On disturbance and ripple waves in downwards annular flow: Observations by simultaneous PLIF and PIV/PTV

Ivan Zadrazil* and Christos N. Markides

Department of Chemical Engineering, Imperial College London, London SW7 2AZ, UK

* Corresponding author. Email: i.zadrazil06@ic.ac.uk

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Abstract

1. Introduction

An interfacial flow of gas and liquid where the liquid occupies the area around the circumference of a pipe and the gas is located in the pipe core is defined as annular flow. This two-phase flow regime presents a challenge due to its complexity and multi-scale character, and thus is not fully understood even after decades of research (Webb and Hewitt, 1975; Azzopardi, 1997; Alekseenko et al., 2012). Comprehensive characterisation, classification and understanding is not only important from a fundamental but also from an industrial point of view, since these flows are highly important in many practical areas, such as, in oil-and-gas industry (distillation columns, raisers and transport pipelines), and the chemical and pharmaceutical industries (reactors, evaporators and condensers).

The nomenclature describing the different classes of waves that appear in these flows was established in the 19070s, based on the observations derived from direct photographic evidence, local liquid film thickness and pressure drop measurements. Thus, downwards annular flows have been generally described in terms of small amplitude ripple waves, and large amplitude, high-speed disturbance waves. Both of these wave types are said to cover the liquid substrate, i.e. a thin liquid region that is located between the waves (Chu and Dukler, 1974, 1975). Yet, it should be noted that a clear, unambiguous and generally accepted definition of the different wave classes is still lacking. The experimental work presented in this paper is aimed at observing and characterising wave behaviour in downward annular flows, also with information on the liquid film velocity underneath the waves. To this end we have performed a series of simultaneous Planar Laser Induced Fluorescence (PLIF) and Particle Image/Tracking Velocimetry (PIV/PTV) measurements.

2. Methodology

The measurements were performed on the Downwards Annular Flow Laser Observation Facility (DAFLOF). This facility consists of 3 m long, 32.4 mm nominal bore fluorinated ethylene propylene (FEP) pipe, where the annular flow is introduced at the top of the pipe using a specially designed injector, which forms circumferentially uniform liquid films (Yujie et al., 2013). The investigated liquid and gas Reynolds numbers were in the range of Re_L = 306 – 1,530 and Re_G = 0 – 84,600, respectively. The laser-based measurements were performed 2.35 m downstream of the injector (i.e. 72 *D*). The visualisation section was enclosed in an optical correction box in order to minimize any distortions that would arise from the round FEP test section.

In this work, the gas-liquid downwards annular flows were measured by laser-based optical characterisation techniques, i.e. simultaneous utilization of PLIF and PIV/PTV. A double-pulsed frequency-doubled 532 nm Nd:YAG laser equipped with a sheet optics was used for the flow illumination in a 2-D plane. Rhodamine-B dye and Rhodamine-B particles (10 µm mean diameter) were used for the PLIF and PIV/PTV measurements, respectively. The fluorescent light was recorded by a CMOS camera which was positioned at a right angle with respect to the laser sheet. Additional details of the flow facility and laser system used can be found in Zadrazil et al. (2013).

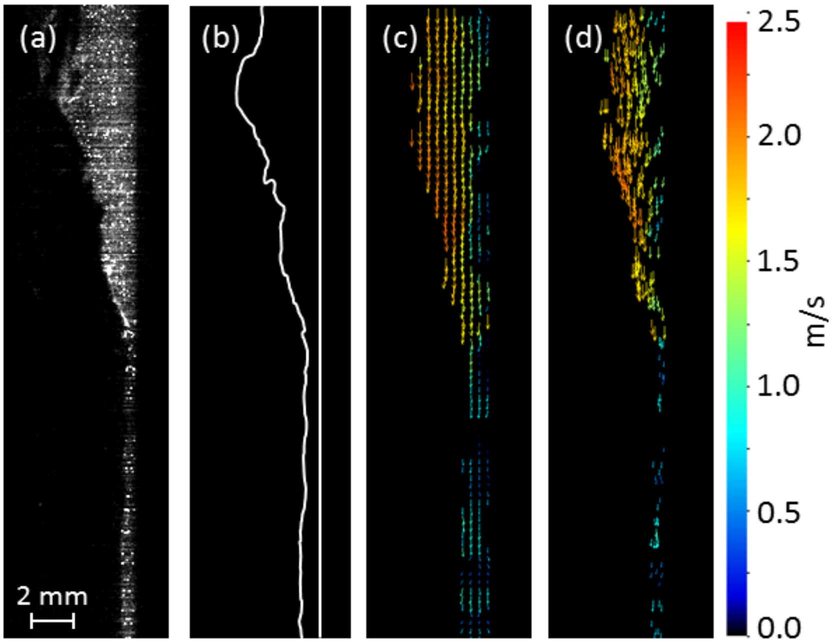

Figure 1: Example of: (a) raw instantaneous image, (b) interfacial information and wall position extracted from image such as the one in (b), (c) instantaneous velocity vector map obtained from an image pair such as the one in (b), and (d) instantaneous PTV vector map obtained from a PIV vector map such as the one in (c).

