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Latest Developments on He II CO-Current Two-Phase Flow Studies

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Abstract

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LATEST DEVELOPMENTS ON HE II CO-CURRENT TWO-PHASE FLOW STUDIES

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ABSTRACT

Large scale experiments were performed at CEA Grenoble with the support of CERN to simulate and understand the HeII cooling circuit of the LHC. This paper describes the latest results obtained in HeII co-current two-phase flow configuration. First we summarize thermal and hydraulic behaviour of flows obtained in a 40 mm I.D., 86 m long tube inclined at 1.4% which resembles closely the LHC heat exchanger tube. For low vapour velocities, the flow pattern is found to be stratified. A model based on this observation has been developed which fits very well the measured pressure losses. However the wetted surface predicted by the model underestimates the measured one, notably for high vapour velocities. In that case, liquid droplets entrainment takes place. Droplets landing on the tube wall increase the wetted surface. Thus we infer that for higher vapour velocities, the stratified two-phase flow model should not be applied anymore. In order to validate the range of availability of the model, and begin to draw a flow pattern map, a 20 mm I.D. horizontal test sector was built and experiments were performed. First results are presented here, including the observation of the stratified-annular flow transition.

INTRODUCTION

For large superconductive devices (e.g. LHC[1] or TESLA[2]), HeII two-phase flow has to be employed as the cold source. Unlike water or oil two-phase flow for which a rich literature exists, very few studies [1-5] have been performed with HeII. As for classical fluids, the first approach consists of drawing a flow pattern map. Then, for practical application reasons (stability, pressure losses,...), pipe diameter, mass flow rate and quality have to be chosen to remain if possible in the stratified flow regime.

In the framework of LHC cooling scheme studies, experiments were performed on a 40 mm I.D. pipe and a HeII two-phase flow model was implemented. Main results are presented here. Furthermore, in order to explore the range of validity of our stratified two-phase flow model, new experiments with a 20 mm I.D. pipe have been carried out and are discussed here.

DESCRIPTION OF THE EXPERIMENT

Test Loop

The two types of tube studied and their arrangement in our test facility are shown in fig. 1a and fig. 1b.
Figure 1a for the 40 mm I.D., 86 m long pipe inclined at 1.4% has already been described in detail[3].
The test loop mainly consists of an inlet box used to create the inlet quality, the 86 m line which can be heated using the Joule effect, and an outlet saturated bath where liquid in excess is vapourized.
The important measurement-set consists of the total mass flow rate (determined at room temperature), saturated temperature at the extremities of the line (used to calculate pressure losses), all values of injected power (in order to calculate the quality), temperature increase in the pressurized chamber when power is on (which gives access to the thermal exchange) and visualization of the flow.

Modifications in case of 20 mm I.D. pipe

As shown in figure 1b, the 86m long line has been removed and the section between boxes B1 and B2 is now occupied by the 20 mm I.D. horizontal test section. This 1.3 m long test section contains a visual test section at each extremity and a thermal test section in the middle.

RESULTS

The 40 mm I.D., 86 m long tube inclined at 1.4 %

Hydraulic results. The theoretical flow pattern map of HeII according to the Taitel and Dukler[6] theory, is plotted on figure 2. According to this map the flow should remain stratified for the whole range in which we conducted our measurements. This gives us confidence in a model based on separated two-phase flow. A code solving mass, energy and momentum balance for each phase was developed. The convergence was ensured by equating pressure losses in the vapour and in the liquid phase[4]. As the prediction gives a large void fraction (mainly due to the ratio between liquid and vapour density), a simple calculation with vapour at saturation flowing alone in the whole cross section of the tube was also tested. Figure 3 shows comparison between calculated and experimental pressure losses in case of quasi adiabatic two-phase flow.

