NASA/TM—2009-215496

Bubble Point Measurements With Liquid Methane of a Screen Capillary Liquid Acquisition Device

John M. Jurns
ASRC Aerospace Corporation, Cleveland, Ohio

John B. McQuillen
Glenn Research Center, Cleveland, Ohio

March 2009

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI Program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to *help@sti.nasa.gov*

- Fax your question to the NASA STI Help Desk at 301–621–0134

- Telephone the NASA STI Help Desk at 301–621–0390

- Write to:
  NASA Center for AeroSpace Information (CASI)
  7115 Standard Drive
  Hanover, MD 21076–1320

NASA/TM—2009-215496

Bubble Point Measurements With Liquid Methane of a Screen Capillary Liquid Acquisition Device

John M. Jurns
ASRC Aerospace Corporation, Cleveland, Ohio

John B. McQuillen
Glenn Research Center, Cleveland, Ohio

Prepared for the
2007 Cryogenic Engineering Conference and International Cryogenic Materials Conference
(CEC–ICMC 2007)
Chattanooga, Tennessee, July 16–20, 2007

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

March 2009

Acknowledgments

This work is supported by the NASA Glenn Research Center Propulsion and Cryogenic Advanced Development Project Office. We thank Steven Sinacore, Tim Czaruk, Kathryn Shaw, Chris DeTardo, Mark Spingowski, and William Vaccariello for their test operations support, and Jay Owens and Chris Garcia for their imaging support.

Level of Review: This material has been technically reviewed by technical management.

Available from

NASA Center for Aerospace Information
7115 Standard Drive
Hanover, MD 21076–1320

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

Available electronically at http://gltrs.grc.nasa.gov

Bubble Point Measurements With Liquid Methane of a Screen Capillary Liquid Acquisition Device

John M. Jurns
ASRC Aerospace Corporation
Cleveland, Ohio 44135

John B. McQuillen
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Abstract

Liquid acquisition devices (LADs) can be utilized within a propellant tank in space to deliver single-phase liquid to the engine in low gravity. One type of liquid acquisition device is a screened gallery whereby a fine mesh screen acts as a "bubble filter" and prevents the gas bubbles from passing through until a crucial pressure differential condition across the screen, called the bubble point, is reached. This paper presents data for LAD bubble point data in liquid methane (LCH_4) for stainless steel Dutch twill screens with mesh sizes of 325 by 2300 and 200 by 1400 wires per inch. Data is presented for both saturated and sub-cooled LCH_4, and is compared with predicted values.

Introduction

Propellant management devices (PMD) can be utilized within the propellant tank in space to deliver single-phase fluid to the engine in low gravity. Varying acceleration and gravity regimes will probably lead to a system design using multiple varieties of PMDs. One type of PMD, a liquid acquisition device (LAD) uses capillary flow and surface tension to acquire liquid.

Capillary flow LADs have been well characterized for storable propellants (Ref. 1). In recent years, on-going research has evaluated LADs in liquid oxygen (LO_2), liquid nitrogen (LN_2) and liquid hydrogen (LH_2). NASA has determined that liquid methane (LCH_4) is also a promising propellant option for future exploration missions. Understanding LCH_4 characteristics and how it performs in cryogenic fluid systems (including LADs) is critical to advancing technology that would utilize LCH_4 as a propellant.

A number of screen weaves are suitable for use in LADs. The weave pattern, which refers to the over/under pattern used in manufacturing the screen, is an important parameter affecting the choice of screen; certain weaves of wires produce much finer pore sizes than other weaves. The tightness of the weave (mesh) and the weave pattern determine the geometry of the pores in the screen. A given mesh screen is designated by two numbers; the first number refers to the number of shute wires per inch and the second number refers to the number of warp wires per inch. In a Dutch twill screen, each shute wire travels over two warp wires before going under a warp wire. Figure 1 shows a detail of the Dutch twill weave pattern.

The geometry of the pore and the fluid surface tension determine the bubble point of the screen. "Bubble point" is defined as the differential pressure across the screen that overcomes the surface tension of the liquid on the screen. A high bubble point (fine screen mesh) is desirable to ensure single phase (liquid) fluid delivery and good wicking of fluid into the screen pores. Fine mesh screens, however, tend to generate a large pressure loss during outflow through the screen. The total pressure loss in the system must be less than the bubble point pressure to prevent vapor ingestion into a LAD channel.

