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9. Kiefner, J. F., and Maxey, W. A., "Periodic Hydrostatic Testing or In-line Inspection to Prevent Failures from Pressure-Cycle-Induced Fatigue," Paper Presented at API's 51st Annual Pipeline Conference and Cybernetics Symposium, New Orleans, Louisiana, April 18—20, 2000.
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Hydrostatic testing for pipelines

After construction of a pipeline is completed, or if pipe has been replaced or relocated, it is necessary to hydrostatically test the pipeline to demonstrate that the pipeline has the strength required to meet the design conditions, and to verify that the pipeline is leak free.

The U.S. Federal Safety Regulations for Pipelines require that pipelines used to transport hazardous or highly volatile liquids be tested at a pressure equal to 125% of the maximum allowable operating pressure (MAOP) for at least 4 continuous hours and for an additional 4 continuous hours at a pressure equal to 110% or more of the MAOP if the line is not visually inspected for leakage during the test. A design factor of 72% of the specified minimum yield strength (SMYS) of the pipe is used to determine the maximum allowable operating pressure. The requirement to test to 125% of the MAOP will therefore cause the pipe to be tested to a pressure equal to 90% of the SMYS of the pipe. See Section 3—Pipe Design for additional information on calculating the MAOP.

The regulations for gas lines specify design factors based on the class location of the pipeline. The class location is determined by the number of buildings in a specified area on either side of the pipeline. Refer to Part 192.111 of the Minimum Federal Safety Standards for Gas Lines for the details on how to determine the class location. See Section 3, Pipe Design for a listing of the design factors for the different class locations. The regulations specify that the test pressure must be maintained for at least 8 h and must be equal to at least 125% of the maximum allowable operating pressure. The regulations should be consulted for the specific testing requirements, as the regulations are subject to change.

Usually, operators will specify a test pressure range from 90% to 95% of the SMYS of the pipe. Some will allow test pressures as high as 100% of the SMYS of the pipe and some will test to slightly beyond the SMYS of the pipe. Specifying a test pressure at least equal to 90% of the SMYS of the pipe will qualify it for the maximum allowable operating pressure. In some cases, the test pressure will be based on the minimum yield strength determined from the mill test reports.

Hydrostatic testing a pipeline is certainly a major operation and should be carefully planned. Most companies have hydrostatic test manuals that detail the procedures to be followed to complete the test. Usually, this work is performed by a hydrostatic testing contractor hired by the pipeline owner, or hydrostatic testing may be included as a part of the main construction contract.

One of the first steps in planning the hydrostatic test operation is to examine the elevation gradient. The gradient, along with the location of the water source, and the pipe design data, will be used to determine the length and number of test sections. Figure 1 shows a typical pipeline elevation gradient.

Where the pipeline traverses hilly terrain, the elevation gradient must be carefully considered in selecting the pipeline test segments. Different companies have differing philosophies on how to do this. Some limit the amount of elevation difference while others may specify a range of allowable percentages of the SMYS of the pipe—i.e. 90—95% or 90—100% of the SMYS of the pipe. In any case, the test gradient should be plotted to be sure the test pressure falls within the specified pressure limits.

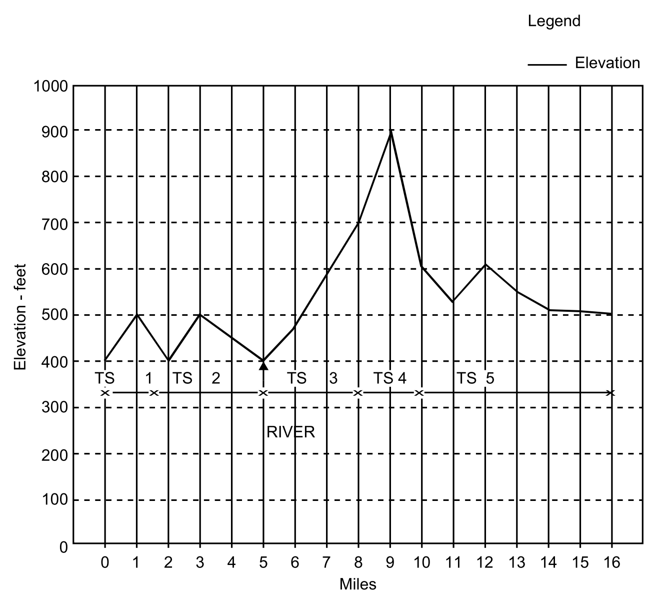

Figure 1. Pipeline elevation profile.

The test gradient must be based on water head in feet, if water is used as the test medium. Water pressure may be converted to head by dividing the pressure by 0.433. If sea water is being used as the test medium, a factor of 0.445 should be used. This assumes a specific gravity of 1.02 for sea water. In any case, the factor of 0.433 should be modified according to the specific gravity of the test medium.

Let's assume that we have a line that is to be tested and the elevation at the test site is 1000 feet and the elevation at the end of the line is 1200 ft. Fresh water will be used as the test medium, and it is desired to test the pipe to a minimum of 90% and a maximum of 96% of the SMYS of the pipe. The pipe is 30-in OD × 0.390″ wt API 5LX X60. There is a difference in elevation of 200 ft and this is equal to 86.6 psig (200 ft × 0.433 = 86.6 psig). A test pressure equal to 90% of SMYS is 1404 psig. Since the test site is lower than the high end of the line, the 86.6 psig is added to 1404 psig to obtain a test site pressure of 1491 psig. The pressure at the end of the line will be 1404 psig, which equates to 90% of SMYS. The pressure at the low point equates to 96% of SMYS.

