hollow cone nozzles (tab. 3), where they remain similar. Nozzle size does not affect the deviation values for any type of the tested hollow cone nozzles, and only a minor effect was noticed for flat fan nozzles (tab. 4).

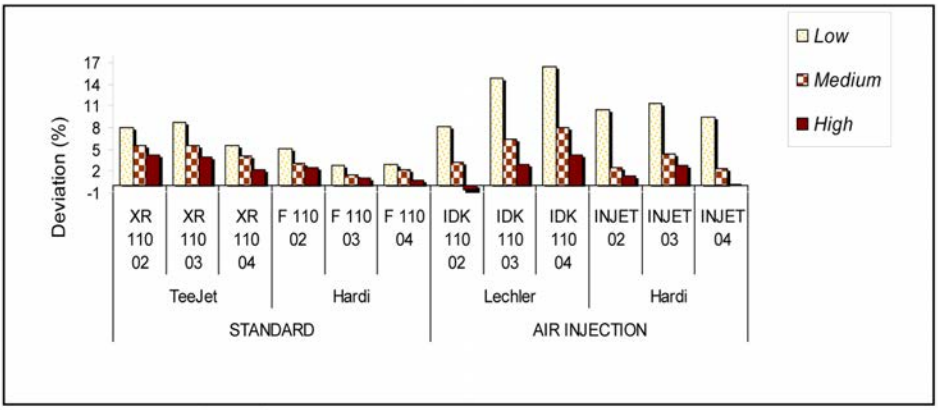

Fig. 3. Deviation values for the flow rate measured at three working pressures with an air-tight adaptor on different models of flat fan nozzles. The value of the pressure level (Low, Medium and High) is different for each nozzle model, so that it fits within its working pressure range.

Tab. 2. Average deviation values (%) between the flow rate measured with an air-tight adaptor and with a hose. The value of the pressure level is different for each nozzle model, so that it fits within its working pressure range. Values followed by the same letter within each row are non-significant (p<0.01)

Flat fan nozzle type	**Pressure**		
	Low	Medium	High
Standard	4.55 a	3.17 b	2.23 b
Air injection	11.55 a	4.78 b	2.26 c

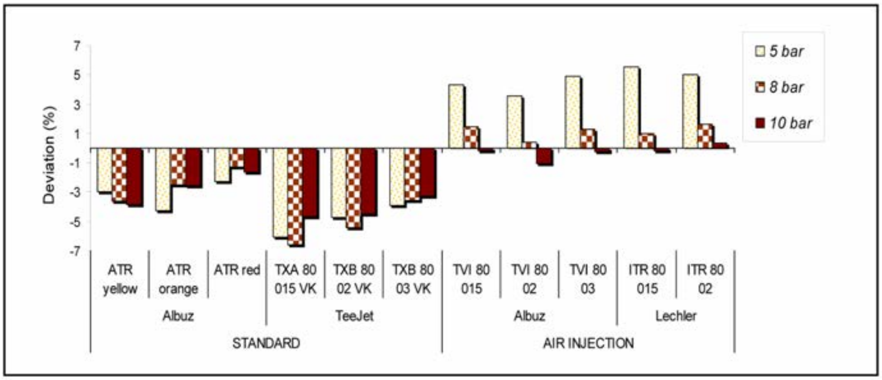

Fig. 4. Deviation values for the flow rate measured at three working pressures with an air-tight adaptor on different models of hollow cone nozzles.

Tab. 3. Average deviation values (%) between the flow rate measured with an air-tight adaptor and with a hose. Values followed by the same letter within each row are non-significant (p<0.01)

Hollow cone nozzle type	**Pressure**		
	5	8	10
Standard	-3.50 a	-3.45 a	-3.02 a
Air injection	4.70 a	1.17 b	-0.24 c

Tab. 4. Average deviation values (%) between the flow rate measured with an air-tight adaptor and with a hose. Effect of nozzle size for flat fan nozzles. Size values are those established in ISO 10625:2005. Values followed by the same letter within each row are non-significant (p<0.01)

Flat fan nozzle type	**Size**		
	02	03	04
Standard	4.60 a	3.22 b	2.12 b
Air injection	5.18 a	6.89 b	6.52 b

Discussion

As it was already shown in previous works (Osteroth 2007, Vanella *et al*. 2001), significant differences were found when air-tight adaptors were used for the nozzle flow measurements, compared with the methodologies that don't imply the modification of the spray formation conditions at the nozzle outlet.

According to the results, it is difficult to establish a clear trend for the measurement deviations. In general, but not in all the cases, the difference is higher when the measurements are carried out at lower pressures. In the case of standard hollow cone nozzles the deviations are negative and they are not significantly affected by pressure changes.

Therefore, measurements with air-tight adaptors are in general more reliable when they are carried out at the higher pressures of the nozzle working range. In the case of standard hollow cone nozzles, the measured deviations at 10 bar were always lower than 5%, as it was the case with standard flat fan nozzles working at 4 bar (Fig.s 3 and 4). Nevertheless, it must be taken into account that the EN 13790:2003 standard only allows for a maximum error of 2.5% of the measurement devices used for the inspection of sprayers in use.

The higher deviations were recorded in the case of flat fan air-injection nozzles working on the lower level of the pressure range. This effect may be caused by plugging the air holes with the air-tight adaptors (Vanella *et al*., 2011), although in the case of air-injection hollow cone nozzles, working at 8 or 10 bar, almost no deviations were measured (Fig. 4).

The possibility of a measurement error, in the case of using air-tight adaptors for nozzle flow rate measurement in the inspection of sprayers in use, should be taken into account. However, the fact that these devices have got clear advantages in relation to the other methodologies, make them widely used by the inspection workshops.

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