

## INFLUENCE OF INTERNAL INTERMITTENCY ON DROP BREAKAGE AND COALESCENCE IN TURBULENT LIQUID-LIQUID DISPERSION

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**Abstract** Break-up and coalescence of droplets in stirred dispersion is considered and the influence of highly intermittent nature of turbulence on scale-up is discussed. Droplet breakup occurs when disruptive stresses overcome the stabilizing ones. Three different situations are taken into account: (a) pure liquid-liquid system with dispersed phase of low viscosity in which the only disruptive stress is due to pressure fluctuations and stabilizing stress is due to interfacial tension, (b) pure system with dispersed phase of high viscosity in which viscous stress generated within the drop increases stabilizing effect, (c) system with surfactant and additional disruptive stress. In all cases internal intermittency causes faster breakage in larger scale when average energy dissipation rate in the tank is maintained. Additionally, for system (a) coalescence was taken into account. In this system drop interfaces are partially mobile and coalescence is faster in larger scale due to intermittency.

Droplets in turbulent flow are broken by stresses generated due to pressure fluctuations. On the other hand collision of droplets may result in drop coalescence if dispersed phase volume fraction is high enough and if the contact time during the collision allows the intervening film between the droplets to drain. The final drop size is a result of dynamic equilibrium between breakage and coalescence. Rates of these processes depend on the energy dissipation rate,  $\varepsilon$ , in a complex way. Breakup takes place when disruptive stresses overcome the stabilizing ones. Typical sizes of droplets in stirred tanks fall within the inertial subrange of turbulence. In this case normal pressure stresses acting on drop  $\tau_p \propto \rho_c \varepsilon^{2/3} d^{2/3}$ . However, energy dissipation field is highly intermittent, which is related to the vortex stretching and the fact that dissipation occurs only in portions of space; as a result high-order velocity structure functions scale as  $\langle u_r^p \rangle \propto r^{\xi_p}$  with  $\xi_p \neq p/3$  but curved. In breakage and coalescence models the Parisi and Frisch [1] concept of singularities concentrated on a set of fractal dimension was applied. Curved function  $\xi_p$  can be obtained using continuous infinity of scaling exponents [2]. Pressure stresses acting on droplets of size  $d$  can, therefore, be given by [3,4]:  $\tau_p = C_p \rho_c \varepsilon^{2/3} L^{2/3} (d/L)^{2\alpha/3}$ , where  $L$  is integral scale of turbulence, directly related to the system scale, and  $\alpha$  is a multifractal exponent. Breakage rate,  $g(d,\alpha)$ , depends on characteristic frequency of eddies of scale  $d$  and probability of their appearance characterized by multifractal exponent. Multifractal exponent allows us to take into account different activity of eddies of the scale equal to drop size. Multifractal spectrum  $f(\alpha)$  of  $\varepsilon$  was given by Meneveau and Sreenivasan [5]. The weakest eddies that can disperse the drop are labeled by multifractal exponent resulting from disruptive and stabilizing stress balance. In this work three different liquid-liquid systems were considered: (a) pure system (not containing any surface active agent) with dispersed phase of low viscosity (toluene,  $\mu_D = 5.5 \cdot 10^{-4} \text{ Pa} \cdot \text{s}$ ), (b) pure system with dispersed phase of high viscosity (silicone oil,  $\mu_D = 0.5 \text{ Pa} \cdot \text{s}$ ), (c) system containing small amount of surfactant, Tween 20, in the continuous aqueous phase. Dispersed phase in case (c) is the same as in case (a). In the case (a) the only disruptive stress is due to dynamic pressure fluctuations,  $\tau_p$ , while the only stabilization is due to shape restoring stress connected with interfacial tension,  $\tau_\sigma$ . In system (b) high viscosity of the dispersed phase increases the stabilizing effect - viscous stress,  $\tau_v$ , is generated within the drop as it deforms. In the case (c) additional disruptive stresses are generated,  $\tau_{\Delta\sigma}$ . They result from the difference in dynamic interfacial tension and static interfacial tension. More details on breakage models for different systems can be found in [4,6,7]. Coalescence in all systems can be neglected in diluted dispersions. Coalescence is also highly reduced in the system containing surfactant and in the system with dispersed phase of high viscosity even if dispersed phase volume fraction,  $\varphi$ , is high. However, in the case (a) coalescence is fast for large  $\varphi$ . Toluene droplets in pure liquid-liquid system (a) have partially mobile interfaces. In this case drops are relatively large and deformed in the contact area. Assuming that the whole kinetic approach energy is transformed into excess surface energy the film radius  $a \propto \varepsilon^{1/6}$ . Drainage time,  $t_c$ , is proportional to film radius. However, its dependence on local energy dissipation rate,  $\varepsilon$ , is more complex because initial film thickness is also a function of  $\varepsilon$ . Interaction time is of the order of time needed for two particles to pass one another or shorter [8]. It was assumed that it results from droplet bouncing and does not depend on energy dissipation rate. Coalescence efficiency is a function of the drainage time to interaction time ratio. Coalescence rate depends also on drop collision rate, which is proportional to  $\varepsilon^{1/3}$ . Details on coalescence model for droplets with partially mobile interfaces one can find in [9,10], while models for droplets with immobilized interfaces are developed in [10,11,12]. Figure 1 shows the effect of scale-up (changing the tank diameter from  $T = 0.15 \text{ m}$  to  $T = 0.3 \text{ m}$ ) on drop size when

