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

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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} \text{ cm}^2/\text{s}), compared
to those of air (0.15 \text{ cm}^2/\text{s}) and water (0.01 \text{ cm}^2/\text{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 \times 10^{-4} \text{ cm}^2/\text{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 \(^4\)He 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 widows 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.

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References
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