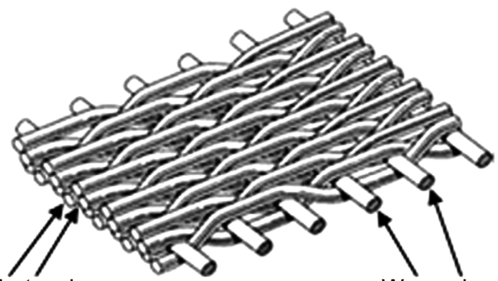

Figure 1.—Dutch twill mesh screen showing weave pattern.

NASA Glenn Research Center has an on-going test program to develop data for LAD performance for a variety of cryogenic propellants (Refs. 2, 5, and 10). This paper presents new bubble point data in LCH_4 for stainless steel Dutch twill screen with a mesh size of 200 by 1400 along with recently reported data (Ref. 5) for a 325 by 2300 screen. Testing was conducted in 2006 and 2007 at Glenn Research Center's Creek Road Complex in the Cryogenic Components Lab 7 (CCL-7). It is a small scale cryogenic fuel test stand designed for component testing (Ref. 6).

Nomenclature

D_P	Effective pore diameter of the screen weave
NBP	Normal Boiling Point
ΔP_{BP}	Bubble Point pressure
ρ	Density
θ_c	Contact angle of the liquid on the screen material
σ	Surface tension

Liquid Methane Bubble Point Tests

Test Hardware Design

Figure 2 shows the cylindrical test article used for bubble point testing installed in the test dewar. A screen sample is welded into the flanged top of the test article. The flanged design allows for rapid change out of various screen samples. A mirror aids in viewing the screen surface. Positioning the mirror over the screen surface provides both a side view and top view from a single camera to allow observation of gas bubbles passing through the screen. Instrument taps on the test article connect to pressure transducers external to a cryogenic test dewar and measure differential pressure across the LAD screen as shown in Figure 3.

Screen Size

The LAD screens used for these tests are welded to the top flange of the test article shown in Figure 2. The screens have a diameter of 6.25 cm (2.5 in.) and a surface area exposed to the liquid of 31.7 cm^2 (4.91 $in.^2$).

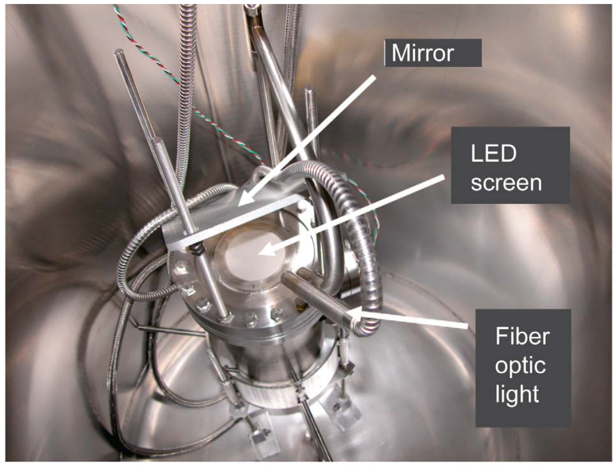

Figure 2.—Test article installed inside the cryogenic dewar.

