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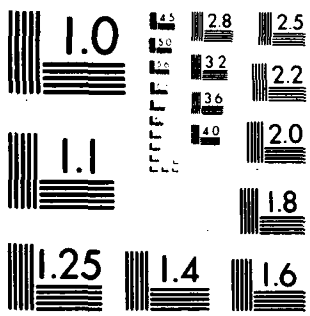

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PROPELLING CHARGE CONTAINER LEAKAGE INSPECTION

MICHAEL J. GOES

DECEMBER 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

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A general overview of the parameters associated with propelling charge container leakage inspection is presented. Empirical methods and computer techniques for determining parameter values and equipment settings were developed and verified by laboratory testing. The equipment requirements and setup procedure for an automated LAP line application are outlined, and the effects of manufacturing variations are discussed. The requirements for acceptance standards are addressed, and considerations for additional and future applications are presented.

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INTRODUCTION

The objective of this report is to provide a basic understanding of propelling charge container leakage inspection, with particular emphasis on automated applications.

The parameters affecting the inspection process are addressed, and methods are developed for determining the parameter values for any given specific set of test conditions. The equipment requirements and equipment setting procedures are examined for a prototype automated inspection station, and consideration is provided for other possible applications, both present and future. The process of setting acceptance standards that are realistic, and which will provide uniformity in test results, for the variety of container-charge combinations to be tested is also addressed.

BACKGROUND

Propelling charge container leakage inspection is employed in both the manufacture of propelling charge containers and the packaging of assembled separate loading propelling charges. The purpose of this quality control inspection technique is to prevent the degradation of propelling charge performance due to the absorption of moisture from the surrounding environment.

Presently adopted inspection methods include a bubble test for empty containers and a pressure decay test for loaded containers. The bubble test is conducted by immersing the empty containers in a water bath, then checking for bubbles as an indication of leakage. It is essentially the same method as employed by a service station attendant checking a tire or inner tube for leaks. The pressure decay test consists of pressurizing a loaded container with air, then monitoring any pressure loss over a set period of time. In the past this test has been conducted manually, with an inspection station operator using gages or manometers as the pressure monitoring devices. The Production Base Modernization program has dictated the necessity of high production rate, automated, Load Assemble and Pack (LAP) lines for propelling charges, which has in turn resulted in the necessity of automatic inspection techniques.

One such automated LAP line, a prototype line constructed by the GATEX Corporation, employed automated electronic leakage detection equipment as a part of the packout operation. The principles involved and lessons learned from this previous application are currently being applied in a prototype automated LAP line, for 155-mm and 8-inch center core ignited propelling charges, being constructed at the MRC Corporation, Hunt Valley, Maryland.

While much of the information contained within this report is directed toward the MRC application, the principles, techniques, and equipment considerations are applicable to leakage detection inspection in general.

PRESSURE DECAY LEAK TEST

The pressure decay leak test consists basically of charging (pressurizing) the loaded propelling charge containers with air to a predetermined pressure, allowing the pressure to stabilize, then monitoring any pressure loss over a given period of time. Any pressure loss is then compared with acceptance standards to determine whether or not the container passes the inspection. This section deals with the specific parameters involved in leakage inspection and presents methods for determining the values of these parameters.

Container Pressurization

The maximum allowable container pressure is limited by either the full-scale value of the leak test pressure monitoring device or the amount which a container may be pressurized without creating a leak through the lid seal, whichever is smaller. In tests conducted by Masly (ref 1), seal leakage was induced at a pressure as low as 34.47 kPa (5 psig), and it was recommended that container pressures be kept below this value.

The pressure of the filled containers is dependent upon four parameters: ullage to be filled, flow rate into the container, fill time, and adiabatic heating effects of compression (pressurization).

Ullage

Ullage, defined as the free air space within the loaded propelling charge containers, is dependent upon the empty volume of the packaging container, and the volume required for the propellant, igniter, flash reducer, and packaging materials.

While variation in ullage will exist from container to container due to container dimensional variations and the quantity and type of packaging materials, a good estimation of the maximum expected ullage can be easily determined. This estimation is accomplished by multiplying the weights of propellant, igniter, and flash reducer by their respective specific volumes, adding the individual volumes resulting from these calculations, then subtracting this sum from the largest calculated value of the empty packaging container volume. Table 1 gives the calculated maximum ullage for a number of propelling charge container-charge combinations.

An alternate method of determining the ullage, hereafter referred to as the pressure-volume method, was used in computing the ullage data reported in reference 1. This method consists of venting a container of known volume, which is greater than or approximately equal to the expected ullage, at a given recorded initial pressure, into the unknown volume. After the pressure and temperature has equalized in both containers, the unknown volume may be determined using the initial volume, initial pressure, and final pressure in the ideal gas relationships.

As expected, and as illustrated in the reported data (ref 1) which is included as appendix A, the calculated maximum ullage exceeds the measured values. Although the actual measured ullage varies as previously mentioned, the calculated values provide a convenient initial condition on which to base the other associated leak test parameters.

Flow Rate and Fill Time

The mass flow rate into the container is essentially a function of upstream and downstream pressures, the gas temperature, the associated gas parameters (e.g., gas constant and ratio of specific heats), and the effects of flow restrictions such as valves, lengths of tubing, and induced changes to flow direction.

The effects of the various flow restrictions within a typical system, such as a container pressurization circuit shown in figure 1, may be combined and classified as a single equivalent orifice. The equivalent orifice is defined as a single orifice which limits the mass flow rate to a value corresponding to the mass flow rate through the actual system. The effects of equivalent orifice size with respect to required fill time are illustrated in figure 2. As illustrated, the time required to fill a 24.2 L (1477 in.^{3}) container to a pressure of 20.68 kPa (3.0 psig) from a constant pres-

Table 1. Calculated ullage data

Container	M13A2	M14A2	M18A2	M19A2	PA37A1	PA37A1	PA66	PA66	PA68
Volume L (in.^{3})	11.86 (724)	11.93 (728)	13.88 (847)	22.76 (1389)	17.88 (1091)	17.88 (1091)	35.4 (2163)	35.45 (2163)	21.14 (1290)
Charge	M4A2	M3A1	M1	M2	M119A1	M119A2	M188	M188A1	M203
Prop[a] type:	M1 MP	M1 SP	M1 SP	M1 MP	M6 MP	M6 MP	M30A2	M31A1	M30A1
Sp vol $m^3/kg \times 10^{-4}$ (in.^{3}/lb)	6.35 (17.6)	6.35 (17.6)	6.35 (17.6)	6.35 (17.6)	6.27 (17.4)	6.27 (17.4)	6.35 (17.6)	6.20 (17.2)	6.35 (17.6)
Weight kg (lb)	5.95 (13.1)	4.81 (10.6)	5.95 (13.1)	12.71 (28)	9.49 (20.9)	9.26 (20.4)	17.25 (38)	22.25 (40)	11.80 (26)
Equiv vol L (in.^{3})	3.78 (230.6)	3.04 (185.6)	3.78 (230.6)	8.08 (492.8)	5.96 (363.7)	5.82 (355)	10.96 (668.8)	13.52 (824.8)	7.50 (457.6)
Igniter[b] type:	CBI	CBI	BP-CL1	BP-CL1	CBI	BP-CL1	BP-CL1	BP CL1	BP-CL1
Sp vol $m^3/kg \times 10^{-4}$ (in.^{3}/lb)	6.20 (17.2)	6.20 (17.2)	5.66 (15.7)	5.66 (15.7)	6.20 (17.2)	5.66 (15.7)	5.66 (15.7)	5.66 (15.7)	5.66 (15.7)
Weight kg (lb)	0.10 (0.22)	0.20 (0.44)	0.14 (0.31)	0.14 (0.31)	0.13 (0.28)	0.13 (0.28)	0.17 (0.38)	0.17 (0.38)	0.14 (0.31)
Equiv vol L (in.^{3})	0.06 (3.8)	0.12 (7.6)	0.08 (4.9)	0.08 (4.9)	0.08 (4.8)	0.07 (4.4)	0.10 (6.0)	0.10 (6.0)	0.08 (4.9)
Flash reducer:	K_2SO_4	K_2SO_4	None	None	K_2SO_4 BP-CL1	K_2SO_4	K_2SO_4 BP-CL1	None	K_2SO_4
Sp vol $m^3/kg \times 10^{-4}$ in.^{3}/lb	3.75 (10.4)	3.75 (10.4)	N/A	N/A	3.75 (10.4) 5.66 (15.7)	3.75 (10.4)	3.75 (10.4) 5.66 (15.7)	N/A	3.75 (10.4)
Weight kg (lb)	0.03 (0.06)	0.23 (0.5)	N/A	N/A	0.34 (.75) 0.11 (.25)	0.45 (1.0)	0.34 (0.75) 0.11 (0.25)	N/A	0.45 (1.0)
Equiv vol L (in.^{3})	0.01 (0.6	0.08 (5.2)	N/A	N/A	0.19 (11.7)	0.17 (10.4)	0.19 (11.7)	N/A	0.17 (10.4)
Total equiv vol L (in.^{3})	3.85 (235)	3.24 (198)	3.86 (236)	8.16 (498)	6.23 (388)	5.07 (370)	11.25 (686)	13.62 (849)	7.75 (473)
Max expected ullage L (in.^{3})	8.01 (489)	8.69 (530)	10.01 (611)	14.60 (891)	11.65 (711)	11.81 (721)	24.2 (1477)	21.53 (1314)	13.4 (817)

[a] MP - multiperforated; SP - single perforated.
[b] CBI = clean burning igniter; BP-CL1 - black powder class 1.

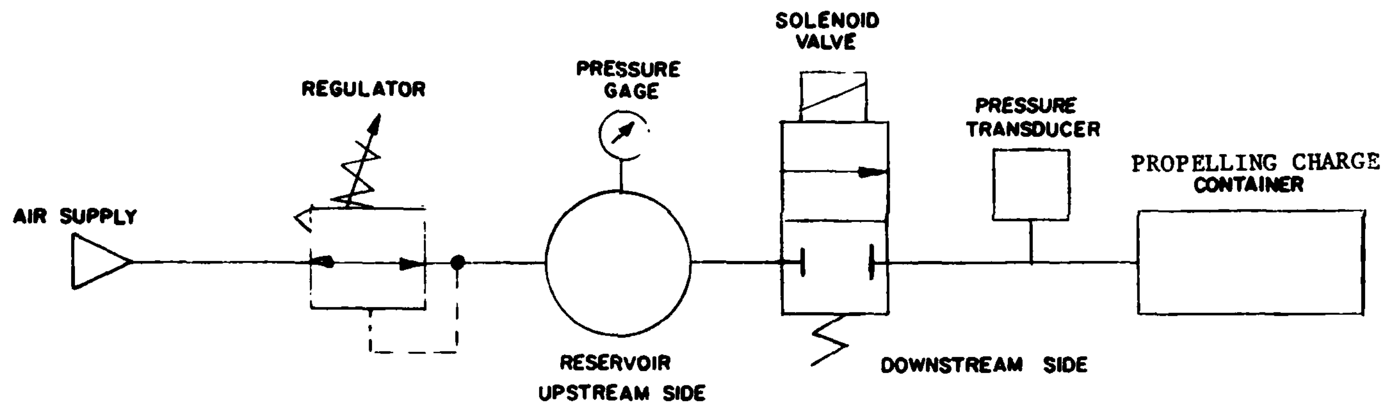


Figure 1. Basic container pressurization circuit

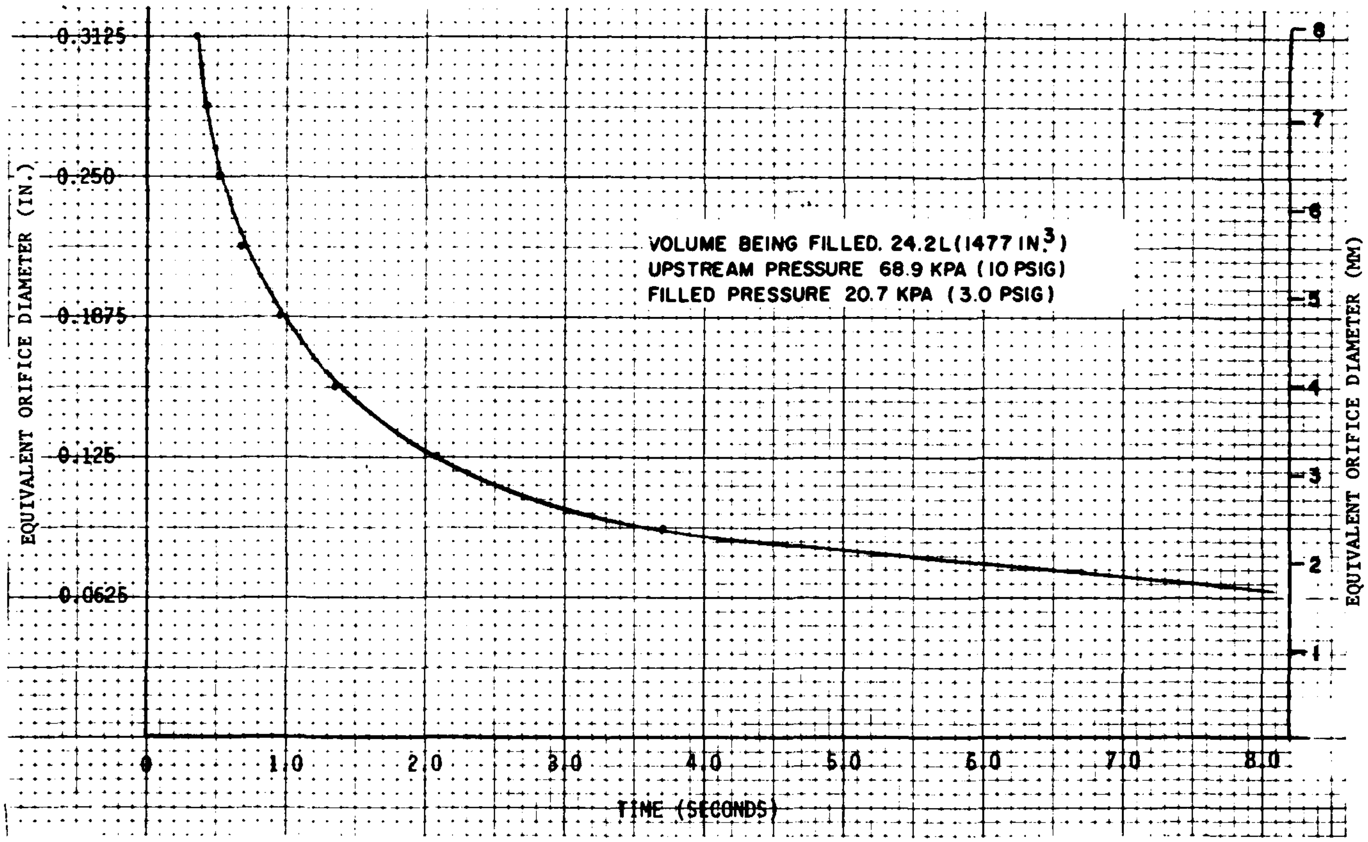


Figure 2. Fill time vs equivalent orifice diameter

sure source increases exponentially as the equivalent orifice diameter decreases. Increasing the supply pressure (upstream pressure) will reduce the fill time as illustrated by figure 3; however, a comparison of figures 2 and 3 shows that fill time is affected to a greater extent by a change of the equivalent orifice diameter than by an increase in the upstream pressure. The point of this comparison is to illustrate the necessity for keeping flow restrictions to a minimum, thus keeping the equivalent orifice diameter for the system as large as possible. Ideally the hole in the container vent plug hole should be the limiting orifice.

The equivalent orifice diameter of any container pressurization circuit may be approximated using the fluid dynamic relationships for an ideal gas and the following procedure. With reference to figure 4, a valve is added to the basic pressurization circuit upstream of the reservoir. The reservoir is pressurized, and allowed to stabilize; then the upstream valve is closed and the pressure recorded. The solenoid valve is then opened for a specified length of time, allowing the reservoir pressure to vent to atmosphere through the associated circuitry and the container lid vent hole. After the solenoid valve has closed, and the pressure in the reservoir has stabilized (pressure remains constant), the final reservoir pressure is recorded. With the initial and final pressure, the vent time, and the reservoir volume known, the equivalent orifice diameter may be computed. The mathematics for determining the equivalent orifice are presented in a computer program included in appendix B.

The test method for determining equivalent orifice diameter was demonstrated experimentally using an empty M19A1 container as the reservoir. By use of the pressure-volume method previously described, the volume of this container was determined to be 22.6 L (1380 in.^{3}). The laboratory pressurization circuit which was used is illustrated schematically in figure 5. First the line connecting the reservoir and test container was disconnected just downstream of the restricting orifice. The reservoir was then pressurized to 68.9 kPa (10 psig) and allowed to stabilize, and the reservoir fill valve was closed. The container fill valve was opened for two seconds, allowing the reservoir pressure to vent to atmosphere. After stabilization, the reservoir pressure was slightly greater than 55.2 kPa (8 psig) as illustrated by figure 6. By use of the previously referenced computer program, equivalent orifice diameter vs final container pressure data was generated for the test parameters. The test results as compared with a plot of the computed data (fig. 7) indicate that the equivalent orifice diameter of the circuit was approximately 2.67 mm (0.105 in.).

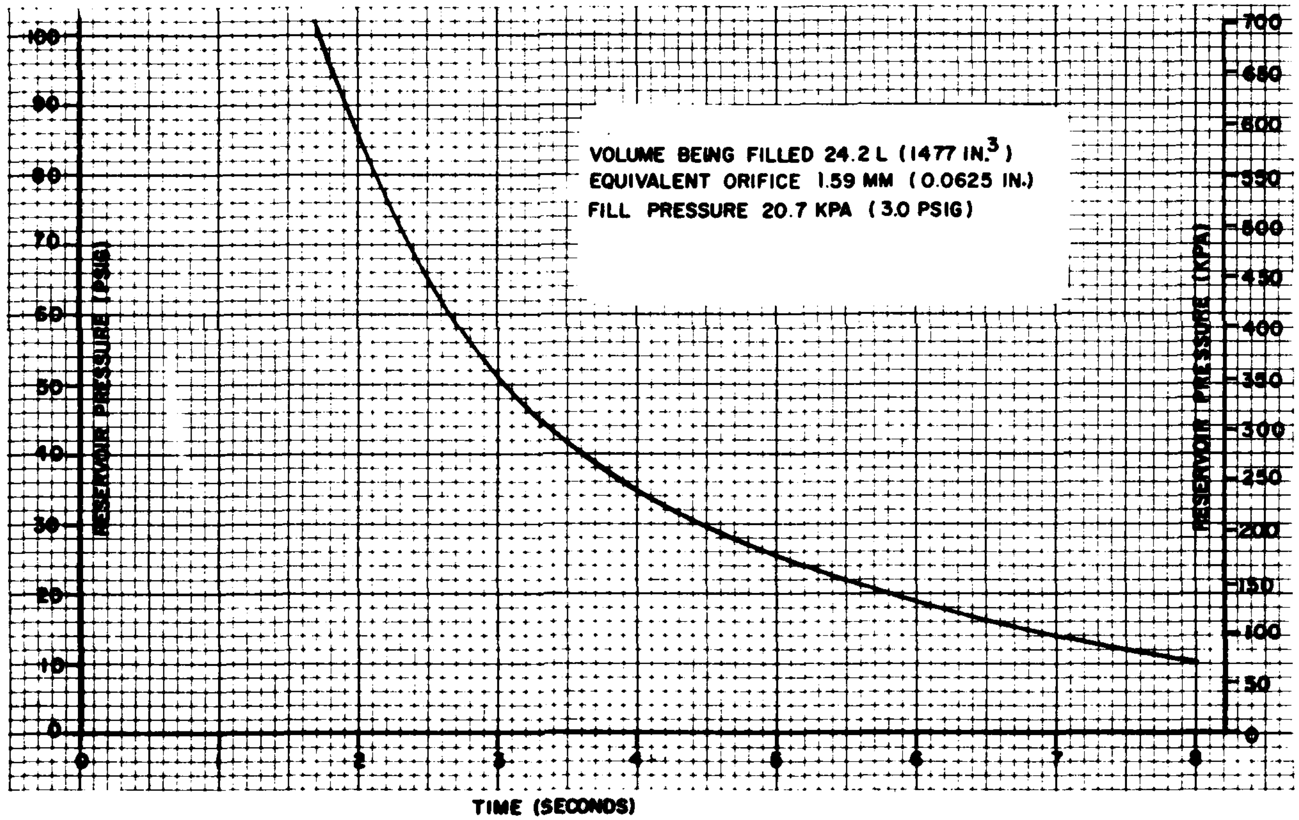


Figure 3. Fill time vs reservoir (upstream) pressure

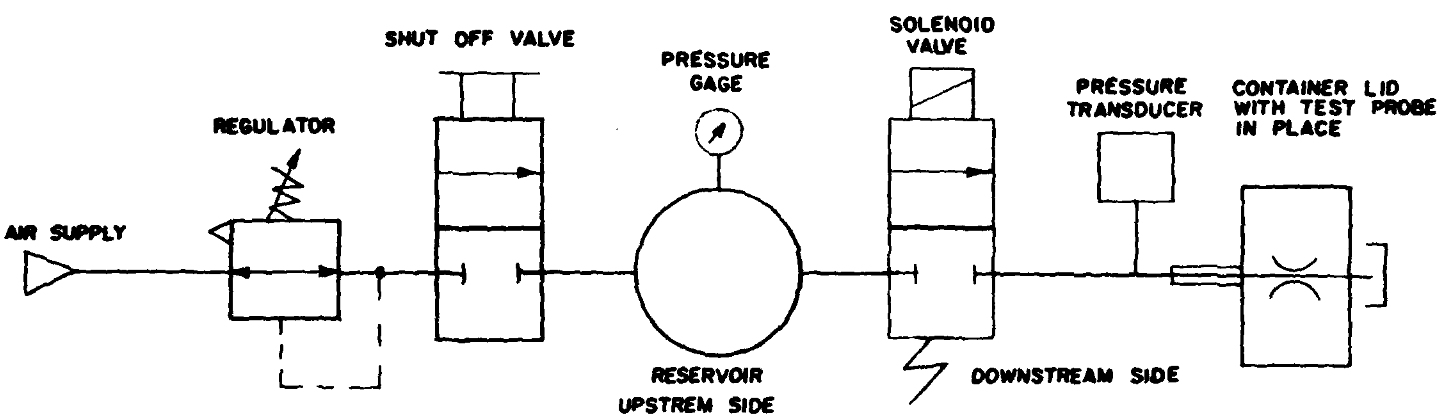
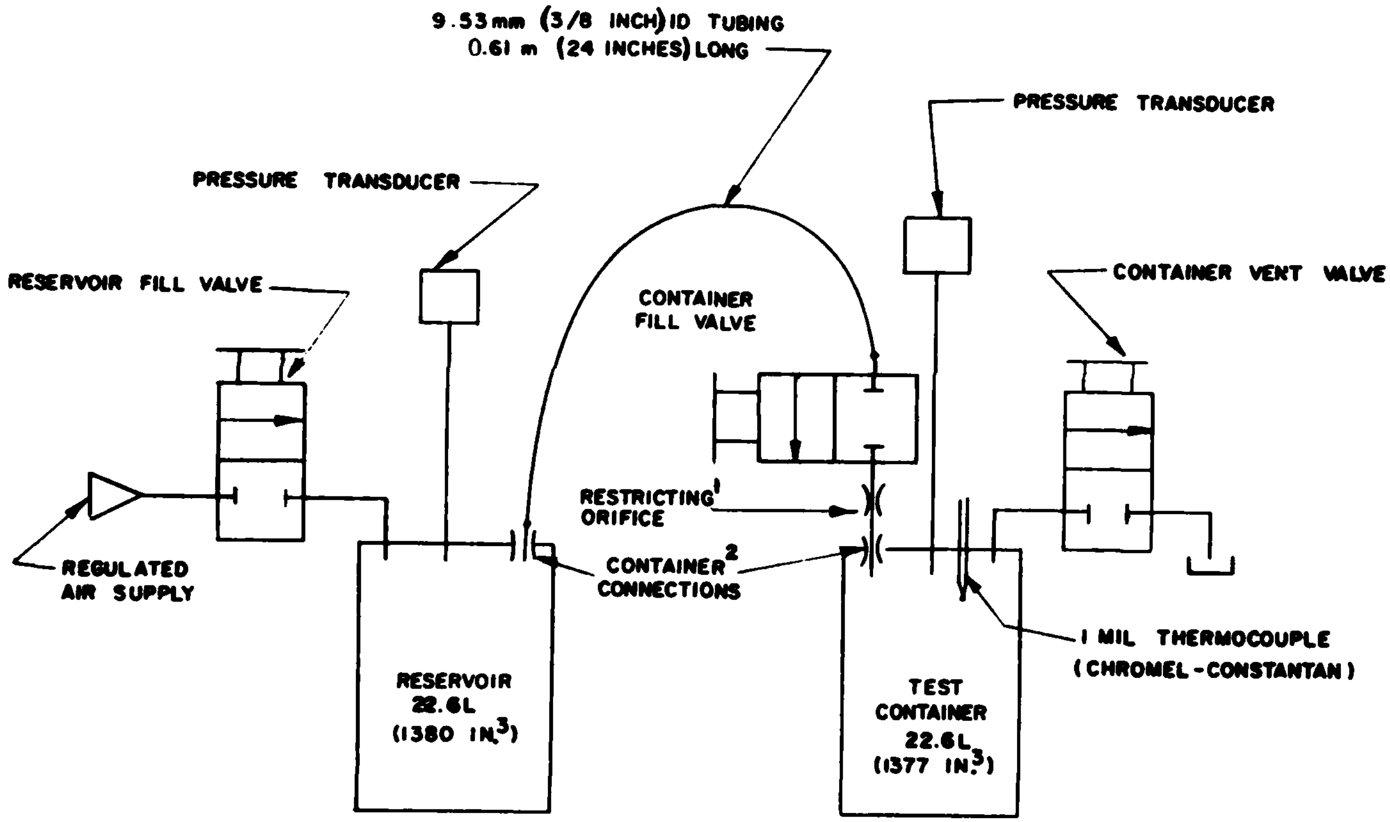


