Flow Conditioning

• There is no flow meter on the market that **needs** flow conditioning.

• All flow meters are effective without any type of flow conditioning.
Flow Conditioning

Why do we want to use flow conditioners then?

• Can eliminate up to 80 – 90% of pipeline swirl.
• Restore flow profile symmetry and eliminate distortions.
• Isolates the flow meter from upstream disturbances.
• Allows much shorter meter runs to be used with much higher repeatability.
• Improves the benefits of many USM diagnostics by providing flow stability.
• Helps with noise or pulsation problems.
• Helps balance the pressure, velocity and flow rate of meter tubes running in parallel.

• They UNLOAD the flow meter, helping it become even more accurate.
Flow Conditioning

What if we have debris in our pipe?

- The debris has to go somewhere, ignoring the flow conditioner won’t make it disappear.
- Install a filter (or another flow conditioner UPSTREAM of the meter run to catch the debris).
- Without something to catch debris, we risk damaging or destroying any sample probes, thermo wells or any other equipment in the pipe.
- Better hope there isn’t a compressor or turbine downstream somewhere.
- If the gaskets are unraveling, recommend switching to Flexitallic CGI gaskets with an inner ring to keep the windings intact.
Flow Conditioning

- Using a flow meter without flow conditioning is simply giving up measurement accuracy and giving up money.

- Is our flow measurement ‘good enough’?

- Shouldn’t we aim for it to be the best, most accurate, lowest uncertainty measurement that is available with our current state of technology?
What is a Flow Conditioner?
What is a Flow Conditioner?
What is a Flow Conditioner?
What is a Flow Conditioner?
Why should we use a Flow Conditioner?

When dealing with flow measurement, we cannot simply stick a flow meter in the pipe, turn it on and expect perfect results.

In the real world, we have to deal with:

- Installation effects
- Swirl
- Flow profile distortion
- Pulsation
- Noise

All of these combine in different ways to generate measurement errors!
Fully Developed Flow

• Fully developed pipeline flow is the ideal state of a fluid in a pipe.

• If we had an infinitely long pipe, this is the flow we would always see.

• It is mathematically predictable.

• It is perfectly symmetrical around the center of the pipe.

• It has no swirl.

• This *should* guarantee us perfect, error free, repeatable measurement.

• Installation effects take us away from this state.
Fully Developed Flow

Normalized Flow Velocity ($V/V_{avg}$) vs. Distance Across Pipe (m)

Legend:
- ▲ 30000000
- ✗ 30000000
- ✶ 30000000
- ▢ 30000000
- ● 15000
- ▫ 10000
- ✷ 6000
- □ 1000
- ◆ 300
Fully Developed Flow
Swirl

- Swirl is the rotation of fluid in a pipe.
- It is caused by any change in piping direction!
- It can also be caused by any partial restriction of a pipe.
Swirl
Swirl
Swirl
Swirl
Swirl

- Swirl causes unpredictable distortions in the flow profile that change over time.

- Swirl flattens and then inverts flow profiles due to centripetal force. The harder the fluid is spinning, the more energy that is pushed to the pipe walls.

- Swirl can cause local effects due to the location of pressure taps (dP measurement) or in the case of Ultrasonic Meters (adding to or subtracting to local path velocity).
Installation Effects

Every pipe fitting generates an installation effect.

- Tees
- Elbows
- Expanders
- Reducers
- Valves
- Probes

All of these objects can combine to create a deviation from perfect fully developed flow.
Installation Effects - Elbows
Installation Effects - Tees
Installation Effects – Tees
Installation Effects – Tees /w Turbulence
Installation Effects - Probes
Installation Effects – Elbows & Orifice Plates
Installation Effects – Reducers
Measurement Errors

• The further we get from our perfect, swirl free, fully developed flow, the more uncertain our measurement becomes.

• Error due to flow profile distortion – deviation from baseline state.

• Error due to swirl itself.

• What if we want to shorten our meter run?

• What do we do?
Without Flow Conditioning

• We can build a meter run without any sort of flow conditioning!

• It just needs to be very long to compensate for installation effects and swirl.

• AGA3-2000 even allows this.

• Table 2-7 shows suggested meter run lengths when a flow conditioner won’t be used...but the runs could end up being 44D, 95D or even up to 145D long!!
Flow Conditioning

A properly designed Flow Conditioner converts this flow...

...Into this.
Flow Conditioning

A properly designed Flow Conditioner converts this flow....

