1 - Overview of Flare Gas Flow Meters
   Introduction, Technology, Selection Criteria

2 - Overview of Flare Gas Flow Meters
   Installation, Operation and Maintenance

3 - Gas Balancing and Gas Allocation

4 - Estimation of Errors and Uncertainty in Volume Measurement

5 - Methods for Estimating Flare and Vent Volumes

6 - Advice on Improving/Redesigning Gas Measurement System in Qatar
Overview of Flare Gas Flow Meters

- Introduction
- Technology
  - Flow Rate Measurement
  - Composition Measurement
- Selection Criteria

Facilitated by
Lex Scheers
Hint Services BV

Qatar Workshop on Measurement/Reporting of Flare Gas
Doha, Qatar
8th and 9th May 2011
The Product Balance

ANALOG BAY

PRODUCTION FACILITY
for each phase
\[ \Sigma \text{in} = \Sigma \text{out} \]

RESERVOIR

GAS

OIL

WATER

SALES GAS
(Fiscal / Custody Transfer)

SALES OIL
(Fiscal / Custody Transfer)

FLARE GAS, OWN USE
(Fiscal ???)

GLOBAL GAS FLARING REDUCTION
A Public-Private Partnership

Qatar Workshop
Doha, 8-9 May 2011
Introduction
- Production Measurements

Fiscal/Sales Allocation
• Taxation / royalty / sales
• Production allocation to partners in joint pipelines

Reservoir Management
• Maximize hydrocarbon recovery at prevailing economic and technical conditions, e.g.
  • Planning primary, secondary and tertiary development
  • Depletion policy, Injection/production balance
  • Production forecast and future project ranking

Operational Control
• Well surveillance
• Artificial lift optimisation
• Process and equipment performance
  • Flaring and Venting monitoring/reporting
• Production targets and constraints
• Allocate bulk measurements to individual wells or reservoir
For any production measurement device (incl. MPFM’s, VMS) we have to compare/consider

1) Costs (OpEx and CapEx),
2) Accuracy
3) “Value of Information”
4) Legislation
5) Reputation

to select the optimum solution

- Production Measurement Costs, Accuracy and Legislation are known
- Determination of the “Value of Information” is more challenging
- Reputation ???

You can’t manage what you can’t measure
Introduction
- Flare and Vent Measurement

- Oil production facilities (associated gas)
  - Sometimes no gas market and gas infra-structure present
  - No economic benefit to re-inject the gas in the reservoir
  - Often associated gas is considered as a nasty by-product
  - Greatly varies in composition

- Gas production facilities
  - Disposal of waste streams
  - Acid gas from sweetening plant
  - Glycol dehydration units
  - Instrument vent gas
  - Process flash gas

In general flare and vent gas has various origins and therefore greatly varies in quantity, gas composition and quality
Introduction
- What is the ideal Gas Flare/Vent Meter?

- Tolerant to wet and dirty gas streams
- Large turndown
  - Small waste streams during normal operations
  - Large streams during blow down, depressurization and emergencies
- Independent of fluid properties (composition)
- Installation without a facility shut-down
- Full bore measurements
- Accuracy of just a few percent
- No upstream or downstream pipe requirements
- Flow regime independent
- On-site and simple calibration

Hence, the ideal Flare Gas Meter does not exist !!!
Graphical Representation of a Flare Flow Measurement System

Primary Devices

Pressure (PI)
Flow (FI)
Temp (TI)
Analyzer (AI)

Secondary Devices (Transmitters)
Pressure (PT)
Flow (FT)
Temp (TT)
Analyzer (AT)

Tertiary Devices (Indicators or DCS)

PE
FE
TE
AE

To Flare
Specifications of a Flare Flow Measurement System

- Uncertainty (at 95% confidence interval) 1 to 5%
- Repeatability 1%
- Turn-down ratio (Rangeability) 1:100 to 1:1000
- Resolution 0.05%
- Pressure Drop low
- Design T & P
- Operating T & P
- Point, Multipoint, Path or Full Bore Measurement
- Protection/Safety
  - Mechanical
  - Electrical
- Others
  - Weight
  - Power
  - Size (Dimensions)
  - Data Processing
  - Communication
Bernoulli’s Equation
- Application to the Orifice/Venturi/Pitot devices

At the same height in the flow:

\[ P_1 + \frac{1}{2} \rho v_1^2 = P_2 + \frac{1}{2} \rho v_2^2 \]

From continuity:

\[ v_1 A_1 = v_2 A_2 \]

Combining:

\[ \Delta P = \frac{1}{2} \rho v_2^2 \left[ 1 - \frac{A_2^2}{A_1^2} \right] \]

Need to know the density !!!
Venturi tube

Type of Measurement
Δp (Bernoulli)

Measurement point/path
Cross Sectional Area

Diameter
2 to 48”

Rangeability
10:1

Straight pipe req’ments
6-20 D upstr. 2-40 D downstr.

Total pressure loss
10-20% of the Δp

P and T required
ActVol = Yes, StdVol = Yes, Mass = Yes

Uncertainty
approx. 1-3% full scale

Composition dependent
Yes, need density

Suitable in wet/dirty gas
Yes, small amounts

Other comments
Eliminate pulsation
**Orifice plate**

<table>
<thead>
<tr>
<th>Type of Measurement</th>
<th>( \Delta p ) (Bernoulli)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement point/path</td>
<td>Cross Sectional Area</td>
</tr>
<tr>
<td>Diameter</td>
<td>1 to 72”</td>
</tr>
<tr>
<td>Rangeability</td>
<td>5:1</td>
</tr>
<tr>
<td>Straight pipe req’mnts</td>
<td>6-20 D upstream, 2-40 D downstream</td>
</tr>
<tr>
<td>Total pressure loss</td>
<td>High</td>
</tr>
<tr>
<td>P and T required</td>
<td>ActVol = Yes, StdVol = Yes, Mass = Yes</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>approx. 2-4% full scale</td>
</tr>
<tr>
<td>Composition dependent</td>
<td>Yes, need density</td>
</tr>
<tr>
<td>Suitable in wet/dirty gas</td>
<td>Yes, small amounts (drainhole)</td>
</tr>
<tr>
<td>Other comments</td>
<td>Pulsation</td>
</tr>
</tbody>
</table>

---

**Diagram:**

- \( d_1 \) = pipe diameter
- \( d_2 \) = orifice diameter
- \( d_{vc} \) = vena contracta diameter

---

*Qatar Workshop*

Doha, 8-9 May 2011
(Averaging) Pitot tube

<table>
<thead>
<tr>
<th>Type of Measurement</th>
<th>Measurement point/path</th>
<th>Δp (Bernoulli)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Point or Multipoint averaging</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 to 72” (insertion)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3:1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8-10 D upstream, 3 D downstream</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low, Nil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ActVol = Yes, StdVol = Yes, Mass = Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>approx. 1-5% full scale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes, need density</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Limited</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Positioning critical</td>
</tr>
</tbody>
</table>

**Diameter**
1 to 72” (insertion)

**Rangeability**
3:1

**Straight pipe req’mnts**
8-10 D upstream, 3 D downstream

**Total pressure loss**
Low, Nil

**P and T required**
ActVol = Yes, StdVol = Yes, Mass = Yes

**Uncertainty**
approx. 1-5% full scale

**Composition dependent**
Yes, need density

**Suitable in wet/dirty gas**
Limited

**Other comments**
Positioning critical

---

![Diagram of Pitot tube](image)
**Type of Measurement**
- Velocity (ActVol)

**Measurement point/path**
- Point or Cross Sectional Area

**Diameter**
- 1 to 24” (insertion)

**Rangeability**
- 20:1 to 100:1

**Straight pipe req’mnts**
- 10 D upstream, 5 D downstream

**Total pressure loss**
- Design dependent (insertion low)

**P and T required**
- ActVol = No, StdVol = Yes, Mass = Yes
  - Design dependent (insertion low)

**Uncertainty**
- approx. 0.5% (insertion much higher)

**Composition dependent**
- No

**Suitable in wet/dirty gas**
- Limited

**Other comments**
- Flow straightening, fouling
### Vortex Flow Meter

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Measurement</td>
<td>Velocity (ActVol)</td>
</tr>
<tr>
<td>Measurement point/path</td>
<td>Cross Sectional Area</td>
</tr>
<tr>
<td>Diameter</td>
<td>1 to 24”</td>
</tr>
<tr>
<td>Rangeability</td>
<td>30:1</td>
</tr>
<tr>
<td>Straight pipe req’ments</td>
<td>10-20 D upstream, 5 D downstream</td>
</tr>
<tr>
<td>Total pressure loss</td>
<td>Design dependent</td>
</tr>
<tr>
<td>P and T required</td>
<td>ActVol = No, StdVol = Yes, Mass = Yes</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>approx. 2%</td>
</tr>
<tr>
<td>Composition dependent</td>
<td>No</td>
</tr>
<tr>
<td>Suitable in wet/dirty gas</td>
<td>Limited</td>
</tr>
<tr>
<td>Other comments</td>
<td>Flow straightening, pulsation</td>
</tr>
</tbody>
</table>
**UltraSonic Gas Flow Measurement (transit time)**

\[ t_{AB} = \frac{L}{C + v_m \cdot \cos(\phi)} \]

\[ t_{BA} = \frac{L}{C - v_m \cdot \cos(\phi)} \]

\[ v_m = \frac{L}{2 \cdot \cos(\phi)} \left[ \frac{1}{t_{AB}} - \frac{1}{t_{BA}} \right] \]

\[ Q = \frac{\pi D^2}{4} \cdot v_m \]

