Math Lab 11 MS 2

Using Graphs and Tables to Solve Problems That Involve Pressure Transducers in Fluid Systems

For best results, print this document front-to-back and place it in a three-ring binder.
Corresponding teacher and student pages will appear on each opening.

TEACHING PATH - MATH SKILLS LAB - CLASS M

RESOURCE MATERIALS

Student Text: Math Skills Lab

CLASS GOALS

1. Teach your students how to use manufacturer's specification bulletins to obtain information about transducers.
2. Teach your students how to solve problems that involve fluid transducers (using manufacturer's specification bulletins and value tables).

CLASS ACTIVITIES

1. Take five or ten minutes to go through the Student Exercises. Make sure that students understand the correct answers.
2. Complete as many activities as time permits. Students already should have read the discussion material and looked at the examples for each activity before coming to this class. (How much you accomplish will depend on the math skills your students already have.) Summarize the explanatory material for the activity: "Using Graphs and Tables to Solve Problems That Involve Pressure Transducers in Fluid Systems." Then have students complete the Practice Exercises given at the end of the activity.
3. Supervise student progress. Help students obtain the correct answers.
4. **Before the class ends, tell your students to read Lab 11F1, "Calibrating a Pressure Gage."**

Math Skills Laboratory

Lab 11 MS 2

MATH ACTIVITY

Activity: Using Graphs and Tables to Solve Problems That Involve Pressure Transducers in Fluid Systems

MATH SKILLS LAB OBJECTIVES

When you complete these activities, you should be able to do the following:

1. ***Use a manufacturer's specification bulletin, graphs and tables to solve transducer problems in fluid systems.***
2. ***Select correct adapters so that standard pressure transducers can be used in extreme temperature conditions.***
3. ***Solve problems that involve pressure-transducer selection and calibration.***

LEARNING PATH

1. ***Read the Math Skills Lab. Give particular attention to the Math Skills Lab Objectives.***
2. ***Study the examples.***
3. ***Work the problems.***

ACTIVITY

Using Graphs and Tables to Solve Problems That Involve Pressure Transducers in Fluid Systems

In this lab, you'll read and interpret data from charts and graphs. You'll also solve fluid-transducer problems.

Product bulletins list transducer characteristics for each model transducer that's available from a manufacturer. A technician must select a transducer based on the intended use.

A wrong choice is expensive and nonproductive. Often, transducer characteristics may not fit a customer's requirement. So the technician must adapt the transducer that's on-hand to fit the requirements.

It's often necessary to measure a fluid's pressure at temperatures either above or below the operating range of available transducers. An available transducer can be used if it can be isolated from the pressure source and extreme temperature with a short piece of pipe or tubing.

The manufacturer provides a graph of "Temperature of Pressure Source" versus "Tubing Length" to help do this. (See Figure 1.) This graph helps technicians choose a transducer to meet their special needs.

NOTE: Example A and Figure 1 represent a problem to be solved with the help of graphical data. This problem is typical of those that engineers and technicians solve daily. Take time to go through Example A and ensure that your students can "read" and interpret the graphical data in Figure 1.

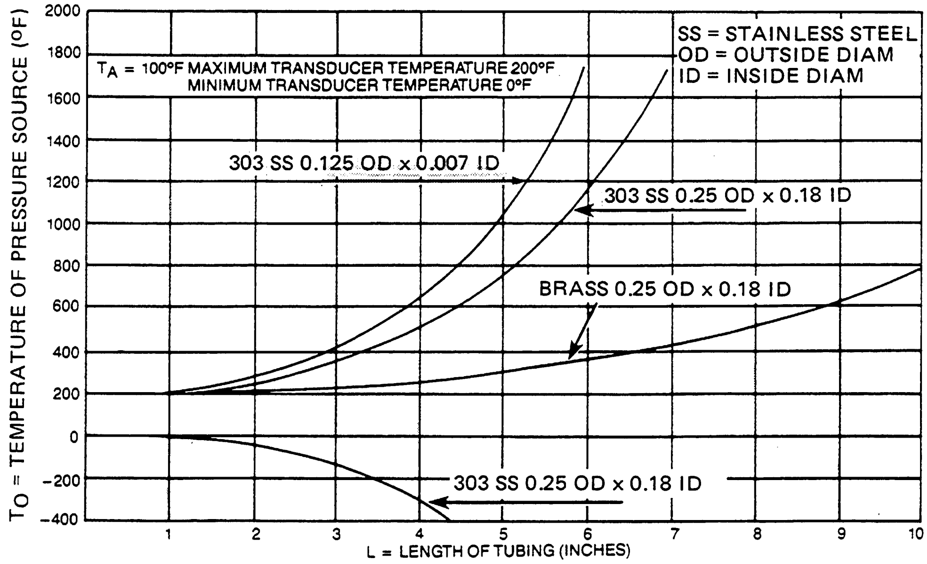


Fig. 1 Tubing length to isolate transducer from temperature source.

