The Nett Oil Conundrum

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How is Dry Oil Quantity Calculated?

In The Calculation Routines I have Seen
Dry Oil Has Been Calculated as Follows:-

- From Measured Gross Observed Volume
- Corrected To Standard Volume By C_{tl} & C_{pl}
- Water Volume Calculated from Water Cut
- Dry Oil Volume Calculated by Difference
- Dry Oil Mass Calculated from Base Density

How is Dry Oil Quantity Calculated?

Put into Mathematical Terms:-

Actual Volume:- Q_{gov} (As measured by Flow Meter)

$\downarrow$

Standard Volume:- $Q_{sv} = Q_{gov} \times C_{tl} \times C_{pl}$

$\downarrow$

Water Volume: $Q_{svw} = Q_{sv} \times wc$ (Water Cut as a Fraction Not Percentage)

$\downarrow$

Dry Oil Volume: $Q_{svo} = Q_{sv} - Q_{svw}$

$\downarrow$

Dry Oil Mass: $Q_{mo} = Q_{svo} \times \rho_{ob}$ (Oil Base Density)

BUT IS THIS ACCURATE?

Should Dry Oil Mass
be Calculated Directly from
Total (Wet) Mass?

So Let Us Look at
The Mathematics & Uncertainties

Determination of Water Cut

There are Two Main Ways to Determine

The Proportion of Water in Oil

Laboratory Analysis

To Give % Volume / Volume at Reference Conditions

By Density Ratio

Water Volume Fraction In Terms of Density

Volumetric Fraction: $\xi_{wat} = \frac{(\rho_{mix} - \rho_{oil})}{(\rho_{wat} - \rho_{oil})}$

m^3 / m^3

Where:

ρ_{oil}	Is the Density of oil in the mixture	(kg/m^3)
ρ_{wat}	Is the Density of water in the mixture	(kg/m^3)
ρ_{mix}	Is the Density of the mixture	(kg/m^3)

This Equation **IS** published in a Standard

BUT: There are Other Relationships For Those Three Densities

Volumetric Oil Fraction: $$\xi_{oil} = \frac{\left(\rho_{wat} - \rho_{mix}\right)}{\left(\rho_{wat} - \rho_{oil}\right)}$$

m^3 / m^3

Where:

ρ_{oil} Is the Density of oil in the mixture (kg/m^3)

ρ_{wat} Is the Density of water in the mixture (kg/m^3

ρ_{mix} Is the Density of the mixture (kg/m^3)

For MASS Fractions of Oil

Mass Fraction Dry Oil: $$\zeta_{oil} = \frac{\rho_{oil}}{\rho_{mix}} \times \frac{(\rho_{wat} - \rho_{mix})}{(\rho_{wat} - \rho_{oil})}$$

kg / kg

Where:

ρ_{oil}	Is the Density of oil in the mixture	(kg/m^3)
ρ_{wat}	Is the Density of water in the mixture	(kg/m^3)
ρ_{mix}	Is the Density of the mixture	(kg/m^3)

The Dry Oil MASS Fraction Can Also be Described as:

Mass Fraction Dry Oil: $\zeta_{oil} = \dfrac{\rho_{oil}}{\rho_{mix}} \times \xi_{oil}$

kg / kg

Where:

ρ_{oil} Is the Density of oil in the mixture (kg/m^3)

ξ_{oil} Is the Volumetric Fraction of Oil (m^3 / m^3)

ρ_{mix} Is the Density of the mixture (kg/m^3)

The Dry Oil MASS Fraction
Or Alternatively as:

Mass Fraction Dry Oil: $\zeta_{oil} = \dfrac{\rho_{oil}}{\rho_{mix}} \times (1-\xi_{wat})$

kg / kg

Where:

ρ_{oil}	Is the Density of oil in the mixture	(kg/m^3)
ξ_{wat}	Is the Volumetric Fraction of Water	(m^3 / m^3)
ρ_{mix}	Is the Density of the mixture	(kg/m^3)

For MASS Fractions of Water

Mass Fraction Water: $\xi_{wat} = \frac{\rho_{wat}}{\rho_{mix}} \times \frac{(\rho_{mix} - \rho_{oil})}{(\rho_{wat} - \rho_{oil})}$

kg / kg

Where:

ρ_{oil}	Is the Density of oil in the mixture	(kg/m^3)
ρ_{wat}	Is the Density of water in the mixture	(kg/m^3)
ρ_{mix}	Is the Density of the mixture	(kg/m^3)

The Water MASS Fraction Can Also be Described as:

Mass Fraction Water: $\zeta_{wat} = \dfrac{\rho_{wat}}{\rho_{mix}} \times \xi_{wat}$

kg / kg

Where:

ρ_{wat} Is the Density of Water in the mixture (kg/m^3)

ξ_{wat} Is the Volumetric Fraction of Water (m^3 / m^3)

ρ_{mix} Is the Density of the mixture (kg/m^3)

What is The Source of These Equations?

