

Spray measurements in SCR systems development

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Introduction

Recently the importance of spray measurements in automotive urea-SCR (Selective Catalytic Reduction) systems development has strongly increased. Since the in-line under floor exhaust systems have been replaced with close-coupled to the engine designs, the distance available for UWS evaporation and urea decomposition has dramatically decreased. Close-coupled to the engine SCRs are preferred due to higher exhaust gas temperature and NO_x reduction [1]. Near-engine location results in decreased distance for water evaporation and urea decomposition. Thus, spray properties need to be properly adjusted to specific SCR system design – this includes injector selection and its location optimization. One needs to be aware that properly adjusted spray alone is not sufficient to assure water evaporation and urea decomposition before the inlet to the catalyst in typical close-coupled SCR design. Therefore, the additional static mixing elements are needed to enhance mixing and provide proper NH₃ distribution at inlet to the catalyst. Majority of work related to static mixer designs and SCR design optimization is done using CFD (Computational Fluid Dynamics) simulations, where full SCR system designs are considered [2]–[5]. These simulations include both spray formation in the gaseous media and spray-wall interaction. Spray modelling in turn requires much data on the spray properties which needs to be determined experimentally. The simplified early-stage development process of SCR systems including experimental spray measurements is shown in Fig. 1.

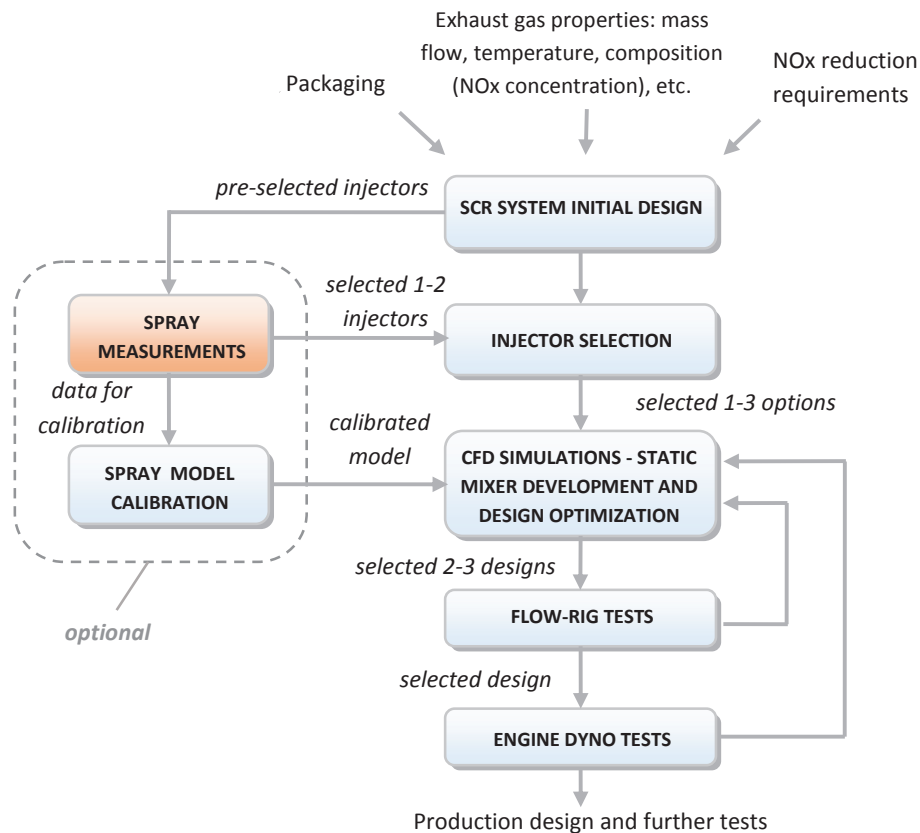


Figure 1. Simplified early-stage development process of SCR systems

As shown in Fig. 1 the spray measurements take place at very initial stage of SCR development in parallel to main activities. This comes out from the fact that the SCR system development can be done basing only on data provided by injector manufacturer, and thus spray measurements can be regarded as optional activities. However, simplified approach (excluding spray measurements) has strong disadvantage since data provided by manufacturer is usually limited while the injector characterization can provide additional data such as droplet spatial distribution which allows to properly select injector to specific system and calibrate spray models. Spray measurements included in the development process allow to directly compare injectors from different manufacturers assuring that the compared data is not affected by different experimental setups.

