International Journal of Heat and Mass Transfer 101 (2016) 502–516

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Review

The static bubble point pressure model for cryogenic screen channel liquid acquisition devices

Jason W. Hartwig *, Yasuhiro Kamotani

Case Western Reserve University, Department of Mechanical and Aerospace Engineering, Cleveland, OH 44106, USA

A R T I C L E I N F O

Article history:
Received 11 August 2015
Received in revised form 4 May 2016
Accepted 6 May 2016
Available online 3 June 2016

Keywords:
Cryogenic
Liquid acquisition device
Evaporation
Condensation
Subcooled
Interface temperature
Bubble point

A B S T R A C T

Inside a propellant tank in microgravity, surface tension forces dominate, and porous screen channel liquid acquisition devices (LADs) are required to separate fluid phases and ensure vapor free liquid flow out of the tank to the transfer line en route to an in-space engine. Maximum bubble point pressure (based on Adamson and Gast, 1997), or the breakdown point, is the primary performance parameter characterizing the LAD. This paper presents a robust empirical equation based off of 45 years of experimental data which models the bubble point pressure in both room temperature as well as cryogenic liquids. The seven parameters which affect the bubble point pressure include the surface tension (liquid type), contact angle, screen pore diameter, liquid temperature, degree of subcooling, and pressurant gas type and temperature. Decreasing temperature increases bubble point pressure due to increased surface tension and screen pore shrinkage. Higher bubble points are always obtained using a non-condensable pressurant gas over a condensable gas. Pressurizing and subcooling the interface adds margin in bubble point whereas elevating the temperature of the pressurant gas acts as a degradation factor. The mean absolute error between 5224 data points and new model is 2.75% of the experimental data across the full range of thermodynamic conditions.

Contents

---

* Corresponding author.
E-mail address: jwh13@case.edu (J.W. Hartwig).

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2016.05.024
0017-9310/Published by Elsevier Ltd.

Nomenclature

D_P	pore diameter, [m]	σ	accommodation coefficient, dimensionless
J_i	mass flux, [kg/m^2 s]	C	condensation
L	length, [m]	E	evaporation
n_{Hot}	warm pressurant gas fitting parameter, dimensionless	G	gas
n_{shute}	number of shute wires per square inch, [#/in]	I	interface
n_{Sub}	subcooled liquid fitting parameter, dimensionless	LV	liquid/vapor
n_{warp}	number of warp wires per square inch, [#/*in*]	O	onset of degradation
P	pressure, [Pa]	ref	reference state
R_G	gas constant, [J/kg K]	SAT	saturation
T	temperature, [K]	SL	solid/liquid
W_a	work of adhesion, [mN/m]	Sub	subcooled
ΔP_{BP}	bubble point pressure, [Pa]	SV	solid/vapor
γ	surface tension, [mN/m]	T	reference state taken at temperature T
θ_C	advancing contact angle, [°]	0	reference state
ξ	coefficient of thermal contraction, dimensionless	295 K	reference state taken at 295 K

1. Introduction

In general, the lowest achievable potential energy state controls the location of the liquid and vapor phases and the liquid/vapor (L/V) interface within a propellant tank. In the 1-g field of Earth, gravity forces the heavier liquid to settle to the bottom and lighter vapor to rise to the top of the tank. Extracting vapor free liquid is straightforward. In the microgravity of Low Earth Orbit (LEO) however, surface tension becomes the controlling force for phase separation because liquid tends to adhere to the walls and the vapor tends towards the center of the tank. Any one of a number of propellant management devices (PMDs) may be required to ensure that the tank outlet is covered with liquid during all phases of a mission to supply vapor free liquid to an in-space engine or fuel depot, as required.

One such PMD, a screen channel liquid acquisition device (LAD), relies on surface tension forces and capillary flow to maintain vapor free liquid transfer to the tank outlet. As shown in Fig. 1, screen channel LADs or gallery arms, tend to follow the contours of the tank walls. The channel side that faces the wall is composed of a finely woven metallic mesh screen while the other sides of the channel are solid. During quiescent conditions or under steady flow, the purpose of the LAD screen is threefold [2]:

1. To maintain communication between tank outlet and bulk propellant during all phases of the mission; when liquid approaches the porous screen, the screen admits liquid into the channel.
2. To separate and control phases; when pressurant gas or vapor approaches the screen, liquid surface tension forces within the screen pores block vapor admittance.
3. To rewet portions of the screen that dry out due to exposure to warm pressurant gas; the screen can wick liquid along the screen.

The basic concept of a screen channel LAD is shown in Figs. 1 and 2. Fig. 2 displays a scanning electron microscopy (SEM) image of a raw stainless steel (SS) 450 × 2750 Dutch Twill screen. The specific weave pattern, number of wires, and metal type characterizes the screen mesh. For example, the 450 × 2750 Dutch Twill weave has 450 larger warp wires and 2750 smaller shute wires per square inch of screen material, where each shute wire passes over two warp wires before going under the next warp wire. The gallery arm is constructed of three sides of solid metal with the screen side facing the tank wall, as shown in Fig. 1. For a total communication LAD, the arms span the length of the tank wall so that there is communication between the propellant pool inside the tank and tank outlet at all times during the mission. While the tank is drained through the LAD by pressurizing the ullage, the LAD allows liquid to flow, but blocks pressurant gas from passing into the channel. Surface tension forces of the liquid within the screen pores, coupled with the screen's natural ability to wick liquid to dry locations both act as a barrier to pressurant gas ingestion. Eventually, the screen will break down once the pressure drop across the screen exceeds the bubble point pressure (defined in Section II).

Screen channel LADs have flight heritage in storable (i.e. propellants that exist as liquids at room temperature) propulsion systems such as the Agena Upper Stage [3,4] Apollo Service Reaction Control System (RCS) [4] and Space Shuttle RCS and Orbital Maneuvering System (OMS) [5–9] but no flight heritage with liquid oxygen

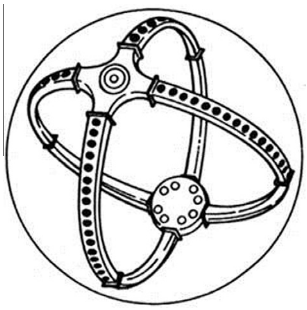

Fig. 1. Total communication screen channel LAD.

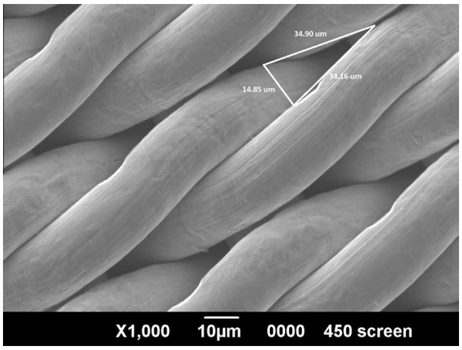

Fig. 2. Scanning electron microscopy image of a 450 × 2750 screen.