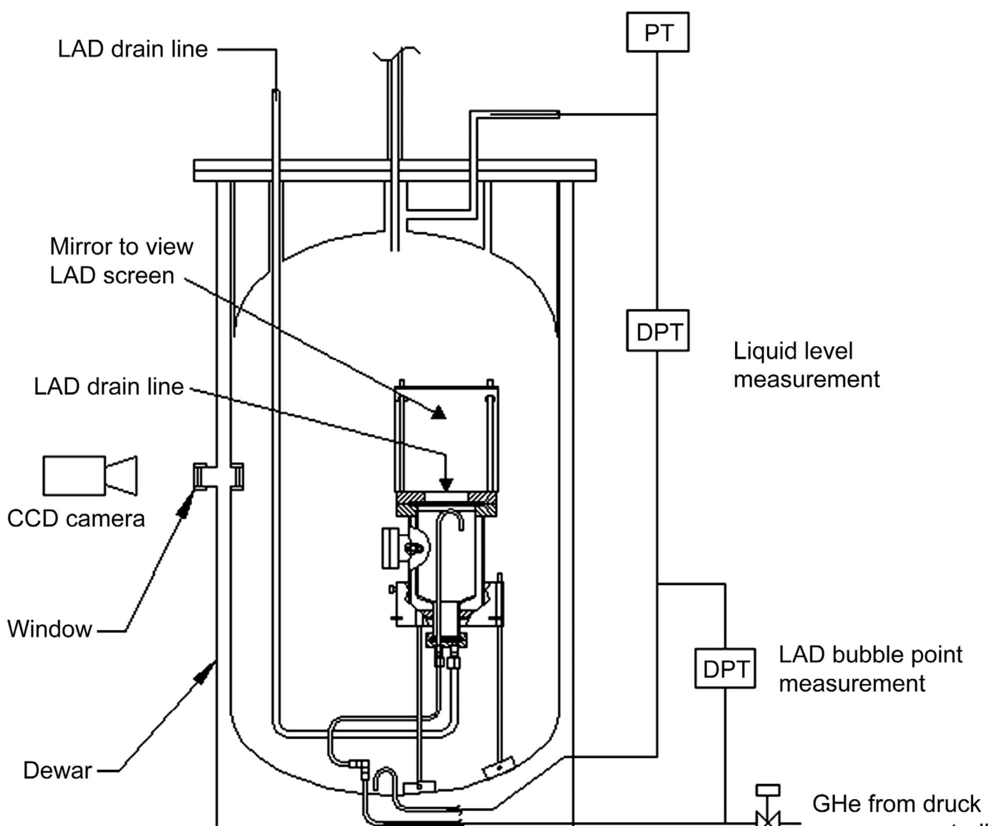

Figure 3.—LAD test article installed inside test dewar showing instrumentation detail.

Test Facility

CCL-7 is a small scale testing facility for concept and component testing. In addition to component screening, the facility can perform propellant transfer, propellant conditioning (warming and sub-cooling), and vent flow tests. CCL-7 safely handles 1130 liter (300 gal) of both LH_2 and LN_2, and 450 liter (120 gal) of LCH_4. Gaseous helium (GHe) and gaseous nitrogen (GN_2) are available on-site.

For this test program, the LAD hardware shown in Figure 3 was installed in one of the test facility dewars. Fluid supply and vent piping, and instrumentation lines pass through the lid of this dewar. The diameter of this dewar is 0.55 m (22 in.). An instrument rake equipped with silicon diodes provides temperature measurements and liquid level indication. The dewar is 1.07 m (42 in.) deep, has an internal volume of 0.23 m^3 (8.1 ft^3), and has a working pressure of 170 KPa (25 psia). A window in the sidewall is located 0.55 m (22 in.) from the bottom of the dewar.

Instrumentation/Data Acquisition

CCL-7 utilizes a PC computer based data collection system. Up to 320 channels of data can be collected at a nominal rate of 1 Hz. Many of the facility channels are pre-configured for standard instruments including thermocouples, pressure transducers, and silicon diodes. A high accuracy (±0.11 percent full scale) 0 to 7.47 KPa (0 to 30 in. H_2O) pressure transducer is used to measure the differential pressure across the LAD screen. Interlocks, alarms and shutdowns protect the research hardware and the facility. Operator controlled open-loop processes are used to provide flexibility.

Video

We observe the LAD screen during test to determine at what differential pressure bubbles break through the screen in order to determine the bubble point pressure. A digital video camera at test facility views the LAD screen through the view port on the side of the test dewar. The video signal is transmitted to the data acquisition computer and is recorded as an AVI format digital movie. The video data is time stamped and synchronized with the data collected to aid in post test data processing.