Now, let's assume a line has a high point elevation of 1100 ft, a low elevation point of 1000 ft, and the elevation at the test site is 1050 ft. The test pressure at the high point will need to be 1404 psig in order to meet the 90% of SMYS requirement. The pressure at the low point will be 1447 psig, and the pressure at the test site will be 1426 psig.

When testing offshore lines, the pressure at or below the water surface will be the same as at the low elevation point due to the offsetting external subsea pressure head. If the line previously described was laid offshore, the test pressure at the water surface would be 1404 psig. The elevations are as follows:

Top of riser	+11 ft
Test site	+7 ft
Water surface	0 ft
Pipe depth	−168 ft

The test pressure at the test site would be 1404 − (7 × 0.445) or 1401 psig. At the top of the riser, the test pressure would be 1404 − (11 × 0.445) or 1399 psig.

The typical profile shown in Figure 1 represents a pipeline that requires testing. The pipeline crosses a river at approximately MP 5, and river water will be used to test the line. Test sections 1—5 have been chosen as indicated. The lengths of sections 3 and 4 are limited by elevation difference. This line was designed to operate at 936 psig or 72% of the SMYS of 30 in × 0.375 in wt API 5LX X52 pipe for Class I locations, and 60% of the SMYS of 30 in × 0.390 in wt API 5LX X60 pipe for Class II locations, and 50% of the SMYS of 30 in × 0.438 in wt API 5LX X65 for Class III locations.

The pipeline crosses one railroad, one highway, and the river. It also includes one main line block valve assembly. The valve assembly, river crossing, and road crossing were pretested before installation and are tested again after installation.

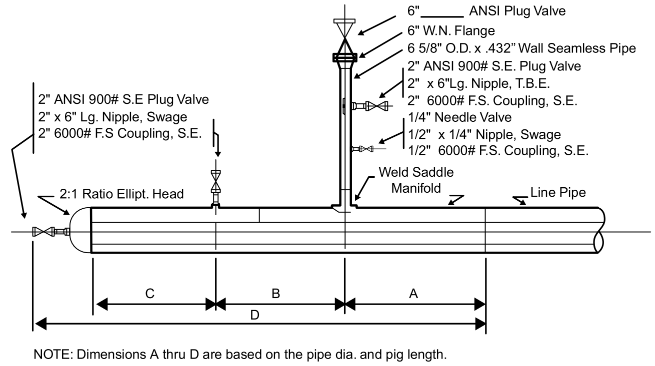

Figure 2. Typical pressure manifold. Courtesy Milbar Hydrotest.

Four test manifolds were installed to facilitate filling the line and for isolating the test sections during the test operation. See Figure 2 for a typical pressure sectionalizing manifold. Two-way pigs were loaded at each of the intermediate manifolds. The pigs are moved by the fill water and are necessary to remove the air from the line.

It is generally a good idea to test the section most distant from the water source first. If it should rupture, then testing on intermediate sections can continue while repairs on the failed section are completed.

The pumps used to fill the line should have sufficient capacity to fill the line at a rate of about 1/2 mile per hour. Water filters should be used and are normally equipped with 100 mesh screens. See Figure 4 for a typical fill site arrangement. Some companies may specify a finer mesh screen. The filling unit should be equipped with a flow meter to measure the amount of water pumped into the pipeline. Temperature recorders will be used to record ambient temperature, the temperature of the pipe and water, and

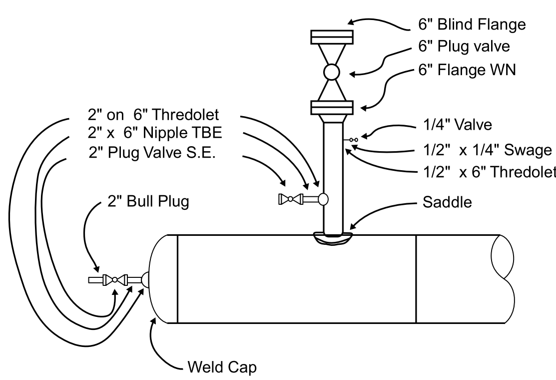

Figure 3. Typical test manifold. Courtesy Milbar Hydrotest.

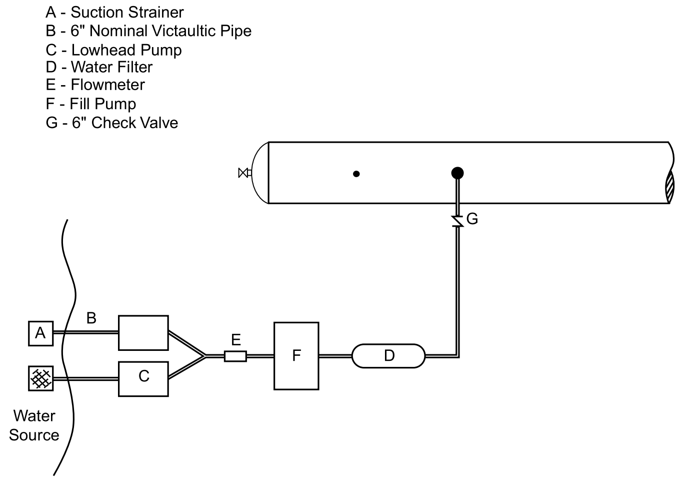

Figure 4. Typical fill site. Courtesy Milbar Hydrotest.

ground temperature. See Figure 5 for typical test thermometer placement. A pressure recorder will be used to provide a recording of the pipeline test pressure. A deadweight tester will be used to calibrate the pressure recorder. A high pressure pump capable of delivering 70—150 gpm at a pressure exceeding the required test pressure will be used in the final pressuring operation. Small high pressure units with a capacity of 6—30 gpm may be used for short sections of large diameter lines and smaller diameter lines.