Figure 4. Modified container pressurization circuit



1. FITTING DRILLED WITH # 36 DRILL (0.106 inches).
2. 1/4 INCH PIPE NIPLES DRILLED TO 25/64 INCH ID.

Figure 5. Laboratory test setup

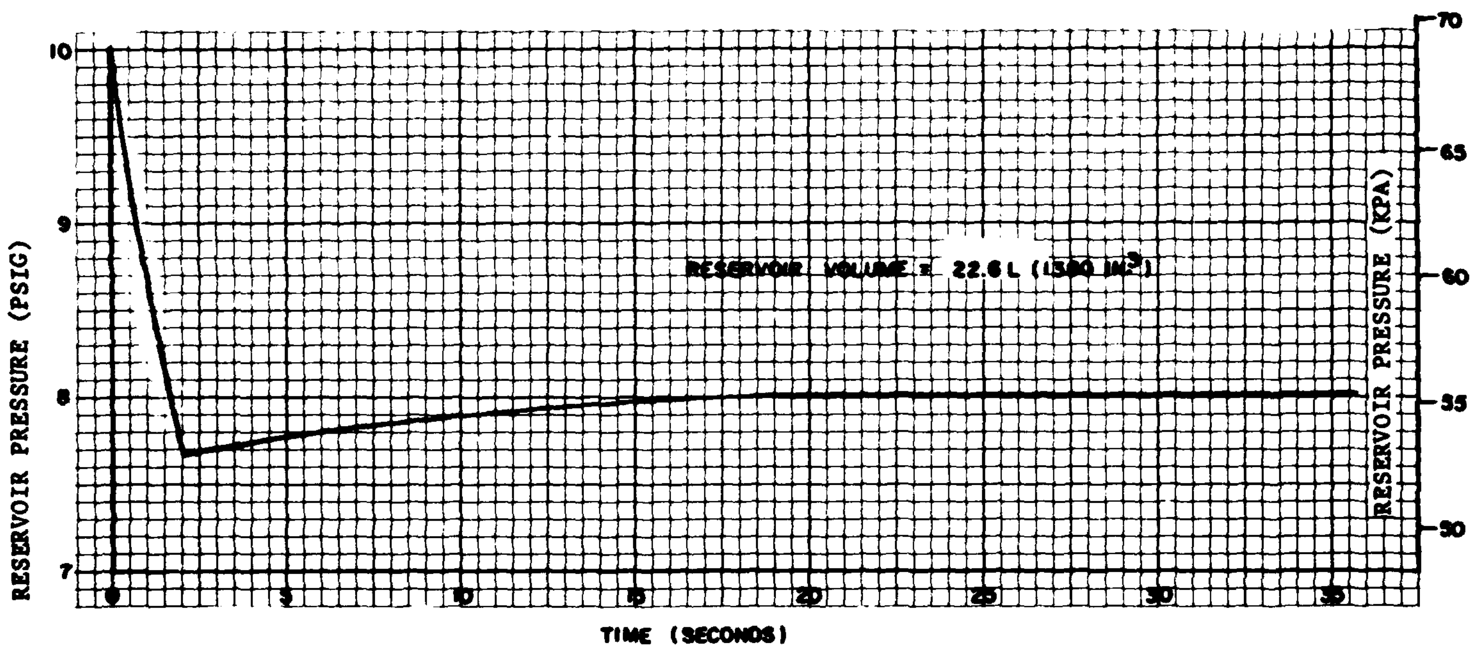


Figure 6. Reservoir pressure vs time—empirical data

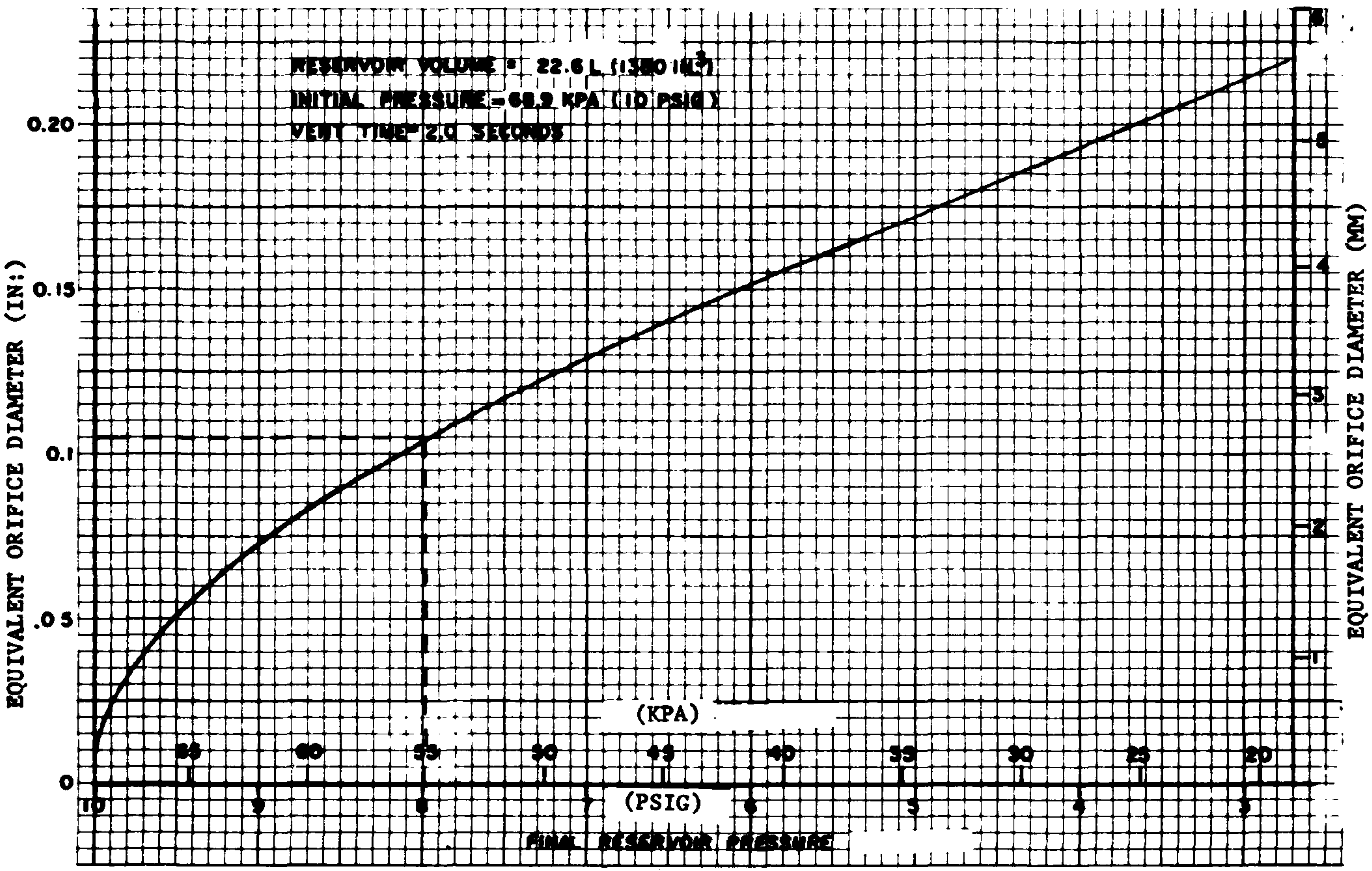


Figure 7. Final reservoir pressure vs equivalent orifice diameter

On automated lines the time allowed for leakage inspection is limited. In pressure decay leak tests the results are largely dependent on the pressure decay monitoring time. With this fact in mind it is desirable to fill the containers as rapidly as possible without creating unmanageable adiabatic heating effects.

Once the equivalent orifice size has been determined for the actual pressurization circuit arrangement, reservoir pressure settings for filling containers with various ullages within the required fill time may be computed. To provide empirical data with which to check the predicted reservoir pressure, the reservoir of figure 5 was pressurized to 136.5 kPa (19.8 psig) and vented into the test container for approximately 1.6 seconds. The pressure-time data (upper curve, fig. 8) was then checked against a plot of reservoir pressures computed for equivalent orifice sizes in the range of 2.54 to 2.79 mm (0.100 to 0.110 in.) (fig. 9). A comparison of the data presented in figures 8 and 9 illustrates that there is a close correlation between the predicted values and the empirical data. The computer program used to calculate the predicted values is included in appendix B.

Adiabatic Heating Effects

The process of filling the containers with air creates an increase in the temperature of the air being compressed within the container. This phenomenon, the adiabatic heating of compression, affects the final filled pressure of the container being tested. Once the container fill valve is closed, the pressure within the container begins to decrease. This pressure decay, due to a gradual decrease in the temperature of the air within the container caused by heat transfer through the container to the surrounding atmosphere, continues until the temperature within the container and the surrounding atmosphere are equal. With reference to figure 8, the effects of adiabatic heating are readily apparent. From the time at which the valve between the reservoir and container was closed, the time required to stabilize exceeds the time scale on the illustration and was, in fact, on the order of 60 seconds.

The maximum temperature generated as a result of adiabatic heating is dependent upon the fill time and the filled pressure of the container. Although the maximum temperature generated in the example illustrated by figure 8 was slightly less than 38.9°C (93°F), temperatures as high as 43°C (110°F) have been generated with the laboratory apparatus. Due to the rapid temperature changes which occur during container pressurization, care should be taken to avoid such a test on containers filled with materials which are sensitive to sudden temperature changes.

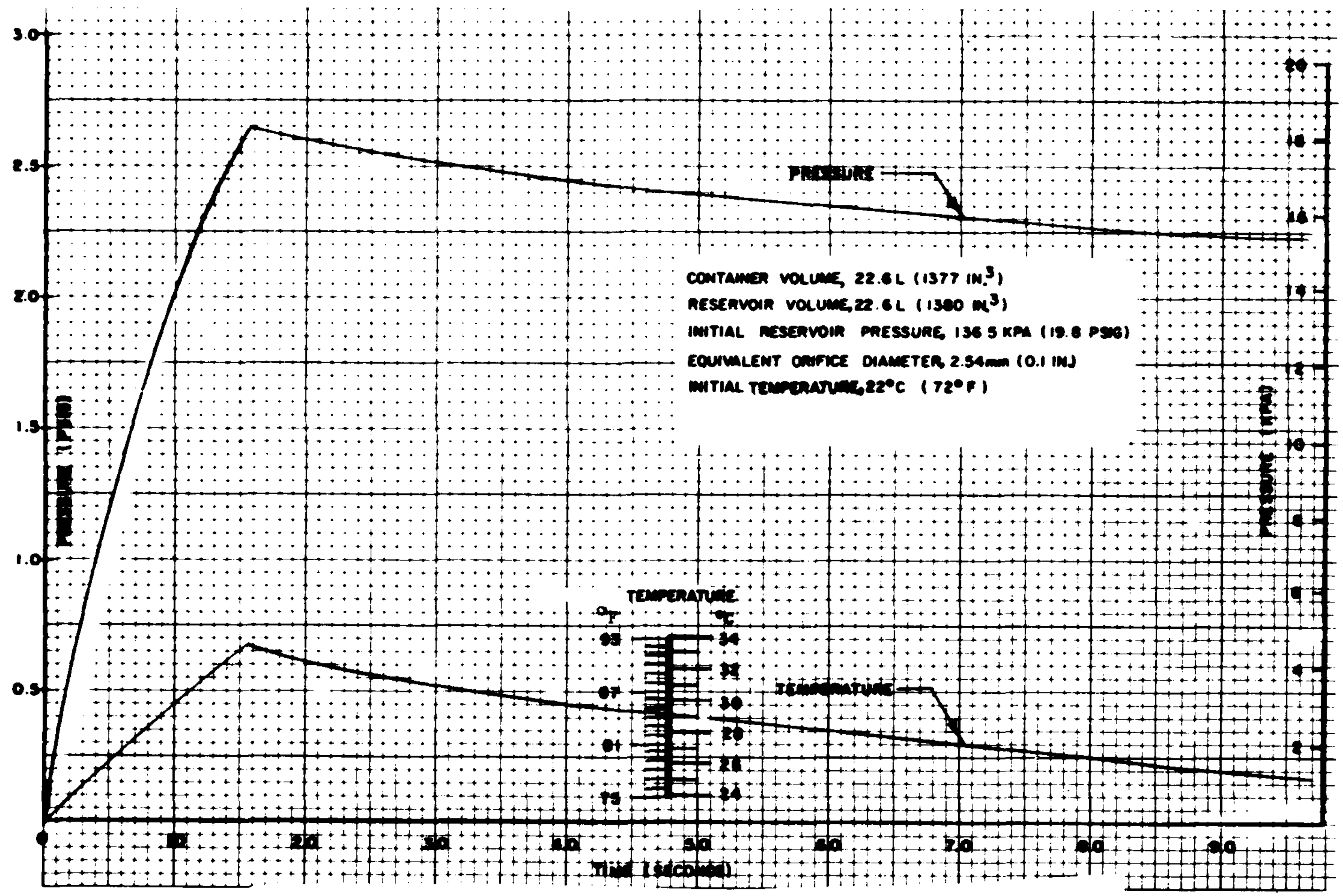


Figure 8. Pressure and temperature vs time--empirical data

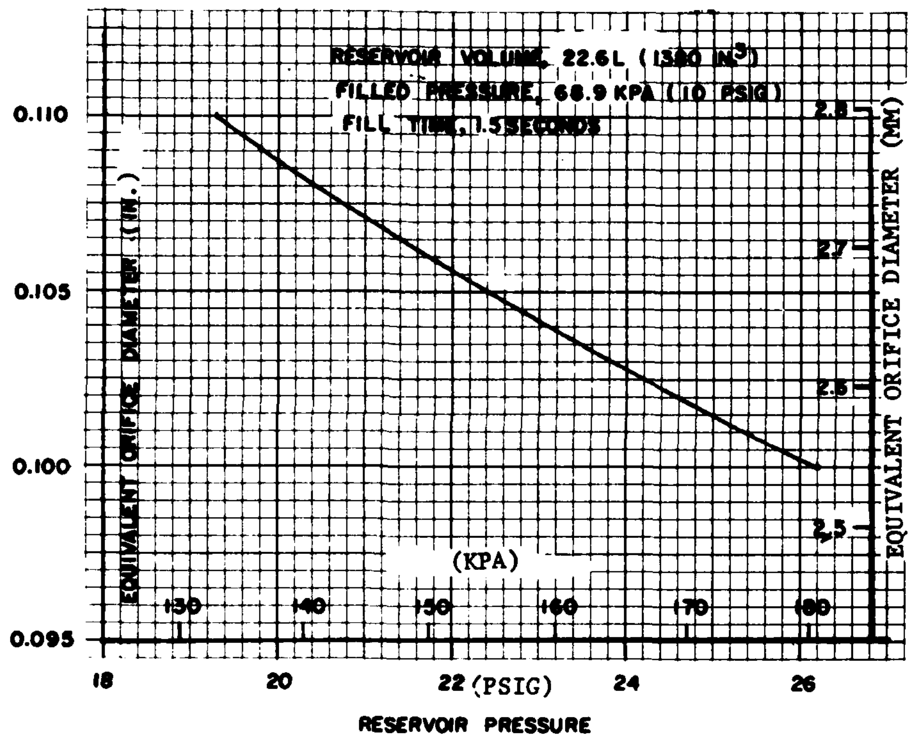


Figure 9. Reservoir pressure vs equivalent orifice diameter

Pressure Stabilization

Pressure stabilization consists of a waiting period during which the effects of adiabatic heating on container pressure are reduced. During this period heat transfer through the container to atmosphere cools the gas and lowers the container pressure. Given a sufficient stabilization period, the effects of an adiabatic heating would be completely eliminated; however, as would normally be the case on an automated line, the length of time for complete stabilization may exceed the total test time. In a situation such as this, the stabilization period is used to reduce the expected pressure drop during the remainder of the test period to a range which can be compensated by the test equipment.

Pressure Decay Monitoring

Once the subject container has been pressurized and the pressure has stabilized, the pressure decay leak test begins. During the pressure decay period the pressure is monitored for a predetermined time interval. At the end of this interval any pressure loss is compared with acceptance standards for the type of container-charge combination being tested and the container is either accepted or rejected.

For the purpose of this report, container leaks will be expressed in terms of equivalent orifice diameter. A container leak may be due to a number of small holes, cracks, or other such flaws within the container; however, for any given pressure drop over a given period of time, the use of an equivalent orifice size provides the user with a relatable physical quantity on which to judge the results.

Figure 10 presents the predicted differential pressure or pressure drop for the various container ullages computed as a function of equivalent orifice size. In all cases the initial test pressure[1] was assumed to be 18.6 kPa (2.7 psig) and the test time was set at 5 seconds. As would be expected, as the ullage increases, the pressure drop over the specified time decreases for any specified orifice size. Consider, for example, an M13A2 con

[1] Test pressure is the container pressure at the beginning of the pressure decay period.

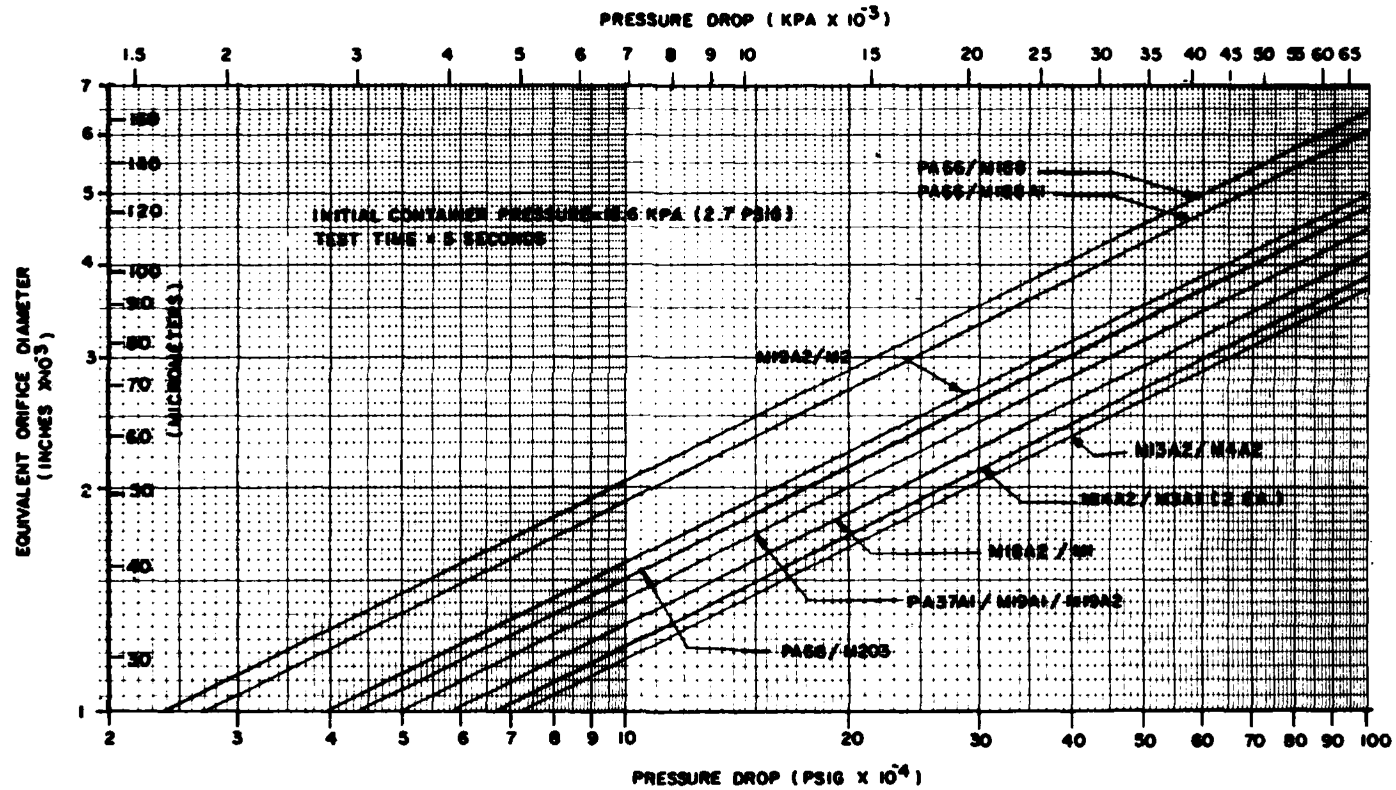


Figure 10. Pressure drop vs equivalent orifice diameter

tainer with an M4A2 charge and a PA66 container with the M188 charge. For a 51 micrometer (0.002 in.) equivalent orifice the predicted pressure drop is approximately 0.020 kPa (0.00295 psig) for the M13A2 container, whereas it is approximately 0.0065 kPa (0.00095 psig) for the PA66 container. The conclusion is that for a specified test time, as the ullage increases, the requirement for equipment sensitivity also increases.

Acceptance Criteria

For a given set of test conditions (container-charge combination, initial pressure, test time, etc.) the pressure loss which will result in a rejected container is determined by the acceptance standard for the given test conditions. The minimum detectable pressure loss is determined by the sensitivity of the test equipment, the test period duration, the container-charge ullage, and the initial test pressure.

The results of previous work on container leak rates reported by Masly (ref 1) are presented in figure 11. This illustration shows that equivalent orifice diameters greater than 12.7 micrometers (0.0005 in.) were detected in approximately 81% of the tested containers. Although these containers had been peviously accepted by the various loading facilities, the reason that this leakage was detected in these tests but was not detected at the loading facility is due to the manner in which the referenced leakage tests were conducted. The tests in which the reported leakage was detected were conducted using sensitive electronic equipment with a 100-second pressure decay time. In comparison, the leakage standard for manual tests states that no detectable leakage should exist during a 15-second interval with the container at 20.68 kPa (3.0 psig). If the gages used in a manual test at a loading facility had minor graduations of 0.69 kPa (0.1 psig) (assuming that an operator could read the gages to half that value), the smallest equivalent orifice diameter which could be detected, as illustrated by table 2, would be on the order of 127 micrometers (0.005 in.) for the smallest container-charge ullage, and 203 micrometers (0.008 in.) for the largest container-charge ullage. With reference to figure 11, over 97% of the electronically tested containers qualified within the acceptance standard specified for the manual test.