Test Objectives/Overview

The purpose of this experimental program was to determine bubble point characteristics of both 200 by 1400 and 325 by 2300 mesh screen LADs by performing bubble point tests in LCH_4. Data exists for isopropyl alcohol (IPA) that can be correlated to storable propellants, but the database needs to be extended to cryogenic propellants. Bubble point data has previously been collected for LN_2, LO_2, and LH_2. This is the first known effort to collect LAD bubble point data for LCH_4. Data was collected for both normal boiling point (NBP) and sub-cooled LCH_4. Bubble point was determined by observing the LAD screen via a CCD video camera and correlating the observed bubble breakthrough with concurrently collected sensor data.

Initial check-out tests were performed at the facility using LN_2. Following those tests, LCH_4 was transported on site and connected to the test facility dewars. The LCH_4 was supplied in portable 450 liter dewars filled by an industrial gas supplier.

Liquid Methane Supply

At the onset of this test program, there was no agreed upon purity specification for propellant grade LCH_4. Liquefied natural gas (LNG) consists largely of LCH_4, with a number of other hydrocarbon constituents and impurities. Although LNG is widely available throughout the world, NASA had determined that it would be unsuitable for use as a propellant due to variations in properties making predictions of accurate performance impossible. Therefore, we used high purity liquid methane (99.9 percent) for these tests. Each shipment of LCH_4 used for testing was supplied with a chemical analysis to verify purity. Subsequent to the start of this test program, MIL SPEC MIL-PRF-32207 “Performance Specification Propellant Methane” was issued. The LCH_4 used for this test most closely matches MIL-PRF-32207 Grade “C” product. Jurns (Ref. 5) provides a more extensive discussion of the LCH_4 purity and availability.

Test Procedure

LAD Screen Bubble Point Tests

For bubble point testing, the LAD test article was placed inside the test dewar as shown in Figure 3. A precision differential pressure controller pressurized the LAD test article with GHe. The pressure controller was referenced to the dewar ullage pressure. This allowed the controller to set the pressure inside the LAD test article from 0 to 12.44 KPa (0 to 50 in. H_2O) above ullage pressure. During fill, the pressure inside the LAD test article was set at approximately 7.47 KPa (30 in. H_2O) above the ullage pressure to prevent the test article from flooding. As the dewar filled and the entire screen surface became wetted, surface tension forces also helped to prevent flooding of the LAD test article. The dewar was filled with LCH_4 to approximately 20 cm (8 in.) above the top of the LAD screen. This liquid head was accounted for in determining the bubble point pressure. After the fill was complete, the pressure in the dewar was increased to approximately 138 KPa (20 psia) with GHe to suppress boiling of LCH_4. The pressure controller was then used to gradually ramp down the pressure inside the test article until gas bubbles were no longer seen coming through the screen. This *reseal* pressure was noted, and the pressure decreased by several more KPa. Note that there is some hystersis and reseal pressure is less than the bubble point pressure. This hystersis was originally noted by Chato (Ref. 2). The pressure was then gradually increased inside the test article in 0.28 KPa (0.1 in. of water) increments until gas bubbles broke through the screen surface. This *bubble point* pressure was noted, and the pressurization/depressurization cycle repeated to obtain additional data.

Fluid Conditioning

We conducted tests with LCH_4 at two different fluid conditions. For the first test series, the dewar was filled with LCH_4 from the portable liquid cylinder while simultaneously being vented to atmospheric pressure, essentially saturating the fluid at NBP (101.2 KPa, 112 K) conditions. The dewar was then pressurized with GHe for bubble point tests. We performed a second series of tests with subcooled liquid. For these tests, the LCH_4 was transferred to a second facility dewar. The pressure in this dewar was reduced using the facility ejectors. This subcooled the LCH_4 to approximately 97 K (175 °R). The subcooled LCH_4 was then transferred to the test dewar for bubble point testing. The LCH_4 did absorb some heat during transfer, and final liquid temperatures were 103 to 107 K (186 to 193 °R) for subcooled tests.

