

# NBS TECHNICAL NOTE 1035

U.S. DEPARTMENT OF COMMERCE /National Bureau of Standards

## A Portable Calibration Densimeter for Use in Cryogenic Liquids

QC  
100  
U5758  
NO 1035  
1891  
652

## NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards<sup>1</sup> was established by an act of Congress on March 3, 1901. The Bureau's overall goal is to strengthen and advance the Nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the Nation's physical measurement system, (2) scientific and technological services for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau's technical work is performed by the National Measurement Laboratory, the National Engineering Laboratory, and the Institute for Computer Sciences and Technology.

**THE NATIONAL MEASUREMENT LABORATORY** provides the national system of physical and chemical and materials measurement; coordinates the system with measurement systems of other nations and furnishes essential services leading to accurate and uniform physical and chemical measurement throughout the Nation's scientific community, industry, and commerce; conducts materials research leading to improved methods of measurement, standards, and data on the properties of materials needed by industry, commerce, educational institutions, and Government; provides advisory and research services to other Government agencies; develops, produces, and distributes Standard Reference Materials; and provides calibration services. The Laboratory consists of the following centers:

Absolute Physical Quantities<sup>2</sup> — Radiation Research — Thermodynamics and Molecular Science — Analytical Chemistry — Materials Science.

**THE NATIONAL ENGINEERING LABORATORY** provides technology and technical services to the public and private sectors to address national needs and to solve national problems; conducts research in engineering and applied science in support of these efforts; builds and maintains competence in the necessary disciplines required to carry out this research and technical service; develops engineering data and measurement capabilities; provides engineering measurement traceability services; develops test methods and proposes engineering standards and code changes; develops and proposes new engineering practices; and develops and improves mechanisms to transfer results of its research to the ultimate user. The Laboratory consists of the following centers:

Applied Mathematics — Electronics and Electrical Engineering<sup>2</sup> — Mechanical Engineering and Process Technology<sup>2</sup> — Building Technology — Fire Research — Consumer Product Technology — Field Methods.

**THE INSTITUTE FOR COMPUTER SCIENCES AND TECHNOLOGY** conducts research and provides scientific and technical services to aid Federal agencies in the selection, acquisition, application, and use of computer technology to improve effectiveness and economy in Government operations in accordance with Public Law 89-306 (40 U.S.C. 759), relevant Executive Orders, and other directives; carries out this mission by managing the Federal Information Processing Standards Program, developing Federal ADP standards guidelines, and managing Federal participation in ADP voluntary standardization activities; provides scientific and technological advisory services and assistance to Federal agencies; and provides the technical foundation for computer-related policies of the Federal Government. The Institute consists of the following centers:

Programming Science and Technology — Computer Systems Engineering.

<sup>1</sup>Headquarters and Laboratories at Gaithersburg, MD, unless otherwise noted; mailing address Washington, DC 20234.

<sup>2</sup>Some divisions within the center are located at Boulder, CO 80303.

# A Portable Calibration Densimeter for Use in Cryogenic Liquids

NATIONAL BUREAU  
OF STANDARDS  
LIBRARY

APR 15 1981

not acc - Cur

QC100

.U5753

no. 1035

1981

C.2

J.D. Siegwarth

J.F. LaBrecque

*NBS technical note*  
...

Thermophysical Properties Division  
National Engineering Laboratory  
National Bureau of Standards  
Boulder, Colorado 80303



---

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

Issued March 1981

NATIONAL BUREAU OF STANDARDS TECHNICAL NOTE 1035  
Nat. Bur. Stand. (U.S.), Tech. Note 1035, 20 pages (March 1981)  
CODEN: NBTNAE

U.S. GOVERNMENT PRINTING OFFICE  
WASHINGTON: 1981

---

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

Price \$1.50 (Add 25 percent additional for other than U.S. mailing)

# CONTENTS

Page

1.	INTRODUCTION . . . . .	1
2.	THE PORTABLE REFERENCE DENSIMETER . . . . .	2
3.	DENSITY MEASUREMENT AND SYSTEMATIC UNCERTAINTIES . . . . .	4
4.	CALCULATIONS OF THE RANDOM UNCERTAINTY FOR THE PORTABLE DENSIMETER . . . . .	8
5.	CONCLUSIONS . . . . .	12
6.	REFERENCES . . . . .	13





# A PORTABLE CALIBRATION DENSIMETER FOR USE IN CRYOGENIC LIQUIDS

J. D. Siegwarth and J. F. LaBrecque

Thermophysical Properties Division  
National Engineering Laboratory  
National Bureau of Standards  
Boulder, Colorado 80303

A portable densimeter designed specifically for calibrating liquefied natural gas densimeters but suitable for density measurement of a wide range of liquids, is described. The densimeter has been compared to the Density Reference System densimeter at the National Bureau of Standards and found to agree to well within the combined systematic error. The density results of this instrument and that of the DRS densimeter are statistically indistinguishable.

Key words: Densimeter; density reference system; liquid methane; LNG.