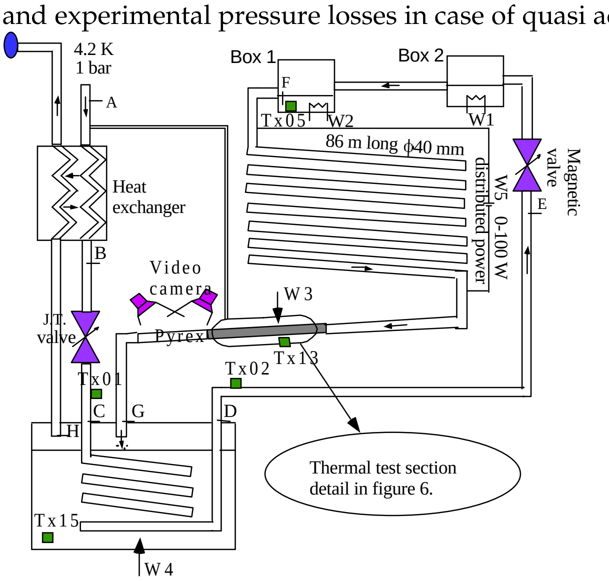

Figure 1a. 40mm I.D. test loop

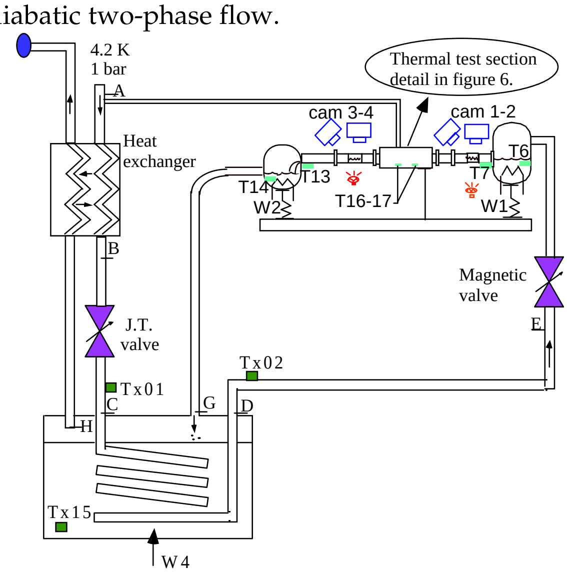

Figure 1b. 20mm I.D. test sector

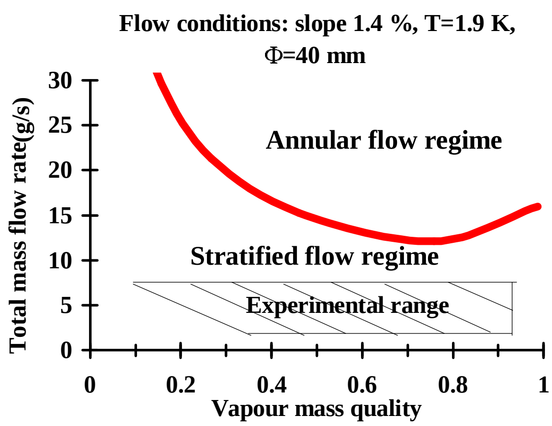

Figure 2. He II flow pattern map in adiabatic flow conditions according to Taitel and Dukler theory (1976)

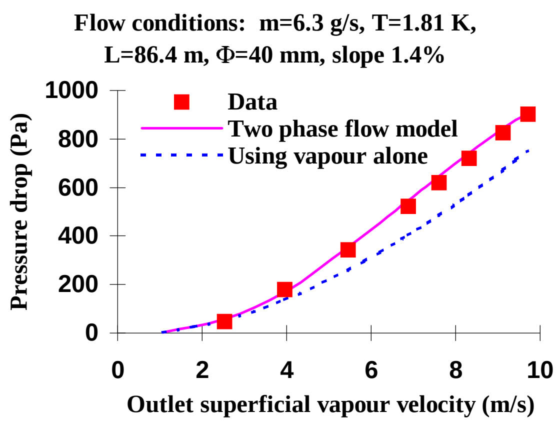

Figure 3. Comparison between experimental and calculated pressure losses in quasi-adiabatic flow conditions

The vapour flow model has an agreement with experimental points better than 20% (compared to 2% in case of two-phase flow model), which may be sufficient for design purposes. However, if the liquid helium inventory or the wetted perimeter is to be known, the vapour model cannot be used and the two-phase flow model must be used instead. Figure 4 shows the comparison of experimental and calculated void fraction in quasi-adiabatic flow condition. With respect to the range explored, the agreement between model and experiments is excellent.