BASIC PHYSICS

BUT

Dry Oil Density & Water Density

Will Have Been Determined by Laboratory Analysis

At **REFERENCE** Conditions

The Mixture Density

Will Normally be Measured by a Densitometer

At **OPERATING** Conditions

Volume Correction Factors

Yes I Know that API Chapter 11.1 2004 Combines C_{tl} & C_{pl}

But for this Exercise it is Best to Keep them as Separated Terms

The Volume Correction Factors for

Oil & Water are Different

Oil Volume Correction Factors >> C_{tl} & C_{pl}

Water Volume Correction Factors >> C_{tw} & C_{pw}

Volume Correction Factors

When We are Dealing With Oil Water Mixtures

It may be Inappropriate to Correct from

Operating to Base (Reference) Conditions

Using Ctl & Cpl

The Issue is Accentuated as the Water Cut Increases

The Mass Fraction Equation Should be Amended to: (To Accommodate Base & Operating Conditions)

Mass Fraction Dry Oil: $$\zeta_{oil} = \frac{\left(\rho_{oil.b} \times C_{tl} \times C_{pl}\right)}{\rho_{mix.f}} \times \frac{\left(\left(\rho_{wat.b} \times C_{tw} \times C_{pw}\right) - \rho_{mix.f}\right)}{\left(\left(\rho_{wat.b} \times C_{tw} \times C_{pw}\right) - \left(\rho_{oil.b} \times C_{tl} \times C_{pl}\right)\right)}$$

kg / kg

Where:

.f Represents Operating (Flowing) Conditions

.b Represents Base (Reference) Conditions

We Need to Correct to Operating Conditions

The Mass Fraction Equation Could be Amended to:

Mass Fraction Dry Oil: $$\zeta_{oil} = \frac{\left(\rho_{oil.b} \times C_{tl} \times C_{pl}\right)}{\rho_{mix.f}} \times \left(1-\xi_{wat.f}\right)$$

kg / kg

We Need to Correct Water Cut to Operating Conditions

$$\xi_{wat.b} = \frac{V_{wat.b}}{V_{oil.b} + V_{wat.b}}$$

$$\xi_{wat.f} = \frac{\dfrac{V_{wat.b}}{C_{tw} \times C_{pw}}}{\dfrac{V_{oil.b}}{C_{tl} \times C_{pl}} + \dfrac{V_{wat.b}}{C_{tw} \times C_{pw}}}$$

The Mass Fraction Equation Could be Amended to:

Mass Fraction Dry Oil: $$\zeta_{oil} = \frac{\left(\rho_{oil.b} \times C_{tl} \times C_{pl}\right)}{\rho_{mix.f}} \times \left(1-\xi_{wat.f}\right)$$

kg / kg

We Need to Correct Water Cut to Operating Conditions

Mathematically this Can Also be Expressed in Terms of Water Cut as:-

At Base Conditions

$$\xi_{wat.b} = \frac{\xi_{wat.b}}{\left(1-\xi\right)_{oil.b} + \xi_{wat.b}}$$

At Operating Conditions

$$\xi_{wat.f} = \frac{\dfrac{\xi_{wat.b}}{C_{tw} \times C_{pw}}}{\dfrac{\left(1-\xi\right)_{oil.b}}{C_{tl} \times C_{pl}} + \dfrac{\xi_{wat.b}}{C_{tw} \times C_{pw}}}$$