## 1. INTRODUCTION

The cryogenic liquids Density Reference System [1] (DRS) at the National Bureau of Standards in Boulder, Colorado, originated as a device for testing calibration and performance of commercially built densimeters for liquefied natural gas (LNG) service. A number of commercial densimeters were tested with this system and the results reported [2]. All the densimeters tested functioned adequately. These tests, however, disclosed a need for better calibration methods for the commercial densimeters.

We implemented a transfer standard program at NBS as a method of providing a suitable calibration for commercially built LNG densimeters. In this program, a manufacturer or user of densimeters selects a commercial densimeter against which he will calibrate his densimeters by comparison in a homogeneous fluid. We periodically calibrate his selected densimeter in the DRS and this becomes the transfer standard.

We rebuilt the density reference system into a flexible configuration so densimeters of various designs could be more easily introduced and more rapidly calibrated [3]. The new DRS was designed also with the intention of demonstrating a type of system that could safely handle combustible gases in an industrial calibration laboratory since for best results, a densimeter should be calibrated in a fluid similar to that in which it will be used.

After the DRS was rebuilt, the availability of an electronic balance capable of weighing 200 g to 0.001 g resulted in our rebuilding the DRS densimeter to incorporate this balance. We found this new balance both compact and sufficiently robust to suggest the possibility of constructing a portable silicon densimeter. This portable densimeter could then be installed in any commercial calibration facility to calibrate the reference densimeter of the facility. This method has the definite advantage that it permits us to test a whole facility rather than just the calibration densimeter used in the facility. The transporting of this portable densimeter should not add any additional uncertainty to the instrument since the reference weight makes it self-calibrating.

We have built such a portable densimeter and tested it in the DRS. We describe this densimeter and these comparison measurements in this report. From these results, we have generated an accuracy statement for this densimeter.

## 2. THE PORTABLE REFERENCE DENSIMETER

The Portable Reference Densimeter (PRD) shown in fig. 1 is very similar to the DRS densimeter described in ref. 3. The PRD is an Archimedes type densimeter consisting of a silicon single crystal float of accurately known weight that is weighed while immersed in the liquid whose density is desired. We weigh the 162 g silicon single crystal with a commercially built electronic balance capable of weighing 220 g to 1 mg. The sensing unit has been removed from the instrument case and installed in a 178 mm diameter closed aluminum case designed to withstand an internal pressure in excess of 1 MPa.

A simplified drawing of this instrument is shown in fig. 1. "A" is the silicon single crystal shown lifted from the suspension cage "B" and clamped between supports "C" and "D". The bottom supports "D" are raised when the 15 mm ID thin walled stainless steel tube "E" is lifted by a pneumatic cylinder actuating the bell crank mechanism "F". The upper supports are fixed to the 25.4 mm OD by 0.6 m long thin wall stainless steel tube "G". This length was dictated by the distance from the top plate to the sample liquid in the DRS where it was tested and may be changed. The cage "B" is suspended from the electronic balance sensing unit "H" by the 1.6 mm diameter tube "I". The balance "H" is mounted on a cantilevered plate "J" so that should gas tight balance case "K", capable of holding 10 bar interval pressure, flex when pressurized the leveling of the balance is unaffected. This permits a lighter construction for the balance case than used for the DRS densimeter. The tungsten reference weight



