Investigation of Single Drop Deformation in Complex Flow Fields

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INTRODUCTION

The behaviour of disperse two-phase systems subjected to flow is often studied by measuring the deformation response of a single drop suspended in a second fluid undergoing shear or elongation. Taylor (1934) was the first to carry out this type of experiments in the 1930's. His work was of great significance to the understanding of the mechanism behind drop deformation and break-up as he recognized that break-up is a direct consequence of the local flow field surrounding the drop. More recent developments in imaging and controller technology have resulted in fully automated experimental setups with higher reproducibility and results for a larger range of experimental parameters, e.g. by Bentley and Leal (1986). However, in practical engineering applications the flow field is usually a complex mixture of shear and elongation making studies on drop behaviour in mixed flows highly interesting. We have carried out single drop experiments in a rotor-stator device which is capable of producing complex planar flow fields. Furthermore we have implemented a numerical model which can be used to simulate drop deformations and breakup under a variety of flow conditions.

EXPERIMENTAL

Here the experimental procedure and some example results are presented. In Fig. 1 a photograph of the setup can be seen. The apparatus consists of two concentric cylinders with teethed walls. The channel formed between the cylinders is filled with the continuous phase liquid. When the cylinders are rotated in opposite directions a complex planar flow field forms in the continuous liquid.

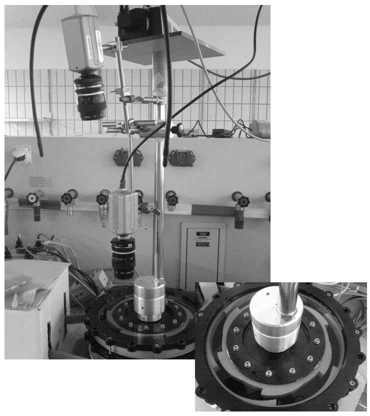

Figure 1: Experimental setup.

An experiment consist of monitoring the deformation and position of a single disperse drop as it is influenced by the flow generated in the channel. In order to monitor the drop a two-camera system is utilized. One camera is used for monitoring the drop deformation while the second camera is used to determine the drop position in the channel. Subsequent image analysis allows us to quantify the data obtained from the cameras by calculating the time dependent deformation parameter D and drop coordinates. The parameter D is defined as $D = (L - W)/(L + W)$ where L and W is the length and with of the drop. The local flow field surrounding the drop is found from numerical calculations. From the position of the drop one can then estimate a local shear and elongation rate which in turn can be used to calculate a local capillary number defined as $Ca = \frac{G r_0 \mu_c}{\sigma}$, where G is the sum of the magnitude of the shear and elongation rate, r_0 is the initial drop radius, μ_c is the viscosity of the continuous phase and σ is the interfacial tension. In Fig. 2 an example plot of D and Ca can be seen which shows how the deformation follows the capillary number.

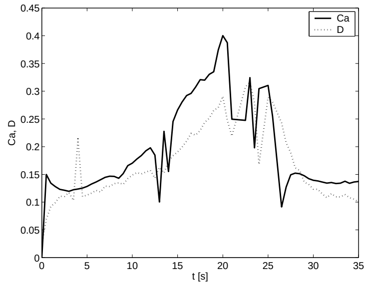

Figure 2: Experimental deformation D and numerically calculated capillary number Ca as a function of time.

Depending on the viscosity ratio between the drop and continuous phase a critical capillary number exists where a drop will break up. However, due to the complex physics involved in this process detailed mechanical models are often applied in order to simulate and study the break-up process (see e.g. Li *et al.* (2000)).

MODELLING

As a tool for studying flow induced drop deformation and break-up we have implemented a model based on Finite Element discretization of the flow field combined with the Volume of Fluid (VOF) method for tracking drop interfaces. In order to simplify our calculations we only do simulations for pure Stokes flow. Due to the nature of the VOF method a stationary calculational mesh can be used even though large topological changes of the interface are present. The problem of interface tracking is solved by defining a VOF function F which is identical with volume fraction of the drop phase at a given point in our domain. In its discrete form the VOF function is defined in VOF cells such that for cells inside and outside the drop phase $F = 1$ and $F = 0$ respectively. Cells that contain both phases, i.e. interface cells, will have $0 < F < 1$. Using the VOF distribution it is possible to calculate the interface normal which is used for applying the interfacial tension using either the method of Brackbill *et al.* (1992) or Lafaurie *et al.* (1994) and for advecting the VOF function in time. Fig. 3 shows the results from a single drop simulation in planar shear after break-up. In the simulation $Ca = 0.42$ was used which is approximately the critical Ca-number for a system with equal viscosities and Reynolds number of zero.

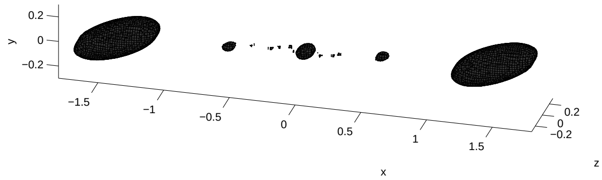

Figure 3: Simulation of drop break-up in planar shear with $Ca = 0.42$

The figure shows how the drop is split up into 2 main drops with 3 smaller drops in between which is the typical break-up behaviour in shear when the Ca number is close to the critical capillary number. By varying the boundary conditions of our calculational domain as linear combinations of pure shear and pure elongation we can simulate a flow which resembles the local flow in the rotor-stator device. Our present goal is therefore to use the known local flow field from experiments as an input to our model in order to investigate whether or not we are able to simulate the experimentally observed drop behaviour.

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