Effervescent atomization of extra-light fuel-oil: Experiment and statistical evaluation of spray characteristics

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Abstract

This paper presents an experimental and statistical analysis of an effervescent atomizer. The spray data were obtained from experimental measurements by means of a Dantec phase/Doppler particle analyzer (P/DPA) and analytical and statistical analysis was performed using MATLAB software. The main goal of this work was to analyze the spray characteristics and to find analytical functions that would fit the experimentally obtained drop size distributions. The fitted distributions were then discretized for modeling purposes and the modeled spray was verified against the experimental data. The discrete spray will be later used for combustion modeling.

Introduction

Liquid sprays can be generated by various atomizers. For combustion purposes, as in this case, effervescent atomizers are gaining on popularity. The effervescent atomizer is a twin-fluid atomizer with internal mixing, which means that besides the liquid there is one more fluid, typically air, that mixes with the liquid before leaving the atomizer body. This type of atomizer was first introduced by Lefebvre and his colleagues in the late 1980s [1]. Unlike other twin-fluid atomizers, which usually use the air stream to shatter the liquid, the mechanism of drop formation in the case of the effervescent atomizer is rapid air bubble expansion at the atomizer nozzle due to pressure drop. This mechanism makes it possible to use lower injection pressures and larger exit orifice diameters without compromising the drop distribution and has many advantages compared to conventional atomizers [2].

When modeling a liquid fuel flame, it is of crucial importance to authentically represent the spray and its characteristics. The simpler approach is to predict only a few representative parameters (e.g. SMD, MMD), but if one wishes to represent the spray more precisely it is necessary to predict the entire drop size distribution. This method has been developed and studied in numerous papers. Sovani et al. [2] and Jedelsky et al. [3] suggest that Rosin-Rammler distribution is appropriate for effervescent atomizers. Moreover, Jedelsky et al. also uses log-normal distribution to fit the experimental data. Calay et al. [4] and Cleary et al [5] use the two above mentioned distributions to model flashing jets. Ayres et al. [6] presents a more theoretical approach by predicting joint distribution for both size and velocity of the droplets in sprays using the maximum entropy formalism. A comprehensive list of drop size distributions can be found in [7].

Modern CFD software codes often allow users to choose from predefined atomizer models and thus avoid modeling of the internal flow which is responsible for primary atomization. These models use physical atomizer parameters to calculate initial drop sizes, velocities and positions. An alternative would be to model both the internal and external flow in the atomizer, but such computations are only just emerging and due to extreme computational requirements they are not viable in most applications. In the case of Ansys Fluent, the model for effervescent atomizer is not available and therefore is necessary to use a simpler model (for example cone injection) and to set it up carefully to obtain the spray characteristics as required. CFD modeling and numerical studies of sprays are discussed in [4] or in the work of Xiong et al. [8].

Measurement and Data Processing

The extra-light fuel-oil spray was generated using the effervescent atomizer described in [9] as configuration E38. Drop sizes and drop velocities were measured using a Dantec phase/Doppler particle analyzer (P/DPA) in 6 radially equidistant sampling points at 150 mm from the atomizer orifice.

The data from each measurement point were analyzed in a software written in MATLAB code and discrete spray characteristics were obtained. Three distribution functions were used to fit the experimental data - log-normal distribution, Rosin-Rammler distribution and Modified Rosin-Rammler distribution. The log-normal distribution is a basic and one of the simplest drop size distributions and it was used primarily for comparison.

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The Rosin-Rammler and Modified Rosin-Rammler distributions were chosen due to the fact that Ansys Fluent can use these distributions to sample fuel drops entering the computational domain. Other distributions (Nukiyama and Tanasawa, Upper-Limit Function, Maximum Entropy Method [7]) are expected to be implemented in the MATLAB code in the future.

The fitted distributions were then compared with the experimental data. The best fit was chosen and discretized either manually or automatically (using Ansys Fluent) depending on the type of the distribution. Finally, a computation in Ansys Fluent was performed and the results were once again compared with the experimental data.