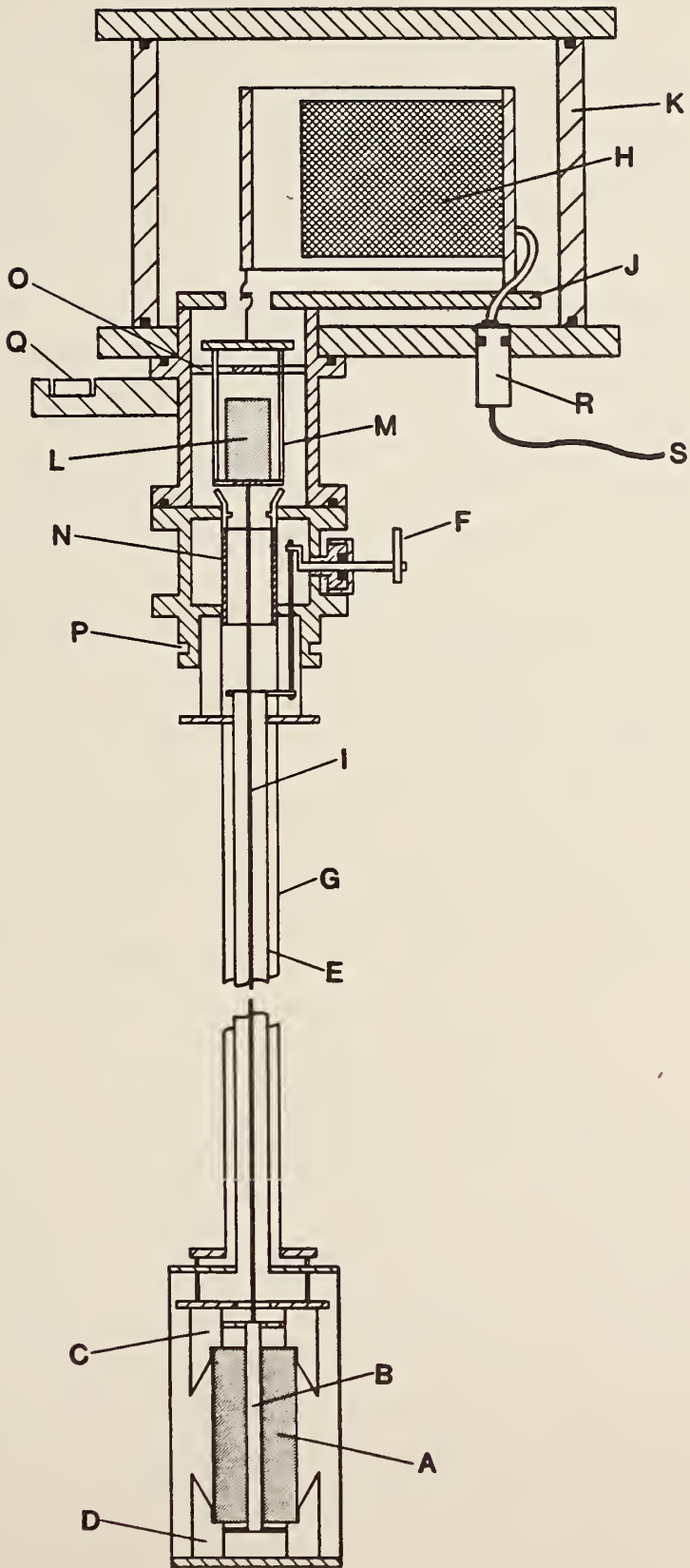


Figure 1. Portable Reference Densimeter

"L", used to monitor the balance calibration, is shown placed on its suspension cage "M". This cage replaces a section of the suspension tube "I". Some swivel joints in this suspension permits flexing but not rotation. A pneumatic-cylinder driven bell crank, similar to "F" but not shown in the drawing raises "N" which lifts the reference weight "L" off the suspension and clamps it against the fixed top support "O". The "O" ring seal at "P" connects this densimeter into an LNG sample container. This joint is a gland seal rather than a flange seal so the instrument can be tilted according to the bull's eye level "Q" to align the suspension "F" to tube "E". A gas tight seal "R" is provided for the electrical leads "S". The case "K" is clamped together with sufficient bolts through the flanges to withstand a 10 bar internal pressure.

The apparent mass of the reference weight is approximately the same as that of the silicon float when the latter is suspended in liquid methane. We compared this apparent mass value, corrected to a true mass value by using the temperature and pressure of the sample gas to determine the buoyant effect, to the true mass values of the tungsten as determined by precision weighing. This procedure provides a continual monitoring of the balance calibration. Tungsten was chosen for the reference weight because its high density reduces the magnitude of the buoyancy correction hence any effect of uncertainty in the gas density in the region of the reference is minimized.

### 3. DENSITY MEASUREMENT AND SYSTEMATIC UNCERTAINTIES

The density of the liquid in which the float is immersed is given by the relation [3]:

$$\rho = \rho_S (1 - (M_a - M_{a0})/M_S) \quad (1)$$

where  $M_S$  ( $=162.2502 \pm 0.0005$  g, 99% confidence interval) is the true mass of the silicon single crystal,  $M_a$  is the apparent mass value with the silicon on the suspension and immersed in the liquid,  $M_{a0}$  is the weight of the suspension in the liquid (this reading is zero  $\pm 0.001$  g as a general rule because the balance is zeroed in this configuration) and  $\rho_S$  is the density of the single crystal silicon at the liquid temperature and pressure. The silicon single crystal density at 110 K from ref. 2 is assumed to be  $2.3308 \pm 0.00007$  g/cm<sup>3</sup>. This includes both the estimated experimental uncertainty in the density and the thermal expansivity.

The true mass values of the silicon crystals and the reference weights for the DRS and the PRD are given in table 1 along with an estimate of total uncertainty for each value. Total uncertainty is defined as  $\pm$  the sum of the systematic error limit plus the 99% confidence limit for the average of the  $n$  weighings. Each true mass value is an average of  $n$  weighings made on separate days. The systematic error in each case is the systematic uncertainty specified for the set of class S weights used.

The estimated errors for the various measured quantities are shown in table 2 which is similar to the same table in ref. 3. We have not included the error for temperature gradient and drift of a liquid sample [3] because we are now examining the systematic error of the densimeter only, not the densimeter plus sample container. As before [3], the total systematic error shown in table 2 is assumed to be the square root of the sum of the squares of the individual contributions.

