Common Types of Gas Meters

Types of Gas Meters

- Positive Displacement Meters
- Inferential Meters

Material quoted in part from Sensus publication
Common Positive Displacement Meters

Positive Displacement Meters

Diaphragm Meters

Rotary Meters

Material quoted in part from Sensus publication
Common Inferential Meters

Inferential Meters

- Turbine Meters
- Orifice Meters
- Ultrasonic Meters

Material quoted in part from Sensus publication
Calculating Flow Rate Measured by an Inferential Meter

\[ Q = V \times A \]

Where:
- \( Q \) = Flow Rate in CFH
- \( V \) = Gas Velocity
- \( A \) = Flow Area

Inferred Flow Rate = A flow rate derived indirectly from evidence
(e.g. velocity through a known area)
Advantages and Disadvantages of Turbine Meter

**Advantages**
- Good Rangeability
- Compact, Easy to Install
- Direct Volume Readout
- No Pressure Pulsations
- Wide Variety of Readouts
- Will not shut off gas flow

**Disadvantages**
- Limited Low Flow
- Susceptible to mechanical wear
- Affected by pulsating flow

Material quoted in part from Sensus publication
Let's Start with Explaining a Few Key Definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error</td>
<td>The difference between a measurement and its true value.</td>
</tr>
<tr>
<td>K-factor</td>
<td>A number by which the meter's output pulses are multiplied to determine the flow volume through the meter.</td>
</tr>
<tr>
<td>Meter factor</td>
<td>A number by which the result of a measurement is multiplied to compensate for systematic error.</td>
</tr>
<tr>
<td>MAOP</td>
<td>Maximum allowable operating pressure</td>
</tr>
<tr>
<td>Pressure drop</td>
<td>The permanent loss of pressure across the meter</td>
</tr>
<tr>
<td>Qmax</td>
<td>The maximum gas flow rate through the meter that can be measured within the specified performance requirement.</td>
</tr>
<tr>
<td>Qmin</td>
<td>The minimum gas flow rate through the meter that can be measured within the specified performance requirement.</td>
</tr>
<tr>
<td>Rangeability</td>
<td>The ratio of the maximum to minimum flow rates over which the meter meets specified performance requirement. Rangeability is also known as the turndown ratio.</td>
</tr>
</tbody>
</table>
Conversion to Base Conditions

Base conditions is a set of given temperature and pressure which describes the physical state of gas in flow measurement.

Base conditions are defined jurisdictionally:

In Canada       \( P_b = 101.325 \text{ kPa}, T_b = 15^\circ C \)

In USA          \( P_b = 14.73 \text{ psi}, T_b = 60^\circ F \)
The Ideal Gas Law

Conversion of the measured line volume to base volume relies on the equation of state for the particular gas.

\[ PV = nRT \]  \hspace{1cm} (1)

In this equation
- \( P \) is the absolute pressure
- \( V \) is the volume
- \( n \) is the number of moles of the gas
- \( R \) is the universal gas constant and equals 8.31451 J/mol K.
- \( T \) is the thermodynamic (or absolute) temperature

This equation is valid for \( n \) moles of gas and describes the relation between the volume \( V \), the (absolute) pressure \( P \) and the (absolute) temperature \( T \).
Reinhard Woltman was generally credited to be the inventor of the turbine meter in 1790 for measuring water flow.

Modern gas turbine meters are very accurate and repeatable over a wide flow range.

These meters have a very extensive installed base in the natural gas industry worldwide.
Cut-out View of a Turbine Meter

- Flow volume register
- Index Assembly
- Change gears
- Main rotor
- Nose cone
- Conditioning fins
- Lubrication fitting
- Encoder/sensor
- Top plate
- Meter body

Material quoted in part from Sensus publication
Cut-out View of another Turbine Meter

Index Assembly
Flow volume register
Conditioning plate
Coupling
Main rotor
Main shaft
Meter body
Bearing block

Material quoted in part from iMeter publication
Turbine meters operating at atmospheric pressure show a very non-linear performance curve.

