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THE DETERMINATION OF THE HELIUM SATURATION LEVEL OF AEROZINE-50 AND NITROGEN TETROXIDE

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16. Abstract

Two methods for determining the helium saturation level of Aerozine-50 and nitrogen tetroxide are examined: the bubble-point method for field use and the gas-content method for laboratory use. Data to illustrate the application of the bubble-point method are presented. The gas-content method and the results obtained from its application at the NASA Manned Spacecraft Center White Sands Test Facility are discussed. Equations describing the helium content of Aerozine-50 and nitrogen tetroxide as functions of pressure and temperature are also presented.

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THE DETERMINATION OF THE HELIUM SATURATION LEVEL OF AEROZINE-50 AND NITROGEN TETROXIDE

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SUMMARY

As part of the lunar module propulsion-system development program, tests using helium-saturated propellants to simulate flight conditions were conducted at the NASA Manned Spacecraft Center White Sands Test Facility. Auxiliary conditioning equipment, designed to expose a large surface area of the propellant to gaseous helium in order to ensure rapid absorption of the helium by the propellant, was used to saturate the propellant.

An oversaturation, degassing procedure was used to prepare the large quantities of propellants required for the tests. The propellants were saturated with helium at pressures of 50 to 245 psia. A field procedure, using a bubble-point determination, was developed to indicate the helium saturation level of the propellants. Data were obtained to indicate the relationship between the propellant saturation pressure and the bubble-point pressure. The gas-content data were obtained from the analysis of propellant samples to determine the quantity of dissolved gas in the samples. The gas-content data were then used to formulate equations for the amount of helium dissolved in the propellant at pressures of 92 to 235 psig and at temperatures of 66° to 102° F.

INTRODUCTION

During the lunar module (LM) propulsion-system development program conducted at the NASA Manned Spacecraft Center White Sands Test Facility (WSTF), testing of the LM ascent and descent propulsion systems during operation with helium-saturated propellants became necessary. This requirement resulted in the development of equipment for saturating fuel and oxidizer with gaseous helium at various temperatures and pressures to simulate, within the capability limits of the WSTF equipment, the actual propellant condition of a lunar mission. After the LM is loaded with propellants for a typical flight, the remaining ullage volume is pressurized with gaseous helium prior to launch. During extended inflight periods under zero gravity conditions, the propellants

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**Grumman Aerospace Corporation.

and the helium become evenly dispersed throughout the tank, and the helium is dissolved into the propellants, causing uniform helium saturation of the propellants.

The purpose of this phase of the propulsion development program was to evaluate the LM propulsion system and the engine operation in order to identify and analyze any performance changes caused by helium-saturated propellants. The fuel used for the evaluation was Aerozine-50, a mixture of hydrazine and unsymmetrical dimethylhydrazine in approximately equal proportions by weight. The oxidizer used was nitrogen tetroxide (N_2O_4). Among the factors investigated were shifts in mixture ratio between the Aerozine-50 and N_2O_4, the effects on combustion stability and the changes in engine performance as a result of the mixture-ratio shifts, and the effect of the helium in the propellant.

The existing literature did not contain the data that were necessary to satisfactorily define the helium content of the propellants as a function of temperature and pressure relationships in the temperature and pressure ranges encountered in the testing at the WSTF. Therefore, a means of determining and indicating the helium content of the propellant had to be developed. Two methods were developed to solve this problem: the bubble-point method, which is a field method, and the gas-content method, which is a laboratory procedure that gives the gas content of the propellant at existing sample temperature and pressure. This report describes the two methods and presents the results obtained through the application of the methods.

BACKGROUND

For the testing of the LM ascent and descent propulsion systems at the WSTF, large quantities (up to 1200 gallons) of Aerozine-50 and N_2O_4 were saturated with gaseous helium at pressures ranging from 50 to 245 psia. To promote rapid absorption of the helium by the propellant, equipment was designed to expose a large surface area of the propellant to a helium atmosphere. Figure 1 is a schematic of the final version of the auxiliary conditioning unit (ACU) that was built to perform this operation. The fuel and oxidizer units are identical.

Before the propellant is loaded into its respective ACU, it is vented at atmospheric pressure in the ready storage units for 3 hours to allow any gaseous nitrogen (normally used for the tank or vessel pressure maintained during shipping and storage) dissolved in the propellants to come out of solution. The ACU tank is then loaded with this degassed propellant and is pressurized to the desired level with gaseous helium. Saturation is accomplished by pumping the propellants from the bottom of the ACU tank through 10 top-mounted nozzles, which inject fine sprays of propellant into the helium atmosphere. Heating and cooling units are incorporated into the propellant circulation line to permit propellant temperature conditioning. The ACU is designed to permit either helium or nitrogen saturation by using valves V-1 or V-14, respectively, to select the ACU ullage pressurizing medium. Loading of the spacecraft tanks is normally accomplished by means of a pressure fill through valve V-6 with the pump off.

To ensure 100 percent helium saturation of the propellant at the desired pressure, an oversaturation, degassing procedure was adopted for the preparation of the propellants for a test. In a typical test, the propellants were prepared as follows: (1) the propellant was degassed to remove dissolved gaseous nitrogen; (2) the ACU was loaded with propellant, and the ullage was pressurized with gaseous helium to 300 psia; (3) the propellant was circulated, and the temperature was conditioned until a bubble-point sample indicated that the helium saturation level was above the desired value (the equilibrium saturation-level value at a given temperature and at a pressure of 240 psia); (4) the ACU ullage pressure was readjusted to the desired saturation pressure (240 psia); (5) the propellant was allowed to continue circulating in order to degas to the desired saturation pressure (240 psia); (6) the circulation was discontinued, and the ACU ullage pressure was maintained to allow any excess helium to come out of the propellant; (7) the spacecraft propellant tank was pressurized to the pressure necessary (240 psia) to maintain the desired helium saturation level and was maintained at 240 ± 5 psia throughout the propellant loading in order to minimize helium desaturation; and (8) after loading, bubble-point and gas-content samples of the propellant were obtained to establish the helium content of the propellant.

