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THERMOHYDRAULIC BEHAVIOUR OF HEII IN STRATIFIED CO-CURRENT TWO-PHASE FLOW AT HIGH VAPOR VELOCITIES

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Abstract

Recent experiments conducted with a co-current flow of saturated superfluid helium at CEA-Grenoble have shown a transition from stratified two phase flow to droplet mist flow at high vapor velocities. The two phase co-current stratified flow was circulated through a 40 mm inner diameter, 10 m long tube, with a slope ranging between 0 and 1.4%. Mass flow rates and temperatures ranged between 1 and 7 g/s, 1.8 and 2 K respectively. These various conditions allowed a comparison of the flow behavior for same void fraction but different vapor mass flows. Some evidences of atomization without any transition from stratified to annular flow are given.

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Thermohydraulic Behaviour of HeII in Stratified Co-Current Two-Phase Flow at High Vapor Velocities

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Recent experiments conducted with a co-current flow of saturated superfluid helium at CEA-Grenoble have shown a transition from stratified two phase flow to droplet mist flow at high vapor velocities. The two phase co-current stratified flow was circulated through a 40 mm inner diameter, 10 m long tube, with a slope ranging between 0 and 1.4%. Mass flow rates and temperatures ranged between 1 and 7 g/s, 1.8 and 2 K respectively. These various conditions allowed a comparison of the flow behavior for same void fraction but different vapor mass flows. Some evidences of atomization without any transition from stratified to annular flow are given.

INTRODUCTION

In the framework of LHC studies, we have performed several experiments on He II co-current two-phase flow. It was found that for high vapor velocities, the heat transfer between the He II flow and the pipe wall is significantly better than what can be accounted for the liquid to wall interface of a stratified two-phase flow pattern. Wall capacitive sensors were developed and used to check the potential transition toward an annular flow regime. This increase in wet perimeter could also be due to deposition of liquid droplets. Liquid droplets coming from the atomization of the liquid-vapor interface get dispersed on the tube wall and increase the wet surface. Optical measurements able to detect liquid droplets in the vapor flow were used. After a description of the accuracy of these various sensors, including our thermal sensor, we present results showing a significant increase in heat transfer at high vapor velocities. In that case, no annular transition was found and optical measurement showed presence of liquid droplets in the middle of the pipe.

SENSOR CALIBRATION AND ACCURACY

Thermal heat transfer box

The principle of the measurement has been already presented[1] and a scheme of this device is shown on figure 1. Calibration was performed in a separate cryostat where both heat exchanger pipe and pressurized bath were completely filled with liquid He II. A global heat transfer coefficient (corresponding to heat conductivity of copper and Kapitza conductance on the inner and outer pipe perimeter) was determined.

When the pipe is only partially filled with liquid, one expects a heat transfer proportional to the wet perimeter. Surface tension may be introduced to calculate the capillary length and to relate accurately the wetting to the liquid level inside the pipe in case of smooth stratified flow. Furthermore, the conduction inside the copper wall induces a cooling fin effect which increases the heat transfer. Finally, the Rollin film can also transport part of the injected heat. These various terms are quantified in our case.

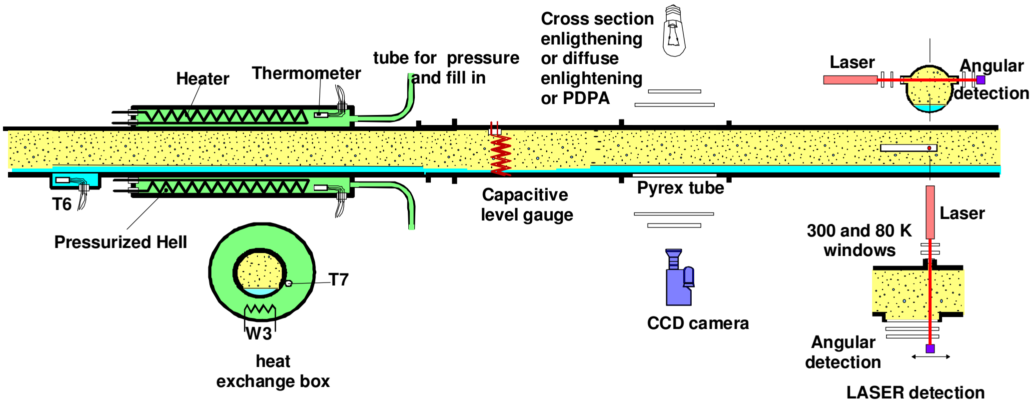

Figure 1. Scheme of the instrumentation

Among them, we checked the assumption that the liquid level at the wall is equal to the interface liquid level, i.e. the surface tension can be neglected. Results of the difference between wet perimeter with and without taking into account surface tension always remain less than 1 % of the pipe perimeter when the liquid level is below the mid-height of the tube.

Concerning heat transported by the Rollin film, a rough estimation is given by the limit of the burn out of the film. Using typical values of 3 10^{-8} m and 0.3 m/s for the thickness and the critical velocity of the Rollin film, one can find 0.025 Watt removed by the film in our 0.4 meter long heat transfer box. For a typical value of 1 Watt injected in the heat transfer box, neglecting this film contribution corresponds to a relative error of 2.5 %.