Dry Oil Mass Direct from Total Mass

By Using the **Dry Oil Mass Fraction**

We Can Calculate the

Dry Oil Mass Directly from the **Measured Total Mass**

$$Q_{m.o} = Q_m \times \zeta_{oil}$$

Where:

$$Q_m = Q_{gov} \times \rho_f$$

As Measured by the Flow Meter & Densitometer

Now Let Us Look at Uncertainties

The Following Calculations were Based Upon

Pressure	10 Bar	
Temperature	30 °C	
Dry Oil Density	850 kg/m^3	± 0.1 %
Produced Water Density	1020 kg/m^3	± 0.02 %
Measured Density (Densitometer)	Calculated	± 0.0338 %
Water Cut	Defined Variable	± 0.5 %

(Values Based Upon Legacy Information)

First:
Uncertainty in Standard Volume

Assuming that the Conventional Approach to Calculating the Standard Volume is Taken

Using the Normal Oil Calculation

$$\text{Standard Volume:-} \quad Q_{sv} = Q_{gov} \times C_{tl} \times C_{pl}$$

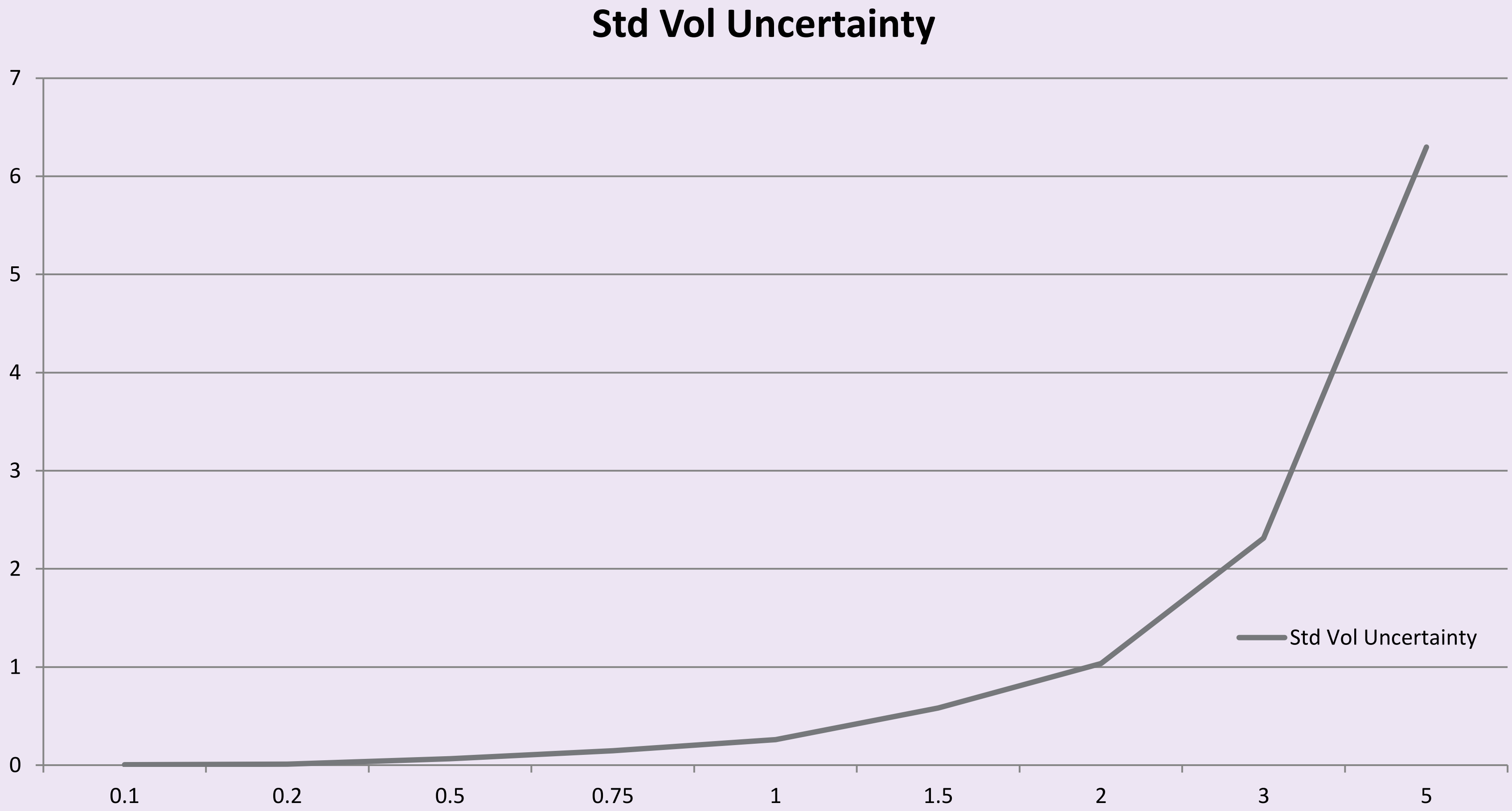
As the Water Cut Increases this will Bias the Result

