

# Uncertainty in Gas Density

## Measured and Calculated

Oil and Gas Focus Group  
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# Gas Field Allocation

- Field allocation
  - On gross energy
  - On a component basis
  - Gas composition required
- Gas density
  - Continuous direct measurement
  - By calculation using EOS, composition, P, T
  - Use of both provides useful cross check



# Densitometer Density

- Vibrating cylinder
  - Excited at it's natural frequency
  - Period is primarily a function of density

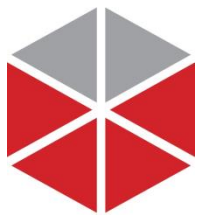
$$\rho_u = K0 + K1\tau + K2\tau^2$$

- Temperature Correction

$$\rho_t = \rho_u[1 + k18(t - t_c)] + K19(t - t_c)$$

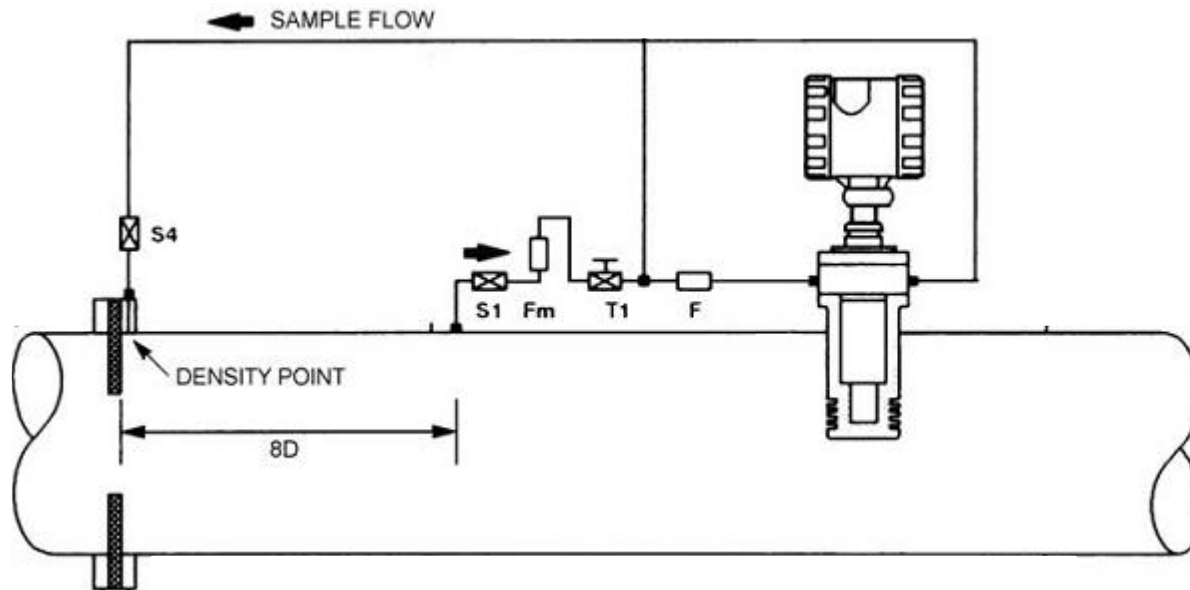
- VOS Correction

$$\rho_A = \rho_t \left[ \frac{1 + \left(\frac{K}{\tau c_c}\right)^2}{1 + \left(\frac{K}{\tau c_g}\right)^2} \right] \quad \rho_A = \rho_t \left[ 1 + \frac{K3}{\rho_t + K4} \left( \left(\frac{SG}{\gamma(T)}\right)_c - \left(\frac{SG}{\gamma(T)}\right)_g \right) \right]$$



# Densitometer Installation

- Pressure recovery method
- Density measured at
  - P2, T3
  - Densitometer measures density within transducer



GCAS – Conditional Based Monitoring For Gas Chromatographs



# Densitometer Density

- Density referred to upstream tapping

$$\rho_1 = \rho_A \frac{P_1 T_3 z(P_2, T_3)}{P_2 T_1 z(P_1, T_1)}$$

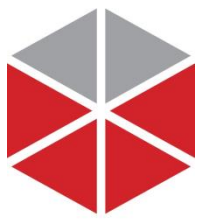
- Full functional relationship used for uncertainty calculation

$$\rho_1 = \{(K0 + K1\tau + K2\tau^2)[1 + k18(t - t_c)] + K19(t - t_c)\} \times \left[ \frac{1 + \left(\frac{K}{\tau c_c}\right)^2}{1 + \left(\frac{K}{\tau c_g}\right)^2} \right] \frac{P_1 T_3 z(P_2, T_3)}{(P_1 - \Delta P_o) (T_3 + \mu_{JT} \Delta P_o (1 - \beta^{1.9})) z(P_1, T_1)}$$