Finally, if the heat conductivity of copper is not negligible as compared to Kapitza conductance, some heat is transported through the copper at an azimutal position higher than that of liquid level. This quantity can be computed using the full equation and the ANSYS code. Heat conductivity of the copper used and Kapitza conductance were measured separately and can be described respectively by the following laws $\lambda_{(W/mK)}=6.32T_{(K)}$ and $h_{(W/m^2K)}=880T^3{}_{(K)}$ in the range of 1.8 - 2.2 K. The numerical solution leads to a typical value of a wet perimeter 1 mm smaller than the apparent wet perimeter due to the cooling fin effect.

<u>Wall liquid level capacitive gauge</u>

Description and fabrication of the sensors were given elsewhere[2] and we focus here on the principle of the measurement. Basically, two electrodes are glued on the inner pipe diameter. The capacitive response of this sensor depends on the wet surface and on the thickness of the liquid film covering the wet surface.

In first approximation, once the liquid thickness of the wet part is higher than the gap between the two electrodes (100 microns), the measurement directly indicates the wet area. On the contrary if the liquid film is thinner than a few microns, the sensor does not detect the presence of this liquid. Figure 2a shows this dependence from calculations performed with ANSYS code. It clearly indicates that this type of sensor is not sensitive to the Rollin film.

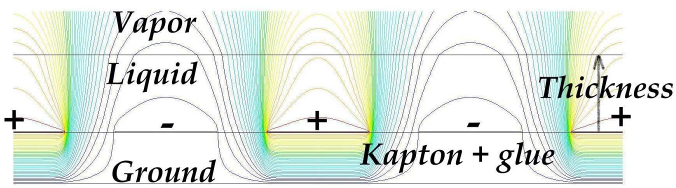

Figure 2a Equipotential lines
The case of liquid toluene is plotted here to visualize the difference in dielectric constant with the vapor

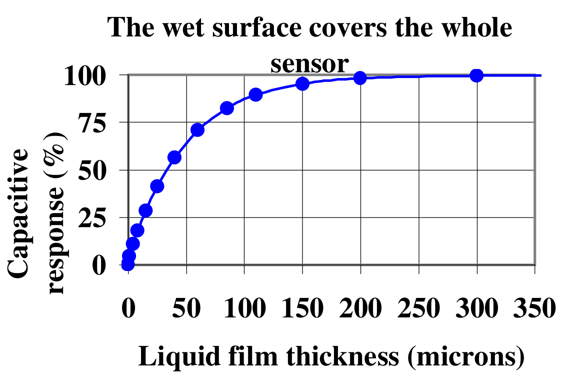

Figure 2b Relative variation of the capacitor with the thickness of wet layer

The inner perimeter is covered by four of these sensors separated by a gap of 2 mm. This implies that the measurement is blind between 23.5 % (end of sensor glued at the low part of the pipe) and 26.5 % (beginning of the two "lateral" sensors).

Optical techniques

Various optical techniques[3] were used to characterize the mist flow. We only discuss here on light scattering at the middle of the pipe. It mainly gives access to the interfacial droplet area Σ, where :

$\Sigma = \sum_{i=0}^{n} 4\pi\, r_i^2 / V$ (with n droplet number, r_i droplet radius and V volume explored by the laser beam)

RESULTS AND ANALYSIS

All measurements presented here were acquired for a 1.4 % slope and a saturated temperature of 1.8 K.

Heat transfer results

Figures 3 show the heat which can be extracted from the heat transfer box as a function of the temperature difference between the pressurized liquid inside the box and the saturated flow. The slope of the curve gives direct access to the apparent wetting using the formula :

$$S = \frac{1}{h}\frac{\Delta W}{\Delta T} \quad \text{where} \quad h = \frac{1}{S_{total}}\frac{\Delta W_{calibration}}{\Delta DT_{calibration}}$$

