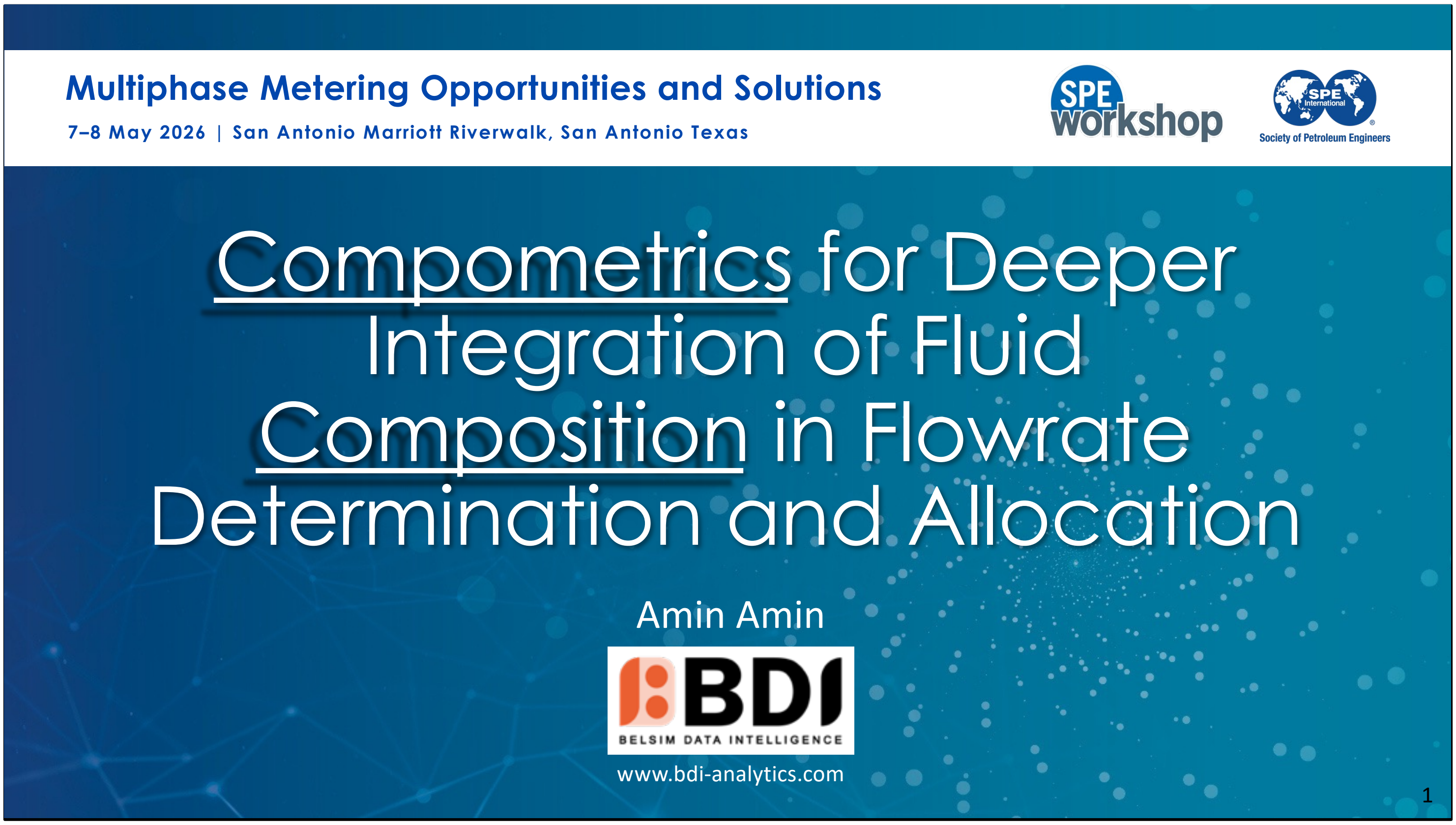


Multiphase Metering Opportunities and Solutions

7–8 May 2026 | San Antonio Marriott Riverwalk, San Antonio Texas

Compometrics for Deeper Integration of Fluid Composition in Flowrate Determination and Allocation

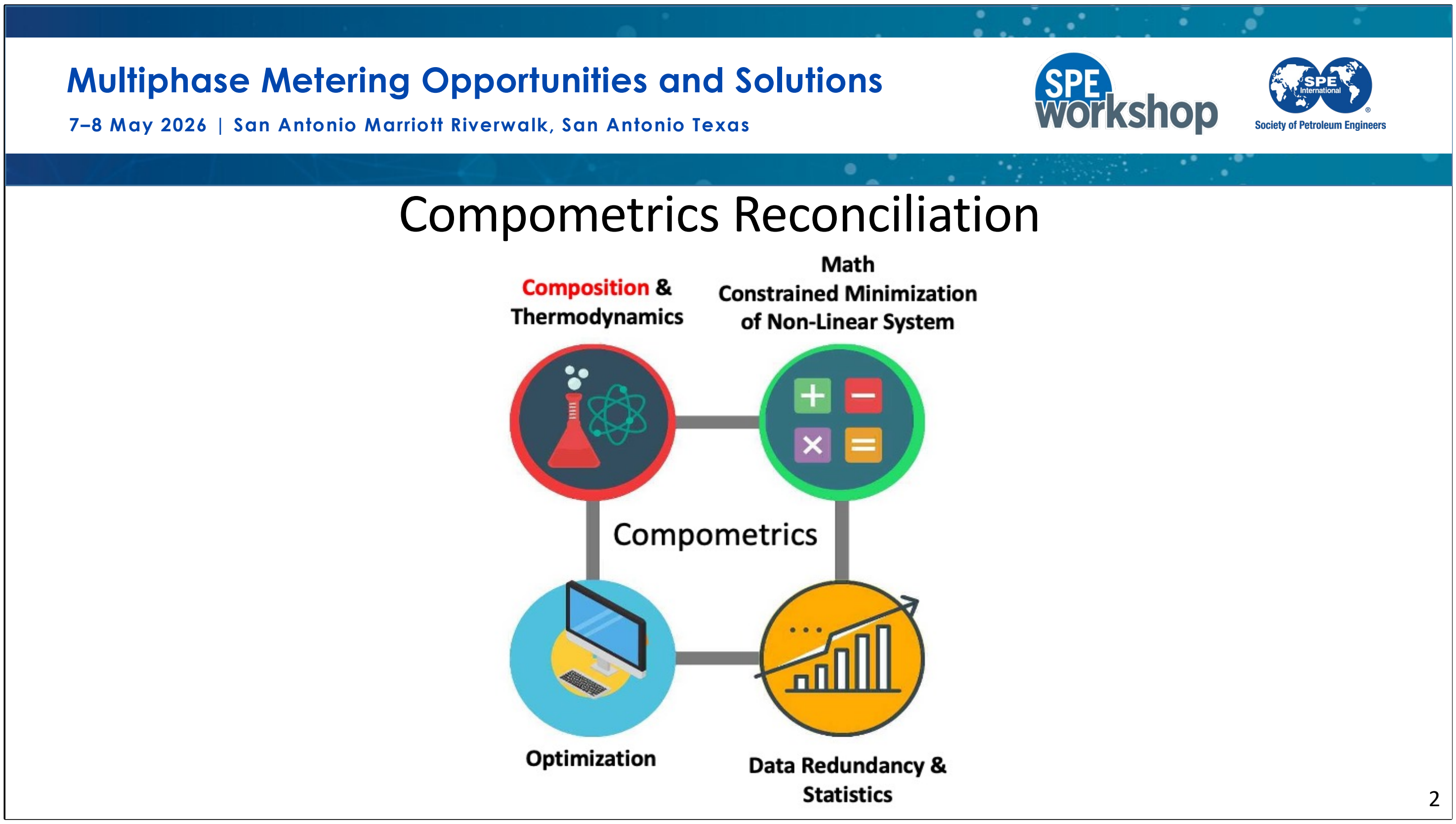
Amin Amin

www.bdi-analytics.com

This presentation introduces ***Compometrics***, a process modeling technique that integrates fluid composition, thermodynamics, data redundancy, measurement uncertainty, and constrained nonlinear minimization to improve flowrate determination and allocation. Positioned as a sub-model of **Data Validation and Reconciliation**, Compometrics uses compositional information rather than aggregate fluid properties such as shrinkage or flash factors to reconcile measured and calculated values across multiphase systems.

The approach is validated using wet-gas flowloop test data, demonstrating that, first, inlet gas and liquid compositions, flowrates, and uncertainties can be propagated to reproduce reference wet-gas compositions and heating values, and, inversely, back-calculated the flowrates from the inlet and outlet compositions alone. It then extends the method to practical applications, including wet-gas liquid loading determination from reservoir fluid density, production and network allocation, subsurface zonal allocation, and multiphase flowmeter fluid model validation.

Across these use cases, the approach is presented as a cost-effective “soft” solution that adds independent redundancy to conventional flow measurement, reduces reliance on frequent well testing or laboratory recombination, and improves confidence in allocation and metering results through uncertainty-aware reconciliation.