Deadweight pressure and temperature readings are recorded after the prescribed test pressure has been reached and the pressures and temperatures have stabilized. A pressure vs. time plot may also be made. Readings are usually made at 15-min intervals for the first hour and at 30-min intervals thereafter. The procedure for accepting a leakage test will vary from company to company. Some will accept the leakage test if there is no pressure drop in a 3-h period.

A pressure—volume plot may be required, especially if the test pressures approach or exceed the SMYS of the pipe. The plot is made manually during the pressuring operation by recording pump strokes on the *X*-axis and pressure on the *Y*-axis. A straight line will be produced until the plastic range of the pipe is reached or until a leak occurs. This type of plot is also useful should a joint of lighter wall thickness or lower yield strength pipe be inadvertently placed in the pipeline.

Small leaks during the testing operation can be difficult to locate. A change in the water/pipe temperature may give the appearance of a leak. If the temperature of the pipe/water decreases, the test pressure will decrease. An increase in water/pipe temperature will cause the test pressure to increase. The effect of a temperature change may be estimated using the equations and data contained in Appendices A and B. To achieve any degree of accuracy in these

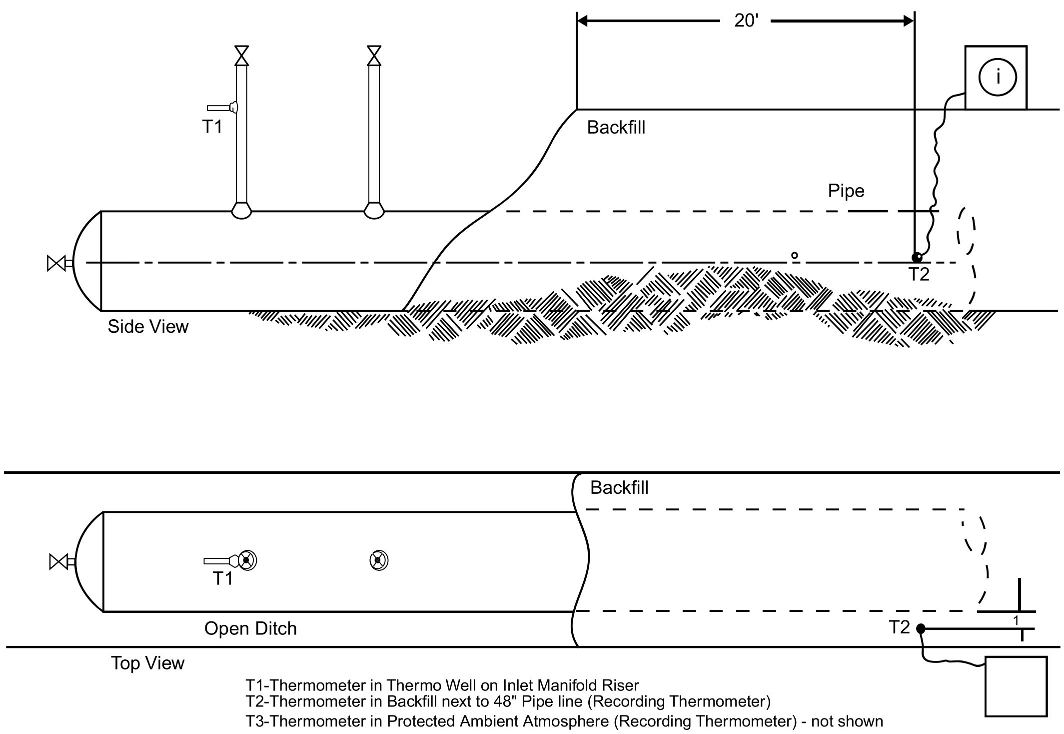

Figure 5. Test thermometer placement. Courtesy Milbar Hydrotest.

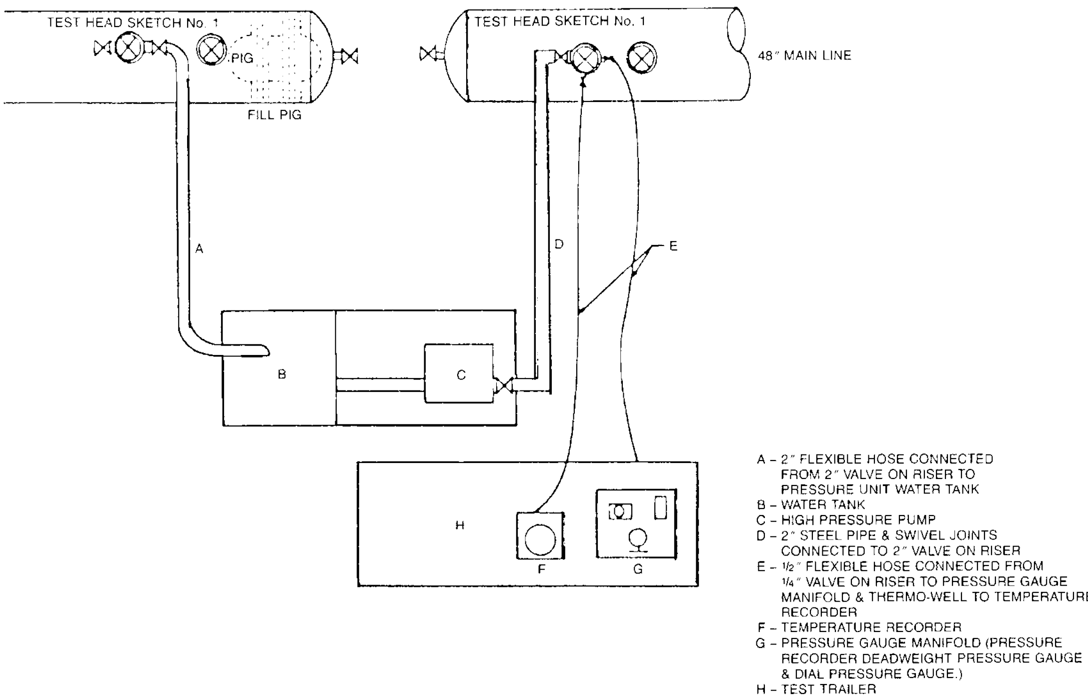

Figure 6. Typical pressure unit setup. Courtesy Milbar Hydrotest.

calculations, it will be necessary to have accurate temperature and pressure readings.