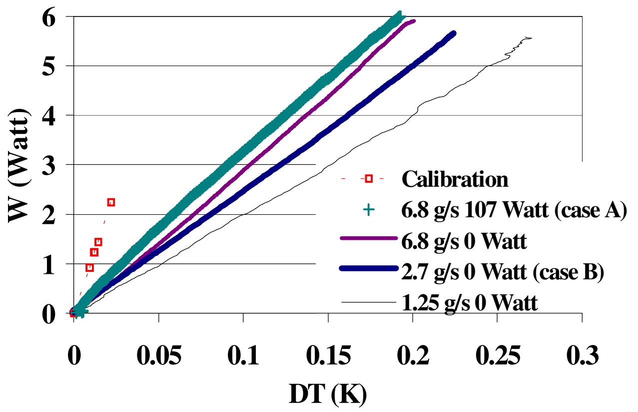

figure 3a Wall heat transfer

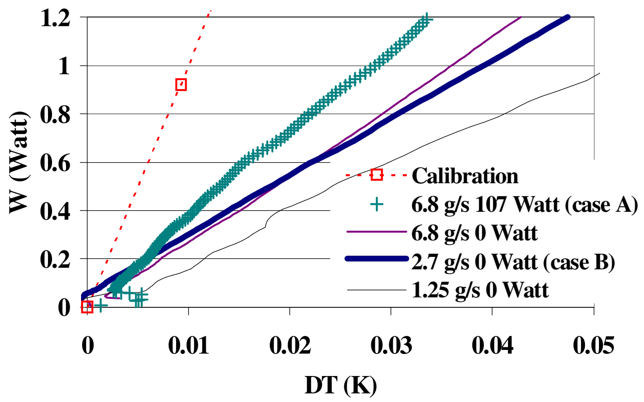

figure 3b behavior at low heat flux

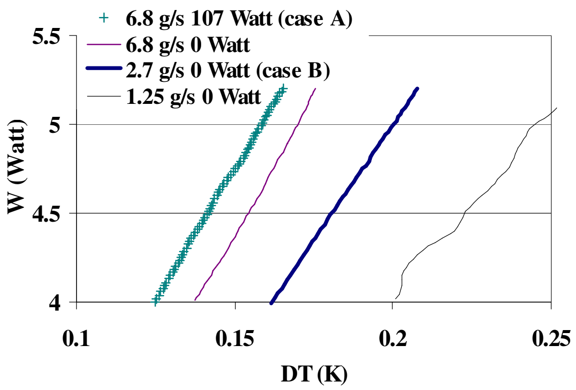

figure 3c behavior at high heat flux

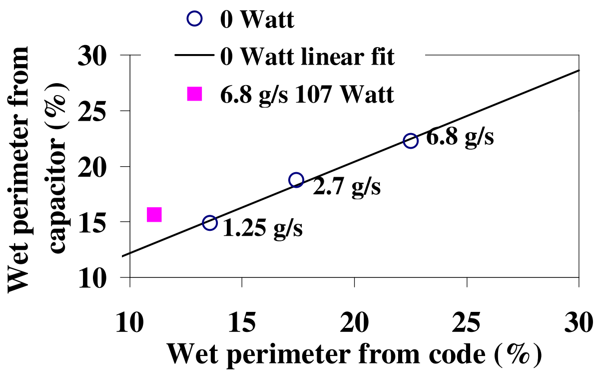

figure 4 Comparison between calculated and measured wet perimeter

The liquid mass flow remaining for 6.8 g/s and 107 Watt (case A) is lower than those of 2.7 g/s and 0 Watt (case B). Furthermore, in case A the liquid flow is accelerated by the vapor flow drag. This implies a larger void fraction in case A, and one expects the heat transfer to be lower than that of case B. On the contrary, the heat transfer is the highest for the case A (see slope of curves in figure 3a). As the heat transfer directly depends on wet perimeter, the hypothesis of a smooth stratified flow is no more valid in that case. Furthermore, the local slope of case A decreases as the heat flux increases (see figure 3b and 3c) which could be the signature of a partial dry out of the over wetting.

Capacitive sensor results

To check a transition to a partial annular film, capacitive sensors were used. As seen on figure 4, wet perimeter in case A is much lower than in case B, even if it remains a little higher than the predicted value. First conclusion is the absence of transition to an annular flow.

Comparison with optical measurements

Assuming the liquid droplet deposition will create a thin film which has little influence on capacitive sensors, the over wetting can be defined as the difference between the wetting calculated from heat transfer measurement and wetting extracted from capacitive measurements.

In order to compare this over wetting with interfacial droplet area, all measurements were normalized using the maximum value obtained for 120 Watt power injected.

The very good correlation obtained in figure 5 gives some evidence of the role of droplets in the increase of heat transfer at high vapor velocities.

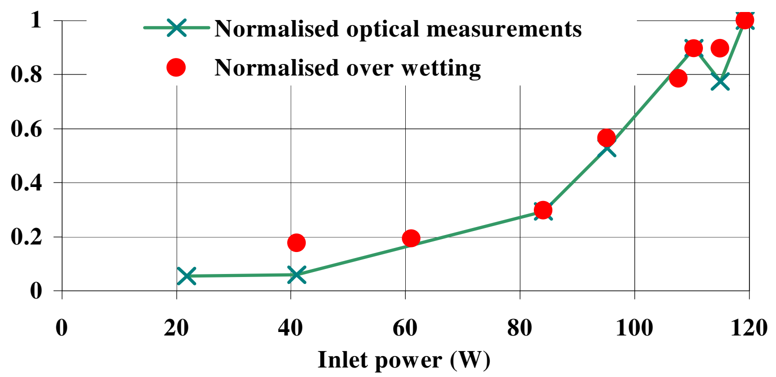

Figure 5 Attempt to correlate optical measurements and over wetting

CONCLUSION

Measurements performed at high vapor velocities in a quasi horizontal co-current superfluid two-phase flow have shown a transition from pure stratified vapor/liquid flow to a stratified mist/liquid flow. Few references of such a flow pattern exist and other runs[4] are planned to further investigate it.

First results tend to indicate a high concentration of droplets at the low part of the tube. The droplet deposition in this region could then create a thin film and increase the wet perimeter.

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