LETTON HALL GROUP

North Sea FLOW Measurement Workshop

St. Andrews Bay Resort,
22nd-25th October 2002

Determination of Measurement Uncertainty for the Purpose of Wet Gas Hydrocarbon Allocation

by

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bp

FLOW

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Determination of Measurement Uncertainty for the Purpose of Wet Gas Hydrocarbon Allocation

- Introduction. The Allocation Problem. Proportional Allocation.
- API RP85. Uncertainty-Based Allocation
- Proportional versus Uncertainty-Based Allocation
- Mass Transfer Effects on Uncertainty
- Monte Carlo Modeling of Process Uncertainty
- Bias Errors in Measurement
- Conclusions

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The Allocation Issue - How to Assign the Imbalance?

Allocation
How to Assign the Imbalance?

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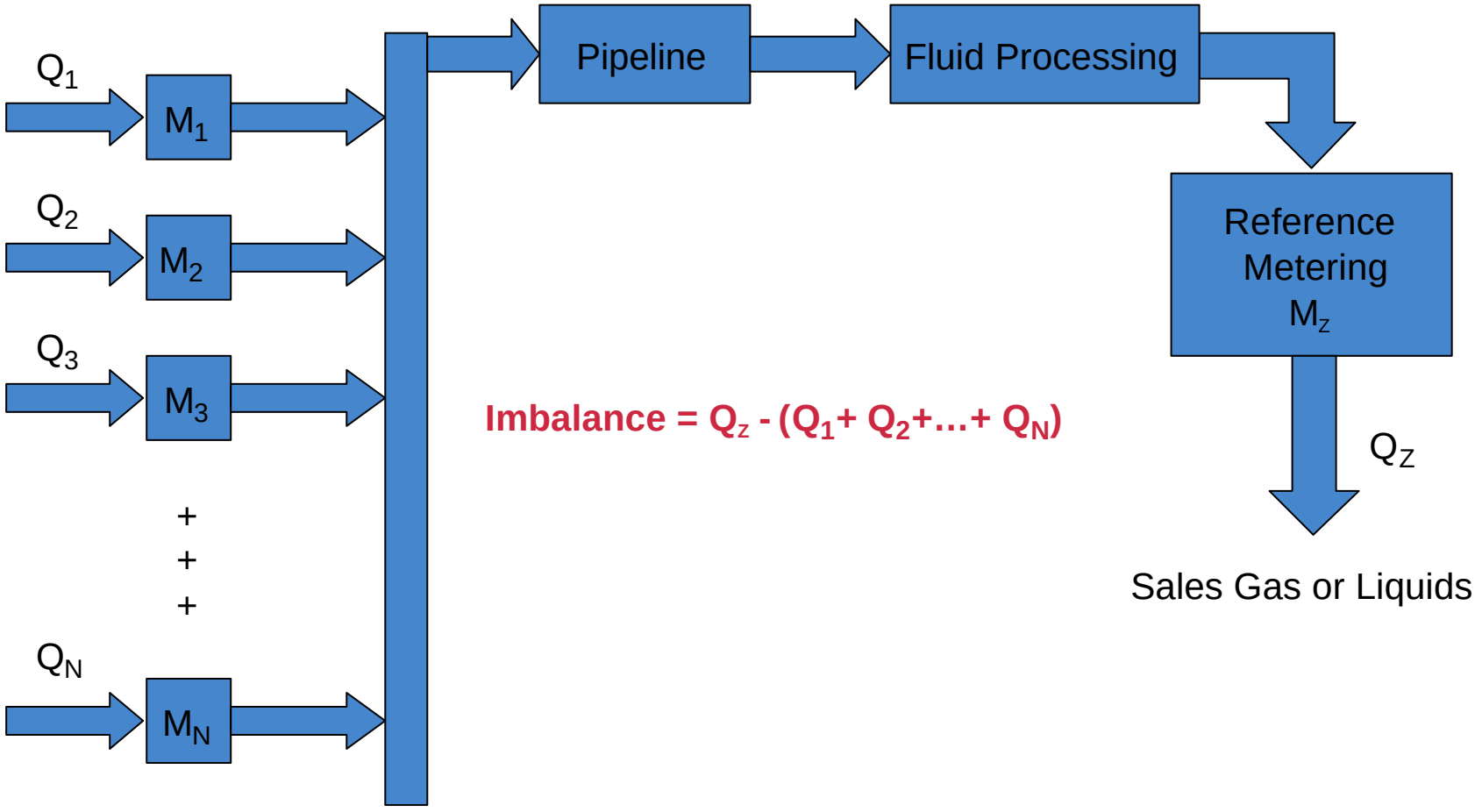

Imbalance = Q_z - (Q_1+ Q_2+…+ Q_N)

Allocation Factors

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Allocation Factor, a_i : The Fraction of the Imbalance Which is Allocated to the *i*th well stream.

Allocation to the ith stream is

$$\tilde{Q}_i = Q_i + a_i \cdot I$$

Proportional Allocation (PA)

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Imbalance is distributed among the *N* allocation meters in proportion to their measured readings.