...Into this.
Flow Conditioning

- CPA50E 10&10 OIMLR137 25m 11500 Horizontal 5D Downstream
- CPA50E 10&10 OIMLR137 25m 11500 Vertical 5D Downstream
- CPA50E 10&10 OIMLR137 25m 11500 Horizontal 8D Downstream
- CPA50E 10&10 OIMLR137 25m 11500 Vertical 8D Downstream
- CPA50E 10&10 OIMLR137 25m 11500 Horizontal 15D Downstream
- CPA50E 10&10 OIMLR137 25m 11500 Vertical 15D Downstream
Elbows – Swirl Removal

Swirl Vectors

1. NoFC-DEOOP1-2K-5-20-CH4x1 Swirl, Horizontal Line
2. NoFC-DEOOP1-2K-5-20-CH4x1 , Vertical Line
3. 55E-DEOOP1-3K-5-20-CH4x1 Swirl, Horizontal Line
4. 55E-DEOOP1-3K-5-20-CH4x1 , Vertical Line

Distance from Flow Conditioner (Inside Pipe Diameters)

Transverse Velocity Components

August-24-15

CPA Flow Conditioning 2015
Tees – Swirl Removal

Swirl Vectors

Distance from Flow Conditioner (Inside Pipe Diameters)

Transverse Velocity Components

NoFC-DTOOP1-3K-5-20-CH4x1 Swirl, Horizontal Line
NoFC-DTOOP1-3K-5-20-CH4x1, Vertical Line

Swirl Vectors

Distance from Flow Conditioner (Inside Pipe Diameters)

Transverse Velocity Components

SSE-DTOOP1-3K-5-20-CH4x1 Swirl, Horizontal Line
SSE-DTOOP1-3K-5-20-CH4x1, Vertical Line
<table>
<thead>
<tr>
<th>Configuration</th>
<th>4D Downstream</th>
<th>10D Downstream</th>
<th>13D Downstream</th>
<th>15D Downstream</th>
<th>20D Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>No FC, Single Elbow, 5 &amp; 5</td>
<td>7.269</td>
<td>3.188</td>
<td>2.452</td>
<td>2.159</td>
<td>0.905</td>
</tr>
<tr>
<td>CPA 55E, Single Elbow, 5 &amp; 5</td>
<td>7.185</td>
<td>0.475</td>
<td>0.342</td>
<td>0.301</td>
<td>0.209</td>
</tr>
<tr>
<td>NoFC, Single 45, 5 &amp; 5</td>
<td>6.725</td>
<td>3.057</td>
<td>2.317</td>
<td>2.007</td>
<td>1.226</td>
</tr>
<tr>
<td>55E, Single 45, 5 &amp; 5</td>
<td>6.190</td>
<td>0.419</td>
<td>0.289</td>
<td>0.243</td>
<td>0.150</td>
</tr>
<tr>
<td>No FC, Dual Elbows In Plane 1D, 5 &amp; 5</td>
<td>9.860</td>
<td>9.421</td>
<td>7.415</td>
<td>6.488</td>
<td>4.322</td>
</tr>
<tr>
<td>CPA 55E, Dual Elbows In Plane 1D, 5 &amp; 5</td>
<td>8.892</td>
<td>1.008</td>
<td>0.878</td>
<td>0.794</td>
<td>0.556</td>
</tr>
<tr>
<td>No FC, Dual Elbows In Plane 5D, 5 &amp; 5</td>
<td>6.875</td>
<td>5.250</td>
<td>4.845</td>
<td>4.529</td>
<td>3.357</td>
</tr>
<tr>
<td>CPA 55E, Dual Elbows In Plane 5D, 5 &amp; 5</td>
<td>6.596</td>
<td>0.517</td>
<td>0.476</td>
<td>0.449</td>
<td>0.355</td>
</tr>
<tr>
<td>No FC, Dual 45’S In Plane 1D, 5 &amp; 5</td>
<td>3.673</td>
<td>2.141</td>
<td>1.765</td>
<td>1.586</td>
<td>1.121</td>
</tr>
<tr>
<td>CPA 55E, Dual 45’S In Plane 1D, 5 &amp; 5</td>
<td>3.560</td>
<td>0.286</td>
<td>0.253</td>
<td>0.228</td>
<td>0.188</td>
</tr>
<tr>
<td>No FC, Dual Elbows Out Of Plane 1D, 5 &amp; 5</td>
<td>11.335</td>
<td>9.442</td>
<td>7.456</td>
<td>6.358</td>
<td>4.493</td>
</tr>
<tr>
<td>CPA 55E, Dual Elbows Out Of Plane 1D, 5 &amp; 5</td>
<td>11.311</td>
<td>1.114</td>
<td>0.965</td>
<td>0.901</td>
<td>0.735</td>
</tr>
<tr>
<td>No FC, Dual Elbows Out Of Plane 5D, 5 &amp; 5</td>
<td>5.116</td>
<td>1.666</td>
<td>1.109</td>
<td>0.924</td>
<td>0.534</td>
</tr>
<tr>
<td>CPA 55E, Dual Elbows Out Of Plane 5D, 5 &amp; 5</td>
<td>5.050</td>
<td>0.298</td>
<td>0.200</td>
<td>0.174</td>
<td>0.123</td>
</tr>
<tr>
<td>No FC, Dual Tees In Plane 1D, 5 &amp; 5</td>
<td>3.648</td>
<td>1.454</td>
<td>1.146</td>
<td>0.978</td>
<td>0.628</td>
</tr>
<tr>
<td>55E, Dual Tees In Plane 1D, 5 &amp; 5</td>
<td>3.510</td>
<td>0.217</td>
<td>0.179</td>
<td>0.184</td>
<td>0.130</td>
</tr>
<tr>
<td>No FC, Dual Tees Out Of Plane 1D, 5 &amp; 5</td>
<td>22.961</td>
<td>22.375</td>
<td>18.841</td>
<td>17.174</td>
<td>19.463</td>
</tr>
<tr>
<td>55E, Dual Tees Out Of Plane 1D, 5 &amp; 5</td>
<td>22.846</td>
<td>1.700</td>
<td>1.546</td>
<td>1.490</td>
<td>1.358</td>
</tr>
<tr>
<td>No FC, Dual Tees Out Of Plane 5D, 5 &amp; 5</td>
<td>4.162</td>
<td>4.252</td>
<td>4.267</td>
<td>4.188</td>
<td>3.607</td>
</tr>
<tr>
<td>55E, Dual Tees Out Of Plane 5D, 5 &amp; 5</td>
<td>5.096</td>
<td>0.416</td>
<td>0.402</td>
<td>0.384</td>
<td>0.301</td>
</tr>
</tbody>
</table>
## Flow Conditioner Swirl Reduction