If the densimeter is used in liquids at temperatures well removed from 110 K an expression for  $\rho_S(T)$  is related to the 0°C density by

$$\rho_S(T) = \rho_S(0^\circ\text{C})(1 - 3\beta(T) + \text{negligible terms}) \quad (2)$$

where

$$\rho_S(0^\circ\text{C}) = 2.32940 \pm 0.00007 \text{ g/cm}^3$$

and the thermal expansivity

$$\beta(T) = - (L(273.2) - L(T))/L(273.2) \quad (3)$$

where  $L$  is a crystal dimension. Gibbons [4] gives values of  $\beta(T)$  for  $T = 40$  to  $300$  K at intervals of  $10$  K. He reports the probable error for expansivity to be less than  $0.5\%$  at each point. Gibbons does not define probable error, but in one definition [6] it is  $0.6475$  times the standard deviation. This suggests that his estimated standard deviation for expansivity is less than  $0.8\%$  for each value. He also does not mention if inherent systematic error in his experimental apparatus was considered. Differences between his values and those of other experimenters are noted in the paper.

As a possible aid to interpolation in Gibbon's table for the expansivity of silicon the following fourth degree polynomial was fit to his values of  $\beta(T)$  for  $T = 70$  to  $300$  K:

TABLE 1. Weight Values

	Avg of n Measure- ments	<u>n</u>	*99% Conf Limits for Average	Systematic Error from Class S Weights	Total Uncer- tainty	% Total Uncer- tainty
DRS Silicon Crystal	127.4351g	6	<u>± .00022g</u>	<u>± .00020g</u>	<u>± .00042g</u>	<u>± .0003</u>
DRS Reference Weight (brass)	102.9022g	1	<u>± .00055g</u>	<u>± .00017g</u>	<u>± .00072g</u>	<u>± .0007</u>
PRD Silicon Crystal	162.2502g	5	<u>± .00025g</u>	<u>± .00024g</u>	<u>± .00049g</u>	<u>± .0003</u>
PRD Reference Weight (tungsten)	132.2457g	1	<u>± .00055g</u>	<u>± .00018g</u>	<u>± .00073g</u>	<u>± .0006</u>

\*From  $t / \sqrt{n}$  where  $\sigma$  is estimated to be 0.00017g based on the pooled standard deviation of silicon weighings (9 degrees of freedom). The Student-t statistic for a 99% confidence interval in this case is 3.25.

Table 2. Systematic Errors

<u>Variable, x</u>	<u><math>\partial\rho/\partial x</math></u>	<u>Max Magnitude</u>	<u><math>\delta x</math></u>	<u><math>\partial\rho/\rho(\%)*</math></u>
Silicon crystal mass	$(\rho_S - \rho)/M_S$	0.012 cm <sup>-3</sup>	5 x 10 <sup>-4</sup> g	0.0015
Apparent masses silicon	$-\rho_S/M_S$	0.015 cm <sup>-3</sup>	0.001 g	0.0038
Suspension	$\rho_S/M_S$	0.015 cm <sup>-3</sup>	0.001 g	0.0038
Silicon density	$\rho/\rho_S$	0.17	7 x 10 <sup>-5</sup> g/cm <sup>-3</sup>	0.0030
TOTAL				0.006

\*for  $\rho = 400 \text{ kg/m}^3$



$$\beta(T) = (-0.11620 - 7.72448 \times 10^{-4}T - 5.40814 \times 10^{-6}T^2 + 6.2707 \times 10^{-8}T^3 - 9.83286 \times 10^{-11}T^4) \times 10^{-3} \quad (4)$$

The residual standard deviation from this fit is  $9.6 \times 10^{-7}$ . The target absolute residual of the polynomial values from those of Gibbons is  $2.5 \times 10^{-6}$  which occurs for  $T = 240$  K. This maybe an aberrant point, the next largest in absolute value is  $-1.7 \times 10^{-6}$  for  $T = 90$  K. A plot of these residuals show a non-random pattern, so another method of interpolation may improve the fit. The estimated standard deviations for the values of  $\beta(T)$  predicted by the above polynomial range from  $7.8 \times 10^{-7}$  at 70 K and 300 K to  $3.4 \times 10^{-7}$  at 150 K. If we take three times the largest of these,  $2.3 \times 10^{-6}$ , as our estimated random uncertainty for  $\beta(T)$  then the systematic error eq (4) introduces into the density determination is approximately  $|\partial\rho/\partial\beta|_{T=0^\circ\text{C}} \times (2.3 \times 10^{-6})$ , where  $|\partial\rho/\partial\beta|_{T=0^\circ\text{C}}$  is, differentiating eq (2),  $3 \times 2.3294 = 7.0 \text{ g/cm}^3$ . Thus, if eq (4) is used for the  $\beta(T)$  calculation, another  $1.6 \times 10^{-5} \text{ g/cm}^3$  (.007%) would be added in quadrature to the total in table 2. Even if this error were a factor of 10 larger, it would contribute little to the total systematic error.

#### 4. CALCULATIONS OF THE RANDOM UNCERTAINTY FOR THE PORTABLE DENSIMETER

The PRD has been tested in the Density Reference System. The accuracy and precision of the DRS densimeter and the portable densimeter are essentially independent of liquid composition. Their accuracy and precision depend primarily upon the accuracy and precision of the balance and how well the weight and density of the silicon crystals are known. The ability to make an accurate comparison will, of course, depend upon conditions within the sample holder. The liquid needs to be relatively quiet, well mixed and of a fairly uniform temperature in the volume in which the measurements are being made.