Allocation factor for the ith stream is

$$a_i = \frac{Q_i}{\sum_1^N Q_j}$$

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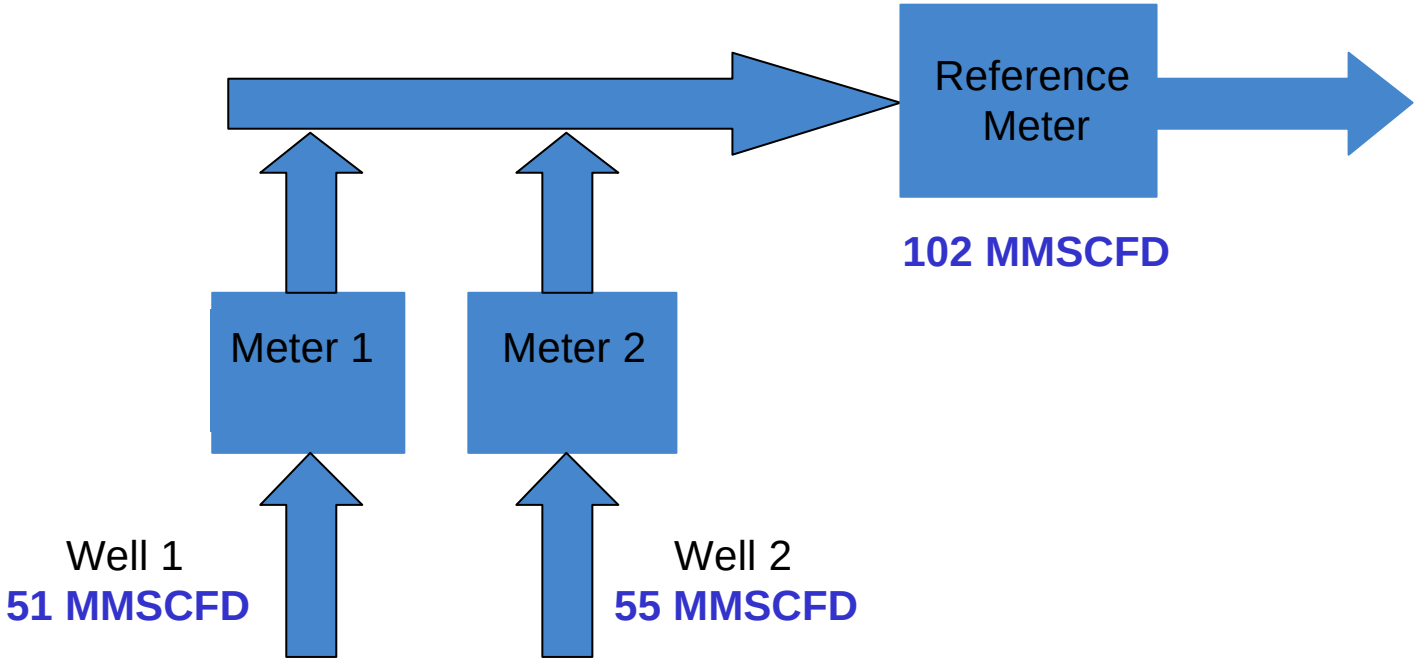
Thoughts on Allocation



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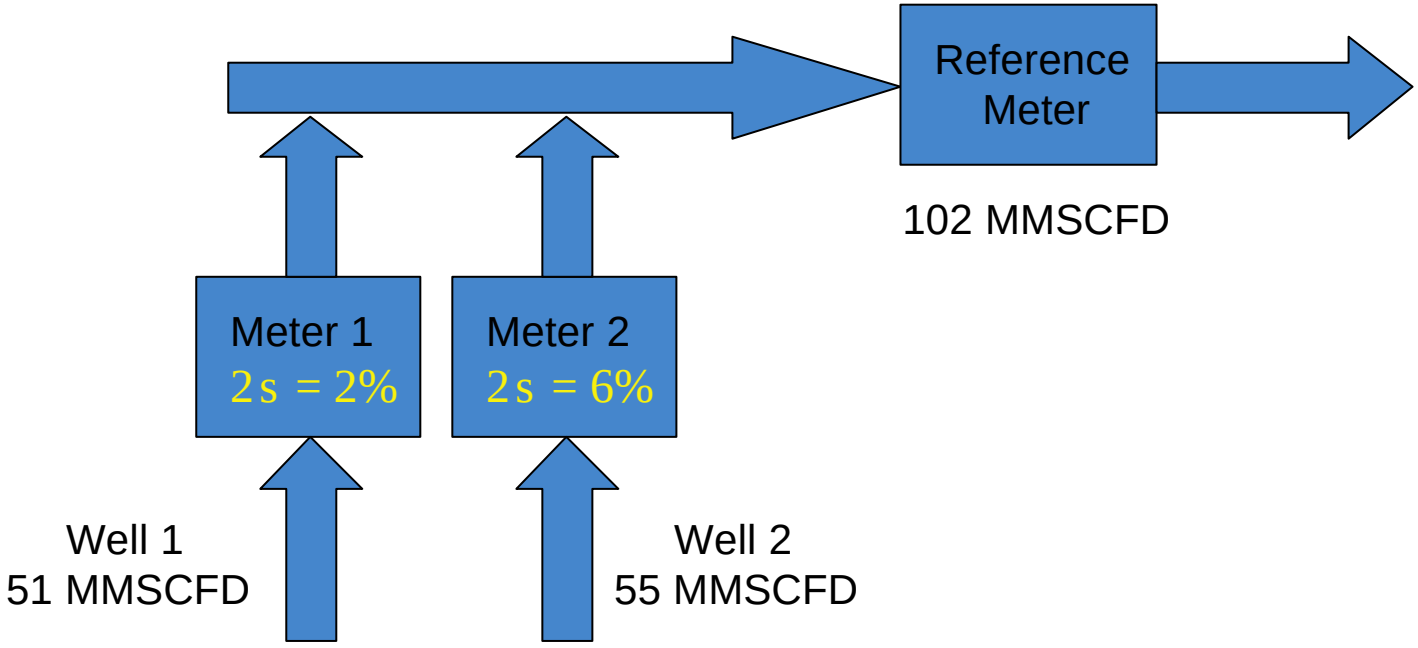
Thoughts on Allocation