Multiphase Metering Opportunities and Solutions

7–8 May 2026 | San Antonio Marriott Riverwalk, San Antonio Texas

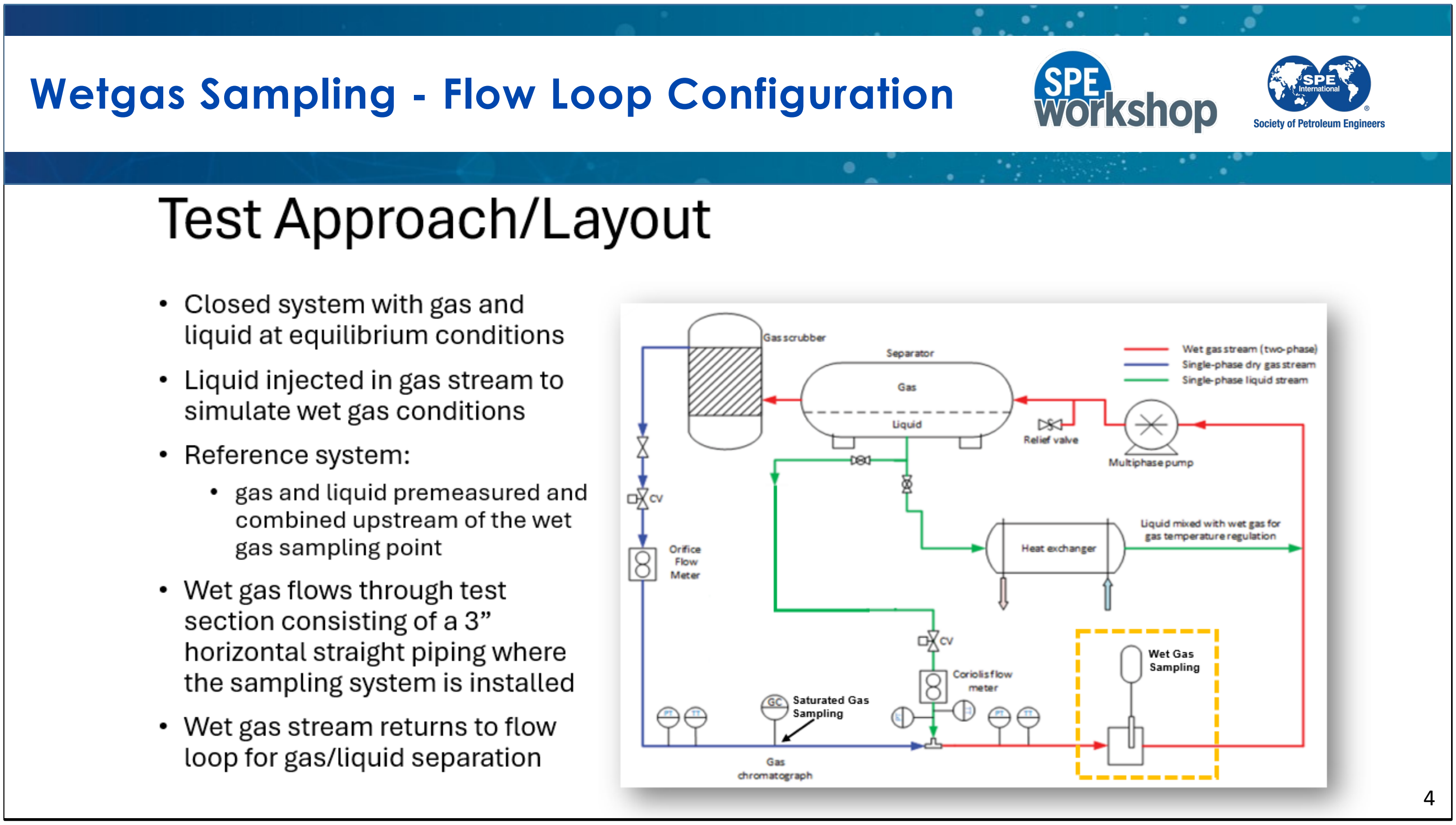
Compometrics Reconciliation

Compometrics is a process modeling technique that uses data redundancy and statistics (uncertainty) and constrained minimization of non-linear systems to fully integrate fluid composition and thermodynamics in process optimization

Uses the fluid source information, i.e., composition, rather than aggregate fluid parameters such as Shrinkage, Flash…

It is a sub-model of Data Validation and Reconciliation (DVR)

- Outline
    - Validation – Flowloop Test Data
    - Compositional Reconciliation
    - Wetgas Liquid Loading from Fluid Density
    - Zonal and Production Allocation
    - MPFM Fluid Model Optimization

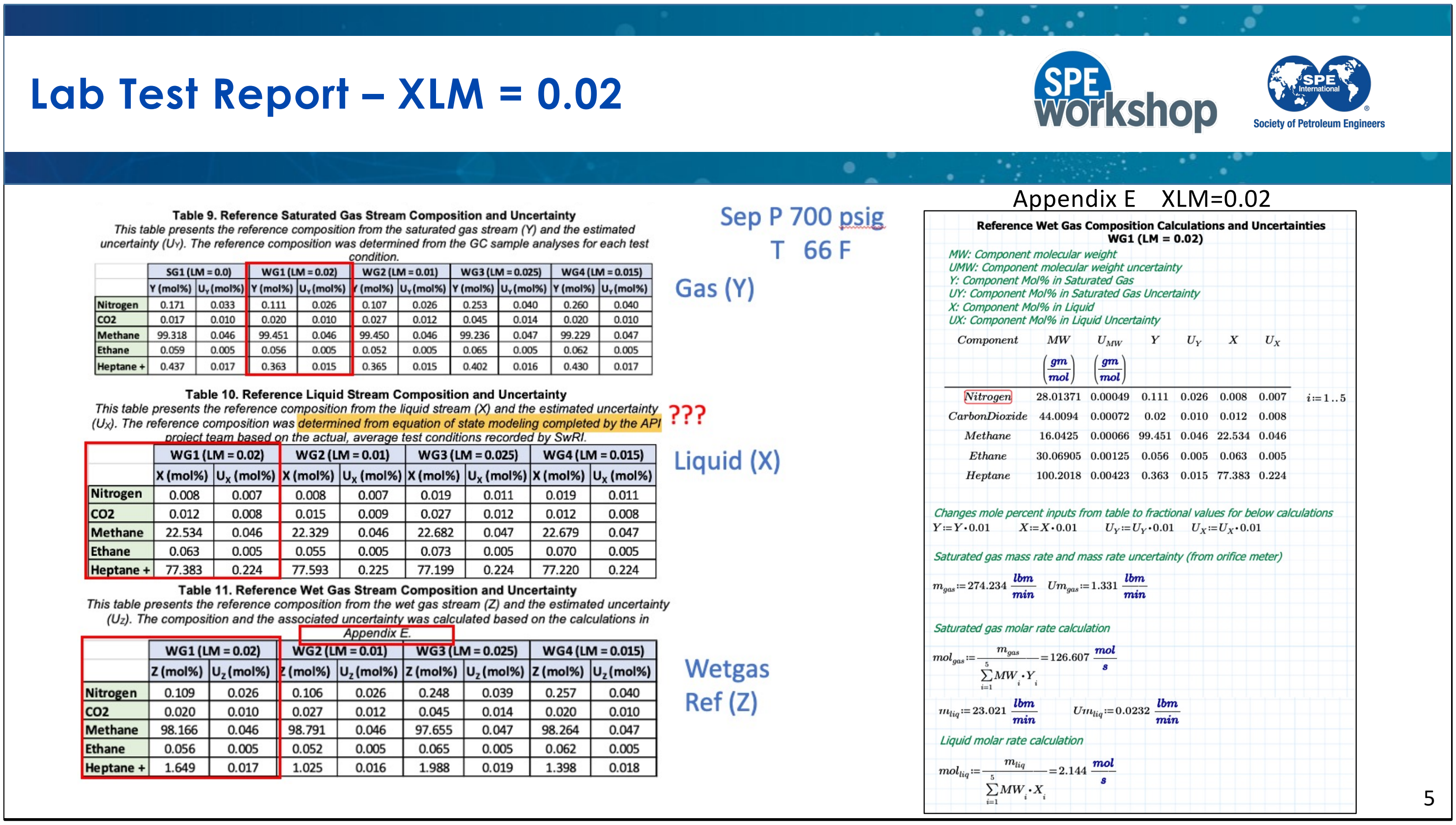


Wetgas Sampling - Flow Loop Configuration

Test Approach/Layout

- Closed system with gas and liquid at equilibrium conditions
- Liquid injected in gas stream to simulate wet gas conditions
- Reference system:
  - gas and liquid premeasured and combined upstream of the wet gas sampling point
- Wet gas flows through test section consisting of a 3” horizontal straight piping where the sampling system is installed
- Wet gas stream returns to flow loop for gas/liquid separation

The API Wetgas Sampling Flowloop Experiment at SWRI shows the wetgas mixing point with inlets from the saturated gas and liquid lines. A binary composition of Methane and Heptane is used. The flowloop pressure and temperature are first established by circulating gas, then liquid is introduced at the mixing point until the desired Lockhart-Martinelli number (XLM) is reached. Both the saturated gas and liquid flow rates are measured, along with their composition. This establishes the Ref theoretical mixture composition (Z). The composition uncertainty is evaluated by the lab using the inlet Ref gas and Ref liquid composition uncertainties and the uncertainties of the orifice and Coriolis flowmeters. Samples are then taken from the wetgas mixed stream for the different XLM mixes to compare their composition with the Ref theoretical mixture composition.



Lab Test Report – XLM = 0.02

Table 9. Reference Saturated Gas Stream Composition and Uncertainty

This table presents the reference composition from the saturated gas stream (Y) and the estimated uncertainty (UY). The reference composition was determined from the GC sample analyses for each test condition.

	SG1 (LM = 0.0)		WG1 (LM = 0.02)		WG2 (LM = 0.01)		WG3 (LM = 0.025)		WG4 (LM = 0.015)	
	Y (mol%)	U_Y (mol%)	Y (mol%)	U_Y (mol%)	Y (mol%)	U_Y (mol%)	Y (mol%)	U_Y (mol%)	Y (mol%)	U_Y (mol%)
Nitrogen	0.171	0.033	0.111	0.026	0.107	0.026	0.253	0.040	0.260	0.040
CO2	0.017	0.010	0.020	0.010	0.027	0.012	0.045	0.014	0.020	0.010
Methane	99.318	0.046	99.451	0.046	99.450	0.046	99.236	0.047	99.229	0.047
Ethane	0.059	0.005	0.056	0.005	0.052	0.005	0.065	0.005	0.062	0.005
Heptane +	0.437	0.017	0.363	0.015	0.365	0.015	0.402	0.016	0.430	0.017

Sep P 700 psig

T 66 F

Gas (Y)

Table 10. Reference Liquid Stream Composition and Uncertainty

This table presents the reference composition from the liquid stream (X) and the estimated uncertainty (UX). The reference composition was determined from equation of state modeling completed by the API project team based on the actual, average test conditions recorded by SwRI.

???

	WG1 (LM = 0.02)		WG2 (LM = 0.01)		WG3 (LM = 0.025)		WG4 (LM = 0.015)	
	X (mol%)	U_X (mol%)	X (mol%)	U_X (mol%)	X (mol%)	U_X (mol%)	X (mol%)	U_X (mol%)
Nitrogen	0.008	0.007	0.008	0.007	0.019	0.011	0.019	0.011
CO2	0.012	0.008	0.015	0.009	0.027	0.012	0.012	0.008
Methane	22.534	0.046	22.329	0.046	22.682	0.047	22.679	0.047
Ethane	0.063	0.005	0.055	0.005	0.073	0.005	0.070	0.005
Heptane +	77.383	0.224	77.593	0.225	77.199	0.224	77.220	0.224

Liquid (X)

Table 11. Reference Wet Gas Stream Composition and Uncertainty

This table presents the reference composition from the wet gas stream (Z) and the estimated uncertainty (UZ). The composition and the associated uncertainty was calculated based on the calculations in Appendix E.