# Densitometer Uncertainty

Input	Nominal Value	Expanded Uncertainty	Divisor	Relative Standard Uncertainty	Relative Sensitivity	
Manufacturers Specification (0.15%)	37.930	0.057	2	0.075	1.0002	0.075
Repeatability (kg/m3)	0.01	0.026	2	0.013	1	0.013
Period (us)	587.27	0.1	2	0.009	7.9727	0.068
Measured Temperature (DegC)	35.00	0.5	2	0.714	-0.0014	-0.001
Densitometer Temperature (DegC)	35.00	0.5	2	0.714	-0.1726	-0.123
Upstream Pressure	40.00	0.1	2	0.125	-0.0142	-0.002
Differential Pressure	500	1.25	2	0.125	0.0137	0.002
Joule Thomson	0.377	0.004	2	0.500	-0.0007	0.000
Uncertainty in VOSm	359.56	0.899	2	0.125	0.0196	0.002
Uncertainty in VOSc	365.94	0.915	2	0.125	-0.0189	-0.002
Transducer K - VOS	2.10E+04	52.5	2	0.125	-0.0007	0.000
Compressibility (T1, P1)	0.880	0.001	2	0.050	-1.0000	-0.050
Relative standard uncertainty						0.1677
Coverage Factor						2
Expanded Uncertainty %						0.3354
Expanded Uncertainty (kg/m3)						0.1272



# Calculated Density

- Density calculated from composition
  - AGA Report No. 8
  - Line density calculated from process measurement instruments
- Composition by Gas Chromatography
  - Utilises gas component thermal conductivity
  - Relationship between conductivity and molecular weight
  - Response compared to known composition

$$\text{Response Factor} = \frac{\text{Peak Area}}{\text{WRM Mole\%}}$$



# Calculated Density

- Assume
  - Suitable sampling and conditioning adds no additional error
  - Analysis cycle time and lag time are negligible
- Main Sources of uncertainty
  - Repeatability of the GC
  - Linearity of the GC
  - Quality of the working reference mixture
  - Reproducibility of the GC
  - Calculation Method





# Calculated Density

- Component based uncertainty
  - Uncertainty analysis of field GC data
- Field data uncertainty analysis
  - Uncertainty of the WRM ( $U_{\text{wrm}}$ )
  - Uncertainty from GC repeatability data ( $U_{\text{repeatability}}$ )
  - Uncertainty from GC reproducibility data ( $U_{\text{reproducibility}}$ )

$$U_{x(i)} = \sqrt{U_{x(i),\text{wrm}}^2 + U_{x(i),\text{repeatability}}^2 + U_{x(i),\text{reproducibility}}^2}$$

$x(i)$  = component  $i$  within WRM



# Calculated Density Uncertainty

Input	Nominal Value	Expanded Uncertainty	Divisor	Relative Standard Uncertainty	Relative Sensitivity	
Methane	75.4034	0.0823	2	0.04117	-0.2611	-0.0107
Nitrogen	0.4987	2.1067	2	1.05336	0.0004	0.0004
CO2	1.7792	0.7185	2	0.35926	0.0188	0.0067
Ethane	12.2682	0.7295	2	0.36474	0.0676	0.0246
Propane	6.9195	0.5477	2	0.27384	0.0488	0.0134
i-Butane	0.8902	1.1180	2	0.55898	0.0200	0.0112
n-Butane	1.6175	0.8125	2	0.40626	0.0364	0.0148
neo-Pentane	0.1023	3.5620	2	1.78100	0.0032	0.0056
i-Pentane	0.2253	1.4805	2	0.74025	0.0069	0.0051
n-Pentane	0.1968	1.8003	2	0.90013	0.0061	0.0055
Hexane	0.0988	2.9953	2	1.49765	0.0041	0.0061
Pressure	40.0000	0.2500	2	0.12500	1.1368	0.1421
Temperature	35.0000	1.4286	2	0.71429	-0.1735	-0.1239
AGA 8	N/A	0.1000	2	0.05000	1.0000	0.0500
Relative standard uncertainty						0.1987
Coverage Factor						2.0000
Expanded Uncertainty %						0.3973
Expanded Uncertainty (kg/m3)						0.1507



# Measured Density Only?

- *Accurate determination of the Pressure and temperature at the densitometer is required*
  - *"In DECC's experience, failure to take account of this factor in the design of densitometer installations is one of the principal causes of significant mismeasurement in North Sea applications" DECC Guidance notes for Petroleum Measurement Issue 8*
- *Compositional analysis required in allocation and accounting*
  - Gas pipeline allocation is normally performed on a component mass basis
  - The value of natural gas at the point of sale is a function of its calorific value



# Calculated Density Only?

- No cross check available
  - Requires an increased degree of scrutiny on critical elements of the sampling and analysis systems
  - VOS potentially a verification tool
- Common density used in all streams
  - Correlated uncertainties
- Calculated uncertainty is dependent upon of secondary instrumentation
  - Pressure, Temperature



# Summary

- Uncertainty in density from instrument measurement is estimated at  $\pm 0.3354\%$  from theoretical analysis
- Uncertainty in density from compositional analysis is estimated at  $\pm 0.3973\%$  from field data analysis
- A combination of both methods offers potential cross-correlation verification
- Correct installation and operation are critical to the accuracy in each instance



# Uncertainty in Gas Density Measured and Calculated

Thank-you for your time

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