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Guidelines and Pass/Fail Criteria for Static Liquid Pressure Test of Marine Oil Terminal Pipelines

By: Bud Pingree, P. E.
Michael Edwards, P. E.

Presented by Omar Estrada, SPEC Services, at Prevention First 2004

Abstract

This paper discusses the development and results of a California State Lands Commission Project entitled *Pipeline Static Liquid Pressure Test Procedure and Criteria Project 2002-05*. The purpose of this project was to 1) create a test procedure to ensure consistent quality data collection during a hydrostatic pressure test of a pipeline at a marine oil terminal, 2) perform a sensitivity analysis of the factors affecting test results, 3) and create a spreadsheet format pass/fail criteria that was tailored to the testing of marine oil terminal pipelines. SPEC Services, Inc. was the contractor selected to perform the project. The final versions of the procedure and spreadsheet were made available to pipeline testing companies and marine oil terminal operators. As test results using these new testing tools become available, California State Lands Commission will evaluate their effectiveness. Upon sufficient validation, these newly developed testing tools may become regulatory requirements.

Introduction

The Marine Facilities Division (MFD) of the California State Lands Commission has jurisdictional authority to regulate pipelines at liquid bulk petroleum marine terminals (MOTs). As part of Marine Facilities Division's effort to eliminate "oil" leaks and spills at MOTs, California Code of Regulations Title 2, Division 3, Chapter 1, Article 5.5 (2 CCR 2560-2571) was adopted August 12, 1997. All MOT "oil" pipelines (containing any petroleum product or fraction thereof during transfer operations) now require a periodic hydrostatic liquid pressure test for at least four hours at or above 125% of its maximum allowable operating pressure. A one-, three-, or five-year test interval between successive tests is allowed dependent upon class designation, cathodic protection, and location.

2 CCR 2560-2571 specifies that hydrostatic testing be conducted in accordance with Code of Federal Regulations Part 195 of Title 49 (49 CFR195) dated October 1, 1996, with the exception that an additional four-hour leak test under 49 CFR195.303 is not required. 49 CFR195 Subpart E prescribes minimum requirements for pressure testing. These minimum requirements are targeted towards buried interstate pipelines transporting hazardous liquids, and also lack sufficient detail.

MFD Engineering staff have reviewed many hydrotest results and have found, among different marine oil terminals and pipeline testing companies, many inconsistencies in test procedures, data collection, data analysis, and pass/fail criteria. Two common problems are test medium specific properties and temperature data collection. Change-in-volume calculation errors were common when hydrocarbon test mediums were used. Pipeline testers failed to use property values specific to the given test medium when calculating change-in-volume. For many tests, pipeline testers used only one temperature data collection point when there were clearly more than one pipeline environment (e.g. both buried and aboveground segments).

To eliminate this problem of pipe test inconsistencies and improve the test quality, MFD saw a need to develop both a test procedure and pass/fail criteria specific to marine terminal pipelines that was easy to understand, easy to implement, and not cost prohibitive.

The project included the following:

1) Development of a procedure for performing a hydrotest that would provide guidelines that an operator could follow, which would lead to a high probability of passing a test provided that there is no actual leakage.
2) Formulation of a pass/fail criteria for both water and hydrocarbon test mediums.
3) Formulation of a pass/fail criteria for a range of pipeline lengths, diameters, test mediums, temperature and pressure variations.
4) Determination the suitability of various hydrocarbons as acceptable test mediums.
5) Modification of the existing California State Fire Marshal spreadsheet program or development of a new spreadsheet program that incorporates the pass/fail criteria.
6) Recommendation of a minimum required temperature accuracy for the various test mediums.

Procedure

The procedure was written as a guideline to be followed in planning, executing, and analyzing the hydrotest. The procedure was developed to be easily followed yet sufficiently detailed to ensure adequate consistency. The ultimate goal of the procedure is to help the marine terminal operator obtain a definitive, repeatable, and verifiable test. Contained within the procedure are guidelines for planning the test, performing the test, and analyzing results.

Planning the Test

To achieve an accurate and representative test, adequate planning is required. Some necessary information needs to be gathered prior to the test. The following information should be gathered days or weeks before the actual test: presence of pressure relief devices, test medium information, delineation of individual pipeline test segments, and required test instrument accuracy. Just prior to test start-up, pre-test calculations should be performed to detect the presence of entrained air.

The presence of pressure relief devices must be determined prior to the test. Usually these devices have a set pressure at or 5 – 10 % above the maximum allowable operating pressure. Such pressure relief devices must be isolated prior to conducting the test.

In accordance with 2 CCR 2561(q) Marine oil terminal operators may test pipelines filled with high flashpoint (>= 140 °F) hydrocarbon product or water. The recommended test medium of choice is water. Water is less sensitive to changes in temperature compared to hydrocarbon. Because water volume is less sensitive to temperature changes, the difficulty in obtaining a satisfactory test is reduced. Another benefit to using water as a test medium is that it is benign to the environment if spilled or leaked. If a common high flashpoint hydrocarbon test medium is used, specific properties (e.g. coefficient of thermal expansion and compressibility) are available for generic hydrocarbon-types in the pass/fail spreadsheet. However, exact hydrocarbon-specific properties should be obtained from the test facility to increase the accuracy of pre-test and post-test calculations.