	WG1 (LM = 0.02)		WG2 (LM = 0.01)		WG3 (LM = 0.025)		WG4 (LM = 0.015)	
	Z (mol%)	U_Z (mol%)	Z (mol%)	U_Z (mol%)	Z (mol%)	U_Z (mol%)	Z (mol%)	U_Z (mol%)
Nitrogen	0.109	0.026	0.106	0.026	0.248	0.039	0.257	0.040
CO2	0.020	0.010	0.027	0.012	0.045	0.014	0.020	0.010
Methane	98.166	0.046	98.791	0.046	97.655	0.047	98.264	0.047
Ethane	0.056	0.005	0.052	0.005	0.065	0.005	0.062	0.005
Heptane +	1.649	0.017	1.025	0.016	1.988	0.019	1.398	0.018

Wetgas Ref (Z)

Appendix E XLM=0.02

Reference Wet Gas Composition Calculations and Uncertainties
WG1 (LM = 0.02)

MW: Component molecular weight
UMW: Component molecular weight uncertainty
Y: Component Mol% in Saturated Gas
UY: Component Mol% in Saturated Gas Uncertainty
X: Component Mol% in Liquid
UX: Component Mol% in Liquid Uncertainty

Component	MW $\left(\frac{gm}{mol}\right)$	U_{MW} $\left(\frac{gm}{mol}\right)$	Y	U_Y	X	U_X
Nitrogen	28.01371	0.00049	0.111	0.026	0.008	0.007
CarbonDioxide	44.0094	0.00072	0.02	0.010	0.012	0.008
Methane	16.0425	0.00066	99.451	0.046	22.534	0.046
Ethane	30.06905	0.00125	0.056	0.005	0.063	0.005
Heptane	100.2018	0.00423	0.363	0.015	77.383	0.224

$i := 1..5$

Changes mole percent inputs from table to fractional values for below calculations

$Y := Y \cdot 0.01 \quad X := X \cdot 0.01 \quad U_Y := U_Y \cdot 0.01 \quad U_X := U_X \cdot 0.01$

Saturated gas mass rate and mass rate uncertainty (from orifice meter)

$m_{gas} := 274.234 \frac{lbm}{min} \quad Um_{gas} := 1.331 \frac{lbm}{min}$

Saturated gas molar rate calculation

$$mol_{gas} := \frac{m_{gas}}{\sum_{i=1}^{5} MW_i \cdot Y_i} = 126.607 \frac{mol}{s}$$

$m_{liq} := 23.021 \frac{lbm}{min} \quad Um_{liq} := 0.0232 \frac{lbm}{min}$

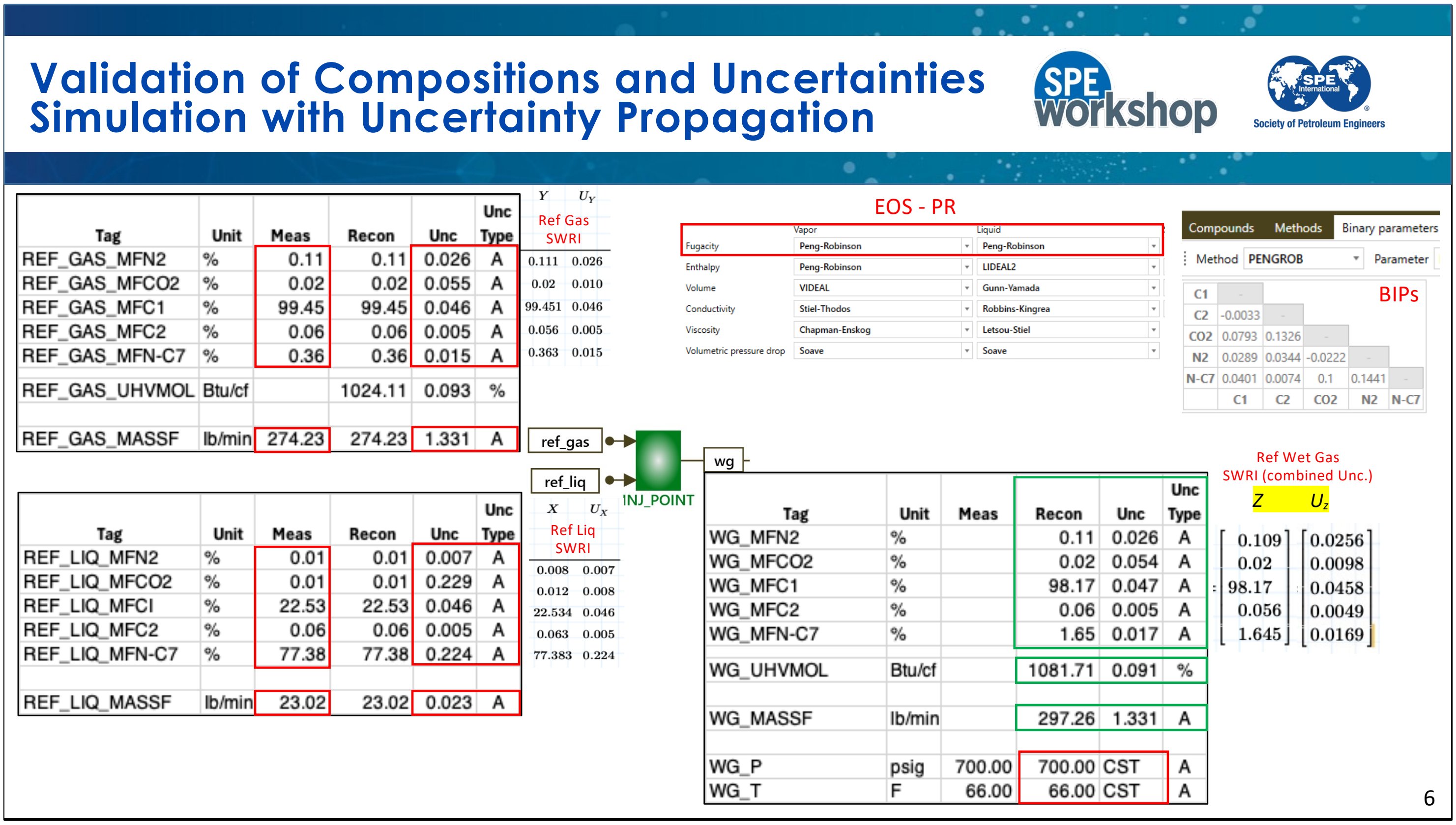
Liquid molar rate calculation

$$mol_{liq} := \frac{m_{liq}}{\sum_{i=1}^{5} MW_i \cdot X_i} = 2.144 \frac{mol}{s}$$

Lab sample composition measurement and uncertainty tables for XLM 0.01, 0.015, 0.02, 0.025, for the Ref Saturated Gas, the Ref Liquid, and the Ref Theoretical Wetgas streams

Case of XLM 0.02 was selected for the study

These are extracts from the Flowloop Experiment results, including the uncertainty calculations performed in Appendix E



Validation of Compositions and Uncertainties Simulation with Uncertainty Propagation

Tag	Unit	Meas	Recon	Unc	Unc Type
REF_GAS_MFN2	%	0.11	0.11	0.026	A
REF_GAS_MFCO2	%	0.02	0.02	0.055	A
REF_GAS_MFC1	%	99.45	99.45	0.046	A
REF_GAS_MFC2	%	0.06	0.06	0.005	A
REF_GAS_MFN-C7	%	0.36	0.36	0.015	A
REF_GAS_UHVMOL	Btu/cf		1024.11	0.093	%
REF_GAS_MASSF	lb/min	274.23	274.23	1.331	A

Ref Gas SWRI

Y	U_Y
0.111	0.026
0.02	0.010
99.451	0.046
0.056	0.005
0.363	0.015

EOS - PR

	Vapor	Liquid
Fugacity	Peng-Robinson	Peng-Robinson
Enthalpy	Peng-Robinson	LIDEAL2
Volume	VIDEAL	Gunn-Yamada
Conductivity	Stiel-Thodos	Robbins-Kingrea
Viscosity	Chapman-Enskog	Letsou-Stiel
Volumetric pressure drop	Soave	Soave

Method PENGROB Parameter

BIPs

C1	-				
C2	-0.0033	-			
CO2	0.0793	0.1326	-		
N2	0.0289	0.0344	-0.0222	-	
N-C7	0.0401	0.0074	0.1	0.1441	-
	C1	C2	CO2	N2	N-C7

Tag	Unit	Meas	Recon	Unc	Unc Type
REF_LIQ_MFN2	%	0.01	0.01	0.007	A
REF_LIQ_MFCO2	%	0.01	0.01	0.229	A
REF_LIQ_MFCI	%	22.53	22.53	0.046	A
REF_LIQ_MFC2	%	0.06	0.06	0.005	A
REF_LIQ_MFN-C7	%	77.38	77.38	0.224	A
REF_LIQ_MASSF	lb/min	23.02	23.02	0.023	A

Ref Liq SWRI

X	U_X
0.008	0.007
0.012	0.008
22.534	0.046
0.063	0.005
77.383	0.224

Tag	Unit	Meas	Recon	Unc	Unc Type
WG_MFN2	%		0.11	0.026	A
WG_MFCO2	%		0.02	0.054	A
WG_MFC1	%		98.17	0.047	A
WG_MFC2	%		0.06	0.005	A
WG_MFN-C7	%		1.65	0.017	A
WG_UHVMOL	Btu/cf		1081.71	0.091	%
WG_MASSF	lb/min		297.26	1.331	A
WG_P	psig	700.00	700.00	CST	A
WG_T	F	66.00	66.00	CST	A

Ref Wet Gas SWRI (combined Unc.)

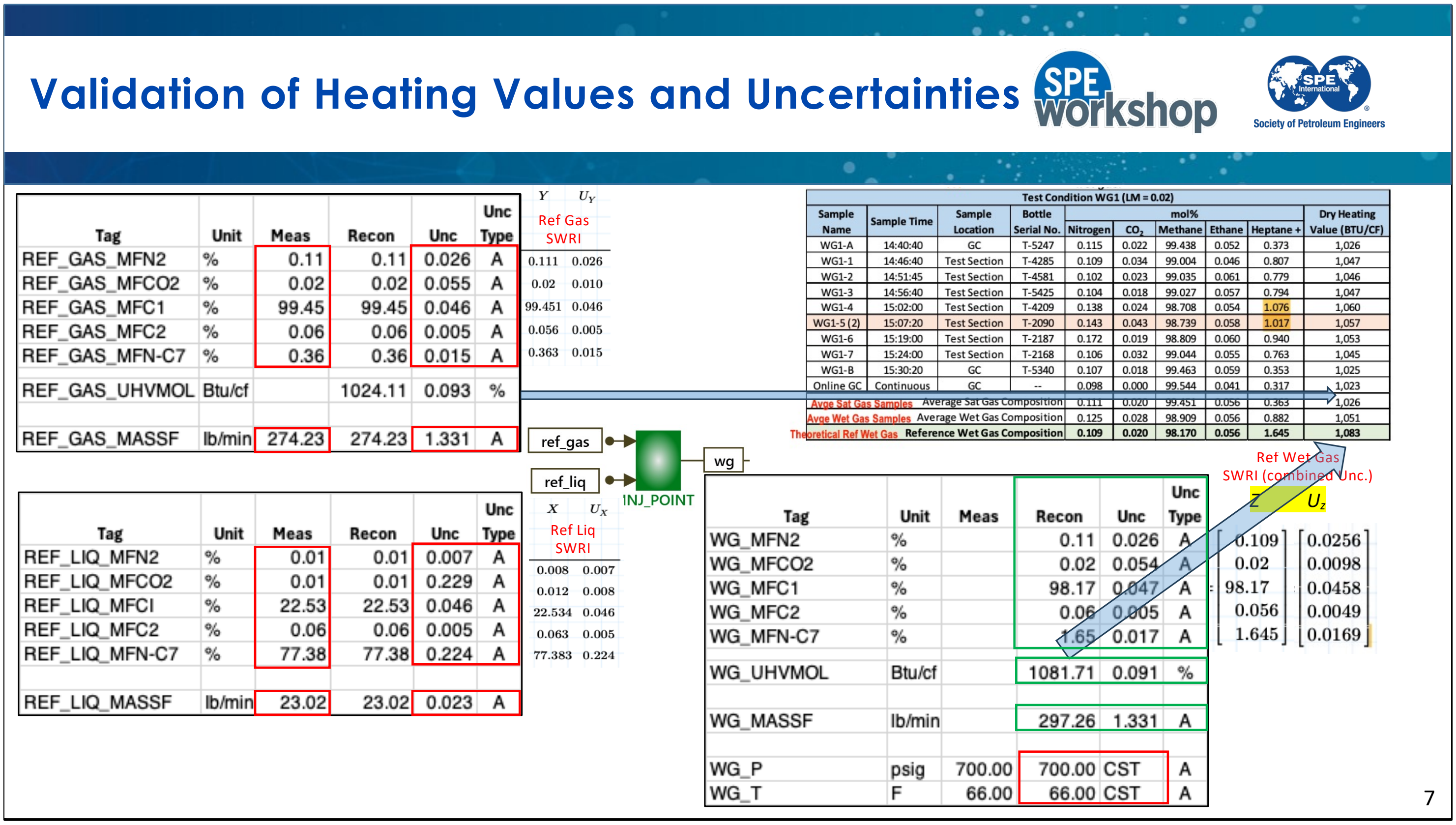
Z	U_z
0.109	0.0256
0.02	0.0098
98.17	0.0458
0.056	0.0049
1.645	0.0169

>> Explain the SIMULATION inlet and outlet streams and tags, measured and calculated, uncertainty type:
The Compometrics model depicts the experiment by showing the mixing or liquid injection point and the tags for the inlet and outlet (mixture) streams. Only the relevant experiment tags are shown, including compositions in mole percent, flow rates, and gas and wetgas heating values. The columns for each stream show the measured values (Meas), the reconciled values (Recon), the uncertainty (Unc), and the uncertainty type (A=Absolute, %=relative at the 95% confidence level).