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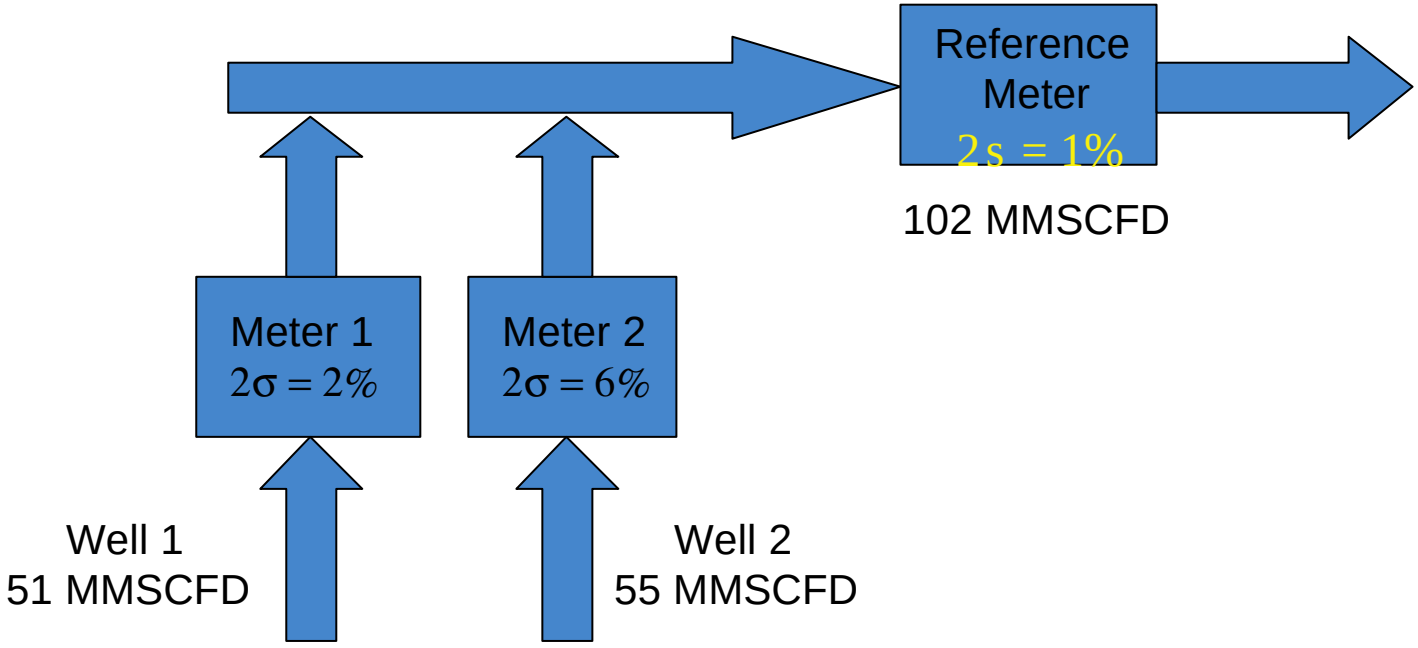
Thoughts on Allocation



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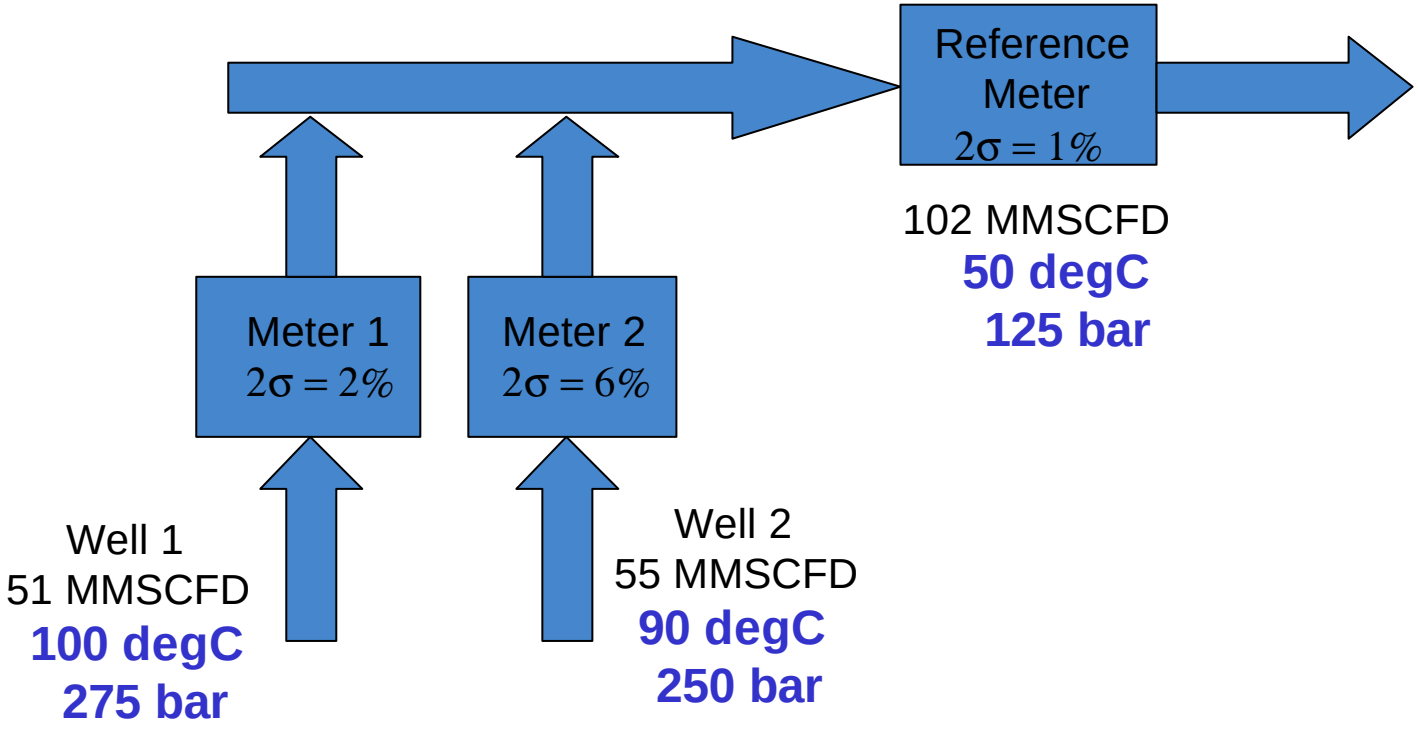
Thoughts on Allocation



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Uncertainty-Based Allocation

An Alternative to Proportional Allocation

Development History

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- Q1 2001 - MMS Approves Canyon Express Project Contingent on Development of API Recommended Practice for Allocation.
- Q3 2001 - API TAG Formed. BP, Shell, TFE, Exxon, Marathon.
- Q4 2001 - Interchange with ISO TC 193, SC 3, WG 1
- Q2 2002 - After Internal Review of Three Draft Versions, Outside Comment Solicited.
- August 2002 - Final Version with Incorporated Response to Comments Submitted for Ballot to API Upstream Committee, Drilling and Production Subcommittee 85.