<table>
<thead>
<tr>
<th>Description</th>
<th>10D Downstream</th>
<th>13D Downstream</th>
<th>15D Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPA 55E, Single Elbow, 5 &amp; 5</td>
<td>-85.08%</td>
<td>-86.05%</td>
<td>-86.06%</td>
</tr>
<tr>
<td>55E, Single 45, 5 &amp; 5</td>
<td>-86.31%</td>
<td>-87.53%</td>
<td>-87.90%</td>
</tr>
<tr>
<td>CPA 55E, Dual Elbows In Plane 1D, 5 &amp; 5</td>
<td>-89.30%</td>
<td>-88.16%</td>
<td>-87.76%</td>
</tr>
<tr>
<td>CPA 55E, Dual Elbows In Plane 5D, 5 &amp; 5</td>
<td>-90.16%</td>
<td>-90.19%</td>
<td>-90.09%</td>
</tr>
<tr>
<td>CPA 55E, Dual 45’S In Plane 1D, 5 &amp; 5</td>
<td>-86.62%</td>
<td>-85.69%</td>
<td>-85.63%</td>
</tr>
<tr>
<td>CPA 55E, Dual Elbows Out Of Plane 1D, 5 &amp; 5</td>
<td>-88.20%</td>
<td>-87.05%</td>
<td>-85.82%</td>
</tr>
<tr>
<td>CPA 55E, Dual Elbows Out Of Plane 5D, 5 &amp; 5</td>
<td>-82.10%</td>
<td>-81.94%</td>
<td>-81.15%</td>
</tr>
<tr>
<td>55E, Dual Tees In Plane 1D, 5 &amp; 5</td>
<td>-85.08%</td>
<td>-84.35%</td>
<td>-81.18%</td>
</tr>
<tr>
<td>55E, Dual Tees Out Of Plane 1D, 5 &amp; 5</td>
<td>-92.40%</td>
<td>-91.80%</td>
<td>-91.32%</td>
</tr>
<tr>
<td>55E, Dual Tees Out Of Plane 5D, 5 &amp; 5</td>
<td>-90.21%</td>
<td>-90.59%</td>
<td>-90.83%</td>
</tr>
</tbody>
</table>
Meter Types

• All volumetric flow meters can be flow conditioned: Orifice, Ultrasonic, Venturi, Coriolis Vortex, Turbine, Cone, Mag, etc.

• Every meter type responds differently to the effects of swirl and flow profile distortion.

• Volumetric flow meters are looking for ‘good flow’. Flow with minimal swirl and good flow profiles.

• A flow conditioner is simply trying to improve the flow that the meter is seeing.
CPA once said....

• It’s far easier to measure good flow with a bad meter, than trying to measure bad flow with a good meter.
Orifice Meters

- A thin plate with a very sharp chamfered hole creates a significant pressure drop.

- The flow rate of the fluid is proportional to the pressure drop.

- So why is there a problem?
Orifice Meters

Velocity: Magnitude (m/s)
Orifice Meters with Swirl
### Orifice Meters

- In orifice measurement, swirl can change the pressure differential that is being measured.

<table>
<thead>
<tr>
<th>Velocity (fps)</th>
<th>Velocity (m/s)</th>
<th>Swirl (Degrees)</th>
<th>P1 (Pa)</th>
<th>P2 (Pa)</th>
<th>Bulk Density (ρ)</th>
<th>K</th>
<th>deltaP (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>15.24</td>
<td>0</td>
<td>5598181</td>
<td>5458170</td>
<td>36.84</td>
<td>32.73</td>
<td>140011</td>
</tr>
<tr>
<td>50</td>
<td>15.24</td>
<td>20</td>
<td>5591067</td>
<td>5471339</td>
<td>36.74</td>
<td>28.06</td>
<td>119728</td>
</tr>
<tr>
<td>50</td>
<td>15.24</td>
<td>45</td>
<td>5560318</td>
<td>5497955</td>
<td>36.68</td>
<td>14.64</td>
<td>62363</td>
</tr>
</tbody>
</table>
## Without Flow Conditioning