Two uncertainty issues:

1) Travel time measurement \((t_{AB}, t_{BA})\)
   Instrument error

2) Installation parameters \((L, A, \phi)\)
   Geometry error

**Symbols:**
- \(C\) = Velocity of sound
- \(D\) = Pipe diameter
- \(L\) = Acoustic path length
UltraSonic Gas Flow Measurement (transit time)

<table>
<thead>
<tr>
<th>Type of Measurement</th>
<th>Velocity (ActVol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement point/path</td>
<td>Path or multi-path</td>
</tr>
<tr>
<td>Diameter</td>
<td>&gt; 3”</td>
</tr>
<tr>
<td>Rangeability</td>
<td>up to 2000:1</td>
</tr>
<tr>
<td>Straight pipe req’ments</td>
<td>10-30 D upstream, 5-10 D downstream</td>
</tr>
<tr>
<td>Total pressure loss</td>
<td>Nil</td>
</tr>
<tr>
<td>P and T required</td>
<td>ActVol = No, StdVol = Yes, Mass = Yes</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>approx. 1-5% (no of paths)</td>
</tr>
<tr>
<td>Composition dependent</td>
<td>No</td>
</tr>
<tr>
<td>Suitable in wet/dirty gas</td>
<td>Moderate (LVF &lt; 0.5%)</td>
</tr>
<tr>
<td>Other comments</td>
<td>Elimination of swirl</td>
</tr>
</tbody>
</table>

**Note:**

Speed of sound (also measured) is related to density
GE Sensing GF 868 Flare Gas Meter

![Diagram of the GE Sensing GF 868 Flare Gas Meter]

- **Inside view of a bias 90 flare gas installation**

**Components:**
- Preamplifier
- Upstream Transducers
- Downstream Transducers
- Temperature Transmitter
- Digital Analog and Alarm Output
- Pressure Transmitter

**Markings:**
- GE Sensing & Inspection
- GF868 Flare Gas Meter
- Flow direction marker

**Additional Information:**
- Qatar Workshop
- Doha, 8-9 May 2011
- GE Sensing
- GF868 Flare Gas Meter
- Inside view of a bias 90 flare gas installation

---

**Technical Details:**
- **Transducers:** Upstream and Downstream
- **Transmitters:** Pressure, Temperature
- **Outputs:** Digital Analog, Alarm
- **Additional Equipment:** Preamplifier

---

**Integration:**
- The diagram illustrates the integration of various components in the flare gas installation, emphasizing the flow direction and the placement of transducers and transmitters for accurate measurement and monitoring.
Fluenta FGM 160 Flare Gas Meter
### Optical Laser TwoFocus (L2F)

<table>
<thead>
<tr>
<th>Type of Measurement</th>
<th>Velocity (ActVol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement point/path</td>
<td>Point</td>
</tr>
<tr>
<td>Diameter</td>
<td>Any (insertion)</td>
</tr>
<tr>
<td>Rangeability</td>
<td>up to 3000:1</td>
</tr>
<tr>
<td>Straight pipe req’ments</td>
<td>10-30 D upstream, 5-10 D downstream</td>
</tr>
<tr>
<td>Total pressure loss</td>
<td>Nil</td>
</tr>
<tr>
<td>P and T required</td>
<td>ActVol = No, StdVol = Yes, Mass = Yes</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>approx. 3-7%</td>
</tr>
<tr>
<td>Composition dependent</td>
<td>No</td>
</tr>
<tr>
<td>Suitable in wet/dirty gas</td>
<td>Moderate</td>
</tr>
<tr>
<td>Other comments</td>
<td>Elimination of swirl</td>
</tr>
</tbody>
</table>
Optical Transit Time Velocimeters - LaserTwoFocus (L2F) Meters

Pro's
- High turn-down
- High accuracy
- Gas composition independent
- Insertion type

Con's
- Point measurement
- Measures particle velocity
**Type of Measurement**
**Measurement point/path**
**Diameter**
**Rangeability**
**Straight pipe req’ments**
**Total pressure loss**
**P and T required**
**Uncertainty**
**Composition dependent**
**Suitable in wet/dirty gas**
**Other comments**

---

Mass  
Point  
Any (insertion)  
1000:1  
8-10 D upstream, 3 D downstream  
Nil  
ActVol = Yes, StdVol = No, Mass = No  
approx. 1-3%  
Yes, need thermal conductivity  
No  
Positioning, fouling,

---

**Endress & Hauser, t-mass 65I**
**Size:** 2.5-60”
**Turndown:** 100:1
**Accuracy:** 1%
Composition Monitoring

- Some FlowMeters are composition dependent
  - e.g. $\Delta p$-Meters, Thermal Mass Flow Meters,
  - Is relationship composition ↔ correction known
  - Is sensitivity to composition high or low

- Convert volumetric flowrate to mass or energy flowrate (or vv)
- Determine heating value of the gas
- Emission measurement, e.g. $H_2S$, $SO_2$ or GHG reporting

Ways to monitor composition:
1) Spot sampling and off-line analyses
2) Flow proportional sampling and off-line analyses
3) Continuous on-line analyzers
Composition Monitoring
1) Spot sampling and analyses

- Manual sample
- Laboratory analyses
- Low cost
- Representativeness in wet gas streams (??)
  - Not suitable for LVF or GVF measurement
  - Suitable for separate liquid composition and gas composition
- Flow proportionality (??)
Composition Monitoring

2) Flow proportional sampling and off-line analyses

- Flow-proportional auto-sampler
- Laboratory analyses
- Medium
- Representativeness in wet gas streams
  - ✗ Not suitable for LVF or GVF measurement
  - ✔ Suitable for separate liquid composition and gas composition
Composition Monitoring
3) Continuous on-line analyzers

- Only applicable for clean/processed gas
- Need for conditioning units (sample train)
- Higher maintenance
- Higher costs
- Often used in "custody transfer", not so much in flare measurement

Daniel® Model 500
Gas Chromatographs
## Flowrate conversions

### Actual Conditions <> Standard Conditions

<table>
<thead>
<tr>
<th>Technology</th>
<th>Actual Volume $q_v$</th>
<th>Standard Volume $Q_v$</th>
<th>Mass $q_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>UltraSonic (V)</td>
<td>Output</td>
<td>$Q_v = q_v \left( \frac{P_f T_b Z_b}{P_b T_f Z_f} \right)$</td>
<td>$q_m = q_v \cdot \rho_f$</td>
</tr>
<tr>
<td>Vortex</td>
<td>Output</td>
<td>$Q_v = q_v \left( \frac{P_f T_b Z_b}{P_b T_f Z_f} \right)$</td>
<td>$q_m = q_v \cdot \rho_f$</td>
</tr>
<tr>
<td>Optical</td>
<td>Output</td>
<td>$Q_v = q_v \left( \frac{P_f T_b Z_b}{P_b T_f Z_f} \right)$</td>
<td>$q_m = q_v \cdot \rho_f$</td>
</tr>
<tr>
<td>UltraSonic (M)  (VoS)</td>
<td>$q_v = \frac{q_m}{\rho_f}$</td>
<td>$Q_v = \frac{q_m}{\rho_b}$</td>
<td>Output</td>
</tr>
<tr>
<td>Thermal</td>
<td>$q_v = Q_v \left( \frac{P_b T_f Z_f}{P_f T_b Z_b} \right)$</td>
<td>Output</td>
<td>$q_m = Q_v \cdot \rho_b$</td>
</tr>
</tbody>
</table>

**Note:** $\rho_f$ and $\rho_b$ are flowing (actual) and base density.
Continuous Flare and Vent Measurement
- Conclusion/Reminders

- Ultrasonic is the preferred choice
  - Liquid content should be < 0.5% by volume
    (if >0.5% use liquid knock out vessel)
  - Excellent rangeability
  - Good accuracy
  - No frequent calibration required
  - Possibility to measure gas density
  - Independent of gas composition or density (for Volume Measurement)
  - Diagnostics on board
  - Possibility for “dry calibration”
  - Possibility for independent verification through speed of sound
2 Overview of Flare Gas Flow Meters