Turbine meters operating in a high pressure line display a much more linear and predictable characteristic.
The Law of Conservation of Energy

Kinetic Energy = Dynamic Energy of Mass in Motion

\[ KE = \frac{1}{2} M V^2 \]

Where:
- \( KE \) = Kinetic energy of the moving gas molecules
- \( M \) = Mass of gas molecules
- \( V \) = Velocity of gas molecules

In a turbine meter, a portion of the linear kinetic energy of the moving gas molecules is converted into rotational energy of the rotor.
Principle of Turbine Meters

Analysis of an Ideal Rotor

- $\bar{r}$ is the average of the rotor radius
- $Q$ is the volume flow rate
- $A$ is the annular flow area
- $\beta$ is the blade angle
- $V_1, V_2$ are the gas velocities at point (1) and (2)
- $\omega_1, \omega_2$ is the fluid velocity relative to the rotor blades
- $\omega_i$ is the ideal angular velocity

\[
\frac{\omega_i}{Q} = \frac{\tan \beta}{\bar{r}A} \quad (1)
\]
\[
Q = \frac{rA \omega_i}{\tan \beta} \quad (2)
\]

The angular velocity of the rotor is proportional to the volume flow rate

\[
Q \propto \omega_i \quad (3)
\]
Index Assembly

The index assembly typically houses a readout register of flow volume and one or more sets of encoder disc and sensor for generating flow output pulses for electronic measurement systems.
The primary rotor of a dual-rotor turbine meter is basically the same as that of a single-rotor design. A second rotor is added for checking and/or improving the measurement integrity of the primary rotor under various flow conditions.

- Adjusted Volume at Initial Calibration
- Basic Adjustment Principle
- Operating Changes in Retarding Torque
- Self-Checking Feature
Construction of a Turbine Meters

Material quoted in part from Sensus publication
The main rotor is calibrated to register 110% of the actual flow passing through the meter. The sensing rotor is calibrated to register 10% of the actual flow. By design of the two rotors and their placement in the meter body, the flow error experienced by the sensing rotor matches that of the main rotor. The “Adjusted Volume” therefore provides a very accurate account of the true flow.

\[ V_{\text{adjusted}} = V_{\text{main}} - V_{\text{sensing}} \]

The sensing rotor correction factor \( \Delta \) is provided by factory calibration.
Dual-Rotor Turbine Meter

The Auto-Adjust Turbine Meter Equations:

\[
\bar{\Delta} = \left[ \frac{V_{\text{sensing}}}{V_{\text{adjusted}}} \times 100 \right] = \left[ \frac{V_{\text{sensing}}}{V_{\text{main}} - V_{\text{sensing}}} \times 100 \right] \quad (1)
\]

\[
\Delta A = \left[ \frac{V_{\text{sensing}}}{V_{\text{main}} - V_{\text{sensing}}} \times 100 \right] - \bar{\Delta} \quad (2)
\]

Where:

- \( V_{\text{main}} \) = volume by main rotor
- \( V_{\text{sensing}} \) = volume by sensing rotor
- \( V_{\text{adjusted}} \) = adjusted volume
- \( \bar{\Delta} \) = average value of the factory sensing rotor % adjustment
- \( \Delta A \) = % deviation in field operation from factory calibration

Material quoted in part from Sensus publication
The Auto-Adjust self-checking Indicator:

\[
\Delta A = \left[ \frac{V_{\text{sensing}}}{V_{\text{main}} - V_{\text{sensing}}} \right] \times 100 - \bar{A}
\]

The parameter \( \Delta A \) (delta A) is a self-checking indicator of the performance of an auto-adjust turbine meter. It shows the amount of adjustment the meter is making, thereby warning the user of meter or flow conditioning problems.
An ideal turbine meter has a flat error curve extending from $Q_{\text{min}}$ to $Q_{\text{max}}$.
Performance curve of a “Real” Gas Turbine Meter

Causes for “non-ideal” turbine meter behaviours:

- Dirty gas
- Mechanical friction
- Perturbations
- Density effect
- Reynolds effect

Typical performance curve of a turbine meter

Material quoted in part from iMeter publication
Of course Nothing is Perfect……

Performance curve of a “real” gas turbine meter

Material quoted in part from iMeter publication
Of course Nothing is Perfect

The accuracy of a gas turbine meter is influenced by mechanical friction at low flow rate and Reynolds number at high flow rate.

Recent research has shown that relatively large measurement errors can occur if a turbine meter was not calibrated at or near its operating pressure.
Dirt accumulated on the rotor blades has a tendency to speed up a turbine meter, thus resulting in overestimated flow volume.

Material quoted in part from iMeter publication
Dirt accumulated in bearings slows down a turbine meter, therefore results in underestimated flow volume.

Good bearings

Damaged bearings

Flow rate Q

Material quoted in part from iMeter publication
Impact of Damaged Bearings

At a constant inlet pressure, increase in mechanical friction due to bearing wear has more significant effect on **low flow** accuracy.

