

California State Lands Commission
A Procedure for the Hydrostatic Pressure Testing of Marine Facility Piping

1.0 SCOPE

The purpose of this methodology is to provide a useful alternative that a marine facility operator can implement to facilitate hydrotest planning, performance and interpretation. Providing precise and complete test data will allow the facility operator and California State Lands Commission (CSLC) to more effectively assess the validity of hydrostatic pressure tests.

This methodology is intended for use in conjunction with the recently developed CSLC testing calculation (spreadsheet) applicable to testing of marine facility piping and pipelines under the jurisdiction of the California State Lands Commission as defined in Article 5.5 of the California Code of Regulations. This is not regulation; however using these tools may help to improve the consistency and quality of data collected during the test.

2.0 CODES AND STANDARDS

The following codes and standards are referenced or provide additional information and guidelines for conducting pressure testing of pipelines or piping:

- California Code of Regulations, Article 5.5, Marine Terminal Oil Pipelines
- Department of Transportation, 49 CFR Part 195, Transportation of hazardous liquids by pipeline
- American Society of Mechanical Engineers, B31.4, Pipeline Transportation Systems For Liquid Hydrocarbons and Other Liquids
- American Petroleum Institute, Recommended Practice 1110, Pressure Testing of Liquid Petroleum Pipelines

3.0 PLANNING THE TEST

3.1 Test Pressure

Prior to the hydrotest, the pipeline operator should determine the minimum and maximum test pressure ranges. These test pressures should take into account the current status of the pipe, maximum operating pressures and the applicable federal, state, and local regulations. In accordance with Article 5.5, the pressure during the test must be maintained to be at least 125% of the maximum allowable operating pressure (MAOP) for that pipeline. In general, the lowest pressure reading during the test period will be one factor in limiting the maximum allowable operating pressure in the system. Both flange ratings and the presence of pressure relief devices must be considered when setting the test pressure. Pressure ratings for flanges located with the tested pipeline must be identified and

recorded. Pressure relief devices must also be identified and recorded. These devices should be removed or isolated as necessary.

3.2 Test Mediums

It is recommended that the test be conducted in water. However, liquid hydrocarbons with a flashpoint greater than 140 degrees Fahrenheit or 60 degrees centigrade can also be used as the test medium. Fluid properties for these test mediums should be obtained prior to the test for pre-test and post-test calculations. Data for common hydrocarbon test mediums are provided in the spreadsheet; however these should be compared to specific fluid properties obtained from the terminal or refinery.

NOTE: Liquid hydrocarbons typically expand more due to temperature changes than does water, and it may be more difficult to obtain satisfactory test results, especially when aboveground pipeline segments are tested. Another drawback to using hydrocarbon as a test medium for pipelines that are located either over water or are submerged is that product may spill into the water if a leak occurs during the test

3.3 Test Segments

- 3.3.1 The facility operator shall provide an accurate description of the piping section to be tested. It is recommended that the facility operator develop an isometric drawing showing the piping section with accurate pipe lengths, locations of fittings and valves, pipe diameters, wall thickness and pipe grade (elevation) information. Also, the drawing should show the lengths of the aboveground and belowground sections that will be tested. Accurate as possible pipeline lengths shall be determined prior to the test (from a scale drawing or by direct measurement using a tape measure or walker wheel).
- 3.3.2 It is recommended that a pipeline undergoing test be segmented so that the test is conducted against blind flanges. This eliminates the chances of fluid bypass through valves, which reduces the accuracy of the results. When a full blind flange cannot be inserted to isolate the pipeline segment, consider using a pan blind.
- 3.3.3 If testing against blinds is not possible, the pipeline operator could consider performing a static test to assess the integrity of the valve(s) that will be used for sectioning. The pipe section could be pressurized to a pressure below the Maximum Operating Pressure (MOP) and each valve checked by visual, audible or remote means for fluid bypass. Any fluid bypass through a valve can drastically reduce the accuracy of the test data collected and may cause test results to fall outside the acceptance criteria calculated from the spreadsheet.