The pipeline test temperature may be affected by river/creek crossings along the pipeline route. Also, if cold river water is used, there will be a changing temperature gradient. Air, either trapped or entrained, will also affect the pressure-temperature calculations since the coefficient of expansion for air is not the same as for water. If the calculations are made and the decrease in pressure cannot be attributed to a temperature change, then it may be necessary to sectionalize the test section by manifolding and repressuring the shorter segments to facilitate locating the leak. Once the leak has been located and repaired, testing operations can resume.

Air compressors will be required to remove the water once the testing is complete. The maximum head for this particular project was 450 ft (195 psig). Allowance will need to be included for friction loss in the cross-over manifolds. The compressors will need to have sufficient capacity to remove the water at about the same rate as the fill rate. Most portable compressors are limited to approximately 125 psig. In this case, booster compressors will be needed for the 195 + psig. See Figure 7 for a typical dewatering connection.

Upon completion of testing, the test pressure is bled off to leave approximately 10–20 psig at the high point in the test section. Dewatering may be accomplished using the air compressors discussed earlier. Some companies may elect to displace the test water with the material that will normally be pumped through the line. This is usually the case with crude oil and refined product pipelines. Pipelines used to transport natural gas and certain chemicals are usually dewatered using compressed air. Care must be exercised in the dewatering operation to make sure that no air is introduced into the test section, thus minimizing the possibility of air locks. An air lock is probably the most severe problem involved in dewatering. Air locks are caused by air accumulating in the downhill leg and water accumulating in the uphill leg, which creates a manometer in the pipeline. In some instances, extremely high pressures may be required to overcome the manometer. Care should be exercised to be sure the maximum allowable pipeline operating pressure is not exceeded. It may also be necessary to tap the line and vent air at the high points.

If it is necessary to pipe the water away from the right-of-way, welded pipe should be used. The pipe must be securely anchored. The use of tractors and skids will probably provide sufficient anchoring.

Always use a valve to control the amount of water being bled from the pipeline.

If there will be a delay in placing the pipeline in operation, and it is decided to leave the test water in the line until operations begin, consideration should be given to the use of a corrosion inhibitor. Long-term storage of the line may necessitate the use of oxygen scavengers in addition to the inhibitor.

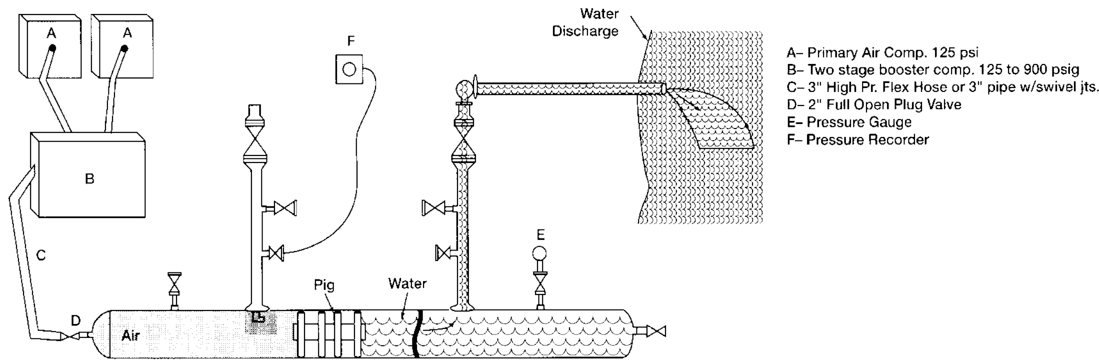

Figure 7. Dewatering arrangement. Courtesy Milbar Hydrotest.

FIELD PRESSURE & TEST REPORT

Page ______ of ______

Contractor or Company: ______

Pipe Line Description: ______

Section Tested: From: ______ To: ______

Test Section No.: ______ Length: ______

Type and Size of Pipe: ______ O. D. x ______ W.T. x Grade ______ Manufacturer: ______

Pressure Unit No.: ______ Gallons per Stroke: ______ Fill Unit No.: ______

Pressure Unit Location: ______ Water Source: ______

Time and Date Test Started: ______ AM PM ______ Test Pressure (Maximum): ______ PSIG

Time and Date Test Ended: ______ AM PM ______ Pressure Volume Plot: Yes ______ No ______

Section Accepted ______ Section Leaking ______ Section Ruptured ______

DEADWEIGHT RECORDED READING (PSIG)

TIME	PRESSURE	TEMP DEG.F	TIME	PRESSURE	TEMP DEG. F	TIME	PRESSURE	TEMP DEG. F
Date: ______								
AM PM			AM PM			AM PM		

Strokes per 10 psi: ______ Remarks: ______

Milbar Supt. ______ Inspector ______

Witness: 1. ______ 2. ______

Gauges and Recorders Last Tested ______ Deadweight Serial No. ______

Figure 8. Typical test report. Courtesy Milbar Hydrotest.