Let's find out how to read this graph. First, there are special conditions to be met:

- The vessel whose pressure is to be measured must be in a thermally insulated place. This is done to limit radiant heat transfer to the transducer. Then the major source of thermal input is only through the connecting tube that carries the fluid.
- The pressurized fluid should have a coefficient of thermal conductivity of less than 0.4 Btu/hr·ft·F°. A wide range of liquids and gases have a thermal conductivity less than this value.
- The ambient temperature around the transducer should be at 100°F.

When these conditions are satisfied, you can use the graph in Figure 1 to solve the problem in Example A.

Example A: *Choosing a Transducer to Measure Pressure of a Liquid at 600°F*

Given: A pressure transducer is required for sensitive detection of oil-pressure changes due to wear in oil pumps. The pressurized oil reaches static temperatures of 600°F. Available transducers operate in a 0°F- to-200°F-range, with ambient air temperature around the transducer at 100°F.

Find: The proper tubing to adapt the 0°F- to-200°F-transducer for use in measuring pressures of the 600°F oil.

Solution: Use the graph given in Figure 1.

a. The hydraulic oil temperature is 600°F. Find this value as "T_o" on the left side of the graph in Figure 1.

b. The curves on the graph represent different types of tubing. The abbreviations used to identify the tubing are as follows:
SS = stainless steel; OD = outside diameter of the tube in inches; ID = inside diameter of the tube in inches.

c. Select a specific type of tubing. Find the length from the appropriate line on the graph.

(1) 303 SS (0.125 OD x 0.007 ID)—Moving from left to right on the 600°F horizontal line for this type of tubing gives a length of 3.8 inches.

(2) 303 SS (0.25 OD x 0.18 ID)—Using the same procedure, the required length is 4.4 inches.

(3) Brass (0.25 OD x 0.18 ID)—Using same procedure, the length is 8.8 inches.

Note: The size of tubing for choices "(2)" and "(3)" is the same. However, brass conducts heat better than stainless steel. If the brass tube is used, it must be 4.4 inches longer than the stainless steel tubing (8.8 in − 4.4 in = 4.4 in).

NOTE: Be sure that students know how to use Table 1.
For example:

- Convert 10 atmospheres to Pascals.

$$10\,\cancel{\text{atm}} \times \underbrace{1.013 \times 10^5 \frac{\text{Pascals}}{\cancel{\text{atm}}}}_{\text{FROM TABLE}} = 10.13 \times 10^5\,\text{Pascals}$$

- Convert 15 psi to Pascals.

$$15\,\cancel{\text{psi}} \times \underbrace{6.895 \times 10^3 \frac{\text{Pascals}}{\cancel{\text{psi}}}}_{\text{FROM TABLE}} = 1.03 \times 10^5\,\text{Pascals}$$

Transducer manufacturers publish their product bulletins for a wide number of users. In the bulletins, the transducer characteristics are standardized to specifications of measurement outlined by the American National Standards Institute.

For example, in SI units, the Pascal (Pa) is established as the standard unit for pressure or stress. The Pascal is the same as 1 N/m^2. Table 1 is a sample of unit relationships found in a manufacturer's bulletin. It allows quick conversion from other pressure readings to Pascals.

This and similar tables of conversions appear in most manufacturers' transducer bulletins where pressure is being measured. Information such as that contained in Table 1 (below) and Table 2 (next page) helps the customer choose transducers from among off-the-shelf standard models and make the necessary unit conversions for measuring pressures.

TABLE 1.

To Convert to Pascals	Multiply by
atmosphere	1.013×10^5
bar	1.000×10^5
dyne/centimeter	1.000×10^{-1}
inch of mercury (0°C)	3.386×10^3
inch of water (4°C)	2.491×10^2
kilogram/meter^2	9.806
pound/inch^2 (psi)	6.895×10^3
pound/foot^2	4.788×10^1
torr (mm of mercury 0°C)	1.333×10^2

Let's consider a common pressure transducer that's often used. It's called a "bourdon tube."