- Installation
- Operation
- Maintenance

Facilitated by
Lex Scheers
Hint Services BV

Qatar Workshop on Measurement/Reporting of Flare Gas
Doha, Qatar
8th and 9th May 2011
Objectives in each project phase for Metering and Allocation

1 Concept/select phase
Review the existing contractual documents, governmental regulations and check on technical feasibility Develop a high level metering and allocation philosophy
➢ High level metering and allocation philosophy

2 Define/Design phase
Develop detailed engineering specifications for metering and allocation
➢ Final Metering and Allocation design

3 Execute phase
Detail the requirements needed for procurement and construction
➢ Detail Metering and Allocation Manual

4 Operate phase
Ensure systems are in place for sustainable operation
➢ Update Philosophy and Manual (Logbooks)
Design, Installation, Operation of Flare Gas Measurement Systems

Design phase

- Include in the conceptual and detailed design phase
- Metering Spec’s to be agreed with “data customers”
- Develop full set of algorithms (flow rate calc’s and allocation)
- Prepare maintenance program
- Develop calibration requirements
- Integral part of an overall Measurement and Allocation philosophy
- Agree on data handling
  - signal processing
  - reporting in HC accounting system

- Often retrofitting is done but this today is hardly acceptable, a flare gas measurement system is an absolute must
  - to close the gas balance (no gas inflow downstream of meter)
  - to fulfill legislative requirements
  - reputation
Design, Installation, Operation of Flare Gas Measurement Systems

- **Safety**
  - Staff
  - Equipment
- **Location**
  - Knock-out drums needed
  - Accessibility
  - Single or Multiple meters
- **Piping**
  - Flow profile
  - Straight runs up- and downstream
  - Flow conditioners
  - Sampling arrangements
- **Process conditions**
  - P and T measurement
  - Composition measurement
- **Requirements**
  - Accuracy
  - Availability
  - Continuous measurement

- **Flare Gas Meter**
  - Min/Max flowrate
  - Min/Max gas velocity
  - Rate of change
  - Typical gas composition
  - Change of gas composition
  - Effect of fouling
  - Pressure range
  - Temperature range
  - Ambient temperature
  - Sensitivity to liquids
  - Gas density (z-factor)
  - Gas flowrate calculations
  - Meter output
  - Diagnostics software
  - Signal processing

- **Competence**
  - Service of vendor
  - Training own staff
Velocity profile and velocity integration [1]

- **Laminar Flow**
- **Turbulent Flow**

- **Point**
- **Multi-Point**
- **Path Averaging**
Velocity profile and velocity integration [2]

Velocity and Area Weighted Velocity
(Using Equation 5.6 from Miller's Handbook)

Ref : API MPMS 14.10 [2007]
# Flare Meter Datasheet

- Ref MPMS API 14.10

## Flare Meter Datasheet

<table>
<thead>
<tr>
<th>Component</th>
<th>I/O</th>
<th>Output Type</th>
<th>Range</th>
<th>Eng. Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>Local Display</td>
<td>Analog Output # 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethane</td>
<td>Fault Contacts</td>
<td>Analog Output # 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propane</td>
<td>Alarm Contacts</td>
<td>Analog Output # 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n-Butane</td>
<td></td>
<td>Pulse Output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n-Pentane</td>
<td></td>
<td>Analog Input # 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n-Hexane</td>
<td></td>
<td>Analog Input # 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td></td>
<td>Analog Input # 3</td>
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<td></td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethylene</td>
<td></td>
<td>Modbus®</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Notes

64. A) Upstream piping components & upstream/downstream straight lengths. Attach diagram.

65. B)

66. C)

67. E)
## Qualitative Rating of Options for Flare Gas Meters [1]

<table>
<thead>
<tr>
<th>Technology</th>
<th>Sensitivity to Mist/Liquid</th>
<th>Sensitivity to Fouling</th>
<th>Ability to Detect Fouling</th>
<th>Installed Costs</th>
<th>P/T Req’ed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orifice</td>
<td>Moderate</td>
<td>Physical Inspection</td>
<td>Low/High</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Venturi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal</td>
<td>High</td>
<td>High</td>
<td>Physical Inspection</td>
<td>Low</td>
<td>Yes (Am³)</td>
</tr>
<tr>
<td>Mass Flow</td>
<td>High</td>
<td>High</td>
<td>Diagnostics</td>
<td>High</td>
<td>No (Am³)</td>
</tr>
<tr>
<td>Optical</td>
<td>Moderate</td>
<td>High</td>
<td>Diagnostics</td>
<td>High</td>
<td>Yes (mass)</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>Low &lt; 5% liquid</td>
<td>High</td>
<td>Diagnostics</td>
<td>Low/High</td>
<td>No (Am³)</td>
</tr>
<tr>
<td>Vortex</td>
<td>Low</td>
<td>Moderate</td>
<td>Physical Inspection</td>
<td>High</td>
<td>No (Am³)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Yes (mass)</td>
</tr>
</tbody>
</table>
### Qualitative Rating of Options for Flare Gas Meters [2]

<table>
<thead>
<tr>
<th>Technology</th>
<th>Composit. Dependent</th>
<th>Flow Capacity</th>
<th>Range-ability</th>
<th>Accuracy</th>
<th>Calibrat. Frequency</th>
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</thead>
<tbody>
<tr>
<td>Δp</td>
<td>Yes</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Thermal Mass Flow</td>
<td>Yes</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Optical</td>
<td>No</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>UltraSonic</td>
<td>No</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Vortex</td>
<td>No</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
Typical Uncertainties

**Orifice Flow meter (ISO 5167)**
- Discharge coefficient (for $\beta < 0.6$):
  - approx. 0.5%
- Expansion factor ($\varepsilon$), uncertainty $4*\Delta p/P$:
  - approx. 0.1-0.3%
- Geometry:
  - approx. 0.2%
  - approx. 0.7-1.0%

**Turbine Flow meters**
- Using calibration facilities:
  - approx. 0.3-0.5%

**UltraSonic Flow meter**
- Using calibration facilities:
  - approx. 0.3%

---

Not these are ideal uncertainties, in practice uncertainties could easily be a factor 3-5 higher.
Methods for spot checks or verification of existing flare gas meters

Preferably:

- No shut down
- Personnel operating in flare area
  - Need for strict procedures and policies
  - Safety (thermal radiation, toxic gases, noise)
- Need for sampling and injection points
- Periodic checks detect fouling and/or meter drift

Ways to execute spot checks:
1. Insertion flow meters
2. Tracer dilution technology
3. Pulse velocity technique
Methods for spot checks [1]
- Insertion flow meters

- Movable insertion flow meter enables measurement of flow profile
- Insertion point needs 20 D upstream, 5D downstream straight length
- Uncertainty of 5-10% possible

- Insertion turbine meter
  - Mechanical device
- Thermal anemometer (thermal mass flow meter)
  - Great sensitivity
  - No wet or dirty gas applications
- Pitot tube
  - Relatively simple concept
  - Mechanically more complex to insert
Methods for spot checks [2]  
- Tracer dilution technology

Provided \( Q_p \gg Q_i \), the concentration of tracer in the pipe is:

\[
C_i \frac{c_i}{c_p} = \text{Tracer concentration in the injected solution} \quad [\text{mol/m}^3]
\]

\[
Q_i = \text{Injection flow rate of tracer solution} \quad [\text{m}^3/\text{s}]
\]

\[
Q_p = \text{Liquid flow rate in pipeline} \quad [\text{m}^3/\text{s}]
\]
Methods for spot checks [2]
- Tracer dilution technology

- Injection of tracer (with known injection rate) upstream
- After sufficient mixing sampling of the gas
- Analyses for the tracer
- Perform mass balance to determine the total gas flowrate:
  “the dilution of tracer is a measure for the total gas flowrate”
- Sufficient mixing of tracer is required
- Sampling at least 20 D from injection tracer point
- Background correction
  - Sample without tracer injection to find out background
- Tracer requirements:
  - Stable or inert substance
  - Reasonable price
  - Easy onside analyses
- Uncertainty 4-8% possible

Example is SF$_6$
Methods for spot checks [3]
- Pulse velocity technique

- Radioactive tracer injection upstream
- Detection of passing the first pulse
- Detection of passing of second pulse
- Velocity is distance detectors ($\Delta S$) over ($\Delta T$) time delay
- Need for dedicated contractor company and procedures to handle radioactive substances
- Uncertainty in order of 1-2% possible
Meter Loops
- A low cost method of monitoring meter health

- How would you like a very easy way to see if your meters are working at any time?
  - Daily
  - Hourly
  - Takes 10 seconds / check

