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Automatic pressure compensation

Application

This test applies to all liquid measuring devices that are equipped with an automatic pressure compensator. These will typically be found only in high vapour pressure liquid measuring applications and only in conjunction with automatic temperature compensation (ATC).

Definitions and abbreviations

APC
Automatic pressure compensation

ATC
Automatic temperature compensation

Ctl (m)
Correction for the temperature effects on the liquid in the meter.

Cpl (m)
Correction for the pressure effects on the liquid in the meter.

$Cpl_{applied}$
Correction for the pressure on the liquid as calculated and used by the register (method #2). Same as Cpl_{true}, except the value is calculated manually and not displayed by the register.

$Cpl_{theoretical}$
Correction for the pressure on the liquid as calculated for actual test conditions (methods #1 and #2)

Cpl_{true}
Correction for the pressure on the liquid as indicated and used by the register (method #1).

Equilibrium vapour pressure (P_e)
The pressure at which a liquid state and vapour state are in equilibrium at a given temperature in a closed system.

Pressure, absolute (P_{abs})[1]
Gauge pressure as corrected for atmospheric pressure. Zero referenced to a perfect vacuum.

Pressure, atmospheric (P_{atm})[1]
Constant value for assumed atmospheric pressure (101.325 kPa).

Pressure, gauge (P_{gauge})[1]
Pressure as indicated by a pressure gauge. Zero referenced to ambient pressure.

Description

An automatic pressure compensator is a device which incorporates the necessary components and software to automatically determine a correction factor for the effect of pressure on the liquid volume as it is being measured. It is referred to as the correction for the pressure on the liquid (Cpl). This factor is multiplied by the gross or uncompensated volume to determine the corrected volume at reference pressure conditions. For liquefied gases (e.g., liquefied petroleum gas [LPG]), the reference pressure is the equilibrium vapour pressure of the product at the temperature of the liquid at the time of measuring. Note that for normally liquid products, the reference pressure is the atmospheric pressure (i.e., 101.325 kPa).

The registers used for pressure compensation applications must be approved under the Terms and Conditions for the Approval of Electronic APC Incorporated into Electronic Registers. They are used in conjunction with a pressure transducer, a temperature sensor and either an inline densitometer or programmed with a fixed reference density of the liquid being measured. Using these inputs, the register will calculate the pressure correction factor applicable to the measuring conditions in the measuring element.

Pressure transducers used for pressure compensation must be approved according to the Terms and Conditions for the Approval of Pressure Transducers.

Notes:
Compensation factors are combined in the register through multiplication (e.g., Ctl × Cpl × MF). This is not the same as the prohibited composite meter factor.

Measuring systems incorporating automatic pressure compensation functions are typically installed at bulk loading facilities for high vapour pressure products (e.g., liquefied gases). Although automatic pressure compensation can be applied to liquids with low vapour pressures, such as gasoline and distillate, the scope of this procedure does not address these applications.

[1] Pressure (absolute) = pressure (gauge) + pressure (atmospheric)

Purpose

The purpose of this procedure is to confirm the ability of the pressure transducer used to measure the pressure is within the limit of error (LOE) as found in section 5.2 of the Terms and Conditions for the Approval of Electronic APC Incorporated into Electronic Registers and the automatic pressure compensation system is using the proper Cpl factor within the applicable LOE as found in section 5.1.

References

Terms and Conditions for the Approval of Pressure Transducers

Terms and Conditions for the Approval of Electronic APC Incorporated into Electronic Registers

American Petroleum Institute's (API) Manual of Petroleum Measurement Standards, Chapter 11.2.2M.

Test equipment and reference material

- Certified pressure gauge with a minimum division size of 5 kPa (accuracy of ±10 kPa up to 1 MPa reading and ±1% for readings above).
- Block and bleed valve and adapter if required for inspection purposes.
- Certified thermometer with a minimum division size of 0.1 °C.
- Certificate of accuracy or certificate of designation as a local standard for the thermometer and pressure gauge.
- Approved volume correction tables for the American Petroleum Institute's (API) Manual of Petroleum Measurement Standards, Chapter 11.2.2M.

Note: All electronic equipment used in a vapour environment must be intrinsically safe.