During the course of the referenced testing it was noted that the majority of the containers exhibited a residual pressure which was released when the vent plugs were removed. This pressure, a partial pressure caused by the residual ethyl ether drying agent,

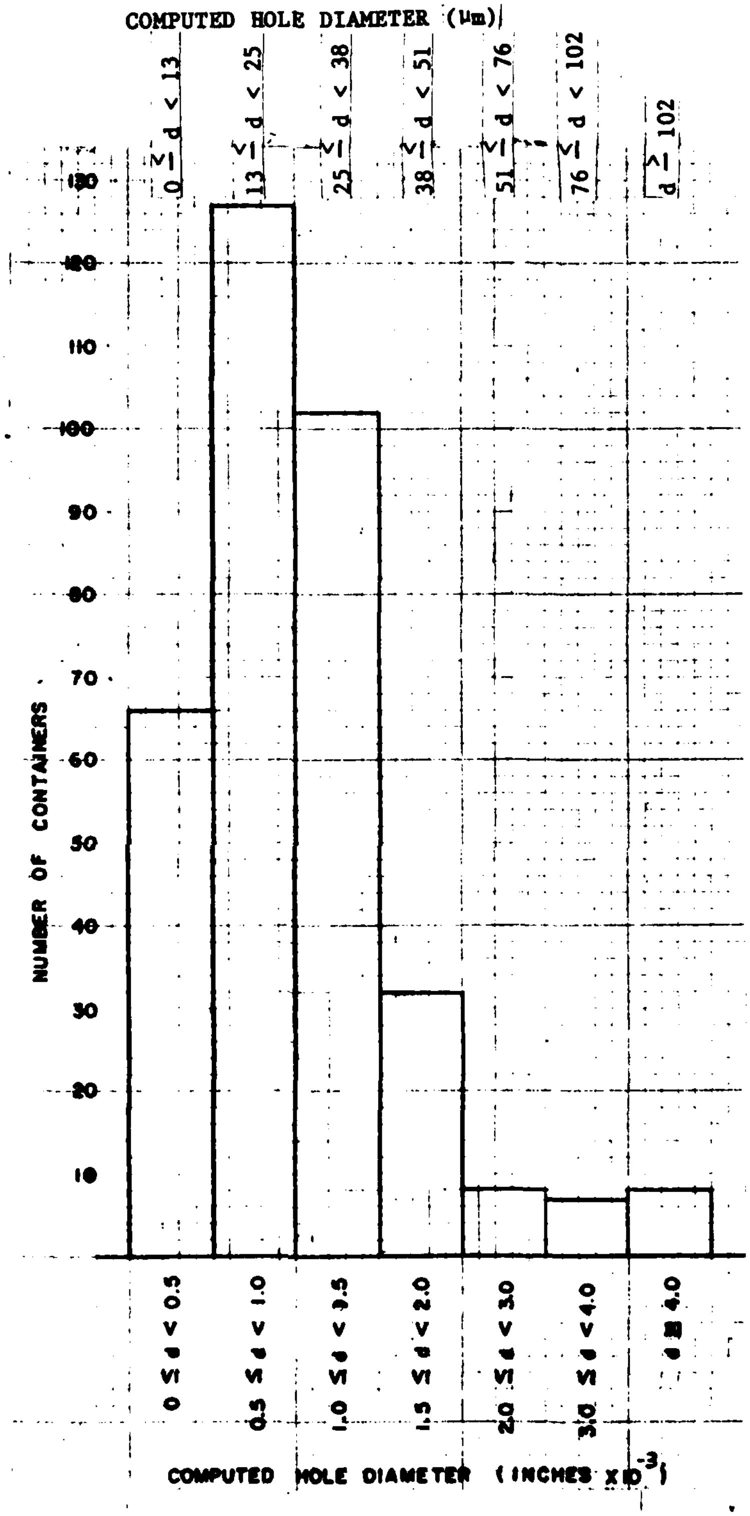


Figure 11. Hole diameter data

Table 2. Equivalent orifice diameter data--manual test*

Container: M13A1 Charge: M4A2-- Ullage volume: 8.0 L (489 cu in.)				Container: PA66 Charge: M188-- Ullage volume: 24.2 L (1477 cu in.)			
Orifice Diameter		Pressure Loss		Orifice diameter		Pressure Loss	
(μm)	(in.)	(kPa)	(psig)	(μm)	(in.)	(kPa)	(psig)
25	0.001	0.0160	0.00232	25	0.001	0.0053	0.00077
51	0.002	0.0639	0.00927	51	0.002	0.0212	0.00307
76	0.003	0.1437	0.02084	76	0.003	0.0476	0.00691
102	0.004	0.2551	0.03700	102	0.004	0.0846	0.01228
127	0.005	0.3979	0.05772	127	0.005	0.1322	0.01917
152	0.006	0.5718	0.08295	152	0.006	0.1902	0.2759
178	0.007	0.7764	0.11262	178	0.007	0.2586	0.03752
203	0.008	1.0112	0.14668	203	0.008	0.3375	0.04896
229	0.009	1.2757	0.18505	229	0.009	0.4267	0.06189
254	0.010	1.5693	0.22763	254	0.010	0.5262	0.07632

* Initial test pressure = 20.7 kPa (3.0 psig); pressure decay test time = 15.0 seconds.

was not readily evident in those containers with equivalent orifice diameters greater than 76 micrometers (0.003 in.). Since the record of propellant performance in the past has been satisfactory, it is suggested that an equivalent orifice diameter of 76 micrometers (0.003 in.) be used in determining the nominal maximum acceptable container leakage criteria.

For any specified initial pressure and test period, the pressure loss due to a specific equivalent orifice diameter decreases as the ullage increases. To assure uniformity in test results the maximum allowable pressure loss should be specified for each specific container-charge combination. In addition, the acceptance specifications must include the acceptable temperature range for conducting the tests, the initial test pressure, and the length of the test period.

With regard to pressure stabilization, a period of 60 seconds is a sufficient stabilization time for manual applications; however, for high-production-rate, automated applications the test equipment must be capable of compensating for the pressure losses caused as a result of the adiabatic heating of compression.

In the automated applications, given a nominal maximum acceptable equivalent orifice diameter, variations will exist in the measured pressure loss. These variations will be caused by temperature variations and initial pressure differences between containers due to a number of reasons. However, these variations will not adversely affect the test results as long as the acceptance standard provides acceptance criteria with a given range. As an example, assume that the nominal maximum acceptable equivalent orifice size is specified as 76 micrometers (0.003 in.), the initial test pressure is specified as 18.6 kPa (2.7 psig), the test time is 5 seconds, and the temperature of test performance is specified at 22°C (72°F). The effects of the tolerance extremes for a tolerance of ±10% on the initial test pressure and test time are presented in figure 12, for the extremes in container ullages. All other initial test pressure and test time combinations within the tolerance range (± 10%) will be between the extremes. To allow for the variation in test parameters, the acceptance standard for each of the two container-charge examples could be as follows:

Container--PA66
Charge--M188
Initial test pressure--18.6 kPa (2.7 psig) ± 10%
Test time--5 seconds ± 10%
Temperature range--22°C (72°F) ± 10%
Pressure loss--shall not exceed 1.7×10^{-2} kPa (2.5×10^{-3} psig)

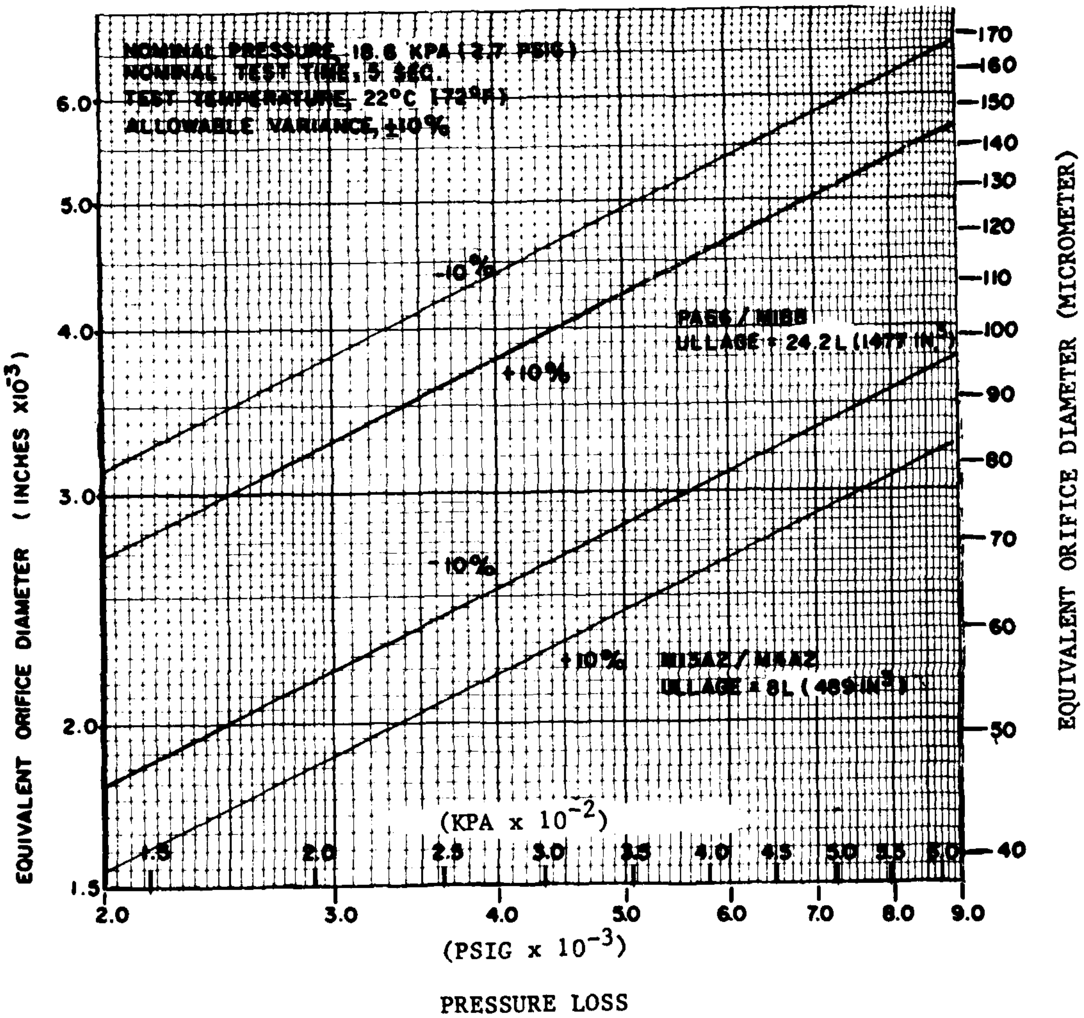


Figure 12. Pressure drop vs equivalent orifice diameter for tolerance extremes

Container--M13A2
Charge--M4A2
Initial test pressure--18.6 kPa (2.7 psig) ± 10%
Test time--5 seconds ± 10%
Temperature range--22°C (72°F) ± 10%
Pressure loss--shall not exceed 5.2×10^{-2} kPa (7.6×10^{-3} psig)

Now assuming that the loading facility has adjusted the equipment at the lower end of the tolerance range, the maximum pressure loss specified will, in both cases, correspond to an equivalent orifice diameter of approximately 89 micrometers (0.0035 in.), which realistically is acceptable.

Temperature variations within the loading facility will most likely occur on a daily basis. As long as the variations are within the specifications, the effects will be negligible. In the event that the temperature within the loading facility is below 18°C (65°F), the manufacturer would be wise to adjust the equipment toward the high end of the specified tolerance. If the temperature is above 27°C (80°F), then the equipment should be adjusted toward the low end of the tolerance range.

Care must be exercised in setting specific acceptance standards. The sensitivity and precision of the electronic test method will most likely exceed that expected of the presently incorporated test methods. Once properly setup and adjusted, the electronic test equipment will effectively eliminate the possibility of erroneous test results due to operator errors. The increase in sensitivity and precision will allow for a more rigid and exact means of leakage inspection. However, if the standards for inspections being done manually do not reflect the required adjustments to make them coincide with the electronic equipment standard, quite probably the observed rejection rate will increase on the automated lines. Of the possible adjustments to upgrade the standards for manual tests, increasing the test time will most likely achieve the best results.

PROTOTYPE AUTOMATED EQUIPMENT

System Description and Operation

The subject propelling charge container leakage inspection station is incorporated in the packout section of a prototype automated LAP line being assembled by the MRC Corporation. The function of this inspection station is to check containers for 155-mm and 8-inch center-core-ignited propelling charges for holes, cracks, or an unsatisfactory lid seal.

Testing for leakage is accomplished through the use of electronic pressure decay leak detection equipment. USON Corporation[2] Model 310 leak test equipment is used on the MRC Corporation packout line and is similar to that used previously on the GATEX LAP line.[3]

Both the GATEX line and the MRC line are designed to operate at a rate of 600 containers per hour; however, while the GATEX line performed the leak test on a single container as it passed through the leak test station, the MRC line leak test is performed on two containers at a time. This difference allows a longer test period on the MRC line without sacrificing the high production rate. The ability to test two containers simultaneously is due to the use of a T-shaped test probe fixture which is allowed to pivot at the center of the packout carousel. This feature permits the test probes to remain in place as the carousel is indexed through an additional station from where the test was initiated.

Once containers are indexed into the leak test station, test probes are lowered into the container vent plug holes and seated in place. After this seating occurs the leak test is initiated. This test basically consists of filling the loaded containers with air to a predetermined pressure, then measuring any pressure loss over a set time interval. The USON leak test equipment carries out this pressure decay measurement and provides an accept or reject signal dependent upon the program control settings on the leak test equipment. Accepted propellant containers are further processed at the remaining packout stations; however, additional processing is not done on those rejected at the leak test station. This station bypass feature is handled automatically by the packout controller which monitors the various inspection and process stations. In the event that a container was rejected at a station prior to the leak test inspection, the controller would prevent the leak test from being conducted. At the end of the packout line all rejected containers are segregated for manual processing.

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[2] Information concerning USON equipment is published with the permission of USON Corporation, letter dated 13 May 1980, signed W. J. Rapson Jr.

[3] The GATEX LAP line is a prototype LAP line developed by GATEX Corporation for standard 155-mm and 8-inch propelling charges.

The leak test cycle (fig. 13), which is controlled by the USON equipment, consists of the previously mentioned sequence--container pressurization, pressure stabilization, electronic memory setting, and leak test decay period. With the exception of the memory setting time the various steps involved in the test are settable by the user. For the MRC packout line, the total time allowed for this test cycle was specified as 9.5 seconds.

Leak Test Hardware

The leak test hardware consists basically of the T-bar which pivots about the center of the packout carousel, the test probes and actuators, the associated pressurization circuitry, and the USON leak detection equipment.

Container Pressurization Circuit

The container pressurization-leak detection circuit initially proposed by MRC is illustrated schematically in figure 14. In operation, the quick-fill tank is filled to a predetermined regulated pressure. With containers in the leak test station the test probes are lowered into the vent plug holes and fill valves 6, 7, and 8 are opened for a preset period of time, with air from the quick-fill tank and the regulators flowing into the containers. At the end of the fill time the pressure would be monitored for an overfilled condition. In the case where a container was overfilled, the appropriate overfill valve would be opened to exhaust the excess pressure.

This circuit, as proposed, has problems associated with it. Since the circuit is designed to fill two containers at a time, in the case of the leak test being performed on only one container, the possibility of overpressurizing that particular container is very likely. This action would result in the overfill valves being opened to adjust the excess pressure. As the schematic illustrates, the overfill valves are connected to the supply line for the quick-fill tank; therefore, opening the over-fill valve would result in additional pressurization of the already overfilled container. This program is easily rectified by disconnecting the A-sides of overfill valves 6 and 7 from the quick-fill supply line and allowing them to vent to atmosphere.

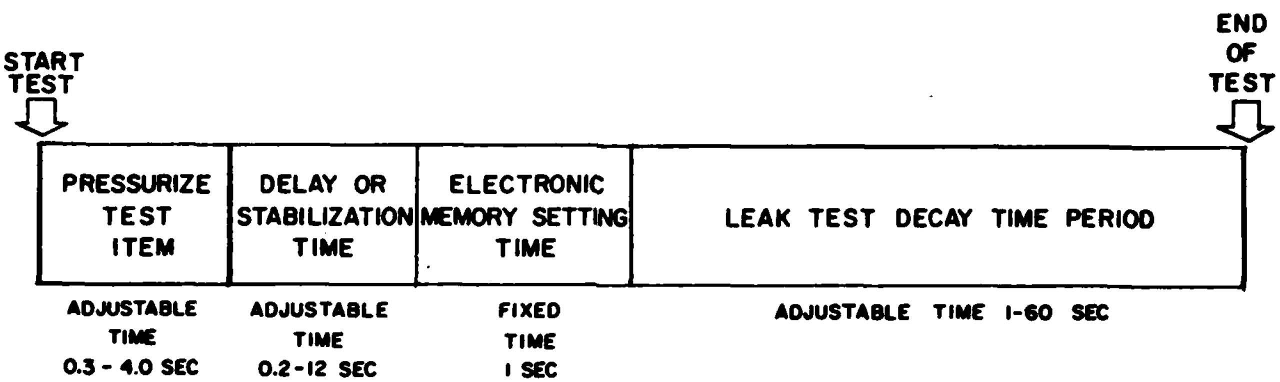

Figure 13. USON pressure decay leak test

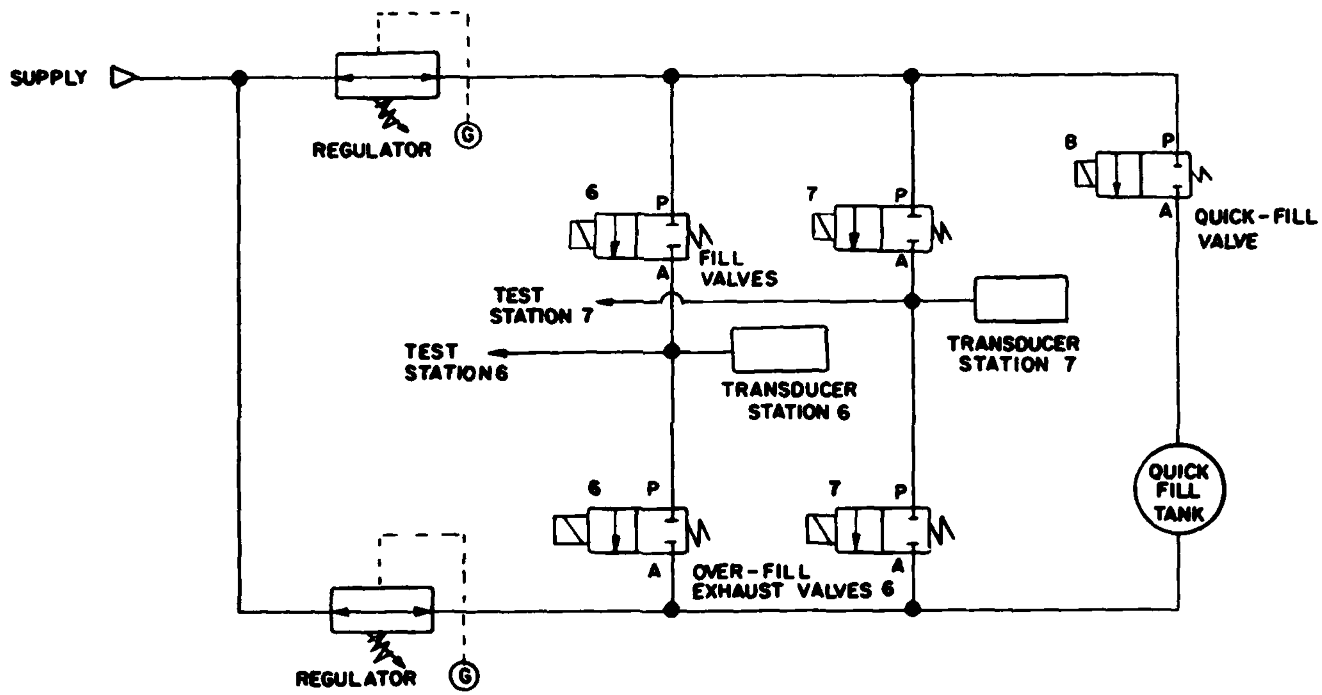

Figure 14. MRC pressurization circuit

In the case of the leak test being performed on both containers, with one of the two containers exhibiting gross leakage, both containers would be underfilled and therefore rejected.

On the basis of these potential problems a revised pressurization circuit is suggested. A possible circuit illustrated in figure 15 consists of two separate container pressurization circuits connected to commom air supply. With reference to figure 15, the air supply (1) should be from a dry compressed air source at a pressure range of 551.5 to 1034.1 kPa (80 to 150 psig) delivered through a minimum of 1/4-inch schedule 40 pipe.

The air filter (2) must be capable of operating at the specified air supply pressure and should be capable of removing condensation and particulate matter of 50-micrometer size or larger. The filter must also have either a manual or automatic draining capability for the removal of accumulated condensation and particulates.

The regulators (3) are used for the purpose of charging the reservoirs (5); therefore, they must have a large enough flow rate to be capable of charging the reservoirs between pressurization cycles. Precision regulators of the relieving variety are recommended to assure consistency in the filled pressure of the containers. A pressure range of 13.8 to 1034.1 kPa (2 to 150 psig) should be capable of handling all of the regulated pressure requirements.

Gages (4) may be incorporated on the regulators or at the reservoirs; however, it would be desirable to monitor the actual reservoir pressure. The pressure range for the gages must be equivalent to the expected range of reservoir pressures required for pressurizing the various containers. Minor graduations on the dial should be no greater than 1.72 kPa (0.25 psig) for accuracy in setting the reservoir pressure.

The reservoirs (5) should be as large as possible. At a minimum they should be approximately twice the volume of the greatest expected ullage. Empty containers may be used; however, they should be modified as illustrated in figure 16. Since the data compiled with reference to the MRC application was based on a reservoir volume of 34.9 L (2129 in.^{3}), which is the nominal volume of an empty PA66 container, these containers are suggested as reservoirs in this application. With reference to figure 16, the recommended modifications consist of drilling a 14 mm (35/64 in.) hole in the bottom of the container into which is welded a short section of 1/4-inch schedule 40 steel pipe. A short section of 1/8-inch schedule 40 pipe is welded in the container lid vent plug hole,

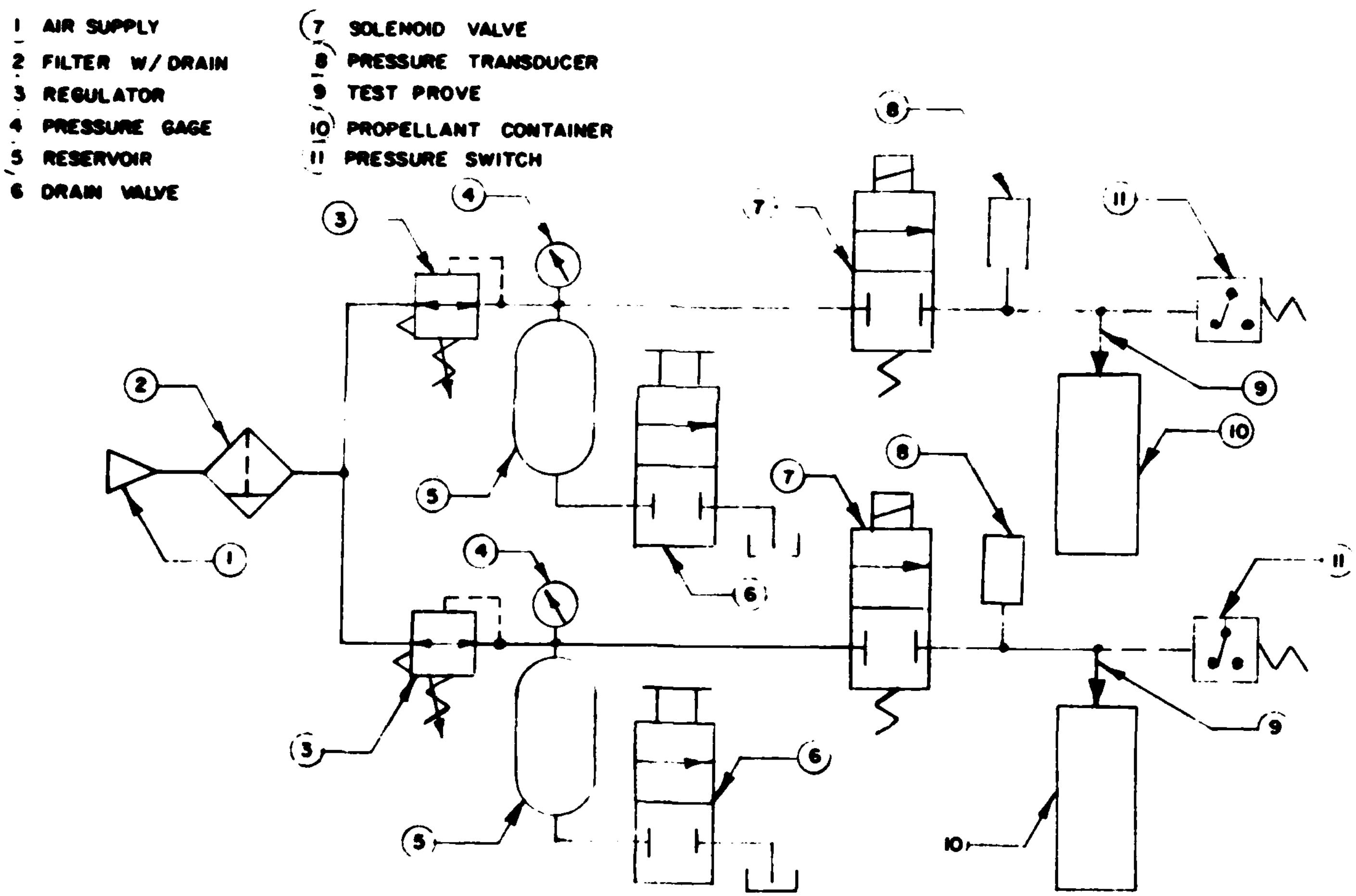

Figure 15. Suggested pressurization circuit

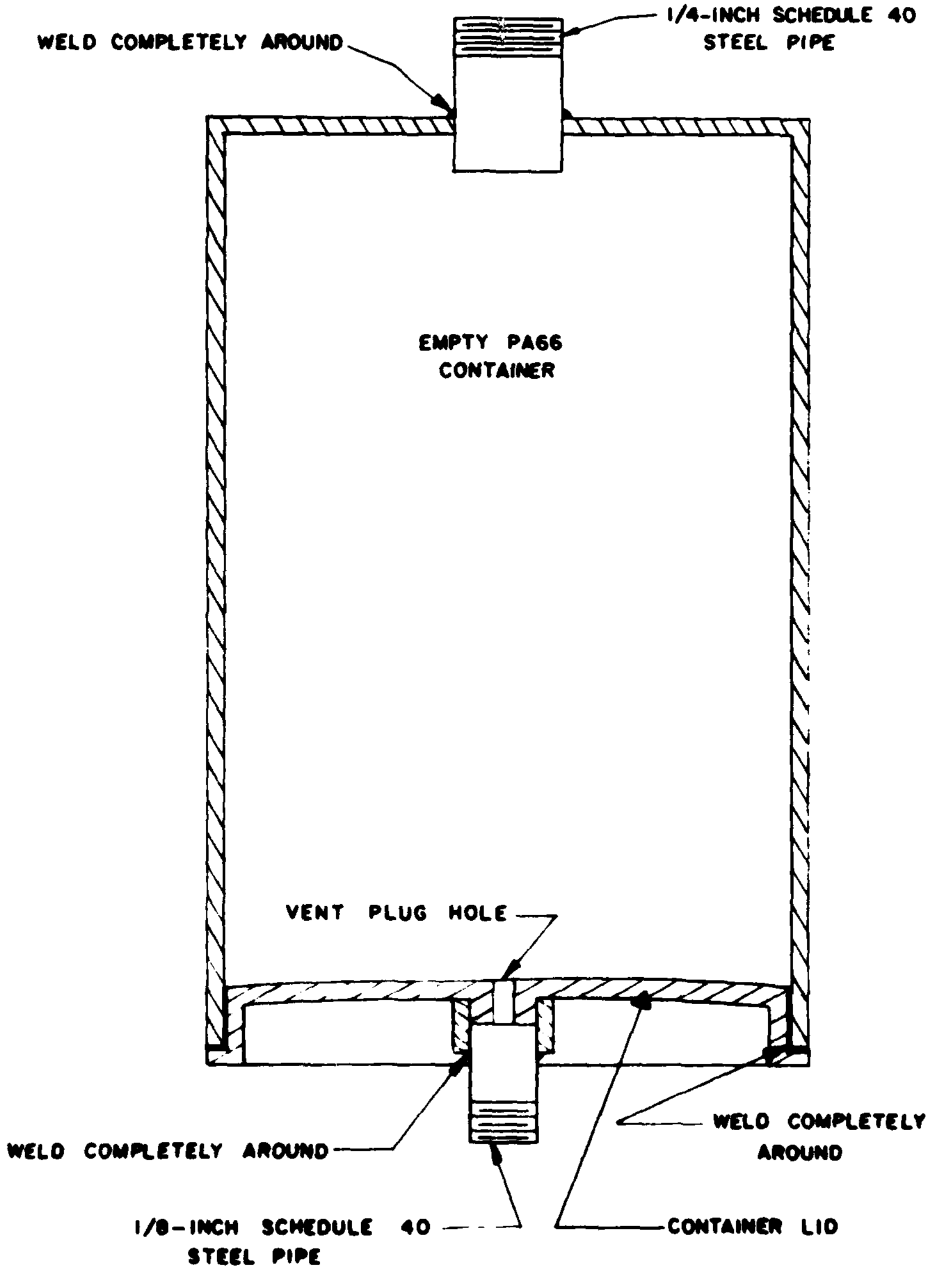

Figure 16. Container modifications for reservoir applications

then the lid is sealed and fastened securely in place. If possible the lid should be welded in place to assure a good seal. Sealing may be accomplished by removing the flange at the top of the container, removing the rubber seal from the container lid, and welding the lid in place. Once modified, the container should be mounted in a bottom-up configuration, as close to the test probe as equipment constraints will allow.