Test Results/Observations

Bubble point pressure shown in Equation (1) (Ref. 7) is calculated from the LaPlace equation:

$$\Delta P_{BP} = \frac{4\sigma\cos\theta_c}{D_p} \tag{1}$$

Here, σ is the surface tension of the liquid and θ_c is the contact angle of the liquid on the screen material. For LCH_4, $\theta_c \approx 0$ so $\cos\theta_c = 1$ (Ref. 12). The effective pore diameter of the screen weave is D_P. Note that the standard practice for determining the effective pore diameter for a particular screen is to measure ΔP_{BP} with a special bubble-point apparatus using IPA as a reference liquid (Ref. 10) and calculating D_P for the screen weave from Equation (1). This value of D_P was then used to compute the theoretical bubble-point pressure for the LAD screen in LCH_4. The D_P based on that data was determined to be 0.0222 mm (0.000873 in.) for the 200 by 1400 mesh screen and 0.0144 mm (0.000567 in.) for the 325 by 2300 mesh screen. Surface tension values for these tests were obtained from the NIST thermodynamic fluid property software program GASPAK (Ref. 8). The source in this program for surface tension properties is Sprow & Prausnitz (Ref. 9). Surface tension values were chosen based on the temperature of the LCH_4 at the screen interface. IPA bubble point tests were performed on the identical screen used for this test series (Ref. 10). Table 1 shows average values of predicted and measured bubble point pressures from tests.

TABLE 1.—LCH_4 MEASURED AND PREDICTED ΔP_{BP}

Number of repeat tests	LCH_4 Temperature, (K)	LCH_4 Condition	Surface tension, (N/m)	ΔP_{BP} Measured, (KPa)	Std Dev, (KPa)	ΔP_{BP} Predicted, (KPa)	% error	ΔP_{Reseal} Measured, (KPa)
200 by 1400 mesh, D_p = 0.0222 mm								
11	113 to 114	NBP	0.0128	2.28	0.04	2.29	–0.5	1.66
10	104 to 107	Subcooled	0.0146	2.70	0.05	2.59	4.1	1.65
325 by 2300, D_p = 0.0144 mm								
18	112 to 114	NBP	0.0133	3.51	0.09	3.63	–3.3	2.32
12	103 to 104	Subcooled	0.0152	4.32	0.09	4.15	4.1	2.61

Comparison With Historical Data

Bubble point data has previously been reported for IPA (Refs. 2, 4, 10, and 11), LH_2 (Refs. 2, 4, and 11), LN_2 (Refs. 2 and 10), and LO_2 (Ref. 10). Predicted values for bubble point pressure were calculated using Equation (1). Cady (Ref. 11) reported bubble point values for LH_2 based on liquid saturated at 344.7 KPa (50 psia). Kudlac (Ref. 10) reported bubble point predictions for LO_2 and LN_2 were based on saturated liquid at NBP. Chato (Ref. 2) did not report fluid conditions, but a review of data from the Chato tests indicated that LN_2 temperature was 79.2 K (142.5 °R), and LH_2 temperature was 21.9 K (39.6 °R). Using surface tension values for these conditions, predicted bubble point values were calculated using Equation (1). Plots of predicted and measured bubble points versus surface tension for both 200 by 1400 and 325 by 2300 LAD screen are shown in Figure 4.

LCH_4 ΔP_{BP} Predictions Based on Surface Tension

Equation (1) predicts bubble point reasonably well for NBP liquid. However, LCH_4 test data summarized in Figure 5 shows that it appears to under-predict bubble point pressure for subcooled liquid. Although Equation (1) calculates bubble point only as a function of screen pore diameter and surface tension, both Kudlac (Ref. 10) and Dodge (Ref. 7) state that bubble point is also influenced by liquid viscosity and density. However, neither of these terms is included in Equation (1).

In an attempt to improve the correlation for bubble point, Jurns (Ref. 5) considered other treatments of pressure drop of a bubble through a screen. These efforts are ongoing, and relate to better understanding the transition between a no-flow condition and flow of bubbles through the screen, as well as considering the possible influence of viscosity.

Test data and Equation (1) predictions are plotted for both 200 by 1400 and 325 by 2300 mesh screens in Figure 5. We note that although there is some scatter in the data, Equation (1) does appear to under-predict observed test results for both screens.