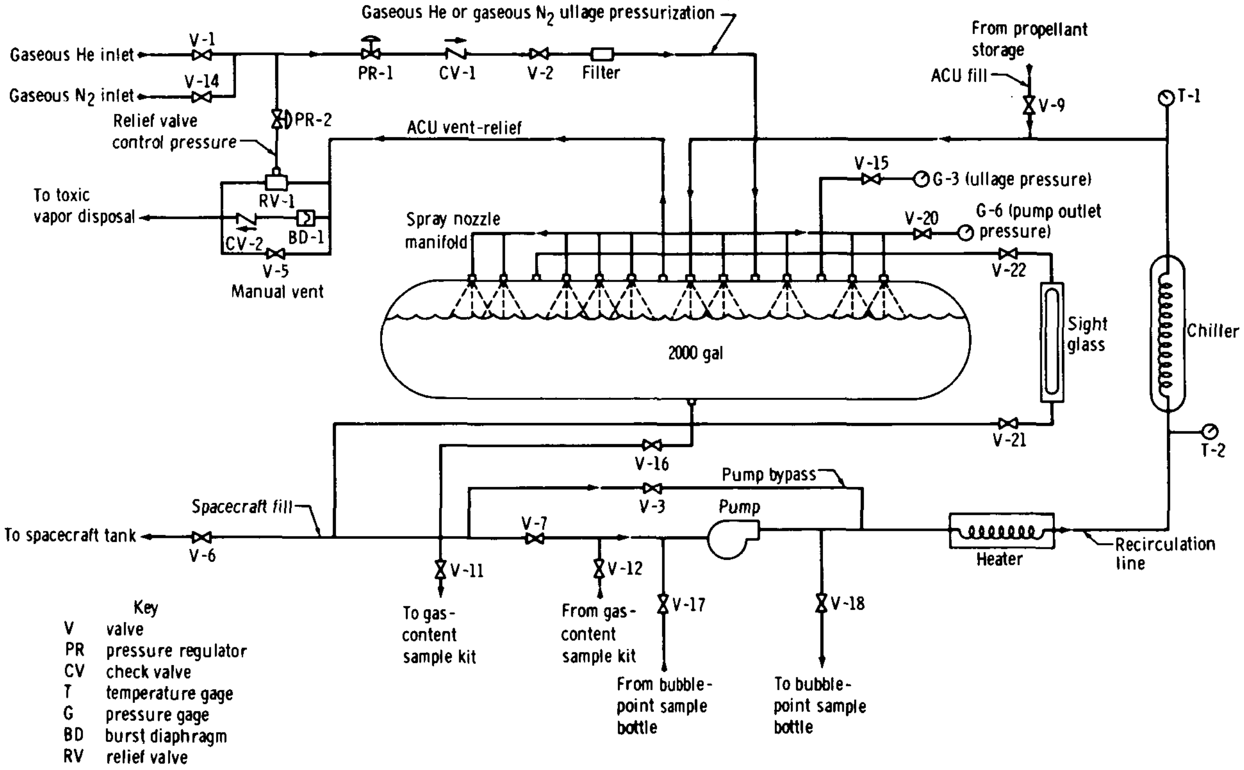


Figure 1. - Auxiliary conditioning unit.

BUBBLE-POINT PROCEDURE AND RESULTS

At a specific temperature and pressure, any liquid will hold a given quantity of gas in solution. Increasing the gas pressure will increase the quantity of gas that can be held by the liquid. Under any set of conditions, a liquid that holds the maximum quantity of gas in solution is said to be 100 percent gas saturated, and the pressure of the liquid is the 100 percent gas saturation pressure under those particular liquid conditions. If the pressure is reduced while all other conditions remain the same, the quantity of gas that can be held in solution is reduced, and the liquid then contains more gas than it can hold in solution at the new lower pressure and is oversaturated. The excess dissolved gas will come out of solution; and, if the pressure is reduced sufficiently, the excess gas may be observed as small bubbles.

The bubble-point technique was developed to provide an on-the-spot method for determining the 100 percent gas saturation pressure of the propellants. The bubble point, for this application, may be defined as the pressure at which gas coming out of solution can be visually detected. For any set of liquid conditions, the bubble point will always occur at some pressure below the 100 percent gas saturation pressure.

The bubble-point sample kit, which taps into the saturated propellant line in the ACU, is shown schematically in figure 2. The bubble-point sample kit is initially prepared for use by closing the propellant inlet valve (V-4), the propellant outlet valve (V-3), and the vent needle valve (NV-1). The system is then pressurized with gaseous helium to approximately the helium saturation pressure by opening and then closing the gaseous helium supply valve (V-2). Valves V-4 and V-3 are then opened, allowing propellant to circulate through the sight glass. When a sample is taken, valves V-3 and V-4 are closed, trapping a sample of helium-saturated propellant under pressure in the sight glass. The sight glass is observed until all excess gas bubbles rise to the top of the glass; that is, until equilibrium is reached. The pressure on the entrapped sample is slowly vented through the vent needle valve (NV-1) until gas bubbles begin to appear in the sight glass. The pressure at which these bubbles form (the bubble point) is observed on the pressure gage (G-1). The gas trapped in the pneumatic reservoir enables the sample pressure to be vented slowly and, thus, improves the bubble-point resolution.

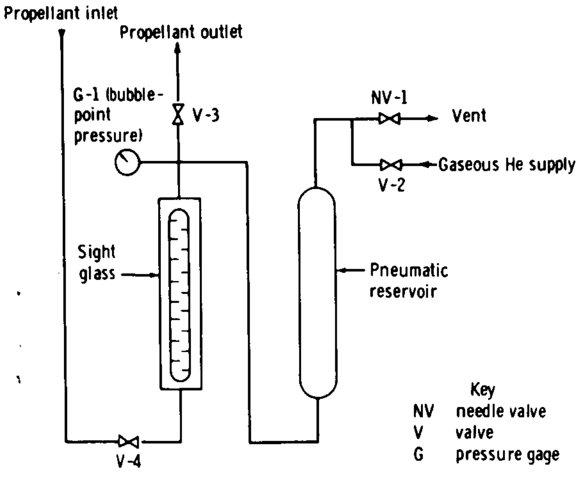


Figure 2. - Bubble-point sample kit.

In plotting the data shown in this report, the 100 percent helium saturation pressure was assumed to be equal to the ACU ullage pressure. Operationally, obtaining an accurate bubble-point reading depends upon the technique used. The bubbles, which usually form one at a time, are small and difficult to detect. To improve the accuracy of the bubble-point readiness, several configurations of sight-glass assemblies were used. All bubble-point data included in this report were derived from the use of the optimum sight-glass configuration.

Figures 3 to 8 are plots of the N_2O_4 bubble points as a function of the calculated 100 percent helium saturation pressure at various temperatures. Tables I to VI present the bubble-point pressure, the calculated 100 percent helium saturation pressure, the actual 100 percent helium saturation pressure, the difference between the actual and the calculated values, and the percent error at various temperatures. Figures 3 to 8 show a definite temperature effect — the higher the temperature, the smaller the difference between the helium saturation pressure and the bubble-point pressure. The exception is the plot for 60° F (fig. 5), which shows a larger change in pressure between the helium saturation pressure and the bubble-point pressure than the plots for 50° and 45° F show. No known physical property of N_2O_4 would cause this phenomenon; however, it should be noted that relatively few data points are plotted at 60° F. The average error for all of the N_2O_4 data is 4.7 percent.