3.4 Line Fill

To obtain accurate results, it is important that the entire piping system, and especially any elevated piping sections, be reasonably free of air or other entrapped gas. If testing with water, the facility operator should prepare a line fill plan that removes product completely and reduces the amount of air in a test section. Eliminating air increases the accuracy of the test results and too much air may “mask” leaks during the pressure test. A common method for filling a piggable line involves using a pig to displace fluid with water. If this is not feasible, the water flush should be at a fast enough rate, appropriate for the pipe size, volume, and fluid displaced, that will ensure a completely turbulent interface between the water and displaced fluid. If eliminating trapped air/gas from the tested pipeline is problematic, it is strongly recommended to install high point vent valves. If high point vents are installed, bleed trapped air/gas completely from the valves.

The spreadsheet calculates an estimated line fill volume based upon the theoretical ratio of volume change to pressure change (DV/DP) as discussed in the following section. This value can be used for line fill planning and verification purposes.

3.5 Pre-test Calculations

3.5.1 DV/DP Definition

DV/DP is defined as the change in volume for an associated change in pressure of a known volume under pressure. Two DV/DP calculations are used in these guidelines, a theoretical and a field value. A theoretical DV/DP will give the expected volume change for an associated change in pressure for the specified volume under test assuming that the volume under pressure is free of entrained gas. The field value of DV/DP is the actual volume change for an associated change in pressure for the specified volume under test. If air exists within the line under pressure, this value will be different than the theoretical value. This procedure provides guidelines for calculating both DV/DP's and acceptable differences between the theoretical and field values of DV/DP.

3.5.1 Theoretical DV/DP

Prior to start-up of test activities, the facility operator should perform a pre-test calculation to obtain a theoretical value of the DV/DP for the verified volume of pipe under test and the appropriate test medium. This information can be used to determine whether entrained gas exists in the line under test.

The theoretical DV/DP for aboveground (unrestrained) pipe is calculated through the following equation:

$$\frac{DV}{DP} = V * \left[\left(\frac{D}{E * t} \right) \left(\frac{5}{4} - \nu \right) + C \right]$$

The theoretical DV/DP for buried (restrained) pipe is calculated through the following equation:

$$\frac{DV}{DP} = V * \left[\left(\frac{D}{E * t} \right) (1 - \nu^2) + C \right]$$

where,

V = volume of the segment for the individual pipe diameter, D (gallons),

D = outside diameter of pipe (in),

E = elastic modulus of steel pipe (psi),

t = wall thickness of pipe (in),

ν = poisson's ratio of steel pipe,

C = compressibility of test media (in³/in³/psi).

NOTE: For a test segment with multiple diameters, sum the individual DV/DP's of each pipe diameter to obtain a total DV/DP for the entire test section.

NOTE: The DV/DP constant provides useful data with which to predict how much fluid will be required to bring up a test segment to pressure. For example, for a fully packed line at 0 psi, with a desired pressure of 100 psi and DV/DP constant of 0.50 gallons/psi, the amount of fluid which will be required to bring the segment to test pressure will be 100 psi x 0.50 gallons/psi = 50 gallons. This will be the minimum amount, if trapped air is present the required amount of fluid to reach test pressure could be much larger.

See Section 4.4 of this procedure for information about field DV/DP. The spreadsheet can be used to calculate the theoretical value of DV/DP.

Test Sensitivity

During a hydrotest several factors will affect the accuracy of test results. An overview of these factors follows:

3.6.1 Fluid Temperature

Fluid temperature is affected by a variety of factors including ambient temperature, weather conditions, pipe location, test media source, pipe color, etc. For buried pipe, the expected fluctuation due to ambient temperature effects should be small due to the insulation provided by soil. For aboveground pipe, external conditions will have the greatest impact. As fluid temperature increases, the hydrotest pressure should be expected to increase. As fluid temperature decreases, the hydrotest pressure should be expected to decrease. Pressure data that does not trend with temperature changes in fluid data should be carefully analyzed. Data that does not trend correctly may indicate the existence of a leak or poor placement of the temperature recording instrumentation.