The drain valve (6) is attached to the 1/8-inch schedule 40 pipe which now faces downward. This valve is nothing more than a general purpose, manually operated, on-off valve which will be used periodically to drain off any accumulated condensation within the reservoir.

At the other end (now the top) of the reservoir the connection to the 1/4-inch schedule 40 pipe will be either a 1/4-inch pipe tee or cross, depending on whether or not a gage will be employed at the reservoir. If possible, the regulator should be connected directly to this fitting. If it cannot, then 1/4-inch schedule 40 pipe or tubing of an equivalent size should be incorporated as the interconnection; however, the length of this supply line must be kept to a minimum to avoid undue pressure losses. If incorporated at the reservoir, the pressure gage may be mounted in any convenient location, with the pressure tap line running to one of the remaining ports in the pipe cross.

The solenoid valves (7) must have an equivalent orifice, as specified by the valve manufacturer, no less than 4.8 mm (0.1875 in.) in diameter. Valves with a larger orifice size should be employed wherever possible to reduce restriction to flow. The Skinner valves which were supplied to MRC by USON have a 1.6 mm (1/16 in.) equivalent orifice. Use of these valves would severely restrict flow from the reservoir to the container, resulting in very high required reservoir pressures for filling the larger containers. Therefore, these valves should be replaced by valves with a larger equivalent orifice. They may, however, be used in the capacity of air pilot actuators for larger pilot actuated valves.

The solenoid valves (7) may be mounted in either of two positions: directly on the reservoirs (5) or at the test probes (9). In either case, the connecting line between the reservoirs and test probes must be of a diameter larger than the valve equivalent orifice and must be kept as short as possible. The valve manufacturer's mounting recommendations must be strictly adhered to. The reason for this requirement is that valves are often designed to operate in a specific physical orientation, and mounting them in a different orientation will affect their operation.

The pressure transducers (8) must have a usable range equal to the expected range of operation pressures for the leak test operation. They also have the pressure sensitivity needed to sense the pressure drop expected for the specified leak rate or maximum acceptable hole size and must be relatively insensitive to variations in temperature. Ideally, the pressure transducers would be inserted into the container; however, since this insertion is not physically possible, they must be mounted downstream from the valve exit ports as close to the end of the test probes as the equipment constraints will allow. Due to the fact that the pressure transducers are not in the containers, during pressurization the pressure at the transducer will normally be greater than the container pressure. The pressure at the transducer will be a function of reservoir pressure, the pressure drop across the valve, and any connecting lines or other restrictions to flow. Therefore, pressure transducers must be capable of withstanding overpressures of a minimum of twice their rated full-scale value without loss of calibration or damage to the transducer. If this overpressure capability is not possible, then a large equivalent orifice valve could be placed between the transducer and air-flow passage. This valve would be programmed to open after the pressurization valve closes. Another method would be to place an orifice between the air-flow passage and the pressure transducer and to place a valve on the transducer side which vents to atmosphere during the pressurization period. The alternative is to replace the interconnections between the reservoir and container to reduce the flow restrictions to a level where lower initial reservoir pressures may be used.

The test probe (item 9, fig. 15) used on the MRC leak test stations is illustrated by figure 17. The hole through the center of the probe is specified as 3.2 mm (0.125 in.) in diameter. If all other flow restrictions are kept to a minimum, this passage will be the limiting orifice in the system. In the intended application, the 3.2 mm (0.125 in.) hole through the probe will probably be acceptable. Assuming that all other restrictions are kept to a minimum, the equivalent orifice diameter for the system is estimated to be in the range of 2.3 mm to 2.8 mm (0.09 to 0.11 in.). If, however, this diameter is determined to be less than the estimated lower value, the hole through the probe should be opened up to the largest possible diameter and all other flow restrictions should be reduced.

The pressure switches (item 11, fig. 15) are proposed as replacements for the overfill exhaust valves of figure 14. Due to the short time alloted for the leak test, attempts to adjust the pressure in overfilled containers would adversely effect the remainder of the test. It is, therefore, recommended that no attempt be made to adjust for these conditions. If all of the equipment is

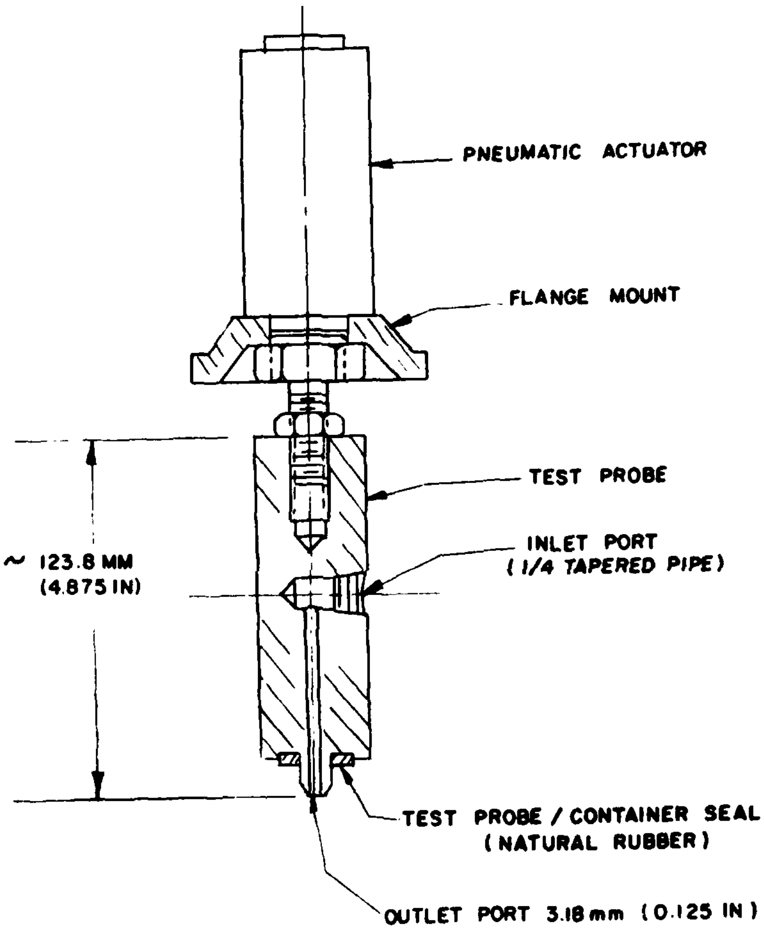

Figure 17. MRC test probe

properly set up and adjusted, then an overfilled condition would signal that either there may be something extra in the overfilled container, or else there was an equipment malfunction. The proposed pressure switches would be mounted in close proximity to the pressure transducers and would be enabled during the pressure decay period of the leak test. They would be set to actuate at the full-scale pressure transducer value. If actuated, a reject signal would be sent to the packout line controller which could subsequently signal an overfilled condition. Although the overpressure exhaust valves should be eliminated, the use of these proposed pressure switches is an option for the user.

USON Leak Detection Equipment (ref 2)

The MRC packout line employs USON Model 310 Leak Detection Equipment at each of the two leak test stations. The USON equipment consists of automatic solid state electronic leak detection monitors used in conjunction with strain-gage-type pressure transducers. As previously mentioned, the leak test cycle is fully programmable with the output from the leak detection monitor being a go, no-go indication. The electronic memory is reset for each test, eliminating the necessity of an external reference pressure.

Program Controls and Control Setting

The program controls illustrated in figure 18 are located under a panel on the top rear section of the leak detection monitoring units. The overfill exhaust time and the exhaust time controls will not be used in the MRC application. Of those remaining controls, the following are analog-type controls: zero, span, fill time, set point, test time, and low pressure set point. Digital controls are sensitivity range, stabilization time, compensation amplitude, and compensation time. Wherever possible, once set, the analog controls should not be readjusted. This procedure will help to assure repeatability of test results. Setting the program controls will require the use of a stopwatch or other such time recording instrument. In addition, the two meters mounted on the front of the leak detection monitor (figs. 19 and 20) will be used in setting various controls.

With reference to figure 20 the upper meter (percent pressure) indicates gage pressure in percent of transducer full-scale value. On the equipment employed on the MRC line, 100% represents a pressure of 20.68 kPa (3.0 psig).

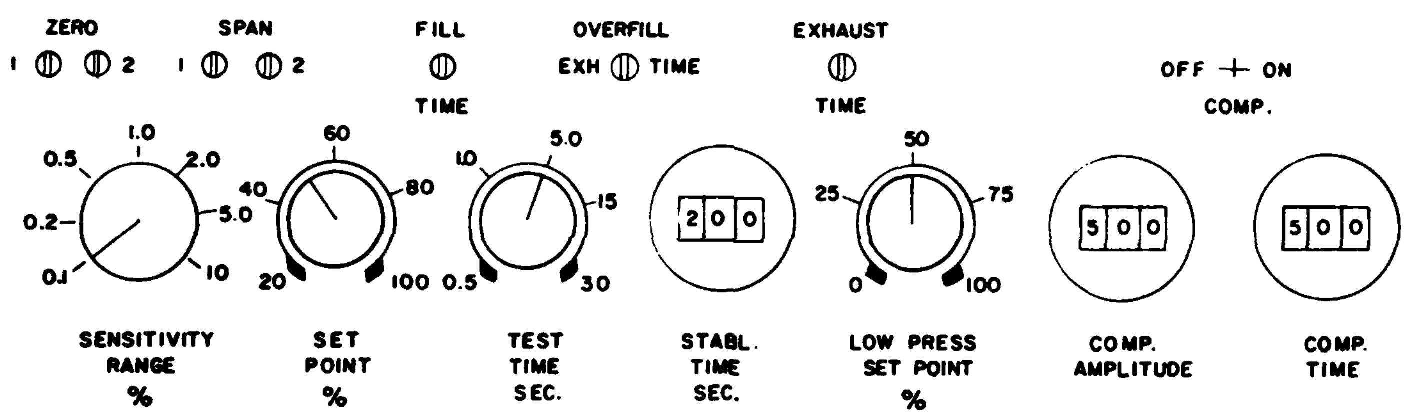

Figure 18. USON program control

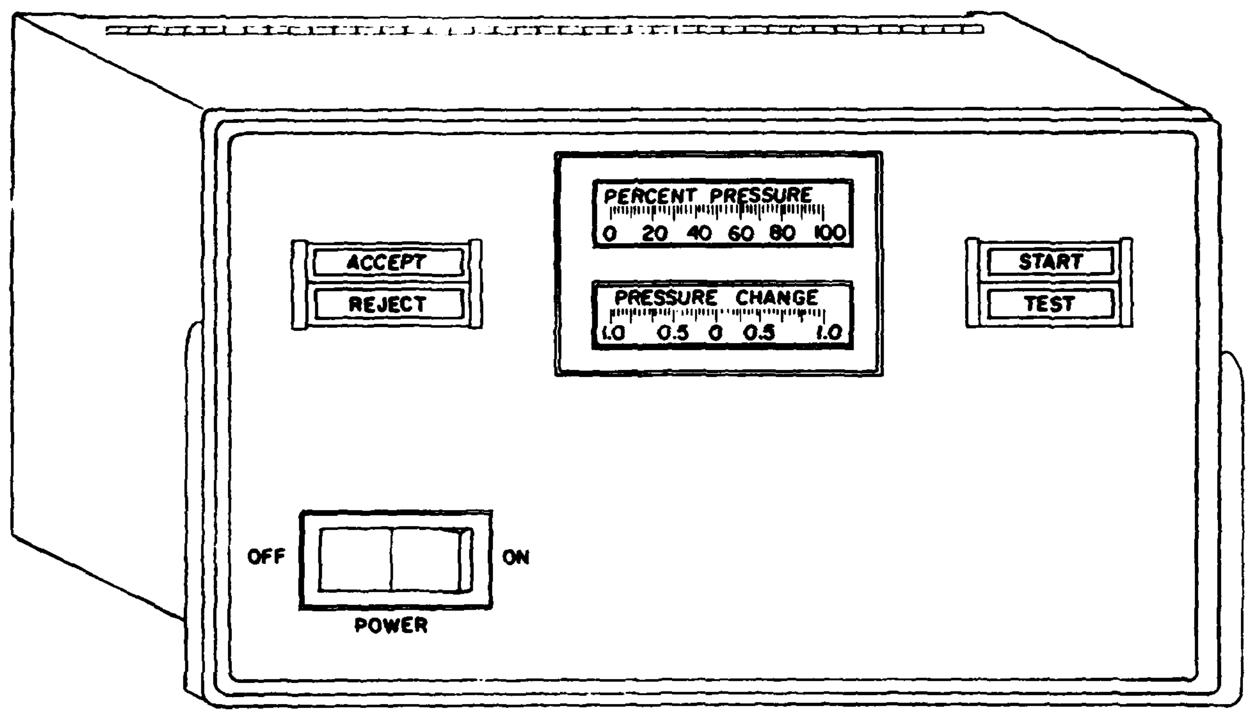

Figure 19. USON equipment front panel

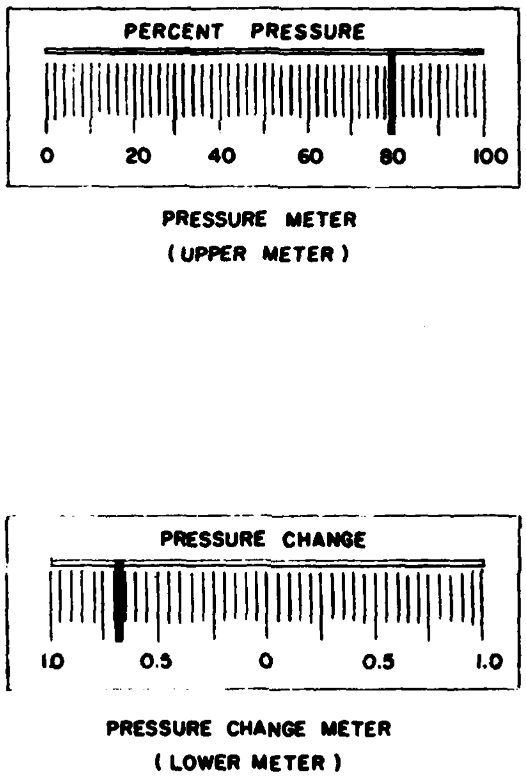

Figure 20. Pressure-indicating meters

The lower meter (pressure change) indicates the pressure change (leakage) in increments of 0 to 1.0. Movement to the left is pressure loss and movement to the right is pressure increase. The scale is expressed as a percentage of the full-scale value of the upper meter. This percentage is dependent upon the sensitivity setting which is discussed separately.

For the MRC leak test the recommended breakdown of the specified 9.5-second cycle time is as follows:

Fill time	1.5 second
Stabilization time	2.0 seconds
Memory setting (fixed)	1.0 second
Pressure decay leak test	5.0 seconds

Clockwise rotation of all controls increases the setting and counter-clockwise rotation decreases the settings.

Zero Adjustment

The zero control adjusts the pressure transducer zero pressure setting with respect to the upper meter (percent pressure) on the leak detection monitor. To check the zero pressure setting, depress the start switch (container to be removed from test station) and check that the pointer in the upper meter is at zero. If it is not at zero, use a small screwdriver to adjust the setting. The start switch must be depressed after each adjustment to allow the equipment memory to reset in the monitor. When in operation, the zero settings should be checked periodically. If at any time the pressure transducers are removed or replaced, the zero pressure settings must be checked prior to operation.

Span Adjustment

This control is used to set the full-scale input voltage level of the pressure transducer into the electronic amplifier. To set the span it is first necessary to apply the required pressure to the pressure transducer.

Attach an accurate calibrated pressure gage with a range of 9 to 34.5 kPa (0 to 5 psig) to the pressurization circuit between the solenoid valve and the test probe. Using a small empty propellant container which is known not to leak, insert the test probe, and open the solenoid valve. With the valve open, adjust the pressure regulator until the pressure in the test container is stable at 20.68 ± .34 kPa (3.0 ± 0.05 psig). Next depress the start button and check the pointer on the upper meter, which should be at 100%. If it is not, adjust the span with a small screwdriver in the same manner as the zero control was adjusted until the pointer is at 100%. Remember that the start button must be depressed after each adjustment. The span should also be checked periodically, and whenever the transducer is removed and replaced.

Fill Time Adjustment

The fill time control (on some models of USON equipment the SOL control) is used to set the length of time that the solenoid valve is open. Using a stopwatch, adjust the fill time potentiometer with a small screwdriver, depressing the start button after each adjustment, until the stopwatch reading is consistently between 1.4 and 1.6 second (ideally 1.5 second).

Sensitivity Range

The sensitivity range control is incrementally settable from 0.1% to 10%. The particular value at which this control is set directly affects the scale on the pressure change meter. To determine the scale of the pressure change meter, multiply the sensitivity setting by the full-scale value of the upper meter (percent pressure). For example, a full-scale right or left needle deflection on the lower meter with a sensitivity setting of 0.1%, and a full-scale upper meter value of 20.68 kPa (3.0 psig) represent a pressure change of 0.021 kPa (0.003 psig). This control will be used in conjunction with the set point for setting the accept/reject criteria for each container.

Set Point

The set point control, which is adjustable from 20% to 100%, is used to program the accept/reject point on the pressure change-meter as a percentage of the pressure corresponding to a full right or left deflection of the lower meter pointer. For example, if the set point control is set at 60%, the accept/reject point would be 60% of the value represented by a full right or left needle deflection of the lower meter. Using the same example as used for the sensitivity range, the value corresponding to a full right or left point deflection was calculated to be 0.021 kPa (0.003 psig); therefore, for a set point of 60% the accept/reject point would be 60% of 0.021 kPa or 0.0126 kPa (0.0018 psig). Any pressure drop during the test time period greater than 0.0126 kPa would represent a reject, and those containers with a pressure loss no greater than 0.126 kPa would be accepted.

Test Time

The test time control is used to adjust the pressure decay leak test period. This time begins when the green test light on the front of the monitor goes on and ends when either the accept or reject light goes on. This control should be adjusted with a stopwatch to a time between 4.9 and 5.1 seconds (ideally 5 seconds).

Stabilization Time

The stabilization time control is used to adjust the pressure stabilization period which occurs immediately after the solenoid valves close. It is settable from 0.05 to 10 seconds with a setting of 100 equal to 1 second. This control should be set at 200 for the MRC leak tests.

Low Pressure Set Point

In containers with gross leakage or in the case where a container was not pressurized, the pressure at the start of the pressure decay period would be zero. As a result there would not be a pressure drop over the test time period and such a container would normally be accepted. The low pressure set point control is used to set a minimum test pressure below which a reject indication occurs. This control is settable as a percentage of the upper meter full-scale reading. A setting of 60 on the low pressure set point dial should be adequate for the MRC line. This setting means that any container with a filled pressure less than 12.4 kPa (1.8 psig) will be rejected.

Compensation Network Adjustment

The compensation network is used to electronically eliminate the pressure loss occuring immediately after pressurization as a result of the adiabatic heating effects of compression. The controls (which consist of the comp switch, comp amplitude, and comp time) will require adjustment each time the container-charge combination is changed. Using the pressure time curve illustrated in figure 21 as an example, the method for adjusting these controls follows.

The maximum pressure loss which can be compensated is 10% of the upper meter reading for any particular test. With reference to figure 21, the container pressure at the end of the memory setting period (4.6 seconds elapsed time) was approximately 16.5 kPa (2.4 psig), which corresponds to an upper meter reading of 80% (full-scale equals 20.68 kPa). In the example the maximum compensation is 10% of the upper meter reading, or 1.65 kPa (.24 psig).