Results and Discussion

The drop size distributions relative to the sampling points in the measured spray showed to be often bimodal. The distributions obtained from the measurement points close to the atomizer centerline exhibited unimodal behavior, but bimodality manifested itself as the distance from the centerline increased (see Figure 1). Fitting of the three above-mentioned unimodal distributions to the experimental data was performed as a standard approach and the best approximation was selected.

A bimodal approximation, more accurate than the standard unimodal approximations of the effervescent spray, was investigated as a potential improvement. It is planned to apply such an approach in future combustion simulations.

Spray characteristics obtained from the MATLAB code were properly discretized and distribution parameters were then used as input in Ansys Fluent to set up appropriate injections. The model spray was finally validated by comparing the predicted data with the experimental data in terms of drop diameter and drop velocity.

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References

[1] Lefebvre, A.H., Wang, X.F., Martin, C.A., *Propulsion and power* 4:293-298 (1988).
[2] S.D. Sovani, P.E. Sojka, A.H. Lefebvre, *Progress in Energy and Combustion Science* 27 (2001) 483-521.
[3] J. Jedelský, M. Jícha, J. Sláma, *19th International Conference on Liquid Atomization and Spray Systems - ILASS Europe*, Nottingham, UK, 2004, pp. 521-526.
[4] R. Calay, A. Holdo, *Journal of Hazardous Materials* 154 (2008) 1198-1209.
[5] V. Cleary, P. Bowen, H. Witlox, *Journal of Hazardous Materials* 142 (2007) 786-796.
[6] D. Ayres, M. Caldas, V. Semiao, M.D.G. Carvalho, *Fuel* 2001 (2000) 383-394.
[7] E. Babinsky, P.E. Sojka, *Progress in Energy and Combustion Science* 28 (2002) 303-329.
[8] H. Xiong, J. Lin, Z. Zhu, *Atomization and Sprays* 19 (2009) 75-90.
[9] J. Jedelsky, M. Jicha, J. Slama, J. Otahal, *Energy & Fuels* (2009).

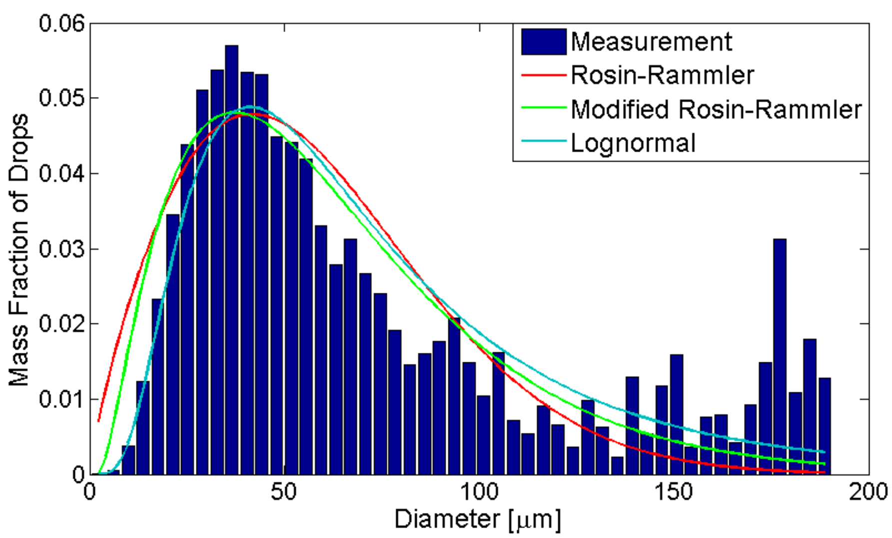

Figure 1. Drop size histogram with fitted curves at radial distance from atomizer centerline 10 mm, axial distance 150 mm, gas-liquid ratio (GLR) 10%, atomizing pressure 0,3 MPa.