### Table 2-7—Orifice Meter Installation Requirements Without a Flow Conditioner

<table>
<thead>
<tr>
<th>Diameter ratio β</th>
<th>a. Single 90° elbow, b. Two 90° elbows in the same plane with S &gt; 30D₁, c. Two 90° elbows in perpendicular planes with S &gt; 15D₁</th>
<th>Minimum Straight Unobstructed Meter Tube Length from the Upstream Side of the Orifice Plate (in multiples of published internal pipe diameter, D₁)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Two 90° elbows in the same plane, &quot;S&quot; configuration S ≤ 10D₁</td>
<td>Two 90° elbows in perpendicular planes, S ≤ 5D₁</td>
</tr>
<tr>
<td>UL</td>
<td>UL</td>
<td>UL</td>
</tr>
<tr>
<td>≤ 0.20</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>0.30</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>0.40</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>0.50</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>0.60</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>0.67</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>0.75</td>
<td>44</td>
<td>44</td>
</tr>
</tbody>
</table>

**Recommended length for maximum range β ≤ 0.75:**

| Diameter ratio β | 44 | 44 | 44 | 95 | 44 | 44 | 44 | 44 | 44 | 44 | 145 | 4.5 |

**UL:** Minimum meter tube length upstream of the orifice plate in internal pipe diameter (D₁)(see Figure 2-6). Straight length shall be measured from the downstream end of the curved portion of the nearest (or only) elbow or of the tee or the downstream end of the conical portion of reducer or expander.

**DL:** Minimum downstream meter tube length in internal pipe diameters (D₁)(see Figure 2-6).

S = Separation distance between piping elements in internal pipe diameter (D₁) measured from the downstream end of the curved portion of the upstream elbow to the upstream end of the curved portion of the downstream elbow.

* These installations exhibit the strong effect of Reynolds number and pipe roughness on the recommended length due to the rate of swirl decay. The present recommendations have been developed for high Reynolds numbers and smooth pipes to capture the worst case.

Note: The tolerance on specified lengths for UL and DL is ± 0.25D₁.
Straight Pipe

From GRI 97/0207
Straight Pipe – Elbows Out Of Plane

MRF HPL Results for 4-inch Bare Meter Tube Downstream of Two 90° Elbows Out-of-Plane
Values of Upstream Meter Tube Length, A = 17 D, 29 D, 45 D

From GRI 97/0207
Straight Pipe – 50% Closed Gate Valve

MRF HPL Results for 4-inch Bare Meter Tube Downstream of 50% Closed Gate Valve
Values of Upstream Meter Tube Length, A = 17 D, 29 D, 45 D

From GRI 97/0207
Straight Pipe – High Swirl

MRF HPL Results for 4-inch Bare Meter Tube
High Swirl Combined with a Tee
Values of Upstream Meter Tube Length, A = 17 D, 29 D, 45 D

$\Delta C_d$, % Deviation from baseline $C_d$ value

Orifice $\beta$ ratio

From GRI 97/0207
Tube Bundles

From GRI 97/0207
Tube Bundle Data

Tube Bundle Performance at Beta 0.75
17D Meter Run
Results from GRI Report No. 97/0207 "Development of a Flow Conditioner Performance Test"

Deviation From Baseline Cd

Distance From Tube Bundle Outlet to Orifice Plate (Pipe Diameters)
Tube Bundles & Straightening Vanes

- Tube bundles can be very problematic in custody transfer applications.

- AGA3 test data has shown them to be have very unpredictable behavior in scenarios with various upstream configurations.

- A low pressure drop combined with a long length (2 – 3D) result in an inability to properly redistribute the flow profile, while locking in distortions.

- Testing has found tube bundles to cause errors in straight pipe baseline scenarios!

- AGA3 itself shows in table 2-8 that there are configurations where a tube bundles cannot even be used!
17D with Tube Bundle

Table 2-8a—Orifice Meter Installation Requirements With 1998 Uniform Concentric 19-Tube Bundle Flow Straightener for Meter Tube Upstream Length of $17D_i \leq UL < 29D_i$:

<table>
<thead>
<tr>
<th>Diameter Ratio, $\beta$</th>
<th>Single 90° elbow $R/D_i = 1.5$</th>
<th>Two 90° elbows out of plane $S \leq 2D_i$ $R/D_i = 1.5$</th>
<th>Single 90° tee used as an elbow but not as a header element</th>
<th>Partially closed valves (at least 50% open)</th>
<th>High swirl combined with single 90° Tee</th>
<th>Any fitting (catch-all category)</th>
<th>Downstream meter tube length</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>UL2</td>
<td>UL2</td>
<td>UL2</td>
<td>UL2</td>
<td>UL2</td>
<td>UL2</td>
<td>DL</td>
</tr>
<tr>
<td>0.20</td>
<td>5 – 14.5</td>
<td>5 – 14.5</td>
<td>5 – 14.5</td>
<td>5 – 11</td>
<td>5 – 13</td>
<td>5 – 11.5</td>
<td>2.8</td>
</tr>
<tr>
<td>0.30</td>
<td>5 – 14.5</td>
<td>5 – 14.5</td>
<td>5 – 14.5</td>
<td>5 – 11</td>
<td>5 – 13</td>
<td>5 – 11.5</td>
<td>2.8</td>
</tr>
<tr>
<td>0.40</td>
<td>5 – 14.5</td>
<td>5 – 14.5</td>
<td>5 – 14.5</td>
<td>5 – 11</td>
<td>5 – 13</td>
<td>5 – 11.5</td>
<td>3.0</td>
</tr>
<tr>
<td>0.50</td>
<td>11.5 – 14.5</td>
<td>9.5 – 14.5</td>
<td>11 – 13</td>
<td>b</td>
<td>b</td>
<td>11 – 13</td>
<td>3.2</td>
</tr>
<tr>
<td>0.60</td>
<td>12 – 13</td>
<td>13.5 – 14.5</td>
<td>Not allowed</td>
<td>Not allowed</td>
<td>Not allowed</td>
<td>Not allowed</td>
<td>3.9</td>
</tr>
<tr>
<td>0.67</td>
<td>13</td>
<td>13 – 14.5</td>
<td>Not allowed</td>
<td>Not allowed</td>
<td>Not allowed</td>
<td>Not allowed</td>
<td>4.2</td>
</tr>
<tr>
<td>0.75</td>
<td>Not allowed</td>
<td>14</td>
<td>Not allowed</td>
<td>Not allowed</td>
<td>Not allowed</td>
<td>Not allowed</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Recommended tube bundle location for maximum range of $\beta$:

- UL1 = UL – UL 2 (see Figure 2-6).

Note 1: Lengths shown under the UL2 column are the dimensions shown in Figure 2-6, expressed as the number of published internal pipe diameters ($D_i$) between the downstream end of the 1998 Uniform Concentric 19-Tube Bundle Flow Straightener and the upstream surface of the orifice plate.

Note 2: The tolerance on specified lengths for UL, UL2, and DL is \( \pm 0.25D_i \).

Note 3: Not allowed means that it is not possible to find an acceptable location for the 1998 Uniform Concentric 19-Tube Bundle Flow Straightener downstream of the particular fitting for all values of UL.

From AGA Report No. 3, 2000 Edition
Plate Based Isolating Flow Conditioners

Distance from CPA 50E Outlet to Orifice Plate (Pipe Diameters)
dP Uncertainty

Discharge coefficient (AGA-3) Expansion factor

Sources of uncertainties in orifice metering

Compressibility factor (AGA-8) Isentropic exponent

Flowing medium quality
- gas composition
- gas viscosity
- liquid contaminants
- solid contaminants

Primary element

Secondary devices
- gauge line
- static/dynamic dp transducer
- static pressure transducer
- temperature transducer
- chart recorder
- flow computer
- leaks

Deficiencies of geometric similarity
- Orifice plate
  - surface roughness
  - deposits
  - local edge damage
- Orifice plate holder
- Meter tube
  - surface roughness
  - diameter
  - circularity
  - waviness
- Pressure taps
  - diameter
  - position
  - edge quality
  - leaks
- Thermowell
  - upstream location
  - profile distortions at orifice position

Deficiencies of dynamic similarity
- Tube bundle in perfect flow
- single elbow
- two elbows in plane
- two elbows out-of-plane
- multi run header
- throttling valve
- reducer
- expander
- swirl
- flow conditioners

Undeveloped velocity profile
- inlet mean velocity profile
- Fluctuating component of velocity profile
Cone Meters

- Similar to other dP devices.

- Have a high pressure and a low pressure tap.

- Has a unique geometry that forces flow to the outside of the pipe.

- High pressure tap is in a similar location as with a orifice plate or venturi, but low pressure tap is in the center of the element geometry.

- Supposed to be highly immune to installation effects and swirl, requires only 0 – 3 upstream pipe diameters and no flow conditioning.
Cone Meters

- Similar to other dP devices.

- Have a high pressure and a low pressure tap.

- Has a unique geometry that forces flow to the outside of the pipe.

- High pressure tap is in a similar location as with a orifice plate or venturi, but low pressure tap is in the center of the element geometry.

- Supposed to be highly immune to installation effects and swirl, “requires” only 0 – 3 upstream pipe diameters and no flow conditioning.
Cone Meters
Cone Meters
Cone Meters, with Upstream Disturbances
Cone Meters, with Upstream Disturbances
Cone Meters, with Swirl
Cone Meters

- Do cone meters need flow conditioner and a minimum amount of upstream pipe?

- Tees upstream, 13D of straight pipe, 0.6b, ~0.5% deviation from baseline.

- 30 degrees of swirl, 13D of straight pipe, 0.6b, ~4.6% deviation from baseline.
Turbine Meters

- Fluid rotation in the direction of the meter rotation causes the meter to under register.

- Fluid rotation in the opposite direction of the meter rotation causes the meter to over register.

- Dual rotor designs are less susceptible to this.

- Often, turbine meters will have straightening vanes in the inlet in an basic attempt at flow conditioning.
Turbine Meters

- Turbine meters with nose cones redirect flow towards the outside of the fluid passage.

- This movement amplifies disturbances within the flow profile.

- Turbine meters need to see a well flow conditioned bulk fluid flow.