Procedure (visual check of installation)

- Confirm that the register and pressure transducer are approved (Notice of Approval).
- Confirm that the installation of the pressure transducer meets section 5.0 of the Terms and Conditions for the Approval of Pressure Transducers. Also see Figure 1 below:
  - The pressure tap is 1 m or less downstream of the measuring element and there are no pressure interfering elements between the tap and the meter.
  - There is a ¼ inch FNPT pressure tap outlet installed adjacent to the pressure transducer.

- There is a sealable needle valve installed at the pressure tap to permit isolating the tap from the main product line for testing purposes.

- Confirm that the correct product density at reference temperature (e.g., 15 °C) is programmed in the register. In the case of an inline densitometer, ensure it is acceptable for use in the application.
- Confirm that installation of the pressure transducer (A) is as per the installation shown in Figure 1.

A. Pressure transmitter.

B. Pressure transmitter sealable isolation needle valve (block and bleed preferred). Note: the bleed valve may be a separate valve in the pressure tap piping.

C. Pressure tap plug.

D. Pressure standard.

E. Pressure tap sealable isolation needle valve (block and bleed preferred).
Note: the bleed valve may be a separate valve in the pressure tap piping.

F. Pressure standard isolation needle valve.

- Ensure that the pressure tap isolation valve (E) is closed and remove any plugs or caps (C) that may be present on the pressure tap. Caution: there may be residual pressure between the tap and the cap.
- Install local pressure standard (D) using suitable thread sealant. If the pressure tap isolation valve (E) is not of the block and bleed type and a separate bleed valve has not been provided, install a bleed valve between the pressure tap and the local standard.

Note: Suitability of the pressure manifold to meet all legal and safety requirements is to be determined by the device owner. If a conflict arises between Measurement Canada (MC) design criteria and safety requirements, details should be forwarded to the Volumetric Specialist for resolution. In no case should an inspector modify a manifold design in order to complete a pressure test.

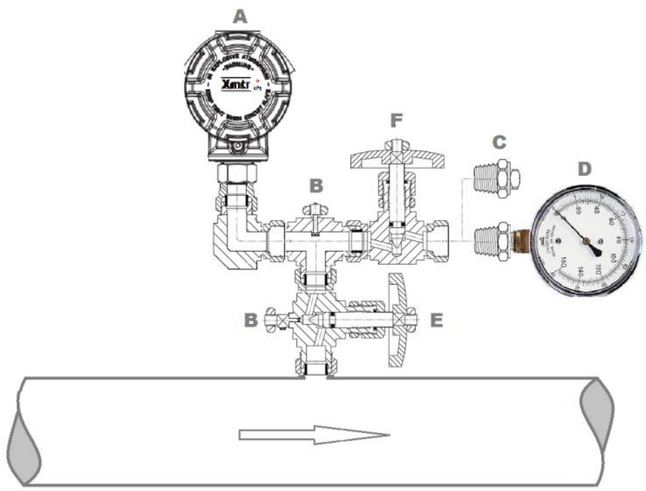

Figure 1 - Pressure transmitter and inspection tap

Note: This is but one possible allowable installation. Many others will be acceptable as well. Consult your volumetric specialist for more information.

Testing the pressure transducer

Pressure transducers may be found with unapproved displays at the transducer location. The raw pressure transducer signal may be modified or scaled within the approved register before being used to determine the Cpl factor. Therefore, pressure values should always be read from the approved register and not from any display that may be present on the transducer.

Where the system pressure and a pressure standard are used to test the accuracy of the pressure transducer, open the isolation valve (E), start a test run and flow product until the flow rate and pressure have stabilized. Close the isolation valve and record both the pressure displayed at the register and at the pressure standard.

Note: If the pressure remains stable, the isolation valve may not need to be closed to take a reading.

Pressure transducers may also be tested with a certified pressure simulator.

Ensure that the pressure readings are within the applicable tolerance specified in section 5.2 of the Terms and Conditions for the Approval of Electronic APC Incorporated into Electronic Registers. Repeat the above for at least 3 more pressures across the expected pressure range for testing. Note that the static vapour pressure in the system, with the pump off, may be used as one of the test points.

Table 1 Pressure reading - Limits of error

Indicated pressure	Limit of error
less than 1 MPa	± 50 kPa
between 1 and 4 MPa	± 5% of known pressure
more than 4 MPa	± 200 kPa

Ensure that the temperature as indicated by the register is tracking, within acceptable limits, to the temperature indicated by the temperature standard. If this is not the case, this issue must be resolved before proceeding.