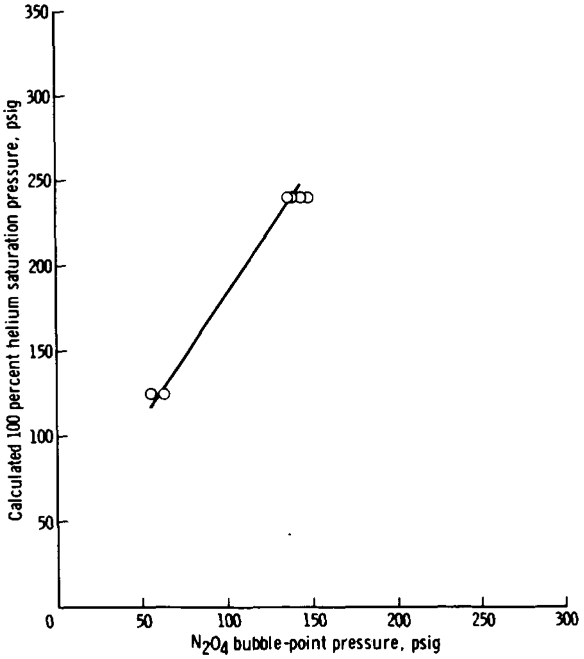


Figure 3. - Nitrogen tetroxide bubble-point pressure as a function of calculated 100 percent helium saturation pressure at 45° F.

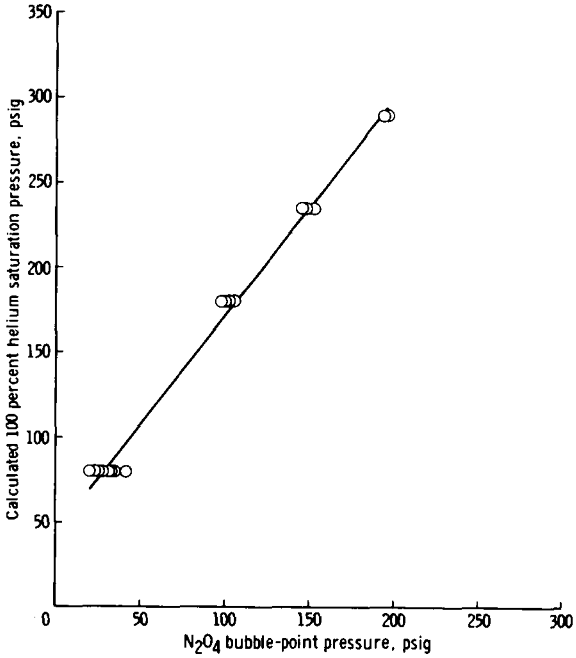


Figure 4. - Nitrogen tetroxide bubble-point pressure as a function of calculated 100 percent helium saturation pressure at 50° F.

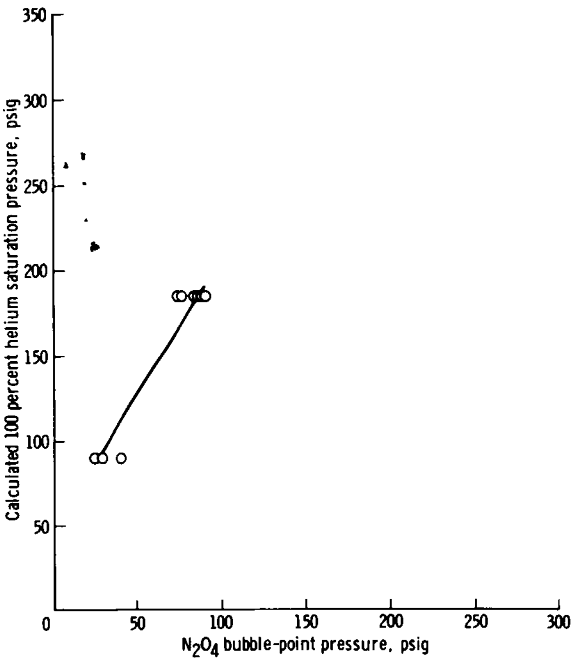


Figure 5. - Nitrogen tetroxide bubble-point pressure as a function of calculated 100 percent helium saturation pressure at 60° F.

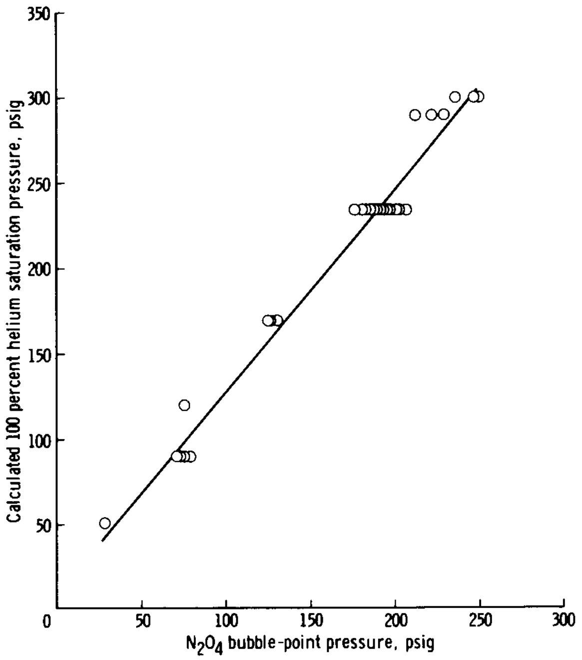


Figure 6. - Nitrogen tetroxide bubble-point pressure as a function of calculated 100 percent helium saturation pressure at 70° F.

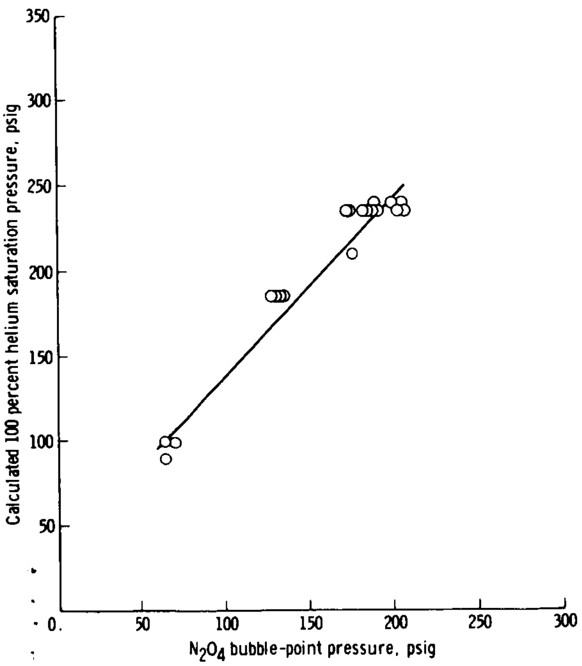


Figure 7. - Nitrogen tetroxide bubble-point pressure as a function of calculated 100 percent helium saturation pressure at 80° F.