If after dewatering, residual moisture in the pipeline poses a problem, it will be necessary to clean and dry the pipeline. See Section 6 for drying details.

A permit to discharge the water may be required, especially if there is a possibility the water may enter a stream of water. This should be determined and permits obtained, if required, in the planning phase of the testing operation. A "splash" plate or bales of hay may be used when dewatering to prevent erosion.

The most important aspect of any test operation is complete and accurate documentation, since it will become a permanent record that must be retained for as long as the facility tested remains in operation. Federal Pipeline Safety Regulations for pipelines transporting liquids require that these records include the following information:

- the pressure recording charts;
- test instrument calibration data;
- the names of the operator, of the person responsible for making the test, and of the test company used, if any;
- the date and time of the test;
- the minimum test pressure;
- the test medium;
- a description of the facility tested and the test apparatus;
- an explanation of any pressure discontinuities, including test failures, that appear on the pressure recording charts; and,
- where the elevation differences in the section under test exceed 100 ft, a profile of the pipeline that shows the elevation and test sites over the entire length of the test section.

The records required by the Federal Pipeline Safety Regulations for pipelines transporting gas are similar to those required for pipelines used to transport liquids.

A typical test report is shown in Figure 8. If failures occur during the test, a report documenting the failure and the suspected reasons for the failure should be completed. A typical form is shown in Figure 9.

A daily operating log should be used to record activities associated with the test, operating status of the test equipment in use, engine rpm, and any unusual circumstances that occur during the test. A typical form is shown in Figure 10.

PIPE LINE FAILURE REPORT

1. Company ____________________
2. Section tested ____________________
3. Time of failure __________ AM, PM. Date ____________________
4. Location of failure: ____________________
5. Pressure, psig, at point of failure ____________________
6. Description of failure: Leak __________, Break __________, Length of failure __________
7. If leak, fill in blanks: __________ gallons lost per hour, __________ pounds lost per hour.
8. Describe any peculiarities or defects on failed part, such as corrosion or evidence of prior damage, etc. ____________________
9. Possible cause of failure ____________________
10. Pipe size: __________ OD x __________ Wt., Grade __________ Mfg. by __________ ____________________
11. Repairs: Pipe installed __________ OD x __________ Wt., Grade __________ Mfg. by __________, Length of joint or pup __________
12. Date repaired __________ 19 ____ By __________
13. Remarks (Damage to property, persons injured, etc.) ____________________

Figure 9. Pipeline failure report. Courtesy Milbar Hydrotest.

DAILY OPERATING REPORT

COMPANY & CONTRACTOR ______________________ DATE ________

LOCATION (City) ______________________ CONTRACT NO. ________

PIPE LINE DESCRIPTION: ______________________

PERSONNEL: ______________________

EQUIPMENT: ______________________

ACTIVITIES: ______________________

______________ COMPANY REP. ______________ CONTRACTOR REP. ______________ MILBAR SUPT.

Figure 10. Daily Operation Report. Courtesy Milbar Hydrotest.

APPENDIX A

Volume of water required to fill test section

$$V = L \times \left(3.1416 \times d^2/4\right) \times 12/231 \quad (1)$$

$$V = 0.0408 \times d^2 \times L$$

where

L = Length of test section, feet,
d = Inside diameter of pipe, inches,
V = Gallons required to fill @ O psig.

Volume required at test pressure

$$V_{tp} = V \times F_{wp} \times F_{pp} \times F_{pwt} \quad (2)$$

V_{tp} = Gallons contained in test section at test pressure P, and temperature T—°F,

F_{wp} = Factor to correct for the compressibility of water due to increasing pressure from 0 psig to test pressure P, psig,

F_{pp} = Factor to correct for volume change in pipeline due to pressure increase from 0 psig to test pressure P, psig,

F_{pwt} = Factor to correct for the change in water volume and pipe volume due to change in pipe and water temperature from base of 60 °F to pipe and water test temperature, T—°F.

$$F_{wp} = 1/\left[1 - \left(4.5 \times 10^{-5}\right) \times (P/14.73)\right] \quad (3)$$

P = Test pressure, psig.

$$F_{pp} = 1 + \left[(D/t) \times \left(0.91P/30 \times 10^{6}\right)\right] + \left[3.6 \times 10^{-6}(T - 60)\right] \quad (4)$$

D = Outside diameter of pipe, inches,
t = Pipe wall thickness, inches,
T = Pipe temperature, °F.

$$F_{pwt} = F_{pt}/F_{wt} \quad (5)$$

F_{pt} = Factor to correct for change in pipe volume due to thermal expansion of the pipe from base temperature of 60°F.

$$F_{pt} = 1 + \left[(T - 60) \times 18.2 \times 10^{-6}\right] \quad (6)$$

F_{wt} = Factor to correct for thermal change in specific water volume from 60°F to test water temperature. Refer to Table 1.