The following table provides some calculated data for the expected fluid temperature increase over a four-hour period for standard pipe diameters and wall thickness. Table 1 below is provided to show the relative sensitivity of fluid (water) temperature to ambient temperature for highly idealized cases. In this case ambient temperature is held constant assuming a four-hour test period and initial water temperature of 60°F:

TABLE 1 Expected Temperature of Water in Pipe Over a 4-Hr. Period for Constant Ambient Temperatures (°F), 60°F Initial Fill			
Nominal Pipe Diameter	Constant Ambient Temperature		
	70°F	80°F	90°F
2	66.8	74.7	82.9
2.5	66.1	73.3	80.9
3	65.2	71.4	78.1
3.5	64.6	70.2	76.2
4	64.1	69.2	74.6
6	62.7	66.2	70
8	62	64.6	67.5
10	61.6	63.6	65.9
12	61.3	62.9	64.8
14	61.1	62.6	64.3
16	60.9	62.2	63.6
18	60.8	61.9	63.1
20	60.7	61.7	62.7
22	60.6	61.5	62.4

Nominal Pipe Diameter	Constant Ambient Temperature		
	70°F	80°F	90°F
24	60.6	61.3	62.2
26	60.5	61.2	62
28	60.5	61.1	61.8
30	60.4	61	61.6
32	60.4	60.9	61.5
34	60.4	60.9	61.4
36	60.3	60.8	61.3
42	60.3	60.7	61.1
48	60.2	60.6	60.9

3.6.2 Entrained Air

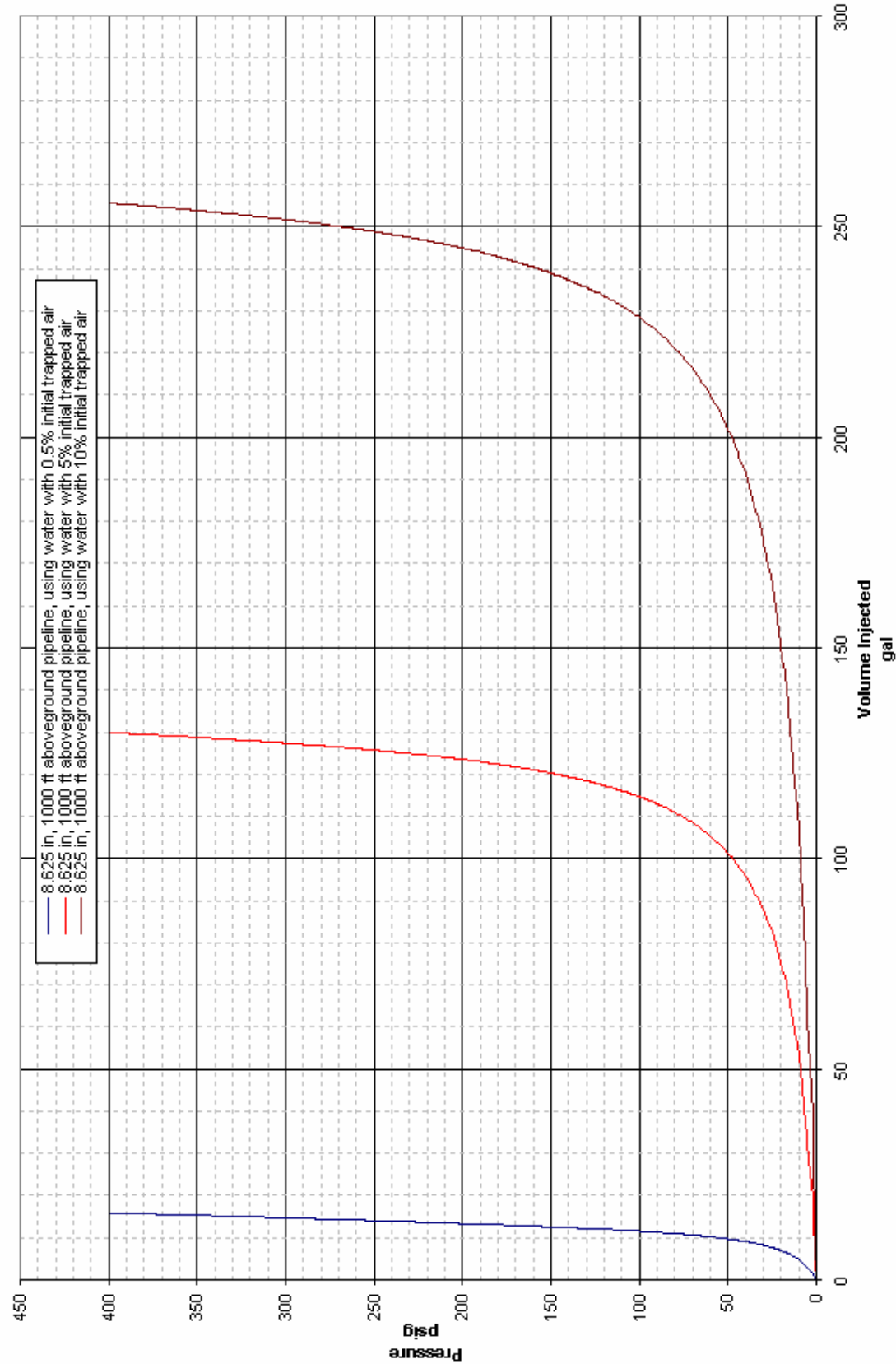
Entrained air may prevent stabilization of the testing fluid during a test or may mask the presence of an actual leak. The first indication of significant amount of entrained air will usually occur during pressurization. Pressurization will not be immediate since water injected into the test section must displace a significant volume of highly compressible air. Also, expanding air may prevent the detection of an actual leak in the test segment. If a small leak is present, the expected pressure loss due to the leak may not be apparent since expanding air within the pipeline will tend to keep the pressure constant. This is the primary reason for using DV/DP's to determine the percentage of air that is present and for eliminating air in the test section.

