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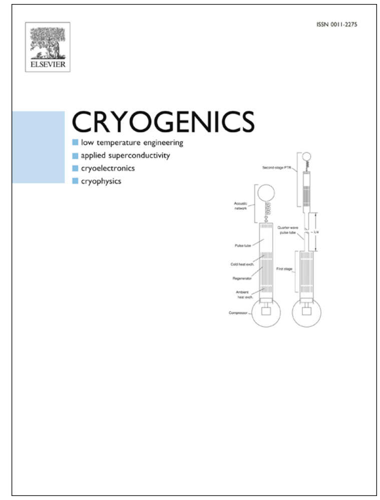

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Void fraction measurement in cryogenic flows. Part I : Design and validation of a void fraction capacitive sensor

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Abstract

This manuscript presents the design of a capacitive void fraction sensor for cryogenic LN2 two phase flows and its validation at room conditions. The capacitive void fraction sensor is first designed by means of Electric Field Analysis (EFA) simulations taking into account specific technical constraints coming from the test section in which it should be accommodated. Then it is manufactured and validated using a proper combination of fluids (Polydimethylsiloxane (PDMS) and air) having a dielectric constant ratio similar to the one encountered in LN2/GN2 two phase flows. The validation is performed through comparison with void fraction measured by means of optical visualizations and shows how the capacitive measurement technique robustness allows obtaining reasonable accurate values of void fraction also for the substitute fluid case. The sensor presented in this manuscript was used to evaluate the void fraction during LN2 chilldown of a rectangular cooling channel and the results are presented in the second part of this work.

Keywords: capacitive sensor, void fraction, chilldown, electric field analysis

1. Introduction

Cryogenic fluids are used in a wide range of industrial applications and for a variety of reasons. In the energy industry, for example, natural gases such as methane are liquefied by pressurization and cooled down to cryogenic temperatures for an easy storage and transportation. Liquid nitrogen is often used in the biotechnology industry as well as in the food industry to keep biodegradable material in good conditions for long storage times. In the aerospace industry, liquid hydrogen (LH2) and liquid oxygen (LOX) are widely used as cryogenic rocket engine propellants for launcher propulsion e.g. the European Ariane 5, American Delta IV and the Japanese H-II.

As the boiling temperatures of cryogenic fluids are very low, various two phase flow phenomena are frequently encountered during their processes such as boiling [1], cavitation [2] and flashing [3]. Occasionally, they might lead to detrimental situations. As an example, during a chilldown process in a pipeline the physical state of the carrier fluid will evolve from vapor phase to liquid phase passing through film boiling and nucleate boiling. When the liquid is in a two phase flow condition, the proper functioning of some devices installed along the pipeline, such as pumps or valves, can be compromised or can become unstable having therefore a detrimental impact on the flow control. This situation is particularly critical for engines powered by cryogenic fluids such as the pre-cooled turbo jet (PCTJ) engine for the hypersonic airplane in development by the JAXA (Japan Aerospace eXploration Agency) or for the European Launch Vehicle Ariane powered by LH2/LOx. The development of flow control systems which can operate reliably at two phase flow conditions needs to rely on sensors which can measure the level of vapor presence in the fluid, i.e. the void fraction. Although various types of void fraction sensors are already developed[4], the research in this field is still ongoing. Indeed most of the void fraction sensors are intrusive and cannot be used for cryogenics flows. In this paper we focus on a particular type of the sensor which uses the capacitance properties of fluids and gases to determine the void fraction. This choice has been driven by the non-intrusiveness of the capacitive sensors and by the possibility of enhancing its sensitivity and accuracy with an accurate design.

More in particular, in this paper the development and the validation of a capacitive sensor capable to determine the void fraction of LN2 bubbly flows in a small rectangular cross section pipe is reported. The rectangular pipe cross section has been chosen since it complies with the need of monitoring the heat transfer process in representative cooling channels of rocket thrust chambers. Due to the high thermal sensitivity of LN2 and the difficulty in producing controlled cryogenic bubbly flows, the validation of the sensor was performed at room temperature conditions using a couple of fluids with dielectric constants comparable to the ones encountered in LN2/GN2 two phase

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