Damaged bearings slow down a turbine meter considerably

---

Material quoted in part from iMeter publication
The spin time of a turbine meter is a very good indicator of its condition.
Spin Time Effect on Proof

Effect of spin time on the proof of a T-35 Mark-II turbine meter

Quote from Sensus Turbo-Meter Installation & Maintenance Manual MM-1070 R9
Lubricating a Turbine Meter

HOLD LUBRICATING GUN IN THIS POSITION
WHEN LUBRICATION METER
PART NUMBER 005-24-460-00

PROTECTIVE CAP
ALEMITE FITTING
LUBRICATION VALVE

NOTE
The Turbo-meter will not be lubricated unless the check valve in the meter tube fitting is opened. One or two pumps of the gun after the gun is primed, will open the check valve.
Lubricating a Turbine Meter

a. Be sure lubrication system valve is securely closed.
b. Remove Alemite fitting.
c. Fill inlet of valve with recommended Turbo-Meter oil.
d. Re-install Alemite fitting securely.
e. Cycle lubrication system valve full open to full closed three times.
f. Repeat steps “a” through “e” above.
g. Leave lubrication system valve closed.
A single K-factor is often used to express the calibration of a turbine meter. It is simple but does not represent the operating characteristics of the meter throughout the entire flow range.

<table>
<thead>
<tr>
<th>Test Point</th>
<th>Test Meter Indicated Flow Rate (% Q_{max})</th>
<th>Test Meter &quot;As-Found&quot; % Error</th>
<th>K-factor (pulses/cubic foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.00</td>
<td>-0.25</td>
<td>103.3883</td>
</tr>
<tr>
<td>2</td>
<td>20.00</td>
<td>0.00</td>
<td>103.3883</td>
</tr>
<tr>
<td>3</td>
<td>50.00</td>
<td>0.25</td>
<td>103.3883</td>
</tr>
<tr>
<td>4</td>
<td>75.00</td>
<td>0.33</td>
<td>103.3883</td>
</tr>
<tr>
<td>5</td>
<td>100.00</td>
<td>0.35</td>
<td>103.3883</td>
</tr>
</tbody>
</table>
## Meter Factors

<table>
<thead>
<tr>
<th>Test Point</th>
<th>Master Meter Ref. Flow Rate (% Q&lt;sub&gt;max&lt;/sub&gt;)</th>
<th>Test Meter Indicated Flow Rate (% Q&lt;sub&gt;max&lt;/sub&gt;)</th>
<th>Test Meter Meter factors (Reference Volume or Flow Rate / Indicated Test Meter Volume or Flow Rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.025</td>
<td>10.000</td>
<td>1.0025</td>
</tr>
<tr>
<td>2</td>
<td>20.000</td>
<td>20.000</td>
<td>1.0000</td>
</tr>
<tr>
<td>3</td>
<td>49.875</td>
<td>50.000</td>
<td>0.9975</td>
</tr>
<tr>
<td>4</td>
<td>74.750</td>
<td>75.000</td>
<td>0.9967</td>
</tr>
<tr>
<td>5</td>
<td>99.650</td>
<td>100.000</td>
<td>0.9965</td>
</tr>
</tbody>
</table>

Material quoted in part from AGA publication.
### Flow Weighted K-factor and Meter Factor

<table>
<thead>
<tr>
<th>Ql Flow Rate % Q&lt;sub&gt;avg&lt;/sub&gt;</th>
<th>Test Meter &quot;As-found&quot; % Error</th>
<th>Meter factors</th>
<th>K-factor (103.3883 / Final meter factor)</th>
<th>Test Meter Average final meter factor applied % Error</th>
<th>Final meter factor Flow weighted (see Note 1)</th>
<th>K-factor (103.3883 / Final meter factor)</th>
<th>Test Meter Flow weighted final meter factor applied % Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>-0.25</td>
<td>1.0025</td>
<td>0.9986</td>
<td>103.5332</td>
<td>-0.39</td>
<td>0.9975</td>
<td>103.6474</td>
</tr>
<tr>
<td>20</td>
<td>0.00</td>
<td>1.0000</td>
<td>0.9986</td>
<td>103.5332</td>
<td>-0.14</td>
<td>0.9975</td>
<td>103.6474</td>
</tr>
<tr>
<td>50</td>
<td>0.25</td>
<td>0.9975</td>
<td>0.9988</td>
<td>103.5332</td>
<td>0.11</td>
<td>0.9975</td>
<td>103.6474</td>
</tr>
<tr>
<td>75</td>
<td>0.33</td>
<td>0.9967</td>
<td>0.9986</td>
<td>103.5332</td>
<td>0.19</td>
<td>0.9975</td>
<td>103.6474</td>
</tr>
<tr>
<td>100</td>
<td>0.35</td>
<td>0.9965</td>
<td>0.9986</td>
<td>103.5332</td>
<td>0.21</td>
<td>0.9975</td>
<td>103.6474</td>
</tr>
</tbody>
</table>

Note 1: In this example, the meter factor has been weighted by normalizing percent error at 50 percent Q<sub>avg</sub> to zero. Different flow weighting methods may be used for other applications.