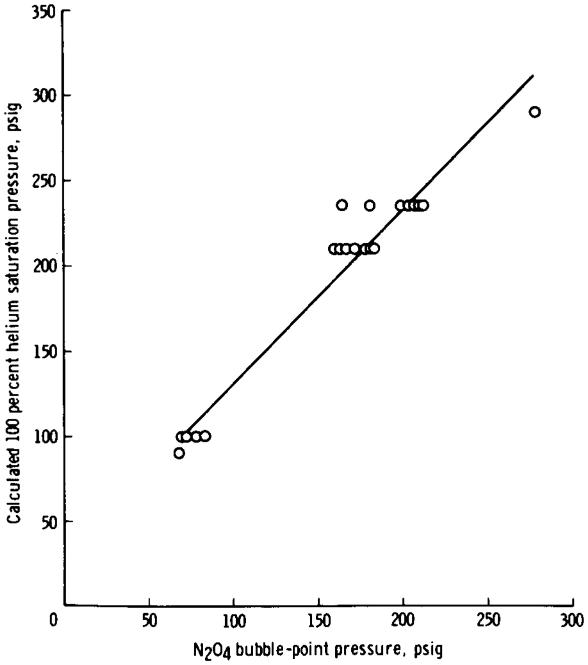


Figure 8. - Nitrogen tetroxide bubble-point pressure as a function of calculated 100 percent helium saturation pressure at 90° F.

Because the N_2O_4 bubble-point readings can be repeated more accurately than the Aerozine-50 bubble-point readings, the N_2O_4 bubble-point readings are easier to determine. The degradation in the repeatability of the Aerozine-50 bubble-point readings is probably a function of operator technique, which is evidently more critical with Aerozine-50 than with N_2O_4. At the same 100 percent helium saturation pressure, the Aerozine-50 contains only about one-third the amount of helium that the N_2O_4 contains; consequently, the bubbles are smaller and rise more slowly in the fuel. In an attempt to obtain a valid relationship between the bubble point and the helium saturation level for Aerozine-50, obviously low bubble-point readings were considered to be caused by poor operator technique and were eliminated.

Table VII presents the fuel bubble-point pressure, the calculated 100 percent helium saturation pressure, the actual 100 percent helium saturation pressure, the difference between the actual and the calculated pressures, and the percent error. Figure 9 is a plot of Aerozine-50 bubble-point pressure as a function of 100 percent helium saturation pressure. However, figure 9 does not show separate plots for different Aerozine-50 temperatures. Because the total gas content of the Aerozine-50 is very low, the apparent effect of temperature on the Aerozine-50 is not as pronounced as the apparent effect of temperature on the N_2O_4. Since the temperature effect on the Aerozine-50 bubble point was smaller than the variations encountered when Aerozine-50 bubble-point readings were repeated, the variations due to the temperature effect could not be accurately determined. The average error for all of the Aerozine-50 data is 6.3 percent.

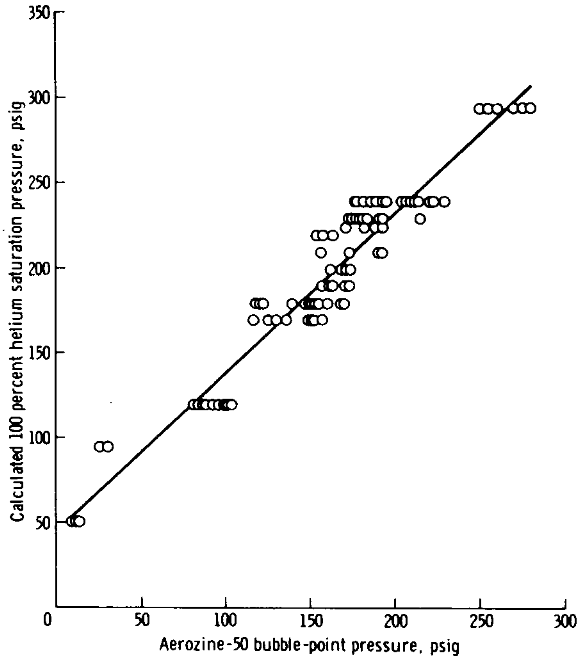


Figure 9. - Aerozine-50 bubble-point pressure as a function of calculated 100 percent helium saturation pressure.

GAS-CONTENT PROCEDURE AND RESULTS

The gas-content method, which uses mass-spectroscopy techniques, was developed to provide a value for the absolute quantity of gas dissolved in a propellant sample. The gas-content sample kit is shown schematically in figure 10. The sample kit, which taps into the spacecraft propellant-tank overfill line, is prepared for use by installing the 80-milliliter-capacity gas sample bottle in the kit. The kit is then purged

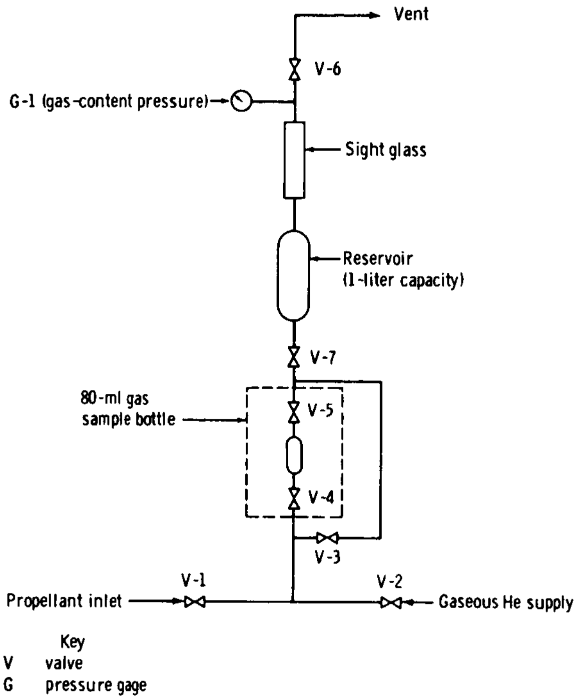


Figure 10. - Gas-content sample kit.