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Allocation By Uncertainty

A means of assigning imbalance on the basis of relative uncertainty of measurement.

$$a_i = \frac{s_i^2}{s_Z^2 + \sum_1^N s_j^2} + \frac{Q_i}{\sum_1^N Q_j} \cdot \frac{s_Z^2}{s_Z^2 + \sum_1^N s_j^2}$$

This formulation is **Uncertainty-Based Allocation (UBA).**

Proportional vs. Uncertainty-Based Allocation

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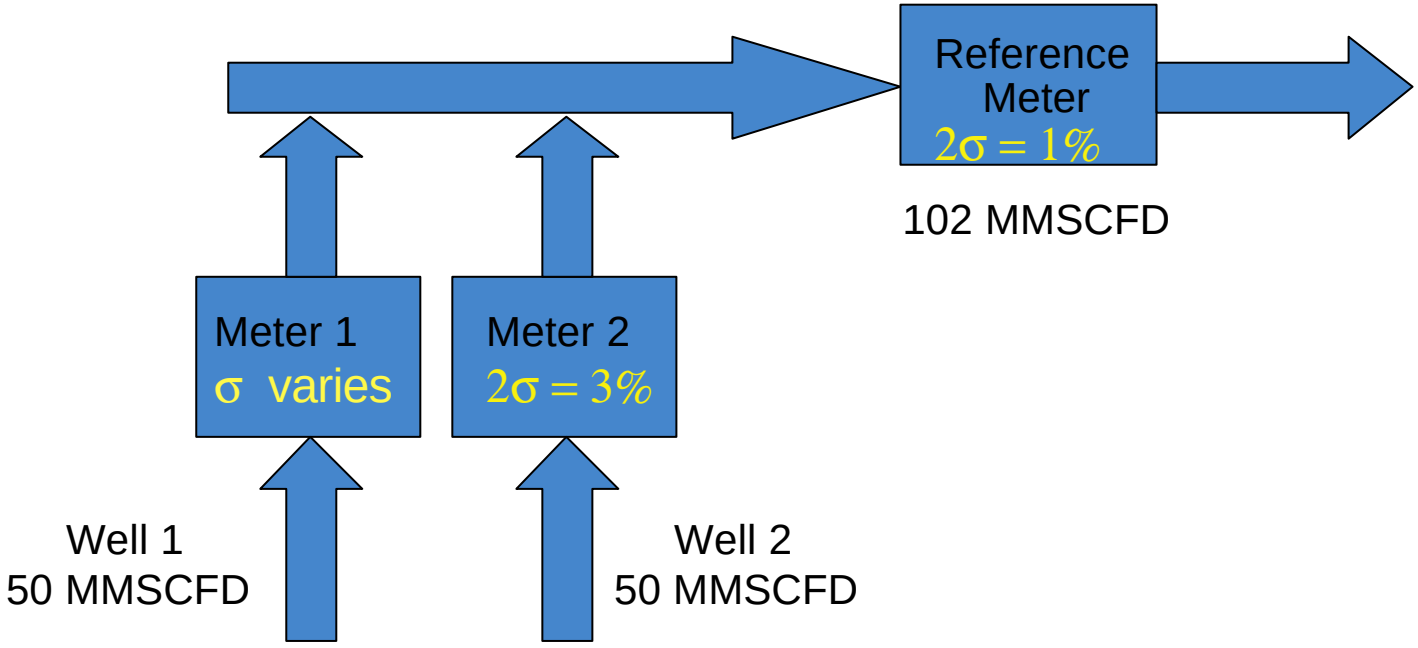

Proportional vs. Uncertainty-Based Allocation

Effect of Meter Uncertainty Variation. Equal Flow.

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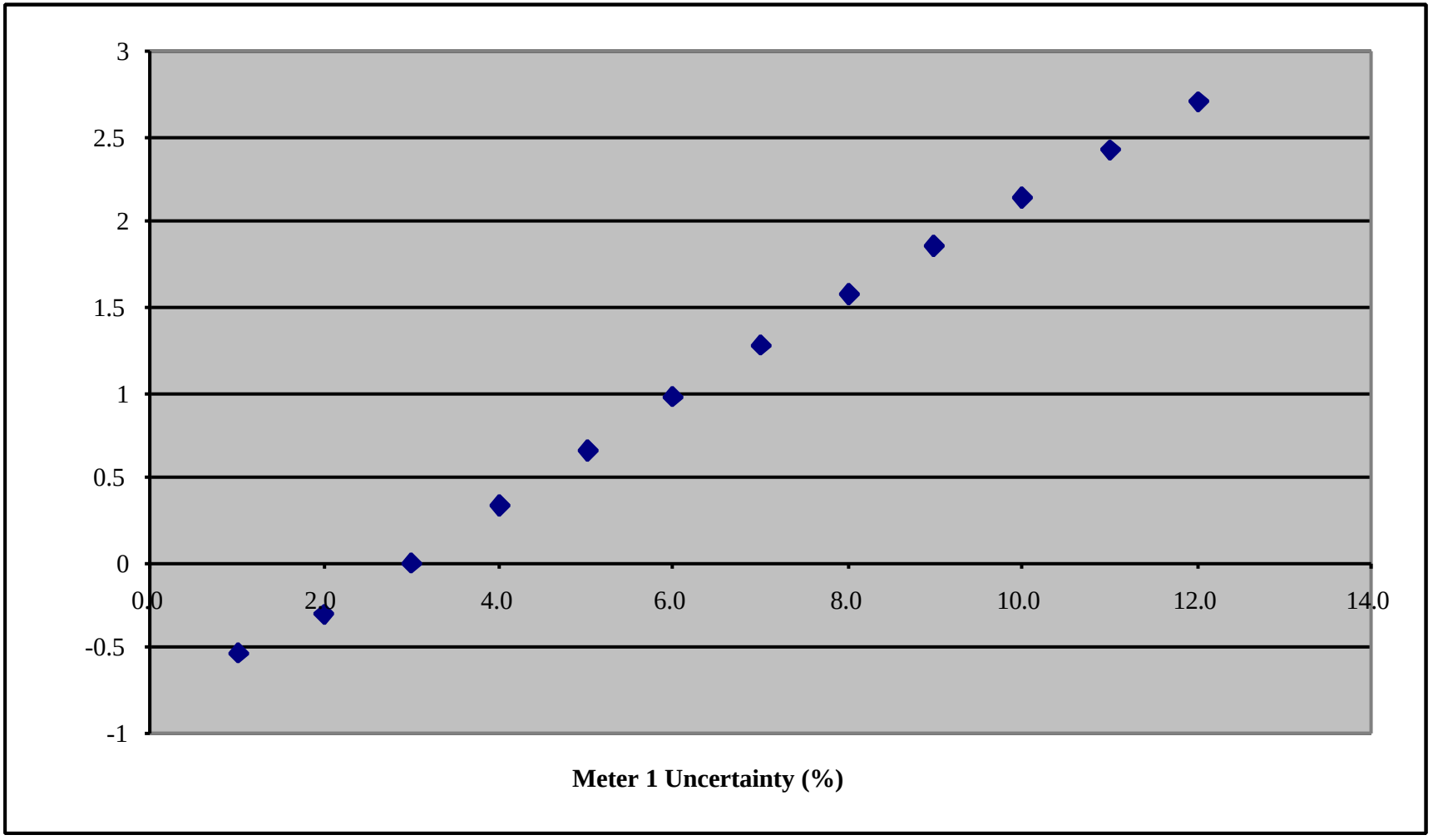