The raw-image pairs were evaluated using an in-house MATLAB interface tracking algorithm (PLIF) and the DaVis software package (PIV and PTV). Typical examples of: (a) raw image, (b) interface position, (c) instantaneous PIV velocity vector map, and (d) instantaneous PTV velocity vector map, are shown in Figure 1. The information derived from the processed images, i.e. film thickness, film roughness, interfacial velocity, instantaneous and time-averaged velocity profiles, and rms profiles will be used for a detailed characterisation of both disturbance and ripple waves.

3. Results

Figure 2 shows preliminary results concerning instantaneous velocity profiles underneath different waves which were observed for falling films (with $Re_G = 0$) at different liquid Reynolds numbers Re_L. The gas-liquid interface and instantaneous velocity profiles were constructed using the PLIF and PIV measurements, respectively. The following observations can be made: (i) the disturbance waves travel at higher velocities than the substrate, (ii) ripples can be found on both substrate and disturbance waves, (iii) some ripples located on the top of disturbance waves have larger velocity than the disturbance wave itself, (iv) some ripples located on the substrate (both upstream and downstream of a disturbance wave) have a velocity lower than the substrate.

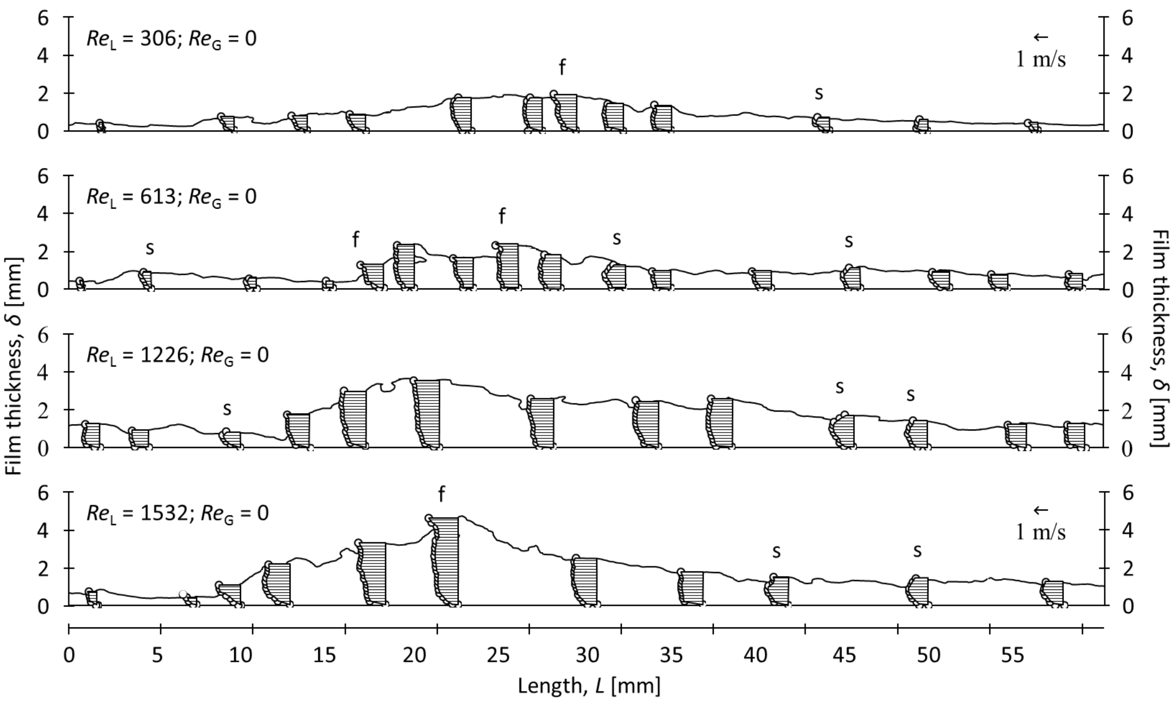

Figure 2: Typical instantaneous local velocity profiles under disturbance waves and substrate at various liquid Reynolds numbers. Labels “f” and “s” indicate fast and slow ripple waves.

4. Conclusions

PLIF and PIV/PTV techniques have been successfully employed to track the gas-liquid interface and to obtain velocity information under the liquid film in gas-liquid co-current downwards annular flows. The results obtained from the subsequent analysis of these measurements (e.g. local thickness, interfacial velocity and velocity profiles of individual ripples and disturbance waves) will help with the classification of the various interfacial phenomena (i.e. waves) observed in these flows. The outcome of this research will address a question of whether ripples and disturbance waves truly belong to fundamentally different classes of waves, and hence whether their occurrence can be associated with some measurable parameter or characteristic of these flows.

5. References

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