The bourdon tube works on the following principle. When a pressure is applied to a fluid in a closed container, that pressure is transmitted evenly to all parts of the container. If the container is a curved tube, increasing the pressure causes the tube to straighten.

This is the same principle that causes a canvas fire hose to become round and try to straighten itself when pressure is applied. The amount of straightening action in the bourdon tube depends on the pressure applied. The straightening action causes a mechanical displacement that can be read on the dial face of a gage.

Suppose someone wanted to measure pressure ranges. You know how to use manometers. If you want a reading that's reasonably accurate, you might use a mercury manometer. For greater accuracy, you would choose a water manometer.

Here's why. One atmosphere of pressure (14.7 psi) will cause mercury (Hg) to rise 29.93 inches in a mercury manometer. One atmosphere will cause water (H_2O) to rise 406.9 inches in a water manometer. Therefore, there would be more graduations on the water scale. But who can put a 406-inch manometer (about 34 feet high) in their workplace?

Table 2 provides the technician with a pressure-conversion chart.

NOTE: Work through an example problem with your students to make sure they can use Table 2.
For example:

- Convert 11.5 psi to in/H_2O.

10.0 psi	=	276.80 in/H_2O	FROM TABLE
1.0 psi	=	27.68 in/H_2O	
0.5 psi	=	13.84 in/H_2O	
11.5 psi	=	318.32 in/H_2O	

- Convert 145 psi to mm/Hg.

100 psi	=	5,171.0 mm/Hg	FROM TABLE
40 psi	=	2,069.0 mm/Hg	
5 psi	=	258.6 mm/Hg	
145 psi	=	7,498.6 mm/Hg	

TABLE 2. PRESSURE CONVERSION CHART

psi	in H_2O	in Hg	mm H_2O	mm Hg	bar	mbar
0.01	0.2768	0.02036	7.031	0.5171	0.0006985	0.6895
0.02	0.5536	0.04072	14.06	1.034	0.001379	1.379
0.03	0.8304	0.06108	21.09	1.551	0.002068	2.068
0.04	1.107	0.08144	28.12	2.069	0.002758	2.758
0.05	1.384	0.1018	35.15	2.586	0.003447	3.447
0.06	1.661	0.1222	42.19	3.103	0.004137	4.137
0.07	1.938	0.1425	49.22	3.620	0.004826	4.826
0.08	2.214	0.1629	56.25	4.137	0.005516	5.516
0.09	2.491	0.1832	63.28	4.654	0.006205	6.205
0.1	2.768	0.2036	70.31	5.171	0.006895	6.895
0.2	5.536	0.4072	140.6	10.34	0.01379	13.79
0.3	8.304	0.6108	210.9	15.51	0.02068	20.68
0.4	11.07	0.8144	281.2	20.69	0.02758	27.58
0.5	13.84	1.018	351.5	25.86	0.03447	34.47
0.6	16.61	1.222	421.9	31.03	0.04137	41.37
0.7	19.38	1.425	492.2	36.20	0.04826	48.26
0.8	22.14	1.629	562.5	41.37	0.05516	55.16
0.9	24.91	1.832	632.8	46.54	0.06205	62.05
1	27.68	2.036	703.1	51.71	0.06895	68.95
2	55.36	4.072	1406	103.4	0.1379	137.9
3	83.04	6.108	2109	155.1	0.2068	206.8
4	110.7	8.144	2812	206.9	0.2758	275.8
5	138.4	10.18	3515	258.6	0.3447	344.7
6	166.1	12.22	4219	310.3	0.4137	413.7
7	193.8	14.25	4922	362.0	0.4826	482.6
8	221.4	16.29	5625	413.7	0.5516	551.6
9	249.1	18.32	6328	465.4	0.6205	620.5
10	276.8	20.36	7031	517.1	0.6895	689.5
14.7	406.9	29.93	10,340	760.2	1.014	1014
15	415.2	30.54	10,550	775.7	1.034	1034
20	553.6	40.72	14,060	1034	1.379	1379
25	692.0	50.90	17,580	1293	1.724	1724
30	830.4	61.08	21,090	1551	2.068	2068
40	1107	81.44	28,120	2069	2.758	2758
50	1384	101.8	35,150	2586	3.447	3447
100	2768	203.6	70,310	5171	6.895	6895
150	4152	305.4	105,500	7757	10.34	10,340
200	5536	407.2	140,600	10,340	13.79	13,790
250	6920	509.0	175,800	12,930	17.24	17,240

Note: To find 11.5 psi, for example, *add* values for 10 psi, 1 psi and 0.5 psi.