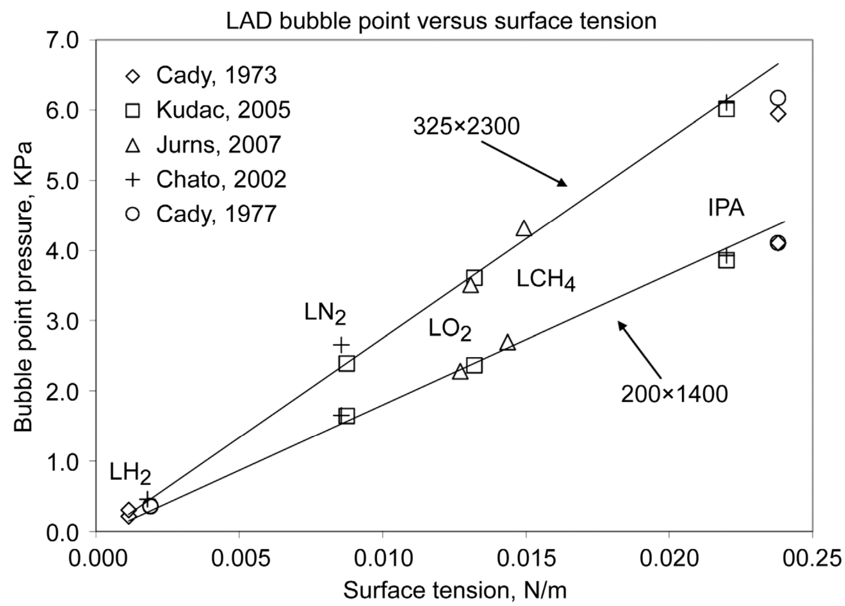

Figure 4.—Bubble point data and predictions for LO_2, LN_2, LCH_4, LH_2, and IPA.

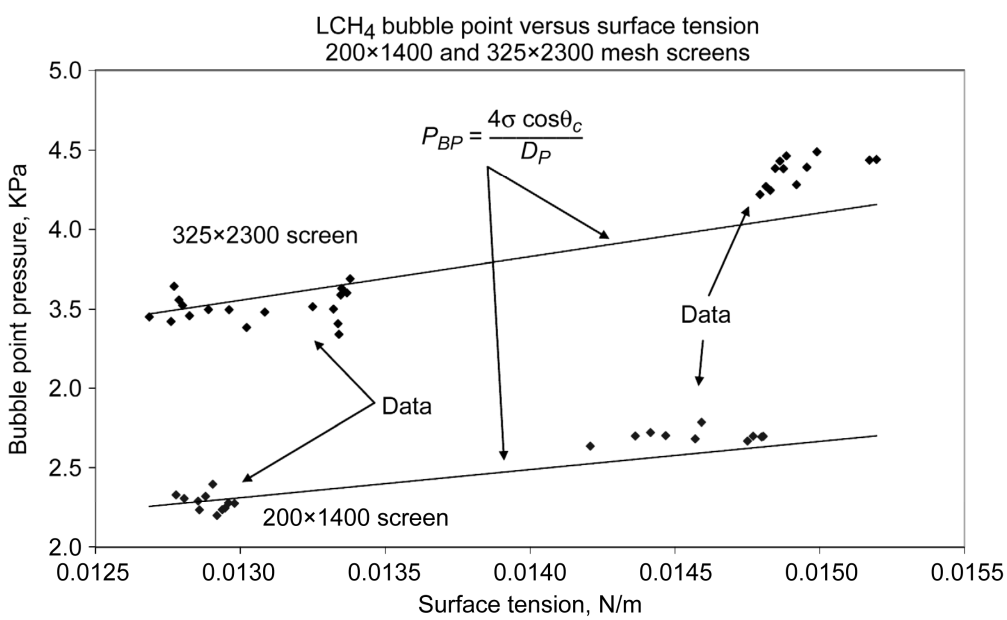

Figure 5.—LO_2 bubble point data and predictions based on Equation (1).