Theoretically it should be Calculated as:

$$\text{Standard Volume:-} \quad Q_{sv} = Q_{gov.o} \times C_{tl} \times C_{pl} + Q_{gov.w} \times C_{tw} \times C_{pw}$$

But this would be impractical

Uncertainty in Standard Volume Due to Increasing Water Cut



Uncertainty in Dry Oil Mass Using Volumetric Method

Remember the Calculation Sequence

Actual Volume:- Q_{gov} (As measured by Flow Meter)

$\downarrow$

Standard Volume:- $Q_{sv} = Q_{gov} \times C_{tl} \times C_{pl}$

$\downarrow$

Water Volume: $Q_{svw} = Q_{sv} \times wc$ (Water Cut as a Fraction Not Percentage)

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Dry Oil Volume: $Q_{svo} = Q_{sv} - Q_{svw}$

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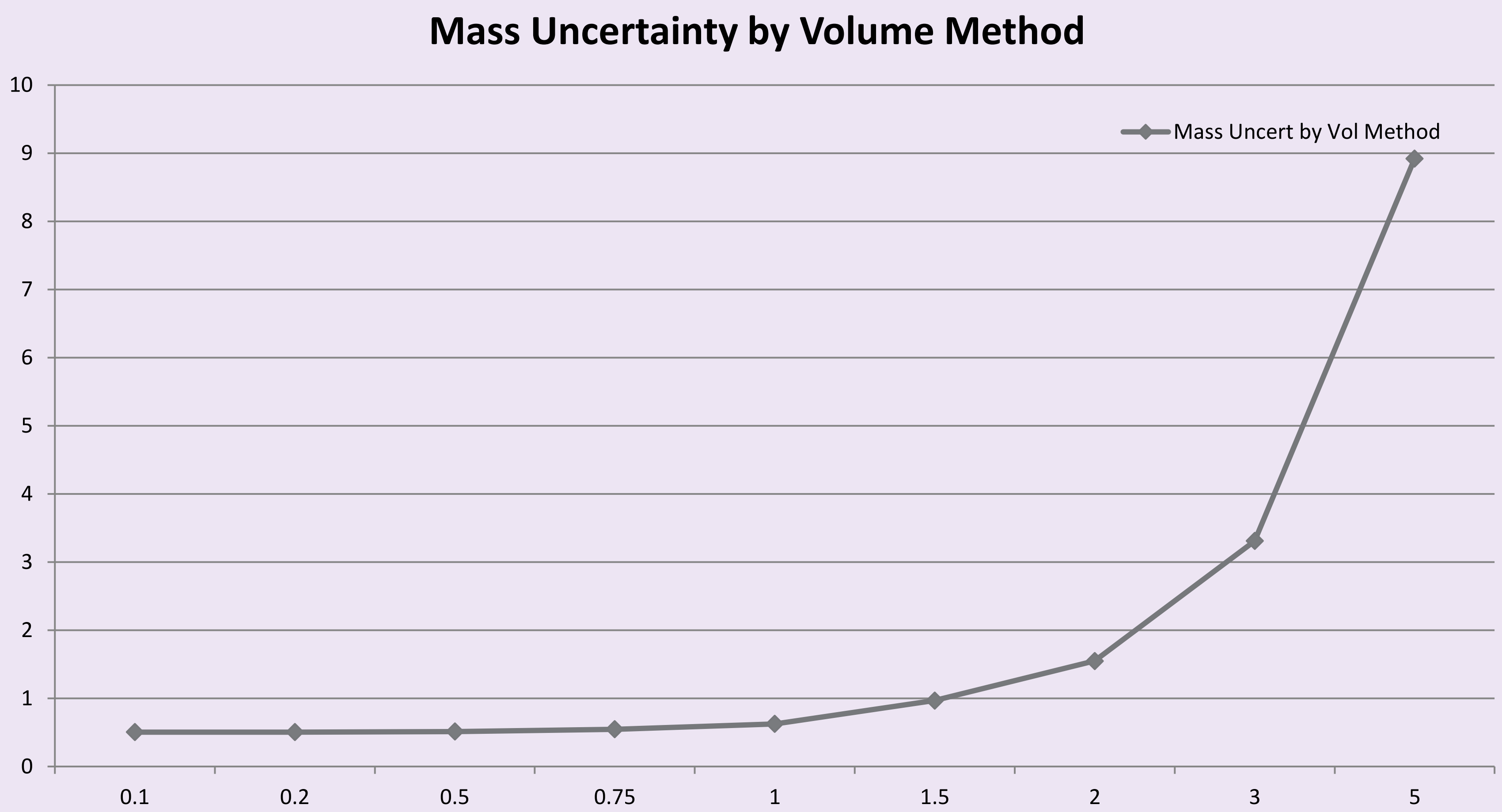
Dry Oil Mass: $Q_{mo} = Q_{svo} \times \rho_{ob}$ (Oil Base Density)

