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Hydrodynamics and heat transfer in vertical upward and downward annular flow boiling

Abstract: Flow boiling is encountered in many industrial processes and the annular flow regime is of a great interest, due to its relatively high heat transfer coefficient (HTC). Flow boiling is however, characterized by a complex interplay of hydrodynamics, mass transfer, heat transfer and interfacial phenomena, which explains that most of the time HTC is predicted by correlations involving several dimensionless numbers. In annular flow, bubble nucleation at the wall can still be observed, disturbing the flow in the liquid film in the wall vicinity, impacting the wall shear stress. The liquid film is sheared by the vapor core at high velocity, inducing disturbance waves at its interface by Kelvin Helmholtz instabilities. The increase in the interfacial shear stress due the disturbance waves has a strong impact on the interfacial heat transfer.

To analyze the interplay between hydrodynamics and heat transfer in annular flow, we have performed dedicated experiments in a 6mm diameter tube with HFE-7000 as working fluid, in vertical upward and downward flows. The test section is a sapphire tube coated outside by an ITO deposit heated by Joule Effect. This transparent test section allows flow visualizations and characterization of disturbance waves at the surface of the liquid film. From pressure drop and void fraction measurements, liquid film thickness, wall and interfacial shear stress were measured. Heat transfer coefficient was determined by measurement of the wall temperature and heating power. The wall shear stress increased with the wall heat flux due to the bubble nucleation at the wall. Following a similar approach to Kim and Mudawar (2013) a correlation for the wall shear stress taking into account the forced convection and the bubble nucleation was derived and provided a good estimation of the experimental data. From image processing of the high-speed visualizations, velocities (Uw) and frequencies (Fw) of the disturbance waves in annular flow were measured. The interfacial shear stress was found to directly depend of the product $Uw \times Fw$ and a prediction of the interfacial friction factor was proposed in flow boiling for both upward and downward flows. The hydrodynamics of the turbulent liquid film was described by an eddy diffusivity model, using heat-flux-dependent wall shear stress correlations. The damping of the eddy diffusivity at the interface is based on the roll waves velocities characterized by image processing. Finally the profile of the eddy heat diffusivity was integrated across the liquid film to calculate the heat transfer coefficient. This theoretical modeling provides a good prediction of the heat transfer coefficient in both upward and downward flow and clearly points out the direct link between the hydrodynamics in the liquid film and the heat transfer coefficient in annular flow boiling.

Biography: Catherine Colin is Professor at the University of Toulouse and Researcher at the Institute of Fluid Mechanics in Toulouse (IMFT). She obtained her PhD in 1990 in Toulouse and joined IMFT as CNRS researcher. She became full Professor in 2002. Her main research topics are two-phase flow in normal and microgravity conditions, bubble dynamics, breakup and coalescence, turbulence modelling, pool and convective boiling. She is involved in several national and international networks and projects on two-phase flow for space applications and nuclear industry. She is authors of 150 publications in peer review journals or proceedings of international conferences and 15 keynotes lectures in international conferences. She was associated editor of Experimental Thermal and Fluid Science (2010-2018) and is associated editor of International Journal of Multiphase flows. She was involved the scientific committees or co-chair of several international conferences (International Conference on Multiphase Flow, International Conference on Boiling and Condensation heat transfer, Experimental Heat Transfer Fluid Flow and Thermodynamics). She was vice Chair in charge of research at the Polytechnic National Institute of Toulouse (2016-2020).