In this DVR modeling, ALL measurements (in this case, the compositions and flowrates) are also reconciled and compared with the original raw measurement values. Any differences will raise a penalty alert (not shown here).

For the purpose of this experiment and the representing model:

- No vapor equilibrium calculation is required to evaluate the Ref mixture composition (theoretical), but EOS and thermodynamics are built in the model for when needed to evaluate other properties such as density, shrinkage and flash.
- The slide compares model calculation, values, and uncertainties, against the flowloop evaluations – matching results
- The inlet compositions and flowrates uncertainties are propagated to the mixture composition uncertainties – matching results



Validation of Heating Values and Uncertainties

Tag	Unit	Meas	Recon	Unc	Unc Type
REF_GAS_MFN2	%	0.11	0.11	0.026	A
REF_GAS_MFCO2	%	0.02	0.02	0.055	A
REF_GAS_MFC1	%	99.45	99.45	0.046	A
REF_GAS_MFC2	%	0.06	0.06	0.005	A
REF_GAS_MFN-C7	%	0.36	0.36	0.015	A
REF_GAS_UHVMOL	Btu/cf		1024.11	0.093	%
REF_GAS_MASSF	lb/min	274.23	274.23	1.331	A

Ref Gas SWRI

Y	U_Y
0.111	0.026
0.02	0.010
99.451	0.046
0.056	0.005
0.363	0.015

Tag	Unit	Meas	Recon	Unc	Unc Type
REF_LIQ_MFN2	%	0.01	0.01	0.007	A
REF_LIQ_MFCO2	%	0.01	0.01	0.229	A
REF_LIQ_MFCI	%	22.53	22.53	0.046	A
REF_LIQ_MFC2	%	0.06	0.06	0.005	A
REF_LIQ_MFN-C7	%	77.38	77.38	0.224	A
REF_LIQ_MASSF	lb/min	23.02	23.02	0.023	A

Ref Liq SWRI

X	U_X
0.008	0.007
0.012	0.008
22.534	0.046
0.063	0.005
77.383	0.224

Test Condition WG1 (LM = 0.02)									
Sample Name	Sample Time	Sample Location	Bottle Serial No.	mol%					Dry Heating Value (BTU/CF)
				Nitrogen	CO_2	Methane	Ethane	Heptane +	
WG1-A	14:40:40	GC	T-5247	0.115	0.022	99.438	0.052	0.373	1,026
WG1-1	14:46:40	Test Section	T-4285	0.109	0.034	99.004	0.046	0.807	1,047
WG1-2	14:51:45	Test Section	T-4581	0.102	0.023	99.035	0.061	0.779	1,046
WG1-3	14:56:40	Test Section	T-5425	0.104	0.018	99.027	0.057	0.794	1,047
WG1-4	15:02:00	Test Section	T-4209	0.138	0.024	98.708	0.054	1.076	1,060
WG1-5 (2)	15:07:20	Test Section	T-2090	0.143	0.043	98.739	0.058	1.017	1,057
WG1-6	15:19:00	Test Section	T-2187	0.172	0.019	98.809	0.060	0.940	1,053
WG1-7	15:24:00	Test Section	T-2168	0.106	0.032	99.044	0.055	0.763	1,045
WG1-B	15:30:20	GC	T-5340	0.107	0.018	99.463	0.059	0.353	1,025
Online GC	Continuous	GC	--	0.098	0.000	99.544	0.041	0.317	1,023
Avge Sat Gas Samples	Average Sat Gas Composition			0.111	0.020	99.451	0.056	0.363	1,026
Avge Wet Gas Samples	Average Wet Gas Composition			0.125	0.028	98.909	0.056	0.882	1,051
Theoretical Ref Wet Gas	Reference Wet Gas Composition			0.109	0.020	98.170	0.056	1.645	1,083

Ref Wet Gas SWRI (combined Unc.)

$$Z = \begin{bmatrix} 0.109 \\ 0.02 \\ 98.17 \\ 0.056 \\ 1.645 \end{bmatrix} \quad U_z = \begin{bmatrix} 0.0256 \\ 0.0098 \\ 0.0458 \\ 0.0049 \\ 0.0169 \end{bmatrix}$$

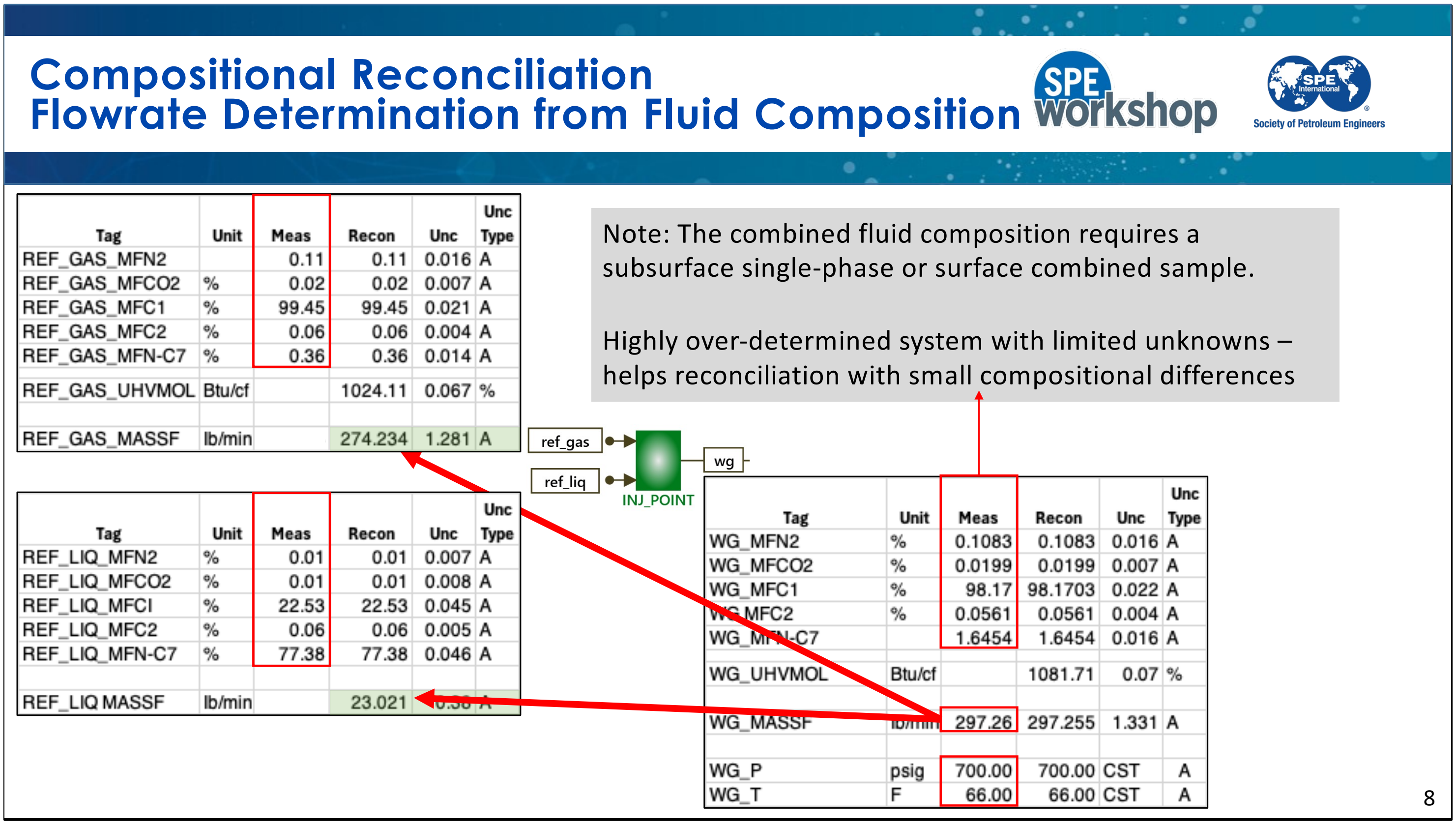
Tag	Unit	Meas	Recon	Unc	Unc Type
WG_MFN2	%		0.11	0.026	A
WG_MFCO2	%		0.02	0.054	A
WG_MFC1	%		98.17	0.047	A
WG_MFC2	%		0.06	0.005	A
WG_MFN-C7	%		1.65	0.017	A
WG_UHVMOL	Btu/cf		1081.71	0.091	%
WG_MASSF	lb/min		297.26	1.331	A
WG_P	psig	700.00	700.00	CST	A
WG_T	F	66.00	66.00	CST	A

The model heating values for the Reference Saturated Gas Sample and Reference Wetgas Samples match the flowloop values

In addition, the model evaluates the relative uncertainty of the heating values (not provided by the flowloop)

>>Remember the measured gas and liquid flowrates from this slide for later!

Q: Are you aware of process simulators that also propagate the combined uncertainties of measured and unmeasured variables?



Compositional Reconciliation
Flowrate Determination from Fluid Composition

Tag	Unit	Meas	Recon	Unc	Unc Type
REF_GAS_MFN2		0.11	0.11	0.016	A
REF_GAS_MFCO2	%	0.02	0.02	0.007	A
REF_GAS_MFC1	%	99.45	99.45	0.021	A
REF_GAS_MFC2	%	0.06	0.06	0.004	A
REF_GAS_MFN-C7	%	0.36	0.36	0.014	A
REF_GAS_UHVMOL	Btu/cf		1024.11	0.067	%
REF_GAS_MASSF	lb/min		274.234	1.281	A

Tag	Unit	Meas	Recon	Unc	Unc Type
REF_LIQ_MFN2	%	0.01	0.01	0.007	A
REF_LIQ_MFCO2	%	0.01	0.01	0.008	A
REF_LIQ_MFCI	%	22.53	22.53	0.045	A
REF_LIQ_MFC2	%	0.06	0.06	0.005	A
REF_LIQ_MFN-C7	%	77.38	77.38	0.046	A
REF_LIQ MASSF	lb/min		23.021	0.36	A

Note: The combined fluid composition requires a subsurface single-phase or surface combined sample.