- How would you like to know WHICH meters are not working?
  - Takes 15 seconds

- How would you like to know this for (almost) no cost?
  - Cost is very low
    - Meters already in place in most cases
    - Only cost is programming, a bit of math and displaying the results
    - Can be done in PI system
Meter Loop Basics

- Sum of flow out should equal sum of flow into loop (at std or mass conditions)

- If all meters are working, Meter Loop Factor is close to 1.00

\[
\frac{\sum Q_{g_{\text{out}}}}{\sum Q_{g_{\text{in}}}} = \frac{\sum Q_{g_{M2}}}{\sum Q_{g_{M1}}} = 1.00
\]
### Meter Loop Basics

- If Meter Loop Factor 1 = 1.20 and Meter Loop Factor 2 = 0.80, either one or both of the M2 meters is not working.

\[
\frac{\sum Q_{gM2}}{\sum Q_{gM1}} = 1.20
\]

\[
\frac{\sum Q_{gM3}}{\sum Q_{gM2}} = 0.80
\]
Continuous Flare and Vent Measurement

- Conclusion/Reminders

- Metering and Allocation should be included in the development process as early as the conceptual design phase
  - M&A philosophy
  - M&A final design
  - M&A Manuals

- The uncertainty of a field-measurement is not the uncertainty quoted by the manufacturer of the meter

- Systematic errors are often dominating the uncertainty as quoted by the manufacturer

- Verification/Calibration tools should be available

- Meter loops are low-cost and a handy verification tool
Gas Balancing and Gas Allocation

Facilitated by
Lex Scheers
Hint Services BV

Qatar Workshop on Measurement/Reporting of Flare Gas
Doha, Qatar
8th and 9th May 2011
The Product Balance

FLARE GAS, OWN USE
(Fiscal ???)

SALES GAS
(Fiscal / Custody Transfer)

SALES OIL
(Fiscal / Custody Transfer)

PRODUCTION FACILITY
for each phase
\[ \Sigma \text{in} = \Sigma \text{out} \]

RESERVOIR

GAS

OIL

WATER

WATER DISPOSAL

SALES GAS

(Sale

SALES OIL

(Sale

FLARE GAS, OWN USE

(Gas

+ Own Use

WATER
Old Billy Joe had 3 children and 17 horses.

After his death the horses should be allocated according to his will.

John: $1/2$

Billy: $1/3$

Jane: $1/9$
Allocation Example 2

1/2 \times 17 = 8.500 \text{ horses}

1/3 \times 17 = 5.667 \text{ horses}

1/9 \times 17 = 1.889 \text{ horses}
Allocation Example 3

The family borrowed 1 horse from the next-door neighbour, so there are now 18 horses.
Allocation Example 4

\[
\begin{align*}
1/2 \times 18 &= 9.000 \text{ horses} \\
1/3 \times 18 &= 6.000 \text{ horses} \\
1/9 \times 18 &= 2.000 \text{ horses}
\end{align*}
\]

Total 17 horses allocated to the kids and they can return the borrowed horse back to the neighbour.
Gas/Condensate/Oil Allocation

Requirements

- Equitable
- Transparent
- As much as possible existing standards (API, ISO)
- Auditable
- Applicable to wide spread of production systems
- Flexible
- Acceptable
- Independent of well/reservoir characteristics
- Equipment, should be proven and economical viable
- Thermodynamics, should be sound and solid
- Costs vs. uncertainty considerations (Accuracy cost money)

Basic principle
What goes in should come out
Conservation Rules

- Conservation of Mass (kg, tonnes)
- Conservation of Standard Volume (Sm$^3$, Scft)
- Conservation of Actual Volume (Am$^3$, cft, bbls)
- Conservation of Mols (kmol)
- Conservation of Energy (MJ, BTU, etc)
Oil Shrinkage and Gas Expansion

- Dead crude oil and water and T (and p) changes
  No mass transfer from liquid to gas phase or vice versa
  - Due to temperature changes (ASTM tables)
  - Due to mixing (dislike molecules (API Chapter 12-3))

- Live crude oil / condensate /gas and p and T changes
  Boiling liquids and condensing gas
  Mass transfer from liquid to gas phase and vice versa
  - HySys (PRO II) models
  - Shrinkage testers
  - Black Oil or other models
Oil Shrinkage and Gas Expansion

Separator

Production Process

Stock Tank

Q

V = 10,000 Sm³/d
\( \rho = 0.90 \text{ kg/m}^3 \)
M = 9,000 kg

V = 12,094 Sm³/d
\( \rho = 0.85 \text{ kg/m}^3 \)
M = 10,280 kg

V = 100 Sm³/d
\( \rho = 750 \text{ kg/m}^3 \)
M = 75,000 kg

V = 97 Sm³/d
\( \rho = 760 \text{ kg/m}^3 \)
M = 73,720 kg

S = 0.97

E = 1.2094

Total Mass M = 84,000 kg

M = 84,000 kg
A single and accurate measurement is used to reconcile number of less accurate well measurements

\[ Q_1 + Q_2 + Q_3 + \ldots + Q_i \neq Q_{Tot} \]

\[ RF = \frac{Q_{Tot}}{\sum_{i} Q_i} \quad \text{Reconciliation Factor} \]

\[ \{Q_1\}_{Re} = RF \cdot Q_1 \]
\[ \{Q_2\}_{Re} = RF \cdot Q_2 \]

And now:
\[ \{Q_1\}_{Re} + \{Q_2\}_{Re} + \ldots + \{Q_i\}_{Re} = Q_{Tot} \]
Reconciliation Factor (RF)

\[
RF = \frac{\sum FiscalisedOil + \sum Fiscalised(\Delta Stock)}{\sum (Well Test \times Days) - \sum Low / Off}
\]

or in words

\[
RF = \frac{Total \text{ oil actually produced}}{Total \text{ oil thought to be produced}}
\]

Under ideal conditions RF should be equal to 1
The purpose of a reconciliation calculation is:
To manage the discrepancies between the reported fiscalised total production and the calculated (measured) total of well volumes plus/minus other streams.

Notes:
1) The highest degree of accuracy is obtained by means of direct (on-line) measurement at the point where data is required
2) No reconciliation process improves the certainty of a measurement
3) The often used accepted range of a reconciliation factor of 0.95 to 1.05 is not supported as a legitimate target. Reconciliation factors can vary more widely and still be acceptable. Trends of the factors over time are important.
Single Stage Reconcilation

\[ RF = \frac{Q_{Tot}}{\sum_{i=1}^{n} Q_{Ai} + \sum_{i=1}^{m} Q_{Bi}} \]

\[ \{Q_{Ai}\}_{Rec} = RF \cdot Q_{Ai} \]
\[ \{Q_{Bi}\}_{Rec} = RF \cdot Q_{Bi} \]
Two Stage Reconciliation
- Improved control

\[ RF = \frac{Q_{Tot}}{Q_A + Q_B} \]

\[ \{Q_A\}_{Rec} = RF \cdot Q_A \]

\[ \{Q_B\}_{Rec} = RF \cdot Q_B \]

\[ RF_A = \frac{\{Q_A\}_{Rec}}{n} \sum_{i=1}^{n} Q_{Ai} \]

\[ RF_B = \frac{\{Q_B\}_{Rec}}{m} \sum_{i=1}^{m} Q_{Bi} \]

\[ \{Q_{Ai}\}_{Rec} = RF_A \cdot Q_{Ai} \]

\[ \{Q_{Bi}\}_{Rec} = RF_B \cdot Q_{Bi} \]
Reconciliation with systematic errors

BEFORE RECONCILIATION

AFTER RECONCILIATION

RANDOM ERROR BAND +/- 10%

SYSTEMATIC ERROR
Reconciliation
- Another warning

Systematic error in well flow metering, e.g. 10% due to over-reading in wet gas measurement or wrong calibrations

Reconciliation factor (RF)

$$RF = \frac{Q_{Tot}}{\sum_{i} Q_i} = \frac{1}{1.1} = 0.91$$

Poor $R$, however good final accuracy in well production data.
Reconciliation
- Another warning

Systematic error throughout the system, e.g. 10% due to wrong calibrations

Reconciliation factor (RF)

\[ RF = \frac{Q_{Tot}}{\sum_{i} Q_i} = \frac{1.1}{1.1} = 1.00 \]

Excellent R, however poor final accuracy in well production data
Different types of Allocation Processes

Volumetric balances
- Flow proportional
- Uncertainty based
- By difference

Mass/Energy balances (per component or bulk)
- Flow proportional
- Uncertainty based
- By difference

Preferred method for complicated gas developments:
- Mass based allocation per component
  (component based allocation)
Mass Based Allocation per Component [1] - LNG project
Mass Based Allocation per Component [2] (simplified)

Split of sales products (LNG, LPG, Condensate) is done based on quality of gas supply, e.g.
A heavy gas (rich or C_{5+}) producer should get more from the condensate sales or
A lean gas (mainly C_1 or C_2) producer should mainly be paid from the LNG sales