Material quoted in part from AGA publication.
## Typical Turbine Meter K-factors by Calibration

### 1. High frequency pulse output from rotor shaft sensor

<table>
<thead>
<tr>
<th>Pulses per rev of main rotor shaft</th>
<th>Internal Gearing Reduction</th>
<th>External Gearing Reduction</th>
<th>Driven Change Gear</th>
<th>Driving Change gear</th>
<th>Cubic feet per output rev</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 x 15</td>
<td>122.056</td>
<td>72</td>
<td>51</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

\[ \text{K-factor} = \frac{4 \times 15 \times 122.056 \times 72 \times 51}{100} = 103.383 \text{ pulses/cu ft} \]

### 2. High frequency pulse output from rotor shaft sensor

<table>
<thead>
<tr>
<th>Test flow rate</th>
<th>( % Q_{\text{max}} )</th>
<th>K-factor (Average of 5 calibration values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test flow rate No. 1</td>
<td>10</td>
<td>10000</td>
</tr>
<tr>
<td>Test flow rate No. 2</td>
<td>25</td>
<td>10000</td>
</tr>
<tr>
<td>Test flow rate No. 3</td>
<td>50</td>
<td>10000</td>
</tr>
<tr>
<td>Test flow rate No. 4</td>
<td>75</td>
<td>10000</td>
</tr>
<tr>
<td>Test flow rate No. 5</td>
<td>100</td>
<td>10000</td>
</tr>
</tbody>
</table>

\[ \text{K-factor} = \frac{10 \times 10000 \times 96.9650}{103.1300} = 103.383 \text{ pulses/cu ft} \]

*Volumes corrected to P & T conditions of the test meter.*
Shifting Error Curve by Change Gear

Turbine Meter Calibration
Change Gear Shift - Example

- 0.24% Error Shift due to change gear adjustment

As-Found with 72/51 Chg Gears
As-Left with 75/53 Chg Gears

<table>
<thead>
<tr>
<th>Test Point</th>
<th>Master Meter Red. Flow Rate (% of Q_{max})</th>
<th>Test Meter Indicated Flow Rate (% of Q_{max})</th>
<th>Test Meter &quot;As-Found&quot; with 72/51 Change Gears</th>
<th>Test Meter &quot;As-Left&quot; with 75/53 Change Gears</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.023</td>
<td>10.00</td>
<td>-0.25</td>
<td>-0.49</td>
</tr>
<tr>
<td>2</td>
<td>20.000</td>
<td>20.00</td>
<td>0.00</td>
<td>-0.24</td>
</tr>
<tr>
<td>3</td>
<td>49.875</td>
<td>50.00</td>
<td>0.25</td>
<td>0.01</td>
</tr>
<tr>
<td>4</td>
<td>74.759</td>
<td>75.00</td>
<td>0.33</td>
<td>0.09</td>
</tr>
<tr>
<td>5</td>
<td>98.655</td>
<td>100.00</td>
<td>0.35</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Material quoted in part from AGA publication.
Calibration adjustment of the mechanical output of a turbine meter is typically accomplished by choosing an appropriate set of change gears.
Linearization of flow meter

If the error of a flow meter is known, it can be corrected for. Some flow computers have the ability to carry out this correction. First the correction data resulting from calibration are fed into the instrument. Next, the appropriate correction factor at the particular flow rate is determined and applied. The result will be perfectly linear.
FOREWORD

This Report is published as a recommended practice and is not issued as a standard. It is presented in the form of a performance-based specification. Research conducted in support of this report has demonstrated that turbine meters can accurately measure natural gas when calibrated and installed according to the recommendations contained herein. Turbine meters should meet or exceed the requirements specified in this Report and users should follow the applicable installation and maintenance recommendations. This version of AGA Report No. 7 is intended to supersede all prior versions of this document.

Appendix B of this Report contains the equations needed to convert volume measured at actual (line) conditions to equivalent volume at base conditions, or to mass. These equations may be used to perform such calculations with any type of positive displacement or inferential meter that registers in units of volume.