Chart 1 shows the effect of pipeline pressure versus volume injected for various quantities of trapped air for 1000 ft of 8.625" pipe. The chart shows how air can effect the volume required to reach full test pressure.

3.6.3 Coefficient of Thermal Expansion

The coefficient of thermal expansion of the test medium effects the calculated volume and pressure changes versus a change in temperature (DV/DT & DP/DT). Mediums with high thermal coefficients are very sensitive to changes in temperature. Therefore, for the same temperature recording accuracy, a product test would potentially show a higher volume or pressure change when compared with water as a test medium. This is the primary reason for using water as a test medium and for taking accurate temperature data.

Chart 1
Pressurization vs. Volume Added



3.7 Test Accuracy

The Pass/Fail criteria that has been developed is dependent upon three variables that effect the calculated volume loss or gain during a hydrotest. These variables are the change in pressure during the test, the change in temperature experienced by the fluid during the test and the change in fluid volume (though bleeding, injecting or leaks) during the test. This section discusses the recommended accuracy of the instrumentation to be used in the hydrotest.

3.7.1 Pressure Recording

Pressure recording devices should have an accuracy of +/- 1 psi. A typical deadweight tester has this accuracy and shall be used for the test. A typical "clock" type chart recorder can be used for documentation purposes but should not be relied upon for providing actual pressure data that will be used in post-test calculations. Electronic pressure recorders with higher resolution may provide more frequent and accurate data sampling to enable pressure trending during the test.

3.7.2 Temperature Recording

Regardless of the test medium used, the temperature recording device should have a high accuracy. The output resolution for a water test should be 0.1°F and for a hydrocarbon test the recommended resolution is 0.01°F. A typical "clock" type chart recorder can be used for documentation purposes but should not be relied upon for providing the temperature data that will be used in post-test calculations.

3.7.3 Volume Measurements

Accurate determination of fluid volumes bled or injected should be accounted for during a test. Volumes should be measured using the most precise graduations available. As a rule of thumb, if the theoretical DV/DP in gallons/psi is greater than 0.1 gallon/psi, then measurements should be taken to the nearest gallon. If the DV/DP is between 0.1 and 0.01 gallon/psi then the measurements should be taken to the nearest pint (1/8 gallon). For DV/DP's less than 0.01 gallons/psi, the measurements should be taken to the nearest ounce (this can be done by using a standard measuring cup).