Highly over-determined system with limited unknowns – helps reconciliation with small compositional differences

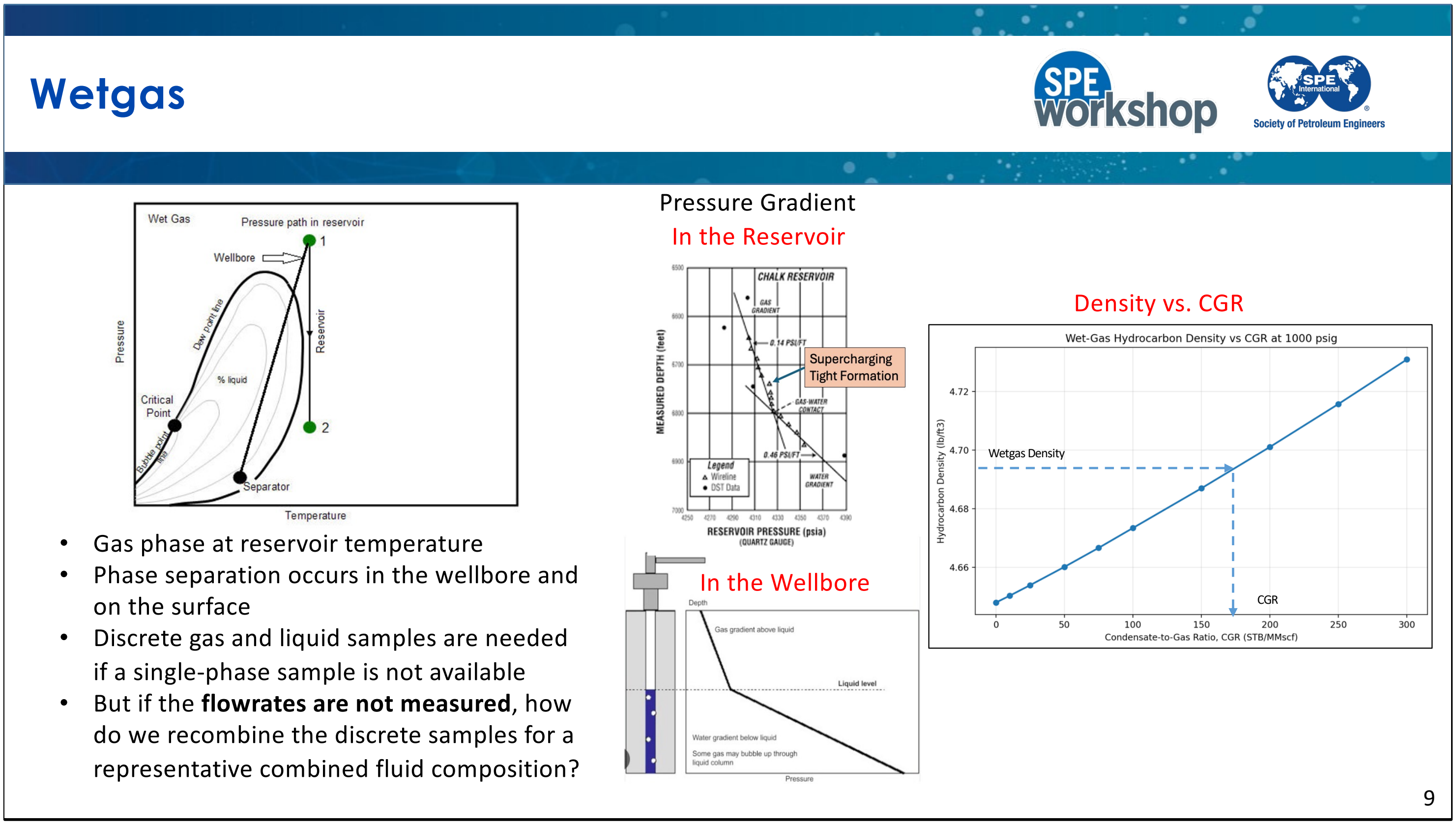
Tag	Unit	Meas	Recon	Unc	Unc Type
WG_MFN2	%	0.1083	0.1083	0.016	A
WG_MFCO2	%	0.0199	0.0199	0.007	A
WG_MFC1	%	98.17	98.1703	0.022	A
WG_MFC2	%	0.0561	0.0561	0.004	A
WG_MFN-C7		1.6454	1.6454	0.016	A
WG_UHVMOL	Btu/cf		1081.71	0.07	%
WG_MASSF	lb/min	297.26	297.255	1.331	A
WG_P	psig	700.00	700.00	CST	A
WG_T	F	66.00	66.00	CST	A

The basis of Compometrics is to reconcile inlet streams and outlet stream compositions to establish the relative contributions (ratios) of input streams. Here, the model uses the Ref compositions and their uncertainties at the inlet and outlet to independently estimate the inlet flow rates (in green). This matches the original inlet flow rates from previous slides.

This is done independently and in addition to the physical flowrate measurements performed by flowmeters or other devices.

DVR processing then reconciles the flow rates from different sources (physical and compositional) to enhance accuracy.

Examples will be shown where this is applicable when the mixed output stream composition is available.



Wetgas

- Gas phase at reservoir temperature
- Phase separation occurs in the wellbore and on the surface
- Discrete gas and liquid samples are needed if a single-phase sample is not available
- But if the **flowrates are not measured**, how do we recombine the discrete samples for a representative combined fluid composition?

Pressure Gradient

In the Reservoir

In the Wellbore

Density vs. CGR

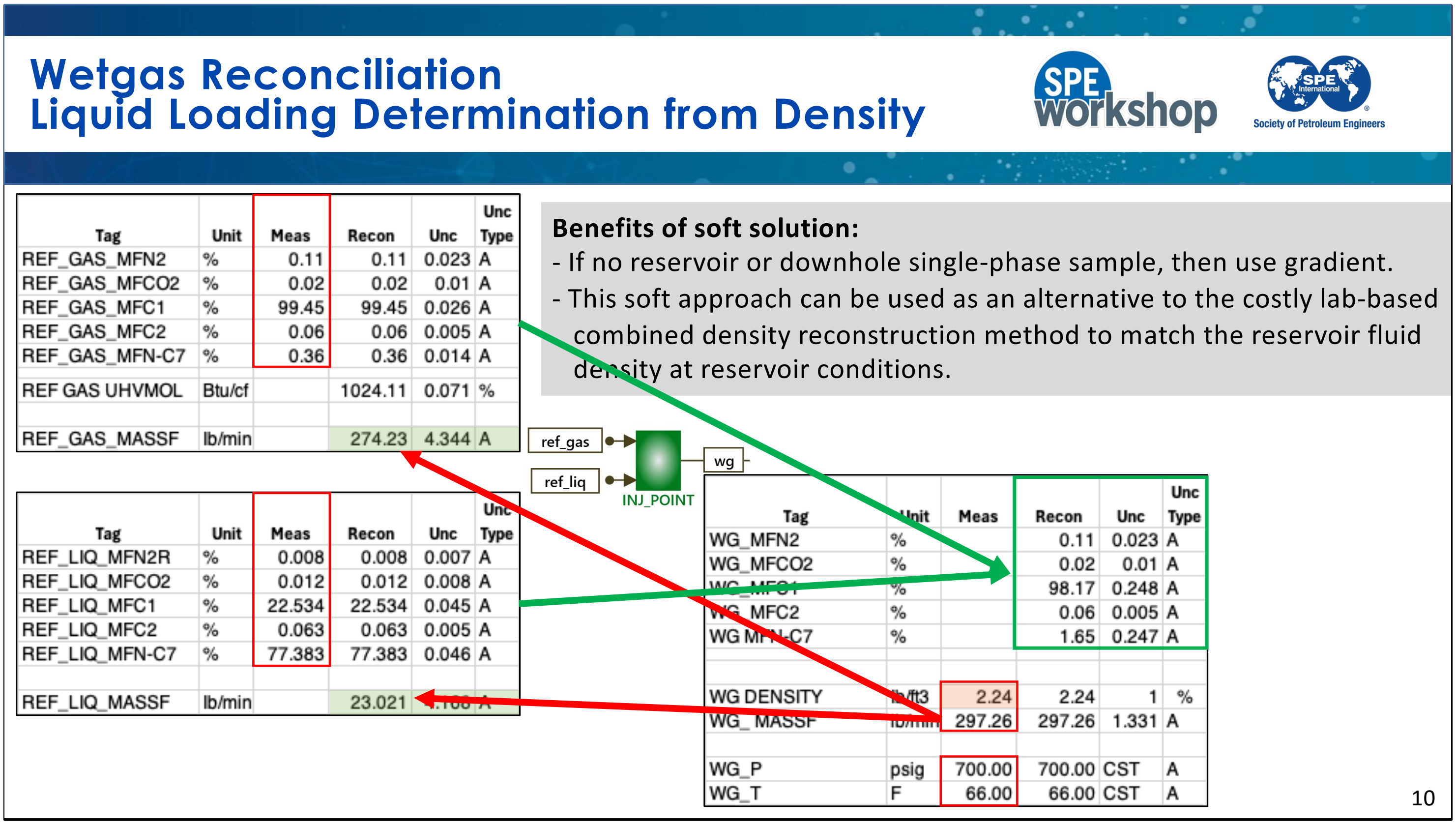
Wetgas Application

This is the first application: Wet gas's unique feature is that the gas composition at reservoir temperature remains unchanged over time because it remains above the dew point.

We start by obtaining discrete phase samples (i.e., gas and liquid samples in equilibrium) at the surface from a multiphase flowing stream (assuming no well test or other flowrate measurements were available). To combine the samples at the appropriate ratio (CGR) the **wetgas reservoir density** can be used as the reference, leading to a representative reservoir fluid sample.

If single-phase reservoir samples are not available, the reservoir wetgas density can be obtained from the pressure gradient of an open-hole pressure survey or a downhole shut-in pressure survey.

The liquid is gradually introduced into the gas sample in the laboratory cell at the reservoir or wellbore pressure and temperature. A density versus CGR plot is generated to determine the CGR required to combine the discrete gas and liquid samples into a representative combined sample.



Wetgas Reconciliation
Liquid Loading Determination from Density

Tag	Unit	Meas	Recon	Unc	Unc Type
REF_GAS_MFN2	%	0.11	0.11	0.023	A
REF_GAS_MFCO2	%	0.02	0.02	0.01	A
REF_GAS_MFC1	%	99.45	99.45	0.026	A
REF_GAS_MFC2	%	0.06	0.06	0.005	A
REF_GAS_MFN-C7	%	0.36	0.36	0.014	A
REF GAS UHVMOL	Btu/cf		1024.11	0.071	%
REF_GAS_MASSF	lb/min		274.23	4.344	A

Benefits of soft solution:
- If no reservoir or downhole single-phase sample, then use gradient.
- This soft approach can be used as an alternative to the costly lab-based combined density reconstruction method to match the reservoir fluid density at reservoir conditions.

