

Modeling of drop sizes from effervescent atomization of gelatinized starch suspensions

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Abstract

The applicability of previously published models for prediction of representative drop sizes resulting from effervescent atomization has been evaluated for usage with gelatinized starch suspensions. The calculated results are in qualitative agreement with experimental ones, but show an overprediction and reduced sensitivity to material properties. Analysis of the model shows that the material properties are neglected in a significant step.

Introduction

Effervescent atomization is a type of air-assisted atomization which is distinct in the formation of a two-phase flow prior to atomization [1]. It is a promising method for atomization of higher viscous and viscoelastic liquids [2]. The goal of this ongoing investigation is to evaluate the applicability of effervescent atomization for gelatinized starch suspensions and later for application to spray drying of these fluids. The focus of the present work is evaluation of the applicability of existing models for prediction of representative drop sizes for these fluids. The models are based on material properties and the parameters atomization [2],[3].

Materials and Methods

The models published by Lund et al. [3] and Geckler and Sojka [2] are separated into two steps. The first step is a geometric calculation of the resulting liquid sheath thickness, and therefrom the ligament diameter d_L . It is based on the nozzle outlet diameter, air to liquid ratio by mass (ALR) and fluid densities. Since the velocities of gas and liquid can not be measured from these experiments an iterative calculation method is used [4]. The second step is based on a stability analysis of the ligaments breaking up. The optimal wave length for ligament break-up is calculated according to Weber [5] with consideration of the fluid properties. The resulting drop size is calculated from the volume of the resulting ligament according to equation 1, and defined as the Sauter mean diameter $x_{1,2}$.

$$x_{1,2} = d_L \cdot \left[\frac{3}{2} \cdot \sqrt{2} \cdot \pi \cdot \sqrt{1 + \frac{3 \cdot \eta_l}{\sqrt{\rho_l \cdot \sigma_l \cdot d_L}}} \right]^{1/3} \quad (1)$$

For the present experimental work, suspensions of water and gelatinized native corn starch (CS) or native waxy corn starch (WCS) were used in the weight percentages shown in table 1. Drop size distributions were aquired using a Sympatec Helos/Vario KF laser diffraction sizing system. The volume flow of gas and liquid were controlled with rotameters for calculation of the ALR. Feed pressures of gas and liquid were read from pressure gauges. Surface tensions of the fluids were determined via a Wilhelmy-plate. Shear viscosities η of the CS suspensions were measured with cone geometry and rotational rheometry – complex viscosities $|\eta^*|$ of the WCS suspensions were measured using cone geometry and oscillating measurements.

Results and Discussion

The Sauter mean diameters calculated according to the published model [2] show a significant overprediction compared to the experimental data (see figure 1; Mod. orig.). A thorough revision of the model disclosed a minor error in the first step of the geometric calculation which resulted in a doubling of the ligament diameter.

The values calculated according to the corrected model of Geckler and Sojka [2] better fit the experimental data for both CS and WCS, as can also be seen in figure 1 (Mod. corr.). Still, there is need for improvement of the model to better fit the experimental data since neither the sensitivity of $x_{1,2}$ to starch concentration nor the absolute values are calculated accurately. Analyses of the corrected model showed one possible reason: The first step is a strictly geometrical model calculation of the ligament diameters as described above and therefore

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depends on neither surface tension nor rheological properties. This is likely to be a major problem since the calculated ligament diameter is dependent only on ALR, and not on the material properties of the liquid.

Another problem to be solved in future investigations is the correct definition of the material properties used when considering surface tension and rheological properties and their measurement is a fairly complex system.

A question also open for further investigation is the choice of characteristic diameter from the measured drop size distributions. Since the calculated drop sizes represent a monodispers distribution Sauter mean diameter and volumetric mean diameter are identical. The measured Sauter mean diameter shows less total deviation from the calculated values, but when considering the measured volumetric mean diameter the spread of the calculated values in dependence on starch concentration fits better.

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Nomenclature

- $x_{1,2}$ Sauter mean diameter [m]
- d_L diameter [m]
- η_l viscosity [Pa·s]
- ρ_l density [$\text{kg}\cdot\text{m}^{-3}$]
- σ_l surface tension [N/m]

References

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Table 1. Rheological properties of gelatinized starch suspensions

weight percentage	CS 3,5 %	CS 4,5 %	CS 5,5 %
viscosity η_L [Pa·s]	0,00362	0,00609	0,01368
weight percentage	WCS 2,0 %	WCS 2,5 %	WCS 3,0 %
complex viscosity $ \eta_L^* $ [Pa·s]	0,1195	0,2755	1,4333

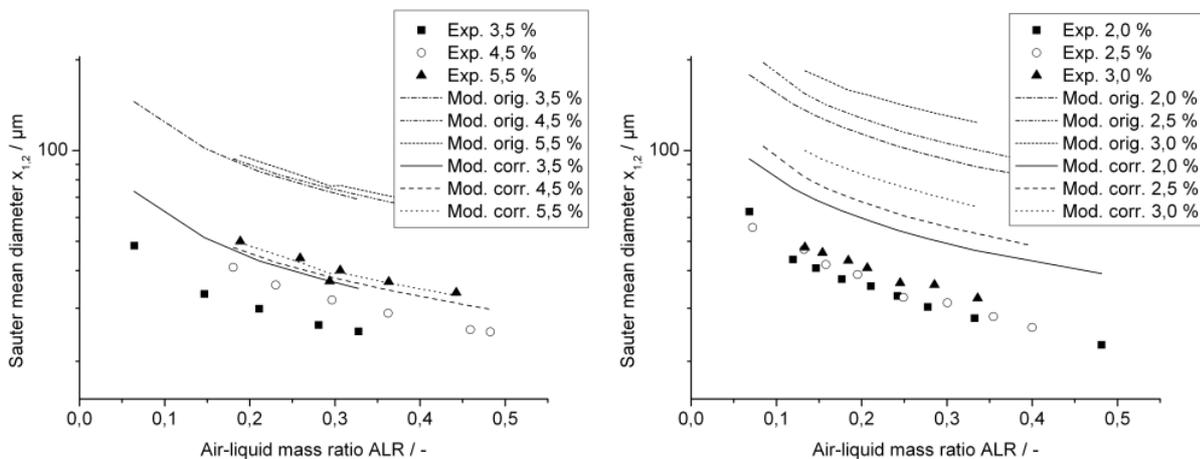


Figure 1. Experimental data (dots) and drop sizes from model (lines; Mod. orig. → original model, Mod. corr. → corrected model) for CS (left) and WCS (right)