When additional spray measurements are included, the main activities in SCR system development remain the same, however the input data is different. In that case, directly after creating initial SCR system design which is done basing mainly on vehicle and engine features as well as target market needs (emissions limits), the initially preselected injectors are tested experimentally. Initial injector preselection is done using injector manufacturer data and CAD (computer aided design) simulations, i.e. fitting spray cones into exhaust system. Based on spray measurements the injector (max. 2 injectors – second as the alternative option) is selected to be used in the developed SCR systems. Moreover, the experimental data on spray properties is used to calibrate numerical models, which are then used to develop static mixers and optimize SCR design including injector location in the system. In this study the spray measurement procedure is shown, and techniques used to determine required spray parameters are discussed.

Material and methods

The spray parameters needed to select injector and calibrate spray models include spray angles (plume directions, plume angle and visualisation angle), spray tip penetration evolution and droplet size distribution. High speed imaging with global illumination was used for global spray parameters determination (visualisation angle, single plume angle, jet directions and spray tip penetration). As for the droplet size distribution, sprays for SCR applications due to relatively large droplets (typically around $100\mu\text{m}$) and low number density offer huge potential in terms of applied techniques. In this study shadowgraphy with long distance microscope was used to determine droplet size distribution. Due to frequency of the laser limited to 10 Hz only one image per injection was taken, and the droplet size distribution was composed for 100 consecutive injections.

Due to limited field of view in shadowgraphy setup, additionally LIF/Mie approach (Laser Induced Fluorescence and Mie scattering) was used to determine qualitative droplet size distribution across the whole spray cloud. The LIF/Mie method was coupled with structured illumination to minimize noise signals caused by background reflections and multiple scattering. The setup for LIF/Mie measurements with structured illumination is shown in Fig. 2.

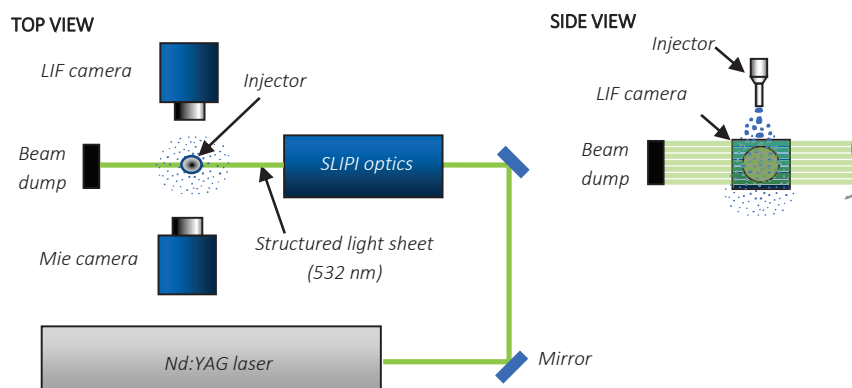


Figure 2. Schematic diagram of complete experimental setup [6]

Results and Discussion

The acquired data was used in both development stages, injector selection and spray model calibration for full SCR system CFD simulations. Injector selection was done basing on shadowgraphy results. The selection was done by both qualitative and quantitative comparison of the results. The raw shadowgraphy images were compared qualitatively in terms of spatial dispersion of the droplets (Fig. 3). Additionally, the droplet distribution was compared quantitatively (Fig. 4).

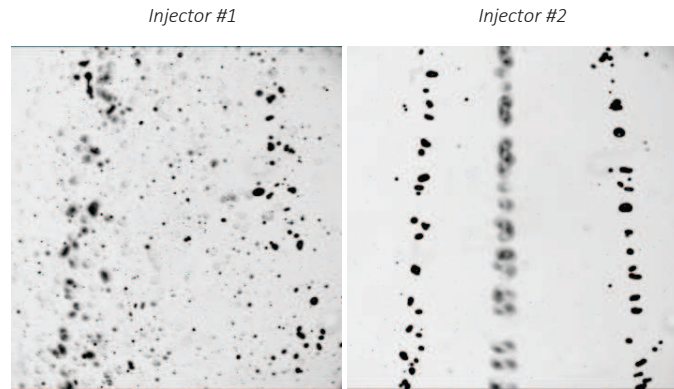


Figure 3. Shadowgraphy images of two tested injectors

The qualitative image comparison indicated that the droplets generated by injector #1 are more evenly distributed over the whole spray cloud while those emerged from injector #2 tend to travel along nozzle axes. The qualitative overview suggested also that injector #1 produces more medium and small droplets than injector #2. This was confirmed by quantitative comparison of droplet size distribution (Fig. 4). Moreover, it can be observed that injector #2 produced very large droplets (>200 μm), which were supposed to agglomerate either on inlet to the catalyst or exhaust system walls. Therefore, injector #1 was selected to be used in developed SCR system.