Assume (as an example)
LNG = C_1 and C_2
LPG = C_3 and C_4
Condensate = C_{5+}
Mass Based Allocation per Component [3] (real)

For each company and each component

\[ m_{i,k} \]

For each company and each component

- i = 12 Components
  - C1, C2, ........, CO₂, N₂

- k = 3 Companies

\[ m_{i,LNG}, m_{i,LPG}, m_{i,Cond} \]

3 separate money pots

\[ $_{LNG}, $_{LPG}, $_{Cond} \]
Mass Based Allocation per Component \([4]\) (real)

**Step 1**

Split money pots per component, hence from 3 “money pots” to 36 “money pots”

For LNG (based on MJ):

\[
$\text{LNG},i = \frac{m_{i,\text{LNG}} \cdot CV_i}{12 \sum_{i=1}^{12} m_{i,\text{LNG}} \cdot CV_i} \cdot $\text{LNG}
\]

For LPG (based on weight):

\[
$\text{LPG},i = \frac{m_{i,\text{LPG}} \cdot MW_i}{12 \sum_{i=1}^{12} m_{i,\text{LPG}} \cdot MW_i} \cdot $\text{LPG}
\]

For Cond (based on weight):

\[
$\text{Cond},i = \frac{m_{i,\text{Cond}} \cdot MW_i}{12 \sum_{i=1}^{12} m_{i,\text{Cond}} \cdot MW_i} \cdot $\text{Cond}
\]

Note:

\(m_{i,\text{LNG}}, m_{i,\text{LPG}}\) and \(m_{i,\text{Cond}}\) are moles of outgoing sales streams

36 separate money pots
Mass Based Allocation per Component [5] (real)

Step 2
Contribution per component and component, hence from 36 “money pots” to 108 “money pots”

For LNG (based on MJ):

\[ S_{k,LNG,i} = \frac{m_{i,k} \cdot CV_i}{\sum_{k=1}^{3} m_{i,k} \cdot CV} \cdot S_{LNG,i} \]

For LPG (based on weight):

\[ S_{k,LPG,i} = \frac{m_{i,k} \cdot mw_i}{\sum_{k=1}^{3} m_{i,k} \cdot mw_i} \cdot S_{LPG,i} \]

For Cond (based on weight):

\[ S_{k,Cond,i} = \frac{m_{i,k} \cdot mw_i}{\sum_{k=1}^{3} m_{i,k} \cdot mw_i} \cdot S_{Cond,i} \]

Note: 
\( m_{i,k} \) are moles of incoming streams

108 separate money pots
Mass Based Allocation per Component [6] (real)

Step 3
Sum to get company totals

\[
\$k = \sum_{i=1}^{12} \$k,LNG,i + \sum_{i=1}^{12} \$k,LPG,i + \sum_{i=1}^{12} \$k,Cond,i
\]

summation over 3 x 12 money pots
Uncertainty based Allocation [1]
- Imbalance is split based on uncertainties

Imbalance equals:

\[ Q_{Tot} - \sum_{i} Q_i = 21,500 - 22,000 = -500 \]

Assumption is that imbalance is caused by intrinsic uncertainties of individual measurements, hence larger uncertainties contribute more that very accurate measurements.
Uncertainty based Allocation [2]

\[ \left( \sigma_j \right) \left( \sigma_j \right)^2 \]

\[ \begin{align*}
250 & \text{ (62,500)} \\
125 & \text{ (15,625)} \\
260 & \text{ (67,600)} \\
99 & \text{ (9,801)}
\end{align*} \]

\[ \sum_{j=1}^{4} \left( \sigma_j \right)^2 = 155,526 \]

\[ Q_1 = \frac{\left( \sigma_1 \right)^2}{\sum_{j=1}^{4} \left( \sigma_j \right)^2} = 5,000 + \frac{62,500}{155,526} \cdot (-500) = 4,799 \]

\[ Q_2 = 4,950 \]

\[ Q_3 = 6,283 \]

\[ Q_4 = 5,468 \]

\[ Q_{Tot} = 21,500 \]

Assume OK

same principle for well 2, 3 and 4
## Uncertainty based Allocation [3]
### - Difference Flow Proportional and Uncertainty Based

<table>
<thead>
<tr>
<th>Entry Point</th>
<th>Entry Point Theoretical Production [m³]</th>
<th>Meter Uncertainty [%]</th>
<th>StDev [%]</th>
<th>Entry Point Measured Production [m³]</th>
<th>Flow Proportional Production [m³]</th>
<th>Uncertainty Based Production [m³]</th>
<th>Difference in UBR compared with FPR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5,000</td>
<td>5.00%</td>
<td>2.50%</td>
<td>125</td>
<td>5,000</td>
<td>4,886</td>
<td>4,799</td>
</tr>
<tr>
<td>2</td>
<td>5,000</td>
<td>2.50%</td>
<td>1.25%</td>
<td>63</td>
<td>5,000</td>
<td>4,886</td>
<td>4,950</td>
</tr>
<tr>
<td>3</td>
<td>6,500</td>
<td>4.00%</td>
<td>2.00%</td>
<td>130</td>
<td>6,500</td>
<td>6,352</td>
<td>6,283</td>
</tr>
<tr>
<td>4</td>
<td>5,500</td>
<td>1.80%</td>
<td>0.90%</td>
<td>50</td>
<td>5,500</td>
<td>5,375</td>
<td>5,468</td>
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<td>0.00%</td>
<td>0</td>
<td>21,500</td>
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<td></td>
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<td></td>
<td></td>
<td>-500</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Levels of Allocation [1]

- **Well Allocation** - Determines the quantity of oil, water and gas produced from an individual well. Data mainly used for reservoir management.  
  Typical metering accuracy $\pm 10\%$

- **Field Allocation** - Determines the quantity of oil, water and gas produced from all the wells within a reservoir/field. Data used for reservoir management, sales and tax.  
  Typical metering accuracy $\pm 1$ to $5\%$

- **Platform Allocation** - Apportions the quantity of oil, water and gas exiting a facility between the different fields that enter the facility. Data used for tariff purposes.  
  Typical metering accuracy $\pm 1\%$ or $2\%$ for gas,  
  $\pm 0.25\%$ for oil
Levels of Allocation [2]

- **Terminal Allocation** - Apportions the oil, water and gas exiting a Terminal between the different input Platforms. Date used for tariff and oil tanker lifting and gas sales purposes.
  
  Typical metering accuracy: ±1% for gas, ±0.25% for oil

- **Downstream Gas Allocation** - Apportionment of gas entering and exiting an onshore gas distribution network. Data used to balance the inflow and outflow and for tariff.
  
  Typical metering accuracy: ±1% for gas
Estimation of Errors and Uncertainty in Volume Measurement

Facilitated by
Lex Scheers
Hint Services BV

Qatar Workshop on Measurement/Reporting of Flare Gas
Doha, Qatar
8th and 9th May 2011
Systematic, Random and Spurious Errors

1) Random Errors
   - Natural errors in accordance with the laws of chance (normal distribution)
   - Can be reduced by increasing number of measurements

2) Systematic Errors
   - Cannot be reduced by increasing the number of measurements
   - Can be corrected for if all influences are known

3) Spurious Errors
   - Human Errors, Misreadings, Instrument Malfunctioning
   - Should not be incorporated into statistical analyses
   - Use rejection criteria (e.g. Dixons outlier test).
Systematic, Random and Spurious Errors

- **Systematic Error**
- **Random Error**
- **Spurious Error**

Uncertainty band or 95% confidence level

Measured value vs. Time graph

- True value
- Uncertainty band
- Data points

Qatar Workshop
Doha, 8-9 May 2011
Uncertainty - Repeatability, Systematic and Random Errors

- Random Error
- Systematic error plus random error
- Poor accuracy
  - Poor repeatability
- Good accuracy
  - Good repeatability

Actual Value
Uncertainty
- Confidence interval

The confidence interval, also known as the range of uncertainty, is an interval within which the true value of the measured quantity, corrected for all known systematic errors, can be expected to lie with a stated degree of confidence.

Common practice is to use the 95% confidence level, which corresponds to plus/minus two standard deviations, when the measurements are distributed normally about a mean.

Note:
More precise the 95% confidence level is covered by a range between $m_s - 1.96 \, s_s$ and $m_s + 1.96 \, s_s$
Uncertainty - Confidence interval

Uncertainty = 10%, With 95.45% confidence interval this means St Dev = 5

Uncertainty approx. 2 * St Dev

2 * StDev will be used for 95% confidence interval
Uncertainty
- Absolute and Relative Errors

Relative error $\frac{x+\Delta x}{x} \times 100\%$
A relative error of +/- 10% in a flow measurement of 250 m$^3$/d means that the true value lies in the range 225 m$^3$/d to 275 m$^3$/d, i.e. +/- 10% relative to 250 m$^3$/d.