Adjustment to the compensation network controls requires the comp switch turned off, the sensitivity switch set at 10%, and all other controls left at their original settings. With the controls set as previously mentioned, and a nonleaking container in the leak test station, the start button is depressed, which initiates a leak test. As the test proceeds, observe the pressure loss on the lower meter. If the pressure loss goes off scale, then the magnitude of the loss is greater than 10% and beyond the ability of the equipment to compensate for it. Should this occur, check the container and leak detection circuit for leaks. If no leakage exists, then the stabilization period will have to be increased until the observed loss remains within the required 10% (full-scale on the lower meter). In the example the pressure loss from the end of the memory setting period (4.6 seconds elapsed time) until the end of the pressure decay period (9.6 seconds elapsed time) is approximately 1.4 kPa (0.20 psig). The full-scale value (1.0) of the lower meter represents a pressure change of 10% or 2.07 kPa (0.3 psig); therefore, the 1.4 kPa pressure loss would be represented by a reading of 0.67 (1.4/2.07) on the lower meter. Since the minor divisions on the lower meter represent a reading of 0.05, the actual meter reading could be taken as either 0.65 or 0.70. Using the 0.70 reading for the example, the comp amplitude setting is determined by multiplying the percentage value of the lower meter expressed in decimal form by the upper meter reading. For a sensitivity switch setting of 10%, the 0.70 reading represents 7%, which expressed in decimal form is 0.07 (7/100). The comp amplitude setting for the example is 0.07 x 80 (upper meter reading was previously specified as 80%) or 5.60. The comp ampli-

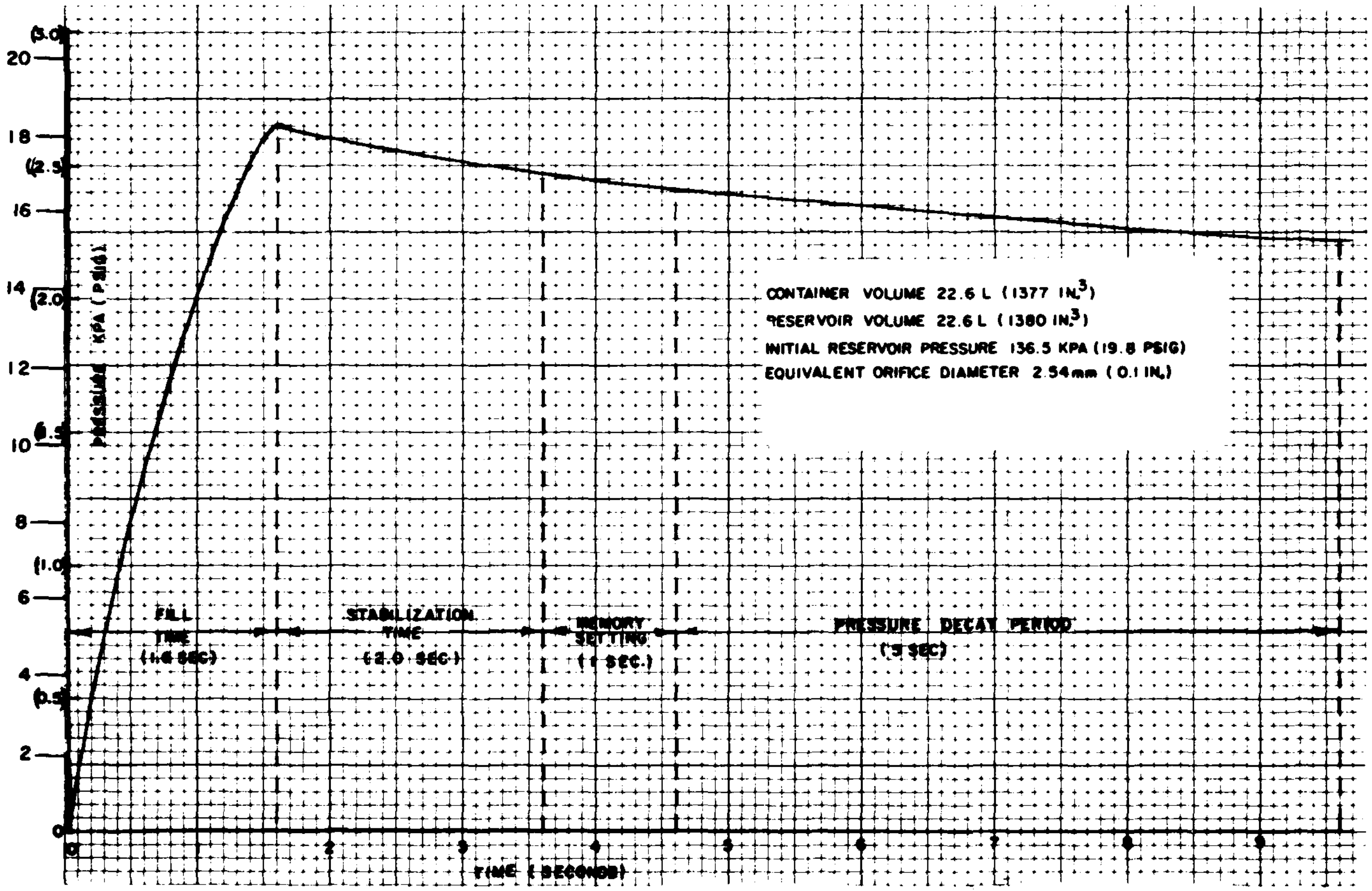

Figure 21. Pressure vs time (MRC application)

tude dial reads 000 to 999, which represents 0% to 9.99%; therefore, the dial would be set to 560.

Next the comp time dial is set at 500 as an initial starting point, the comp switch is turned on, and the start button is depressed to begin a test. The pressure change meter (lower meter) should remain close to zero for the duration of the pressure decay period. If it does not remain close to zero, then adjustments to the comp amplitude and comp time controls will be required. These adjustments are made as follows:

1. If the meter indicator moves to the left, stops, then reverses, or if it stays close to zero then goes to the right near the end of the test, the comp time setting is too large and needs to be reduced (lower number setting).

2. If the meter indicator moves to the right, stops, then reverses, or if it remains around zero then moves left near the end of the test, the comp time setting is too low and needs to be increased (higher number).

3. If the indicator moves steadily to the right then stops, the comp amplitude setting is too high and should be set to a lower number.

4. If the indicator moves steadily to the left then stops, the comp amplitude setting should be increased (higher number).

The magnitude of the change to the control settings should correspond to the amount of change observed on the lower meter. If the change is large on the lower meter, then try a large change to the control setting, if the change is small then only change the setting a minor amount. Each time a change is made the start button must be pushed to begin a new test.

Once the settings are sufficiently close to hold the pressure decay near zero, the sensitivity setting is advanced to the next finer range and the process of adjusting the controls repeated. This procedure is continued until the required sensitivity range is reached and the proper adjustments are made. Once the control settings are adjusted properly for each container-charge combination, a record of these settings should be kept to reduce the setup time for a container-charge change. It may be necessary to periodically check the compensation network control settings.

Calibration Procedures

Equipment calibration should be checked prior to the initial startup of the line and periodically during the course of operation. As a matter of convenience these periodic checks could be done in conjunction with scheduled maintenance on the equipment. Using a setup similar to that used to adjust the span control,[4] the method of checking equipment calibration is as follows:

Set the sensitivity range switch to the 10% position, turn the comp switch off, and leave all other control settngs as they are.

Disconnect the solenoid valve connector from the rear of the equipment, then, holding this valve open, adjust the container pressure to 20.7 kPa (3.0 psig) in the manner previously used to adjust the span control.

The upper meter reading should be 100%. If it is not, adjust the span control as previously described.

Close the solenoid valve, then crack the leak valve to create a slow leak, and depress the start button.

At the end of the test close the leak valve and record both the lower meter reading and the pressure gage reading. If the pressure gage reading has not dropped by 10% to a reading of 18.6 kPa (2.7 psig), reopen the leak valve and run another test. Continue this process until a 10% loss is recorded.

Once a pressure loss of 10% has been reached the lower meter should be full-scale to the left (a reading of 1.0), and the upper meter reading should be 90%.

Should adjustment be required on the pressure change scale, it will be necessary to adjust the gain potentiometer located on the amplifier circuit board (position 2 from front, in circuit card rack). Turn off power before removing circuit board. The potentiometer is a four turn, screwdriver-adjustment potentiometer about 3/8 of an inch in diameter and labeled "GAIN" on the board (ref 2).

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[4] A tee should be added to the circuit to which is attached a small valve to be used to create a slow leak in the system.

The sensitivity range switch is a voltage dividing switch on the voltage input from the pressure transducer. The output of this switch is to the input electronics section. It is really not necessary to verify each setting of the sensitivity range switch, since verifying any one position checks the calibration of the electronics.

If major adjustments are required, it is recommended that the manufacturer be consulted.

Sensitivity Range and Set Point Adjustments

For the purpose of illustrating the method of adjusting the sensitivity range and set point controls the following acceptance standard examples will be used:

Container--PA37A1
Charge--M119A1
Initial test pressure--18.6 kPa (2.7 psig) ± 10%
Pressure decay test time--5 seconds ± 10%
Temperature range--22°C (72°F) ± 10%
Pressure loss--shall not exceed 3.6×10^{-2} kPa (5.2×10^{-3} psig)

Container--PA66
Charge--M188
Initial test pressure--18.6 kPa (2.7 psig) ± 10%
Pressure decay test time--5 seconds ± 10%
Temperature range--22°C (72°F) ± 10%
Pressure loss--shall not exceed 1.7×10^{-2} kPa (2.5×10^{-3} psig)

With reference to table 3, which lists the maximum acceptable pressure loss for various sensitivity range and set point settings, check if the acceptance standard value corresponds to a value appearing in the table. If so, then the controls are set to the highest percentage setting of the sensitivity range control and that specific set point which corresponds to the acceptance standard value. If, for example, the acceptance standard was 0.00414 kPa, then the sensitivity range control would be set at 1.0% and the set point at 20%, as opposed to the other possible settings of 0.5% and 40% or 0.2% and 100%.

If the acceptance standard values do not appear in table 3, then values may be chosen from table 3 which are close to but do not exceed the acceptance standard value, or the actual setting of

Table 3. USON equipment sensitivity range and set point data

Set point	Sensitivity range setting 0.1%	0.2%	0.5%	1.0%	2.0%	5.0%	10.0%
	Maximum acceptable pressure loss in kPa (psig)						
20.%	0.0041 (0.0006)	0.0083 (0.0012)	0.0207 (0.0030)	0.0414 (0.0060)	0.0827 (0.0120)	0.2068 (0.0300)	0.4136 (0.0600)
30.%*	0.0062 (0.0009)	0.0124 (0.0018)	0.0310 (0.0045)	0.0620 (0.0090)	0.1241 (0.180)	0.3102 (0.0450)	0.6205 (0.0900)
40.%	0.0083 (0.0012)	0.0165 (0.0024)	0.0414 (0.0060)	0.0827 (0.0120)	0.1655 (0.0240)	0.4136 (0.0600)	0.8273 (0.1200)
50.%*	0.0103 (0.0015)	0.0207 (0.0030)	0.0517 (0.0075)	0.1034 (0.0150)	0.2068 (0.0300)	0.5171 (0.0750)	1.0341 (0.1500)
60.%	0.0124 (0.0018	0.0248 (0.0036)	0.0620 (0.0090)	0.1241 (0.0180)	0.2482 (0.0360)	0.6205 (0.0900	1.2409 (0.1800)
70.%*	0.0145 (0.0021)	0.0290 (0.0042)	0.0724 (0.0105)	0.1448 (0.0210)	0.2895 (0.0420)	0.7239 (0.1050)	1.4477 (0.2100)
80.%	0.0165 (0.0024)	0.0331 (0.0048)	0.0827 (0.0120)	0.1655 (0.0240)	0.3309 (0.0480)	0.8273 (0.1200)	1.6546 (0.2400)
90.%*	0.0186 (0.0027)	0.0372 (0.0054)	0.0931 (0.0135)	0.1861 (0.0270)	0.3723 (0.0540)	0.9307 (0.1350)	1.8614 (0.2700)
100.%	0.0207 (0.0030)	0.0414 (0.0060)	0.1034 (0.0150)	0.2068 (0.0300)	0.4136 (0.0600)	1.0341 (0.1500)	2.0682 (0.3000)

* Approximated set point control settings

the set point for the appropriate sensitivity range may be approximated. Since the set point control is an analog control, care should be exercised when approximating values. In all cases the set point dial should be set at a position slightly less than the required value.

The maximum allowable pressure loss for each of the examples does not correspond directly with any of the values listed in table 3. For the PA37A1-M119A1 combination the allowable loss of 0.036 kPa (0.0052 psig) lies between the 80% and 90% set point values for a sensitivity range setting of 0.2%, and between 30% and 40% for a sensitivity range setting of 0.5%. The actual set point value is 86.9% (0.036/0.0414 x 100) for the 0.2% range and 34.8% (0.036/0.1034 x 100) for the 0.5% range. In this case the 80% value, or an approximated 85% value, for the 0.2% sensitivity range setting would be appropriate. In the case of the PA66-M188 combination the specified maximum pressure loss of 0.017 kPa (0.0025 psig) lies between 80% and 90% for the 0.1% sensitivity range and between 40% and 50% for the 0.2% range. Due to the possible difficulty in adjusting the compensation network at the 0.1% range, a value in the 0.2% range is recommended. Also, since the actual set point value in the 0.2% sensitivity range is 41%, the 40% setting would be appropriate.

With reference to figure 22, which is a plot of the tolerance extremes for the acceptance standard examples, the recommended sensitivity range and set point settings for the PA66-M188 combination correspond to equivalent orifice diameters of 75 mircometers (0.00295 in.) on the +10% plot and 86 micrometers (0.0034 in.) on the -10% plot. In the case of the PA37A1-M188 combination the 0.2% range 80% set point corresponds to equivalent orifice diameters of approximately 73 micrometers (0.0029 in.) on the +10% plot and approximately 85 micrometers (0.0033 in.) on the -10% plot. In all cases the detectable equivalent orifice diameters are well within the acceptable range and close to the actual required value of 76 micrometers (0.003 in.); therefore, it is evident that setting the set point control at a value slightly less than the required value has little effect on the validity of the test.

Additional Applications

Other applications for the leakage detection equipment previously described include manual LAP lines, container manufacturing lines, and container reconditioning lines; however, prior to incorporating this equipment, a number of factors must be considered.

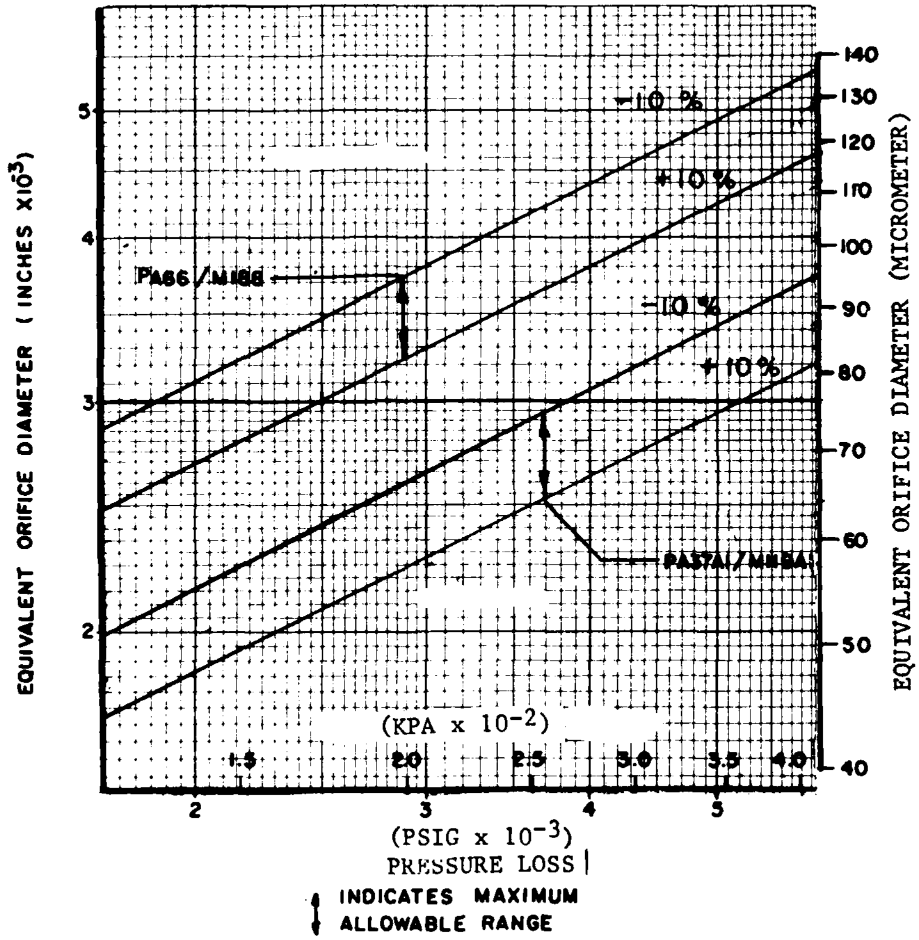


Figure 22. Pressure loss vs equivalent orifice diameter (MRC application)

One consideration is whether the existing line is due for replacement by an automated line. If so, then the cost of reconditioning the present inspection station to accept such inspection equipment may prove to be prohibitive unless the inspection equipment could also be used on the automated line.

Additionally, as compared with lines which have the pressure monitoring device(s) manually attached, the electronic equipment is less expensive and is relatively easy to install on lines which presently use a test probe or a series of probes at the leakage inspection station.

As previously mentioned, the acceptance standards must reflect the effects of increased precision and sensitivity in those areas of the manufacturing cycle not using the more sophisticated inspection methods. If, for example, such equipment is installed on a manual LAP line, then the leakage inspection technique for container manufacturing and reconditioning must be upgraded.

An alternative to upgrading the other inspection processes is to set the acceptance standards for the level of accuracy presently achieved. In a case such as this, the benefit gained by the use of more sophisticated test equipment is the possible increase in production rate and elimination of the human error factors.

When installing such equipment on container manufacturing and reconditioning lines, the test volume will be larger for the empty containers. As a result, adjustments will be required for both the total time required for the test and for the specific equipment requirements.

Future considerations for automated leakage inspection should include use of the computer which is normally installed as the central process controlling device on automated lines. Thus the only auxiliary equipment needed to perform this inspection would be possibly the pressure transducers. The pressure transducers would in turn provide a signal to the computer which would be programmable for the given test conditions. In fact, given preprogrammed acceptance standards, the computer may be able to determine the ullage, using the pressure-volume method previously explained, and then inspect for leakage using the appropriate acceptance standard to fit the volume.

In future applications it is recommended that the length of time alloted for leakage inspection be increased. To do so without affecting the production rate will require an increase in the number of containers being tested at a time. Lengthening the total test period will allow a longer fill time, stabilization period, and pressure decay monitoring interval, resulting in fewer potential problems with the inspection process.

CONCLUSIONS

Because the volume of the packaging materials was not used in the ullage calculations, the calculated maximum ullage was found to be larger than the actual measured values. The calculated values should therefore be used in determining the other leakage inspection parameters.

To achieve acceptable container fill times and/or reasonable reservoir pressures, the container pressurization circuit must be designed with minimum restriction to flow. The maximum flow restriction should be the container lid vent plug hole.

The restriction to flow (equivalent orifice diameter) through a container pressurization circuit may be easily determined using the empirical method described in the first section of this report.

Because container lid seal leaks can be induced by container pressures on the order of 34.5 kPa (5 psig), care should be taken to keep container pressures below the 34 kPa range.

The heat transfer effects following an adiabatic compression (container pressurization) causes resulting pressure loss which could possibly be interpreted as a leak or which could mask an actual container leak; therefore, a stabilization period is required immediately after pressurization to either negate the effect of adiabatic heating or to reduce the effects to a level which may be compensated by the leak detection equipment.

Due to the rapid temperature changes which occur in a container during both pressurization and decompression, care should be exercised to avoid such a test on materials sensitive to rapid temperature changes.

The majority of the 350 loaded containers previously tested (ref 1) exhibited equivalent orifice diameters on the order of 76 micrometers (0.003 in.) or less. Due to the past acceptable performance of similarly packaged and inspected propelling charges, the 76 micrometer equivalent orifice is an acceptable upper limit for leakage inspection.

Tolerances of ±10% may be specified for the pressure decay test period, the container pressure for the initial pressure decay period, and the temperature at which the test is conducted without adversely affecting the test results.

Because, for a given set of test conditions, the observed acceptable pressure loss will be different for each specific container-charge combination, the maximum allowable pressure loss must be specified in the acceptance standard for each container-charge combination.

The minimum detectable pressure loss is dependent upon the sensitivity of both the test method and the test equipment; therefore, the inspection process must be equivalent for container manufacturing, reconditioning, and LAP line operations.

If the techniques outlined within this report are followed, the inspection equipment presently being assembled on the prototype LAP line by the MRC Corporation should be adequate to detect equivalent orifice diameters (leaks) on the order of 76 micrometers (0.003 in.) within the specified 9.5-second total test period.

RECOMMENDATIONS

The calculated maximum ullage should be used for determining the values of the leakage inspection parameters.

To eliminate the possibility of pressure induced lid seal leakage, container pressures should not exceed 27.6 kPa (4 psig).

Acceptance standards for each container-charge combination should specify the container pressure at the beginning of the pressure decay period, the pressure decay test time, the temperature at which the testing should be conducted, and the maximum allowable pressure loss over the specified test time. The standards should also allow for a tolerance on the initial test parameters not to exceed ±10%. Acceptance standards for leakage inspection should be similar with respect to the specified accuracy required during container manufacturing, reconditioning, and loading processes.

Future automated leakage inspection stations should be designed to test a number of containers at a time. This procedure will allow an increase in the total test cycle time, which in turn will reduce the required equipment sensitivity, and will eliminate the potential problems associated with a short test period, and will not adversely affect the production line manufacturing and checkout rate.

REFERENCES

1. John R. Masly, "Propelling Charge Container Leak Rate," Technical Report ARLCD-TR-79021, ARRADCOM, Dover, NJ, August 1979.

2. USON Corporation, "Model 300 Series Leak Testers, Operating Instructions and Product Data," Operators Manual, Houston, Texas, 1975.

APPENDIX A

ULLAGE DATA

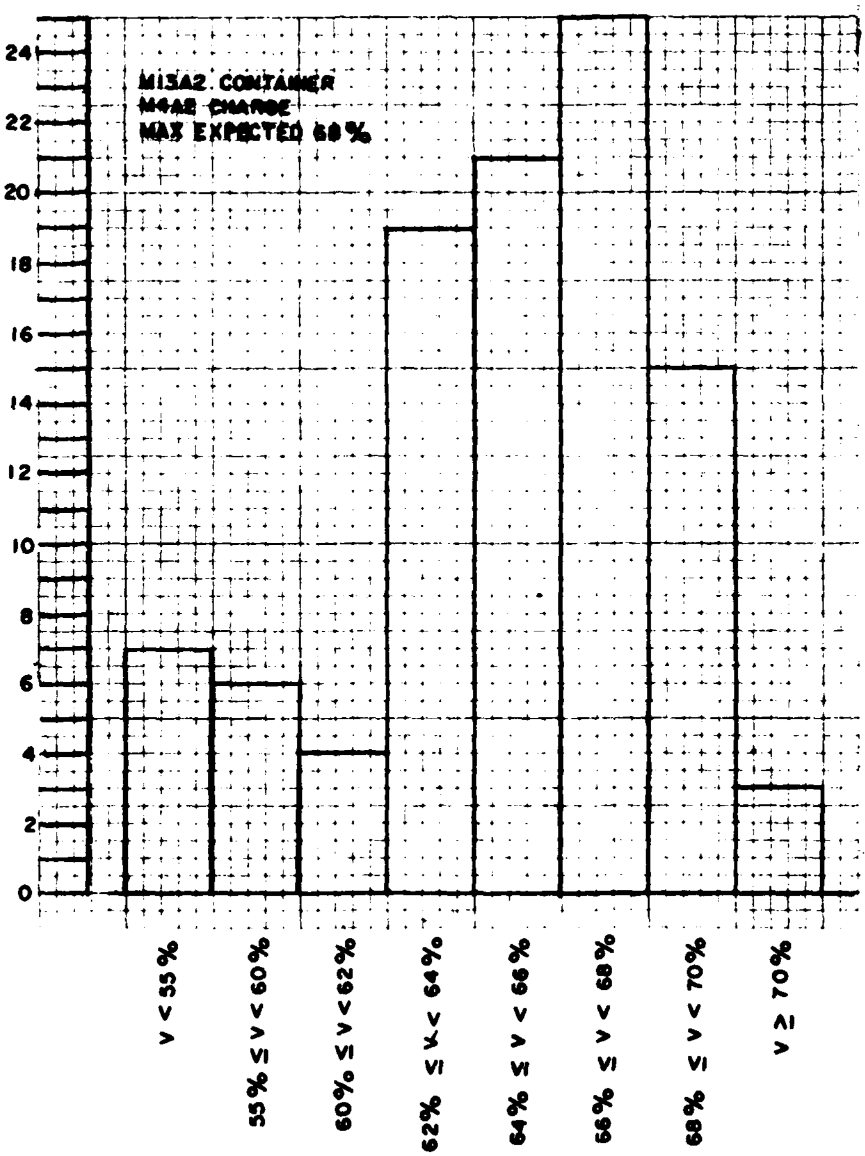


Figure A-1. Ullage data, M13A2 container

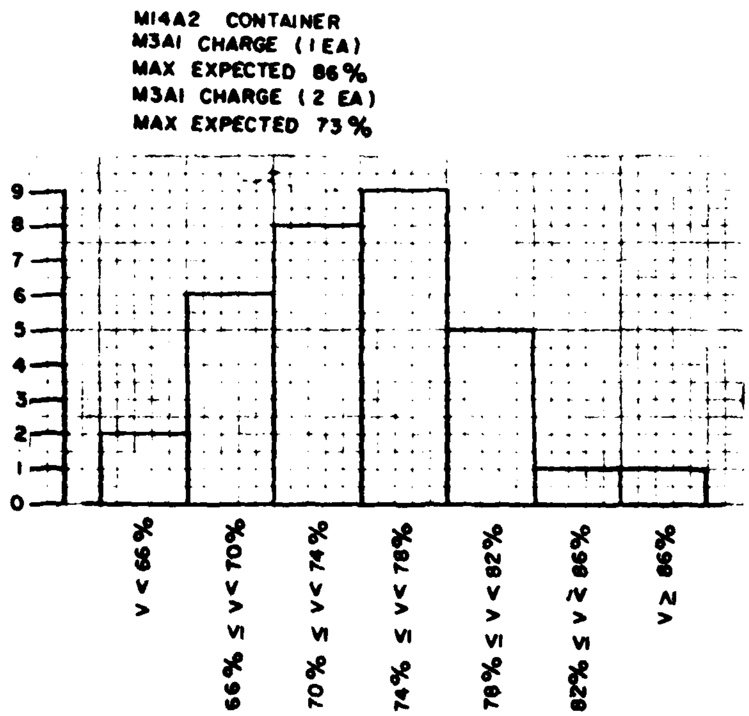
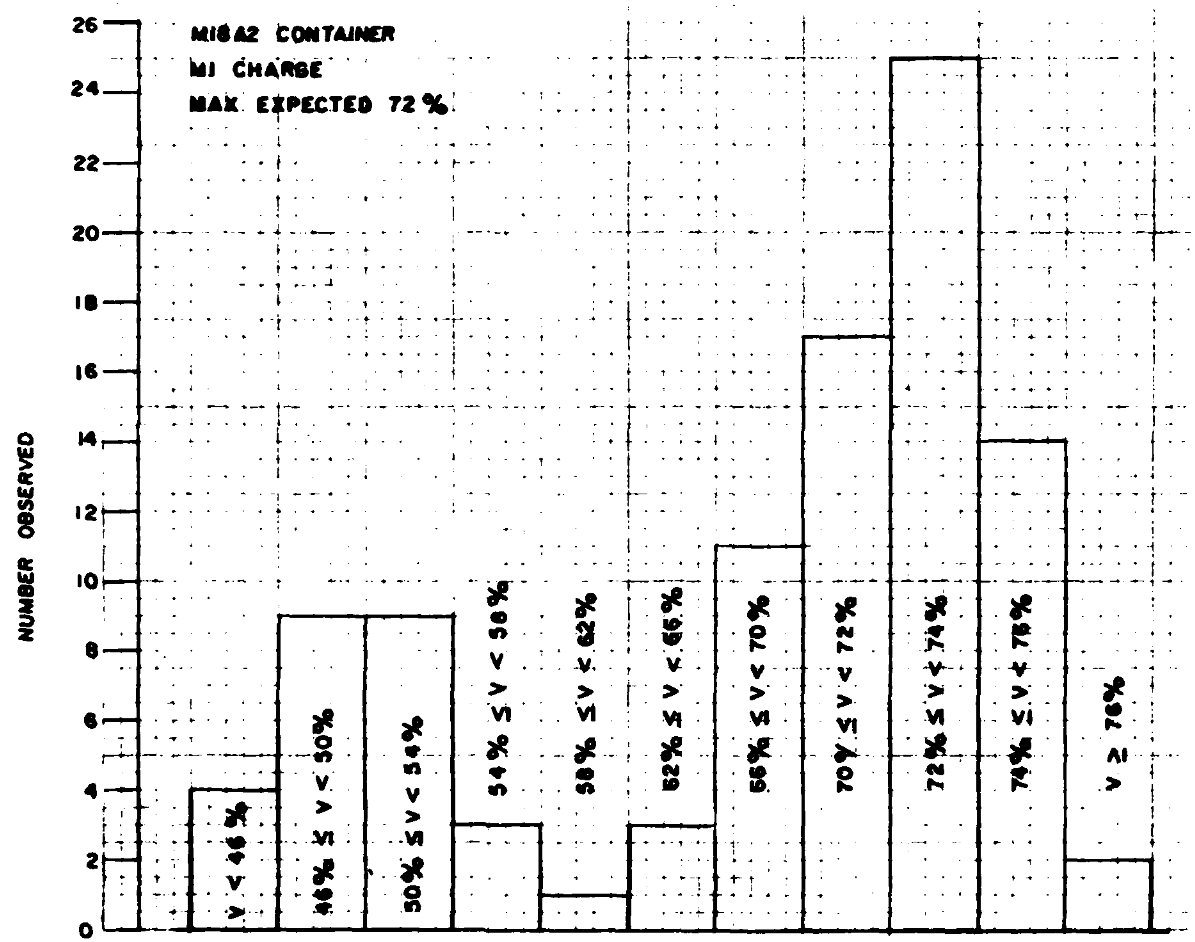