The liquids chosen for comparing the two densimeters were saturated liquid methane and a saturated LNG like mixture. The DRS densimeter has been tested in those liquids [3]. The comparison of the two densimeters is based on data taken from two fillings of the liquid sample holder, for a total of 35 density values.

We first filled the DRS sample holder with liquid methane, took a series of measurements in the range of 110 to 125 K, then added nitrogen (about 1% to 2%) and propane (about 4% to 6%) to simulate LNG and took another series of measurements in the same temperature range.

The series of measurements for a liquid sample in the DRS were made by either heating or cooling the saturated liquid to a target temperature, waiting for the liquid to come to equilibrium, and taking the desired schedule of readings. The sample was stirred and the readings were repeated giving a duplicate set of readings for each temperature. It is reasonable to assume that the random error of the duplicate density values described above would correlate more closely than values obtained at another temperature.

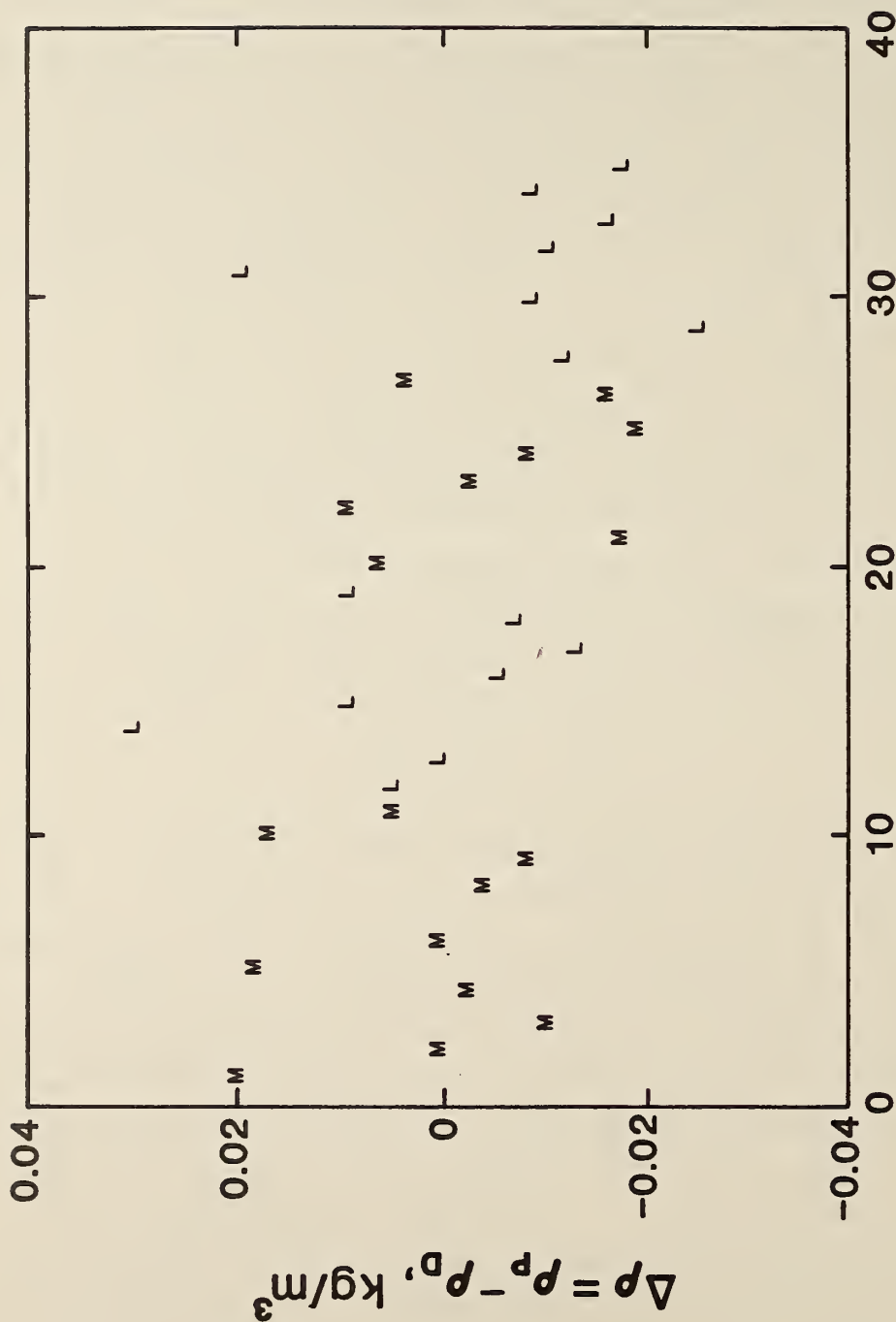
Because of the large correlation between duplicate readings, only one of each of the duplicates can be usefully employed in the analysis. We have arbitrarily chosen to use the first of each duplicate in our analysis. The second of each would provide essentially the same information. Using both duplicates would complicate the analyses without providing any increase in information.