with gaseous helium by opening the sample-bottle valves (V-4 and V-5), the propellant bypass valve (V-3), the reservoir isolation valve (V-7), and the vent needle valve (V-6). After the kit has been purged for approximately 3 minutes, valve V-6 is closed. The kit is then pressurized (as indicated by the gas-content pressure gas (G-1)) to the propellant line pressure and then leak checked. Before the propellant is allowed to flow into the gas sample bottle, the propellant bypass valve (V-3) and the helium source pressure valve (V-2) are closed. Valve V-1 is opened to allow propellant to flow into the gas sample bottle, while the vent needle valve (V-6) is left slightly open. Valve V-6 is then opened to allow the pressure in the gas sample bottle to drop 1 to 2 psig below the propellant supply pressure. Valves V-6 and V-4 are closed when the propellant is visible in the sight glass. Valve V-1 is then closed and valves V-2, V-3, V-7, and V-6 are opened in order to purge the propellant in the reservoir from the sample kit prior to the removal of the 80-milliliter-capacity gas sample bottle.

The gas sample bottle is packed in ice and delivered to the laboratory, where the weight of the propellant trapped in the gas sample bottle is determined in order to verify that the bottle is completely filled with propellant. Because even a small gas pocket contains more gas than is normally dissolved in the propellant, an incompletely filled gas sample bottle is unacceptable. The procedure for removing the dissolved gases from the propellant sample bottle is described in the following paragraphs.

Figure 11 is an illustration of the laboratory setup used for the extraction of the dissolved gas. After the 80-milliliter-capacity gas sample bottle is attached to the degassing chamber, the chamber is evacuated to less than 50 microns, the valve downstream from the chamber is closed, and the sample is introduced into the degassing chamber. The propellant that is introduced into the degassing chamber is frozen by cooling the chamber with liquid nitrogen. With the propellant frozen, the valve downstream from the degassing chamber is opened, and the noncondensable gases are transferred to the gas-holding ball by using the Toepler pump (a mercury-piston displacement pump with mercury-seal check valves) until no more gas can be transferred (as observed by the manometer readings). The valve downstream from the degassing chamber is closed, and the frozen propellant is liquefied with warm water. The liquefied propellant is agitated until no more gas can be extracted from the sample. The propellant sample is then refrozen, and the noncondensable gas is removed and collected in the gas-holding ball. The freezing-melting process is repeated three times to ensure complete gas removal. At this point, the pressure of the gas trapped in the gas-holding ball is recorded. From this pressure and the known volume of the gas-holding ball, the quantity of gas removed from the propellant is calculated in terms of standard temperature and pressure (STP) conditions (14.7 psia and 70° F) by using gas-law relationships.

The gas that is removed from the propellant sampler is analyzed by mass spectroscopy to establish the percentages of helium, nitrogen, and oxygen present. Thus, for each sample, the quantity of dissolved gas, in terms of cubic centimeters at STP per gram of propellant, is obtained for a given propellant temperature and pressure condition. Only data from samples having a helium content of 90 percent or more by volume were used in the data treatment. Tables VIII and IX summarize the selected gas-content data, along with the ACU temperature and pressure conditions.

Examination of the data by graphical means indicated that, for the measurement ranges encountered, the relationship between temperature or pressure and helium content for a given constant pressure or temperature is linear. This fact permitted the use of a linear regression computer program to establish the relationship between helium content and propellant pressure and temperature. The linear regression analysis of the data established the following equations:

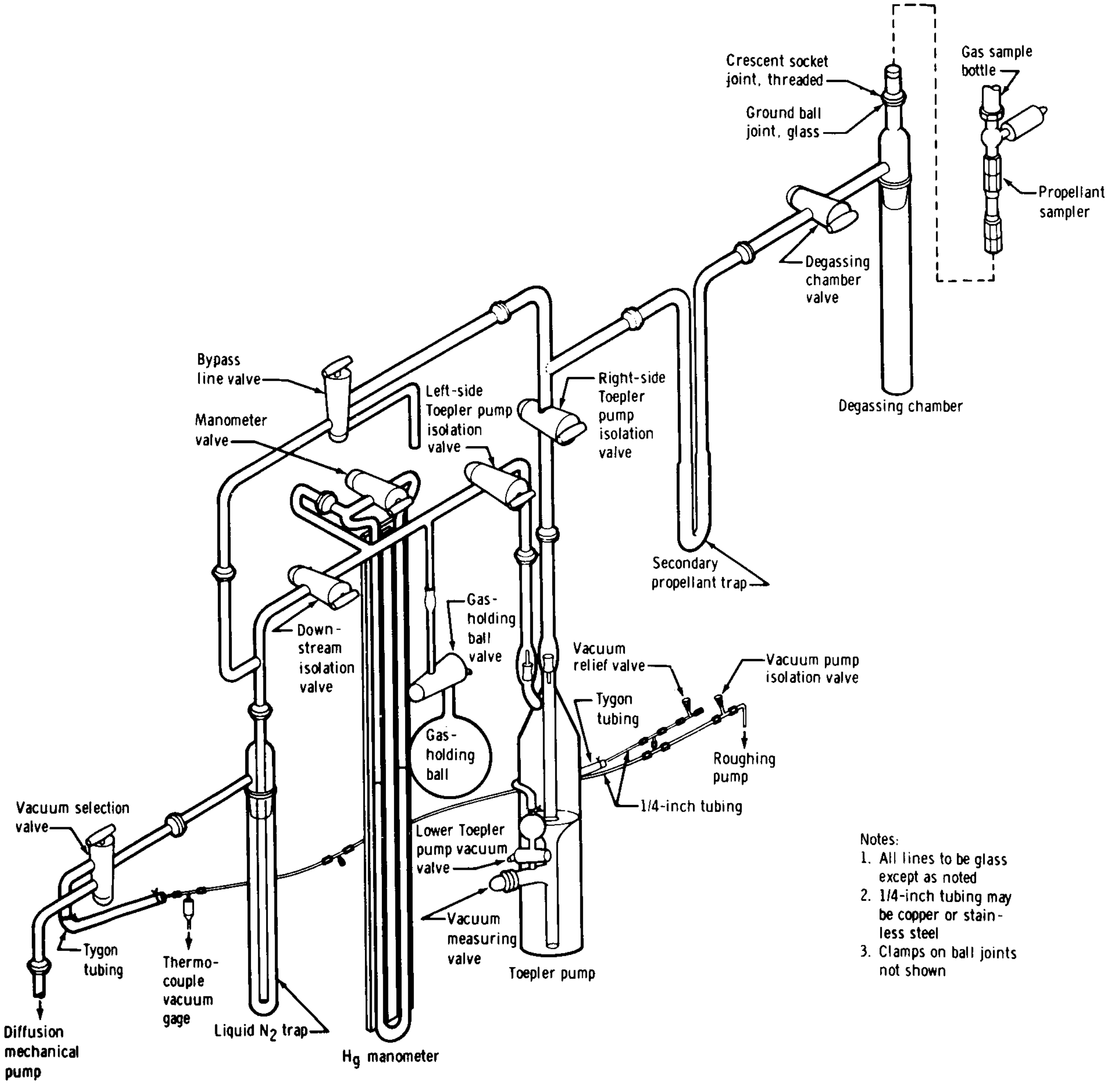
$$\text{Helium content of Aerozine-50} = -0.0257 + (0.000275 \times \text{pressure}) + (0.000869 \times \text{temperature}) \tag{1}$$