geometric similarity ( $D/T = 1/3$ , where  $D$  is impeller diameter) and average energy dissipation rate in the tank is maintained. Drop size distributions were predicted by solving the population balance equation. In all diluted liquid-liquid systems smaller droplets are produced in larger scale, where local values of integral scale of turbulence are larger. In pure liquid-liquid system with toluene droplets and high dispersed phase volume fraction,  $\phi = 0.3$ , similar droplets are produced in both scales, which results from the fact that coalescence of droplets with partially mobile interfaces is faster in larger scale and compensates for faster droplet breakage.

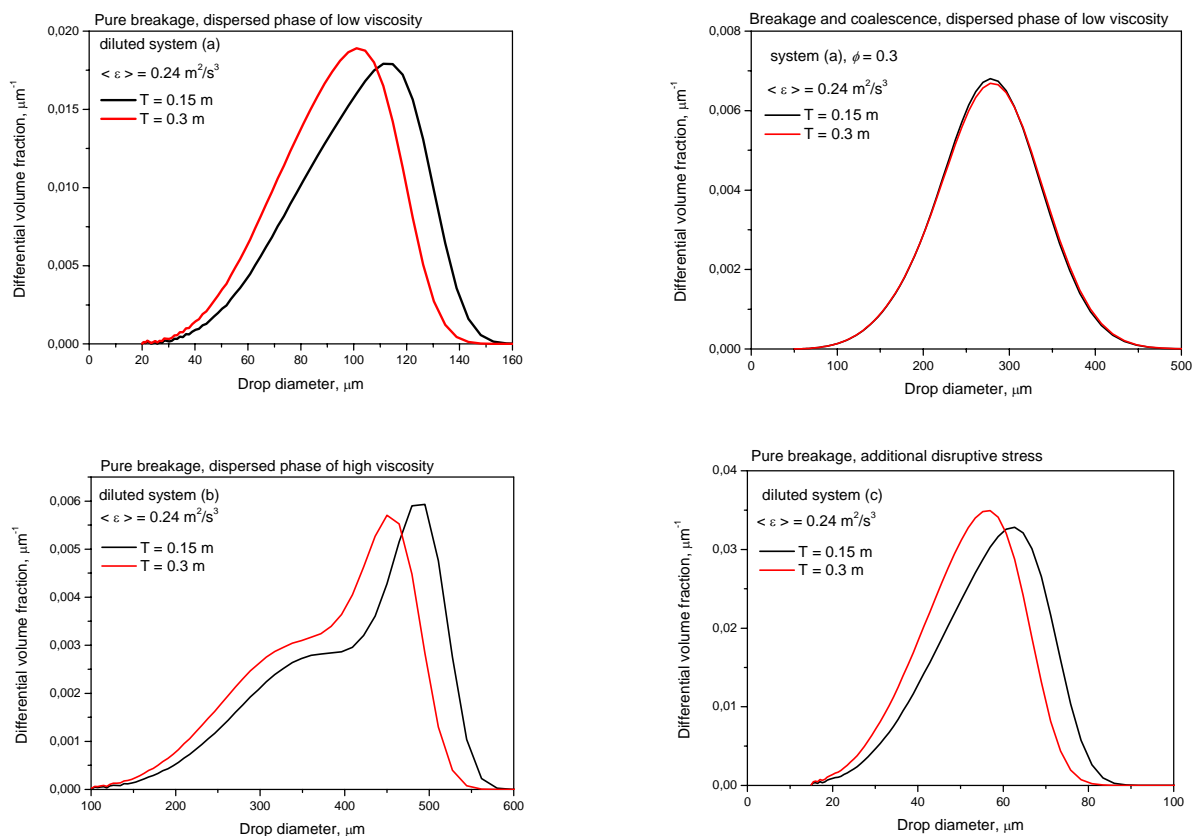


Figure 1. Influence of the system scale on drop size distributions.

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