Sample calculation:

Pipe Size: 10.750 in. OD × 0.279 in. w.t. X-52
Length: 5 miles
Test pressure: 2430 psig
Temperature: 50°F

Use equation 1 to determine the initial line fill volume, V.

$$V = 0.0408 \times (10.75 - (2 \times 0.279))^2 \times 5280 \times 5$$
$$= 111,888 \text{ gallons}$$

Volume required to achieve test pressure $= V_{tp}$
$= V \times F_{wp} \times F_{pp} \times F_{pwt}$.

$$F_{wp} = 1/1 - \left[\left(4.5 \times 10^{-5}\right) \times (2430/14.73)\right] = 1.007479.$$

$$F_{pp} = 1 + \left[(10.75/0.279) \times \left(0.91 \times 2430/\left(30 \times 10^{6}\right)\right)\right] + \left[3.6 \times 10^{-6} \times (50 - 60)\right] = 1.002804$$

$$F_{pwt} = F_{pt}/F_{wt}$$

$$F_{pt} = 1 + \left[(50 - 60) \times 18.2 \times 10^{-6}\right] = 0.999818$$

$$F_{wt} = 0.9993061 \text{(from Table 1)}$$

$$F_{pwt} = 0.999818/0.9993061 = 1.000512$$

$$V_{tp} = 111,888 \times 1.007457 \times 1.002804 \times 1.000512 = 113,099 \text{ gals.}$$

Incremental volume required to reach test pressure, P.

$$= 113,099 - 111,888 = 1211 \text{ gals.}$$

After a period of time, the test pressure, P has decreased to 2418 psig and the temperature of the pipe and test water has decreased to 48°F. The calculation procedure previously described may be repeated to determine if the pressure decrease is attributable to the decrease in temperature.

V = 111,888 gals,
P_1 = 2422 psig,
T_1 = 48°F,
F_{wp1} = 1.007454,
F_{pp1} = 1.002796,
F_{pt1} = 0.999781,
F_{wt1} = 0.999217(from Table 1),

$$F_{pwt1} = 0.999781/0.999217 = 1.000565,$$
$$V_{pt1} = 111,888 \times 1.007454 \times 1.002796 \times 1.00565 (@\ 2422 \text{ psig and } 48°\text{F}),$$
$$V_{tpl} = 113,101 (\text{Volume at reduced temperature—represents volume that would be required to raise test procedure to original value at } 48°\text{F}),$$
$$V_{tp} = 113,099 (\text{Volume at initial test conditions}).$$

To restore the pressure to the original test pressure, 2 gals of water could be added to the test section. If more than two gallons are required to restore the test pressure, there is the possibility that a leak may exist.

When making these calculations, care must be exercised to be sure that accurate temperature and pressure data is available. Where test sections are long, it is very likely that the temperature will not be uniform throughout the test section and thus affect the accuracy of the calculated results.

Table 1
F_{wt}—Factor to correct for the thermal change in the specific volume of water from 60°F to the test water temperature

Temp. (°F)	F_{wt}	Temp. (°F)	F_{wt}
35	0.9990777	70	1.0010364
36	0.9990590	71	1.0011696
37	0.9990458	72	1.0012832
38	0.9990375	73	1.0014229
39	0.9990340	74	1.0015420
40	0.9990357	75	1.0016883
41	0.9990421	76	1.0018130
42	0.9990536	77	1.0019657
43	0.9990694	78	1.0021222
44	0.9990903	79	1.0022552
45	0.9991150	80	1.0024178
46	0.9991451	81	1.0025561
47	0.9991791	82	1.0027251
48	0.9992168	83	1.0028684
49	0.9992599	84	1.0030435
50	0.9993061	85	1.0031919
51	0.9993615	86	1.0033730
52	0.9994112	87	1.0035573
53	0.9994715	88	1.0037133
54	0.9995322	89	1.0039034
55	0.9996046	90	1.0040642
56	0.9996683	91	1.0042601
57	0.9997488	92	1.0044357
58	0.9998191	93	1.0046271
59	0.9999074	94	1.0047972
60	1.0000000	95	1.0050043
61	1.0000803	96	1.0052142
62	1.0001805	97	1.0053915
63	1.0002671	98	1.0056067
64	1.0003746	99	1.0057884
65	1.0004674	100	1.0060090
66	1.0005823	101	1.0061949
67	1.0006811	102	1.0064207
68	1.0008031	103	1.0066108
69	1.0009290	104	1.0068417

APPENDIX B

How to use charts for estimating the amount of pressure change for a change in test water temperature

Example.

Pipe data	18 OD × 0.375 in wt
Water temp. at beginning of test	70°F
Water temp. at time *T*	66°F
Test pressure	1800 psig

Calculate

$$D/t = 18/0.375 = 48$$

where

D = Pipe OD, in,
t = Pipe wall thickness, in.