Some experiments have been performed with distributed heating injected along the 86 m line. Once again, agreement between the two-phase flow model and the experimental pressure losses is very good (figure 5).

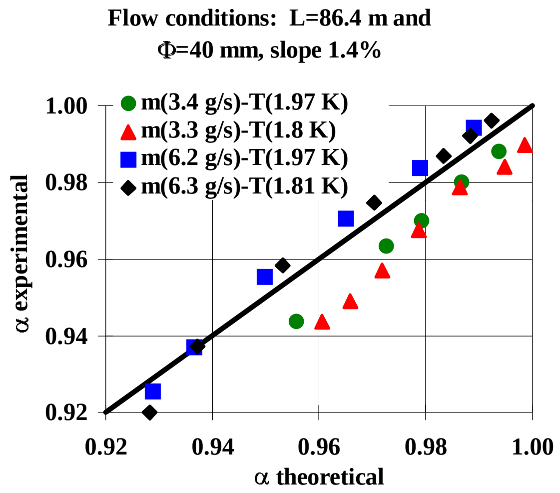

Figure 4. Experimental and calculated void fraction in quasi-adiabatic flow conditions

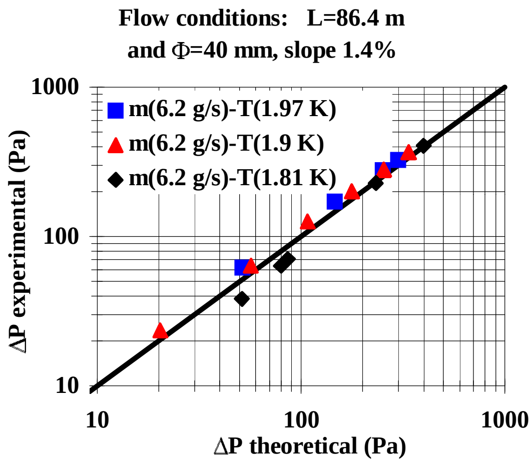

Figure 5. Comparison between experimental and calculated pressure losses for a distributed power injected along the 86 m line

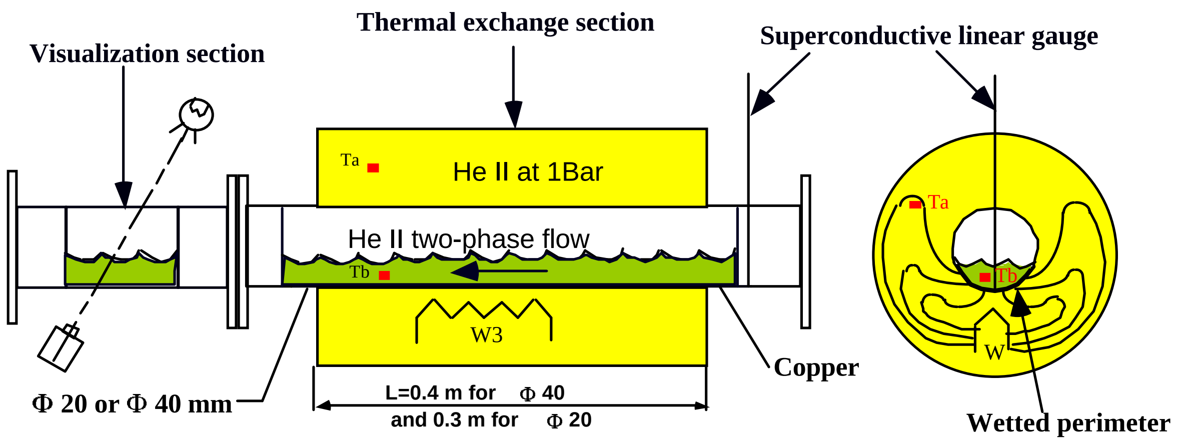

Figure 6. Various methods for measuring wetting of the tube wall

Thermal results. In the LHC cooling configuration, where the tube containing the He II two-phase flow is used as a heat exchanger, the wetted surface is a major parameter. In order to investigate the wetted perimeter, different measurement methods were used (figure 6).

