Physical Analysis of multimodality in atomization processes

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Abstract

This paper reports an analysis of the physics of atomization processes using a Bayesian approach based on a Markov chain Monte Carlo (MCMC) algorithm, taking into account eventual multimodality and heterogeneities in drop size distributions. This approach allows the identification of subgroups in multimodal or heterogeneous drop size distributions, overcoming the limitations of presenting its moments alone and hindering the eventual presence of different natures of droplet formation. The method is assessed with measurements performed on spray impaction and is further applied to physically interpret multijet atomization processes.

Introduction

Statistical analysis is an essential tool for the characterization of atomization processes. Typically, fragmentation of the bulk liquid results in a broad and non-Gaussian size distribution, often dependent on the hydrodynamic mechanisms generating droplets. In the cases where more than one of these mechanisms is present, the drop size distribution characterizing the outcome of atomization may be multimodal or heterogeneous.

The main objective of the work presented here is to explore the applicability of using finite mixtures of probability density function in the physical analysis of drop size distributions, since these can better capture some specific or hidden properties of droplets size data such as multimodality and unobserved heterogeneities, using a Bayesian approach based on a Markov chain Monte Carlo (MCMC) algorithm. The assessment of the MCMC approach for the physical interpretation of atomization phenomena is made and whether the model is overfitting the number of components or not is also evaluated. Finally, the approach presented is applied to provide further insight into multijet atomization.

Materials and Methods

Finite mixture distributions appear in a natural way when the mean of a variable "looks" different among observed subjects. This informal indicator of heterogeneity suggests the use of statistical models involving discrete latent variables such as clustering or latent class models. Finite mixture distributions arise as marginal distributions of such models. These statistical models can also capture many specific properties of real data such as multimodality, skewness, kurtosis and unobserved heterogeneity. For the purpose of the present work, we employ a Bayesian approach based on a Markov chain Monte Carlo (MCMC) algorithm as described in [1].

Results and Discussion

The statistical method is assessed with spray impact experiments and this paper shows how can it successfully identify typical groups of droplets within the entire drop size spectra. Therefore, the MCMC algorithm has been applied to study the case of multijet atomization which consists of a liquid disintegration process which generates droplets of polydispersed sizes through the simultaneous impact of N_j cylindrical jets. In a previous work [2] it has been observed that more than 2 jets generate a spray from tridimensional structures with periodic patterns associated with the formation of ligaments and further disruption into droplets, but the relation with the known atomization mechanisms for a 2-impinging jet spray is still scarce.

In this work, the MCMC approach used to physically interpret liquid atomization considers the entire spray. The mixture of K normal distribution functions which best describes drop spectra for the multijet spray in all atomizers is for $K = 2$, indicating that there are two dominant groups of droplets, eventually implying two

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atomization mechanisms. As depicted in Figure 1, these groups have distinct sizes, however, while the group of larger droplets does not significantly change between atomizers, except for a slight increase in the mean, the group of smaller droplets is not affected in the mean, but in the polydispersion associated with the variance, especially for $N_j = 4$.

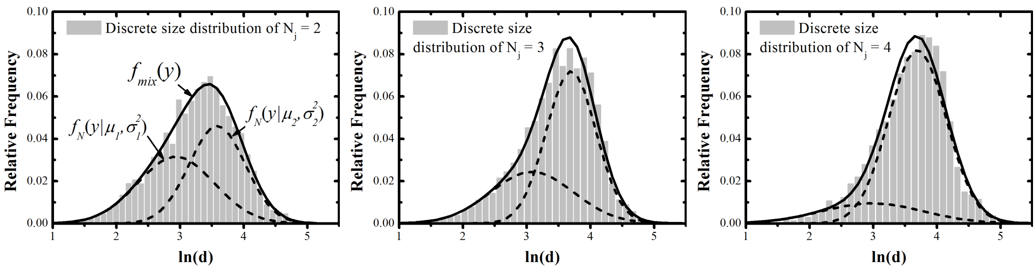

Figure 1. Mixed Normal distribution function with $K = 2$ for the atomizers with $N_j = 2, 3, 4$.

To illustrate the physical interpretation deduced from the statistical method applied to drop size measurements, Figure 2 contains images taken for each multijet spray. The spray pattern formed by the impact of two jets is described, according to Santoro and Anderson [3] by three types of periodic structures: 1) surface waves; 2) edge ligaments; 3) and detached ligaments. The latter can be considered the main atomization mechanism and as been correlated with the geometric parameters for two impinging jets atomization [3]. Using this correlation on our multijet experiments as shown that the expected average drop size of 4.881 μm is close to the overall value of 3.7 μm (see $f_N(y|\mu_2, \sigma_2^2)$ in Figure 1). Therefore, the physical interpretation of the statistical results depicted in Figure 1 is that, for $N_j = 2$, the formation of droplets through edge ligaments is as likely to occur as those formed through ligament detachment in surfaces waves propagating from the impact point (both have similar weights η_k), however, the inclusion of more jets tends to mitigate such drop size group. Also, the similar characteristics of the group of droplets produced from detached ligaments imply that the same atomization mechanism is probably at work independent of the number of atomizers. Nevertheless, further studies are required to verify this at a more fundamental level.

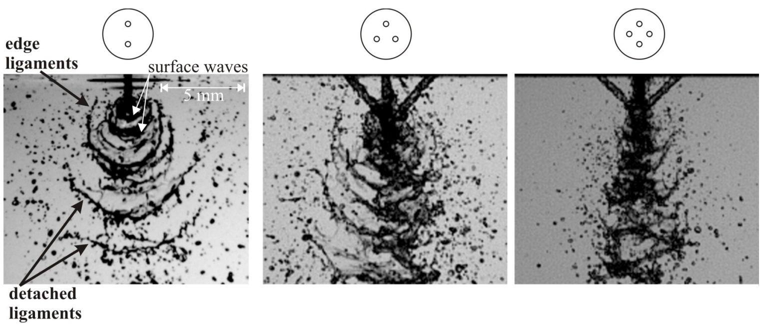

Figure 2. Illustration of the atomization process for $N_j = 2, 3, 4$, including the top-view of jet exit positioning relatively to the side-view of the spray.

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