

DESIGN AND IMPLEMENTATION OF AN EXPERIMENTAL APPARATUS FOR THE VISUALISATION OF LIQUID HELIUM FLOWS

Marco La Mantia^{1,3}, Miloš Rotter¹, Josef Šebek² and Ladislav Skrbek¹

¹Department of Low-Temperature Physics, Faculty of Mathematics and Physics, Charles University in Prague, V Holešovičkách 2, 180 00 Praha 8, Czech Republic

²Department of Magnetism and Low Temperatures, Institute of Physics, Academy of Sciences of the Czech Republic, Na Slovance 2, 182 21 Prague 8, Czech Republic

³e-mail: lamantia@nbox.troja.mff.cuni.cz

Flow visualisation techniques have been recently applied for the investigation of various cryogenic flows of liquid helium, e.g. see [1, 2]. Quantitative techniques, such as PIV (Particle Image Velocimetry) and PTV (Particle Tracking Velocimetry), have been proven indeed very fruitful in many scientific and industrial areas of research during the last decades, e.g. see [3]. However, such a promising experimental approach is still in its infancy in the analysis of low temperature flows and the ways to optimise it are yet to be fully investigated due to a number of technical and fundamental difficulties, e.g. the optical access to the helium bath and choice of suitable tracer particles.

At the pressure of 1 bar ⁴He is liquid, if the temperature is lower than 4.2 K. It is called normal helium (or He I) at temperatures larger than 2.17 K and is characterised by extremely low values of the kinematic viscosity (of the order of 10^{-4} cm²/s), compared to those of air (0.15 cm²/s) and water (0.01 cm²/s) [4]. If the temperature is further decreased, liquid ⁴He is called He II and can be considered inviscid in the zero-temperature limit: this is why it is also called superfluid.

The unique properties of He II are described by the two-fluid model, e.g. see [5]. It is assumed that He II is made of two fluids, normal and superfluid helium. The former is viscous and carries entropy while the latter is inviscid and does not carry entropy. The total density of He II is not a function of temperature but the corresponding densities of its normal and superfluid components do depend on temperature. The ratio between the density of the superfluid component and the total density of He II increases steeply as the temperature decreases and, for example, is equal to 0.986 at 1.1 K [6]. If a volume of He II is heated, the normal component flows away from the heater while the superfluid component moves towards the heater in order to have a null flow rate. This phenomenon is called thermal counterflow and has not any equivalent in classical fluid mechanics.

Besides, the superfluid component of He II has been described as a quantum fluid, see again [5] for further details. This leads to the result that superfluid flow is irrotational. It follows that for a multiply connected fluid region the circulation of the superfluid velocity is not null and equal to an integer multiple of the quantum of circulation, which is the ratio of the Planck constant and ⁴He atomic mass, i.e. $9.97 \cdot 10^{-4}$ cm²/s [7]. This result can be seen as a quantum restriction to the superfluid motion. In other words, just quantised vortices – line singularities where the superfluid density is null – can exist in superfluid helium. For example, if a cylindrical volume of He II is rotating along its vertical axis, in the zero-temperature limit, the quantised vortices will align themselves parallel to the rotation axis in order to mimic solid body rotation, e.g. see [1]. The

description of superfluid helium as a quantum fluid is very relevant for the implementation of flow visualisation techniques at low temperatures. For example, the complex interactions between tracer particles, quantised vortices and macroscopic eddies in cryogenic flows are far from being completely understood and new experiments are required to verify the current theoretical understanding of these coupled phenomena, e.g. see [7, 8].

In order to fulfil such a need of novel experimental data we are currently establishing the first cryogenic flow visualization laboratory in Europe. Experimental investigation of selected cryogenic flows over wide ranges of governing dynamical parameters spanning from laminar to developed turbulent regime using all forms of cryogenic ^4He as working fluids are being planned. All these classical and quantum flows will be mainly probed by using quantitative flow visualisation techniques, i.e. PIV and PTV. The experimental apparatus consists of the following parts. A custom-made low-loss cryostat equipped with five sets of 25 mm diameter windows that minimise the heat input into the helium bath, enabling horizontal as well as vertical optical access, was designed and is currently being manufactured. A seeding system with a fast computer-controlled valve to supply the helium bath with the desired amount of hydrogen and deuterium micron-sized solid tracers is also currently being built. These low-temperature related parts are to be used with an off-the-shelf tuneable-power continuous wave solid state laser, fast digital camera (ca. 6200 fps) and relevant hardware and software to implement the PIV and PTV techniques for cryogenic flows.

Acknowledgments

We would like to thank Simone Babuin, Gregory Bewley, David Schmoranzler, František Soukup and Vaclav Uruba for fruitful discussions and valuable help. Besides, we acknowledge the support of Marie Curie Advanced Cryogenic Course, COST Action MP0806, MS 0021 620834, AVOZ 10100520 and GAČR 202/08/0276.

References

- [1] GP Bewley, DP Lathrop and KR Sreenivasan, 2006: *Visualisation of quantized vortices*, Nature 441, 588
- [2] T Zhang and SW Van Sciver, 2005: *Large-scale turbulent flow around a cylinder in counterflow superfluid ^4He (He II)*, Nature Phys 1, 36-38
- [3] M Raffel, CE Willert, ST Werely and J Kompenhans, 2007: *Particle image velocimetry – a practical guide*, Springer
- [4] JJ Niemela and KR Sreenivasan, 2006: *The use of cryogenic helium for classical turbulence: promises and hurdles*, J Low Temp Phys 143, 163-212
- [5] DR Tilley and J Tilley, 1990: *Superfluidity and superconductivity*, Institute of Physics Publishing
- [6] WF Vinen and JJ Niemela, 2002: *Quantum turbulence*, J Low Temp Phys 128, 167-231
- [7] YA Sergeev and CF Barenghi, 2009: *Particles-vortex interactions and flow visualisation in ^4He* , J Low Temp Phys 157, 429-475
- [8] SW Van Sciver and CF Barenghi, 2009: *Visualisation of quantum turbulence*, Progress in Low Temperature Physics: Quantum Turbulence (Edited by M Tsubota and WP Halperin), Springer, 247-303