NOTE: Point out that the data shown in Table 3, "Pressure Versus Altitude," indicates that at what we call SEA LEVEL (or 0 altitude), the pressure is 14.70 psi, 29.921 in/Hg or 760 mm/Hg. These are, of course, the values we have been using for standard atmospheric pressure--the pressure at "sea level."

NOTE: At 80,000 ft (about 15.2 miles), the pressure has decreased from 14.7 psi at sea level to only about 0.40 psi. Outside of the Earth's atmosphere, in outer space, the pressure drops to 0.0 psi.

For more accuracy, and to avoid using a 34-foot water manometer, you can use a bourdon tube. It has a dial face that's calibrated in inches of "H_2O," inches of "Hg," "psi" or "bars of pressure." It can give accurate pressure reading.

Let's work through Example B to find how this is done. Use the values given in Table 2.

Example B: ***Converting Units on a Bourdon-Tube Pressure Gage***

Given: A manufacturer says that a bourdon-tube transducer measures pressures between 1 psi and 100 psi.

Find: The range of pressures in "inches of H_2O" that correspond to the bourdon-tube transducer range of 1 psi to 100 psi.

Solution: From Table 2, reading down the psi column to "1 psi" and across to the column labeled "in H_2O," you find that 1 psi = 27.68 inches of H_2O. Reading down the psi column to "100 psi" and across to the "in H_2O" column, you find that 100 psi = 2768 inches of H_2O.

Therefore: 1 psi = 27.68 inches of H_2O
100 psi = 2768 inches of H_2O

The corresponding range of pressures is 27.68 in H_2O to 2768 in H_2O.

The conversions are linear, since 2768 inches of H_2O is 100 times greater than 27.68 inches of H_2O. Therefore, any linear bourdon-tube transducer can exchange the psi gage face dial of (0-100) psi for a gage-face dial of (0-3000) inches of H_2O. The resulting readout will then be in "inches of H_2O."

Table 3 gives data on pressure versus altitude. The "psi" column in Table 3 shows that 14.7 psi is the pressure at sea level (0-feet altitude). Thus, an aneroid barometer sitting on the beach should read 14.70 psi pressure (or 1014 millibars of pressure, from Table 2).

That's information you know.

An aneroid barometer (an altimeter) mounted in an aircraft located on the beach would read "zero ft" above sea level. In this case, the beach (sea level) is the reference point. Altimeters use sea level as a reference point and measure altitude in feet above sea level. The number of feet above sea level (altitude) depends on the pressure of the air at that altitude.

Table 3 gives the altitude in feet for various pressure readings in units of "in Hg," "mm Hg" and "psi." For instance, Denver, Colorado, advertises itself as the "mile-high city." Table 3 shows that at one mile (5280 ft) above sea level, the corresponding air pressure is about 12 psi.

Transducers used to control pressures for fuel injection systems in automobiles and trucks need to be calibrated for different elevations. That's because trucks that travel in mountains sense a different atmospheric pressure (reference level) than those that travel at sea level. Failure to calibrate the transducers correctly would result in improper air/fuel ratios and poor performance.

TABLE 3. PRESSURE VERSUS ALTITUDE

Altitude (Feet)	Pressure		
	in/Hg	mm/Hg	psi
−1,000	31.02	787.9	15.25
−500	30.47	773.8	14.94
0	29.921	760.0	14.70
500	29.38	746.4	14.43
1,000	28.86	732.9	14.18
1,500	28.33	719.7	13.90
2,000	27.82	706.6	13.67
2,500	27.31	693.8	13.41
3,000	26.81	681.1	13.19
3,500	26.32	668.6	12.92
4,000	25.84	656.3	12.70
4,500	25.36	644.2	12.45
5,000	24.89	632.3	12.23
10,000	20.58	522.6	10.10
15,000	16.88	428.8	8.28
20,000	13.75	349.1	6.75
30,000	8.88	225.6	4.36
40,000	5.54	140.7	2.72
50,000	3.426	87.30	1.689
60,000	2.132	54.15	1.048
70,000	1.322	33.59	0.649
80,000	0.820	20.83	0.403

ANSWERS TO STUDENT EXERCISES

Problem 1:

a. From Table 3--at 2500 ft (altitude above sea level)--the transducer gage should be set to a correct zero of 13.41 lb/in^2 atmospheric pressure.

b. From Table 3--

Sea level ⟶ Atmospheric pressure = 29.921 inch Hg
2500 ft ⟶ Atmospheric pressure = 27.31 inch Hg
Difference = 2.611 inch Hg

The decrease in atmospheric pressure is 2.611 inch Hg.