Figure A-2. Ullage data, M14A2 container



ULLAGE VOLUME (% OF EMPTY CONTAINER VOLUME)

Figure A-3. Ullage data, M18A2 container

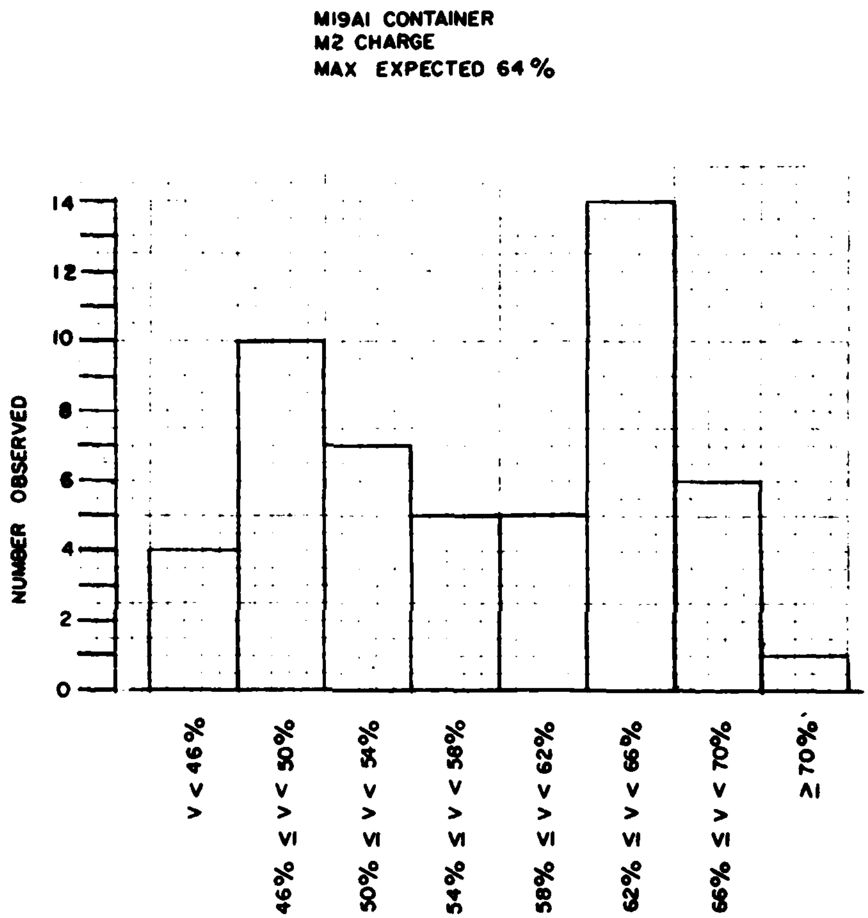


Figure A-4. Ullage data, M19A1 container

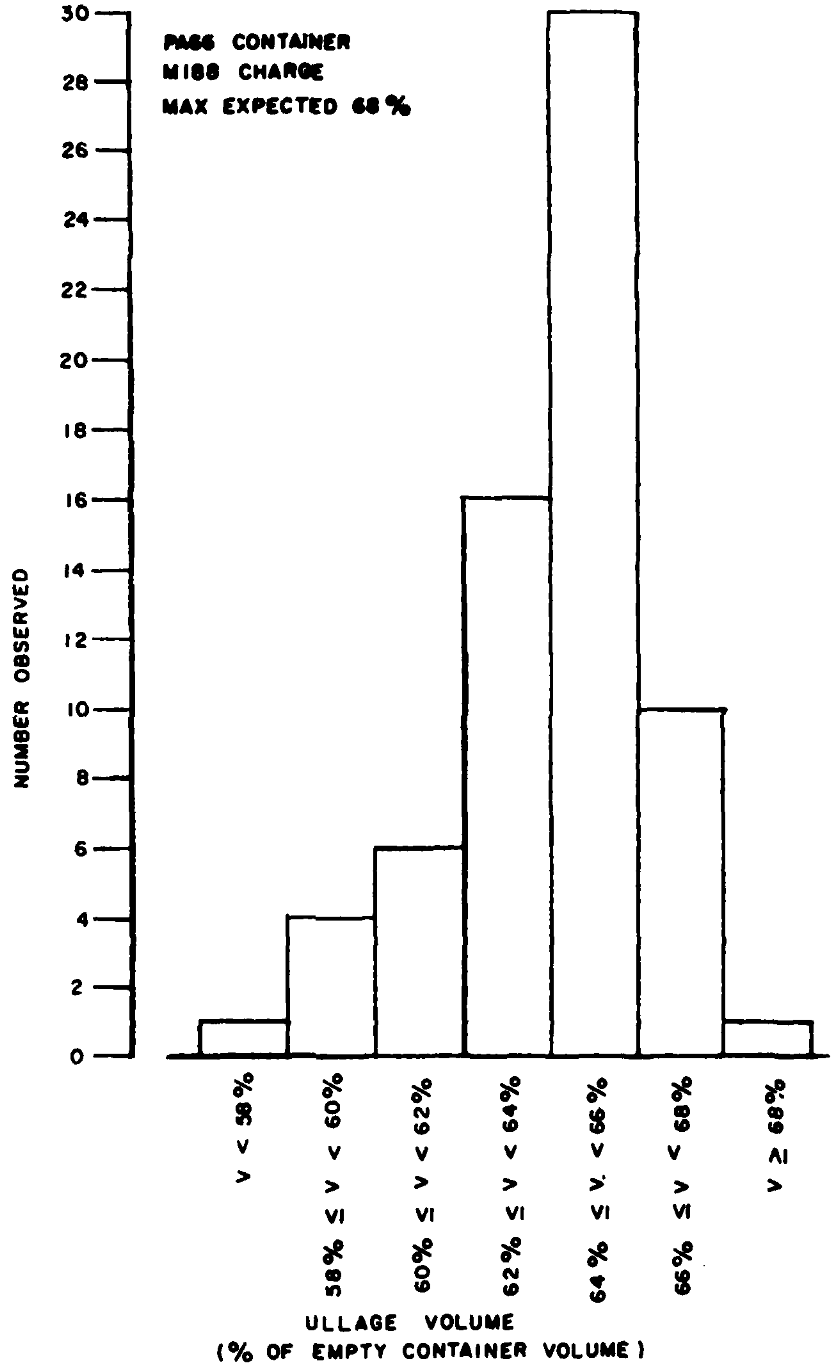


Figure A-5. Ullage data, PA66 container

APPENDIX B

COMPUTER PROGRAMS

The flow equations utilized in the computer programs are based on the equations of one dimensional flow through ducts and wind tunnels.[B1] The continuity equation for flow in a channel or duct of varying area is given by the expression

$$\rho u A = \rho^* a^* A \tag{1}$$

where ρ is the gas density
u is the gas velocity
A is the flow area
$*$ denotes sonic conditions
a^* is the velocity of sound.

Equation 1 may be rewritten as

$$\frac{A}{A^*} = \frac{\rho^*}{\rho}\frac{a^*}{u} = \frac{\rho^*}{\rho_o}\frac{\rho_o}{\rho}\frac{a^*}{u} \tag{2}$$

with the subscript o denoting the upstream reservoir conditions.

The ratios on the right hand side of equation 2 may be expressed as functions of Mach Number as

$$\frac{\rho^*}{\rho_o} = \left(\frac{2}{\gamma+1}\right)^{1/(\gamma-1)} \tag{3}$$

$$\left(\frac{u}{a^*}\right)^2 = \frac{\gamma+1}{\frac{2}{M^2} + \gamma-1} \tag{4}$$

$$\frac{\rho_o}{\rho} = \left(1+\frac{\gamma-1}{2}M^2\right)^{1/(\gamma-1)} \tag{5}$$

where: γ is the ratio of specific heats
M is the Mach Number.

Using equations 3, 4, and 5 in equation 2, and simplifying, the expression becomes

$$\left(\frac{A}{A^*}\right)^2 = \frac{1}{M^2} \quad \frac{1}{\gamma+1}\left(1 + \frac{\gamma-1}{2}M^2\right)^{\frac{\gamma+1}{\gamma-1}} \tag{6}$$

B1 H. W. Liedmann and A. Roshko, "Elements of Gas Dynamics," Wiley and Sons Inc., 1957.

This result is valid only for isentropic flow because the relationship used for ρ_o/ρ is isentropic. Using the relationship

$$\frac{P_o}{P} = \left(1 + \frac{\gamma-1}{2}M^2\right)^{\gamma/(\gamma-1)} \tag{7}$$

equation 6 may be rewritten in terms of the pressure ratio as

$$\frac{A^*}{A} = \frac{\left[1 - \left(\frac{P}{P_o}\right)^{\frac{\gamma-1}{\gamma}}\right]^{1/2} \left(\frac{P}{P_o}\right)^{1/\gamma}}{\left(\frac{\gamma-1}{2}\right)^{1/2} \left(\frac{2}{\gamma+1}\right)^{[(\gamma+1)/2(\gamma-1)]}} \tag{8}$$

Since the mass flow through any section of the channel must be constant, equation 1 may be rewritten as

$$m = \rho^* \; a^* \; A^* \tag{9}$$

Relating the mass flow (m) to the sonic conditions using equation 3 and the relationship

$$\frac{a^*}{a_o} = \left(\frac{2}{\gamma+1}\right)^{1/2}$$

the mass flow equation becomes

$$m = \left(\frac{2}{\gamma+1}\right)^{[(\gamma+1)/2(\gamma-1)]} \rho_o \; a_o \; A^* \tag{10}$$

which for air may be reduced to

$$m = 0.579 \; \rho_o \; a_o \; A^* \tag{11}$$

where a_o is the velocity of sound in the upstream reservoir.

Using equations 8 and 11, the mass flow through a channel may be expressed in terms of the density and speed of sound in the upstream reservoir, the pressure ratio across the channel, and the ratio of specific heats of the gas (C_p/C_v).

The actual measurable flow through an orifice or channel will differ from the theoretical value due to nonconservative forces such as friction. A correction factor, the nozzle discharge coefficient, must be included in order to achieve results which closely match the actual mass flow. Choosing a typical value of 0.90[B2] for the discharge coefficient (C_d), equation 11 becomes

$$m = 0.521 \; \rho_o \, a_o \, A^* \qquad (12)$$

Equations 8 and 12 may be used in conjunction with the general gas law equation

$$pV = nRT, \text{ with } n = m/M \qquad (13)$$

where:
- p is absolute gas pressure
- V is volume
- R is the universal gas constant
- T is temperature (absolute)
- m is the mass of gas
- M is the gas molecular weight

to determine container and/or reservoir pressures given the specific initial conditions.

With the exception of program BACKFL, the following parameters are common to the computer programs in this report;

C: discharge coefficient

PMET: psi to kPa conversion

VMET: $in.^3$ to liter conversion

DMET: inches to mm or micrometers

VULG: ullage volume ($in.^3$)

VMET: ullage volume (liters)

PINL: upstream pressure (psig)

P1: upstream pressure (psig)

VTIM: vent time (seconds)

[B2] A. H. Shapiro, "The Dynamics and Thermodynamics of Compressible Fluid Flow," vol I, Ronald Press, New York, 1953.

ETIM: elapsed time (seconds)

DTM: integration time increment (seconds)

XMWT: gas molecular weight

GA: ratio of specific heats (γ)

T: temperature (°F)

XMASS: computed from equation 13 (m)

RHO: gas density (ρ)