This Report is the cumulative result of years of experience of many individuals and organizations acquainted with the measurement of natural gas. Changes may become necessary from time to time. When revisions to this Report are deemed advisable, recommendations can be forwarded to: Operating and Engineering Section, American Gas Association, 400 North Capitol Street, NW, 4th Floor, Washington, DC 20001, USA.
3.2 Operating Pressures
The operating pressure of the meter shall be within the range specified by the meter manufacturer. The manufacturer shall specify the maximum allowable operating pressure for the meter design and construction. Turbine meters, in general, do not have a minimum operating pressure limit although error may be increased if used under conditions for which the meter has not been calibrated. Section 6 provides information on calibration requirements.

3.3 Temperatures, Gas and Ambient
The meter shall be used within the manufacturer's flowing gas and ambient air temperature specifications. Depending upon material of construction, turbine meters can operate over a flowing gas and ambient temperature range of -40 to +165°F (-40 to 74°C). It is important that the flowing gas temperature remain above the hydrocarbon dew point of the gas to avoid possible meter damage and measurement error. The manufacturer shall provide gas temperature and ambient air temperature specifications for the meter, as they may differ from the above.

3.4 Effect of Gas Density
Gas density can have three principal effects on the performance of the gas turbine meter:
• Rangeability - The rangeability of a turbine meter increases as gas density increases.
• Pressure Drop - The pressure loss across a turbine meter increases as the gas density increases.
• Error – Operating characteristics may change as gas density changes.

Material quoted in part from AGA publication.
6.3.3 Calibration Configuration
To minimize errors, meters should be calibrated in the same configuration as that intended in service. However, most test facilities routinely perform calibrations in the recommended configuration described in Section 7.2. Research (Reference 2) has shown that the errors of meters calibrated in this manner will be acceptable when installed in any of the configurations described in Section 7.2. For applications with more severe installation configurations, the user should consult the manufacturer or test facility operator for experimental data to determine an adequate calibration configuration.

6.3.4 Calibration Facilities
Test facilities used for meter calibration shall be able to demonstrate traceability to relevant national primary standards and to provide test results that are comparable to those from other such facilities.
AGA -7 General Performance Tolerances

Repeatability: ±0.2% from $Q_{\min}$ to $Q_{\max}$

Max peak-to-peak: 1.0% above $Q_t$

Error:

Maximum error: ±1.0% from $Q_t$ to $Q_{\max}$

±1.5% from $Q_{\min}$ to $Q_t$

Transition flow rate: $Q_t$ not greater than 0.2 $Q_{\max}$

Material quoted in part from AGA publication
AGA 7 - Installation for In-line Meter

NOTES: [1] Recommended spacing, unless otherwise supported by published test data for the flow conditioning element.
[2] Flange connections or protrusions allowed within this upstream section.
[3] For recommended size of blow down valve, see Table 1. Locate downstream of meter.
AGA 7 - Typical Meter Set Assembly

NOTES:

1) Recommended spacing, unless otherwise supported by published test data for the flow conditioning element.
2) No pipe connections or protrusions allowed within this upstream section.
3) Size of pressure loading line and valve to be the same as recommended blow down valve sizing (see Table 1).
AGA 7 - Short-Coupled Installation

NOTES:
1. Recommended spacing, unless otherwise supported by published test data for the flow conditioning element.
2. No pipe connections or protrusions allowed within the upstream section.
3. Size of pressure loading line and valve to be the same as recommended blow down valve sizing, (Table 1).
4. Turbine meter must have integral flow conditioner.

Material quoted in part from AGA publication.
AGA 7 - Close-Coupled Installation

NOTES: [1] Turbine meter must have integral flow conditioning element.
[2] Size of pressure-loading line and valve to be the same as recommended blow down valve sizing. (Table 1).

Material quoted in part from AGA publication.
AGA 7 - Angle-Body Meter Installation

Horizontal Installation (Inlet in Horizontal Plane, Outlet Down)

- 90° Elbow or Tee
- Maximum Reduction One Nominal Pipe Size

Optional
- Filter
- or Strainer

Inlet Piping 10 Nominal Pipe Diameters Long (5 Nominal Pipe Diameters with 19 tube bundles)

Pressure Tap

Optional
- 19 Tube Bundle
- or Flow Conditioning Element

Optional
- Valve

Recommended Pressure-Loading Line and Valve for operation above 500 psi [3]

Recommended
- Blow Down Valve Downstream [2]

Optional
- Flow Limiting Device

Optional
- Valve

Temperature Well

NOTES
1. Recommended spacing, unless otherwise supported by published test data for the flow conditioning element.
2. No pipe connections or protrusions allowed within the upstream section.
3. Size of pressure loading line and valve to be the same as recommended blow down valve sizing. (see Table 1).