Note: Pressure transducer isolation valves (E) must be sealed in the open position before and after the inspection. Failure to do so may allow a false pressure reading to be used for calculating Cpl. Pressure tap isolation valves (F) must be sealed in the closed position before and after an inspection to ensure no product is lost through the pressure tap. In addition, the pressure tap should be plugged anytime the pressure standard is not installed.

The pressure transmitter should be tested at 4 test points from low pressure to high pressure. Testing in this order will help to ensure that there is no pressure differential in the test piping and the product flow line. Use the following general procedure:

1. Remove seal and close isolation valve (E) to pressure manifold.
2. Open bleed valve (B) to relieve pressure in manifold. Remove inspection port plug or cap (C).
3. Install pressure standard (D) using suitable sealant. Open valve (F) and close bleed valve (B).
4. Slowly open isolation valve to pressurize manifold (E). Bleed valve (B) may be used to purge any trapped vapour or air from pressure manifold.
5. Start pump and pressurize to maximum pump pressure.
6. Close isolation valve as required. Record pressure readings from standard and device under test (DUT).
7. Stop pump and bleed manifold to less than 100 kPa. Close bleed valve (B).
8. Activate pump and open isolation valve (E) slowly and allow pressure to build to desired lowest test pressure.
9. Close isolation valve (E) and record pressure readings from standard and DUT.
10. Repeat for each desired pressure test point from low and working to high pressure.

Calculating the correction for the pressure on the liquid (method #1)

Note: If Ctl and Cpl are not available individually from the approved register, then use method #2 to conduct the inspection. This should be a relatively uncommon scenario as both Ctl and Cpl are required on modern approved registers with APC. Section 5.3 (2) of the Terms and Conditions for the Approval of Electronic APC Incorporated into Electronic Registers requires that the system provide Cpl or gross volume at reference pressure for inspection purposes.

- Reset the meter register to zero and then circulate a quantity of product to at least 2,000 times the minimum graduation, as defined in section 20 of SVM-1.
- During the test run, record the pressure (Pt) from the certified pressure standard and the temperature (Tt) taken from the certified temperature standard at 25%, 50%, 75% and 95% of the test volume.
- After the test run, record the following readings from the register:
  - Net registered volume
  - Gross registered volume
  - Average Ctl (m) factor (correction for temperature of the liquid in the meter)
  - Average Cpl (m) factor (correction for pressure of the liquid in the meter)
- Calculate the average pressure reading of the pressure standard and the average temperature readings of the temperature standard for the test run, taking into account the pressure and temperature standard corrections from the respective certificates of calibration.
  - Calculate the average run temperature (°C) from the recorded values for Tt.
  - Calculate the average run pressure (kPa gauge) from the recorded values for Pt.
  - Convert gauge pressure at the meter to absolute pressure.

Using the average pressure and temperature values as measured by the certified standards, calculate the theoretical Cpl value at the meter as follows:

$$Cpl_{\text{theoretical}} = 1/(1 - (Pt - P_e) \times Ft)$$

Where:

- Pt Average pressure at the meter, as indicated by the pressure standard converted to absolute pressure (kPa absolute).
- P_e Equilibrium vapour pressure of the product at the average temperature indicated by the temperature standard (kPa) absolute).
- Ft Liquid compressibility factor from the appropriate API table at the certified average temperature and reference density programmed in the register.

Note: Most reference tables provide the value of the equilibrium vapour pressure (P_e) in units of absolute pressure, and not gauge pressure. To convert from gauge to absolute pressure and vice versa, use the following equations:

$$P_{gauge} = P_{absolute} - P_{atm}\ (101.325\ kPa)$$

$$P_{absolute} = P_{gauge} + P_{atm}(101.325\ kPa)$$

Interpretation of results

As per section 5.1(1) of the Terms and Conditions for the Approval of Electronic APC Incorporated into Electronic Registers, ensure that the true Cpl measurement indicated at the register is within 0.2% of the theoretical Cpl value as calculated above.