The model used to analyze the data is:

$$\Delta\rho_{ij} = \rho_{Tij} - \rho_{Dij} = \mu + \alpha_i + e_{ij} \quad (5)$$

where  $\rho_{Tij}$  is the  $j$ th density determined by the portable densimeter on the  $i$ th set of runs,  $\rho_{Dij}$  is the corresponding density value determined by the DRS densimeter,  $\mu$  represents any systematic difference between the two methods,  $\alpha_i$  represents a shift in the mean for measurements on the  $i$ th set of runs, and  $e_{ij}$  represents any random contribution to the  $j$ th measurement on the  $i$ th set of runs. A set of runs are those measurements made with a particular mixture in the liquid sample holder.

Figure 2 is a plot in chronological order of the  $\Delta\rho_{ij}$ . There are four sets of runs shown in this figure, two for methane and two for the LNG like mixture. The symbol "M" is for a methane value and "L" is for LNG. In this plot can be seen the extent of any shifts,  $\alpha_i$ , in the mean of the  $\Delta\rho_{ij}$  from one set of runs to the next. We know from our study of the DRS, ref. 3, that such shifts occur and appear to be random. In the DRS study, only methane data was used to study the variability of the  $\alpha_i$  because the comparison was between the DSR densimeter and the Haynes-Hiza [5] temperature relationship for saturated liquid methane. Because the Haynes-Hiza relationship depends on pure methane, the  $\alpha_i$  may have partly been the function of contaminants in the methane. The 99% upper bound on the standard deviation of the  $\Delta\rho_{ij}$ , taken from ref. 3, is .036 kg/m<sup>3</sup>. This is the bound we take to represent the variability from one set of runs to the next for each of the two Archimedes densimeters that we are



## CHRONOLOGICAL ORDER

Figure 2. Differences between the densities measured by the Portable Reference Densimeter and the Density Reference System densimeter in the Density Reference System. The L and M symbols are for an LNG like mixture and liquid methane, respectively.



comparing; so that the 99% upper bound on the  $\Delta\rho_{ij}$  could be  $\sqrt{2} \times .036 \text{ kg/m}^3 = .051 \text{ kg/m}^3$ . For the four sets of runs considered in this study, the standard deviation of the  $\alpha_i$  for the means of the  $\Delta\rho_{ij}$  is estimated to be  $0.007 \text{ kg/m}^3$ . So we do not see any conflict in assuming, for the time being, that the new portable densimeter will behave in a manner like the DRS densimeter with respect to the variability in the  $\alpha_i$ .

Based on the  $\Delta\rho_{ij}$  shown in fig. 2, the  $e_{ij}$  has an estimated standard deviation of  $0.0099 \text{ kg/m}^3$ . An upper 99% bound on the standard deviation is  $0.014 \text{ kg/m}^3$ . If we were to divide this equally between the two densimeters, then the 99% upper bound for the standard deviation for variability within sets of runs would be  $0.01 \text{ kg/m}^3$  for each densimeter. This value is less than expected based on the results presented in ref. 3, and suggests that our method of computing the density using the averaged sample temperature may have contributed a significant amount of the variability in our study of the DRS.

Each balance is calibrated by weighing its reference weight in air and adjusting the balance to read the correct apparent mass value in air, not the true mass value. Each reference weight has approximately the same apparent mass value as the corresponding silicon crystal when the latter is submerged in liquid methane.

As a test of the densimeter balance calibrations each reference weight is measured and recorded. At each sample temperature setting, the measured apparent mass value is corrected for gas buoyancy and compared to the true mass value. This correction is readily made for methane or methane-nitrogen samples but not for methane-propane-nitrogen samples because propane suppresses the methane vapor pressure by an uncertain amount and because the gas mixture is slow to reach equilibrium. The method of calculating the buoyancy correction is detailed in ref. 3. The reference weight of the PRD is located in ambient temperature gas. This arrangement and the tungsten weight reduce the buoyancy correction thus reducing associated uncertainties. The true mass value of the reference weight for the DRS densimeter is  $102.9022 \text{ g}$  with a total uncertainty from table 1 of  $\pm 0.72 \text{ mg}$ . Comparison of the reference weight readings for methane and LNG, showed some differences which are attributed to the buoyancy corrections made for the two liquids. A 99% confidence interval for the average of the reference weight true mass values measured in the methane atmosphere is  $102.9024 \text{ g} \pm .0004 \text{ g}$  and that for the average measured in the LNG vapor is  $102.9015 \pm .0004 \text{ g}$ .

While a statistical difference is present between these two values, the difference has no practical significance and both are consistent with the accepted true mass value of the reference weight.