Proportional vs. Uncertainty-Based Allocation

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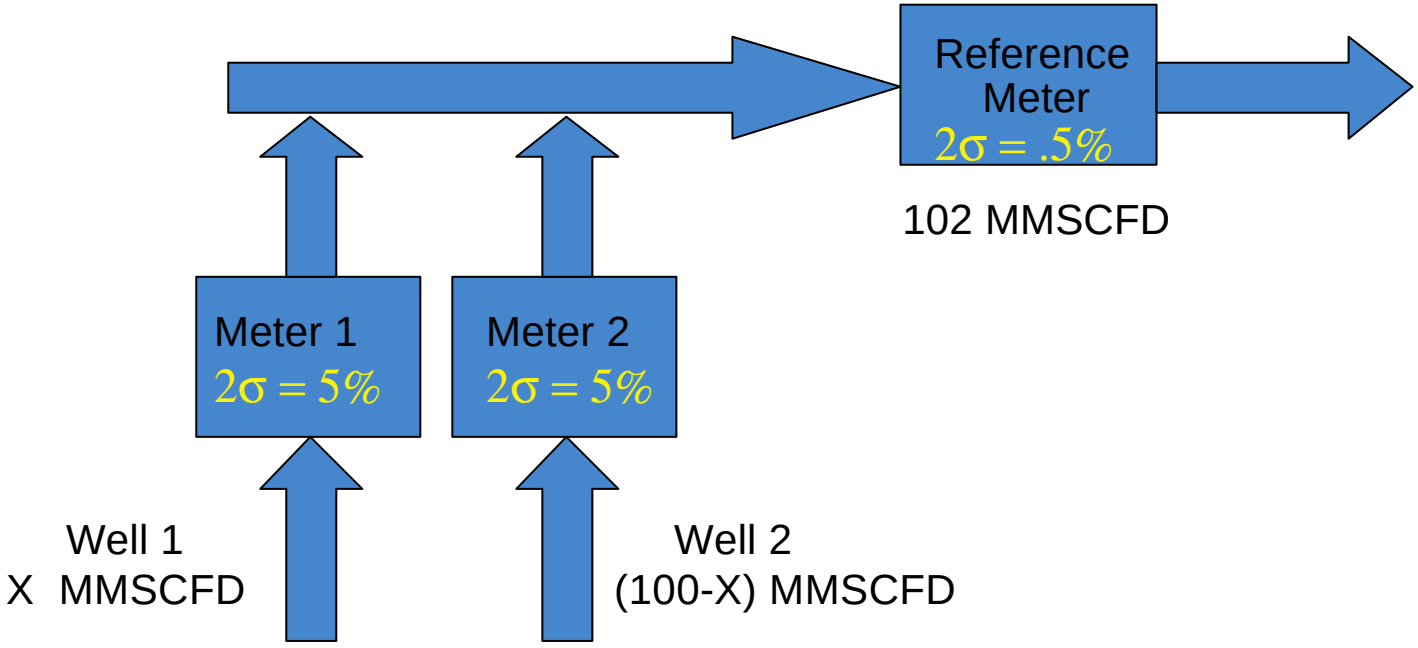

Proportional vs. Uncertainty-Based Allocation

Effect of Throughput Variation. Equal (5%) Uncertainty.