EX3: $[(\gamma-1)/2]^{1/2}$ from equation 8

EX4: $[2/(\gamma+1)]^{[(\gamma+1)/2(\gamma-1)]}$ from equation 8

P2: downstream pressure

RATIO: critical pressure ratio

ASTAR: A* from equation 8

XMDT: m from equation 12

```
C**** THIS PROGRAM CALCULATES THE FLOW OF GAS THROUGH AN ORIFACE BETWEEN TWO
C**** CONTAINERS. THE COMPUTATION IS DONE IN REVERSE SO THAT THE INITIAL
C**** PRESSURE IN THE UPSTREAM CONTAINER CAN BE CALCULATED BASED ON THE
C**** DESIRED FINAL PRESSURE IN THE DOWNSTREAM CONTAINER AND THE DESIRED FILL
C**** TIME.
      PROGRAM BACKFL(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION P1(151),P2(151),RHO1(151),RHO2(151),XM1(151),XM2(151)
C**** ASTAR    - EFFECTIVE FLOW AREA OF THE ORIFACE (SQ.FT.).
C**** DTM      - CALCULATION TIME INTERVAL (SECONDS).
C**** GAM      - RATIO OF SPECIFIC HEATS.
C**** P1I      - FINAL PRESSURE IN THE UPSTREAM CONTAINER (PSIG).
C**** P1       -   UPSTREAM PRESSURE.
C**** P2       - DOWNSTREAM PRESSURE.
C**** P2(151)  - DOWNSTREAM PRESSURE AT THE START OF THE FILL CYCLE.
C**** RATIO    - RATIO OF THE DOWNSTREAM TO THE UPSTREAM PRESSURES USED TO
C****            DETERMINE SONIC FLOW.
C**** RHO1     -   UPSTREAM GAS DENSITY (LB/CU.FT.).
C**** RHO2     - DOWNSTREAM GAS DENSITY (LB/CU.FT.).
C**** T        - GAS TEMPERATURE (F).
C**** V1       -   UPSTREAM CONTAINER VOLUME (CU.IN.).
C**** V2       - DOWNSTREAM CONTAINER VOLUME (CU.IN.).
C**** XMDT     - MASS FLOW OF GAS DURING THE TIME (DTM).
C**** XMWT     - GAS MOLECULAR WEIGHT (LB/LB-MOLE).
C**** XM1      - MASS OF GAS IN THE   UPSTREAM CONTAINER (LB).
C**** XM2      - MASS OF GAS IN THE DOWNSTREAM CONTAINER (LB).
C**** INITIALIZE THE VARIABLES FOR AIR.
      GAM=1.4
      XMWT=28.97
      DTM=0.01
      T=70.

C**** READ IN THE VALUES FOR THE CASE DESIRED.
   70 READ(5,1) P1I,D,V1,V2
    1 FORMAT(F6.1,F8.5,F6.1,F6.1)
      IF(EOF(5)) 80,90
C**** CONVERT THE UPSTREAM PRESSURE TO (PSFA) AND THE VOLUMES TO (CU.FT.)
C**** SET THE FINAL DOWNSTREAM PRESSURE (P2I) TO 2505.6 PSFA (17.4 PSIA).
   90 P1I=(P1I+14.7)*144.
      P2I=17.4*144.
      V1=V1/1728.
      V2=V2/1728.
      K=0
C**** SET THE UPSTREAM AND DOWNSTREAM PRESSURES TO THE FINAL VALUES.
C**** CALCULATE INITIAL VALUES FOR ASTAR AND RATIO.
   50 P1(1)=P1I
      P2(1)=P2I
      ASTAR=0.785398*(D**2)/144.
      RATIO=P2(1)/P1(1)
C**** IF THE FLOW IS SUBSONIC CALCULATE A NEW ASTAR FROM STATEMENT 100.
      IF(RATIO.GT..5283) GO TO 100
      GO TO 110
  100 ASTAR=(0.785398*(D**2)/144.*SQRT(1.-(RATIO**((GAM-1.)/GAM)))*
     +(RATIO**(1./GAM)))/(SQRT((GAM-1.)/2.)*((2./(GAM+1.))**(0.5*(GAM
     ++1.)/(GAM-1.))))
C**** CALCULATE THE DENSITIES AND MASSES OF GAS IN EACH CONTAINER AT THE FINAL
C**** CONDITIONS.
  110 RHO1(1)=P1(1)/(1545.31/XMWT*(T+459.7))
      RHO2(1)=P2(1)/(1545.31/XMWT*(T+459.7))
      XM1(1)=RHO1(1)*V1
      XM2(1)=RHO2(1)*V2
```

```
C**** THE FOLLOWING LOOP DETERMINES THE MASS FLOW DURING TIME (DTM) BASED ON
C**** THE UPSTREAM AND DOWNSTREAM PRESSURES. THE MASS OF GAS IN THE DOWNSTREAM
C**** CONTAINER IS THEN DECREMENTED BY THIS AMOUNT AND THE MASS OF GAS IN THE
C**** UPSTREAM CONTAINER IS INCREMENTED BY THIS AMOUNT. THE PRESSURES AND
C**** DENSITIES AT THIS PREVIOUS POINT IN TIME ARE CALCULATED AND NEW VALUES
C**** ARE OBTAINED FOR ASTAR AND RATIO. THIS CALCULATION CONTINUES UNTIL A TOTAL
C**** FILL TIME OF 1.5 SECONDS IS REACHED.
      DO 10 I=2,151
      XMDT=(2./(GAM+1.))**((GAM+1.)/(2.*(GAM-1.)))*RHO1(I-1)*SQRT(GAM*
     +1716.502*(T+459.7))*ASTAR*DTM
      XM1(I)=XM1(I-1)+XMDT
      XM2(I)=XM2(I-1)-XMDT
      P1(I)=(XM1(I)*(T+459.7)*1545.31)/(XMWT*V1)
      P2(I)=(XM2(I)*(T+459.7)*1545.31)/(XMWT*V2)
      RATIO=P2(I)/P1(I)
      IF(RATIO.GT..5283) GO TO 120
      GO TO 130
  120 ASTAR=(0.785398*(D**2)/144.*SQRT(1.-(RATIO**((GAM-1.)/GAM)))*
     +(RATIO**(1./GAM)))/(SQRT((GAM-1.)/2.)*((2./(GAM+1.))**(0.5*(GAM
     ++1.)/(GAM-1.))))
  130 RHO1(I)=P1(I)/(1545.31/XMWT*(T+459.7))
   10 RHO2(I)=P2(I)/(1545.31/XMWT*(T+459.7))
C**** THE PRESSURE IN THE DOWNSTREAM CONTAINER IS CHECKED.
C****       *IF GREATER THAN ATMOSPHERIC, THE FINAL UPSTREAM PRESSURE IS
C****        INCREMENTED BY 0.1 PSIG AND THE CALCULATION IS REPEATED.
      IF(((P2(151)/144.)-14.7).GT.0.05) GO TO 40
C****       *IF LESS THAN ATMOSPHERIC, THE FINAL UPSTREAM PRESSURE IS DECREMENTED
C****        BY 0.01 PSIG AND THE CALCULATION IS REPEATED.
      IF(((P2(151)/144.)-14.7).LT.-0.05) GO TO 20
C****       *IF ATMOSPHERIC, THE RESULTS ARE PRINTED.
      GO TO 30
   40 P1I=P1I+14.4
      GO TO 50
   20 K=K+1
      IF(K.GT.99) GO TO 30
      P1I=P1I-1.44
      GO TO 50
   30 V2=V2*1728.
```

```
      PROGRAM ORIF(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT)
      DIMENSION PF(10,20),PFM(10,20),PDLT(10,20),PMLT(10,20),
     +DIA(10,20),DIAM(10,20),VULG(10),VULM(10),CN(10),CH(10)
      C=0.90
      PMET=6.894
      VMET=16.39/1000.
      DMET=25400.
      DO 10 I=1,2
      WRITE(6,103)
103   FORMAT(2X,20HENTER CONTAINER TYPE,1X)
      READ(5,503) CN(I)
      WRITE(6,104)
104   FORMAT(2X,17HENTER CHARGE TYPE,1X)
      READ(5,503) CH(I)
503   FORMAT(A6)
100   FORMAT(2X,22HENTER VENT TIME (SEC.))
101   FORMAT(2X,31HENTER CONTAINER VOLUME (CU IN) )
102   FORMAT(2X,32HENTER CONTAINER PRESSURE (PSIG) )
      WRITE(6,101)
      READ(5,501) VULG(I)
      VULM(I)=VULG(I)*VMET
10    CONTINUE
      WRITE(6,102)
      READ(5,502) PINL
      PINM=PINL*PMET
501   FORMAT(F8.2)
502   FORMAT(F8.4)
      WRITE(6,100)
      READ(5,500) VTIM
500   FORMAT(F5.2)
      XMWT=28.97
      T=72.
      GA=1.4
      EX3=SQRT((GA-1.)/2.)
      EX4=(2./(GA+1.))**(0.5*(GA+1.)/(GA-1.))
      DTM=VTIM/50.
      DTM=VTIM/50.
      DO 20 I=1,2
      P1=(PINL+14.7)*144.
      XMASS=(P1/(1545.31/XMWT*(T+459.7)))*(VULG(I)/1728.)
      XMS=XMASS
      D=0.001
      P2=14.7*144.
      DO 30 J=1,10
      P1=(PINL+14.7)*144.
      DIA(I,J)=D
      DIAM(I,J)=DIA(I,J)*DMET
      DO 40 N=1,50
      RATIO=P2/P1
      RHO=(P1/(1545.31/XMWT*(T+459.7)))
      IF(RATIO.GE.1.) GO TO 21
      ASTAR=((3.14159/144.)*((DIA(I,J)**2)/4.)*SQRT(1.-(RATIO**
     +((GA-1.)/GA)))*(RATIO**(1./GA)))/(EX3*EX4)
      IF(RATIO.LE.0.5283) ASTAR=(3.14159/144.)*((DIA(I,J)**2)/4.)
      XMDT=C*0.579*RHO*SQRT(GA*1717.93*(T+459.7))*ASTAR
      XMASS=XMASS-(XMDT*DTM)
      P1=(XMASS*(T+459.7)*1545.31*1728.)/(XMWT*VULG(I))
      IF(P1.LT.2116.8) GO TO 21
      GO TO 40
21    P1=2116.8
      GO TO 22
   40 CONTINUE
 22   PF(I,J)=(P1/144.)-14.7
      D=D+0.001
      XMASS=XMS
      PDLT(I,J)=PINL-PF(I,J)
      PMLT(I,J)=PDLT(I,J)*PMET
30    CONTINUE
20    CONTINUE
```

```
      PROGRAM DATA1(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT)
      DIMENSION PF(50),TFIL(50),DIAM(50),DIA(50),PKPA(50)
      C=0.90
      D=0.05
      PMET=6.894
      DMET=25.4
      VMET=16.39
      XMUT=28.97
      R=1545.31
      G=32.174
      GA=1.4
      EX3=SQRT((GA-1.)/2.)
      EX4=(2./(GA+1.))**(0.5*(GA+1.)/(GA-1.))
      T=72.
      TR=T+459.6
      DTM=0.005
101   FORMAT(2X,28HENTER ULLAGE VOLUME (CU IN) )
102   FORMAT(2X,32HENTER RESERVOIR PRESSURE (PSIG) )
      WRITE(6,101)
      READ(5,501) VULG
      VULM=VULG*VMET/1000.
      WRITE(6,102)
      READ(5,502) P1
      PM=P1*PMET
501   FORMAT(F8.2)
502   FORMAT(F8.4)
      P1=(P1+14.7)*144.
      RHO=P1/(1545.31/XMUT*TR)
      DO 10 I=1,28
      P2=14.7*144.
      XMASS=(P2/(1545.31/XMUT*TR))*(VULG/1728.)
      ETIM=0.00
      DIA(I)=D
      DIAM(I)=DIA(I)*DMET
      DO 20 J=1,2000
      RATIO=P2/P1
      RATIO=P2/P1
      IF(RATIO.GE.1.) GO TO 21
      ASTAR=((3.1416/144.)*((D**2)/4.)*SQRT(1.-(RATIO**
     +((GA-1.)/GA)))*(RATIO**(1./GA)))/(EX3*EX4)
      IF(RATIO.LE.0.5283) ASTAR=(3.1416/144.)*((D**2)/4.)
      XMDT=0.579*RHO*SQRT(GA*1717.93*TR)*ASTAR*DTM*C
      XMASS=XMASS+XMDT
      P2=(XMASS*TR*R*1728.)/(XMUT*VULG)
      IF(P2.GE.2548.8) GO TO 21
      ETIM=ETIM+0.005
   20 CONTINUE
 21   PF(I)=(P2/144.)-14.7
      PKPA(I)=PF(I)*PMET
      TFIL(I)=ETIM
      D=D+0.01
10    CONTINUE
```

```
      PROGRAM DATA2(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,TAPE7)
      DIMENSION PF(50),TFIL(50),PENG(50),PKPA(50)
      C=0.90
      R=1545.31
      G=32.174
      D=0.01
      PMET=6.894
      DMET=25.4
      VMET=16.39
      XMUT=28.97
      GA=1.4
      EX3=SQRT((GA-1.)/2.)
      EX4=(2./(GA+1.))**(0.5*(GA+1.)/(GA-1.))
      T=72.
      TR=T+459.6
      DTM=0.005
101   FORMAT(2X,28HENTER ULLAGE VOLUME (CU IN) )
102   FORMAT(2X,42HENTER EQUIVALENT ORIFICE DIAMETER (INCHES))
      WRITE(6,101)
      READ(5,501) VULG
      VULM=VULG*VMET/1000.
      WRITE(6,102)
      READ(5,502) DIA
501   FORMAT(F8.2)
502   FORMAT(F8.4)
      PABS=19.7*144.
      DO 10 I=1,20
      P2=14.7*144.
      XMASS=(P2/(R/XMUT*TR))*(VULG/1728.)
      ETIM=0.00
      P1=PABS
      RHO=P1/(R/XMUT*TR)
      PENG(I)=(P1/144.)-14.7
      PKPA(I)=PENG(I)*PMET
      DIAM=DIA*DMET
      DO 20 J=1,2000
      DO 20 J=1,2000
      RATIO=P2/P1
      IF(RATIO.GE.1.) GO TO 21
      ASTAR=((3.14159/144.)*((DIA**2.)/4.)*SQRT(1.-(RATIO**
     +((GA-1.)/GA)))*(RATIO**(1./GA)))/(EX3*EX4)
      IF(RATIO.LE.0.5283) ASTAR=(3.14159/144.)*((DIA**2.)/4.)
      XMDT=C*0.579*RHO*SQRT(GA*1717.93*TR)*ASTAR*DTM
      XMASS=XMASS+XMDT
      P2=(XMASS*TR*R*1728.)/(XMUT*VULG)
      IF(P2.GE.2548.8) GO TO 21
      ETIM=ETIM+0.005
   20 CONTINUE
21    TFIL(I)=ETIM
      PABS=PABS+(5.0*144.)
10    CONTINUE
```

```
      PROGRAM DATA3(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT,TAPE7)
      DIMENSION PKPA(50),PF(50),DIAM(50),DIA(50)
      C=0.90
      PMET=6.894
      VMET=16.39/1000.
      DMET=25.4
100   FORMAT(2X,22HENTER VENT TIME (SEC.))
101   FORMAT(2X,31HENTER CONTAINER VOLUME (CU IN) )
102   FORMAT(2X,32HENTER CONTAINER PRESSURE (PSIG) )
      WRITE(6,101)
      READ(5,501) VULG
      VULM=VULG*VMET
      WRITE(6,102)
      READ(5,502) PINL
      PINM=PINL*PMET
501   FORMAT(F8.2)
502   FORMAT(F8.4)
      WRITE(6,100)
      READ(5,500) VTIM
500   FORMAT(F5.2)
      XMUT=28.97
      T=72.
      GA=1.4
      DTM=VTIM/50.
      PP=(PINL+14.7)*144.
      XMASS=(PP/(1545.31/XMUT*(T+459.7)))*(VULG/1728.)
      XMS=XMASS
      D=0.01
      P2=14.7*144.
      DO 10 I=1,50
      P1=(PINL+14.7)*144.
      DIA(I)=D
      DIAM(I)=DIA(I)*DMET
      EX3=SQRT((GA-1.)/2.)
      EX4=(2./(GA+1.))**(0.5*(GA+1.)/(GA-1.))
      EX4=(2./(GA+1.))**(0.5*(GA+1.)/(GA-1.))
      DO 20 J=1,50
      RATIO=P2/P1
      RHO=P1/(1545.31/XMUT*(T+459.7))
      ASTAR=((3.14159/144.)*((DIA(I)**2)/4.)*SQRT(1.-
     +(RATIO**((GA-1.)/GA)))*(RATIO**(1./GA)))/(EX3*EX4)
      IF(RATIO.LE.0.5283) ASTAR=(3.14159/144.)*((DIA(I)**2)/4.)
      XMDT=C*0.579*RHO*SQRT(GA*1717.93*(T+459.7))*ASTAR
      XMASS=XMASS-(XMDT*DTM)
      P1=(XMASS*(T+459.7)*1545.31*1728.)/(XMUT*VULG)
      IF(P1.LE.2116.8) GO TO 21
      GO TO 20
21    P1=2116.8
      GO TO 22
   20 CONTINUE
 22   PF(I)=(P1/144.)-14.7
      PKPA(I)=PF(I)*PMET
      D=D+0.01
      XMASS=XMS
10    CONTINUE
```

```
      PROGRAM DATA4(INPUT,TAPE5=INPUT,OUTPUT,TAPE6=OUTPUT)
      DIMENSION PF(10,20),PFM(10,20),PDLT(10,20),PMLT(10,20),
     +DIA(10,20),DIAM(10,20),VULG(10),VULM(10),CN(10),CH(10)
      C=0.90
      PMET=6.894
      VMET=16.39/1000.
      DMET=25400.
      WRITE(6,300)
300   FORMAT(2X,14HENTER TABLE NO,1X)
      READ(5,600) TAB
600   FORMAT(A3)
      WRITE(6,301)
301   FORMAT(2X,15HENTER FIGURE NO,1X)
      READ(5,601) FIG
601   FORMAT(A2)
      DO 10 I=1,2
      WRITE(6,103)
103   FORMAT(2X,20HENTER CONTAINER TYPE,1X)
      READ(5,503) CN(I)
      WRITE(6,104)
104   FORMAT(2X,17HENTER CHARGE TYPE,1X)
      READ(5,503) CH(I)
503   FORMAT(A6)
100   FORMAT(2X,22HENTER VENT TIME (SEC.))
101   FORMAT(2X,31HENTER CONTAINER VOLUME (CU IN) )
102   FORMAT(2X,32HENTER CONTAINER PRESSURE (PSIG) )
      WRITE(6,101)
      READ(5,501) VULG(I)
      VULM(I)=VULG(I)*VMET
10    CONTINUE
      WRITE(6,102)
      READ(5,502) PINL
      PINM=PINL*PMET
501   FORMAT(F8.2)
502   FORMAT(F8.4)
      WRITE(6,100)
      WRITE(6,100)
      READ(5,500) VTIM
500   FORMAT(F5.2)
      XMUT=28.97
      T=72.
      GA=1.4
      EX3=SQRT((GA-1.)/2.)
      EX4=(2./(GA+1.))**(0.5*(GA+1.)/(GA-1.))
      DTM=VTIM/50.
      DO 20 I=1,2
      PP=(PINL+14.7)*144.
      RHO=PP/(1545.31/XMUT*(T+459.7))
      XMASS=(PP/(1545.31/XMUT*(T+459.7)))*(VULG(I)/1728.)
      XMS=XMASS
      D=0.001
      P2=14.7*144.
      DO 30 J=1,10
      P1=(PINL+14.7)*144.
      DIA(I,J)=D
      DIAM(I,J)=DIA(I,J)*DMET
      DO 40 N=1,50
      RATIO=P2/P1
      IF(RATIO.GE.1.) GO TO 22
      ASTAR=((3.14159/144.)*((DIA(I,J)**2.)/4.)*SQRT(1.-
     +(RATIO**((GA-1.)/GA)))*(RATIO**(1./GA)))/(EX3*EX4)
      IF(RATIO.LE.0.5283) ASTAR=(3.14159/144.)*((DIA(I,J)**2)/4.)
      XMDT=C*0.579*RHO*SQRT(GA*1717.93*(T+459.7))*ASTAR
      XMASS=XMASS-(XMDT*DTM)
      P1=(XMASS*(T+459.7)*1545.31*1728.)/(XMUT*VULG(I))
      IF(P1.LT.2116.8) GO TO 21
      GO TO 40
21    P1=2116.8
      GO TO 22
   40 CONTINUE
 22   PF(I,J)=(P1/144.)-14.7
      D=D+0.001
                                  END

      D=D+0.001
      XMASS=XMS
      PDLT(I,J)=PINL-PF(I,J)
      PMLT(I,J)=PDLT(I,J)*PMET
30    CONTINUE
20    CONTINUE
```

