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Flow Boiling in straight heated tube under microgravity conditions

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Boiling two-phase flow can transfer large heat fluxes with small driving temperature differences, which is of great interest for the design of high-performance thermal management systems applied to space platforms and on-board electronics cooling in particular. However, such systems are designed using ground-based empirical correlations, which may not be reliable under microgravity conditions. Therefore, several two-phase flow (gas-liquid flow and boiling flow) experiments have been conducted in the past forty years and enabled to gather data about flow patterns, pressure drops, and heat transfers including critical heat flux and void fraction in thermohydraulic systems. Previous state of the art and data can be found in the papers of Colin et al. [1], Ohta [2], and Celata and Zummo [3]. However, there is still a lack of reliable data on heat transfer in flow boiling in microgravity. Therefore, the purpose of our study is to clarify gravity effects on heat transfer characteristics and provide a fundamental description of boiling heat transfer for space applications.

Hence, a two-phase flow loop for the study of flow boiling has been built at the *IMFT* (Figure 2) in order to perform experiments in vertical flow both in normal gravity and microgravity during parabolic flights aboard an aircraft.

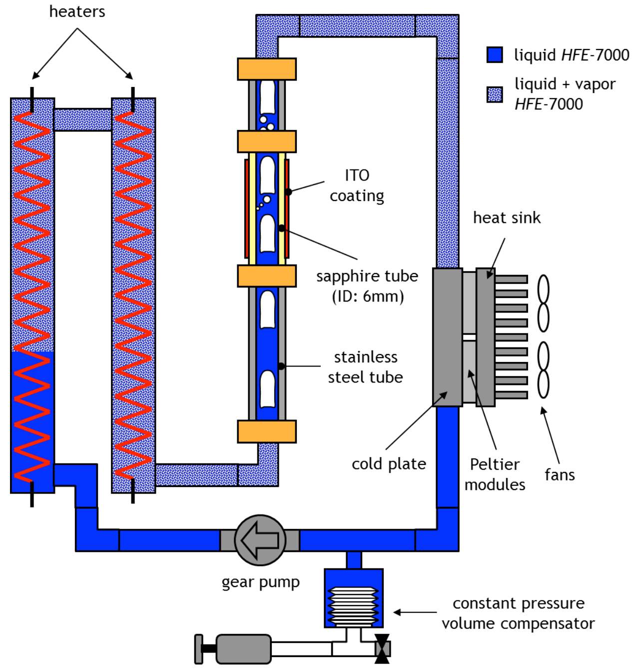


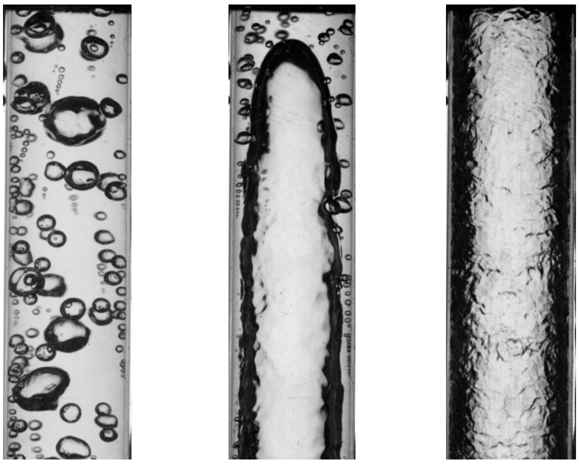
Figure 1: Scheme of the experimental set-up

The test section is a 1mm thick sapphire tube of 6mm internal diameter with an *ITO* coating on its outer surface. The coating is heated by Joule effect and its temperature (external wall temperature) is measured in four locations by Pt100 sensors. Liquid temperature is measured at the inlet and outlet of the test section by thermocouples. High-speed movies of the flow are taken with a *PCO* 1200HS camera. The pressure drop is measured just after the test section on an adiabatic part with two differential pressure transducers Valydine P305D. The mean void fraction upstream and downstream the test section is measured by capacitance probes developed and carefully calibrated at the *IMFT*.

The refrigerant *HFE*-7000, which was chosen for safety reasons in the aircraft and because of its low saturation temperature at atmospheric pressure (34°C), circulates with mass fluxes G between 100 and 1000 kg/s/m². Previous experiments aboard the aircraft showed that the influence of gravity on heat transfer characteristics is negligible for mass fluxes higher than 500 $kg.s^{-1}.m^{-2}$, which enables to investigate lower flow rates. A wide range of flow boiling regimes are studied, from subcooled flow boiling to saturated flow boiling with vapour mass qualities up to 0.7. The wall heat flux density ranges from 0 to 45 000 W/m² (which never allows the *HFE*-7000 to be in pure vapour state). In subcooled boiling, bubbly flow is mainly observed. For saturated conditions, the flow patterns are slug and annular flows depending on the quality value (Figure 2). Transitional flows between these flow areas are studied too.

Experimental data were collected during two parabolic flight campaigns and on-ground. Single-phase flow runs are performed to obtain validations for heat transfer and pressure drop compared to empirical correlations.

- special attention is dedicated to the calculation of the vapour quality that equals the classical thermodynamical quality only in saturated conditions;
- void fraction data give access to the liquid film thickness in annular flow;
- the wall local heat transfer coefficients are deduced from the wall heat flux density and the local wall temperature measurements by using conduction and balance equations. Heat losses are negligible. Kandlikar's and Chen's correlations are used for comparison;
- joint measurements of pressure drop and mean void fraction at the outlet of the test section allow to access to the wall shear stress through the momentum balance equation. It is compared to Lockhart and Martinelli's correlations;
- the interfacial stress can be calculated for annular flow by using an enthalpy balance, and compared to Wallis' model.



(*a*) (*b*) (*c*)

Figure 2: Flows pattern observed in microgravity bubbly flow (*a*) – slug flow (*b*) – annular flow (*c*)

Results obtained under normal gravity and microgravity conditions are compared to existing models in order to obtain reliable and precise closure laws for boiling heat transfer in microgravity.

Bubbly flows correspond to low superficial vapour velocities. Identical flow patterns maps were found in microgravity and normal gravity, except for the transition between slug and annular flow that seems to occur at lower vapour qualities in microgravity.

The trend for liquid film thickness is consistent with thinner liquid films under microgravity conditions, as found by de Jong and Gabriel [4].

Heat transfer values on-ground are in good agreement with classical correlations of the literature. However, significant discrepancies with these correlations are found in microgravity. Flow boiling heat transfer at low mass fluxes under microgravity conditions can be either increased for high vapour qualities or reduced by up to 30% for vapour qualities inferior to a given value that depends on the mass flux, which is consistent with the film thickness data.

Experimental pressure drops data fit the Lockhart and Martinelli's correlation with a good agreement both in normal gravity and microgravity, as found by Awad and Muzychka [5] who tested various data sets in microgravity.

Additional experiments at lower mass fluxes should be conducted in order to validate these trends. Collaboration with another team and comparison to new void fraction and heat transfer models are currently in progress.

Acknowledgements

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