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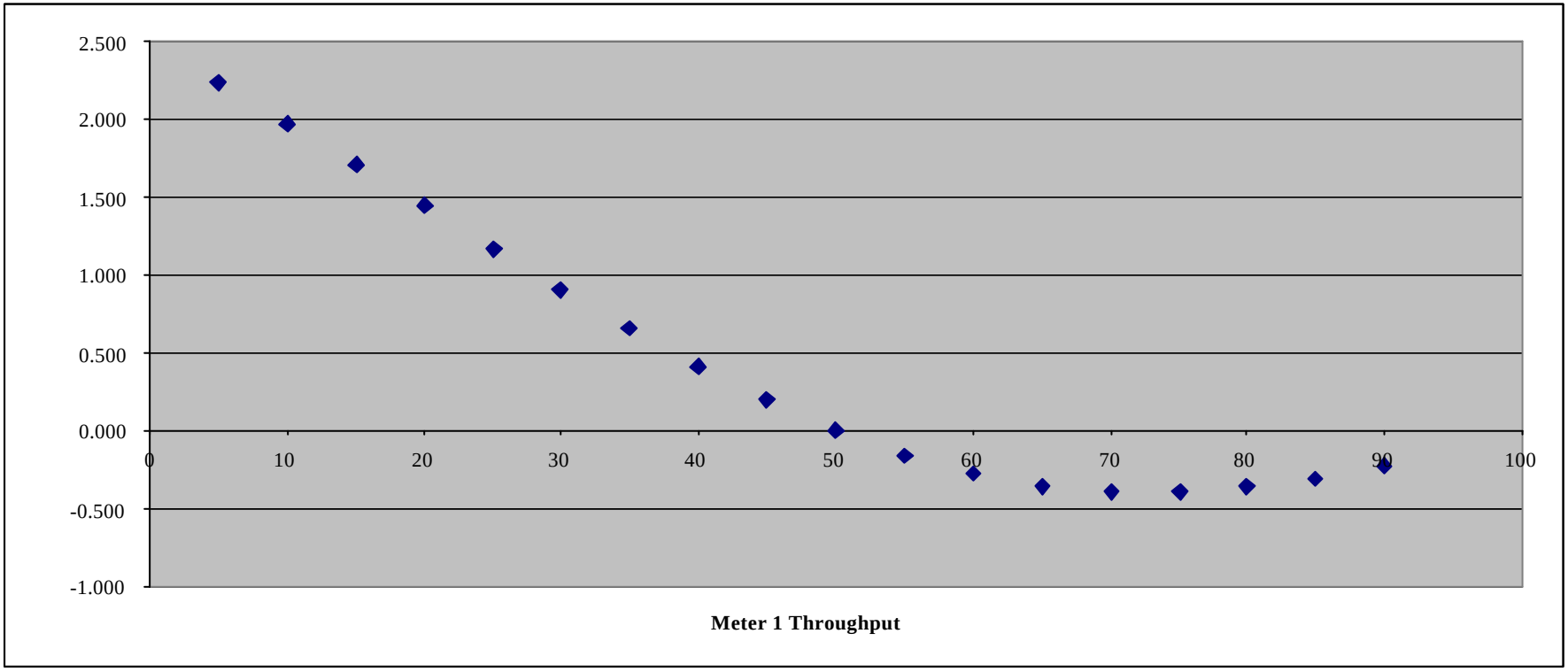

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Uncertainty Determination

Which Uncertainties Affect the Allocation?

- Allocation Meter Flow Rate Measurements
- Reference Meter Flow Rate Measurement
- Measurement of Compositions of Liquid and Gas
- Measurements of Pressure and Temperature
- Precision of the PVT Model

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Mass Transfer Effects on Uncertainty

Uncertainty Determination

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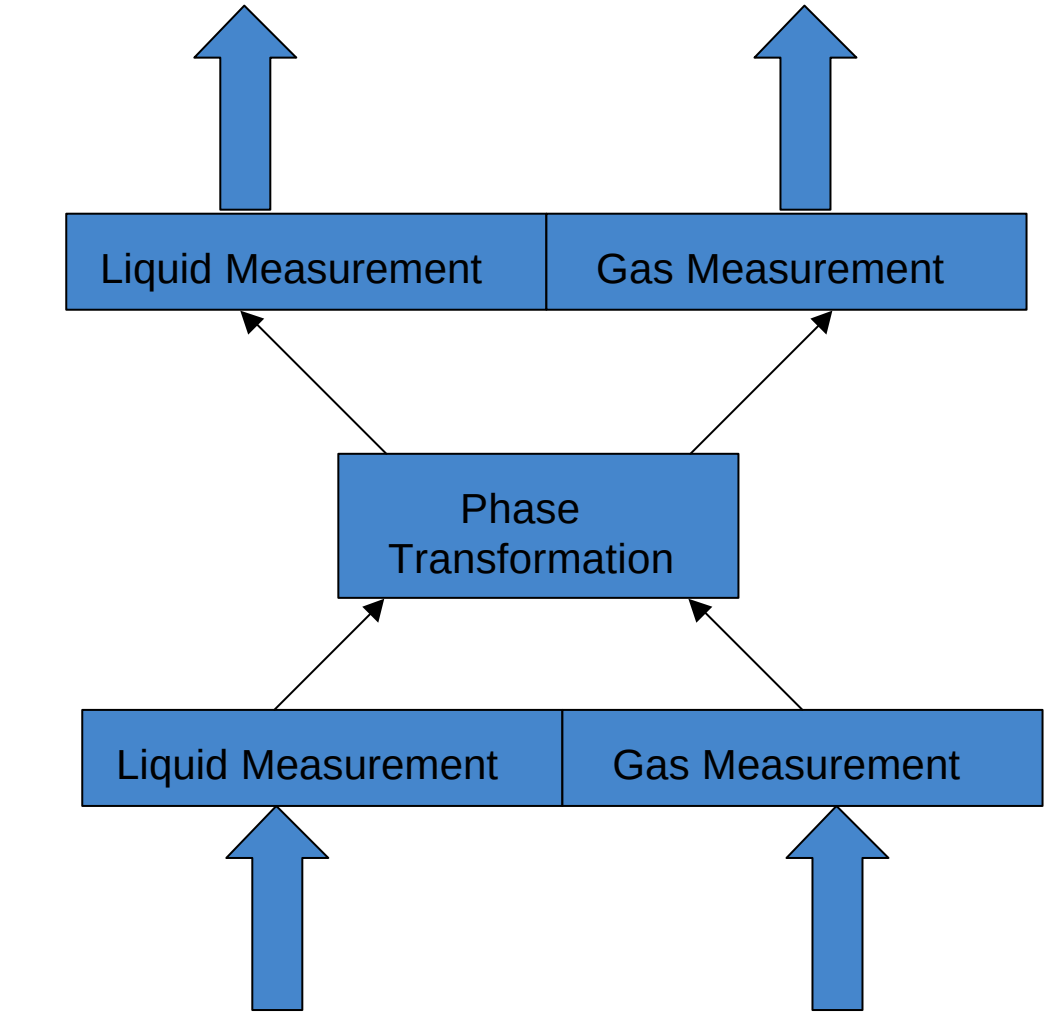

