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ON THE DYNAMICS OF INTERFACIAL INSTABILITY IN VERTICAL COUNTER-CURRENT GAS/LIQUID FLOWS

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Background

Even though thin films are characteristic for various areas of process engineering and widely employed, e.g. as falling liquid films in distillation and absorption columns with structured packings, their dynamic flow behaviour is still not fully understood. Detailed knowledge of the mechanisms at play, especially with regard to interfacial stability, can help to design more efficient mass transfer equipment. The complexity of thin film applications arises from a combination of different interdependent physical processes like turbulent gas flow field, mass and heat transfers and chemical reactions. This multitude of involved phenomena makes detailed experimental investigations over a wide range of operational parameters very difficult. However, with increasing availability of high-performance computing resources, such as the UK's "Advanced Research Computing High End Resource" (ARCHER) at the University of Edinburgh, the physics of thin liquid films can be investigated numerically in unprecedented detail.

Employed Methods

The aim of our work is to identify and characterise mechanisms related to interfacial instability of falling liquid films in counter-current contact with a laminar/turbulent gas. To investigate the dynamics of the considered system, two complementing techniques are employed:

- linear stability analysis
- ultra-high resolution direct numerical simulation (DNS)

This rigorous approach provides insight into fundamental hydrodynamic phenomena like formation and propagation of interfacial waves, liquid entrainment and droplet formation. We study linear stability of the liquid interface by applying a semi-analytical, temporal Orr-Sommerfeld analysis [1, 2]. Its outcome is used to benchmark early stage DNS results.

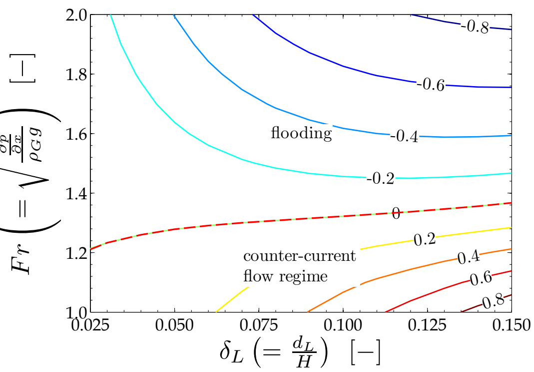

Figure 1: Dimensionless velocity at disturbed liquid interface over a range of relative film thicknesses δ_L and Froude numbers

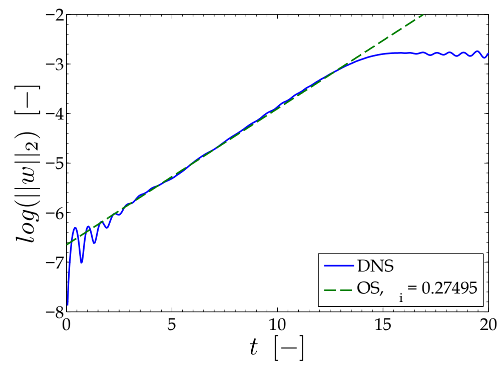

Figure 2: Comparison between DNS and Orr-Sommerfeld analysis; exponential growth rate over simulated dimensionless time

Furthermore, the occurrence and onset of absolute instability is enquired. Analysing the kinetic energy budget of interface disturbances complements the linear stability analysis and determines the source of instabilities [3].

To reveal and understand nonlinear characteristics of the two-phase system in various operational regimes (counter-current, loading, flooding), direct numerical simulations are carried out. To this end, we use a newly developed 2-/3-D in-house solver that uses level-set method for front tracking [4] and allows for viscosity and density contrast. Taking the architecture of the "ARCHER" service into account, the solver employs a hybrid MPI/OpenMP parallelisation scheme.

Key Findings

Different flow regimes are characterised for the unstable system over a wide range of parameters, identifying the onset of flooding and the limits for safe operation (fig. 1). The viscosity contrast at the gas/liquid interface is the main driving force of the instability. A rigorous comparison shows very good agreement between DNS results and linear theroy (fig. 2). The development of interfacial disturbances in the linear and nonlinear regime will be outlined and discussed.

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