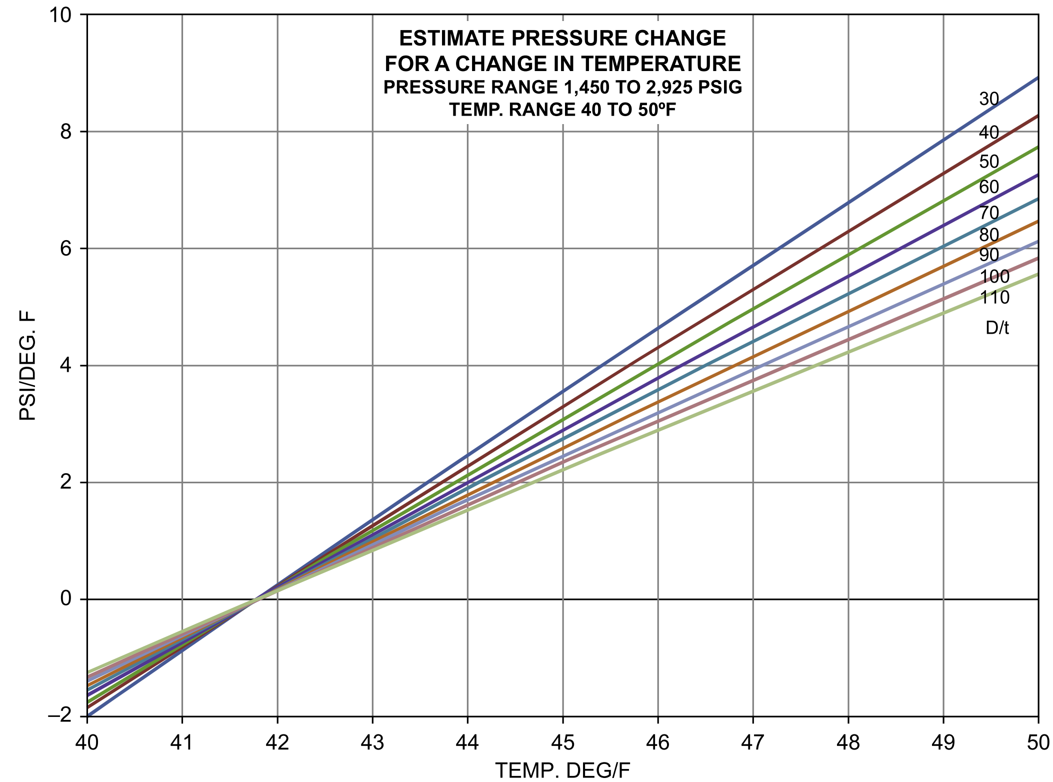

Figure 1.

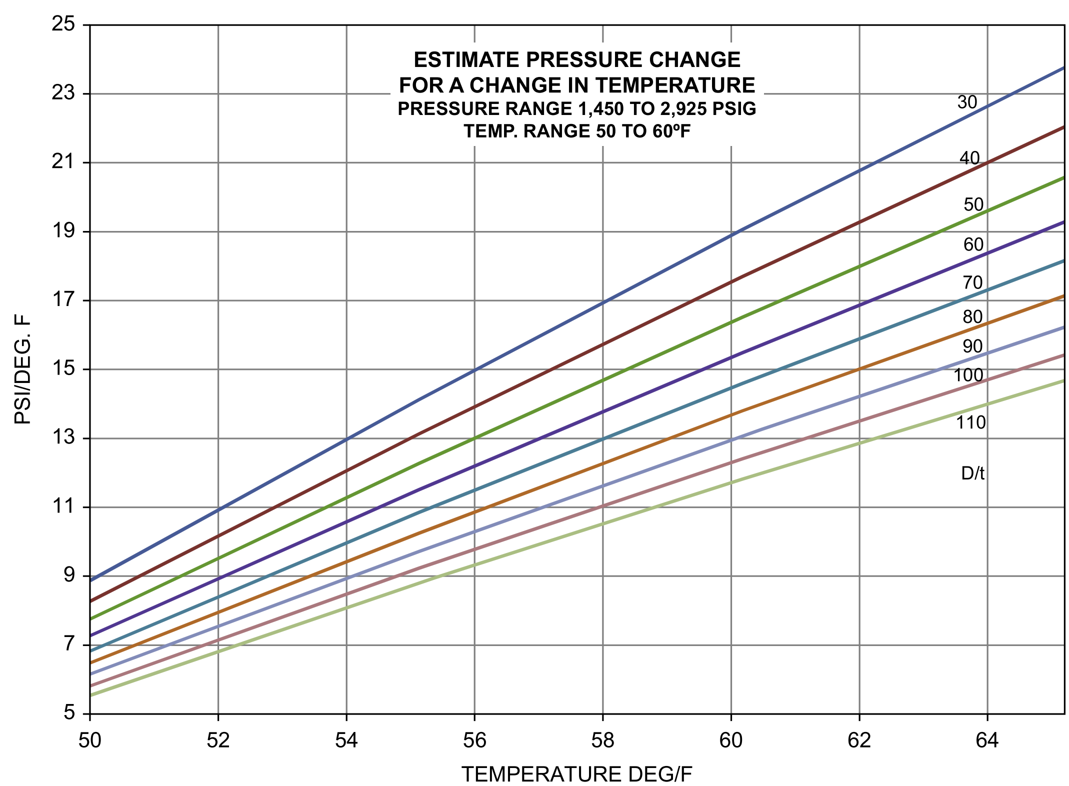

Figure 2.

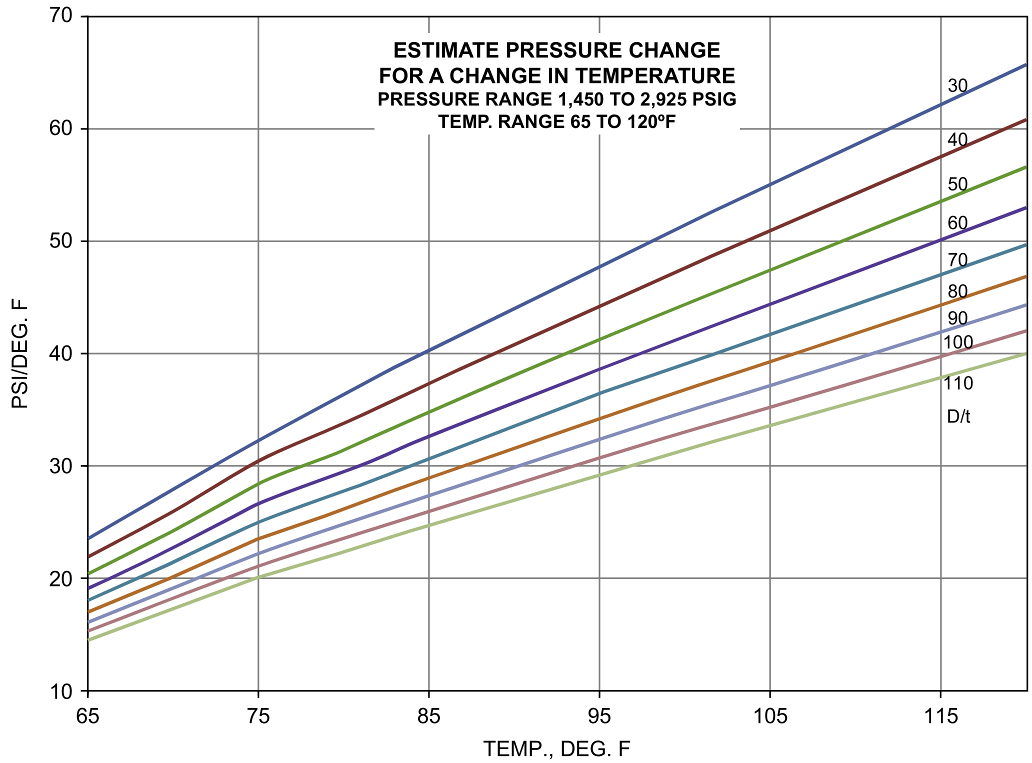

Figure 3.