- Asymmetrical or peaky flow profiles will cause the turbine to over register.
Turbine Meters

Normalized Pipeline Velocity

Normalized Turbine Annulus Velocity
Turbine Meters

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. For recommended size of blow down valve, see Table 1. Locate downstream of meter.
# Turbine Meters

<table>
<thead>
<tr>
<th></th>
<th>Bishop Auckland</th>
<th>Didsbury</th>
<th>GRI MRF HPL</th>
<th>Groningen</th>
<th>pigsar™</th>
<th>Westerbork</th>
<th>TCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Pressure kPa</td>
<td>3000 to 6000</td>
<td>4000 to 6000</td>
<td>1035 to 8275</td>
<td>900 to 4100</td>
<td>1500 to 5000</td>
<td>6200</td>
<td>7040</td>
</tr>
<tr>
<td>Operating Fluid</td>
<td>Natural gas</td>
<td>Natural gas</td>
<td>Nitrogen or Natural gas</td>
<td>Natural gas</td>
<td>Natural gas</td>
<td>Natural gas</td>
<td>Natural gas</td>
</tr>
<tr>
<td>Maximum Flow Capacity</td>
<td>314 kg/s</td>
<td>24 kg/s</td>
<td>44 kg/s</td>
<td>8.2 kg/s</td>
<td>72 kg/s</td>
<td>622 kg/s</td>
<td>770 kg/s</td>
</tr>
<tr>
<td>Primary Reference</td>
<td>N/A</td>
<td>Wöhwa Scale</td>
<td>Wöhwa Scale</td>
<td>CVM meters</td>
<td>Piston Prover</td>
<td>N/A</td>
<td>Rotary Piston Prover</td>
</tr>
<tr>
<td>Secondary Reference</td>
<td>Calibrated turbine</td>
<td>Calibrated nozzles, turbines, orifice</td>
<td>Calibrated nozzles, turbines, orifice</td>
<td>Calibrated turbine</td>
<td>Calibrated turbine</td>
<td>Calibrated turbine</td>
<td>Calibrated turbine</td>
</tr>
<tr>
<td>Uncertainty in Primary Mass Flow</td>
<td>N/A</td>
<td>±0.06%</td>
<td>±0.04%</td>
<td>±0.18%</td>
<td>±0.01%</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Uncertainty in Secondary Mass Flow</td>
<td>±0.21% &lt; 40 kg/s, ±0.25% &gt; 40 kg/s</td>
<td>±0.2%</td>
<td>±0.2%</td>
<td>±0.19%</td>
<td>±0.15%</td>
<td>±0.15% &gt; 16 kg/s, ±0.3% &lt; 16 kg/s</td>
<td>±0.2% &gt; 25 kg/s, ±0.3% &lt; 25 kg/s</td>
</tr>
</tbody>
</table>
3 THE CENTAUR PACKAGE

The CENTAUR package shown in Figure 1 was provided in two parts.
1. The ultrasonic meter with the 1.343 m (6.63D) spool piece followed by a NOVA 50E flow conditioner and the 1.678 m (8.3D) spool piece upstream.
2. The turbine meter with the 2.095 m (10.33D) upstream spool and the 1.35 m (6.66D) downstream spool as the second piece.

Figure 1. The CENTAUR Transfer Standard Package.
Turbine Meters

![Graph showing turbine meter performance vs. pipe Reynolds number](image-url)
Ultrasonic Meters

- Rely on a noise pulse that is transmitted through the fluid and the flow rate is computed using the transit time.

- Transit time is affected by velocity disturbances within the pipe, slowing or speeding up the pulse.

- Multiple paths help to generate a complete picture of the cross sectional flow within the pipe.

- The meter only knows how long it took for the pulse to travel from point A to point B.

- It cannot guess the state of the flow along the way.
Ultrasonic Meters

Uncertainty Result

$\epsilon = \pm 0$

$\tau_{AB} = \int_{A}^{B} \frac{dL}{V}$

AND

$P_{REV} = \frac{L}{2 \cos \phi} \left( \frac{1}{\tan \beta} - \frac{1}{\tan \alpha} \right)$
Ultrasonic Meters

Uncertainty Result

\[ \varepsilon = \pm 0 \]

why:

\[ t_{AB} = \int_{A}^{B} \frac{dl}{V} \times \text{Re} \text{correction factor} \]

\[ f(u(x,y,z)) \]

PIPE

\[ V = \frac{L}{2 \cos \delta \left( \tan \theta - \tan \beta \right)} \]
Ultrasonic Meters

REAL FLOW PROFILE DOWNSTREAM OF INSTALLATION EFFECTS.

Uncertainty Result

E = Lots!

why:

\[ \tau_b = \int \frac{du}{V} \times \text{Re conv factor} \]

we don't know \( U(x,y,z) \)

