Metrological requirements for a laboratory rainfall simulator

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Abstract

The liquid precipitation at the ground level is measured by means of different techniques and technologies for areal and point-scale quantification of rainfall intensity RI (mm/h) and the resulting total precipitation amount h (mm). Point-scale precipitation gauges fall in two main categories: catching type gauges, which collect the liquid equivalent precipitation into a measuring bucket, and non-catching type gauges, where the collection of water is not required. Since the latter category of gauges employ a variety of developing measuring technologies, the implementation of appropriate calibration procedures has been included within the scope of the European Metrology Research Programme MeteoMet 2 (ENV58-REG3). This work reports about a study conducted by the WMO-CIMO Lead Centre “B.Castelli” on Precipitation Intensity (LC-PrIn) aimed at the design and preliminary testing of an advanced laboratory rainfall simulator capable of generating non-continuous water flows (droplets) with controlled RI and the drop size distribution. A real-world drops size distribution is approximated by simplifying the domain of droplets diameter d (mm) in three main categories of fixed size. The technical advantage derived from the availability of such device arises from its suitability to calibrate non-catching type gauges.

1. Introduction

In nature, the liquid precipitations have different micro-physic characteristics that mainly depends on the rainfall intensity (RI), the local climatology and also the chemical composition of the raindrops. Hydro-meteorological applications often characterize the time-space microstructure of precipitation event by means of the drops size distribution *N(D)* ($m^3 mm^{-1}$), where *D* (mm) is the drop equivalent diameter. An example of *N(D)* measurements made by two different non-catching type instruments located in Florence (Italy) is provided by Caracciolo et al. (2008) and reported in Figure 1.

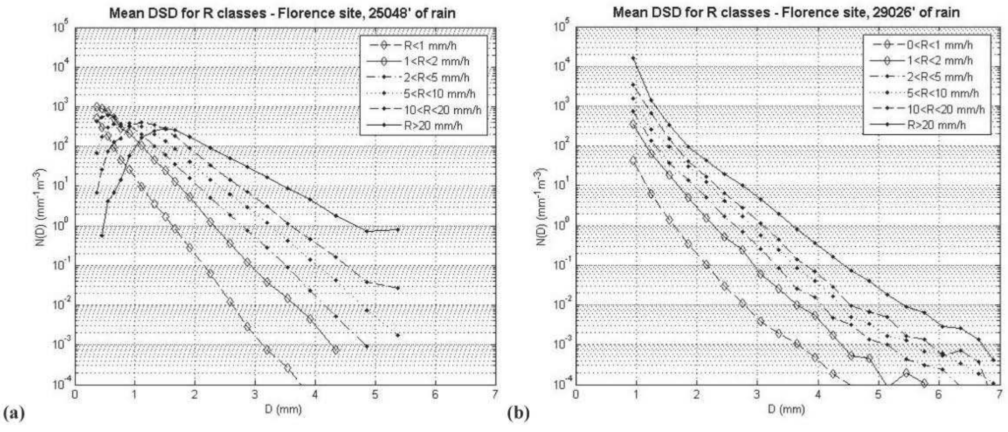

Fig 1: Co-located DSD measurements made by an impact Joss-Waldvogel disdrometer (a) and a X-band radar disdrometer (b) in Florence (Caracciolo et al., 2008).

Modern non-catching type gauges are generally able to provide such information about the internal structure of precipitation and to estimate the terminal velocity v (m/s) and the deriving RI for a given sensing area. This kind of instruments can measure both liquid and solid precipitation using various measuring principles such as optical, piezo-electric and radar.

The recent WMO Field Intercomparison of Rain Intensity Gauges (Lanza and Vuerich, 2009) revealed noticeable error figures of the rainfall intensity measurements made by non-catching type instruments when compared to other commercial catching type gauges (Figure 2). During the campaign, reference RI values were provided by a selection of catching-type gauges whose performance had been validated in the laboratory. Such low performance are ascribed to the yet unsolved difficulties in establishing reliable relations between the rainfall rate and the physical variables measured by optical, acoustic or radar sensor indications.