Absolute error $x+\Delta x$
A absolute error of +/- 10 m$^3$/d in a flow measurement of 250 m$^3$/d means that the true value lies in the range 240 m$^3$/d to 260 m$^3$/d, i.e. +/- 4% relative to 250 m$^3$/d.

An uncertainty of +/- 2% absolute in a watercut measurement of 60% means that the true value lies in the range 58% to 62%.

In multiphase flow fractions (oil, water and gas) and watercut are measured directly as percentages. To avoid dealing with percentages of percentages, errors in these quantities are often quoted in absolute terms.
Uncertainty
- Error Propagation (1)

• Addition and Subtraction

\[ R = x + y \]
\[ R + \Delta R = x + \Delta x + y + \Delta y \]
\[ \Delta R = \Delta x + \Delta y \]

• With addition and subtraction the absolute error in the result is the sum of all absolute errors.

Alternatively

\[ R = x + y \]
\[ \Delta R = \frac{\partial R}{\partial x} \Delta x + \frac{\partial R}{\partial y} \Delta y \]
\[ \Delta R = \Delta x + \Delta y \]
• **Multiplication and Division**

\[ R = x \cdot y \]

\[ R + \Delta R = (x + \Delta x)(y + \Delta y) \]

\[ = (x \cdot y + x\Delta y + y\Delta x + \Delta x\Delta y) \]

\[ \Delta R = y\Delta x + x\Delta y \]

\[ \frac{\Delta R}{R} = \frac{y}{R} \frac{\Delta x}{x} + \frac{x}{R} \frac{\Delta y}{y} \]

• With multiplication and division the relative error in the result is the **sum of all relative errors**.
Uncertainty
- Error propagation (3)

Statistically the errors should be summed according to the Root Mean Square (RMS) method:

\[
\frac{\Delta Q}{Q} = \sqrt{\left(\frac{\Delta X_1}{X_1}\right)^2 + \left(\frac{\Delta X_2}{X_2}\right)^2 + \left(\frac{\Delta X_3}{X_3}\right)^2 + \ldots} \\
\Delta Q = \sqrt{(\Delta X_1)^2 + (\Delta X_2)^2 + (\Delta X_3)^2 + \ldots}
\]

Instead of

\[
\frac{\Delta Q}{Q} = \frac{\Delta X_1}{X_1} + \frac{\Delta X_2}{X_2} + \frac{\Delta X_3}{X_3} + \ldots \]

\[
\Delta Q = \Delta X_1 + \Delta X_2 + \Delta X_3 + \ldots
\]

However, the previously mentioned “worst case” scenario’s often give a good indication how errors can “explode” and check their sensitivity. It also makes calculations easier.
Monte Carlo Simulation
Run multiple calculations whereby the input in each calculation is taken from a given distribution

With today’s computing power this is now available in spreadsheets ➢ Crystal Ball ➢ @Risk
If the sensitivity coefficient is unknown......

Approximate by measuring the effect of a small change in the (sub) variable on the overall measurement......

\[ y = f(x_i) \]  \quad Y, \text{ the measurement is a function of } x

Apply a small variation in x and observe the change in Y

\[ y + \Delta y = f(x_i + \Delta x_i) \]

The sensitivity coefficient is now:

\[ S_x = \frac{\Delta y}{\Delta x} \]

Ref: ISO 5168
Uncertainty Analysis Procedure
- Flare Gas Meter

What are relevant parameters:

• Widely varying flow rates
• Gas Composition (measured / fixed)
• Pressure (measured / fixed)
• Temperature (measured / fixed)
• Geometric uncertainties
• Inlet/Outlet piping effects
Example Gas Flow Meter Uncertainty

Calculation Algorithm of Gas Flow Meter

Pressure $P_R$
Temperature $T_R$
Composition $C_R$
Meter Reading $M_R$

Gas Flow Rate $Q_R$
Example Gas Flow Meter Uncertainty

Uncertainty in Gas Flow Rate due to Pressure Uncertainty:

\[
\left( \frac{\Delta Q}{Q} \right)_P = \frac{Q_R - Q_P}{Q_R} \times 100\%
\]
Example Gas Flow Meter Uncertainty

Uncertainty in Gas Flow Rate due to Pressure Uncertainty :

\[
\left( \frac{\Delta Q}{Q} \right)_T = \frac{Q_R - Q_T}{Q_R} \times 100\%
\]
Example Gas Flow Meter Uncertainty

Same for others ........

Adding all uncertainties results in total gas flow rate uncertainty (i.e. worst case scenario)

\[
\left(\frac{\Delta Q}{Q}\right)_{Total} = \left(\frac{\Delta Q}{Q}\right)_P + \left(\frac{\Delta Q}{Q}\right)_T + \left(\frac{\Delta Q}{Q}\right)_C + \left(\frac{\Delta Q}{Q}\right)_M
\]

Better to use the square root of the sum of squares (i.e. not all uncertainties work against you)

\[
\left(\frac{\Delta Q}{Q}\right)_{Total} = \sqrt{\left(\frac{\Delta Q}{Q}\right)_P^2 + \left(\frac{\Delta Q}{Q}\right)_T^2 + \left(\frac{\Delta Q}{Q}\right)_C^2 + \left(\frac{\Delta Q}{Q}\right)_M^2}
\]

EXAMPLE

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>2.00%</td>
</tr>
<tr>
<td>Temperature</td>
<td>0.10%</td>
</tr>
<tr>
<td>Composition</td>
<td>2.00%</td>
</tr>
<tr>
<td>Meter Reading</td>
<td>1.40%</td>
</tr>
<tr>
<td>Worst Case</td>
<td>5.50%</td>
</tr>
<tr>
<td>RSS</td>
<td>3.16%</td>
</tr>
</tbody>
</table>
## Examples of Composition Effects

<table>
<thead>
<tr>
<th></th>
<th>$CO_2$</th>
<th>$H_2S$</th>
<th>$CH_4$</th>
<th>$C_2H_6$</th>
<th>$C_3H_8$</th>
<th>$H_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base Case</strong></td>
<td>1.00</td>
<td>0.90</td>
<td>97.00</td>
<td>1.00</td>
<td>0.10</td>
<td>-</td>
</tr>
<tr>
<td><strong>Case 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propane Increased</td>
<td>0.53</td>
<td>0.47</td>
<td>51.08</td>
<td>0.53</td>
<td>47.39</td>
<td>-</td>
</tr>
<tr>
<td><strong>Case 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen Added</td>
<td>0.40</td>
<td>0.36</td>
<td>38.80</td>
<td>0.40</td>
<td>0.04</td>
<td>60.00</td>
</tr>
<tr>
<td><strong>Case 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$CO_2$ Increased</td>
<td>12.00</td>
<td>0.80</td>
<td>86.22</td>
<td>0.89</td>
<td>0.09</td>
<td>-</td>
</tr>
</tbody>
</table>
## Errors Related to Use of Fixed Composition for Different Meters

<table>
<thead>
<tr>
<th>Case 1 – Propane Increased</th>
<th>Act. Vol</th>
<th>St. Vol</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Differential Pressure Meter</td>
<td>~ 34%</td>
<td>~ 34%</td>
<td>~ 25%</td>
</tr>
<tr>
<td>Thermal Flow Meter</td>
<td>~ 2%-15%</td>
<td>~ 2%-15%</td>
<td>~ 35%-45%</td>
</tr>
<tr>
<td>Velocity Meter (Optical, US, Vortex)</td>
<td>0%</td>
<td>0%</td>
<td>~ 44%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Differential Pressure Meter</td>
<td>~ 31%</td>
<td>~ 31%</td>
<td>~ 45%</td>
</tr>
<tr>
<td>Thermal Flow Meter</td>
<td>upto 300%</td>
<td>upto 300%</td>
<td>upto 700%</td>
</tr>
<tr>
<td>Velocity Meter (Optical, US, Vortex)</td>
<td>0%</td>
<td>0%</td>
<td>~ 112%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Differential Pressure Meter</td>
<td>~ 9%</td>
<td>~ 9%</td>
<td>~ 8%</td>
</tr>
<tr>
<td>Thermal Flow Meter</td>
<td>~ 2%-5%</td>
<td>~ 2%-5%</td>
<td>~ 15%-20%</td>
</tr>
<tr>
<td>Velocity Meter (Optical, US, Vortex)</td>
<td>0%</td>
<td>0%</td>
<td>~ 15%</td>
</tr>
</tbody>
</table>

Ref : API, MPMS 14.10 [2007]
5 Methods for Estimating Flare and Vent Volumes

Facilitated by
Lex Scheers
Hint Services BV

Qatar Workshop on Measurement/Reporting of Flare Gas
Doha, Qatar
8th and 9th May 2011
You can’t manage if you can’t measure ......