\[ \text{Pipe}V = ? \]
## USM Results

<table>
<thead>
<tr>
<th>Dual Elbows In Plane</th>
<th>1 Path, USM Final</th>
<th>1 Path, 1/4 Path, USM Final</th>
<th>2 Path, USM Final</th>
<th>3 Path, USM Final</th>
<th>4 Path, USM Final</th>
<th>7 Path, USM Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>1D No FC</td>
<td>6.879%</td>
<td>4.359%</td>
<td>3.357%</td>
<td>4.534%</td>
<td>3.365%</td>
<td>0.226%</td>
</tr>
<tr>
<td>5D CPA 55E</td>
<td>4.365%</td>
<td>0.183%</td>
<td>0.313%</td>
<td>1.211%</td>
<td>1.312%</td>
<td>0.202%</td>
</tr>
<tr>
<td>Error Change</td>
<td>-36.54%</td>
<td>-95.80%</td>
<td>-90.67%</td>
<td>-73.29%</td>
<td>-61.01%</td>
<td>-10.72%</td>
</tr>
<tr>
<td>1D No FC</td>
<td>5.231%</td>
<td>2.870%</td>
<td>0.492%</td>
<td>1.629%</td>
<td>1.131%</td>
<td>0.082%</td>
</tr>
<tr>
<td>5D CPA 55E</td>
<td>1.535%</td>
<td>1.519%</td>
<td>0.098%</td>
<td>0.382%</td>
<td>0.266%</td>
<td>0.009%</td>
</tr>
<tr>
<td>Error Change</td>
<td>-70.65%</td>
<td>-47.09%</td>
<td>-80.19%</td>
<td>-76.55%</td>
<td>-76.48%</td>
<td>-89.68%</td>
</tr>
<tr>
<td>Dual Elbows Out Of Plane</td>
<td>1D No FC</td>
<td>4.808%</td>
<td>1.968%</td>
<td>0.619%</td>
<td>1.743%</td>
<td>1.399%</td>
</tr>
<tr>
<td>1D CPA 55E</td>
<td>3.686%</td>
<td>0.466%</td>
<td>0.405%</td>
<td>0.960%</td>
<td>1.064%</td>
<td>0.150%</td>
</tr>
<tr>
<td>Error Change</td>
<td>-23.34%</td>
<td>-76.34%</td>
<td>-34.55%</td>
<td>-44.90%</td>
<td>-23.99%</td>
<td>-36.14%</td>
</tr>
<tr>
<td>5D No FC</td>
<td>2.914%</td>
<td>3.140%</td>
<td>0.310%</td>
<td>0.969%</td>
<td>0.522%</td>
<td>0.186%</td>
</tr>
<tr>
<td>5D CPA 55E</td>
<td>1.150%</td>
<td>1.825%</td>
<td>0.334%</td>
<td>0.181%</td>
<td>0.123%</td>
<td>0.016%</td>
</tr>
<tr>
<td>Error Change</td>
<td>-60.55%</td>
<td>-41.88%</td>
<td>7.80%</td>
<td>-81.35%</td>
<td>-76.42%</td>
<td>-91.25%</td>
</tr>
<tr>
<td>Dual Tees In Plane</td>
<td>1D No FC</td>
<td>4.639%</td>
<td>3.199%</td>
<td>0.015%</td>
<td>1.620%</td>
<td>1.527%</td>
</tr>
<tr>
<td>1D CPA 55E</td>
<td>2.659%</td>
<td>3.139%</td>
<td>0.005%</td>
<td>0.866%</td>
<td>0.880%</td>
<td>0.094%</td>
</tr>
<tr>
<td>Error Change</td>
<td>-42.68%</td>
<td>-1.88%</td>
<td>-69.45%</td>
<td>-46.56%</td>
<td>-42.33%</td>
<td>-34.15%</td>
</tr>
<tr>
<td>Dual Tees Out Of Plane</td>
<td>1D No FC</td>
<td>4.580%</td>
<td>2.421%</td>
<td>0.772%</td>
<td>2.094%</td>
<td>1.388%</td>
</tr>
<tr>
<td>1D CPA 55E</td>
<td>3.553%</td>
<td>1.128%</td>
<td>0.066%</td>
<td>1.147%</td>
<td>1.119%</td>
<td>0.050%</td>
</tr>
<tr>
<td>Error Change</td>
<td>-22.41%</td>
<td>-53.41%</td>
<td>-91.43%</td>
<td>-45.20%</td>
<td>-19.43%</td>
<td>-67.33%</td>
</tr>
<tr>
<td>Dual Tees Out Of Plane</td>
<td>5D No FC</td>
<td>8.184%</td>
<td>1.705%</td>
<td>0.317%</td>
<td>2.755%</td>
<td>2.306%</td>
</tr>
<tr>
<td>5D CPA 55E</td>
<td>3.196%</td>
<td>5.013%</td>
<td>0.115%</td>
<td>1.184%</td>
<td>0.712%</td>
<td>0.055%</td>
</tr>
<tr>
<td>Error Change</td>
<td>-60.95%</td>
<td>194.08%</td>
<td>-63.67%</td>
<td>-57.00%</td>
<td>-69.11%</td>
<td>-69.23%</td>
</tr>
<tr>
<td>Dual 45's In Plane</td>
<td>1D No FC</td>
<td>4.046%</td>
<td>0.907%</td>
<td>0.795%</td>
<td>0.885%</td>
<td>1.373%</td>
</tr>
<tr>
<td>1D CPA 55E</td>
<td>1.530%</td>
<td>0.259%</td>
<td>0.437%</td>
<td>0.150%</td>
<td>0.375%</td>
<td>0.099%</td>
</tr>
<tr>
<td>Error Change</td>
<td>-62.18%</td>
<td>-71.39%</td>
<td>-44.95%</td>
<td>-83.11%</td>
<td>-72.66%</td>
<td>-73.87%</td>
</tr>
</tbody>
</table>
USM Path Layouts
Flow Conditioning Swirl Removal

Flow Conditioner Swirl Reduction

- Swirl, No Flow Conditioner
- Swirl, Flow Conditioner

August-24-15
CPA Flow Conditioning 2015
Flow Conditioning Swirl Removal

Flow Conditioner Swirl Reduction

Swirl Reduction (%) vs. Reynolds Number

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Pressure Drop

• All fittings, obstructions, even pipe itself has a “k factor”.