For low vapour velocities, where interaction between liquid and vapour is weak, a simple model of open channel flow was applied and compared with the two-phase flow model and with the various experimental results (figure 7). The open channel flow model and the two-phase flow model provide about the same level of agreement with measurements. This however with the obvious exclusion of the horizontal flow configuration where the open channel flow model cannot be applied.

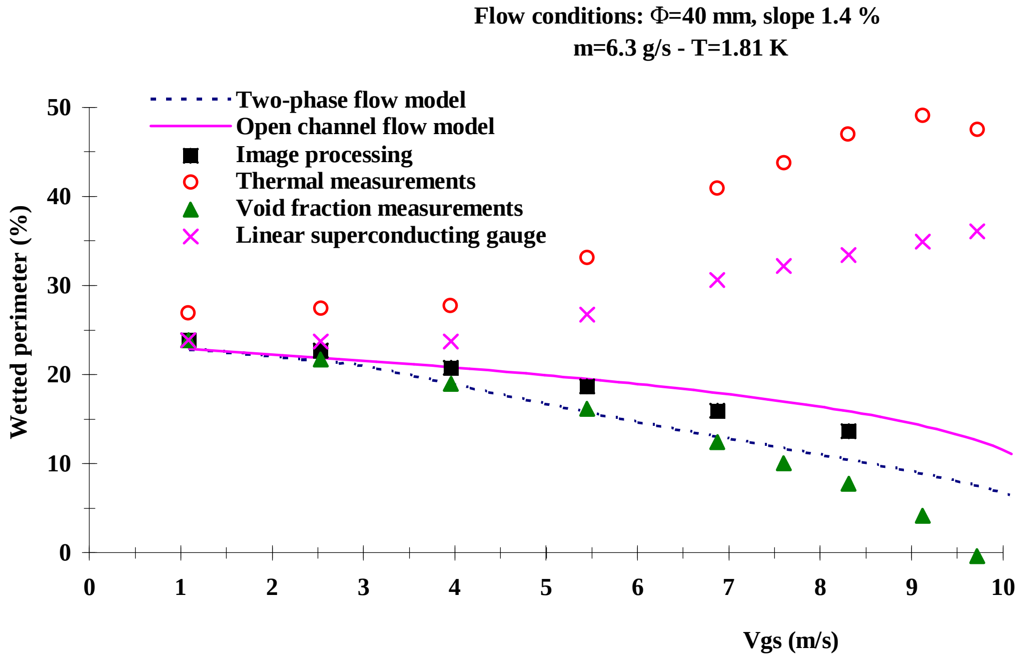

Figure 7. Comparison between different ways to estimate the wetted surface for high vapour velocities

For vapour velocities higher than 4 m/s, atomization occurs and the re-deposition of liquid droplet increases the wetted perimeter as indicated by the thermal measurements. The flow consists of liquid flowing at the bottom (which is always seen by the camera) surrounded by a mixture of vapour and liquid droplets above it. The density of liquid droplets increases as the vapour velocity grows. Hence, the assumption of separated two-phase flow with horizontal interface becomes invalid.

In order to check the range of validity of the separated two-phase flow model, it is important to determine the inception of liquid droplets entrainment. Some correlations which give a critical vapour velocity can be found in the literature[(7-8)] for water two-phase flow. Applying these inception criteria to HeII provides a means to predict the apparition of liquid droplets. For comparison, in the experiments, the critical vapour velocity was chosen as the vapour velocity corresponding to the minimum wetted perimeter given by the thermal measurement. Figure 8 shows the agreement between experimental and calculated values (according to Shi[8]) of the critical vapour velocity.