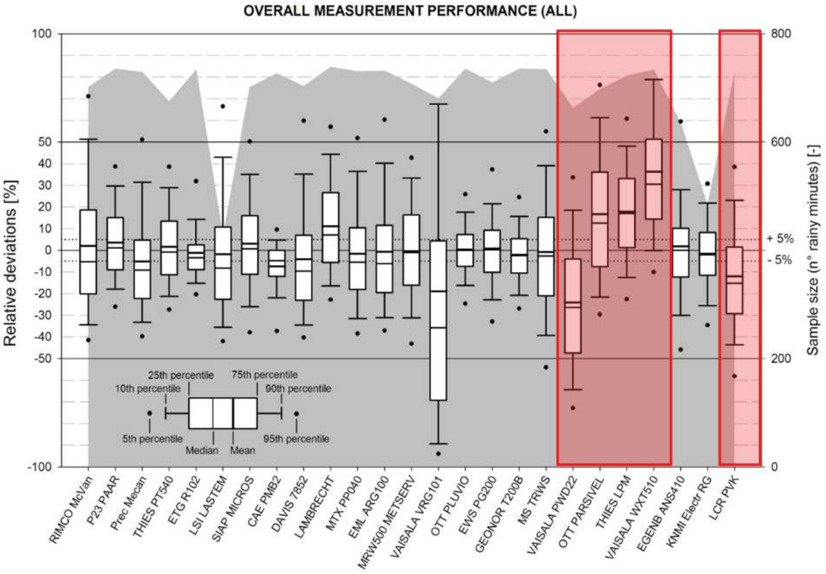

Fig 2: Overall relative deviations (%) of the one-minute RI measurements made by co-located precipitation sensors during the latest WMO Field Intercomparison of Rain Intensity Gauges (Lanza and Vuerich, 2009). The right axis reports the sample size (n. of rainy minutes) and the red boxes highlight the performance of non-catching type gauges.

2. Methods

The Rainfall Simulator (RS) prototyped by the WMO-CIMO Lead Centre “B.Castelli” on Precipitation Intensity (LC-PrIn) is based on the use of independent hydraulic channels driven by volumetric pumping systems that are able to realise different flow rate values (Lanza et al., 2015). Each channel feeds a series of nozzles characterized by the same internal diameter and allows the drops generation of a known constant size.

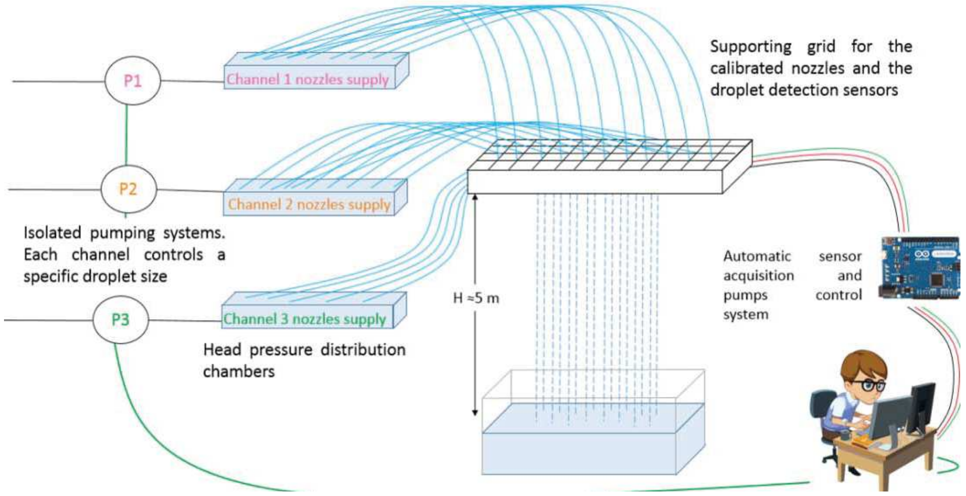

Fig 3: General outline of the LC-PrIn rainfall simulation system.

The current version of the RS simplifies different drop size distributions reported on Figure 1 by classifying the drop diameter axis in three classes. This is achieved by adopting three hydraulic channels and as many groups of nozzles as synthetized in Figure 3.

The control of the drops distribution is performed by measuring the drops dispensing frequency of each nozzle with proximity Infra-Red (IR) light sensors and by adjusting the channel pump speed (i.e. the flow rate) accordingly. Figure 4 shows some details of the pressure head distribution chambers (panel a), the prototype drop dispensers grid (panel b) and the provisional RS tower (panel c). The final assembly of the RS tower is currently under development.