The presence of a significant amount of trapped air within the tested pipeline can be problematic to test accuracy (See Chart 1). When testing a pipeline with water, trapped air can be eliminated by filling the tested line at a rapid enough rate, thereby creating a completely turbulent interface between the incoming water and the displaced fluid. When testing with water or hydrocarbon product, air should be completely bled from high point vents (if installed).

A theoretical ratio of volume change to pressure change (DV/DP) can be used for line fill planning and for verifying if trapped air is significant (>1% by volume).

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:

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

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 ($in^3/in^3/psi$).

Field DV/DP is obtained by bleeding off a measured amount of test volume and recording the corresponding pressure drop. It is recommended to initially pressurize the pipeline test section up to approximately 50 psi, then bleed the pipeline until pressure drops 10 psi. Divide the measured bleed volume (convert to gallons if necessary) by 10 and this gives a Field DV/DP. If Field DV/DP is less than Theoretical DV/DP, this indicates an incorrect pressure reading, incorrect DV/DP calculation, or incorrect bleed volume measurement. If Field DV/DP is greater than Theoretical DV/DP, this indicates the presence of trapped air.

Data Measurement Accuracy

The pass/fail criteria is dependent upon three variables that must be collected during the test to a prescribed accuracy: pressure, temperature, and volume change. Pressure of the tested pipeline must be measured to an accuracy of +/- 1 psi. Temperature measurement accuracy varies depending on test medium. If testing with water, temperature measurement instruments should have an accuracy and resolution of +/- 0.1 °F. If testing with hydrocarbon, temperature measurement instruments should have an accuracy and resolution of +/- 0.01 °F. Increased accuracy is recommended when using a hydrocarbon due to test medium's greater temperature sensitivity. Test medium volume bled or injected into the test system requires accuracy based upon the theoretical DV/DP.

Injected/Bled Volume Accuracy	DV/DP
1.0 gallon	>0.1 gallon/psi
0.125 gallon	0.1>x>0.01 gallon/psi
1 fluid ounce	<0.01 gallon/psi

Performing the Test

If possible, hydrostatic tests should not be performed during weather conditions that are detrimental to data collection and leak detection. Wet, rainy weather make it difficult to visually detect a leak. Sunny, hot days require large amounts of bleed off. Ideal weather conditions are cool, overcast, and no or very light wind.

For each different environment (e.g. aboveground exposed, under dock shaded, buried, etc) a separate temperature measurement must be recorded during the test. Temperature instruments must collect data for each different pipeline environment.

The preferred method of recording test medium temperature is direct measurement. However, this is usually not possible due to lack of thermowells, and lack of strategically located bleed valves. When direct measure is not possible, pipe wall temperature must be collected. To ensure representative temperature data, probes should be placed in accordance with Schematic 2 for either above ground or below ground pipeline locations. For submerged pipelines, seawater temperature should be recorded at the mudline directly above the pipeline.

All accessible above ground/water portions of the tested pipeline should be visually inspected just prior to commencement of the test, at regular intervals during the test, and just after the test concludes. Any leaks should be repaired. Visual inspection results should be documented.

Post Test Analysis

Post test analysis is required to evaluate the test. An *Excel* spreadsheet has been developed to allow data input, calculations, and report output.

Pass/Fail *Excel* Spreadsheet

The spreadsheet is an easy to use tool for inputting test data, analyzing the data, and determining pass/fail. Many drop-down menus are provided to simplify usage. The process is broken down into four steps: test setup data, test planning calculations, actual test data, and interpretation of results.

Test Setup Data

This first step consists of entering data to allow identification of the tester, pipeline, and test equipment. Up to 25 pipeline segments may be entered.

Minimum flange ratings and pressure-limiting component entries are included. These values are checked against the planned test pressure; a warning will be generated if the planned test pressure is greater than 95% of the maximum rated system pressure. Elevation data are also used to check the test pressure against the maximum rated system pressure.

From the test instrument data entered, required calibration is verified.

Test Planning Calculations

Here the planned test pressure and test medium is entered. From this data a theoretical DV/DP (for 1 psi pressure change) and DV/DT (for 1 °F temperature change) is calculated. An allowable range of DV/DP is given to determine if trapped air will severely limit the accuracy of the test. This range is between 95% of the theoretical DV/DP and the DV/DP associated with 1% initial trapped air (volume basis).

Test Data

A worksheet is provided for tracking time, pressure, temperature and bleed or injection volumes during the actual test. Temperature data for up to 25 temperature monitoring devices can be entered.

Interpretation of Results

The View Results worksheet presents a tabular summary of the test results via temperature change, pressure change and volume change. An option is available to use either the theoretical or field DV/DP in calculations.

The Charts worksheet displays the actual pressure, theoretical pressure, acceptable pressure, and bulk temperature vs. time in graphical format. The acceptable pressure range is shown on the chart. This value is the expected accuracy within the tolerance of +/- 1°F (for water as a test medium) or +/-0.1 °F (for hydrocarbon used as a test medium).

Conclusion

California State Lands Commission will continue evaluate the effectiveness of these new testing tools as pipelines are periodically tested. Pending CSLC's judgement of the effectiveness of these new tools, the procedure and spreadsheet may become regulatory. The procedure and pass/fail criteria spreadsheet are available to the general public.

References

1) California Code of Regulation, Title 2, Division 3, Chapter 1, Article 5.5 (2 CCR 2560 – 2571), *Marine Oil Terminal Pipelines*, August 12, 1997.
2) Code of Federal Regulation, Title 49, Part 195, *Transportation of Hazardous Liquids by Pipeline*, October 1, 1996.
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