Material quoted in part from AGA publication.
Low Level Perturbation

A straight AGA-7 compliant meter run produces an uniform flow profile with the same flow velocity across the cross-section of pipe.

An elbow or "tee" introduces a low level perturbation to the flow.
Low Level Perturbation

An additional out-of-plane elbow adds swirl to the already uneven flow profile
An up-stream regulator and out-of-plane elbow cause a high level of swirl and jetting at the meter run
Expanding from a smaller diameter pipe into a larger one introduces jetting which cannot be removed by a tube-bundle flow straightener.

Addition of an out-of-plane elbow upstream compounds the problem by adding a swirl component to the flow.
AGA 7 - Flow Conditioning for Turbine Meter

19-tube bundle straightening vanes

Flow conditioning plate

Material quoted in part from AGA publication
AGA 7 - Meter-Integrated Flow Conditioner

Figure 6: Dimensional Parameters for Integral Flow Conditioning

7.2.2.3 Integral Flow Conditioning
Research (Reference 2) has confirmed that turbine meters with integral flow conditioning in the nosecone flow passages operate satisfactorily in short and close-coupled installations. Those integral flow conditioners tested were similar in design to that shown in Figure 6 and to those evaluated in Reference 8. For this design, the aspect ratios are $H/D \leq 0.15$ and $S/L \leq 0.35$. These parameters are illustrated in Figure 6.

Material quoted in part from AGA publication
Turbine Meter with Integral Flow Conditioner

Integral conditioning plate typically allows a turbine meter to be installed in a non-ideal meter run (e.g. short meter run, elbows....) and maintain its accuracy

Example of a turbine meter with integral conditioning plate
The pressure loss of a turbine meter is directly proportional to the flow pressure and specific gravity and to the square of the flow rate:

\[ \Delta P_m \propto P_m \times G \times Q^2 \]

Where

- \( \Delta P_m \) = pressure drop across meter
- \( P_m \) = absolute flow pressure
- \( G \) = specific gravity of gas
- \( Q \) = flow rate
Pressure Loss Across a Turbine Meter

The pressure loss across a turbine meter is directly proportional to the line pressure and specific gravity and to the square of the flow rate:

\[ \Delta P_m \propto P_{abs} \times G \times Q^2 \]

In which:
- \( \Delta P_m \) is the pressure loss across the meter
- \( P_{abs} \) is the absolute line pressure
- \( G \) is the specific gravity of the gas
- \( Q \) is the flow rate
AGA 7 - Recommended Blow Down Valve Size

Properly sized blow down valve prevent over-spinning of turbine meter during line purge operation

<table>
<thead>
<tr>
<th>Meter Run</th>
<th>Valve Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>Inches</td>
</tr>
<tr>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>80</td>
<td>3</td>
</tr>
<tr>
<td>100</td>
<td>4</td>
</tr>
<tr>
<td>150</td>
<td>6</td>
</tr>
<tr>
<td>200</td>
<td>8</td>
</tr>
<tr>
<td>300</td>
<td>12</td>
</tr>
</tbody>
</table>
Effect of Rapid Rate of Pressure Change

Turbine meter manufacturers often specify a maximum rate of pressure change allowed for their products.

Exposure to rapid pressure change can cause damage to the electronic sensors in a turbine meter.

**Typical maximum rate of pressure change rating for turbine meter:**

100 psig/minute

Pipeline pressure vs Time

Rate of pressure change = \( \frac{\Delta P}{\Delta t} \)

Where

- \( \Delta P \) = maximum pressure change
- \( \Delta t \) = time period during which \( \Delta P \) occurs
Intermittent Flow Characteristic of Turbine Meter

Turbine Meters display different response characteristics while speeding up and slowing down.

- Underestimated volume on rapidly increasing flow
- Overestimated volume on rapidly decreasing flow

Flow Rate (ACFH) vs. Time (in minutes)

Intermittent Flow Response of Turbine Meter

Material quoted in part from iMeter publication
Due to the unsymmetrical transient response of turbine meters, they are susceptible to overestimating the flow volume of pulsating devices such as compressors and regulators.

Turbine meter can track the rising edge of a pulsating flow.

Turbine meter cannot track the falling edge of a pulsating flow because of the inertia of its rotor.