4.0 PERFORMING THE TEST

4.1 Ambient Conditions

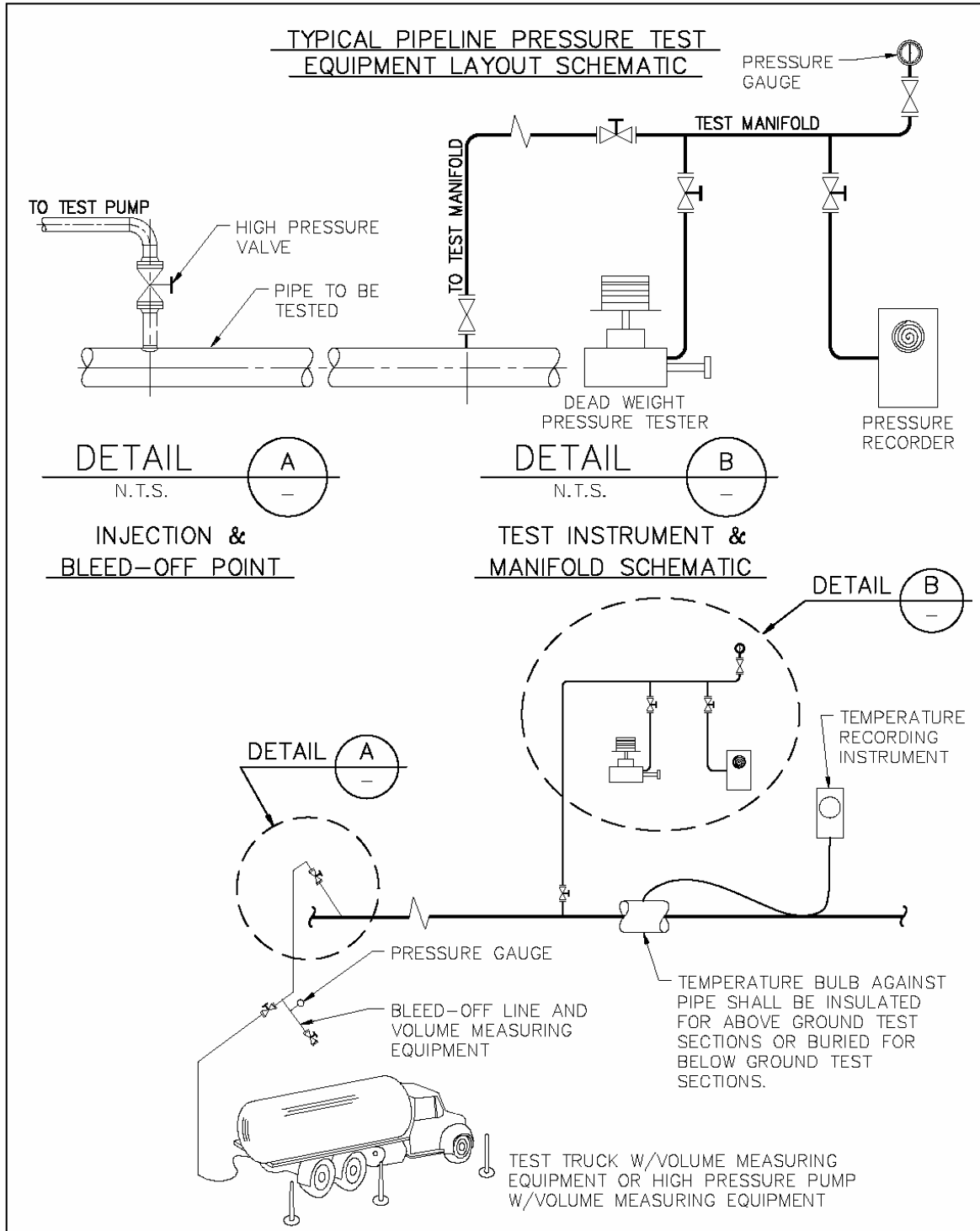
Ambient conditions may have great impact on fluid temperature and the accuracy of hydrostatic test results. Certain ambient conditions may not only provide improved test results but may actually make the hydrotest operations easier. The following guidelines can be used for assessing ambient conditions.

- Hydrostatic tests should not be conducted in rainy or wet conditions since visual leak detection may not be possible.
- Aboveground pipe tests should be conducted on cloudy, overcast or cool days to minimize thermal heating of the fluid. This will reduce the amount bleeding that will be required, which may be significant for large sections of aboveground pipe exposed to the sun on hot days.
- Types of weather/external conditions that should be avoided are very hot (summer), extremely windy, rainy and wet (due to condensate, dew, mist, salt water spray etc.) conditions.