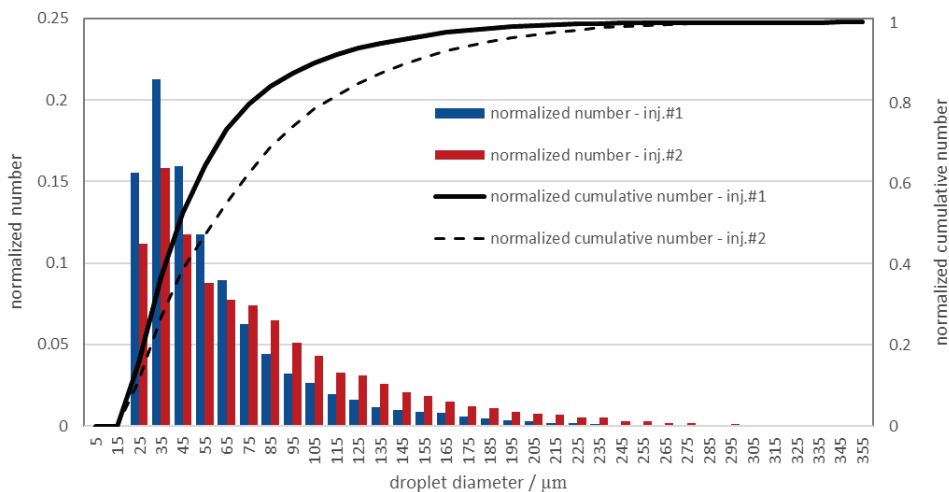


Figure 4. Droplet size distribution for two tested injectors

The experimental data obtained for selected injector was used for spray model calibration similarly as shown in [7]. Droplet size distribution shown in Fig. 4 was used as one of the input parameters for spray model. Spray angles (single plume angle and plumes directions) as well as initial jet velocity (determined by high speed imaging) were also used as input parameters, while the spray tip penetration evolution was used as target parameter for model matching.

Additionally, the selected injector was characterized using simultaneous LIF and Mie scattering visualisation according to setup presented in Fig. 2. These two signals were used to determine qualitative droplet size distribution across the whole spray cloud by means of LIF/Mie ratio. LIF and Mie signals alone can be used for mass distribution determination [8], however LIF/Mie ratio is more useful parameter for spray model performance verification in terms of droplet size distribution across the spray cloud as it was done in this study. The LIF/Mie ratio was used only for qualitative model verification as no size calibration was done. The droplet sizes as presented in Fig. 4 (above 20 μm) according to [9] provide close to linear correlation between Mie signal and droplet size when 3.8 deg solid angle is considered. Thus LIF/Mie ratio could be used in this setup as qualitative SMD (Sauter mean diameter) distribution indicator. LIF, Mie and LIF/Mie ratio results for selected injector are shown in Fig. 5.

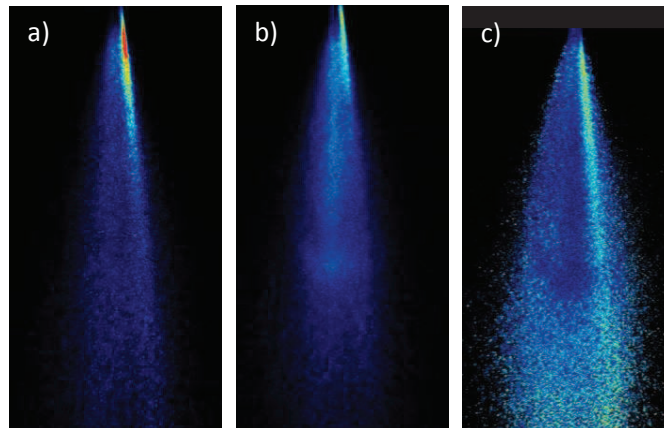


Figure 5. a) LIF, b) Mie, c) LIF/Mie ratio; (adopted from [6])

The spray model was further calibrated in terms of spatial droplet distribution and then used for static mixer development and SCR system design optimization (including injector position optimization).

Taking into account benefits related to direct comparison of sprays generated by different injectors from different manufactures using the same diagnostic setups (as shown in Fig. 3) and additional data available for spray model verification such as LIF/Mie ratio (shown in Fig. 5c), it can be concluded that spray measurement has strong positive impact on SCR systems development.

Nomenclature

CAD	computer aided design
CFD	computational fluid dynamics
LIF	laser induced fluorescence
SCR	selective catalytic reduction
SMD	Sauter mean diameter

Acknowledgments

The study was supported by Polish Ministry of Science through funds for statutory activities in 2017.

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