Conclusions

We have shown in this LAD test series that LCH_4 bubble point data is repeatable and consistent with pre-test predictions for NBP liquid. We also note that Equation (1) appears to under-predict ΔP_{BP} for subcooled LCH_4. Correlation between observed test data and predictions *may* be improved by considering additional terms in Equation (1) and a closer examination of uncertainties in both fluid and screen properties. Future work may include reanalyzing existing data for LO_2, LN_2, and LH_2 to consider these factors. LCH_4 joins the list of cryogenic fluids characterized with LAD screens to demonstrate that they can deliver single phase cryogenic fluid with system pressure losses less than bubble point pressure for the fluid/screen combination.

References

1. Fester D.A. et al. "Surface Tension Propellant Acquisition System Technology for Space Shuttle Reaction Control Tanks," *AIAA 75-1196*, Sept. 1975.
2. Chato D.J. and Kudlac M.T., "Screen Channel Liquid Acquisition Devices for Cryogenic Propellants," *AIAA–2002–3983* 2002.
3. Blatt, M.H, et al., "Low Gravity Propellant Control Using Capillary Devices in Large Scale Cryogenic Tanks," *General Dynamics Report No. GDC-DD70-006*, August 1970.
4. Cady, E.C, *Study of Thermodynamic Vent and Screen Baffle Integration for Orbital Storage and Transfer of Liquid Hydrogen*, NASA-CR-134482 (Aug. 1973).
5. Jurns J.M. et al. "Bubble Point Measurements with Liquid Methane of a Screen Channel Capillary Liquid Acquisition Device," *54th JANNAF Propulsion Meeting, Denver, CO, May 2007.*
6. Jurns, J.M. and Kudlac M.T., "NASA Glenn Research Center Creek Road Complex—Cryogenic Testing Facilities," *Cryogenics 46,* 2006, pp. 98–104.
7. Dodge F.T., "The Applicability of Surrogate Fluids for Ground Testing of Cryogenic Propellant Fluid Management Components," *Final Report, Southwest Research Institute Project No. 18-11969,* Feb. 2006.
8. Fox, J.R., McCarty, R.D., GASPAK version 3.20, CRYODATA Inc., Niwot, CO.
9. Sprow F.B., Prausnitz J.M., "Surface Tensions of Simple Liquids," *Transactions of the Faraday Society 62*, 1097–1104, 1966b.
10. Kudlac M.T., Jurns J.M., "Screen Channel Liquid Acquisition Devices for Liquid Oxygen," *42nd AIAA Joint Propulsion Conference*, Sacramento, July 2005.
11. Cady, E.C., "Effect of Transient Liquid Flow on Retention Characteristics of Screen Acquisition Systems," *NASA-CR-135218* April 1977.
12. Lyerly G.A., Peper H., "Summary Report Studies of Interfacial Surface Energies," *NASA-CR-54175* December 1964.

REPORT DOCUMENTATION PAGE						*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
01-03-2009

2. REPORT TYPE
Technical Memorandum

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Bubble Point Measurements With Liquid Methane of a Screen Capillary Liquid Acquisition Device

5a. CONTRACT NUMBER
NNC06BA07B

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jurns, John, M.; McQuillen, John, B.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
WBS 253225.04.01.02.02.03

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E-16662

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORS ACRONYM(S)
NASA

11. SPONSORING/MONITORING REPORT NUMBER
NASA/TM-2009-215496

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Categories: 20, 28, and 34
Available electronically at http://gltrs.grc.nasa.gov
This publication is available from the NASA Center for AeroSpace Information, 301-621-0390

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Liquid acquisition devices (LADs) can be utilized within a propellant tank in space to deliver single-phase liquid to the engine in low gravity. One type of liquid acquisition device is a screened gallery whereby a fine mesh screen acts as a “bubble filter” and prevents the gas bubbles from passing through until a crucial pressure differential condition across the screen, called the bubble point, is reached. This paper presents data for LAD bubble point data in liquid methane (LCH_4) for stainless steel Dutch twill screens with mesh sizes of 325 by 2300 and 200 by 1400 wires per inch. Data is presented for both saturated and sub-cooled LCH_4, and is compared with predicted values.

15. SUBJECT TERMS
Cryogenic fluids; Methane; Fluid management; Cryogenic fluid storage; Liquefied gasses; Capillary

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	14	STI Help Desk (email:help@sti.nasa.gov)
					19b. TELEPHONE NUMBER *(include area code)* 301-621-0390

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18