CAVITATION IN LIQUID HELIUM DUE TO A VIBRATING QUARTZ FORK

M. Blažková[b], T.V. Chagovets[b], M. Rotter[a], D. Schmoranzer[a], L. Skrbek[a]
Joint Low Temperature Laboratory, [a]Institute of Physics ASCR, v. v. i., Prague
and [b]Faculty of Mathematics and Physics, Charles University, Prague

Introduction

The quartz tuning fork proves to be a robust, cheap and widely available tool for generating and probing oscillatory boundary layer flows, especially at cryogenic conditions [1, 2]. Its peak velocity in helium fluids can be easily varied and detected over seven orders of magnitude, up to very high values of order m/s. An experimental setup containing a quartz tuning fork inside a pressure cell in a glass helium cryostat enables us to experimentally observe additional effects in liquid He, which we ascribe to cavitation (as these are absent in gaseous He), taking place in the vicinity of the fork.

Liquid helium can be prepared extremely clean and wets almost ideally any solid surface – it provides an ideal model system to study cavitation. Numerous studies have been performed over the last fifty years – see [3] for a comprehensive review of the early experiments on nucleation of bubbles in liquid helium, and [4, 5] for more recent results. As many experimental results remain poorly understood, it is of considerable interest to revisit this field using a new tool.

Experimental results and discussion

Our detection protocol is based on sweeping the fixed driving voltage applied to the quartz tuning fork, of the form $U = U_0 \, cos \, \omega t$, across the resonance frequency. At low driving voltages, the response signal from the fork is represented by the absorption and dispersion curves of Lorentzian form [1, 2]. On increasing the driving voltage the response ceases to be Lorentzian, the absorption resonant curve widens and the maximum response shifts towards lower frequency. As explained in detail in our previous publication [2], this behavior is observed in both liquid and gaseous helium and is caused by the transition from laminar to turbulent drag regime. These features occur in both liquid and gaseous helium.

In liquid He I and He II an additional pronounced feature occurs. On further increase of the drive, at high enough amplitude, the observed signal breaks down when the frequency is swept towards resonance. This breakdown event serves as a definition of the critical cavitation velocity $v_{\rm cav}$. When repeating the sweeps, this character of the signal persists but the response is generally not exactly reproducible. When $v_{\rm cav}$ is plotted versus temperature, a striking feature is observed, see Fig. 1. It is a very steep increase in $v_{\rm cav}$ right below the λ-point - here $v_{\rm cav}$ rises by factor 3-5 within about 20 mK. This step-like feature is detailed in the inset of Fig. 1. We have measured this feature with various forks; it displays a reasonable degree of reproducibility for the data series from different runs as well as for the data obtained with different forks.

While performing the cavitation experiments in an open helium bath of a glass cryostat, in He II (where no bubbles are present in the bulk, thanks to its extremely high thermal conductivity) we have indeed visually observed a bubble occurring between the prongs of the vibrating fork. Having available the pressure cell [2], we have performed the measurements showing the dependence of $v_{\rm cav}$ versus an externally applied overpressure at 4.2 K (see Fig. 1, right).

As the "breakdown" effects described above never occurred in gaseous helium, we naturally

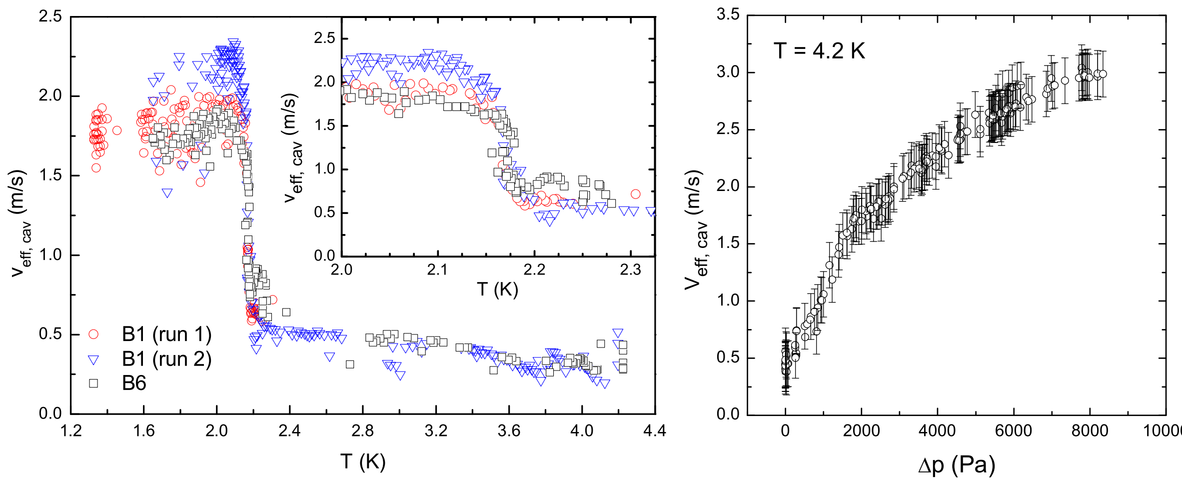

Figure 1: The observed critical cavitation velocity plotted versus the temperature at SVP. The inset magnifies the data in the vicinity of the λ-transition (left). The observed critical cavitation velocity plotted versus the applied overpressure in the cell at 4.2 K (right).

assume that they arise as a consequence of cavitation/boiling processes in liquid He I and He II. The most simple, perhaps naive, explanation would be that due to the Bernoulli equation the local pressure in the flow due to a vibrating quartz fork decreases. The overpressure data at 4.2 K can indeed be fitted by the expected $v_{\rm cav} \propto \sqrt{\Delta p}$ dependence, however, they lead to a pressure drop comparable with the hydrodynamic static pressure head in the cryostat, far too low for what would be required for homogeneous cavitation. Moreover, this simple approach does not explain the almost step-like change in $v_{\rm cav}$ close to T_λ. We believe that in He I thermal effects are influencing the observed velocity, since the vicinity of the fork is locally overheated and cavitation occurs at a temperature which is significantly (about 1 K) higher than that at which the surrounding helium bath is kept. This strongly suggests that combined boiling/cavitation rather than pure cavitation occurs. The steep increase of the cavitation velocity by factor 3-4 observed just below the superfluid transition can be understood as a consequence of the high convective heat transfer efficiency in superfluid He II. Our data do not allow us to unequivocally conclude whether the observed cavitation is heterogeneous or homogeneous in nature; however, homogeneous cavitation [5] would require superflow velocity enhancement past sharp corners by a factor of about 30. We are currently performing more accurate analysis along these thoughts, taking into account the measured values of force and velocity of the fork.

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