Measurement of the thickness of a fluid layer by light absorption

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Abstract A method to measure the thickness of a fluid layer and thus the depth of the interface between two layers has been developed. It uses light absorption by dye and quantitative analysis of video images. Its main advantages are that it is not intrusive and that the places and times for which measurements are made can be chosen after the experiment and so be optimally related to particular phenomena.

1 Introduction

We have developed a method to measure the depth of the interface in a two-layer stratified fluid as a function of position and time. It uses the absorption of light by dye that, in our experiments, also serves the purpose of general flow visualisation. Its basis is the video-recording of the dyed flow, illuminated in an appropriate way, and then the determination of grey levels in the video images. It has been developed during a study of gravity-driven boundary currents in a rotating fluid – extending work reported by Chabert d'Hières et al. (1991). The experiments are being conducted on the big rotating platform of 13 m diameter. However, the method could readily be adapted to smaller scale systems. It has potential applicability to a variety of two (or more) layer flows, for which mixing is sufficiently slight that layer thickness is a well-defined quantity, and for which this thickness is important as an influence on and/or indicator of flow development. Examples from non-rotating fluids include gravity currents (Simpson 1982) and the occurrence (Baines 1984) and development (Lawrence 1985) of internal hydraulic jumps. Such from rotating fluids include instability of a gravity current (Griffiths and Linden, 1981a), evolution of vortices (Griffiths and Linden 1981b), suppression of jet instability by bottom topography (Boyer and Chen 1990), and the propagation of internal waves (e.g. the effect of an embayment on internal Kelvin waves, Ivey and Maxworthy 1992). Measurements of layer thickness, or equivalently interface height, are evidently valuable when this is a theoretically significant quantity and, in particular, may assist with the identification of the dynamical processes responsible for an observed instability. For example, both classical baroclinic instability (Phillips 1954; Hart 1972) and the types of instability proposed by Killworth and Stern (1982) relate to aspects of interface slope or shape. This is an important aspect of our work.

Advantages of the method of interface height measurement to be described below are that it is non-intrusive and that the places and times for which measurements are made can be chosen after the experiment. The latter is of particular importance in experiments such as ours, where one wishes to investigate the conditions leading to instability without initially knowing where manifestation of this instability will occur. Spatial resolution can normally be much finer than achievable with transducers (e.g. conductivity probes). Time resolution is determined by the time between video frames and is thus 1/25 s (in Europe) for a normal camera.

2 Description of the method

The principle of the method is the quantitative measurement of the light absorbed by the layer, dyed to an accurately known concentration, of which one wishes to know the thickness. A video camera is used to record the flow during the experiment; then selected images are re-read and light intensities, in terms of grey levels, analysed using a black and white image processing system. Implementation of this principle involves various considerations and tests; we outline our own procedures, with some more general remarks relating to application to other systems.

The measurements are much easier if the grey level is proportional to the light intensity incident on the camera. This is usually the case for a black and white camera but not for a colour one (Maas, private communication). However, we believe that it would always be desirable to test camera performance in this respect by determining the grey level as a function of aperture for fixed incident light. We carried out more detailed tests of this kind to see whether the desired proportionality existed for various dye colours and various intensity ranges. Objects painted with different food-colouring dyes (the most common type of dye used for flow visualisation in water (Merzkirch 1987), and to different darknesses, as well as a white object, were
recorded and the images analysed. With a CCD black and white camera, SONY type AVC-D7CE, the relationship was linear in all cases, whereas for a CCD colour camera, SONY type DXC-107P, for each colour, the grey level was proportional to the square root of light intensity (Fig. 1). (There is a zero offset; measured grey level is non-zero when the camera lens cap is on. Throughout the following "grey level" refers to the measured value minus this offset.)

The above tests relate, of course, to the complete system of camera, tape recorder, computer and image processing software. However, the choice of camera is the crucial point. The types of the other components used were: recorders SONY (U-matic, PAL) types VO-5800PS and VP-9000P, black and white image processing PC-OEIL on a IBM-compatible computer. An alternative software system (LATTIN) was also tested and gave similar results.

The tests showed that different food-colouring dyes give similar results and there is no evident advantage in using one colour rather than another. In our experiments we used a red dye (azorubine, E122) with the black and white camera.

Use of light absorption to measure the layer thickness requires, of course, that each position in the video image corresponds to light traversing the dyed layer at a given location. There are two possible arrangements. The preferable one is to have light coming directly from below and traversing the layer just once. However, this was not feasible in our system and so illumination was from above with the light passing through the layer twice, with non-specular reflection at the bottom. In principle, each ray should pass twice at the same location; i.e. the light source and the camera should be in effectively the same place. However, it is also essential to eliminate light reflected by the water surface. This necessitates the introduction of screens and some separation of source(s) and camera, arranged so that the two passages of a ray through the layer are sufficiently close.

The arrangement in our experiment consists of two vertical black screens on either side of the camera and a lamp on the other side of each screen, as shown in Fig. 2. The height of the bottom of the screens above the water surface and the lamp positions are chosen so that the appropriate region of the matt white bottom of the floor tank is illuminated by each lamp,