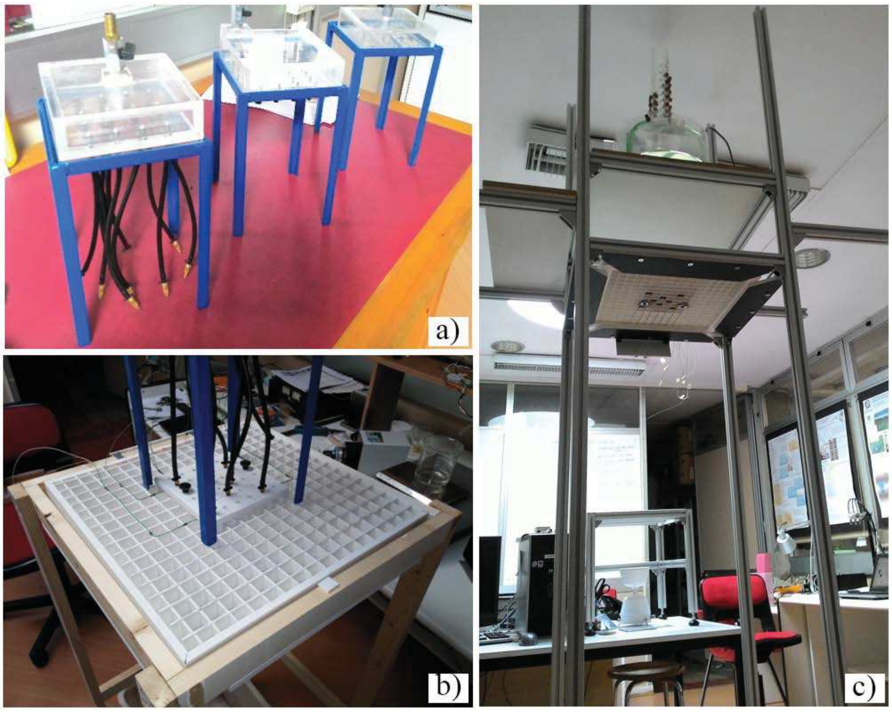

Fig 4: Details of the water pressure head distribution chambers (a), the nozzle supporting grid (b) and the provisional assembly of the RS tower.

The next section outlines the preliminary results of the RS drop forming system tests necessary to establish the mathematical relationships between the channel flow rates, the drops frequency and size. Several nozzle sizes are investigated in order to optimize the width of the simulated drop size classes with respect to the real-world rainfall distributions *N(D)*. The experiments have been conducted by weighing the water dispensed by a single nozzle connected to the pumping system which has been set at given flow rate values and by recording the drops frequency with a proximity IR sensor.

3. Evaluation of the simulator performance

Constant flow rates *Q* (ml/min) tests highlighted steady drops dispensing frequency (Hz) from a single nozzle after an initial transient due to the hydraulic system warm-up (Figure 5). The time response of the pumping units has been previously estimated by means of dedicated laboratory tests reported by Colli et al. (2013). The repetition of single nozzle tests for different flow rates and different nozzles internal diameter *DI* (mm) allowed the definition of the drop frequency/diameter *D* (mm) curves reported on Figure 6. The tested set of *DI* and *Q* values allows covering a drop diameters range equal to 1.5 mm < *D* < 3.5 mm. On the other hand, the drop size distributions measured in the field (Figure 1) has a wider *D* range and particular relevance should be given to the *D* < 1.5 mm region since it’s associated to the higher *N(D)* values. Dedicated testing are currently under progress at the LC-PrIn laboratory in order to obtain smaller droplets by changing the superficial tension of the fluid and to reduce detachment time of the droplet from the nozzle.

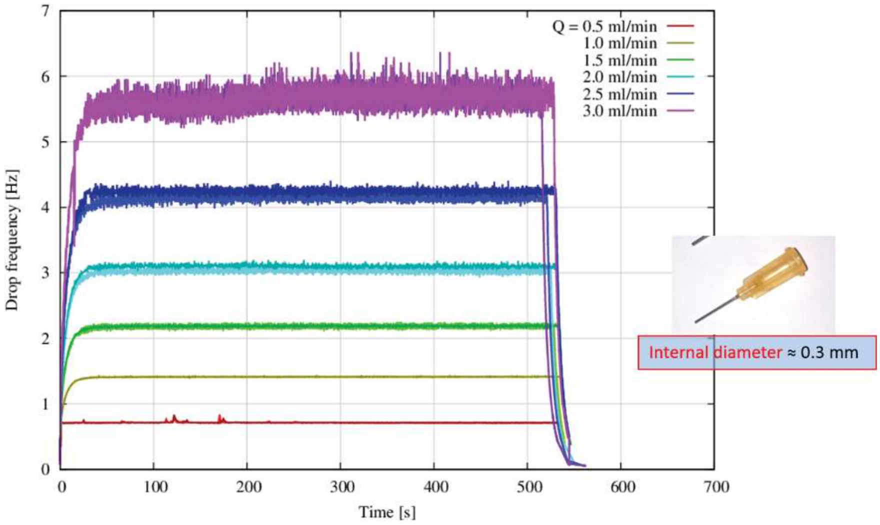

Fig 5: Drop frequency (Hz) time series of a single nozzle dispensing under different constant flow rate *Q* (ml/min) values (Lanza et al., 2015).