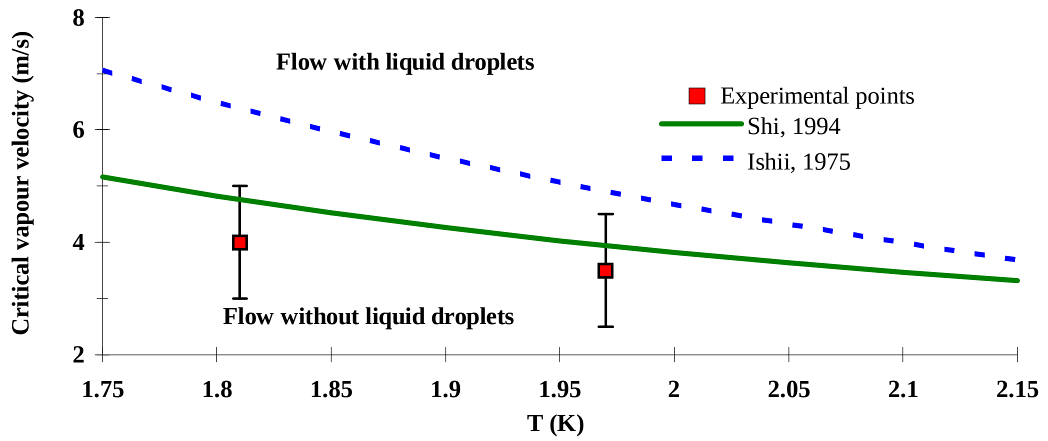

Figure 8. Inception criteria for liquid droplet entrainment

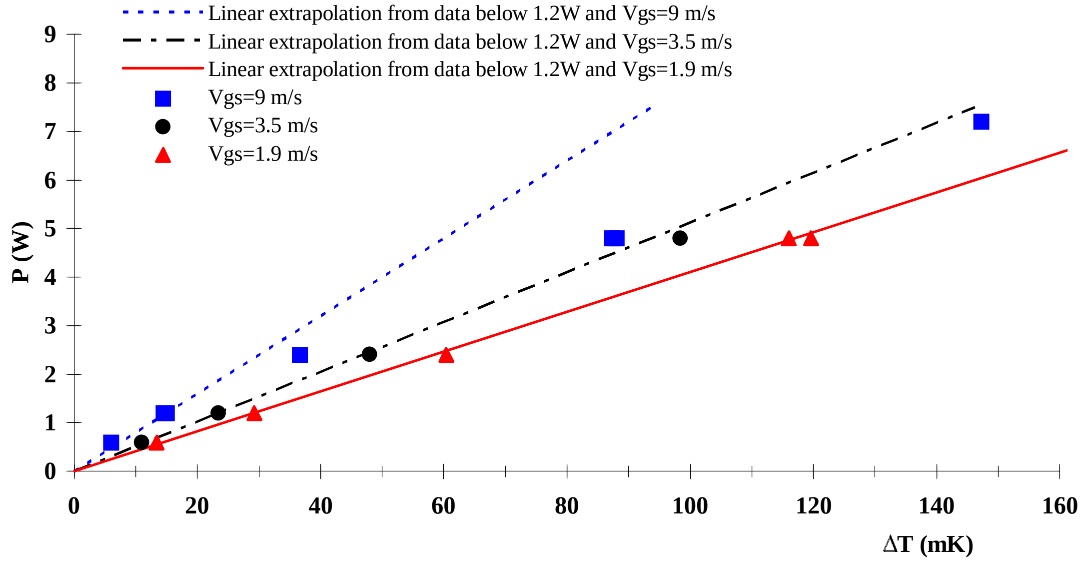

Figure 9. Thermal behaviour for different superficial gas velocities

This criterion is consistent with a non constant thermal exchange with power injected in the pressurized chamber (figure 9). For vapour velocities higher than critical, the heat exchange coefficient (slope of the curve W3(ΔT)) depends on the power applied at the exchange surface: sufficiently high values of applied heat load can vapourize liquid droplets, leaving the corresponding exchange surface dry.

The horizontal 20 mm I.D. tube

The annular transition. One goal of this new test circuit was the investigation of the stratified to annular flow transition boundary. In order to reach this annular flow regime, calculations using the Taitel and Dukler theory were performed and a 20 mm I.D. tube was chosen according to the mass flow rate range achievable in our test facility.
The transition from stratified to annular flow was not very clear to define, as an intermediate transition to atomization was found. Consequently, the wetted surface did not exhibit a sharp step at the annular transition, but grew progressively after atomization until the whole surface was wetted. Then, when the full surface seemed wetted, the discrimination between a liquid droplet re-deposition on the wall and an annular film had to be made. To solve this problem, increasing power levels were injected in the pressurized He II chamber (figure 10), and the results are analysed hereafter.

