Influence of entire turbulence spectrum on modeling breakup in liquid-liquid systems

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Highlights

- Introducing a new breakup model based on the entire energy spectrum of turbulence.
- Validation with direct measurements of breakup rates toward dissipation subrange.
- Improved capability of the kernel prediction for dissipation subrange.

1. Introduction

Breakup models are typically formulated for the inertial subrange of turbulence [1 – 3]. The limitation is that the mother drop falls in the inertial subrange and a limited array of eddies in size and energy causes the breakup. Moreover, lack of experimental data for breakup rates in general and specifically absence of measurements outside the inertial subrange have hindered model developments. Recently, the interest toward entire spectrum of turbulence has been noted, for example Solsvik and Jakobsen presented an analytical solution for the second-order structure function covering the entire spectrum and applied it to extend the commonly used models using arbitrary turbulence properties [4]. We have attempted to address these gaps and improve the understanding of breakup by introducing a new model based upon the model proposed by Andersson and Andersson [3] using the entire spectrum of turbulence. The analytical solution for the structure function presented by [4] and the Pope's number density model for eddies [5] are employed. The predictions are compared with the original model and validated against unique set of experimental data toward the dissipation subrange. The purpose is, therefore, to provide understandings on how the entire spectrum affects the breakup of fluid particles.

2. Methods

The breakup rate in turbulent flows is modelled by the product of an interaction frequency function and a probability function. The interaction frequency is a function of number density of eddies, volume of the mother drops, and a velocity or time scale reflecting the eddy characteristics. The second term, however, indicates the ratio between the disruptive and cohesive stresses and/or energies exerted on drops due to the turbulence in the primary phase. The formulations for the breakup rate in turbulent flows is summarized in reference [3]. We have applied a number density model for the entire spectrum based on Pope [5] and the analyticl solution of structure function based on [4] and proposed a model accounting for the entire spectrum of turbulent energy.

3. Results and discussion

Figure 1 shows the numerical predictions of breakup rates employing the original (a) and the extended (b) models. For comparison purposes two other models [1] and [2] are also presented. The experimental data (symbols) are direct measurements of breakup rates for water-rapeseed oil in a stirred tank with local dissipation rate of 200 m^2s^{-3}, turbulent kinetic energy of 0.4 m^2s^{-2}, and Tylor-scale Re number of 73 in the measurement region. The smallest mother drop diameter falls in the dissipation subrange with no breakup. The general trend of experimental data are captured with the original and extended versions of Andersson & Andersson model, whereas the others fail to predict the experimental data. Using the entire turbulence spectrum results in a significant decrease toward the dissipation subrange providing an improvement in predictions for

this range. This is attributed to the fact that using the entire spectrum reduces the number of eddies to encounter with the drop, also it decreases the efficiency of the encounter due to higher requirements for both energy and stress criteria. Theoretically, for high Re number the predictions for both original and extended models should overlaps. Figure 2 shows the dimensionless breakup rates (extended over original) for the models investigated. Toward the inertial subrange, Andersson & Andersson is the closest to unity. In other words, the deviation from unity can be explained by the intermediate value of Re number for the practical case investigated, and how the models apply the eddy number density and the structure function in their formulations.

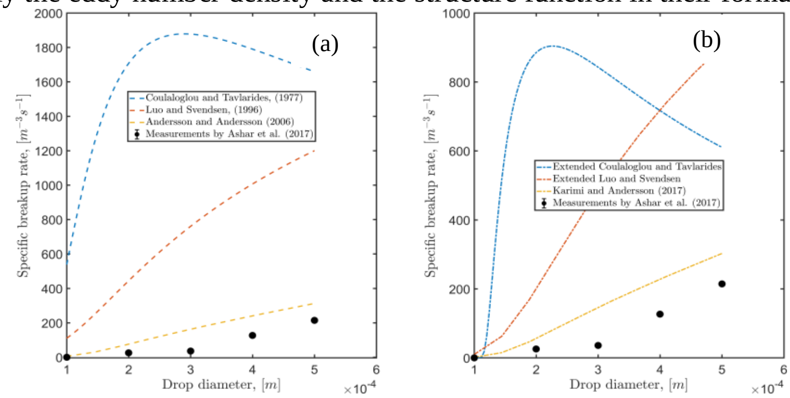

Figure 1. Validation of original and extended models for the breakup rates.

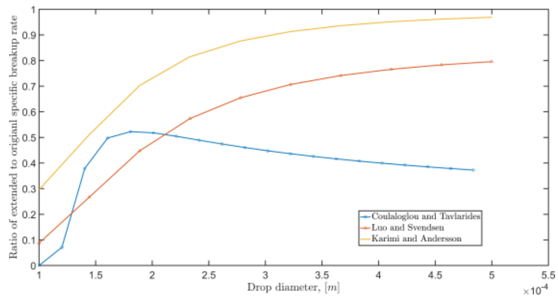

Figure 2. Ratio of breakup rates for extended over original models.

4. Conclusions

A new breakup model is introduced by applying the entire spectrum of turbulent energy. The model relies on the analytical solution of second-order structure function accounting for the entire spectrum of turbulence. Validations with unique set of measurements toward the dissipation subrange showed that the extended models lead to improvements for the predictions of breakup rates in dissipation subrange. Thus, this work provides insights on how the vortices and droplets interact in dissipation range and validates this characteristics with new experimental data for this subrange.

References

[1] C.A. Coulaloglou, L.L. Tavlarides, Chem. Eng. Sci. 32 (1977) 1289–1297.
[2] H. Luo, H.F. Svendsen, AIChE J. 42 (1996) 1225–1233.
[3] R. Andersson, B. Andersson, AIChE J. 52 (2006) 2031–2038.
[4] J. Solsvik, H.A. Jakobsen, AIChE J. 62 (2016) 1795–1820.
[5] S.B. Pope, Turbulent Flows, Cambridge University Press, Cambridge, 2000.

Keywords
Breakup Model; Entire Turbulence Spectrum; Liquid Dispersion; Dissipation Subrange.