4.2 Pressure Recording Equipment

The following pressure recording equipment shall be used during a hydrotest in accordance with Article 5.5: a calibrated deadweight tester with 1 psi increments and a calibrated pressure chart recorder. Pressure recording equipment should be installed so that localized surges from the test pump or bleed lines do not interfere with the readings. A dedicated test manifold that allows each instrument to be blocked in separately is recommended. Pressure transmitters or other type of pressure recording device with the required or better accuracy can also be used, but for record keeping purposes a chart recorder should be provided.

Schematic 1 is provided as a typical example for placement of hydrotest equipment.



SCHEMATIC 1

4.3 Temperature Recorders

4.3.1 Recorder Accuracy

To reduce the impact of temperature change, it is recommended that high-resolution temperature recorders be used. Temperature recorders should include a digital readout. It is recommended that the instrument include options for direct digital printing or output that can be stored, printed or downloaded to a personal computer for record keeping purposes. The recorder should have a resolution of at least 0.1°F for water tests and at least 0.01°F for hydrocarbon tests.

4.3.2 Recording Requirements

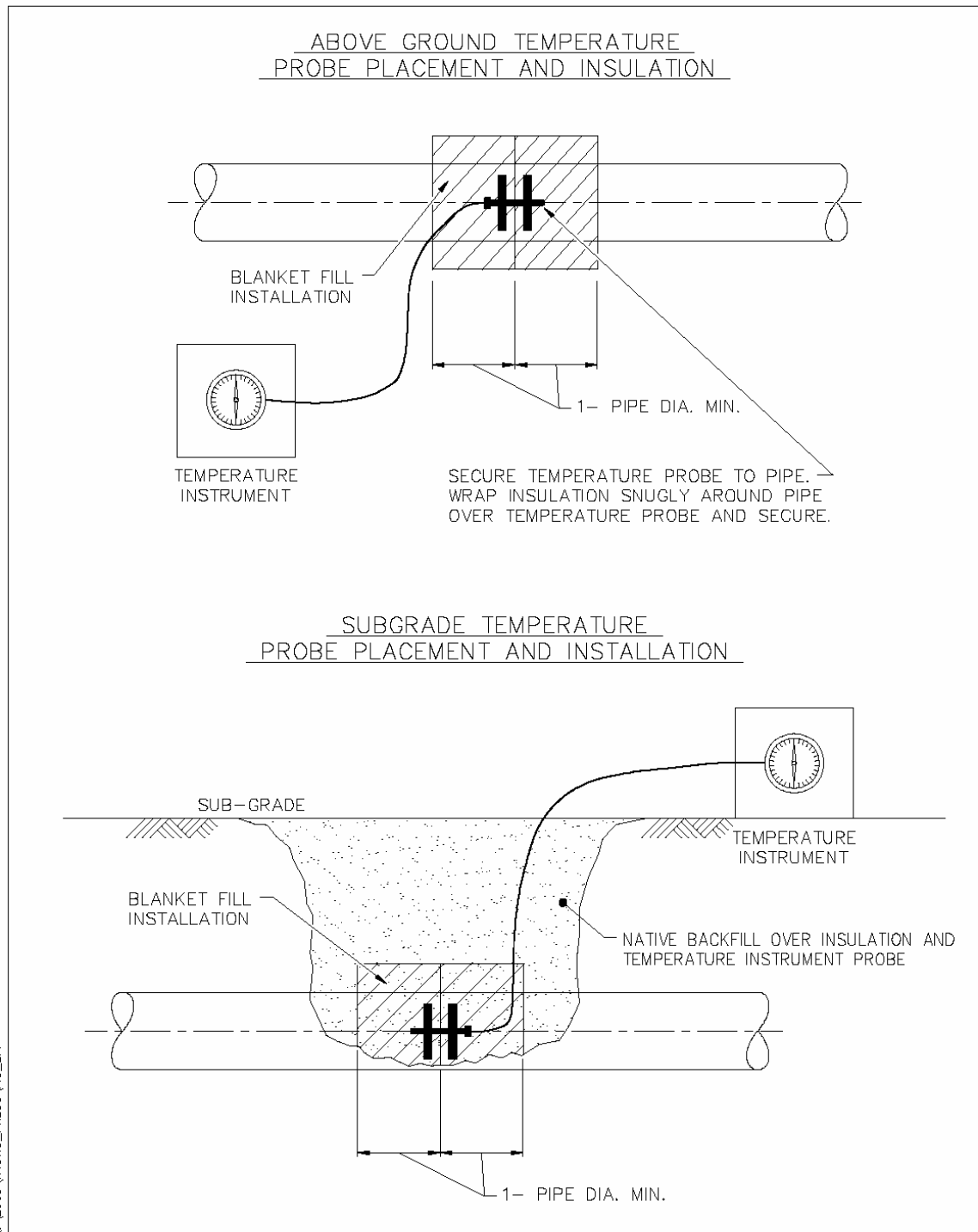
Ambient temperature should be taken with a digital thermometer. It is recommended that the facility operator provide a means for obtaining accurate fluid temperature data for each section of piping to be tested. Multiple recorders should be used where a significant difference in pipe or fluid temperatures can be expected. This could include test sections with:

- significant portions of aboveground and belowground pipe,
- aboveground pipe that has significant variations in pipe diameters,
- aboveground pipe that has significant pipe segments exposed to the sun and shade,
- pipe exposed to seawater.

4.3.3 Recorder Installation

4.3.3.1 The recommended method of determining test medium temperature is to measure it directly. This can be accomplished by using thermowells, or by drawing-off a small amount of test fluid and immediately measuring its temperature (provided the ambient temperature is within 10°F of the test medium temperature and the temperature measuring device has a quick response time). The temperature recorders should be placed and shielded so that extreme environmental conditions (e.g. direct sun, wind) have a minimal effect on the temperature probe.

Schematic 2 is provided as a typical example for placement of the temperature recorder.

**SCHEMATIC 2**

4.3.3.2 If direct temperature measurement is not possible, as an alternative, the methods below may be used.

- For buried test sections, the temperature probe should be buried belowground next to the pipe or in a vault.
- For submerged test sections, seawater temperature should be measured at the approximate median water depth, at the mudline directly above the pipeline.
- For aboveground sections, the temperature probe should be attached underneath the pipe and thermally insulated from ambient temperature effects. It is recommended that insulation extend one pipe diameter on each side of probe.

4.3.3.3 It is recommended that an equalization period be allowed between the time that line flushing takes place and the start of the test. The largest rate of temperature loss or gain should occur after the initial flush when the largest variance between fluid and ambient temperatures exists. The settlement time will depend upon several factors including ambient conditions, temperature of fluid flushed and the diameter/color of the pipe(s) being tested.

4.4 Entrained Air

4.4.1 Field DV/DP

Before the test section is under full test pressure, a field value of DV/DP should be obtained. This value of DV/DP can be compared with the theoretical value of DV/DP calculated under section 3.5 (completed during pre-test calculations). A field value of DV/DP that is smaller than the theoretical DV/DP indicates an incorrect pressure reading, incorrect DV/DP calculation, or incorrect measurement of the volume under test. A field value of DV/DP that is greater than the theoretical DV/DP indicates the presence of entrapped air or other gas in the pipe section.

4.4.2 Obtaining Field DV/DP

During initial pressurization, the test section should be pressurized to approximately 50 psi and allowed to stabilize. Take an accurate pressure reading. Then bleed approximately 10 psi and allow the test section to stabilize. Take another accurate pressure reading. Carefully, measure the volume of the fluid that was bled and convert this to gallons if necessary. Take the volume bled and divide this number by the difference in the pressure readings. This is the field value of DV/DP.

4.4.3 Acceptable DV/DP

The CSLC provided hydrotest calculation spreadsheet determines the acceptable DV/DP range that corresponds to a volume of air that is 1% by volume of the test section. Results that fall outside the range when calculated by the spreadsheet indicate the existence of a significant volume of air in the test section. (A common sign for significant entrained air will be difficulty in initial pressurization.) In these cases, it is recommended that the test section be bled of air at a high point or the line be refilled, then re-check the field DV/DP.

4.5 Pressurization

During pressurization, valves, fittings, flanges and other appurtenances should be checked for leaks (see 4.6 for inspection) and repaired prior to reaching final test pressure. Pressurization should be gradual to ensure that the maximum test pressure, pipe yield strength or maximum design pressure of any appurtenance is not exceeded.