Problem 2:

From Table 3--
At 3500 ft altitude, the atmospheric pressure is 12.92 psi.
To convert psi to millibars, use Table 2 and add values.

psi		millibar
10.00	=	689.5
2.00	=	137.9
0.90	=	62.05
0.02	=	1.379
12.92 psi		890.829 millibar

The answer to Problem 3 is on page T-52c.

Problem 3: From Problem 2, atmospheric pressure at 3500 ft elevation is 12.92 psi or 890.83 millibars. Using Table 1, there are two methods available to solve the problem.

Method 1:

$$12.92 \text{ psi} = 12.92 \text{ psi} \times \frac{6.895 \times 10^3 \text{ Pa}}{1 \text{ psi}}$$

$$12.92 \text{ psi} = (12.92 \times 6.895 \times 10^3) \frac{\cancel{\text{psi}} \cdot \text{Pa}}{\cancel{\text{psi}}}$$

$$12.92 \text{ psi} = 89.0834 \times 10^3 \text{ Pa}$$

12.92 psi = 89,083.4 Pa.

Method 2:

$$890.83 \text{ mbar} = 890.83 \text{ mbar} \times \frac{1.000 \times 10^5 \text{ Pa}}{1 \text{ bar}}$$

$$890.83 \text{ mbar} = 890.83 \times 10^{-3} \text{ bar} \times \frac{1 \times 10^5 \text{ Pa}}{1 \text{ bar}}$$

$$= (890.83 \times 10^{-3+5}) \frac{\cancel{\text{bar}} \cdot \text{Pa}}{\cancel{\text{bar}}} = 890.83 \times 10^2 \text{ Pa}$$

890.83 mbar = 89,083 Pa.

Therefore, 890.83 mbar is equal to 89,083 Pa.

PRACTICE EXERCISES

Solve the following problems.

Problem 1: Given: A pressure transducer mounted at the bottom of a vented water tank monitors pressure to show the depth (in feet) of water in the tank. When the tank is empty, and only atmospheric pressure (14.7 lb/in^2 at sea level) acts on the transducer, the readout gage on the transducer reads "zero."

Find:

a. The ***correct*** zero in lb/in^2 for the gage when the tank is located at a point 2500 ft above sea level. (Use Table 3.)
b. The difference in atmospheric pressure between an altitude of 2500 ft and sea level in inches of mercury (Hg). (Use Table 3.)

Solution:

Problem 2: Given: A quartz, sound-pressure microphone is to be installed in a burglar-detection system. The technician doing the work notes that the microphone is sensitive to pressure changes of 0.0001 psi. The technician notes also that it's been calibrated for a zero-at-sea-level pressure (1014 millibars).

Find: The pressure in millibars at 3500 ft above sea level.

Solution: (***Hint:*** Use Table 3 to find the pressure in psi that corresponds to an altitude of 3500 ft. Then use Table 2 to change psi to millibars.)

Problem 3: Given: The results of Problem 2 and Table 1.

Find: The atmospheric pressure at 3500 ft in Pascals (Pa).

Solution:

Problem 4: Using Table 3 to find normal atmospheric pressure at each city and Table 2 to convert normal atmospheric pressure from psi to mbar, we have:

a.

Denver			Key West		
Normal atmos pres = 12.23 psi			Normal atmos pres = 14.70 psi		
10.00 psi	=	689.5 mbar	10.00 psi	=	689.5 mbar
2.00 psi	=	137.9 mbar	4.00 psi	=	275.8 mbar
0.20 psi	=	13.79 mbar	0.70 psi	=	48.26 mbar
0.03 psi	=	2.068 mbar			
12.23 psi	=	843.258 mbar	14.70 psi	=	1013.56 mbar

