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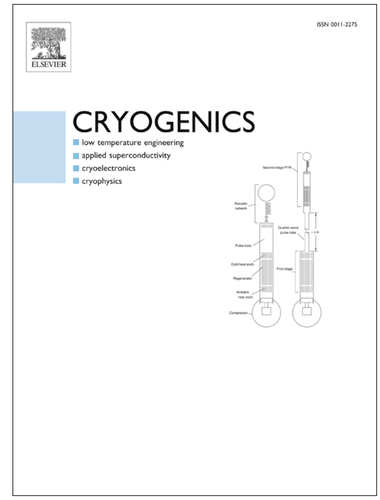

Void Fraction Measurement in Cryogenic Flows. Part II: Void Fraction Capacitive Sensor Performances in Chilldown Experiments

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ACCEPTED MANUSCRIPT

Void Fraction Measurement in Cryogenic Flows.
Part II: Void Fraction Capacitive Sensor Performances in Chilldown Experiments

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Abstract

This manuscript describes the work performed on void fraction measurements a cryogenic flow by means of a customized capacitive sensor. In a preceding activity, described in Part I, the instrument was developed and validated at room conditions. In the current study, the probe is exploited to detect the gaseous content during liquid nitrogen chilldown experiments. The sensor performances are evaluated both numerically and experimentally. The numerical simulations lead to the development of a new calibration formula improving the sensor measurement accuracy down to ±6.0%FS, within 99% confident interval. The experimental campaign mainly reveals a dependency of the sensor performance on the pressure and temperature variations during the cooldown of the test section. The so-called "thermal effect" therefore modeled and two compensation equations are derived. The void fraction results accordingly corrected, match the single-phase flows reference conditions within ±2% discrepancy. Background light visualizations are also performed allowing the optical verification of the flow regimes. For a specific flow condition, a correlation between the recorded light intensity and the capacitive measurements is obtained. By means of the high-speed movies, the capacitive sensor response time is also evaluated to be 100 Hz.

Keywords: capacitive sensor, electric field analysis, void fraction, chilldown, liquid nitrogen, cooling channel, cryogenic

1. Introduction

The void fraction commonly intended as the fraction of a pipe volume that is occupied by the gas phase, is one of the most important parameters required to characterize a two-phase flow. As addressed in [1], [2] and [3] several void fraction measurement techniques have been and are currently investigated. Various measuring principles are exploited, for example optical fibers [4], wire meshes [5], impedance changes [6] or wave propagations (such as x-rays [7] or ultrasounds [8]). However, especially for the very challenging environment and complex phenomenon related to a cryogenic chilldown, there is a lack of well-established and validated measurement methods.

In the present study, a capacitance-based measurement technique for cryogenic fluid is developed. In Part I [1], the void fraction sensor was numerically and experimentally characterized by means of a bubbly flow obtained injecting air in Polydimethylsiloxane at room temperature. Although such a configuration differs from the design application of the sensor (i.e. liquid nitrogen two-phase flow), comparing the capacitive results against optical measurements and the numerical simulations (Electric Field Analysis - EFA) it was concluded that the sensor measures the void fraction within ±7%FS error, for void fraction values up to 38%.

The activity presented in this paper focuses then on the assessment of the capacitive instrument performance in cryogenic conditions. The CHIlldown Experimental Facility (CHIEF) at the von Karman Institute (VKI) is exploited to perform the test campaign [3, 9]. High-speed camera visualizations are also conducted to support the investigation of the sensor capabilities as much as the EFA numerical simulations.

2. Experimental facility

The configuration of the VKI CHIEF, the instrument locations and their nomenclature for the present test campaign are recalled in Figure 1. The preliminary phase of each experiment is dedicated to the chilldown of the upstream elements by means of the by-pass line. In such a way, the inlet of the test section is provided with single-phase liquid nitrogen. The distribution valve is indeed opened to the test section only when the proper upstream pressure and temperature are reached [3, 9, 10].

Kulites cryogenic pressure sensors (CTL-190), connected to a Fylde Micro Analog 2 conditioner, are employed to measure the absolute pressure. The wall temperature is obtained by means of LakeShore Silicon Diodes transducers (DT-670B-SD) cabled to a Temperature Monitor T218Ss. The sensors are embedded in the pipe thickness, at 1 mm from the inner wall sur-

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