Example for electronic automatic pressure compensator (method #1)

Register readings

Product:	LPG
Density:	510 kg/m^3
Net volume:	1992.8 litres
Gross volume:	1911.5 litres
Average temperature (Tm):	0.2 °C
Average pressure (Pm):	731 kPa gauge
Correction for temperature of liquid in meter (Ctl_{true}):	1.0408
Correction for pressure of liquid in meter (Cpl_{true}):	1.0014

Certified standard readings

Average temperature (Tt):	0.3 °C
Average pressure (Pt):	743 kPa (gauge)

From the appropriate lookup tables:

- the theoretical Ctl for 510 kg/m3 LPG at (Tt) 0.3 °C: = 1.0405; and
- the equilibrium vapour pressure (P_e) for LPG at (Tt) 0.3 °C and 510 kg/m3: = 458 kPa (absolute).

The theoretical pressure difference between the average pressure from the standard and the product vapour pressure, converted to absolute pressure, is:

$$(Pt_{gauge} + P_{atm}) - P_e$$

$$(743\ kPa + 101.325\ kPa) - 458\ kPa = 386.325\ kPa_{abs}$$

For a pressure difference of 386.325 kPa and a temperature of 0.3 °C, the API compressibility factor (Ft) is:

$$Ft = 3.8434E\text{–}06\ (1/kPa)$$

The theoretical Cpl at the above conditions (0.3 °C, pressure difference of 386.325 kPa) is 1.0015.

$$Cpl_{theoretical} = \frac{1}{1 - (Pt - P_e) \times Ft}$$

$$Cpl_{theoretical} = \frac{1}{1 - (386.325) \times 3.8434E - 06}$$

$$Cpl_{theoretical} = \frac{1}{0.998515} = 1.0015$$

The actual error in the CPL is calculated as:

$$Cpl_{error} = \frac{Cpl_{true} - Cpl_{theoretical}}{Cpl_{theoretical}} \times 100$$

$$Cpl_{error} = \frac{1.0014 - 1.0015}{1.0015} \times 100$$

$$Cpl_{error} = -0.01\%$$

The LOE of the APC function is ± 0.20% (Terms and Conditions for the Approval of Electronic APC Incorporated into Electronic Registers, section 5.1).

In this case, the actual error (-0.01%) is smaller than the LOE (0.20%) so the APC function is verified.

These calculations will generally be done using the APC worksheet from MC.

Calculating the correction for the pressure on the liquid (method #2)

Note: If the true applied Ctl and Cpl are available individually from the approved register, then use method #1 to conduct the inspection. If they are not available, confirm that the register is approved for automatic pressure compensation. Only very early registers approved with APC will not provide the necessary Ctl and Cpl values individually.

It is possible that the approved register will not be capable of displaying the Cpl values separately from the Ctl values. Instead, a combined correction factor will be calculated and displayed. This presents a challenge for the inspector who must determine if the Cpl and Ctl values are calculated correctly. The following simplified procedure will allow the inspector to isolate the Cpl from the effects of Ctl for purposes of assessing the functionality of the automatic pressure compensation alone.

- Reset the meter register to zero and then circulate a quantity of product equal to at least 2,000 times the minimum graduation, as defined in section 20 of SVM-1.
- During the test run, record the pressure (Pt) from the certified pressure standard and the temperature (Tt) taken from the certified temperature standard at 25%, 50%, 75% and 95% of the test volume.
- After the test run, record the following readings from the register:
    - Net registered volume (net)
    - Gross registered volume (gross)
    - Average temperature (Tm)
    - Average pressure (Pm)
    - Calculate the average Cm factor (combined correction for temperature and pressure of the liquid in the meter). This may be calculated as net registered volume divided by gross registered volume.
- Using the average temperature (Tm) measured at the meter and recorded by the register, determine the applied Ctl from the appropriate API table.
    - Calculate the average run temperature Tm (°C)
    - Calculate the average run pressure Pm (kPa gauge)
    - Convert the average gauge pressure at the meter to absolute pressure

Using the average pressure and temperature values as measured by the certified standards, calculate the theoretical Cpl value at the meter as follows:

$$Cpl_{theoretical} = 1/(1-(Pt-P_e)\times Ft)$$

Where:

Pt	Average pressure at the meter, as indicated by the pressure standard (kPa absolute)
P_e	Equilibrium vapour pressure of the product, at the average temperature indicated by the temperature standard (kPa absolute)
Ft	Liquid compressibility factor from the appropriate API table, at the certified average temperature and reference density programmed in the register

As per section 5.1(1) of the Terms and Conditions for the Approval of Electronic APC Incorporated into Electronic Registers, ensure that the applied Cpl measurement indicated at the register is within 0.2% of the theoretical Cpl value calculated above.