and

$$\text{Helium content of } N_2O_4 = -0.1771 + (0.001568 \times \text{pressure}) + (0.001656 \times \text{temperature}) \tag{2}$$

where helium content is in cubic centimeters STP per gram, pressure is in pounds per square inch gage, and temperature is in degrees Fahrenheit.

The data listed in tables X and XI show the deviation between the measured and calculated helium content as well as the percent error. As indicated in tables X and XI, the maximum deviation does not exceed 2σ. Evaluation of the data in terms of the temperature and pressure measurement uncertainty shows that equations (1) and (2) will provide values within 10 percent of the calculated value.



Notes:
1. All lines to be glass except as noted
2. 1/4-inch tubing may be copper or stainless steel
3. Clamps on ball joints not shown

Figure 11. - Gas-collection system.

CONCLUDING REMARKS

The data obtained from tests conducted at the NASA Manned Spacecraft Center White Sands Test Facility demonstrated that a procedure using a bubble-point determination can be used to indicate the helium saturation level of Aerozine-50 and nitrogen tetroxide. The gas-content data were used to formulate equations for the amount of helium dissolved in the propellants at pressures of 92 to 235 psig and at temperatures of 66° to 102° F. In addition, the gas-content data can be used in conjunction with the bubble-point data to indicate that the helium content of the propellant is equal to or greater than a calculated value, without waiting for a detailed gas-content analysis.

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National Aeronautics and Space Administration
Houston, Texas, November 26, 1970
914-50-R2-00-72

TABLE I. - NITROGEN TETROXIDE 45° F BUBBLE-POINT DATA

Bubble-point pressure, psig	Actual 100 percent He saturation pressure, psig	Calculated 100 percent He saturation pressure, psig	Difference (actual - calculated)	Error,[a] percent
144	240	248	-8	3.3
136	240	237	3	1.2
138	240	240	0	0
136	240	237	3	1.2
136	240	237	3	1.2
55	125	117	8	6.4
60	125	124	1	.8
63	125	129	-4	3.2
63	125	129	-4	3.2
63	125	129	-4	3.2

[a] Average error is 2.4 percent.

TABLE II. - NITROGEN TETROXIDE 50° F BUBBLE-POINT DATA

Bubble-point pressure, psig	Actual 100 percent He saturation pressure, psig	Calculated 100 percent He saturation pressure, psig	Difference (actual - calculated)	Error,[a] percent
193	290	291	-1	0.3
191	290	289	1	.3
195	290	294	-4	1.4
145	230	229	1	.4
151	230	237	-7	3.0
148	230	233	-3	1.3
25	80	75	5	6.2
100	180	172	8	4.4
102	180	174	6	3.3
97	180	168	12	6.7
100	180	172	8	4.4
105	180	178	2	1.1
105	180	178	2	1.1
110	180	184	-4	2.2
105	180	178	2	2.2
40	80	94	-14	17.5
20	80	68	12	15.0
37	80	90	-10	12.5
35	80	88	-8	10.0
38	80	92	-12	15.0
30	80	81	-1	1.2
28	80	79	1	1.2
24	80	74	6	7.5

[a] Average error is 5.1 percent.

TABLE III. - NITROGEN TETROXIDE 60° F BUBBLE-POINT DATA

Bubble-point pressure, psig	Actual 100 percent He saturation pressure, psig	Calculated 100 percent He saturation pressure, psig	Difference (actual - calculated)	Error,[a] percent
82	180	176	4	2.2
89	180	187	-7	3.9
77	180	169	11	6.1
74	180	164	16	8.9
83	180	178	2	1.1
91	180	190	-10	5.5
89	180	187	-7	3.9
88	180	186	-6	3.3
86	180	183	-3	1.7
81	180	175	5	2.8
77	180	169	11	6.1
28	90	93	-3	3.3
41	90	113	-23	25.5
24	90	86	4	4.4
24	90	86	4	4.4
24	90	86	4	4.4

[a] Average error is 5.5 percent.

TABLE IV. - NITROGEN TETROXIDE 70° F BUBBLE-POINT DATA

Bubble-point pressure, psig	Actual 100 percent He saturation pressure, psig	Calculated 100 percent He saturation pressure, psig	Difference (actual - calculated)	Error,[a] percent
245	300	303	-3	1.0
247	300	305	-5	1.7
236	300	292	8	2.7
210	290	261	29	10.0
220	290	273	17	5.9
220	290	273	17	5.9
227	290	281	9	3.1
192	230	239	-9	3.9
193	230	240	-10	4.3
191	230	238	-8	3.5
200	230	248	-18	7.8
184	230	229	1	.4
187	230	233	-3	1.3
186	230	232	-2	.9
178	230	222	8	3.5
174	230	217	13	5.6
199	230	247	-17	7.4
194	230	241	-11	4.8
190	230	236	-6	2.6
174	230	217	13	5.6
180	230	224	6	2.6
183	230	228	2	.9
183	230	228	2	.9
183	230	228	2	.9
181	230	226	4	1.7
187	230	233	-3	1.3
181	230	226	4	1.7
190	230	236	-6	2.6
185	230	230	0	0
194	230	241	-11	4.8
195	230	242	-12	5.2
205	230	255	-25	10.9
124	170	157	13	7.6
124	170	157	13	7.6
125	170	158	12	7.0
129	170	163	7	4.1
77	90	101	-11	12.2

[a] Average error is 4.9 percent.

TABLE IV. - NITROGEN TETROXIDE 70° F BUBBLE-POINT DATA - Concluded

Bubble-point pressure, psig	Actual 100 percent He saturation pressure, psig	Calculated 100 percent He saturation pressure, psig	Difference (actual - calculated)	Error,[a] percent
75	90	98	-8	8.9
74	90	97	-7	7.8
73	90	96	-6	6.7
72	90	95	-5	5.5
26	50	39	11	22.0

[a] Average error is 4.9 percent.