Tag	Unit	Meas	Recon	Unc	Unc Type
REF_LIQ_MFN2R	%	0.008	0.008	0.007	A
REF_LIQ_MFCO2	%	0.012	0.012	0.008	A
REF_LIQ_MFC1	%	22.534	22.534	0.045	A
REF_LIQ_MFC2	%	0.063	0.063	0.005	A
REF_LIQ_MFN-C7	%	77.383	77.383	0.046	A
REF_LIQ_MASSF	lb/min		23.021	[illegible]	A

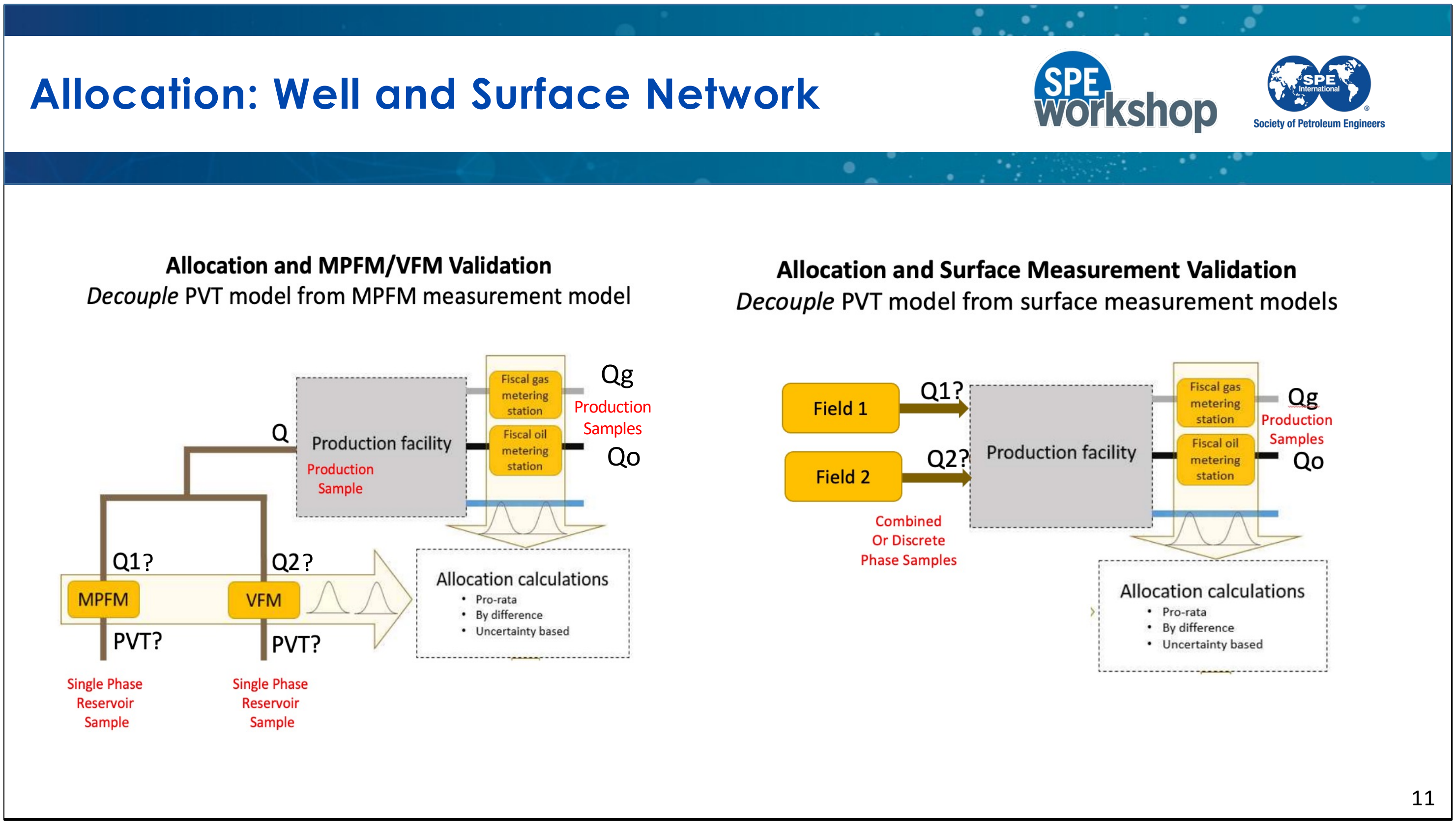
Tag	Unit	Meas	Recon	Unc	Unc Type
WG_MFN2	%		0.11	0.023	A
WG_MFCO2	%		0.02	0.01	A
WG_MFC1	%		98.17	0.248	A
WG_MFC2	%		0.06	0.005	A
WG MFN-C7	%		1.65	0.247	A
WG DENSITY	lb/ft3	2.24	2.24	1	%
WG_MASSF	lb/min	297.26	297.26	1.331	A
WG_P	psig	700.00	700.00	CST	A
WG_T	F	66.00	66.00	CST	A

Instead of physically mixing the discrete samples in the laboratory (at a cost), Compometerics can be used to determine the ratio of the inlet gas and oil streams, or the CGR, from the combined fluid density.

The only measurements used here are the inlet compositions (assuming discrete gas- and oil-phase samples) and the combined stream density of 2.24 lb/ft3. The evaluated inlet streams' flow rates (red arrows) or liquid loading match the original values, albeit with higher uncertainty due to the limited data redundancy compared to the previous case, in which the combined stream composition was used in the reconciliation.

The model then automatically closes the circle by combining the gas and oil samples using the evaluated flowrates to then provide the composition of the combined wetgas stream and uncertainty (green arrows). The combined composition can then be used in an EOS to model the wetgas stream properties for implementation in a wetgas flowmeter.

This soft approach is cost-effective compared with the laboratory approach for determining the CGR using available reservoir fluid density and for evaluating the combined fluid composition for later use in an EOS.



Allocation: Well and Surface Network

Allocation and MPFM/VFM Validation

Decouple PVT model from MPFM measurement model

Allocation calculations
- Pro-rata
- By difference
- Uncertainty based

Allocation and Surface Measurement Validation

Decouple PVT model from surface measurement models

Allocation calculations
- Pro-rata
- By difference
- Uncertainty based

Production Allocation Application

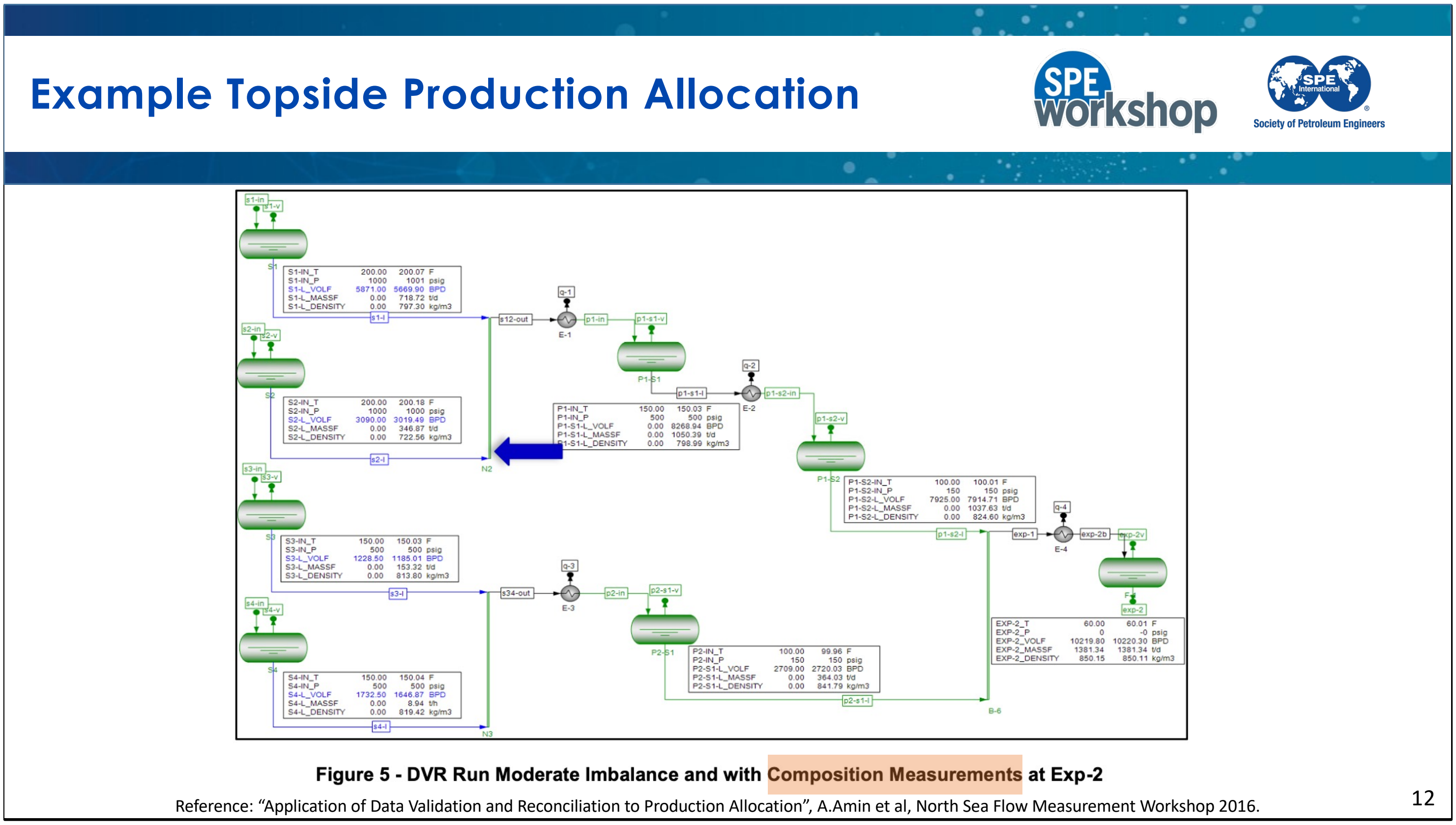
Estimate inlet flow rates from wells or surface networks based on composition reconciliation

Compometrics adds a standalone compositional flowrate determination layer to flowmeter measurements. DVR reconciles all available flow rates and composition in a mathematically sound approach to close the process balance.

Note: DVR is mathematically an all-encompassing allocation methodology that reduces to Uncertainty-Based or Proportional allocation methodologies depending on the assumptions about measurement uncertainties and bias.

>> See Ref
https://nfogm.no/wp-content/uploads/2019/10/06-Assesment-of-Alloction-Systems_DNVGL_Dennis-Putten.pdf

Q: Are you aware of a production allocation methodology that performs multi-tier allocation in one step and estimates the uncertainty of allocated quantities?