Reference Conditions

Allocation Conditions

Uncertainty Determination

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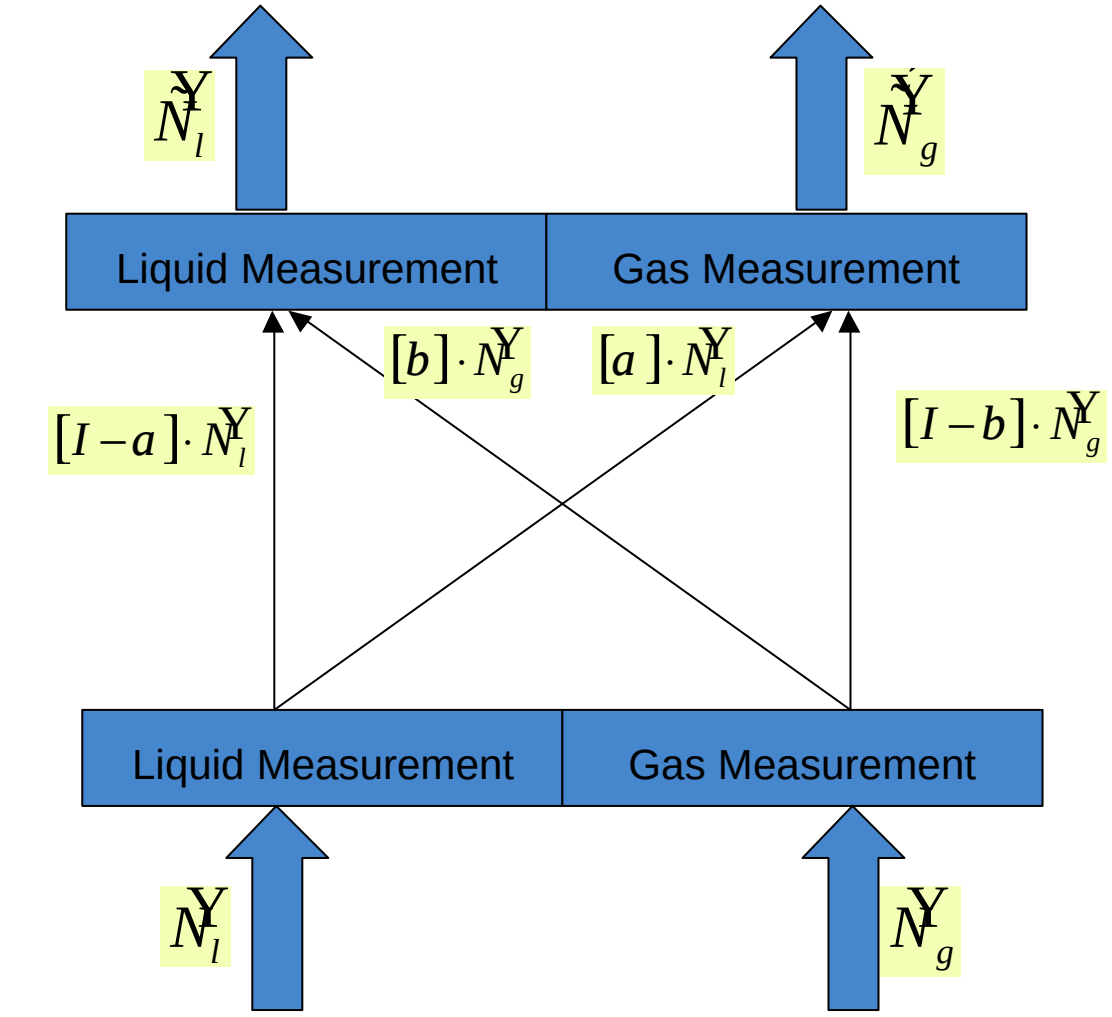

Reference Conditions

Allocation Conditions

Uncertainty Determination

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The Topside molar flow rates can thus be written as

$$\tilde{N}_l = [I - a] \cdot \acute{N}_l + [b] \cdot \acute{N}_g$$

$$\tilde{N}_g = [I - b] \cdot \acute{N}_g + [a] \cdot \acute{N}_l$$

Where the individual coefficients in α and β have been determined from the PVT analysis.

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Component	Liquid Composition	Liquid Mass Flow Rate	Gas Composition	Gas Mass Flow Rate	Condensate Recovery Factors	Recovered Condensate	Flow Rate of Liquid inc Recovered Condensate	Flow Rate of Gas less Recovered Condensate
	mol%	tonne/day	mol%	tonne/day	%gas	tonne/day	tonne/day	tonne/day
Carbon Dioxide	2.72%	0.5374	2.48%	46.3056	0.00%	0.0000	0.5374	46.3056
Nitrogen	0.39%	0.0490	0.30%	3.5655	0.00%	0.0000	0.0490	3.5655
Methane	2.49%	0.1793	82.01%	558.1916	2.00%	11.1638	11.3432	547.0278
Ethane	3.56%	0.4806	7.71%	98.3600	3.00%	2.9508	3.4314	95.4092
Propane	5.32%	1.0532	2.85%	53.3193	6.00%	3.1992	4.2524	50.1202
i-Butane	3.77%	0.9838	0.56%	13.8091	8.00%	1.1047	2.0885	12.7044
n-Butane	5.94%	1.5500	1.06%	26.1387	8.00%	2.0911	3.6411	24.0476
i-Pentane	4.41%	1.4285	0.36%	11.0197	10.00%	1.1020	2.5304	9.9177
n-Pentane	7.02%	2.2739	0.40%	12.2441	10.00%	1.2244	3.4983	11.0197
Hexane	9.34%	3.6136	0.09%	3.2905	16.00%	0.5265	4.1401	2.7640
Heptane	11.22%	5.0475	0.11%	4.6764	20.00%	0.9353	5.9828	3.7411
Octane	13.76%	7.0567	0.37%	17.9315	60.00%	10.7589	17.8156	7.1726
Nonane	14.83%	8.5393	0.01%	0.5441	80.00%	0.4353	8.9746	0.1088
Decane	15.19%	9.7032	0.01%	0.6037	90.00%	0.5433	10.2465	0.0604
Hydrogen Sulfide	0.01%	0.0015	0.00%	0.0000	0.00%	0.0000	0.0015	0.0000
Water	0.03%	0.0024	1.68%	12.8405	75.00%	9.6304	9.6328	3.2101
Total	**100.00%**	**42.5000**	**100.00%**	**850.0000**		**36.04**	**78.56**	**813.82**
Allocation Meter Uncertainties:		**20.00%**		**3.00%**		**3.755%**	**10.887%**	**3.019%**