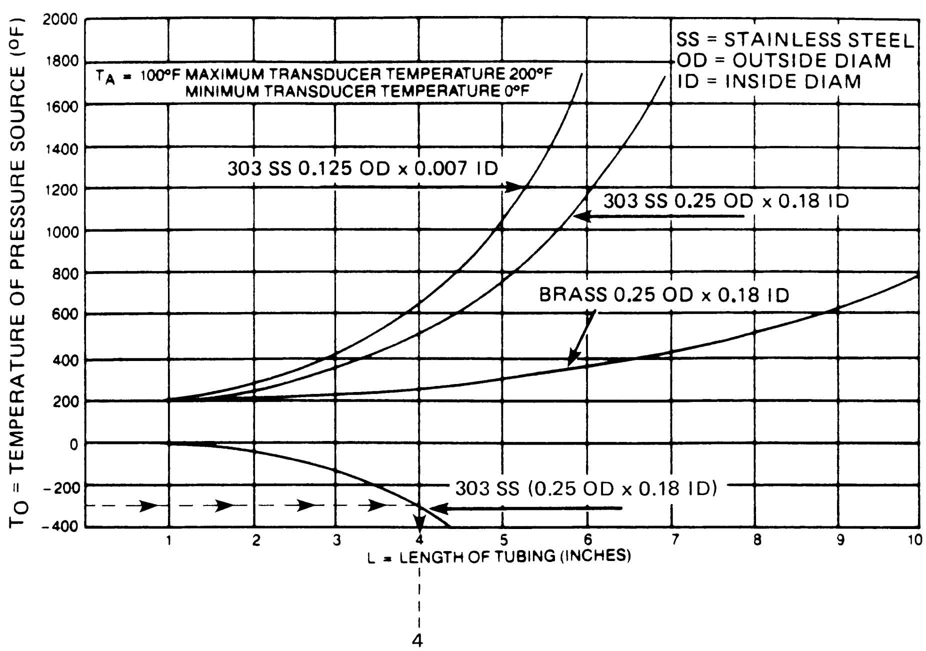
Atlanta			Boise		
Normal atmos pres = 14.18 psi			Normal atmos pres = 13.44 psi		
10.00 psi	=	689.5 mbar	10.00 psi	=	689.5 mbar
4.00 psi	=	275.8 mbar	3.00 psi	=	206.8 mbar
0.10 psi	=	6.895 mbar	0.40 psi	=	27.58 mbar
0.08 psi	=	5.516 mbar	0.04 psi	=	2.758 mbar
14.18 psi	=	977.711 mbar	13.44 psi	=	926.638 mbar

b.

City	1 atm (normal)	Barometer	
Denver	12.23 psi = 843.258 mbar	810 mbar	lower
Key West	14.70 psi = 1013.56 mbar	1015 mbar	steady or slightly higher
Atlanta	14.18 psi = 977.711 mbar	978 mbar	
Boise	13.44 psi = 926.64 mbar	900 mbar	lower

The answer to Problem 5 is on page T-53c.

Problem 5: First, locate the 303 SS (0.25 OD × 0.18 ID) curve on the graph. (See below.) Then, read down the temperature of pressure source (T_o) to T_o = -300°F. Next, read across the -300°F line until it intersects the curve. Finally, read vertically down from the intersection point to the horizontal scale. The desired length is seen to be 4 inches of tubing.



Problem 4: Given: The following weather data and Tables 2 and 3.

City	*Elevation*	*Barometric Reading*
Denver	5374 ft (1638 m)	810 mbar
Key West	3 ft (≃ 1 m)	**1015 mbar**
Atlanta	1062 ft (324 m)	978 mbar
Boise	2694 ft (821 m)	900 mbar

From the above information, the national weather forecaster can determine whether the pressure is above or below the normal pressure at each city. By taking several readings over a period of time, the forecaster can tell also if the pressure is rising or falling.

Find:

a. The normal atmospheric pressure in psi and millibars expected at each city. (Use Table 3.)

b. Compare the atmospheric pressure (Part a above) to the barometer reading (weather data). Determine if the barometer indicates a pressure higher than normal or lower than normal for that city.

Solution: (***Note:*** Choose altitudes in Table 3 that are nearest in value to the actual altitude given for each city.)

Problem 5: Given: A piezoelectric transducer with a temperature operating range of 0°F to -200°F is to be used to monitor ammonia gas pressure in a refrigeration unit. The gas is at –300°F. The gas line where the transducer is to be placed is well-insulated from the cold temperature, so no thermal energy transfer occurs.

Find: The length of 303 SS (0.25 OD × 0.18 ID) tubing needed to isolate the transducer to operate in a 100°F ambient atmosphere.

Solution: (***Hint:*** Use the correct curve in Figure 1.)