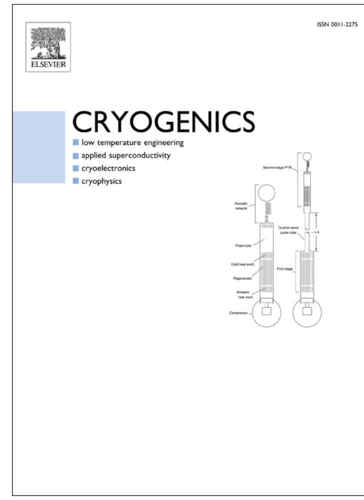
Accepted Manuscript



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PII: S0011-2275(16)30015-7
DOI: http://dx.doi.org/10.1016/j.cryogenics.2016.05.008
Reference: JCRY 2579

To appear in: *Cryogenics*

Received Date: 14 January 2016
Revised Date: 6 May 2016
Accepted Date: 9 May 2016

Wicking of liquid nitrogen into superheated porous structures

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Abstract

Evaporation in porous elements of liquid-vapor separation devices can affect the vapor-free cryogenic propellant delivery to spacecraft engines. On that account, the capillary transport of a cryogenic liquid subjected to evaporation needs to be understood and assessed. We investigate wicking of liquid nitrogen at saturation temperature into superheated porous media. A novel test facility was built to perform wicking experiments in a one-species system under non-isothermal conditions. A setup configuration enabled to define the sample superheat by its initial position in a stratified nitrogen vapor environment inside the cryostat. Simultaneous sample weight and temperature measurements indicated the wicking front velocity. The mass of the imbibed liquid nitrogen was determined varying the sample superheat, geometry and porous structure. To the author's extent of knowledge, these are the first wicking experiments performed with cryogenic fluids subjected to evaporation using the weight-time measurement technique. A one-dimensional macroscopic model describes the process theoretically. Results revealed that the liquid loss due to evaporation at high sample superheats leads to only a slight imbibition rate decrease. However, the imbibition rate can be greatly affected by the vapor flow created due to evaporation that counteracts the wicking front propagation.

Keywords: Wicking, Cryogenic liquids, Imbibition, Porous structures, Capillary pressure

1. Introduction

Cryogenic fluids are widely used in the spaceflight community for high performance propulsion systems. Liquid oxygen and hydrogen are the most common cryogenic propellants. Vapor-free propellant delivery to the engines is of importance for all space mission stages. In the absence of gravity, however, liquid-gas separation becomes challenging. For that reason propellant management devices (PMD) can be implemented inside propellant tanks. Capillary pressure driven flow is an effective solution for the vapor-free liquid transport. Based on this principle, PMDs with porous screen elements [1–3] were designed. A screen PMD, or a screen channel liquid acquisition device (LAD), includes several porous elements that get saturated with a liquid and ensure the liquid transport through them due to the capillary pressure. Vapor ingestion is blocked unless the screen bubble point pressure is not exceeded. An influence of the screen parameters on the LAD performance was investigated in [4–6]. Furthermore, venting might be necessary during ballistic flight phases which could lead to liquid expulsion via the gas ports of upper stage propellant tanks. A gas phase port separator was designed to prevent this undesired effect [7]. The device includes double porous screen elements which shall avoid the expulsion of liquid propellant during venting. A double porous screen element concept and a theoretical model are given in [8].

Evaporation in porous elements can diminish the performance of liquid-vapor separation devices or even lead to their operation failure. Some studies were performed to investigate this effect for storable liquids [9, 10]. Cryogenic liquids are charaterized by low surface tension values and low normal boiling point temperature. For that reason wicking of cryogenic liquids subjected to evaporation requires a thorough investigation and analysis.

Few studies have been done to understand the behavior of cryogenic fluids in porous structures. Zhang et al. [11] demonstrated wicking of liquid nitrogen with a sintered, multi-layer, porous lamination of metal wire in an open cryogenic chamber. Local temperatures of porous and non-porous samples identical in geometry and material were measured by sensors allocated along the sample length. The saturation of the porous sample with liquid nitrogen changed its temperature response to external heating at the sample top. That indicated the liquid presence in the porous structure. Choi et al. [12] studied the flow phenomena of liquid nitrogen subjected to evaporation in glass wool porous media. Experiments were performed to obtain temperature and pressure distributions in the specimens and, thus, to evaluate the tendency of propagation of the liquid-saturated region in porous media. Some numerical simulations were conducted and compared to experimental results. Vanderlaan and Van Sciver [13, 14] investigated different flow regimes of superfluid helium through a random pack of uniform size polyethylene spheres. Pressure and temperature drops across a porous medium were measured and computed for different heat inputs. Similar heat transfer studies have been conducted by Allain et al. [15]. A series of experiments with liquid hydrogen, oxy-