Break-up Mechanisms and Conditions for Vapour Slugs Within Mini-Channels

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Abstract In the present investigation an enhanced Volume Of Fluid (VOF) based numerical simulation framework is applied for the conduction of parametric numerical simulations, aiming to investigate observed break-up phenomena of vapour slugs, within circular mini-channel branches of a hybrid thermosyphon / pulsating heat pipe device, during microgravity experiments. The simulation results identify three prevailing break-up regimes. The effect of fundamental controlling parameters in the resulting break-up characteristics is also examined. An entrainment of a liquid droplet at the trailing edge of the vapour slug, that is responsible for its subsequent "full" break-up, is identified from the simulations. Moreover, it is quite interesting that the value of the applied heat flux, does not seem to influence the break-up regime and its main characteristics.

Keywords: Volume Of Fluid, flow boiling, mini-channel, vapour slug, break-up

1. Introduction

The demand for increasingly higher performances of electronic equipment, has pushed researchers and engineers to develop a new generation of heat dissipation systems based on the local phase-change of a working fluid. Efficient thermal control, especially in space applications, and the need to reduce mechanical elements has become of crucial importance. Two-phase, closed-loop, wickless heat pipes, such as a ThermoSyphon (TS) or a Pulsating Heat Pipe (PHPs), that are the focus of the present investigation, can meet such requirements. In the work of Mangini et al. [1], a novel concept of a hybrid TS/PHP with a diameter bigger than the capillary limit is tested, both on ground and in hyper/micro gravity conditions, during the 61st ESA Parabolic Flight Campaign. The device is filled with FC-72 and it is made of an aluminium tube (I.D. 3 mm) bent into a planar serpentine. The proposed setup and some indicative flow visualization results during the microgravity stages, are depicted in Figure 1.
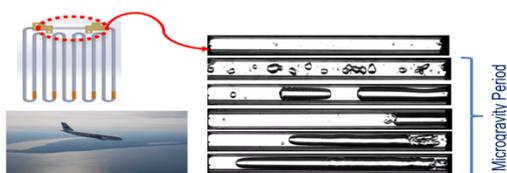

Figure 1. Experimental two-phase flow visualization within a hybrid TS/PHP [1].

During the microgravity duration, the flow is transformed into a slug/plug flow. The high-speed video of the experiments, reveal the development of intense capillary waves at the liquid film that surrounds the Taylor bubbles and in most cases this is accompanied by the break-up of the vapour slugs, close to their tail. Such break-up phenomena are numerically investigated in the present work.

2. Investigation Methodology

For this purpose, an Enhanced VOF method that has been developed in the context of OpenFOAM CFD Toolbox, coupled with heat transfer and phase-change, is applied in order to perform a plethora of parametric numerical simulations aiming to understand the various break-up mechanisms and characteristics. The proposed numerical framework has been presented in detail, extensively validated and successfully applied in the past for the case of quasi-static bubble growth and detachment from submerged orifices in isothermal liquid pools [2], as well as for cases of saturated pool boiling [3]. An additional validation has been performed here against the experimental data on Taylor bubble development in a mini-channel T-junction that are reported in the work of Arias et al. [4] (Figure 2).
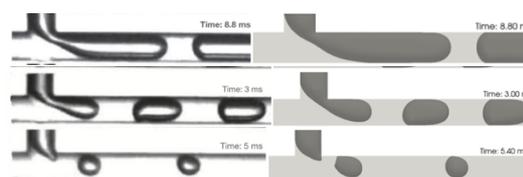

Figure 2. Comparison of experimental (left) [4] and numerical (right) results (present investigation), for three

different cases of Taylor bubble generation in a mini-channel T-junction.

3. Results and Discussion

Four different series of parametric numerical experiments of isolated liquid slugs within a mini-channel were performed, investigating the effect of applied pressure drop, surface tension, initial liquid film thickness and applied heat flux, on the vapour slug dynamics. A mini-channel, 90 mm in length and 3mm in diameter was considered, consisting of a 25 mm long adiabatic section at the beginning, were the vapour slugs were introduced within a developed liquid flow. A certain imposed pressure difference between the inlet and the outlet and a specific heat flux at the heated wall are used in each case. The adiabatic section was followed by a 65 mm heated section. For the base case, the working fluid properties were selected as FC-72 vapour and liquid at their thermodynamic equilibrium point at 1 bar pressure.

The post-processing and analysis of the overall results identified three governing regimes in the dynamic development of the vapour slugs: a "non-break-up" regime; a "partial break-up" regime and a "complete/full break-up" regime. It is quite interesting that in the case of the full break-up, a liquid droplet is entrained within the vapour slug which then leads to its break-up. The three main break up mechanisms and the flow map with the corresponding regimes, are illustrated in Figure 3. The red and green circles represent cases with the same hydrodynamic conditions as the corresponding adiabatic cases but applying heat fluxes of 5000 and 10000 W/m^2, respectively. This indicates that the break-up regime of the slug in each case, does not depend on the applied heat flux to the heated section in the channel. Even though the slug volume in the heated cases increases due to evaporation, the break-up regime remains the same. This can be also visualised in Figure 4, were the time of break up is illustrated for 3 different cases with the same hydrodynamic conditions but with different applied heat fluxes in the heated section of the channel.
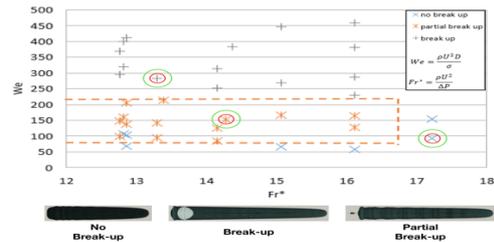
Figure 3. Flow map with different vapour slug break-up regimes (Weber number versus a modified Froude number).
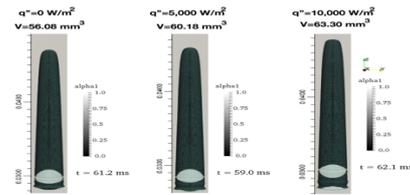
Figure 4. Resulting break-up regime for three different cases of applied heat flux at the heated portion of the mini-channel.

4. Conclusions

An enhanced VOF-based numerical simulation framework is utilized for the investigation of break-up regimes of FC-72 vapour slugs, within adiabatic and heated mini-channels. Three governing regimes are identified: a "non-break-up" regime; a "partial break-up" regime and a "complete break-up" regime. Some interesting phenomena and findings are revealed.

5. References

1. Mangini, D.; Mameli, M.; Georgoulas, A.; Araneo, L.; Filippeschi, S.; Marengo, M. A pulsating heat pipe for space applications: Ground and microgravity experiments. *Int. J. Therm. Sci.* **2015**, *95*.

2. Georgoulas, A.; Koukouvinis, P.; Gavaises, M.; Marengo, M. Numerical investigation of quasi-static bubble growth and detachment from submerged orifices in isothermal liquid pools: The effect of varying fluid properties and gravity levels. *Int. J. Multiph. Flow* **2015**, *74*, 59–78.

3. Georgoulas, A.; Andredaki, M.; Marengo, M. An Enhanced VOF Method Coupled with Heat Transfer and Phase Change to Characterise Bubble Detachment in Saturated Pool Boiling. *Energies* **2017**, *10*, 272.

4. Arias, S.; Legendre, D.; González-Cinca, R. Numerical simulation of bubble generation in a T-junction. *Comput. Fluids* **2012**, *56*, 49–60.