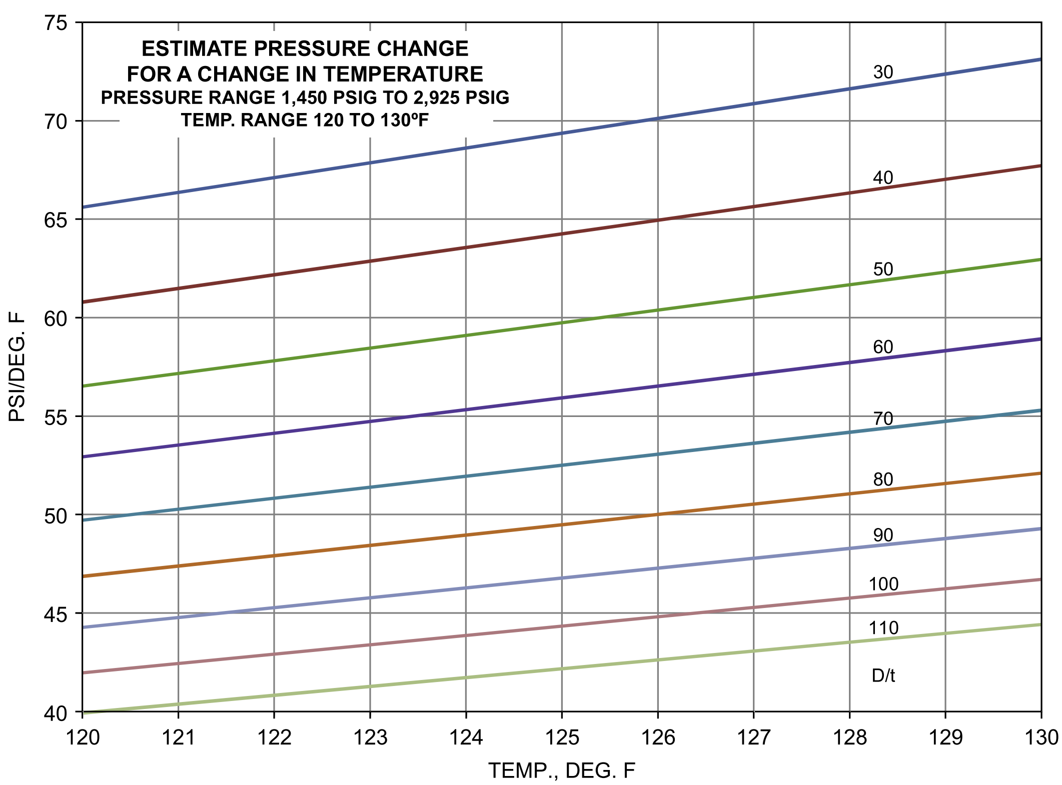

Figure 4.

Calculate

Average temperature $= (70 + 66)/2 = 68°F$

Use the chart in Figure 3. Enter at 68 °F and at the intersection with *D/t* line representing 48, read 23 psig/°F.

Basis for chart development

$$\Delta P = \frac{\beta - 2\alpha}{\frac{D \times (1 - \nu^2)}{E \times t + C}}$$

where

ΔP = psig change per °C,
β = Coefficient of expansion for water,
α = Coefficient of linear expansion for steel 1.116×10^6 per °C,
D = Pipe OD inches,
ν = Poisson's ratio 0.3,
E = Young's modulus for steel 30×10^6,
t = Pipe wall thickness, inches,
C = Compressibility factor for water, cu in/cu in/psig.

$$\beta \times 10^6 = -64.268 + (17.0105 \times T) - (0.20369 \times T^2) + (0.0016048 \times T^2)$$

T = water temperature, °C.

Compressibility factor for water

Pressure range 1450 psig to 2925 psig

Temperature (°C)	Compressibility factor cu in/cu in/psig
0	3.35×10^{-6}
10	3.14×10^{-6}
20	3.01×10^{-6}
50	2.89×10^{-6}

From *PIPECALC 2.0: PRACTICAL Pipeline Hydraulics*, Gulf Publishing Co., Houston, Texas.

Hydrostatic test records

At a minimum, the following records should be made for a hydrostatic test.

- Calculations supporting basis for hydrostatic test. This should take into account the high and low point elevations in the test section.
- Pressure recording charts.
- Test instrument calibration. This should include the pressure recorder and temperature recorder. Record the serial numbers of the instruments used for the test.
- Date and time of the test.
- Temperature of the test medium.
- Test medium used.
- Explanation of any pressure or temperature discontinuities.
- Explanation of any failures that occurred during the test.
- Weather conditions during test.
- Description of pipe in the test section.
- Any permits required for the test.
- Permits for discharge of test water.
- Any other records required by agencies having jurisdiction over the testing/operation of pipelines.
- All records should be signed and dated by the engineer in charge of the test.