Overestimated volume

Flow rate (ACFH)

Time (in minutes)

Intermittent Flow Response of Turbine Meter

Material quoted in part from iMeter publication
Reynolds Number

\[ \text{Reynolds Number} = \frac{\rho v D}{\eta} \]

\( \rho \) = fluid density  \\
\( v \) = flow velocity  \\
\( D \) = pipe diameter  \\
\( \eta \) = fluid viscosity

Recent research conducted at CEESI and SwRI on behalf of AGA has demonstrated that commercially available gas turbine meters have markedly different responses to given volumes of natural gas at different Reynolds number.
Effect Of Fluid And Non-fluid Retarding Torques On Gas Turbine Meter Performance For Reynolds Number Below 100,000 (Source: Invensys Metering Systems)
Flow Profiles at Various Reynolds Number

Laminar if \( Re < 2000 \)

Transient if \( 2000 < Re < 4000 \)

Turbulent if \( Re > 4000 \)

Reynolds Number examples:
- 12" Standard Capacity Meter at 350 psia
  - at 10% of capacity \( Re = 700,000 \)
  - at 95% of capacity \( Re = 6,800,000 \)
The “State” of a gas

To calculate quantity in terms of base or standard volume one needs to know the quantity of matter, e.g. the number of moles, that occupies the actual volume measured under operating conditions.

This is done by using a suitable “Equation of State” for the type of gas measured and by using measured pressure and temperature.
Composition and compressibility

The composition of the gas influences the constants in the Equation of State. This is mostly translated in the “Compressibility factor” or “Z”.

<table>
<thead>
<tr>
<th>Component</th>
<th>Component Mole Percent for Indicated Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gulf Coast</td>
</tr>
<tr>
<td>Methane</td>
<td>96.5222</td>
</tr>
<tr>
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<tr>
<td>Carbon Dioxide</td>
<td>0.5956</td>
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<td>Ethane</td>
<td>1.8186</td>
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<td>Propane</td>
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<tr>
<td>i-Butane</td>
<td>0.0977</td>
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<td>n-Butane</td>
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<td>i-Pentane</td>
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<td>n-Pentane</td>
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</tr>
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<td>n-Heptane</td>
<td>0.0000</td>
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<tr>
<td>n-Octane</td>
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</table>

Material quoted in part from AGA publication
**Elevated Pressure Operation of Turbine Meter**

**12 Inch 45° Rotor Meter Characteristics**

<table>
<thead>
<tr>
<th>Operating pressure (PSI)</th>
<th>Max. flow rate SCFH</th>
<th>Min. flow rate SCFH</th>
<th>Turn Down Ratio</th>
<th>Approx. Maximum Pressure loss In. V.L.C.</th>
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<tbody>
<tr>
<td>0</td>
<td>1.01</td>
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<td>5.787</td>
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<td>10</td>
<td>1.70</td>
<td>7.256</td>
<td>2.0</td>
<td>26.3</td>
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<tr>
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<td>2.74</td>
<td>11.465</td>
<td>4.0</td>
<td>10.9</td>
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<td>41.00</td>
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<td>63.07</td>
<td>152.00</td>
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<td>244.00</td>
<td>260.0</td>
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---

**Elevated Pressure Operation**

1. Maximum Capacity in SCFH increases directly as does the Boyle’s Law pressure multiplier factor.

2. Minimum (Low Flow) Capabilities increases directly with the square root of the Boyle’s Law pressure multiplier factor.
Calculating Rangeability

### 4" T-18 MARK II TURBO METER 45° ROTOR ANGLE

(U.S. Units - Cubic Feet)

<table>
<thead>
<tr>
<th>Compressibility Ratio</th>
<th>Meter Pressure</th>
<th>Maximum Flow Rate</th>
<th>Maximum Flow Rate</th>
<th>Minimum Flow Rate</th>
<th>Minimum Flow Rate</th>
<th>Min. Dial Rate</th>
<th>Max./ Min. Flow Range</th>
<th>Approx. Press Loss</th>
<th>W.G.</th>
<th>W.G.</th>
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<td></td>
<td>PSIG</td>
<td>SCFH</td>
<td>MSCFD</td>
<td>SCFH</td>
<td>MSCFD</td>
<td>ACFH</td>
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<tr>
<td>1.0000</td>
<td>0.25</td>
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<td>430</td>
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<td>26</td>
<td>1,000</td>
<td>15</td>
<td>1.8</td>
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<td>24,000</td>
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<td>460</td>
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<td>911,000</td>
<td>23,540</td>
<td>8,900</td>
<td>314</td>
<td>490</td>
<td>320</td>
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<td>1.1630</td>
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<td>9,500</td>
<td>366</td>
<td>490</td>
<td>340</td>
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<td></td>
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<tr>
<td>1.1828</td>
<td>1,000</td>
<td>1,310,000</td>
<td>31,200</td>
<td>10,000</td>
<td>425</td>
<td>510</td>
<td>400</td>
<td>24.5</td>
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<td>1.2021</td>
<td>1,000</td>
<td>1,659,000</td>
<td>38,150</td>
<td>10,000</td>
<td>536</td>
<td>530</td>
<td>440</td>
<td>27.0</td>
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<td>1.2212</td>
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<td>1,712,000</td>
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<td>598</td>
<td>550</td>
<td>500</td>
<td>30.7</td>
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<td>1.2397</td>
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<td>1,791,000</td>
<td>47,280</td>
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<td>652</td>
<td>570</td>
<td>550</td>
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<td>1.2641</td>
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<td>2,247,000</td>
<td>58,580</td>
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<td>822</td>
<td>640</td>
<td>600</td>
<td>35.8</td>
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<td></td>
</tr>
</tbody>
</table>