The measured true mass value of the reference weight for the portable densimeter is 132.2457 g with a total uncertainty from table 1 of  $\pm 0.73$  mg. Comparison of the average true mass value of the reference weight measured in both methane and LNG atmospheres shows no significant difference between the two values. A 99% confidence interval for the combined average in methane and LNG atmospheres is  $132.2455 \pm .0003$  g, which is consistent with the accepted true mass value for the reference weight.

The analyses of the reference weight true mass values taken during the comparison of the two densimeters show the balance of both densimeters to be both stable and accurate.

## 5. CONCLUSIONS

From our experience with the improved DRS densimeter, we determined that a portable silicon densimeter of essentially the same design and similar accuracy is feasible. We have built such a densimeter and compared its performance to the DRS densimeter by installing it in the DRS. Its performance exceeds the performance of the DRS mainly because of the larger silicon crystal and the relocation and higher density of the reference weight.

The total uncertainty of a single measurement we estimate to be the systematic uncertainty added to three times the estimated within run and the between run variability added in quadrature:

$$3(.036^2 + .014^2)^{1/2} = 0.116 \text{ kg/m}^3 \quad (6)$$

At a density of  $422.63 \text{ kg/m}^3$  (methane normal boiling point) the  $3\sigma$  uncertainty is .027% and, adding the systematic uncertainty of 0.006%, the total uncertainty of one measurement is 0.033%.

The comparison of the DRS and PRD densimeters has also shown the systematic uncertainty of 0.022% for the DRS is over estimated. The agreement between the measured density values suggests that this sample temperature gradient used for the systematic error estimate in ref. 3 is too large. The estimated gradient is the dominant contribution to the systematic error estimate for the DRS [3]. The gradients across the sample in the region of the silicon crystals, whose centers are separated by 15 mm, must be much smaller than estimated in ref. 3.



## 6. REFERENCES

- [1] Siegwarth, J. D., Younglove, B. A., and LaBrecque, J. F., Cryogenic Fluids Density Reference System: Provisional Accuracy Statement, Nat. Bur. Stand. (U.S.), Technical Note 698, (Nov 1977).
- [2] Siegwarth, J. D., Younglove, B. A., and LaBrecque, J. F., An Evaluation of Commercial Densimeters for Use in LNG, Nat. Bur. Stand. (U.S.), Technical Note 697, (Oct 1977).
- [3] Siegwarth, J. D., and LaBrecque, J. F., Cryogenic Fluids Density Reference System: 1980, Nat. Bur. Stand. (U.S.), Technical Note, to be published.
- [4] Gibbons, D. E., Thermal Expansion of Some Crystals with the Diamond Structure, Phys. Rev 122, 136 (1958).
- [5] Haynes, W. M., Hiza, M. J., Measurements of Orthobaric Liquid Densities of Methane, Ethane, Propane Iso Butane and Normal Butane, J. Chem. Thermodynamics 9, 179, (1977).
- [6] Kendall, M. G., and Buckland, W. R., A Dictionary of Statistical Terms, 3rd ed., Hafner Publishing Co., New York, New York, 1971.

U.S. DEPT. OF COMM. <b>BIBLIOGRAPHIC DATA SHEET</b> (See instructions)	<b>1. PUBLICATION OR REPORT NO.</b> NBS TN-1035	<b>2. Performing Organ. Report No.</b>	<b>3. Publication Date</b> March 1981
<b>4. TITLE AND SUBTITLE</b> <p style="text-align: center;">A Portable Calibration Densimeter for Use in Cryogenic Liquids</p>			
<b>5. AUTHOR(S)</b> J. D. Siegwarth, J. F. LaBrecque			
<b>6. PERFORMING ORGANIZATION</b> (If joint or other than NBS, see instructions) <b>NATIONAL BUREAU OF STANDARDS</b> <b>DEPARTMENT OF COMMERCE</b> <b>WASHINGTON, D.C. 20234</b>			<b>7. Contract/Grant No.</b>  <b>8. Type of Report &amp; Period Covered</b>
<b>9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS</b> (Street, City, State, ZIP) Gas Research Institute 10 West 35th Street Chicago, Illinois 60616 (Grant 5014-361-0131)			
<b>10. SUPPLEMENTARY NOTES</b>  <input type="checkbox"/> Document describes a computer program; SF-185, FIPS Software Summary, is attached.			
<b>11. ABSTRACT</b> (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)  A portable densimeter designed specifically for calibrating liquefied natural gas densimeters but suitable for density measurement of a wide range of liquids, is described. The densimeter has been compared to the Density Reference System densimeter at the National Bureau of Standards and found to agree to well within the combined systematic error. The density results of this instrument and that of the DRS densimeter are statistically indistinguishable.			
<b>12. KEY WORDS</b> (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)  Densimeter; density reference system; liquid methane; LNG.			
<b>13. AVAILABILITY</b> <input checked="" type="checkbox"/> Unlimited <input type="checkbox"/> For Official Distribution. Do Not Release to NTIS <input checked="" type="checkbox"/> Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.  <input type="checkbox"/> Order From National Technical Information Service (NTIS), Springfield, VA. 22161			<b>14. NO. OF PRINTED PAGE</b> <p style="text-align: center;">20</p> <b>15. Price</b> <p style="text-align: center;">\$1.50</p>