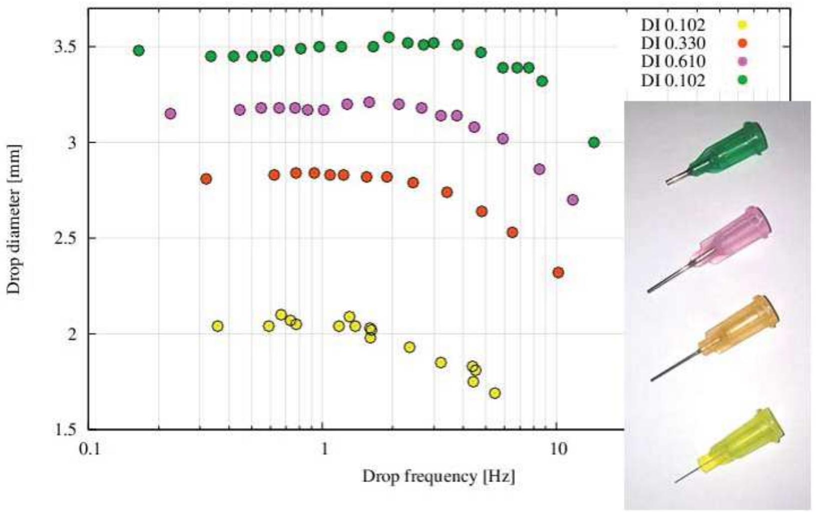

Fig 6: Scatter plot of the drop frequency (Hz) vs. drop diameter *D* (mm) measured during constant flow rate tests of single nozzle (Lanza et al., 2015). The tests were repeated for four different nozzles internal diameter *DI* (mm).

Figure 7 shows the results of preliminary drop frequency tests performed by varying the water mixture and imposing a constant flow rate and nozzle size *DI*. Relevant changes in the resulting drop diameters *D* has been revealed by adding small fractions of alcohol and commercial surfactants to distilled water.

Further tests are currently under execution in order to check the performance of a series of nozzles operating in parallel and connected to the same pumping channel by means of a pressure head distribution chamber (showed in panels a and b of Figure 4).

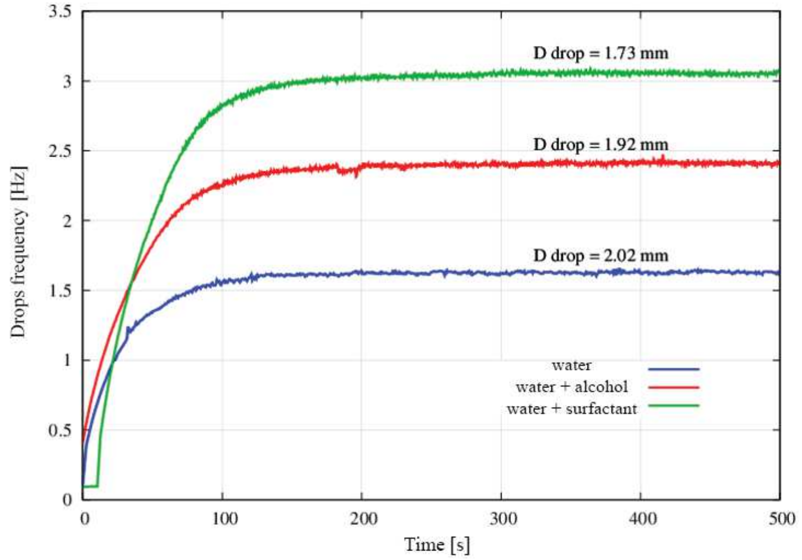

Fig 7: Example of the drop frequency (Hz) time series measured for a single nozzle under constant flow rate Q and varying the water mixture (Lanza et al., 2015). Different drop size *D* (mm) values are reported on the plot.

4. Conclusions

The current Rainfall Simulator (RS) design is based on the approximation of realistic drop size distribution *N(D)* by means different drop forming elements (nozzles) working in parallel and driven by separated water pumping channels. A real-time validation system still has to be included in the RS final assembly and dedicated tests will be performed. More work has to be done in order to generate droplets that fall with terminal velocity values that are comparable to the real precipitation.

The repeatability of the droplet size/frequency relationships has been demonstrated. A warming-up time must be accepted before starting the rainfall simulation, this is particularly true in case of small nozzles (*DI*<=0.303 mm). It's also necessary to expand the analysis to the simultaneous dispensing from a larger number of nozzles (>> 2) in order to check the spatial distribution of the simulated drop size distribution for different gauge sensing areas.

The random position of rain drops over the disdrometers sensing area is here approximated by adopting a large number of operational nozzles. Future developments of this study will be aimed at the choice of optimal drop diameter classes that allow the simulation of realistic *N(D)*. In relation with this, more nozzle sizes and fluid mixture must be tested. In the current RS prototype, the drop size distribution is synthetized in three mean diameter classes.

The uncertainty associated with the generated rainfall intensity and drop size distribution values is currently under quantification by means of dedicated tests performed in a controlled environment.

Acknowledgement

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