*Note*: Maximum flow rate at 100 psi; minimum flow rate at 100 psi. Performance ratings in the above tables are based on +1% measurement accuracy for all pressures and flow rates shown.

Material quoted in part from Sensus publication.
Calculating Rangeability

Pressure Multiplier = \( \frac{(\text{Line Pressure} + \text{Average Atmospheric})}{\text{Base Pressure} \times \text{Compressibility Ratio}} \)

\[
= \frac{(500 \text{psig} + 14.48 \text{psi})}{14.73 \times 1.0863}
\]

\[
= 37.942
\]

Maximum Flow Rate = Meter Rating \( \times \) Pressure Multiplier

\[
= 18,000 \text{acfh} \times 37.942
\]

\[
= 682,956 \text{scfh} = 683,000 \text{scfh from table}
\]

Minimum Flow Rate = Meter Rating \( \times \) Square Root of Pressure Multiplier

\[
= 1200 \text{acfh} \times (37.942)^{0.5}
\]

\[
= 7391 \text{scfh} = 7400 \text{scfh from table}
\]

Range = Maximum / Minimum Flow Rate

\[
= \frac{683,000}{7400} = 92:1
\]

Material quoted in part from Sensus publication
Typical Turbine Meter Installation

Hazardous Area

Non-hazardous Area

Intrinsically safe NAMUR sensor or dry contact

Turbine Meter

Flow Computer / RTU

Pulse amplifier converting NAMUR signal to a standard 24V digital signal
NAMUR Signal

Inductive Sensor

Capacitive Sensor

Typical sensor current versus sensing distance

Supply Voltage = 8.2 VDC
Source impedance ~ 1 kΩ
Turbine Meter Output Signal Format

NAMUR Signal  Digital Signal

Low flow  Low Flow  High Flow  High flow

Material quoted in part from iMeter publication
Turbine Meter Pulse Signal Conditioning

Incorrect supply voltage or source impedance results in missed pulses
### Cost of Measurement Error

#### Turbine Meter Operating at 50 psig

<table>
<thead>
<tr>
<th>Meter Size</th>
<th>Energy Delivered in a 6 year Calibration Cycle *</th>
<th>Cost of Energy Delivered *</th>
<th>Cost of 0.5% Measurement Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inches</td>
<td>MMBtu</td>
<td>US$</td>
<td>US$</td>
</tr>
<tr>
<td>4</td>
<td>1,271,208</td>
<td>8,898,458</td>
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<td>2,478,052</td>
<td>17,346,361</td>
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<tr>
<td>8</td>
<td>4,264,180</td>
<td>29,849,258</td>
<td>149,246</td>
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<tr>
<td>8 HC</td>
<td>6,388,224</td>
<td>44,717,567</td>
<td>223,588</td>
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<tr>
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<tr>
<td>12 HC</td>
<td>16,332,613</td>
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#### Turbine Meter Operating at 500 psig

<table>
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<th>Meter Size</th>
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<th>Cost of Energy Delivered *</th>
<th>Cost of 0.5% Measurement Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inches</td>
<td>MMBtu</td>
<td>US$</td>
<td>US$</td>
</tr>
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</table>

Note 1: Turbine meters operating at 30% of Qmax average
Note 2: Energy content of natural gas based on 1.0205 MBtu/cu.ft.
Note 3: Cost of energy calculated based on $7.00 USD per MMBtu (including delivery)
Questions ?
References:
Sensus repair manuals.
Sensus Turbine Meter hand book.
iMeter Presentation on Turbine Meter
Instromet System Handbook
AGA Report #7
AGA Report #8