# NBS TECHNICAL PUBLICATIONS

## PERIODICALS

**JOURNAL OF RESEARCH**—The Journal of Research of the National Bureau of Standards reports NBS research and development in those disciplines of the physical and engineering sciences in which the Bureau is active. These include physics, chemistry, engineering, mathematics, and computer sciences. Papers cover a broad range of subjects, with major emphasis on measurement methodology and the basic technology underlying standardization. Also included from time to time are survey articles on topics closely related to the Bureau's technical and scientific programs. As a special service to subscribers each issue contains complete citations to all recent Bureau publications in both NBS and non-NBS media. Issued six times a year. Annual subscription: domestic \$13; foreign \$16.25. Single copy, \$3 domestic; \$3.75 foreign.

NOTE: The Journal was formerly published in two sections: Section A "Physics and Chemistry" and Section B "Mathematical Sciences."

**DIMENSIONS/NBS**—This monthly magazine is published to inform scientists, engineers, business and industry leaders, teachers, students, and consumers of the latest advances in science and technology, with primary emphasis on work at NBS. The magazine highlights and reviews such issues as energy research, fire protection, building technology, metric conversion, pollution abatement, health and safety, and consumer product performance. In addition, it reports the results of Bureau programs in measurement standards and techniques, properties of matter and materials, engineering standards and services, instrumentation, and automatic data processing. Annual subscription: domestic \$11; foreign \$13.75.

## NONPERIODICALS

**Monographs**—Major contributions to the technical literature on various subjects related to the Bureau's scientific and technical activities.

**Handbooks**—Recommended codes of engineering and industrial practice (including safety codes) developed in cooperation with interested industries, professional organizations, and regulatory bodies.

**Special Publications**—Include proceedings of conferences sponsored by NBS, NBS annual reports, and other special publications appropriate to this grouping such as wall charts, pocket cards, and bibliographies.

**Applied Mathematics Series**—Mathematical tables, manuals, and studies of special interest to physicists, engineers, chemists, biologists, mathematicians, computer programmers, and others engaged in scientific and technical work.

**National Standard Reference Data Series**—Provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated. Developed under a worldwide program coordinated by NBS under the authority of the National Standard Data Act (Public Law 90-396).

NOTE: The principal publication outlet for the foregoing data is the Journal of Physical and Chemical Reference Data (JPCRD) published quarterly for NBS by the American Chemical Society (ACS) and the American Institute of Physics (AIP). Subscriptions, reprints, and supplements available from ACS, 1155 Sixteenth St., NW, Washington, DC 20056.

**Building Science Series**—Disseminates technical information developed at the Bureau on building materials, components, systems, and whole structures. The series presents research results, test methods, and performance criteria related to the structural and environmental functions and the durability and safety characteristics of building elements and systems.

**Technical Notes**—Studies or reports which are complete in themselves but restrictive in their treatment of a subject. Analogous to monographs but not so comprehensive in scope or definitive in treatment of the subject area. Often serve as a vehicle for final reports of work performed at NBS under the sponsorship of other government agencies.

**Voluntary Product Standards**—Developed under procedures published by the Department of Commerce in Part 10, Title 15, of the Code of Federal Regulations. The standards establish nationally recognized requirements for products, and provide all concerned interests with a basis for common understanding of the characteristics of the products. NBS administers this program as a supplement to the activities of the private sector standardizing organizations.

**Consumer Information Series**—Practical information, based on NBS research and experience, covering areas of interest to the consumer. Easily understandable language and illustrations provide useful background knowledge for shopping in today's technological marketplace.

*Order the above NBS publications from: Superintendent of Documents, Government Printing Office, Washington, DC 20402.*

*Order the following NBS publications—FIPS and NBSIR's—from the National Technical Information Services, Springfield, VA 22161.*

**Federal Information Processing Standards Publications (FIPS PUB)**—Publications in this series collectively constitute the Federal Information Processing Standards Register. The Register serves as the official source of information in the Federal Government regarding standards issued by NBS pursuant to the Federal Property and Administrative Services Act of 1949 as amended, Public Law 89-306 (79 Stat. 1127), and as implemented by Executive Order 11717 (38 FR 12315, dated May 11, 1973) and Part 6 of Title 15 CFR (Code of Federal Regulations).

**NBS Interagency Reports (NBSIR)**—A special series of interim or final reports on work performed by NBS for outside sponsors (both government and non-government). In general, initial distribution is handled by the sponsor; public distribution is by the National Technical Information Services, Springfield, VA 22161, in paper copy or microfiche form.

**U.S. DEPARTMENT OF COMMERCE**  
**National Bureau of Standards**  
Washington, D.C. 20234

OFFICIAL BUSINESS

Penalty for Private Use, \$300

POSTAGE AND FEES PAID  
U.S. DEPARTMENT OF COMMERCE  
COM-215



SPECIAL FOURTH-CLASS RATE  
BOOK

---