TABLE V. - NITROGEN TETROXIDE 80° F BUBBLE-POINT DATA

Bubble-point pressure, psig	Actual 100 percent He saturation pressure, psig	Calculated 100 percent He saturation pressure, psig	Difference (actual - calculated)	Error,[a] percent
60	90	96	-6	6.6
190	240	232	8	3.3
200	240	242	-2	.8
206	240	249	-9	3.7
200	240	242	-2	.8
205	240	248	-8	3.3
200	240	242	-2	.8
186	230	228	2	.9
188	230	230	0	0
203	230	246	-16	6.1
207	230	250	-20	8.7
65	90	101	-11	12.2
189	230	231	-1	.4
185	230	227	3	1.3
184	230	226	4	1.7
173	230	214	16	6.9
175	230	216	14	6.1
175	230	216	14	6.1
175	210	216	-6	2.8
133	180	172	8	4.4
134	180	173	7	3.9
132	180	171	9	5.0
128	180	167	13	7.2
70	100	106	-6	6.0
70	100	106	-6	6.0

[a] Average error is 4.2 percent.

TABLE VI. - NITROGEN TETROXIDE 90° F BUBBLE-POINT DATA

Bubble-point pressure, psig	Actual 100 percent He saturation pressure, psig	Calculated 100 percent He saturation pressure, psig	Difference (actual - calculated)	Error,[a] percent
278	290	312	-22	7.2
211	230	243	-13	5.6
207	230	239	-9	3.9
212	230	244	-14	6.1
204	230	236	-6	2.6
199	230	231	-1	.4
170	230	201	29	12.6
69	90	98	-8	8.9
181	230	212	18	7.8
160	210	191	19	9.0
172	210	203	7	3.3
167	210	198	12	5.7
172	210	203	7	3.3
163	210	194	16	7.6
163	210	194	16	7.6
181	210	212	-2	.9
180	210	211	-1	.5
185	210	216	-6	2.9
84	100	113	-13	13.0
78	100	106	-6	6.0
72	90	100	-10	12.2
70	90	99	-9	10.0

[a] Average error is 6.2 percent.

TABLE VII. - AEROZINE-50 BUBBLE-POINT DATA

Bubble-point pressure, psig	Actual 100 percent He saturation pressure, psig	Calculated 100 percent He saturation pressure, psig	Difference (actual - calculated)	Error,[a] percent
254	295	283	12	4.1
178	240	212	28	11.7
168	200	202	-2	1.0
125	170	162	8	4.7
254	295	283	12	4.1
186	240	219	21	8.7
171	200	205	-5	2.5
130	170	166	4	2.3
253	295	282	13	4.4
190	240	223	17	7.1
173	200	207	-7	3.5
135	170	171	-1	.6
250	295	280	15	5.1
192	240	225	15	6.2
170	190	204	-14	7.3
116	170	153	17	10.0
260	295	289	6	2.0
195	240	228	12	5.0
171	190	205	-15	7.9
149	170	184	-14	8.2
269	295	298	-3	1.0
173	230	207	23	10.0
172	190	206	-16	8.4
151	170	186	-16	9.4
270	295	299	-4	1.3
174	230	208	22	9.5
157	190	192	-2	1.0
148	170	183	-13	7.6
275	295	303	-8	2.7
184	230	217	13	5.6
162	190	197	-7	3.7
148	170	183	-13	7.6
280	295	308	-13	4.4
215	230	247	-17	7.4
162	190	197	-7	3.7
80	120	119	1	.8
173	230	207	23	10.0
175	230	209	21	9.1
147	180	182	-2	1.1

[a] Average error is 6.3 percent.

TABLE VII. - AEROZINE-50 BUBBLE-POINT DATA - Continued

Bubble-point pressure, psig	Actual 100 percent He saturation pressure, psig	Calculated 100 percent He saturation pressure, psig	Difference (actual - calculated)	Error,[a] percent
83	120	122	-2	1.7
172	190	206	-16	8.4
192	230	225	5	2.1
146	180	182	-2	1.1
87	120	126	-6	5.0
204	240	236	4	1.7
176	230	209	21	9.1
144	180	180	0	0
100	120	138	-18	15.0
208	240	240	0	0
191	230	224	6	2.6
150	180	185	-5	2.8
99	120	137	-17	14.0
181	240	215	25	10.4
182	230	216	14	6.1
155	180	190	-10	5.5
101	120	139	-19	15.8
186	240	219	21	8.7
182	230	215	15	6.5
153	180	188	-8	4.4
103	120	141	-21	17.5
191	240	224	16	6.7
182	230	215	15	6.5
153	180	188	-8	4.4
96	120	134	-14	11.7
147	170	182	-12	7.0
187	230	220	10	4.3
150	180	185	-5	2.8
89	120	128	-8	6.6
188	240	221	19	7.9
189	225	222	3	1.3
152	180	187	-7	3.9
89	120	128	-8	6.7
206	240	238	2	.8
192	225	225	0	0
152	180	187	-7	3.9
94	120	132	-12	10.0
210	240	242	-2	.8
182	225	215	10	4.4
148	180	183	-3	1.6

[a] Average error is 6.3 percent.

TABLE VII. - AEROZINE-50 BUBBLE-POINT - Continued

Bubble-point pressure, psig	Actual 100 percent He saturation pressure, psig	Calculated 100 percent He saturation pressure, psig	Difference (actual - calculated)	Error,[a] percent
95	120	133	-13	10.8
214	240	246	-6	2.5
171	225	205	20	8.9
151	180	186	-6	3.3
90	120	129	-9	7.5
229	240	260	-20	8.3
170	225	205	20	8.9
153	180	188	-8	4.4
91	120	130	-10	8.3
221	240	252	-12	2.0
157	220	192	28	12.7
157	180	192	-12	6.7
25	90	67	23	25.5
228	240	260	-20	8.3
163	220	198	2	.9
170	180	204	-24	13.3
30	90	72	18	20.0
212	240	244	-4	1.7
153	220	188	32	14.5
170	180	204	-24	13.3
30	90	72	18	20.0
212	240	244	-4	1.7
193	210	226	-16	7.6
169	180	203	-23	12.8
13	50	56	-6	12.0
214	240	246	-6	2.5
191	210	224	-14	6.6
149	180	184	-4	2.2
13	50	56	-6	12.0
228	240	259	-19	7.9
191	210	224	-14	6.7
160	180	195	-15	8.3
9	50	52	-2	4.0
222	240	253	-13	5.4
192	210	225	-15	7.1
152	180	187	-7	3.9
11	50	54	-4	8.0
221	240	252	-12	5.0
208	240	240	0	0
205	240	237	3	1.2

[a] Average error is 6.3 percent.