Preferred methods to determine the Flare and Vent volumes are measurements in a closed gas balance (no un-measured gas streams and no measurement by difference)

Subsequently, allocation algorithms indicates the quality of the closed balance and provides the final gas figures like:

- sales gas (the largest of all)
- own use (compressors, glycol units, instruments, storage, etc)
- flared and vented gas
- produced gas from wells
- injected gas (into reservoir)
- lift gas for oil production
- others...

However, measurements are not always there (blowdown, pipe rupture, blow-out, etc), hence we need to “guestimate”
Determine the order of magnitude of each gas stream in and out of the facility and its relative importance.
Closing the balance by difference

Where to put a second flow meter with +/- 5% relative error
Which position gives best accuracy?

Production $1100 \text{ m}^3/\text{d}$

Flare installation:
- Flare $+/- 5\%$
- Production $+/- 2.7\%$

Production installation:
- Production $+/- 5\%$
- Flare $+/- 72\%$

Measurement by difference should be avoided. However, if it is the only way then avoid the subtraction of two big numbers to get a small number !!!
Associated (Solution) Gas from Wells

Intermittent Measurement, Test Separator (TS) or just Oil measurement and sampling GOR, WC (BS&W)
- Gas, Oil and Water flow rates
- \( \text{GOR} = \frac{\text{Gas @ St. Conditions (Sm}^3\text{)}}{\text{Oil @ St. Conditions (Sm}^3\text{)}} \)

Continuous Measurement, with Multi-Phase Flow Meters (MPFM)
- Same as welltest

In both cases Gas and Oil from TS or MPFM conditions need to be converted to standard conditions (15°C and 101.325 kPa)
- Correlations
- Oil Shrinkage and Gas Expansion factors
- PVT data and Process Simulation
Well Testing (Conventional) - 3 Phase Test Separator
GOR measurement

\[ Q_{g,formation} = Q_{g,total} - Q_{g,lift} \]
\[ Q_{oil} = (1 - wc) \cdot Q_{liquid} \]
\[ FGOR = \frac{Q_{g,formation}}{Q_{oil}} \]

\[ \frac{\Delta FGOR}{FGOR} = \sqrt{ \left( \frac{\Delta Q_{g, total}}{Q_{g, total} - Q_{g, lift}} \right)^2 + \left( \frac{\Delta Q_{g, lift}}{Q_{g, total} - Q_{g, lift}} \right)^2 + \left( \frac{\Delta wc}{1 - wc} \right)^2 + \left( \frac{\Delta Q_{liquid}}{Q_{liquid}} \right)^2} \]

high-GVF and high-watercut MPFM suitable?
Well Testing (Advanced)
- Multi-Phase Flow Meter (MPM, Norway)

Purpose

- Continuous Oil, Water and Gas flow rate measurement in a multi-phase environment

Technology

- Venturi
- 3D Broadband Tomography
- Gamma Ray Absorption
- Algorithms

Features

- Compact design
- Simple field configuration
- Redundancy
- In-situ gas fluid property measurement
- Water salinity measurement
- Wet Gas and Multiphase mode
- Low sensitivity for changes in fluid property
Most preferred option is to measure all streams in and out, however, sometimes not possible, e.g.

- Production Storage Tanks
- Pipe Rupture/Well Blow-outs
- Emergency Shutdown (Safety Valves, Pressure Relief)
- Instrument/Pneumatic devices
- Well (Facility) Blow-downs
- etc.

Then engineering calculations should be used to “guestimate”
Estimation of Flaring and Venting
- Production Storage Tanks

Lighter HC gases evaporate from storage tanks
- Breathing
- Filling/Emptying
- Flashing

replaced by MPMS Ch 19.1 (2002)

- Correlations, e.g. Standing or Vasquez & Beggs
- Process Simulators, e.g. ProII or Hysys

Standing Correlation
- Valid within a certain range of parameters
  (e.g. Bubble Point, Temperature, GOR, Oil Gravity (API), Vapour Specific Gravity)
- Approx. accuracy 10-15%

\[
R_s = \gamma_g \left( \frac{p}{519.7 \times 10^{\gamma_g}} \right)^{1.2048}
\]

\[
R_s = \text{Solution GOR (m}^3/\text{m}^3) \quad \gamma_g = \text{SG of solution gas (—)} \quad \gamma_o = \text{SG of oil (—)} \\
T = \text{Temperature (K)} \quad p = \text{Pressure (kPa)} \\
\gamma_g = 1.255 + 0.00164 \times T - \frac{1.769}{\gamma_o}
\]
Gas used to power devices (injection pumps) or used to drive instruments (valves, instrument controller, etc)

Determine:
- Average use for each type of device
- Average operation time
- Number of devices

Estimate the monthly vent rate based on above
Estimation of Flaring and Venting  
- Emergency Shutdown (Safety Valves, Pressure Relief)

Depends on:
- Duration
- Temperature and Pressure
- Throat of relief valve
- Gas properties

\[ m = \text{mass flow rate (kg/s)} \]
\[ A = \text{Cross Sectional Area Throat (m}^2\text{)} \]
\[ R = \text{Gas Constant, 8314 kJ/kg/K} \]
\[ T_0 = \text{Temperature (K)} \]
\[ k = \text{Specific Heat Ratio,} \frac{C_p}{C_v} \]
\[ P_0 = \text{Pressure Relief Setpoint (kPa)} \]

\[
m = A \times \frac{p_0}{\sqrt{T_0}} \times \sqrt{\frac{k}{R}} \times \frac{1}{\left(\frac{k + 1}{2}\right)^{(k+1)/(2k-2)}} \times 1000
\]
Monitoring and Reporting

Measured and estimated volumes need to be monitored and reported in a transparent and single database.

Preferable the corporate HC oil and gas accounting system needs to be used for this purpose:

- Linked to the overall gas balance (production, sales, etc)
- To allocate flare and vent volumes back to contributors
- Tax and royalty (Fiscal) reasons
- Reporting of unbalance
- Flaring and Venting as part of the daily reporting
History of Energy Components

- EC has been around in since 1996
- Originally different for each client
- Web based since 2005 (version 8)
- Wide client base
- World Wide Implementations
- On every continent

Selected as the global standard and best practice by oil & gas majors
Energy Components Production
- Overview

- Web based Oracle data base system
  - Users access it using Internet Explorer
  - Flexible, configurable, secure

- Takes production data
  - Well tests, meter readings, tank volumes, samples, pressures, etc.
  - Manually keyed and electronic data input, i.e. PI, SCADA, DCS, etc.

- Allocates fiscal production down to wells and reservoirs

- Provides ad-hoc, daily, weekly, monthly reports.

- Hand-off data to other systems

- Provides tight data controls
  - In support of SOX 404
Energy Components
- Product Overview

4 Main Business Area

PRODUCTION
- Production Downtime
- Production Operations
- Well Testing
- Well & Reservoir

TRANSPORT
- Gas Stream
- Gas Delivery
- Gas Dispatching
- Gas Purchase
- Gas Sales

SALES
- Oil Stream
- Oil Delivery
- Cargo Admin’n
- Oil Sales

REVENUE
- Sales & Purchases
- Inventories
- Tariffs
- Volumes

SAP

Data from Other company ops
JV’s Partners etc.

Operator Company

EC Calculation & Allocation Framework

Well Fluids
Energy Components
- Reporting and Interfaces

Input Data → Calculated Data

Configuration → Reporting

Input Data → Calculated Data → Allocation

Interfaces → Business Objects

Interfaces → MS Excel

Interfaces → MS Access

Interfaces → Oracle system

Interfaces → ODBC system

Interfaces → Metering Atlas

Interfaces → Etc.
Energy Components
- Production

- EC Production is a software package designed to handle the allocation and reporting of oil and gas production.
- EC Production covers the value chain from reservoirs and wells to custody transfer point.
### Example of a Monthly Production Report [1]

#### Watercut

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>XX-122</td>
<td>30.43</td>
<td>77,774.7</td>
<td>7,451.7</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
<tr>
<td>XX-123</td>
<td>30.43</td>
<td>28,385.8</td>
<td>3,002.9</td>
<td>800.0</td>
<td>2.7%</td>
</tr>
<tr>
<td>XX-124</td>
<td>16.93</td>
<td>18,467.3</td>
<td>4,455.9</td>
<td>8,234.0</td>
<td>30.8%</td>
</tr>
<tr>
<td>XX-125</td>
<td>30.43</td>
<td>30,255.3</td>
<td>3,220.9</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
<tr>
<td>XX-126</td>
<td>0.00</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>NA</td>
</tr>
<tr>
<td>XX-127</td>
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<td>71,432.4</td>
<td>6,252.1</td>
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<td>0.0%</td>
</tr>
<tr>
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<td>5,616.7</td>
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<td>0.0%</td>
</tr>
<tr>
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<td>56,935.1</td>
<td>6,424.6</td>
<td>345.0</td>
<td>0.6%</td>
</tr>
<tr>
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<td>14,392.9</td>
<td>3,449.0</td>
<td>0.0</td>
<td>0.0%</td>
</tr>
<tr>
<td>XX-132</td>
<td>29.44</td>
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<tr>
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<td>2,230.8</td>
<td>545.0</td>
<td>3.2%</td>
</tr>
<tr>
<td>XX-134</td>
<td>8.90</td>
<td>5,839.0</td>
<td>1,364.5</td>
<td>4,567.0</td>
<td>43.9%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>414,727.4</strong></td>
<td><strong>49,851.4</strong></td>
<td><strong>30,204.0</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

How is this information determined?