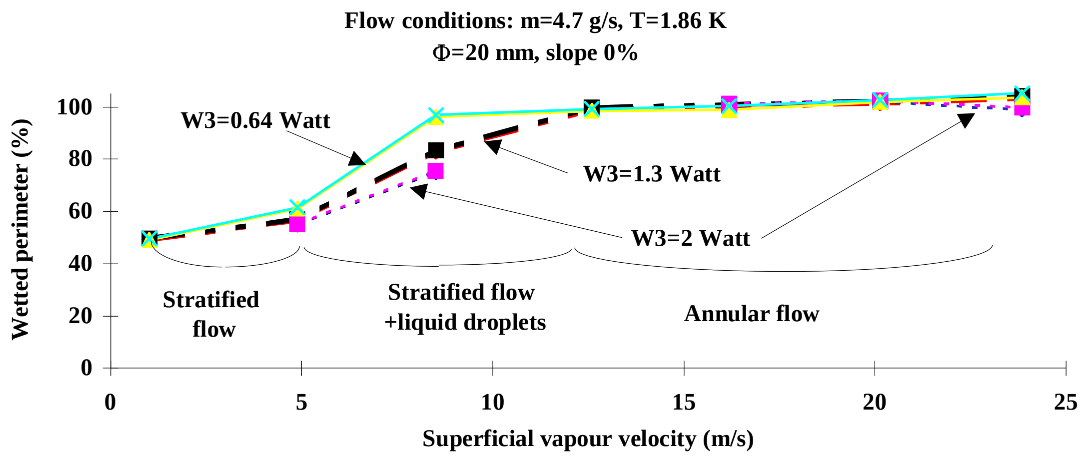

Figure 10. Wetting for different values of power injected in the thermal test section

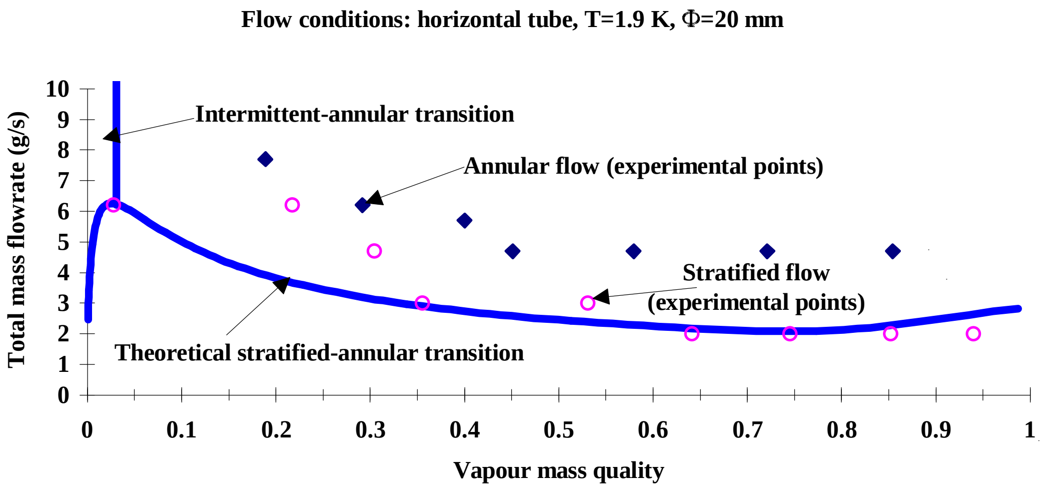

Figure 11. He II theoretical flow pattern map (using Taitel and Dukler 1976) and experimental data

When the flow is stratified without liquid droplets, the wetted perimeter is independent of the power crossing the heat exchange surface. In the atomization regime, the power crossing the wall of the pressurized chamber is able to partly vapourize the liquid droplets before re-deposition, and the wetted perimeter decreases as the power increases. Once the annular regime is reached, the whole perimeter is wetted, whatever the injected power level.
The experimental data have been classified according to the previously explained classification. The last point which belongs to the atomization regime and the first point of the annular regime are placed on figure 11 to check the transition to annular flow.