TABLE VII. - AEROZINE-50 BUBBLE-POINT DATA - Concluded

Bubble-point pressure, psig	Actual 100 percent He saturation pressure, psig	Calculated 100 percent He saturation pressure, psig	Difference (actual - calculated)	Error,[a] percent
208	240	240	0	0
205	240	237	3	1.2
205	240	237	3	1.2
190	210	223	-13	6.1
189	210	222	-12	5.7
174	210	208	2	.9
156	210	191	19	9.0
164	200	199	1	.5
168	200	202	-2	1.0
139	180	175	5	2.8
120	180	157	23	12.7
122	180	159	21	11.7
117	180	154	26	14.4
118	180	155	25	13.9
130	170	166	4	2.3

[a] Average error is 6.3 percent.

TABLE VIII. - NITROGEN TETROXIDE GAS-COLLECTION DATA

Total gas recovered, cc STP/g of propellant	Helium, percent	Helium, cc STP/g of propellant	Nitrogen, cc STP/g of propellant	Oxygen, cc STP/g of propellant	ACU conditions	
					Temperature, °F	Pressure, psig
0.285	98.8	0.282	0.003	0.002	55	234
.285	98.5	.281	.004	.000	55	236
.276	94.4	.261	.015	.000	62	228
.285	92.2	.262	.022	.001	62	228
.330	98.3	.325	.005	.000	78	234
.350	99.4	.348	.002	.000	86	232
.130	99.1	.130	.000	.000	95	92
.140	94.3	.129	.001	.000	70	120
.120	98.4	.120	.000	.000	70	120
.299	98.0	.293	.006	.000	69	237
.329	97.8	.322	.007	.000	69	237
.318	98.2	.312	.005	.000	69	237
.358	98.7	.353	.005	.000	102	235
.319	95.4	.304	.014	.000	69	234
.294	98.4	.289	.005	.000	46	235
.277	99.1	.275	.002	.002	46	235
.268	98.8	.265	.003	.000	46	235

TABLE IX. - AEROZINE-50 GAS-COLLECTION DATA

Total gas recovered, cc STP/g of propellant	Helium, percent	Helium, cc STP/g of propellant	Nitrogen, cc STP/g of propellant	Oxygen, cc STP/g of propellant	ACU conditions	
					Temperature, °F	Pressures, psig
0.119	92.2	0.110	0.008	0.002	101	234
.132	93.0	.123	.008	.001	101	234
.098	93.9	.092	.005	.001	68	233
.115	91.3	.105	.001	.009	68	233
.093	91.2	.085	.007	.001	63	235
.082	91.1	.075	.006	.001	63	235
.093	91.6	.085	.007	.001	80	233
.092	95.9	.088	.003	.000	91	150
.120	94.7	.120	.000	.000	86	240
.140	98.6	.140	.000	.000	92	241
.122	91.1	.111	.010	.001	85	150
.105	98.1	.103	.002	.000	86	150
.116	99.0	.115	.001	.000	87	225
.094	93.6	.088	.006	.000	87	150
.120	99.3	.120	.000	.000	87	226
.120	95.0	.115	.005	.000	87	226
.068	98.2	.067	.001	.000	70	180
.067	99.0	.066	.001	.000	70	180
.130	90.9	.118	.010	.002	60	235
.110	95.9	.106	.004	.000	60	235

TABLE X. - NITROGEN TETROXIDE HELIUM SATURATION DATA — RESULTS OF GAS-COLLECTION DATA[a]

Temperature, °F	Pressure, psig	Measured He concentration, cc STP/g of propellant	Calculated He concentration, cc STP/g of propellant	Difference[b] (measured - calculated), cc STP/g of propellant	Error,[c] percent
55	234	0.282	0.281	0.001	0.3
55	236	.281	.284	-.003	1.1
62	228	.261	.283	-.022	8.4
62	228	.262	.283	-.021	8.0
78	234	.325	.319	.006	1.8
86	232	.348	.329	.019	5.4
95	92	.130	.124	.006	4.6
70	120	.129	.127	.002	1.5
70	120	.120	.127	-.007	5.8
69	237	.293	.309	-.016	5.5
69	237	.322	.309	.013	4.0
69	237	.312	.309	.003	1.0
102	235	.353	.360	-.007	2.0
69	234	.304	.304	0	0
46	235	.289	.267	.022	7.6
46	235	.275	.267	.008	2.9
46	235	.265	.267	-.002	.7

[a] Helium content = -0.1771 + (0.001568 × pressure) + (0.001656 × temperature) where the helium content is in cubic centimeters STP per gram, pressure is in pounds per square inch gage, and temperature is in degrees Fahrenheit.

[b] Average value is 0.009, 1σ value is 0.012, and 2σ value is 0.024.

[c] Average error is 4 percent.

TABLE XI. - AEROZINE-50 HELIUM SATURATION DATA — RESULTS OF GAS-COLLECTION DATA[a]

Temperature, °F	Pressure, psig	Measured He concentration, cc STP/g of propellant	Calculated He concentration, cc STP/g of propellant	Difference[b] (measured - calculated), cc STP/g of propellant	Error,[c] percent
101	234	0.110	0.126	-0.016	14.5
101	234	.123	.126	-.003	2.4
68	233	.092	.097	-.005	5.4
68	233	.105	.097	.008	7.6
63	235	.085	.094	-.009	10.6
63	235	.075	.094	-.019	25.3
80	233	.085	.108	-.023	27.0
91	151	.088	.095	-.007	7.9
86	240	.120	.115	.005	4.2
92	241	.140	.120	.020	14.3
85	150	.110	.089	.022	19.8
86	150	.103	.090	.013	12.6
87	225	.115	.112	.003	2.6
87	150	.088	.091	-.003	3.4
87	226	.120	.112	.008	6.7
87	226	.115	.112	.003	2.6
70	180	.067	.085	-.018	26.9
70	180	.066	.085	-.019	28.8
60	235	.118	.091	.027	22.9
60	235	.106	.091	.015	14.1

[a] Helium content = -0.0257 + (0.000275 × pressure) + (0.000869 × temperature) where the helium content is in cubic centimeters STP per gram, pressure is in pounds per square inch gage, and temperature is in degrees Fahrenheit.

[b] Average value is 0.012, 1σ value is 0.014, and 2σ value is 0.028.

[c] Average error is 13 percent.

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