Uncertainty in Dry Oil Mass By Volumetric Method



Uncertainty in Dry Oil Mass Using Density Ratios

Dry Oil Mass can be Calculated

Directly from the Measured Mass

Using the Density Ratios

Either

Mass Fraction Dry Oil: $\zeta_{\text{oil}} = \frac{\rho_{\text{oil}}}{\rho_{mix}} \times \frac{(\rho_{\text{wat}} - \rho_{\text{mix}})}{(\rho_{wat} - \rho_{\text{oil}})}$

Or

Mass Fraction Dry Oil: $\zeta_{\text{oil}} = \frac{\rho_{\text{oil}}}{\rho_{mix}} \times (1-\xi_{wat})$

Uncertainty in Dry Oil Mass Using Density Ratios

But these Equations must be

Corrected to Operating Conditions

So

Mass Fraction Dry Oil: $$\zeta_{oil} = \frac{\rho_{oil}}{\rho_{mix}} \times \frac{(\rho_{wat} - \rho_{mix})}{(\rho_{wat} - \rho_{oil})}$$

Becomes

Mass Fraction Dry Oil: $$\zeta_{oil} = \frac{(\rho_{oil.b} \times C_{tl} \times C_{pl})}{\rho_{mix.f}} \times \frac{((\rho_{wat.b} \times C_{tw} \times C_{pw}) - \rho_{mix.f})}{((\rho_{wat.b} \times C_{tw} \times C_{pw}) - (\rho_{oil.b} \times C_{tl} \times C_{pl}))}$$

Uncertainty in Dry Oil Mass Using Density Ratio Plus Water Cut

But these Equations must be

Corrected to Operating Conditions

So

Mass Fraction Dry Oil: $\zeta_{oil} = \frac{\rho_{oil}}{\rho_{mix}} \times (1-\xi_{wat})$

Becomes

Mass Fraction Dry Oil: $\zeta_{oil} = \frac{\left(\rho_{oil.b} \times C_{tl} \times C_{pl}\right)}{\rho_{mix.f}} \times \left(1- \frac{\frac{\xi_{wat.b}}{C_{tw} \times C_{pw}}}{\frac{(1-\xi)_{oil.b}}{C_{tl} \times C_{pl}} + \frac{\xi_{wat.b}}{C_{tw} \times C_{pw}}} \right)$