Example Topside Production Allocation

S1-IN_T	200.00	200.07	F
S1-IN_P	1000	1001	psig
S1-L_VOLF	5871.00	5669.90	BPD
S1-L_MASSF	0.00	718.72	t/d
S1-L_DENSITY	0.00	797.30	kg/m3

S2-IN_T	200.00	200.18	F
S2-IN_P	1000	1000	psig
S2-L_VOLF	3090.00	3019.49	BPD
S2-L_MASSF	0.00	346.87	t/d
S2-L_DENSITY	0.00	722.56	kg/m3

S3-IN_T	150.00	150.03	F
S3-IN_P	500	500	psig
S3-L_VOLF	1228.50	1185.01	BPD
S3-L_MASSF	0.00	153.32	t/d
S3-L_DENSITY	0.00	813.80	kg/m3

S4-IN_T	150.00	150.04	F
S4-IN_P	500	500	psig
S4-L_VOLF	1732.50	1646.87	BPD
S4-L_MASSF	0.00	8.94	t/h
S4-L_DENSITY	0.00	819.42	kg/m3

P1-IN_T	150.00	150.03	F
P1-IN_P	500	500	psig
P1-S1-L_VOLF	0.00	8268.94	BPD
P1-S1-L_MASSF	0.00	1050.39	t/d
P1-S1-L_DENSITY	0.00	798.99	kg/m3

P1-S2-IN_T	100.00	100.01	F
P1-S2-IN_P	150	150	psig
P1-S2-L_VOLF	7925.00	7914.71	BPD
P1-S2-L_MASSF	0.00	1037.63	t/d
P1-S2-L_DENSITY	0.00	824.60	kg/m3

P2-IN_T	100.00	99.96	F
P2-IN_P	150	150	psig
P2-S1-L_VOLF	2709.00	2720.03	BPD
P2-S1-L_MASSF	0.00	364.03	t/d
P2-S1-L_DENSITY	0.00	841.79	kg/m3

EXP-2_T	60.00	60.01	F
EXP-2_P	0	-0	psig
EXP-2_VOLF	10219.80	10220.30	BPD
EXP-2_MASSF	1381.34	1381.34	t/d
EXP-2_DENSITY	850.15	850.11	kg/m3

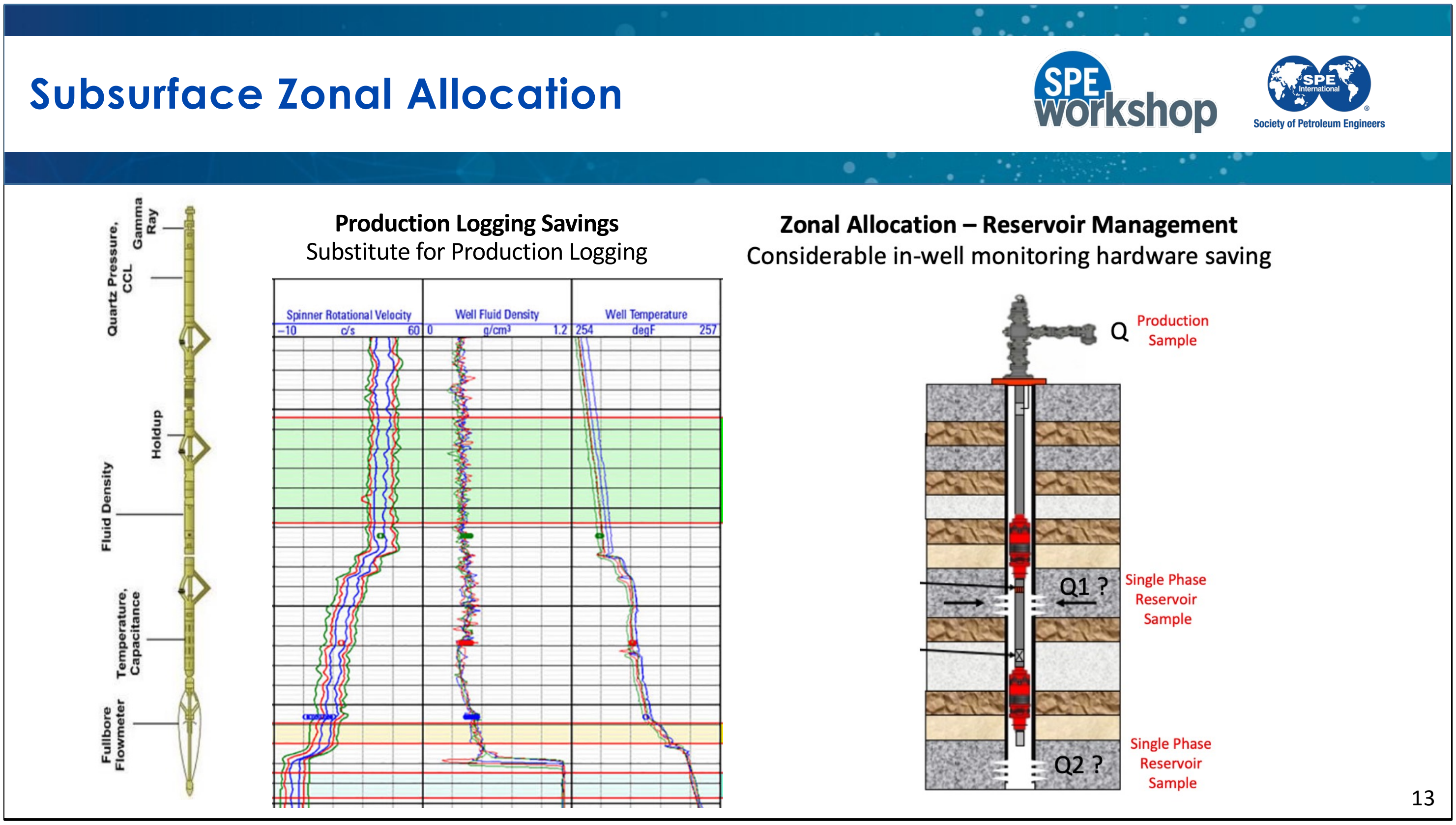
Figure 5 - DVR Run Moderate Imbalance and with Composition Measurements at Exp-2

Reference: “Application of Data Validation and Reconciliation to Production Allocation”, A.Amin et al, North Sea Flow Measurement Workshop 2016.

Example of use of composition information from export points reconciled against inlet separators compositions.

Handles a multi-tiered allocation scheme in a single run.

Check the referenced paper.
https://nfogm.no/wp-content/uploads/2019/02/2016-10-Application-of-Data-Validation-and-Reconciliation-to-Production-Allocation-Amin-Letton-Hall-Group.pdf



Subsurface Zonal Allocation

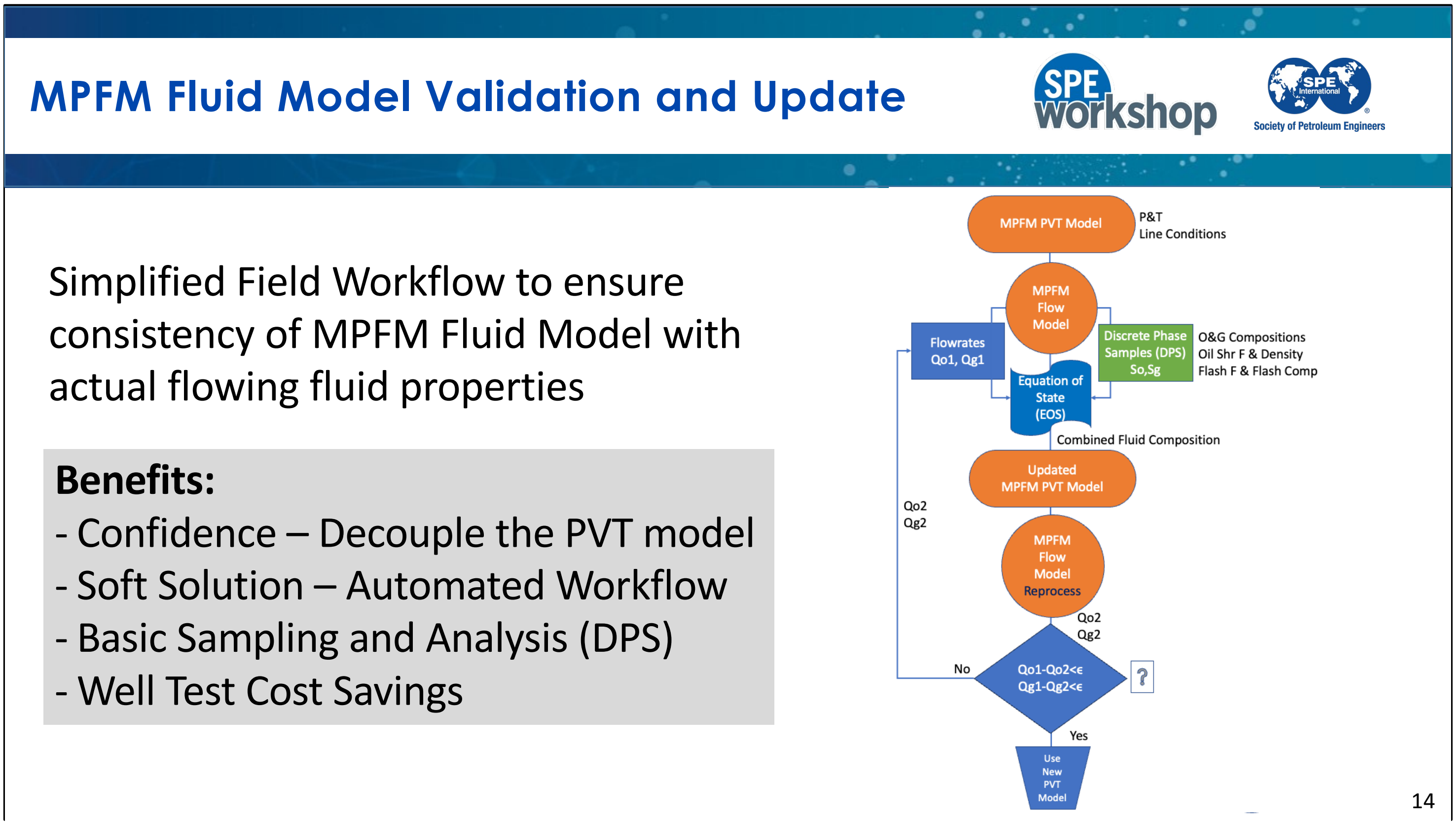
Production Logging Savings
Substitute for Production Logging

Zonal Allocation – Reservoir Management
Considerable in-well monitoring hardware saving

Another application is Zonal Allocation: When isolated layered reservoirs are produced simultaneously and the reservoir fluid composition is known for each layer, a commingled well flowing sample (e.g., by combining test separator liquid and gas samples) can be used to estimate the contribution of each layer.

This soft solution is cost-effective when compared to production logging and downhole testing operations.

Q: What if we don't know the fluid composition of each zone/layer?
A: There is a way around this – open for discussion



MPFM Fluid Model Validation and Update

Simplified Field Workflow to ensure consistency of MPFM Fluid Model with actual flowing fluid properties

Benefits:
- Confidence – Decouple the PVT model
- Soft Solution – Automated Workflow
- Basic Sampling and Analysis (DPS)
- Well Test Cost Savings

MPFM Application
This is a cost-effective and operationally efficient soft solution to MPFM fluid model validation and update, using a forward-simulation and reprocessing workflow. It reduces the need for frequent well tests to validate the MPFM.

It uses discrete-phase gas and oil samples at MPFM conditions to assess the consistency of the MPFM fluid model with the actual fluid passing through the meter.

The workflow can be automated for frequent use to clarify ambiguities and increase the confidence of working interest owners and regulators in the MPFM's performance. It starts at the top using the initial MPFM’s built-in fluid model to estimate initial flow rates (Qo1, Qg1).

The discrete-phase samples obtained from the MPFM flowline (green box) are combined in a forward simulator using the initial flow rates to calculate a new composition, update the MPFM fluid model for reprocessing, and generate a new set of flowrate values (Qo2, Qg2).