4.6 Required Test Information & Measurement Increments

The following information shall be obtained during the static test: a deadweight or pressure reading, a temperature reading of the test medium, an ambient temperature reading (shade), volume bled or lost through leaks in fittings, and volume injected. An accurate pressure reading should be taken before and after fluid is bled or injected into the test section along with a careful measurement of the volume of fluid that is bled or injected. Also, records of the deadweight pressure readings and volumes from the pre- and post-test bleed should also be kept.

It is recommended that at a minimum, data should be read and recorded in 15-minute time increments. NOTE: With digital instrumentation it may be feasible to take continuous test data, which could be readily analyzed in the hydrotest spreadsheet.

4.7 Inspection

For aboveground piping sections, the piping should be visually inspected for leaks, especially at any flanged or threaded connections. If a petroleum product is used as a test medium and for under-the-dock pipelines, it is recommended that these pipelines be directly inspected to the degree possible by boat or under dock access and indirectly by observing the water periodically for an oil sheen. All detected leaks shall be repaired before continuing the test. It is recommended to visually inspect aboveground pipeline segments immediately prior to starting the test, within 15 minutes after commencement of the start of the test and every hour until the test has concluded, and finally after the test has concluded. Document visual inspection results and repaired leaks.

4.8 Testing Against Valves

If the test section cannot be isolated using blinds, then the facility operator should verify that a leak tight seal exists at the block valve between a pipe section under test and the adjacent pipe section(s) not under test. Leakage through valves jeopardizes the chances for a successful test and may lead to data that cannot be correctly correlated.

4.9 Injection

During the test, fluid temperature drop may require the injection of fluid to maintain the minimum test pressure. Provisions for measuring the volume of fluid injected into the test section should be made to provide an accurate account of the volume. Fluid injected should be measured by injecting fluid from a container with a known volume, by counting the pump strokes of a piston type pump with a known displacement or through metering. As a check, an accurate pressure reading before and after fluid injection should be taken. The pressure difference between the before and after pressure readings can then be multiplied by the field DV/DP to obtain a “calculated ” injection volume. This calculated value should be compared with the measured volume as a check. Document the calculated injection volume, actual injection volume and field DV/DP each time it is measured.

4.10 Bleeding

Fluid temperature increase may require that fluid be bled from the piping system to prevent the pipeline from exceeding the maximum test pressure. Fluid bled should be measured with an appropriate type and size container showing accurate gradations. For example, a test section with significant aboveground sections may require a large volume of fluid to be bled and may require a large container. Also when testing with hydrocarbon, proper grounding requirements should be considered in choosing the container type. Section 3.7.3 discusses recommended measurement accuracy for volume measurements.

4.11 Interim Calculations

The facility operator can perform calculations during the test to evaluate the progress of the test. These calculations include calculating DV/DP and change in pressure versus time (DV/DT). Comparing the field DV/DP to the theoretical DV/DP indicates the presence of air as discussed in Section 4.4. Change in pressure versus time can be used to indicate the existence of unexplained fluid loss. Varying or unexplained pressure versus time results should be closely monitored and investigated during a test.

4.12 Depressurization

A final field DV/DP should be taken prior to final depressurization. Depressurization should be gradual and fluid bled into an appropriate container. Document bled volume and calculated field DV/DP.

5.0 POST TEST ANALYSIS

5.1 Required Calculations

Post-test calculations that correlate pressure, temperature and volume bled or injected should be used to evaluate the test data. If multiple temperature probes are used to collect data, a weighted average temperature based on volume should be used to compute change-in-volume calculations; the spreadsheet program will perform this calculation automatically. The test calculation spreadsheet, which accounts for the changes in pressure and volume due to temperature and pressure fluctuations as well as volumes injected or bled during the test using the appropriate testing fluid, has been developed by the CSLC and can be used for this purpose. The spreadsheet is in an Excel program and should run on most personal computers.

5.2 Pass/Fail Criteria

The spreadsheet program distributed by the CSLC includes an analysis that provides acceptable testing criteria after evaluation of the test data. The data indicates an acceptable volume change that uses the accuracy of the measurement instrumentation to determine the allowable volume change. Actual pressure data is plotted versus time along with the theoretical pressure for zero fluid gain or loss and the acceptable test pressure variance. Data that falls outside the acceptable test pressure range should prompt further investigation by the operator.