Uncertainty in Dry Oil Mass

Using either of These Equations

The Dry Oil Mass

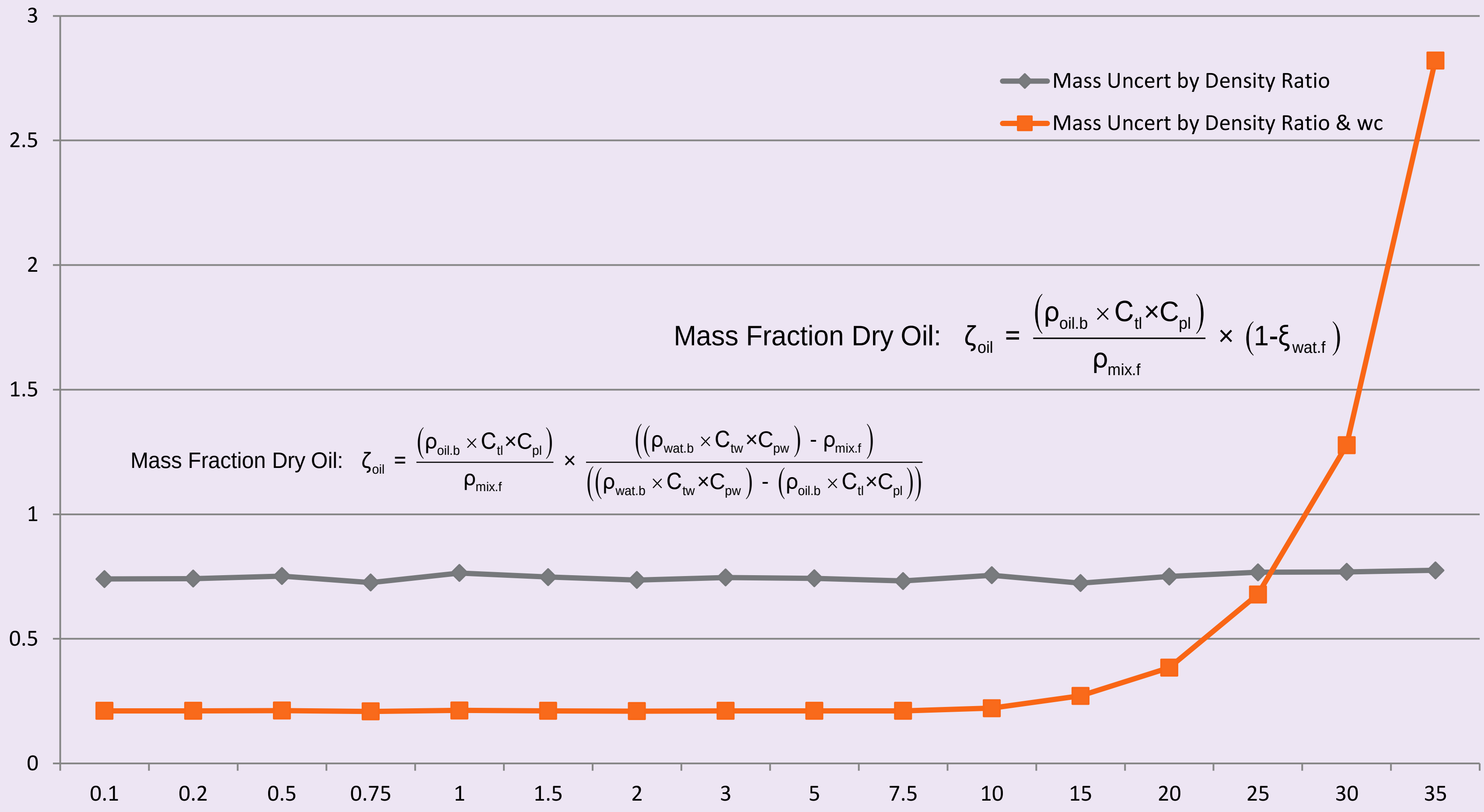
Can be Calculated Directly From the Measured Mass

