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Rough-surface gravity current flows

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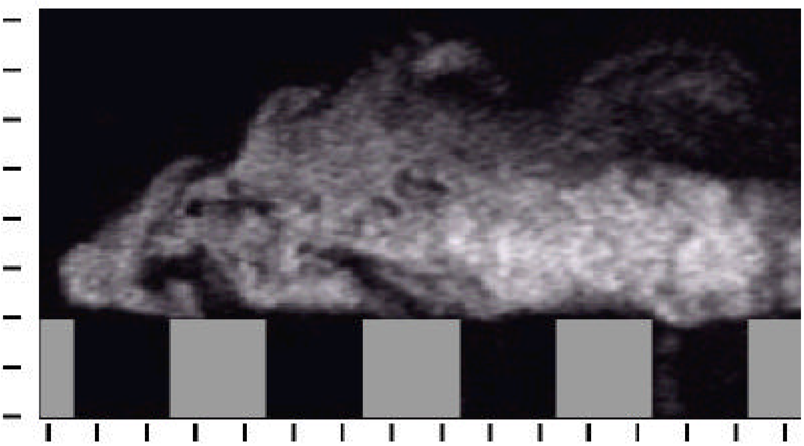
ABSTRACT

A quantitative, full-field planar visualization technique was developed and successfully used to assess the flow dynamics and mixing behaviour of gravity current heads flowing over rough surfaces. Small-scale saltwater modelling, laser-induced fluorescence (LIF) and digital image processing were combined to analyze the roughness effects on the downstream spread and dilution rates of continuous source, parallel channel gravity current flows moving over beam-roughened surfaces. The work was completed in three phases: 1) the development of the modelling, visualization and analysis techniques; 2) the validation of these techniques using published results from well-documented, smooth-surface flow studies and 3) the evaluation of how well the published smooth-surface flow theory extends to rough-surface flows. This paper will focus on the first of these three phases, describing the LIF visualization and analysis techniques used. Extension of smooth-surface theory to the rough-surface gravity current flows considered here will be discussed.

Three series of tests, with source fluid density excesses of 1, 3 and 5%, were performed. The source injection flow rates were 10.3, 10.6 and 10.8 cm^2/s, respectively, which resulted in source buoyancy fluxes of 101, 312 and 530 cm^3/s^3, respectively. Five surface roughness conditions were examined for each series of tests, yielding a total of fifteen tests. These included a smooth-surface condition for each test series, providing a base case against which the rough-surface flow results were compared. The roughness arrays consisted of square-beam elements, 6, 13, 19 and 25 mm on a side, placed perpendicularly to the flow in a repeated array down the length of the water channel.

The experimental facility and techniques developed can successfully provide full-field, planar images of rough-surface gravity current flows to facilitate qualitative and quantitative study of the downstream spread rate and mixing. An image of a gravity current flowing over a rough surface to the left is given in Figure 1. The darker regions internal to the head represent pockets of lighter ambient fluid entrained into the head from the roughness element spaces below. Results from the smooth-surface test cases generally agree very well with the accepted theory and observations in terms of structure, flow dynamics and mixing behaviour. It was demonstrated that the assumption of no mixing between the current head and the ambient fluid, adopted by the constant advance velocity model, is acceptable for smooth-surface flows only. Modifications to this model were developed to allow its extension to rough-surface flows in which larger shear stresses and increased internal head mixing exist. The results of this work should contribute to the on-going development and improvement of predictive models for heavier-than-air-gas (HTAG) dispersions over rough-surfaces.

Fig. 1. Image showing internal mixing regions in a gravity current head with a 1% source fluid density excess flowing over a



19 mm roughness element array. Scales shown are in 1 cm increments.