1. Spot sample once a year (month) at well head
2. Average of well test separator reading
3. Continuous with a Multi-Phase Flow Meter
### Example of a Monthly Production Report [2]

**Net-Oil flowrate**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
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<td><strong>30,204.0</strong></td>
<td></td>
</tr>
</tbody>
</table>

---

**How is this information determined?**

1) **What equipment has been used?**

2) **How often is the data gathered?**

3) **Is equipment calibrated and operating OK?**

4) **What is uncertainty indication?**
Metering Dashboard
- Block Diagram
### Health Module

- Orifice or Venturi Flow Meter for Gas

Where does the information comes from?

<table>
<thead>
<tr>
<th>Information</th>
<th>Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure, $p_{act}$</td>
<td>PI</td>
</tr>
<tr>
<td>Temp, $T_{act}$</td>
<td>PI</td>
</tr>
<tr>
<td>Diff. Pressure, $\Delta p$</td>
<td>(PI)</td>
</tr>
<tr>
<td>Density, $\rho$</td>
<td>LIMS, (PI)</td>
</tr>
<tr>
<td>Flowrate, $Q_{act}$, $Q_{act}$</td>
<td>PI, EC</td>
</tr>
<tr>
<td>$p_{min} / p_{max}$</td>
<td>InTools</td>
</tr>
<tr>
<td>$T_{min} / T_{max}$</td>
<td>InTools</td>
</tr>
<tr>
<td>$Q_{min} / Q_{max}$</td>
<td>InTools</td>
</tr>
<tr>
<td>$\rho_{min} / \rho_{max}$</td>
<td>InTools</td>
</tr>
<tr>
<td>Maint$<em>{last}$ / Maint$</em>{next}$</td>
<td>SAP</td>
</tr>
<tr>
<td>Open Workorder</td>
<td>SAP</td>
</tr>
</tbody>
</table>
Health Module
- Orifice or Venturi Flow Meter for Gas

All Health Rules are configurable by the user

Example Rules

\[
Q_{\text{act}}(\text{PI}) = Q_{\text{act}}(\text{EC})
\]

\[
p_{\text{min}}(\text{InTools}) < p_{\text{act}}(\text{PI}) < p_{\text{max}}(\text{InTools})
\]

\[
T_{\text{min}}(\text{InTools}) < T_{\text{act}}(\text{PI}) < T_{\text{max}}(\text{InTools})
\]

\[
Q_{\text{min}}(\text{InTools}) < Q_{\text{act}}(\text{PI, EC}) < Q_{\text{max}}(\text{InTools})
\]

\[
p_{\text{min}}(\text{InTools}) < p_{\text{act}}(\text{PI, LIMS}) < p_{\text{max}}(\text{InTools})
\]

\[
\rho_{\text{min}}(\text{InTools}) < \rho_{\text{act}}(\text{PI, LIMS}) < \rho_{\text{max}}(\text{InTools})
\]

\[
\rho (\text{PI}) \approx \rho (\text{LIMS})
\]

\[
\text{Maint}_{\text{next}} (\text{SAP}) < \text{Current Date}
\]

\[
\text{Open Workorder (SAP)}
\]
Metering Dashboard

- Features

- Metering Dashboard shows health and details of Metering Systems to all who have an interest in production data.

- Metering Dashboard provides a platform to collaborate between “metering data providers” and “metering data consumers”.

- However, Metering Dashboard is not the cure, it summarizes the status and makes things visible to the users.

- Feedback from various data consumers, i.e. Reservoir Engineers, Petroleum Engineers and Asset managers is very positive.

- We have moved from a “trust me world” into a “show me world”.

6

Advice on Improving/Redesigning Gas Measurement System in Qatar

Facilitated by
Lex Scheers
Hint Services BV

Qatar Workshop on Measurement/Reporting of Flare Gas
Doha, Qatar
8th and 9th May 2011
## Comments to Questionnaire Responds [1]

<table>
<thead>
<tr>
<th>Key items</th>
<th>Response received</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current measurement practice</td>
<td>25% of respondents use meters and 75% use different estimation methods.</td>
<td>Measurements preferred, 25% is low</td>
</tr>
<tr>
<td>Types of meters identified</td>
<td>Orifice and Ultrasonic meters</td>
<td>Orifice not the preferred way (limited turndown), UltraSonic is OK</td>
</tr>
<tr>
<td>Estimation methods used</td>
<td>PE model, Mass balance, estimation from design flow figures for stacks, different engineering calculations (not sure which is used)</td>
<td>Mass balance is the preferred option</td>
</tr>
<tr>
<td>Uncertainty determination</td>
<td>44% of operators accounts for uncertainty and 56% do not account for uncertainty</td>
<td>Key is “management” of uncertainty in measurement or estimation.</td>
</tr>
<tr>
<td>Composition of flared gas</td>
<td>Most respondents measure gas compositional analysis.</td>
<td>Spot/Continuous?</td>
</tr>
<tr>
<td>Method for determining gas composition</td>
<td>38% uses meters such as gas chromatography, mass spectrometer and lab analysis. 46% uses methods such as process steam material balance, design composition and different estimation based on internal approved engineering calculations or process.</td>
<td>Measurement preferred (economics) Internal approved calc’s?</td>
</tr>
</tbody>
</table>
## Comments to Questionnaire Responds [2]

<table>
<thead>
<tr>
<th>Key_items</th>
<th>Response received</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of gas compositional analysis</td>
<td>12 % of respondents do weekly measurement of their compositional analysis, 19% do it continuously, 25% does it as required by internal or external regulatory or approved process, and 25% do it annually or during flaring incidents. 19% do not determine or measure gas compositional analysis at all.</td>
<td>Hence, 75% non-compliant with regulator (high) ...... 19% without compositional analysis seems high</td>
</tr>
<tr>
<td>Laboratory accreditation</td>
<td>87% of respondents do not have accredited lab. 13% have accredited labs. Of the 87% that do not have accredited labs, 19% are in the process to getting accredited.</td>
<td>Opportunity for Improvement</td>
</tr>
<tr>
<td>Calibration frequency for gas flow meters</td>
<td>63% says its not applicable, 31% calibrates yearly and 6% bi-annually</td>
<td>Opportunity for Improvement, at least a bi-annually calibration</td>
</tr>
<tr>
<td>Calibration approach</td>
<td>75% of respondents use third party involvement in gas flow meter calibration and 25% do not have third party involvement.</td>
<td>Seems OK</td>
</tr>
</tbody>
</table>
**Comments to Questionnaire Responds [3]**

<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>Flare data reporting frequency</td>
<td>All respondents report flare data daily, weekly, monthly, quarterly and annually based on MoE's requirements.</td>
<td>Reporting is one, but what is the uncertainty?</td>
</tr>
<tr>
<td>Closed gas balance systems &amp; meters used</td>
<td>49% do not use any meter or are not sure of the meter used. 51% uses either of the following meters; orifice, vortex and ultrasonic.</td>
<td>Opportunity for Improvement, Gas balances are quality indicators, Mass balances are preferred.</td>
</tr>
<tr>
<td>Global standards or guidance used for accounting for flared gas</td>
<td>87% of respondents do not use global standards or guidelines (most operators uses internally approved procedures which varies from operator to operator). 13% uses global standards such as the EU GHG guidelines and the API.</td>
<td>Do is once, Do it right, Do it internationally Regulators and Operators to co-operate and jointly develop a standard</td>
</tr>
</tbody>
</table>
### Comments to Questionnaire Responds [3]

<table>
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<tbody>
<tr>
<td>Suggestions for Flare data management system</td>
<td>Automated data management system, volumetric gas balance, gas feed and production measured and reported accurately in all degassing stations, standard input for all relevant data and sharing data for all locations, unified approach, common flare reporting guidelines, reporting on mass basis to allow simple comparison and standardized regulation of meter flow measurement.</td>
<td>Mass vs Volume balance, Intergrated in HC accounting system (production, injection, sales, etc), Management of uncertainty, Standardization</td>
</tr>
</tbody>
</table>