$$Q_{m.o} = Q_m \times \zeta_{oil}$$

The Following Graph Illustrates the Uncertainty

Up to 35 % V/V Water Cut

Uncertainty in Dry Oil Mass By Density Ratio Methods



Uncertainty in Dry Oil Mass
Comparison of Methods

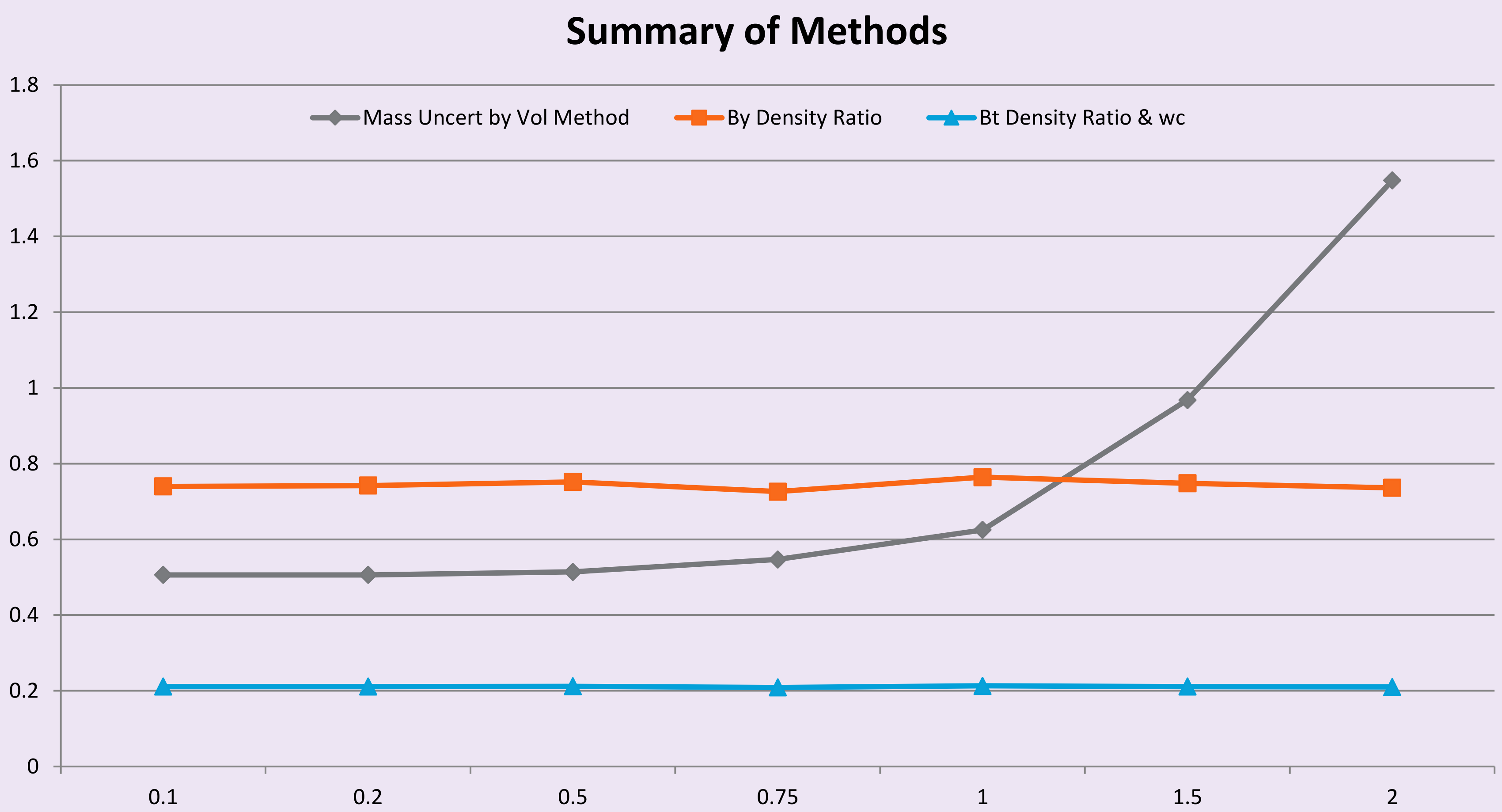
The Following Graph Illustrates the Difference in

The Uncertainty in Dry Oil Mass

As Calculated by the Three Different Methods

X- Axis is 0 to 2.0 % V/V Water Cut

Uncertainty of All Three Methods Compared Due to Increasing Water Cut



Uncertainty in Dry Oil Mass Due to Increasing Water Cut Transcript of Result Table

Water Cut	Mass Uncertainty by Volume Method	Mass Uncertainty by Density Ratio	Mass Uncertainty by Density Ratio & wc	Standard Volume Uncertainty by Ctl / Cpl only
% V/V	%	%	%	%
0.1	0.506	0.74	0.211	0.003
0.2	0.506	0.742	0.211	0.01
0.5	0.514	0.752	0.212	0.065
0.75	0.547	0.726	0.209	0.146
1	0.625	0.764	0.213	0.26
1.5	0.968	0.748	0.211	0.583
2	1.548	0.736	0.21	1.034
3	3.309	0.746	0.211	2.312
5	8.921	0.743	0.211	6.298
7.5	19.354	0.732	0.211	13.68
10	32.921	0.755	0.222	23.275
15	66.874	0.724	0.271	47.285
20	106.723	0.75	0.384	75.463
25	150.06	0.767	0.678	106.107
30	195.541	0.769	1.277	138.268
35	242.406	0.775	2.821	171.406

Summary

The Results Presented Above

Were Based upon a Single Set of

Operating Conditions

And

Uncertainties

Variation in those Conditions will Alter

The Resultant Uncertainties

To Conclude

To Conclude

I Shall Leave it Up to the Industry !!

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