Some results in case of stratified flow. A second goal of this series of experiments was to check whether scaling the tube diameter provided the same flow condition (i.d. stratified flow pattern). At 2 g/s and 2 K, the flow remains stratified and the superficial vapour velocity can be varied from 1 to 8 m/s depending on the quality. On figure 12, the experimental and computed pressure losses exhibited large discrepancies. It is important to mention that large amplitude waves were seen on the video camera. This main difference with previous observation on the 40 mm I.D. sector certainly results in an increase of pressure losses. Unfortunately, as there were many changes (slope, diameter and length) since previous experiments, it was practically impossible to isolate the parameter responsible for this wavy flow behaviour. On figure 12, the extremity effect (difference between the experimental curves) plays an important role, which can also indicate that two-phase flow was not uniform along the 1.3 m long sector. Results presented by Spedding and Hand[9] show that for low vapour velocities, the flow may remain non uniform over a length of several tens of diameter. To solve this problem and check parameters one by one, we intend to build a new linear 40 mm I.D. test sector of 20 m in length, with slope ranging between ± 1.4 %.

CONCLUSION

We have investigated the thermohydraulic behaviour of He II two-phase flow. The general flow pattern map proposed by Taitel and Dukler[6] seems applicable in case of He II, however, more recent models[(7-8)] have to be used to include atomization.

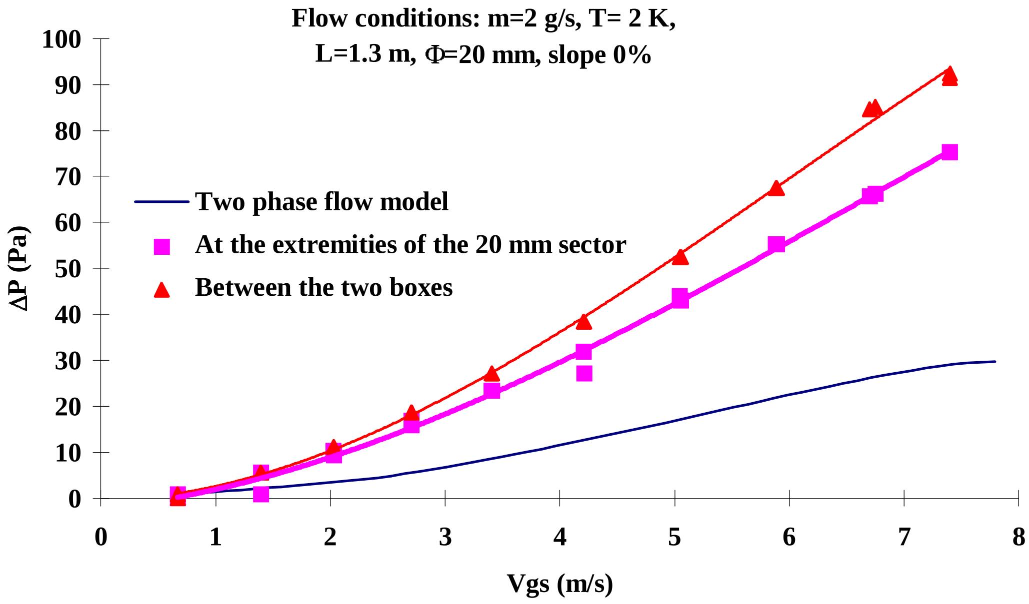

Figure 12. Comparison between experimental and computed pressure losses for the 20 mm I.D., 1.3m long pipe.

A separated two-phase flow model was developed in order to predict pressure losses and wetted area. The experimental wetted area is in agreement with the model until atomization occurs. In this last case, the actual wetted area is always larger than the predicted one, which therefore can be considered (in term of heat transfer) as a conservative value. Concerning pressure losses, experiments done on a 40 mm I.D. tube inclined at 1.4 % show very good agreement with the model, even in case of atomization. Nevertheless, big discrepancies were found using a short, horizontal, 20 mm I.D. tube. Influence of slope, diameter and length will be investigated in a new 20 m long linear test facility in 1998.

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