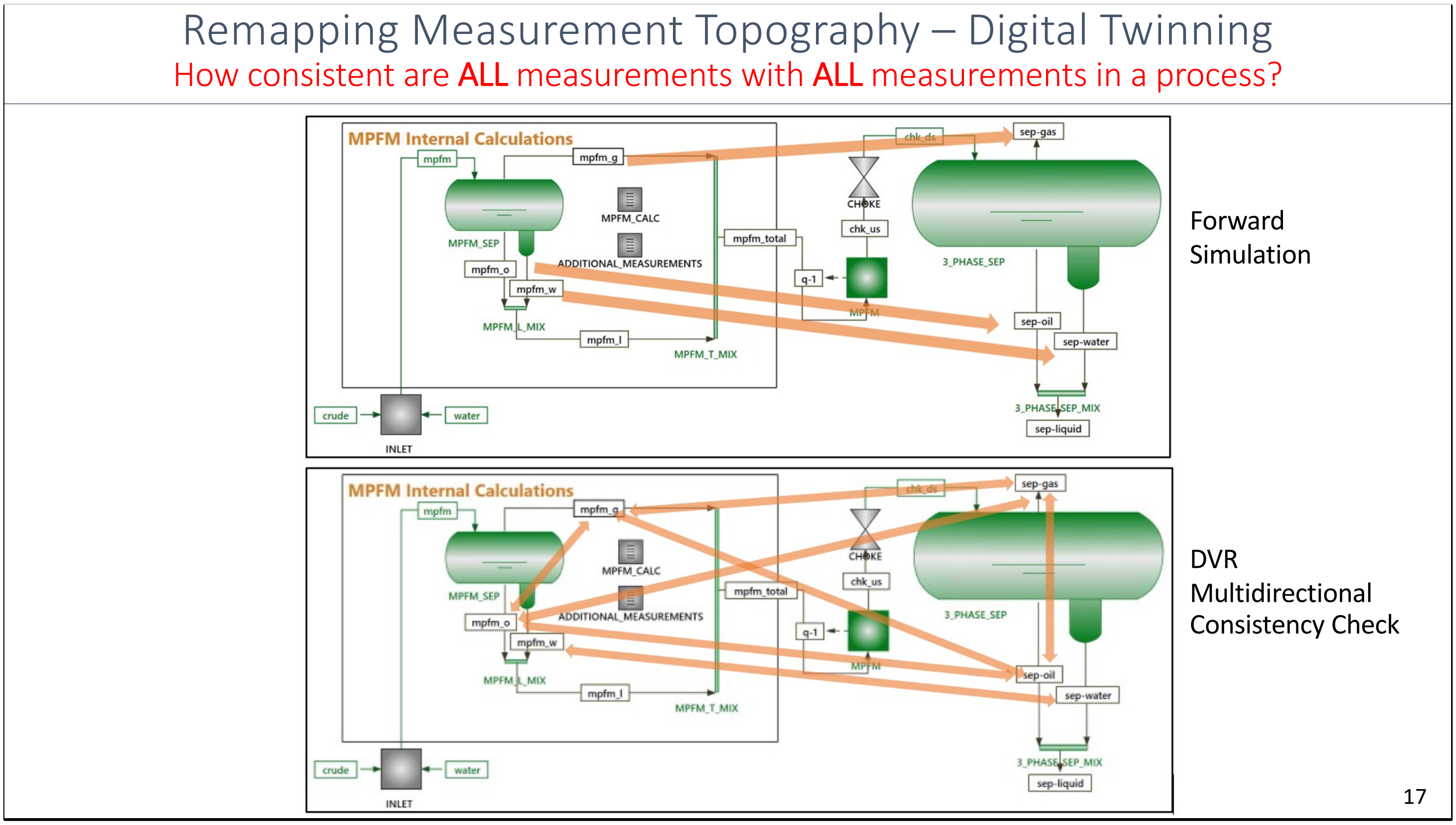
An iterative process can then be used to compare the initial MPFM readings with the new flow rates and reduce the error using sample information.
(This is a localized solution at the prevailing MPFM conditions)

- Compometrics Considerations:
  - Accuracy is enhanced with the **dissimilarity of fluids**
  - Use of labs and/or standards to estimate **composition uncertainty –** ISO 6974, ISO 10723, ASTM D1945, GPA 2261 - repeatability
  - An effective flowrate estimator **independent of flow measurement devices** – thermodynamics ready
  - Cost-effective **soft solution**, adding **redundancy** to flow measurement
  - **Considerable savings:** Wetgas, Network and Zonal Allocation, MPFM Validation…..

Acknowledgment: The authors recognize and thank API for allowing the use of the Wet Gas Sampling data from the Flow Loop Experiment

Thank You!

Questions?



Remapping Measurement Topography – Digital Twinning

How consistent are **ALL** measurements with **ALL** measurements in a process?

Forward Simulation

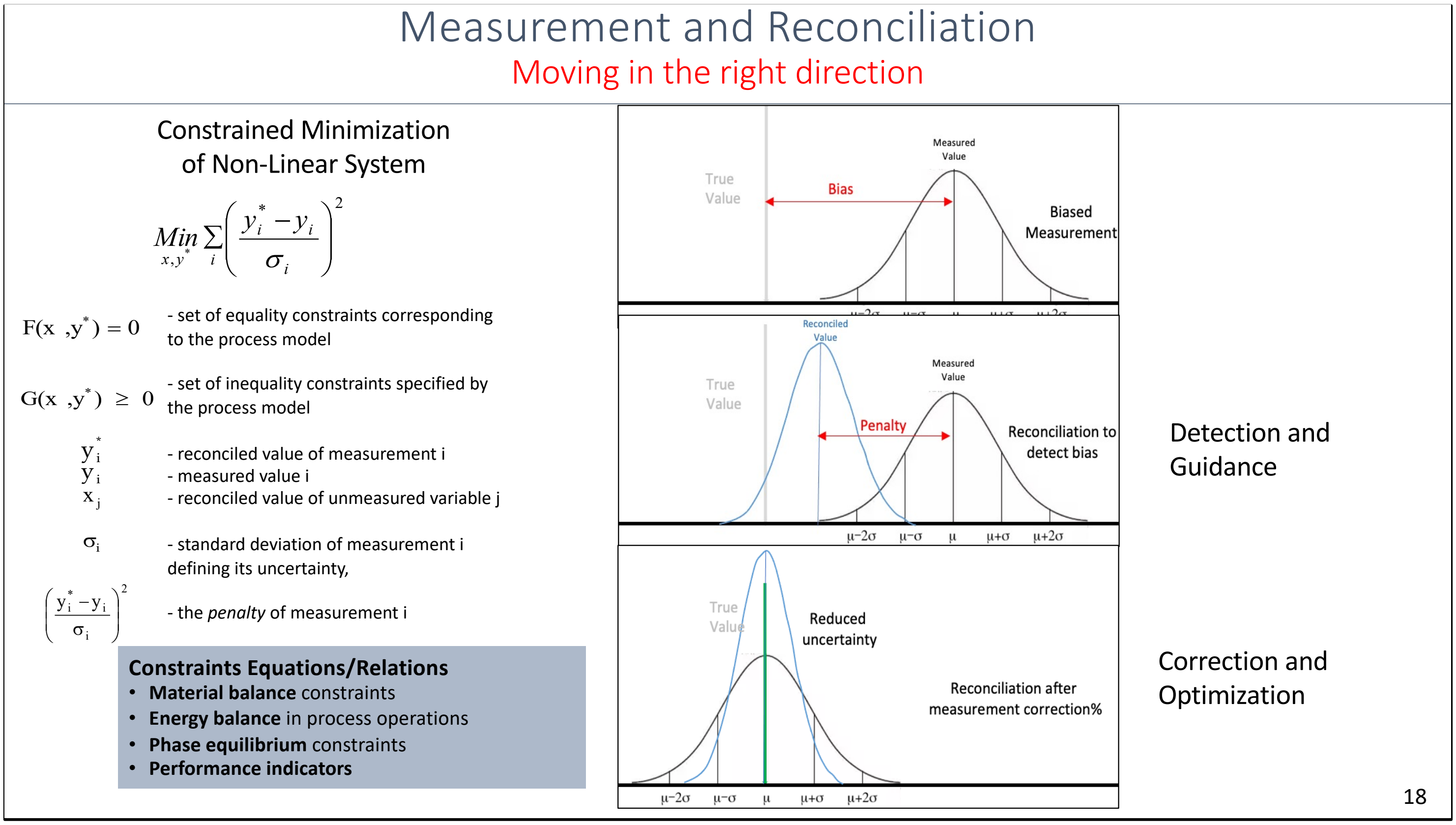
DVR Multidirectional Consistency Check

Compared to forward process simulation techniques, Data Validation and Reconciliation (DVR) leverages data redundancy and cross-checks to detect errors and ensure process and measurement consistency.

All measurements are recomputed (inlet or outlet) in a “spider-like” multidimensional, multidirectional network. It uses process overdetermination with data redundancy to identify measurements and gross process errors (bias) before closing the material, energy, and thermodynamic balances.

In this configuration, input measurement errors (devices and fluids) are not permitted, unlike with traditional unidirectional process simulators, nor will redundant data hamper convergence due to overspecification.

Thanks to data redundancy, the uncertainty of the reconciled data (attached to each measurement) would be lower than that of the raw measurement. This translates into a new measurement topography that is more representative of the process than the original, i.e., a more trusted, physics-based Digital Twin.



Measurement and Reconciliation

Moving in the right direction

Constrained Minimization of Non-Linear System

$$\underset{x,y^*}{Min}\sum_i\left(\frac{y_i^*-y_i}{\sigma_i}\right)^2$$

$F(x\ ,y^*) = 0$ - set of equality constraints corresponding to the process model

$G(x\ ,y^*)\ \geq\ 0$ - set of inequality constraints specified by the process model

y_i^* - reconciled value of measurement i
y_i - measured value i
x_j - reconciled value of unmeasured variable j

σ_i - standard deviation of measurement i defining its uncertainty,

$\left(\frac{y_i^*-y_i}{\sigma_i}\right)^2$ - the *penalty* of measurement i

Constraints Equations/Relations
- **Material balance** constraints
- **Energy balance** in process operations
- **Phase equilibrium** constraints
- **Performance indicators**

Detection and Guidance

Correction and Optimization

To demonstrate DVR methodology, we consider a measurement reading away from the True Value by more than 2 standard deviation.. This indicates bias. In this situation one cannot tell if measurement is reading its true value or not, and cannot tell its relative position with respect to True Value.

As a measurement health-check, DVR uses information from other measurements and redundancy to construct a reconciled value for this specific measurement which tends to move in the direction of the measurement True Value.
The extent of such move is indicated by the measurement penalty and is used to detect potential measurement bias.

Once a bias is detected and corrected, let's say by recalibrating the instrument, the measurement value will read the true value within the measurement uncertainty.
Thanks to added information from redundancy, the reconciled value will also represent the true value but with reduced uncertainty compared to original measurement, hence generating more confidence in the results and improving efficiencies.

Mathematically speaking, DVR is a Constrained Minimization of Non-Linear System.
The objective function is minimized by introducing small adjustments to ALL process measurements simultaneously while obeying the process physical constraints such as mass and energy balance, thermodynamic equilibria, and any other user-imposed constraints. This may involve many tags and equations.
Penalty is also calculated for each measurement following the minimization process.