Using the Ctl value calculated above, calculate the applied Cpl value as follows:

$$Cpl_{applied} = Net/(Gross \times Ctl_{applied})$$

Where:

Net	Net (compensated) registered volume indicated by the approved register at 15 °C and the reference pressure.
Gross	Gross (uncompensated) registered volume indicated by the register at ambient conditions.
Ctl	Volume correction factor from the appropriate API table at the average delivery temperature (Tm) as **indicated by the approved register**.

Interpretation of results

As per section 5.1(1) of the Terms and Conditions for the Approval of Electronic APC Incorporated into Electronic Registers, ensure that the average true Cpl measurement applied at the register is within 0.2% of the theoretical Cpl value as calculated above.

Example for electronic automatic pressure compensator (method #2)

Register readings

Product:	LPG
Density:	510 kg/m^3
Net volume:	1992.8 litres
Gross volume:	1911.5 litres
Average temperature (Tm):	0.2 °C
Average pressure (Pm):	731 kPa gauge
Correction for temperature of liquid in meter (Ctl):	not available from register
Correction for pressure of liquid in meter (Cpl):	not available from register

Certified standard readings

Average temperature (Tt):	0.3 °C
Average pressure (Pt):	743 kPa gauge

From the API tables, the theoretical Ctl for 510 kg/m^3 LPG at an average temperature of 0.2 °C (Tm) = 1.0408. This represents the applied Ctl value at the register.

$$Ctl_{applied} = 1.0408$$

The applied Cpl is then calculated as:

$$Cpl_{applied} = Net\ volume/\left(Gross\ volume\ x\ Ctl_{applied}\right)$$

$$Cpl_{applied} = 1992.8\ litres/(1911.5\ litres\ x\ 1.0408)$$

$$Cpl_{applied} = 1.0017$$

From the API tables, the theoretical Ctl for 510 kg/m^3 LPG at 0.3 °C (Tt): = 1.0405 and the equilibrium vapour pressure (P_e) for LPG at 0.3 °C (Tt) and 510 kg/m^3: = 458 kPa (absolute).

Note: Most reference tables provide the value of the equilibrium vapour pressure (P_e) in units of absolute pressure, and not gauge pressure. To convert from gauge to absolute pressure and vice versa, use the following equations:

$$P_{gauge} = P_{absolute} - P_{atm}\ (101.325\ kPa)$$

$$P_{absolute} = P_{gauge} + P_{atm}(101.325\ kPa)$$

The theoretical pressure difference between the pressure standards and the product vapour pressure is:

$$(Pt_{gauge} + P_{atm}) - P_e$$

$$(743\ kPa + 101.325\ kPa) - 458\ kPa = 386.325\ kPa_{abs}$$

For a pressure difference of 386 kPa and a temperature of 0.3 °C, the API compressibility factor (Ft) is:

$$Ft = 3.8434E\text{–}06\ (1/kPa)$$

The theoretical Cpl at the above conditions (0.3 °C (Tt), pressure difference of 386.325 kPa) is 1.0015.

$$Cpl_{theoretical} = \frac{1}{1 - (Pt - P_e) \times Ft}$$

$$Cpl_{theoretical} = \frac{1}{1 - (386.325) \times 3.8434E - 06}$$

$$Cpl_{theoretical} = \frac{1}{0.998515} = 1.0015$$

The actual Cpl error is calculated as:

$$Cpl_{error} = \frac{Cpl_{applied} - Cpl_{theoretical}}{Cpl_{theoretical}} \times 100$$

$$Cpl_{error} = \frac{1.0017 - 1.0015}{1.0015} \times 100$$

$$Cpl_{error} = 0.02\%$$

The LOE of the automatic pressure compensation function is ± 0.20% (Terms and Conditions for the Approval of Electronic APC Incorporated into Electronic Registers, section 5.1).

In this case, the actual Cpl error (0.02%) is smaller than the LOE (0.20%), so the automatic pressure compensation function is verified.

These calculations will generally be done using the automatic pressure compensation worksheet from MC.