• The k factor is the pressure loss coefficient for a particular piece of piping.

• It is experimentally determined using the measured pressure drop.

\[ \Delta P = \frac{k \rho V^2}{2} \]

• K = Pressure loss coefficient.
• \( \Delta P \) = Pressure drop across a section of pipe or a fitting.
• \( \rho \) = Bulk fluid density, \( kg/m^3 \).
• \( V \) = Bulk fluid velocity, \( m/s \).
Pressure Drop

• For natural gas applications, most plate flow conditioners have a K factor of approximately 2.

• Tube bundles are closer to 0.75 – 1.5.

• What if we are worried about the pressure drop across the flow conditioner?
Relative Pressure Drop

![Graph showing relative pressure drop vs flow rate](image-url)
Pressure Drop – Tube Bundle vs Plate FC

Pressure Loss Coefficient vs Reynolds Number (Viscosity)

- CPA 50E
- AGA 3 19-Tube Bundle
AGA Standards/Meter Run Compliance

- AGA 3 / API 14.3 - Orifice Meter Measurement
- AGA 7 – Turbine Meter Measurement
- AGA 9 – Ultrasonic Meter Measurement
- AGA 11 – Coriolis Meter Measurement
AGA3 Data

CPA 50E, AGA3-2000 Orifice Performance, 5D Upstream, 8D Downstream, Curve Fit

Coefficient of Discharge vs Reynolds Number

- Baseline - 0.652b
- CPA Baseline - 0.652b
- 50% Closed Valve - 0.652b
- 50% Closed Valve 2 - 0.652b
- Heavy Swirl - 0.652b
- Elbows Out Of Plane - 0.652b
- ACT RHG Upper - 0.652b
- ACT RHG Lower - 0.652b

August-24-15 CPA Flow Conditioning 2015
AGA9/OIML R137 Data
Flow Conditioning Conclusion

- Can eliminate up to 80 – 90% of pipeline swirl.
- Help restore flow profile symmetry and eliminate distortions.
- Isolates the flow meter from upstream disturbances.
- Allows much shorter meter runs to be used with much higher repeatability.
- Are applicable for all liquid or gas flows!

The flow conditioner is merely helping out the meter, providing higher reproducibility and lower uncertainty!
Liquids/Pressure Drop Summary

- All fluid flows will benefit from flow conditioning.

- Flow measurement and flow conditioning in liquids is effectively the same as in gases.

- While we do need to be concerned about pressure drop, we have to look at the big picture; The flow conditioner will not be the most significant obstruction in the pipe.

- When dealing with pressure drop, previous common sense assumptions may not apply. Pressure loses through fittings can be complicated depending on the application.

- In some installations, pressure drop is very helpful. It helps balance meter tubes when multiple runs are used in parallel. Otherwise, severe run hogging and meter run imbalances may be experienced.
Final Thoughts

• Swirl is primarily a function of piping geometry (the size and radius of the piping turns are critical for generating the swirl vector).

• Our attempts to make piping assemblies more compact result in tighter fittings that have a higher chance to produce severe turbulence and dynamic effects (vortex shedding, harmonics).

• Steady state installation effects (flow profiles and swirl) are complex enough, most dynamic behaviors are not well understood and aren’t well discussed within corresponding measurement guidelines and standards.

• Try to avoid tight radius tees whenever possible.
Final Thoughts

• Even with the addition of more paths, the addition of a flow conditioner vastly adds to the repeatability and accuracy of a ultrasonic flow meter.

• The flow conditioner can easily cut the errors in half, and in some instances reduce the error by 90%!

• Sometimes we can get lucky and have acceptable performance without a flow conditioner. With measurement repeatability, we need to look at the bigger picture and the general trend of reducing our uncertainty.
Final Thoughts

• The flow conditioner is just making the meter look better.

• Worried about pressure drop? Flow conditioners typically are the lowest dP fitting in a meter run assembly (ie, the accumulation of tees will quickly eclipse the dP of the plate).

• Flow conditioners are recommended for all FLUID applications (liquids and gas)!
Final Thoughts

• Worried about debris plugging up the flow conditioner?

• If there is that much debris in the pipe line, a strainer or filter is heavily recommended.

• Eliminating the flow conditioner will not eliminate the debris, and now you’re at risk of breaking off probes and thermowells, damaging control & safety valves, turbines, compressors, etc.

• If the gasket is unraveling, switch to a CGI style gasket with a inner ring. The gasket unraveling is going to create bigger problems than just a plugged flow conditioner (plugged control valves and potential for leaking flanges).
Thank You

• For Further information

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www.cpacfd.com

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