APPENDIX C

RESERVOIR PRESSURE DATA

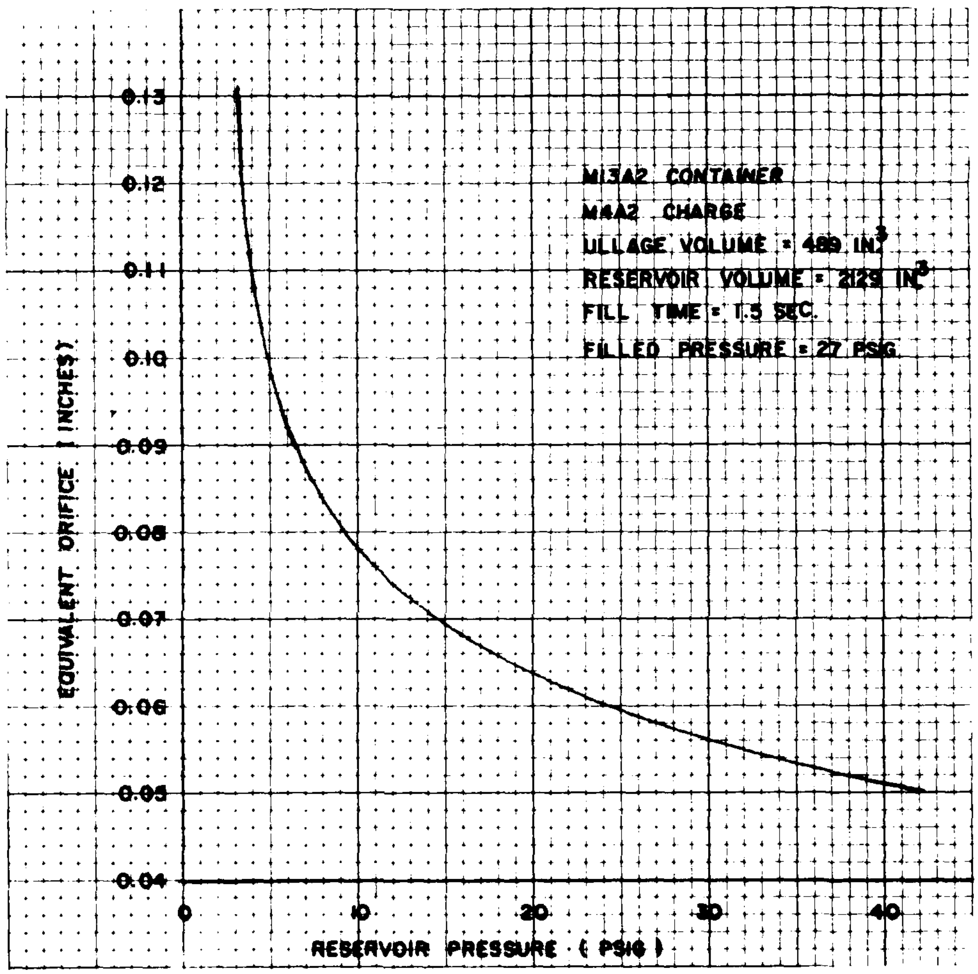


Figure C-1. Reservoir pressure data--M13A2 container and M4A2 charge

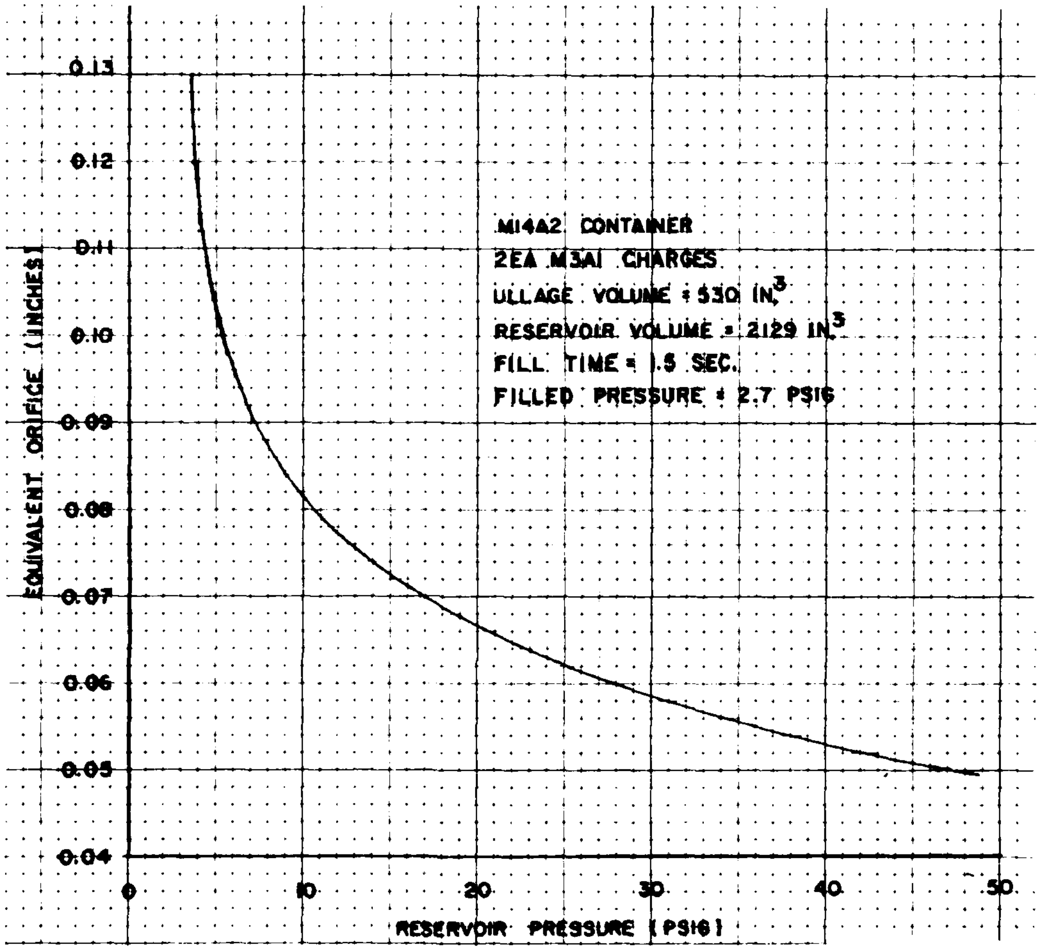


Figure C-2. Reservoir pressure data--M14A2 container and two M3A1 charges

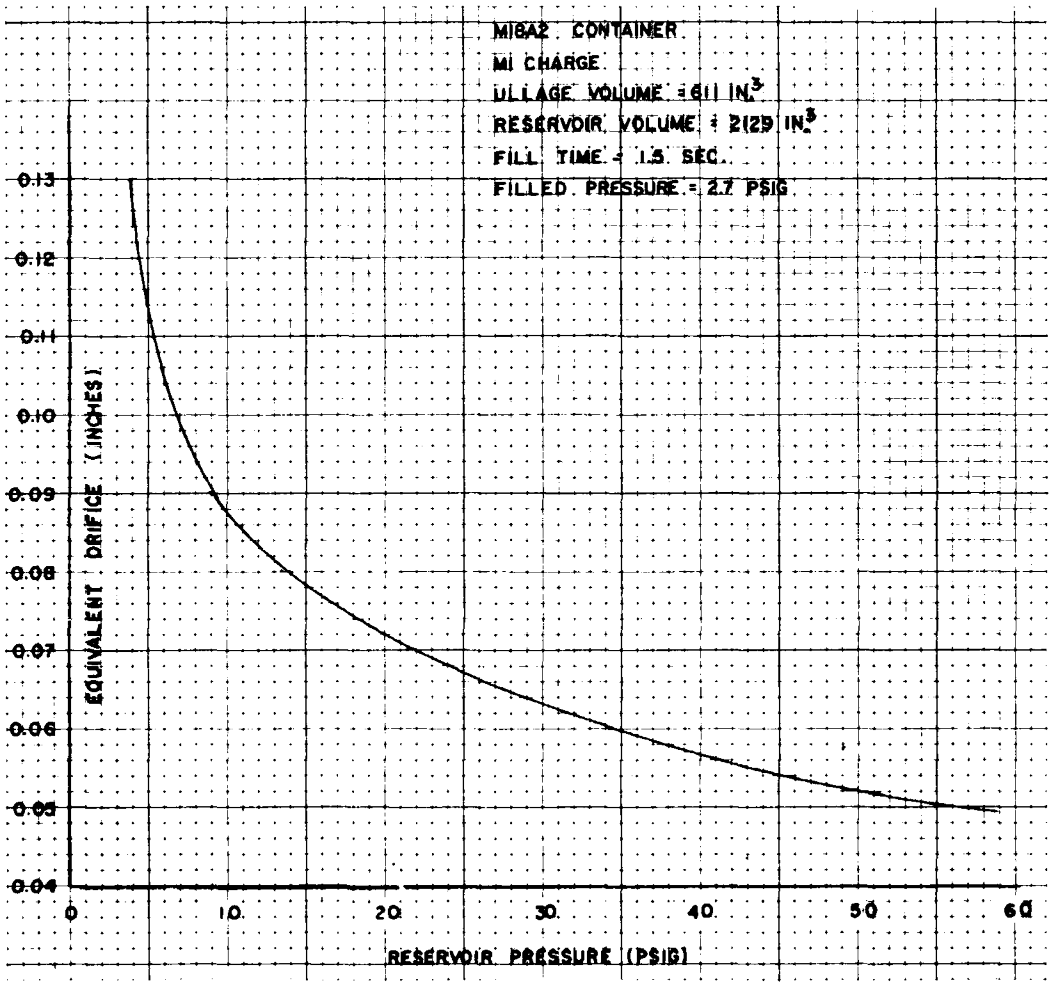


Figure C-3. Reservoir pressure data--M18A2 container and M1 charge

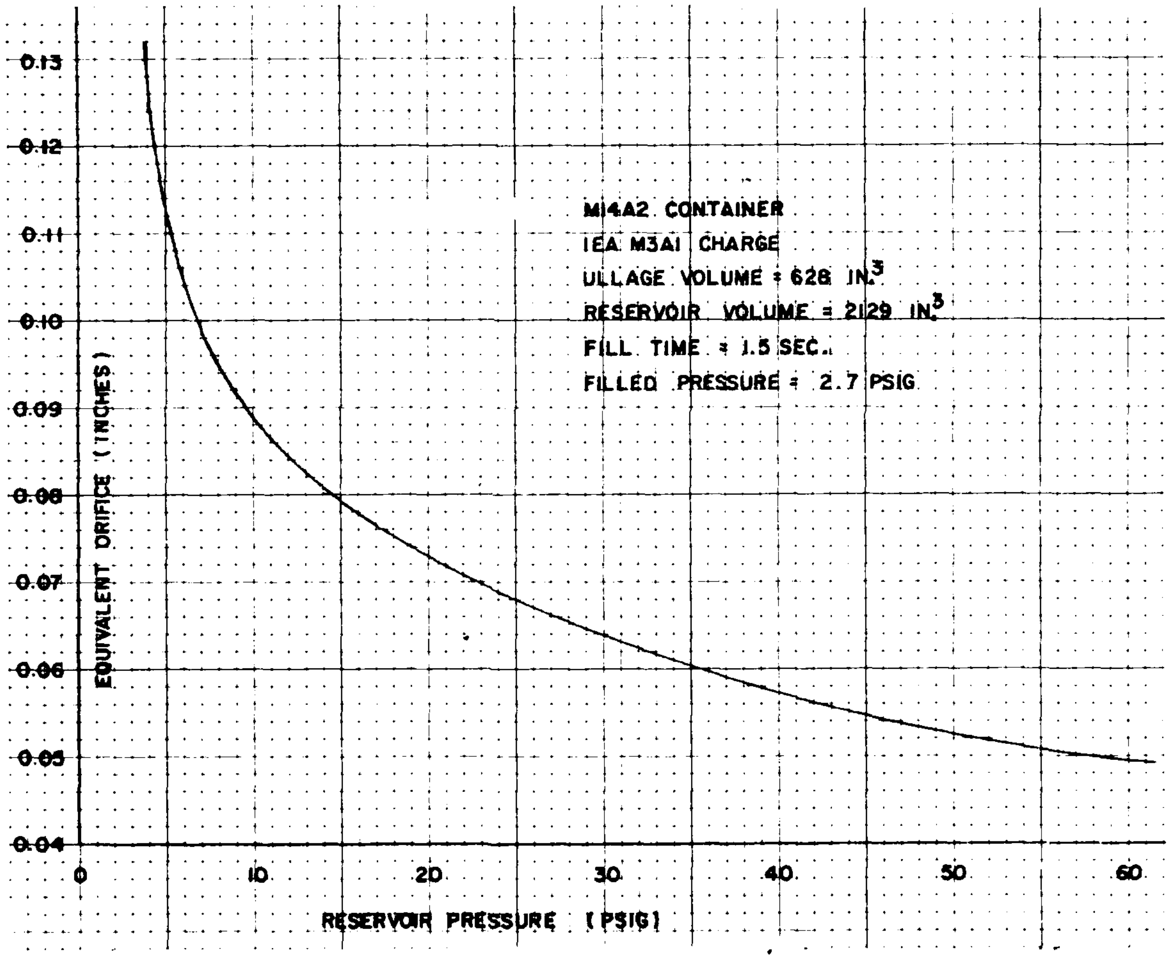


Figure C-4. Reservoir pressure data--M14A2 container and M3A1 charge

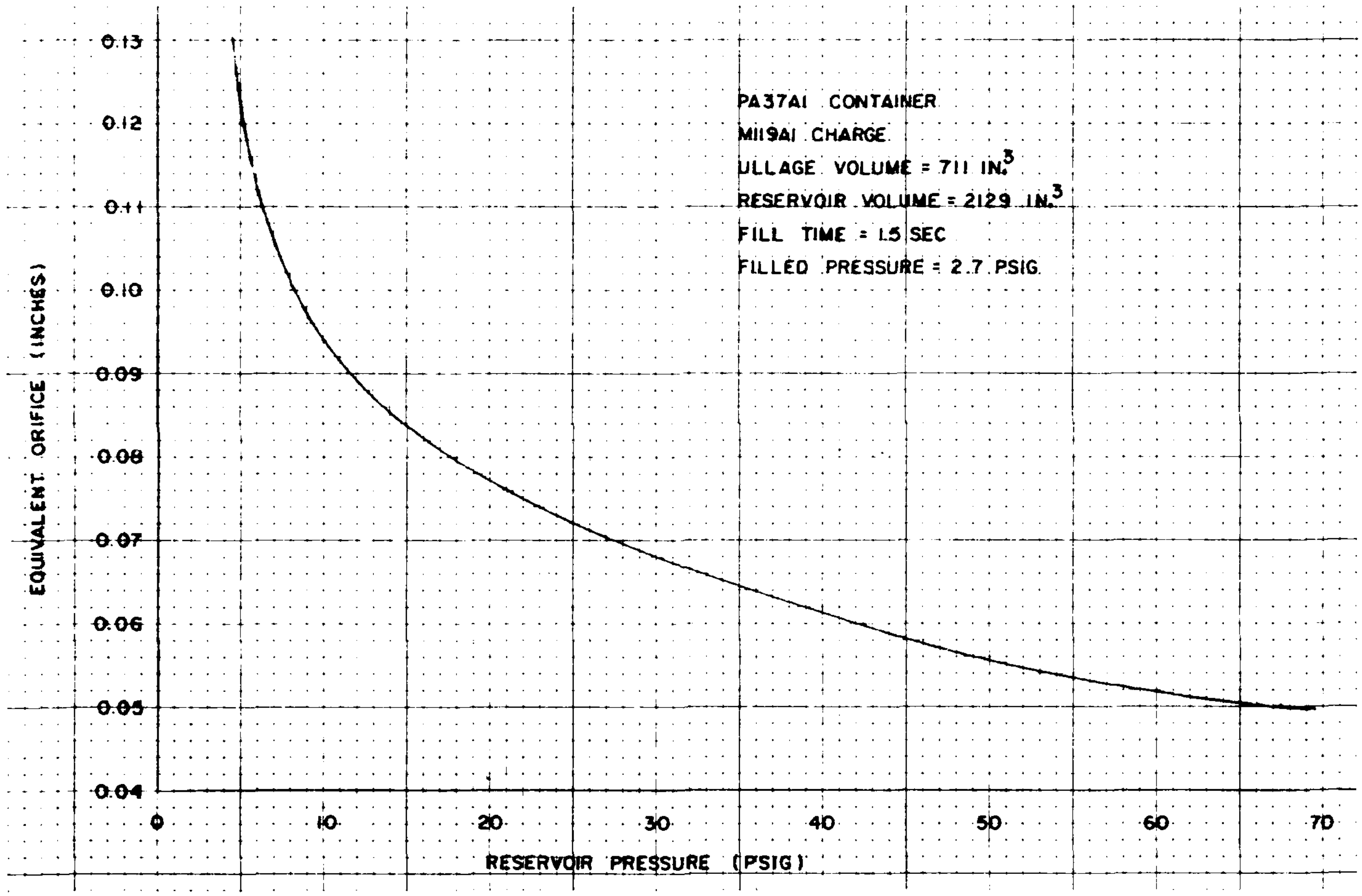


Figure C-5. Reservoir pressure data--PA37A1 container and M119A1 charge

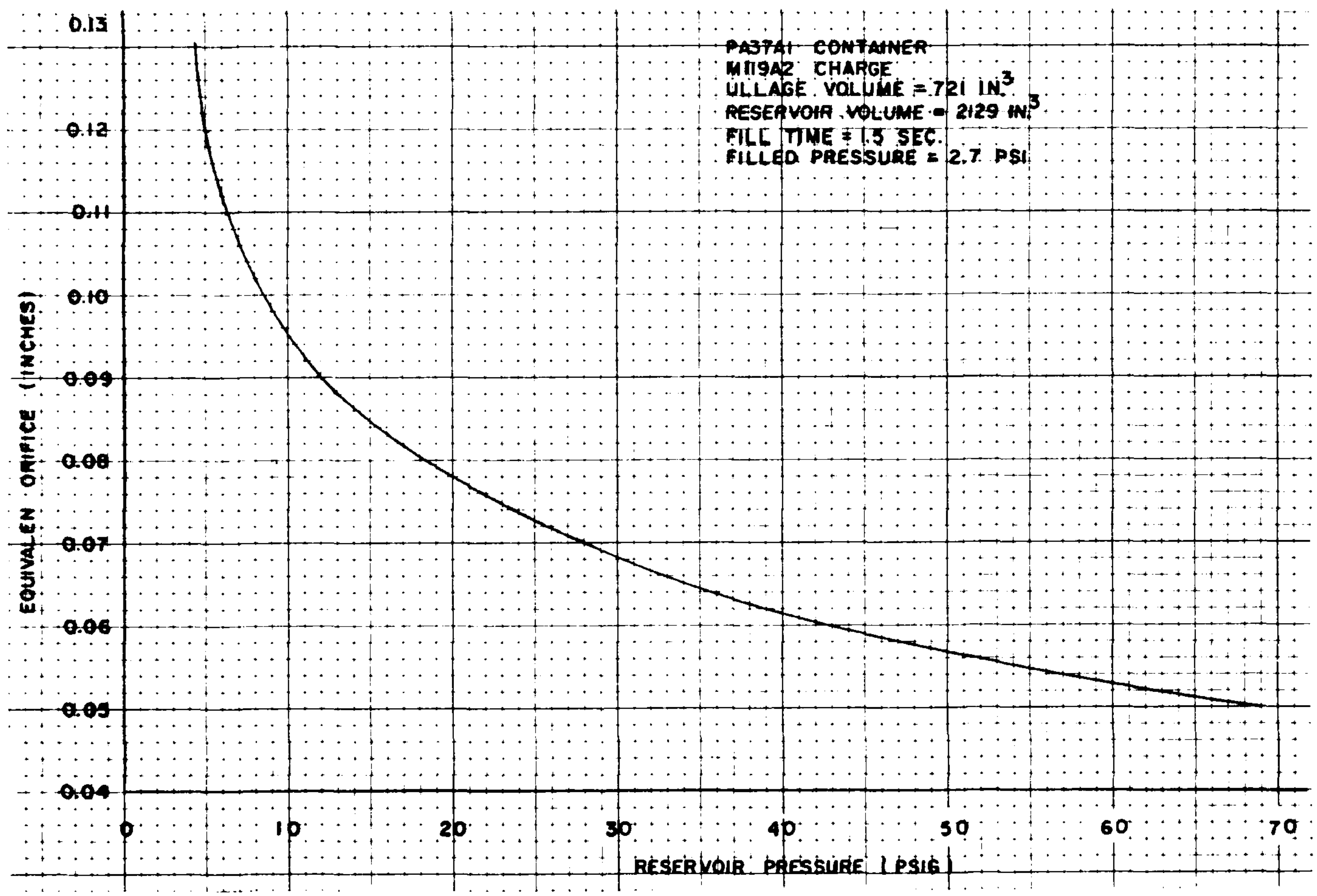


Figure C-6. Reservoir pressure data--PA37A1 container and M119A2 charge

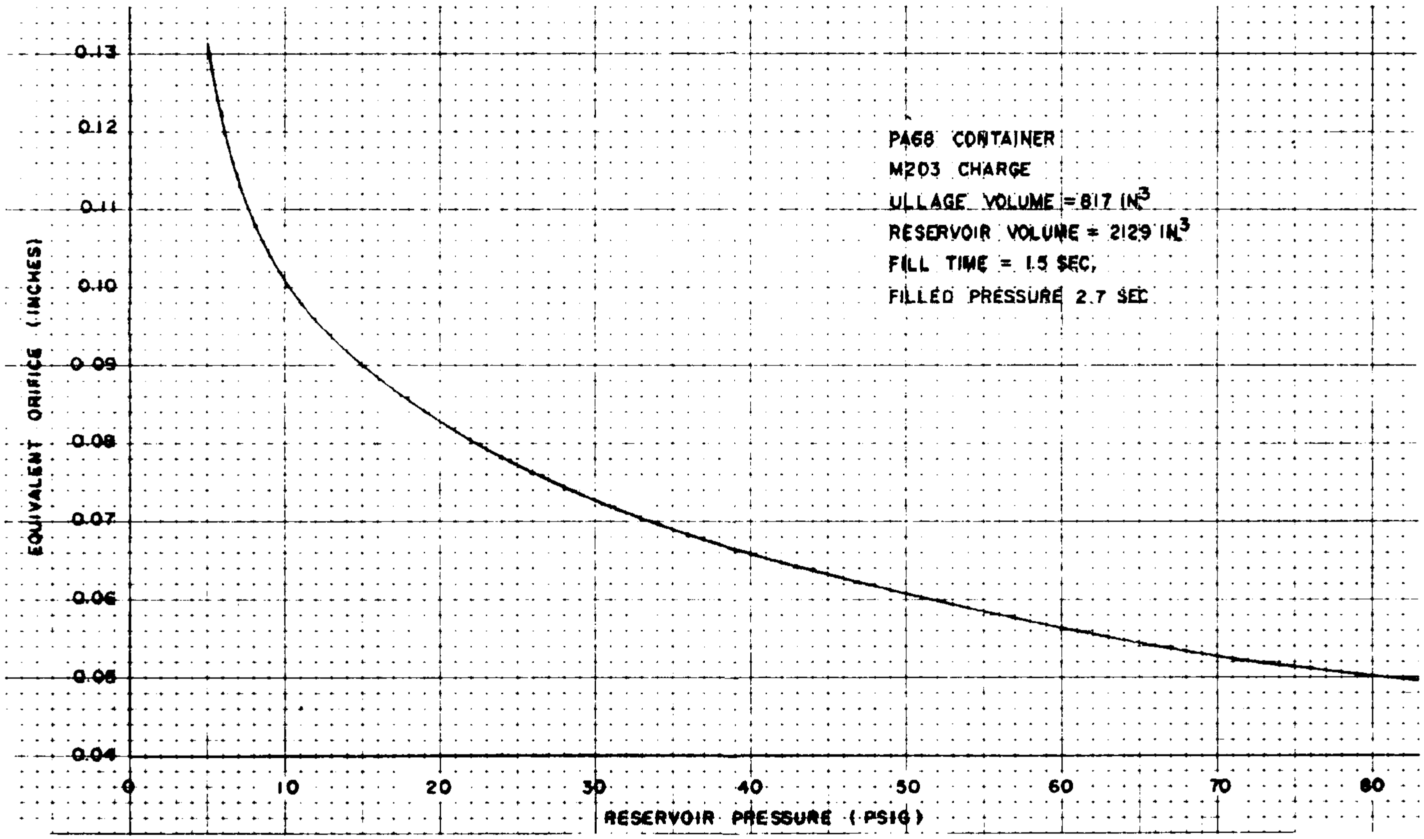


Figure C-7. Reservoir pressure data--PA68 container and M203 charge

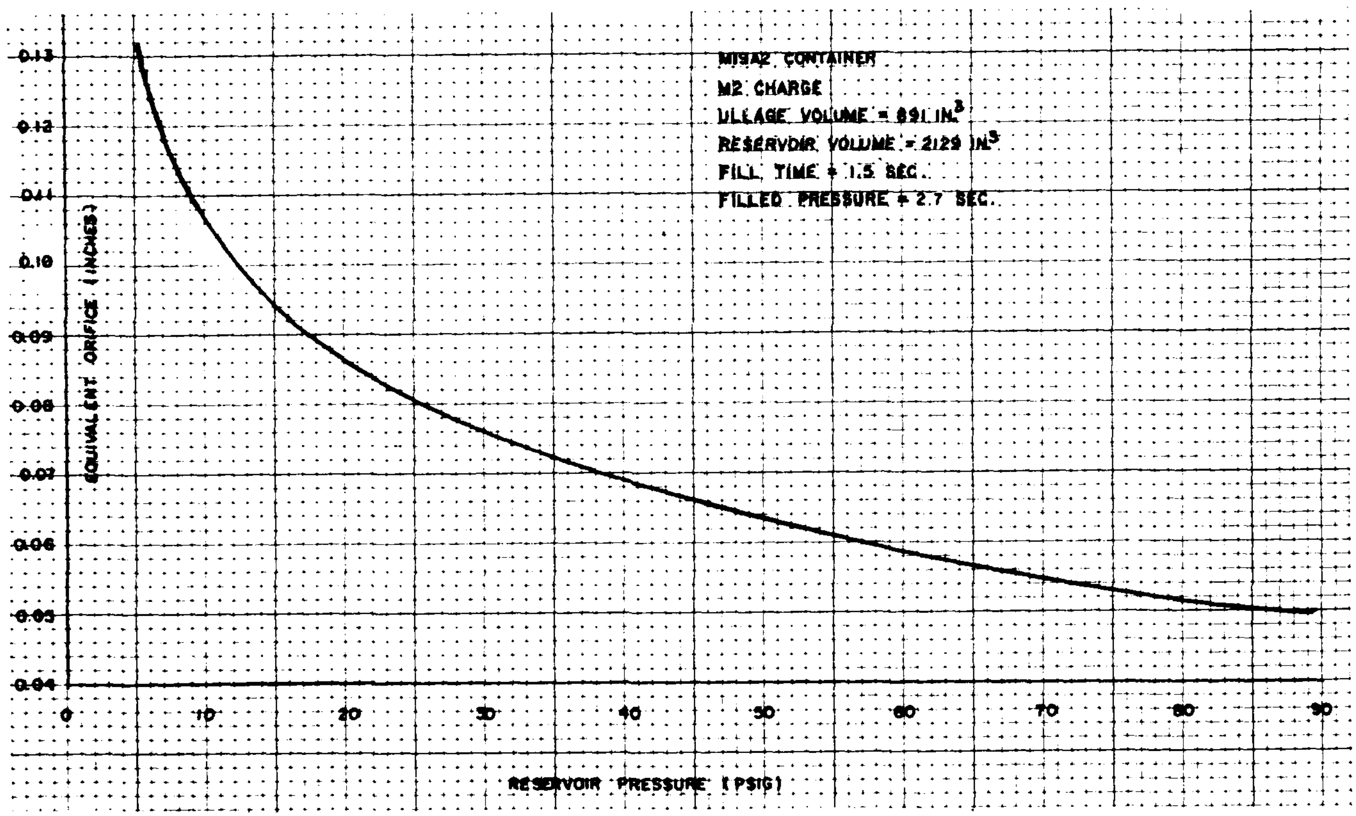


Figure C-8. Reservoir pressure data--M19A2 container and M2 charge

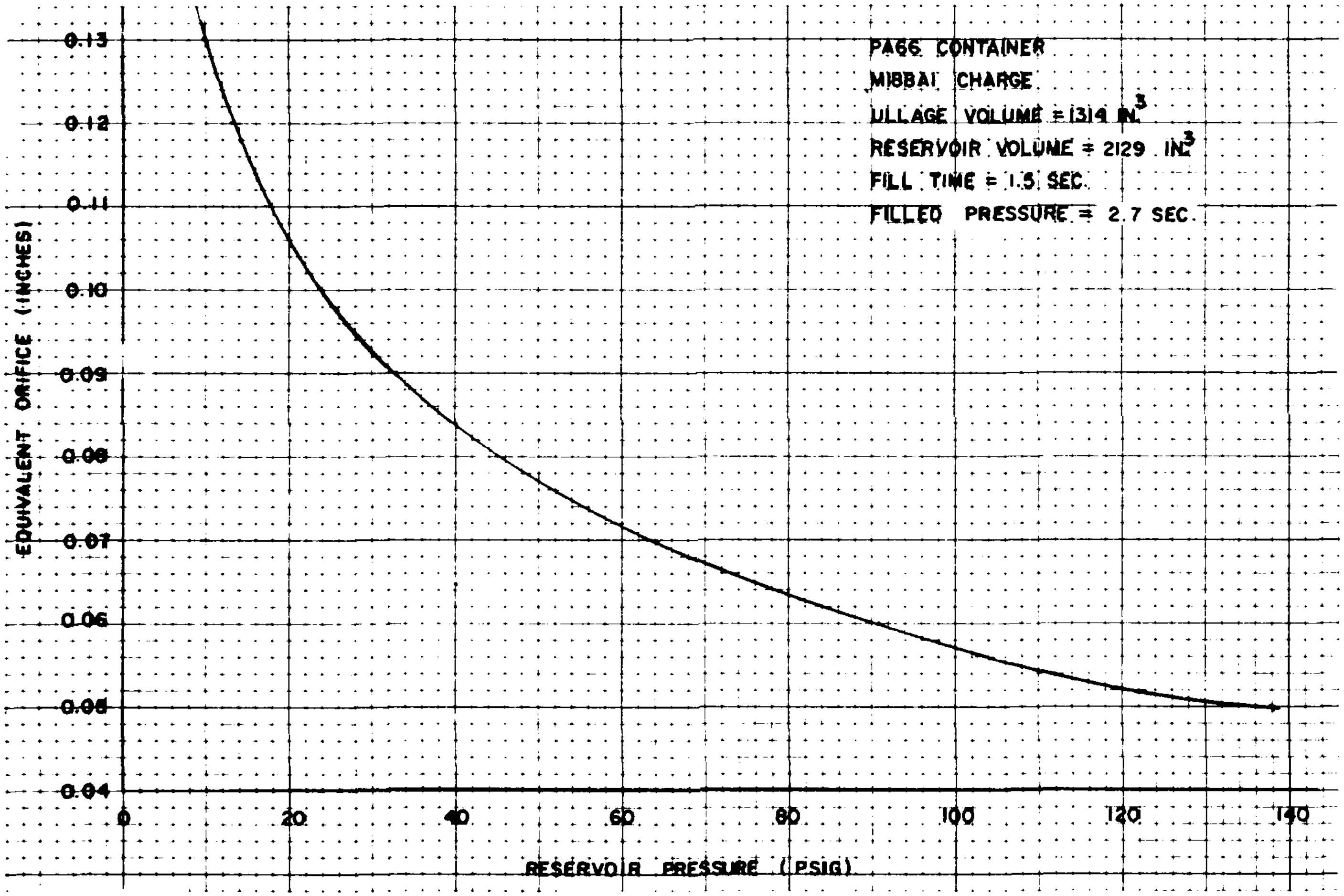


Figure C-9. Reservoir pressure data--PA66 container and M188A1 charge

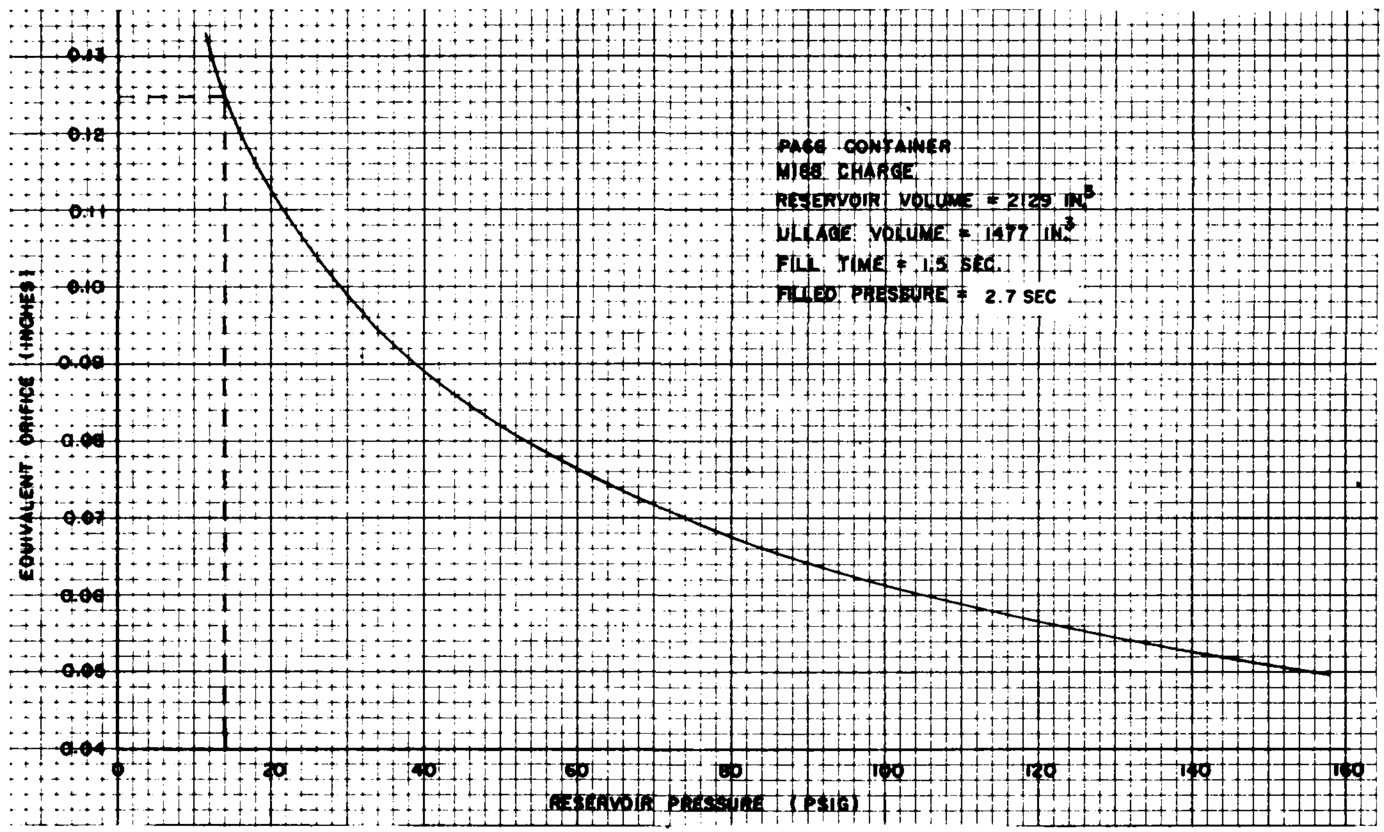


Figure C-10. Reservoir pressure data--PA66 container and M188 charge

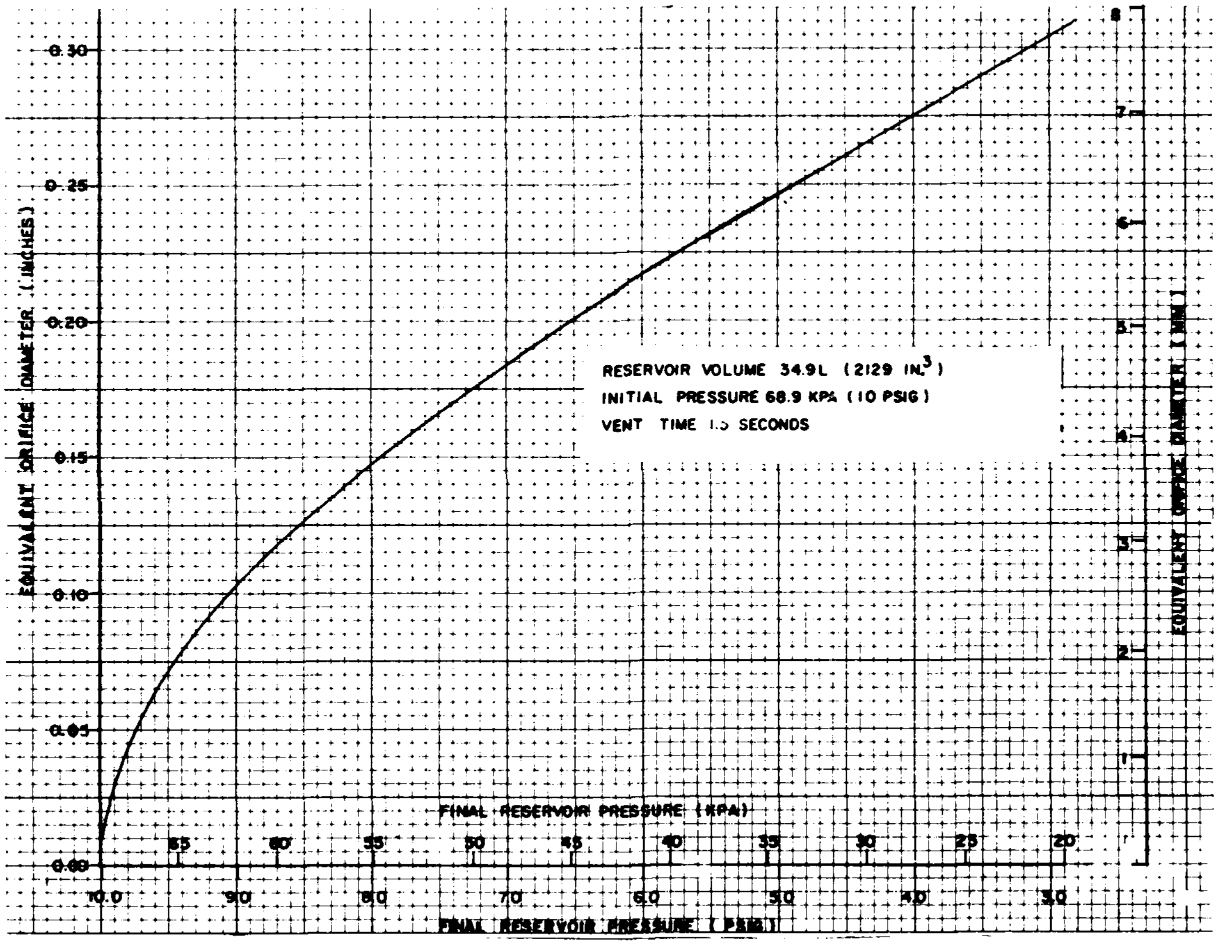


Figure C-11. Final reservoir pressure vs equivalent orifice diameter (MRC application)

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