Liquid Component Uncertainty: **10%** **No Uncertainty on Recovery Factors**

Gas Component Uncertainty: **5%** **Gas Mass Fraction: 95%**

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Component	Liquid Composition	Liquid Mass Flow Rate	Gas Composition	Gas Mass Flow Rate	Condensate Recovery Factors	Recovered Condensate	Flow Rate of Liquid inc Recovered Condensate	Flow Rate of Gas less Recovered Condensate
	mol%	tonne/day	mol%	tonne/day	%gas	tonne/day	tonne/day	tonne/day
Carbon Dioxide	2.72%	1.8968	2.48%	46.3056	0.00%	0.0000	1.8968	46.3056
Nitrogen	0.39%	0.1731	0.30%	3.5655	0.00%	0.0000	0.1731	3.5655
Methane	2.49%	0.6330	82.01%	558.1916	2.00%	11.1638	11.7968	547.0278
Ethane	3.56%	1.6962	7.71%	98.3600	3.00%	2.9508	4.6470	95.4092
Propane	5.32%	3.7172	2.85%	53.3193	6.00%	3.1992	6.9164	50.1202
i-Butane	3.77%	3.4721	0.56%	13.8091	8.00%	1.1047	4.5768	12.7044
n-Butane	5.94%	5.4706	1.06%	26.1387	8.00%	2.0911	7.5617	24.0476
i-Pentane	4.41%	5.0417	0.36%	11.0197	10.00%	1.1020	6.1437	9.9177
n-Pentane	7.02%	8.0255	0.40%	12.2441	10.00%	1.2244	9.2499	11.0197
Hexane	9.34%	12.7538	0.09%	3.2905	16.00%	0.5265	13.2803	2.7640
Heptane	11.22%	17.8147	0.11%	4.6764	20.00%	0.9353	18.7500	3.7411
Octane	13.76%	24.9059	0.37%	17.9315	60.00%	10.7589	35.6648	7.1726
Nonane	14.83%	30.1388	0.01%	0.5441	80.00%	0.4353	30.5741	0.1088
Decane	15.19%	34.2466	0.01%	0.6037	90.00%	0.5433	34.7899	0.0604
Hydrogen Sulfide	0.01%	0.0054	0.00%	0.0000	0.00%	0.0000	0.0054	0.0000
Water	0.03%	0.0086	1.68%	12.8405	75.00%	9.6304	9.6389	3.2101
Total	**100.00%**	**150.0000**	**100.00%**	**850.0000**		**36.04**	**186.15**	**813.96**
Allocation Meter Uncertainties:		**20.00%**		**3.00%**		**3.764%**	**16.187%**	**3.022%**

Liquid Component Uncertainty: **10%**

No Uncertainty on Recovery Factors

Gas Component Uncertainty: **5%**

Gas Mass Fraction: 85%

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Component	Liquid Composition	Liquid Mass Flow Rate	Gas Composition	Gas Flowrate	Condensate Recovery Factors	Recovered Condensate	Flow Rate of Liquid inc Recovered Condensate	Flow Rate of Gas less Recovered Condensate
	mol%	tonne/day	mol%	tonne/day	%gas	tonne/day	tonne/day	tonne/day
Carbon Dioxide	2.72%	0.3954	2.48%	46.8462	0.00%	0.0000	0.3954	46.8462
Nitrogen	0.39%	0.0363	0.30%	3.5974	0.00%	0.0000	0.0363	3.5974
Methane	2.49%	0.1352	82.01%	551.0243	2.00%	11.4564	11.5915	539.5679
Ethane	3.56%	0.3494	7.71%	98.7199	3.00%	2.9081	3.2574	95.8118
Propane	5.32%	0.7579	2.85%	54.6300	6.00%	3.2351	3.9930	51.3949
i-Butane	3.77%	0.7561	0.56%	14.0668	8.00%	1.0986	1.8547	12.9683
n-Butane	5.94%	1.1110	1.06%	26.3996	8.00%	1.9714	3.0824	24.4283
i-Pentane	4.41%	1.0388	0.36%	10.5937	10.00%	1.0780	2.1168	9.5157
n-Pentane	7.02%	1.5433	0.40%	11.4936	10.00%	1.2368	2.7802	10.2567
Hexane	9.34%	2.6129	0.09%	3.3340	16.00%	0.5010	3.1139	2.8330
Heptane	11.22%	3.8038	0.11%	4.7164	20.00%	0.9529	4.7567	3.7635
Octane	13.76%	4.8035	0.37%	17.9678	60.00%	12.6586	17.4621	5.3092
Nonane	14.83%	6.3425	0.01%	0.5367	80.00%	0.4861	6.8286	0.0506
Decane	15.19%	7.0167	0.01%	0.6044	90.00%	0.5439	7.5606	0.0604
Hydrogen Sulfide	0.01%	0.0011	0.00%	0.0000	0.00%	0.0000	0.0011	0.0000
Water	0.03%	0.0018	1.68%	12.6962	75.00%	10.8927	10.8945	1.8035
Total	**100.00%**	**42.5000**	**100.00%**	**850.0000**		**36.04**	**78.49**	**813.96**
Allocation Meter Uncertainties:		**20.00%**		**3.00%**		**9.942%**	**11.738%**	**3.007%**

Liquid Component Uncertainty: **10%**

Gas Component Uncertainty: **5%**

Uncertainty on Recovery Factors: **20%**

Gas Mass Fraction: **95%**

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Uncertainty Determination

Monte Carlo Simulation Models

Straightforward simulation of large, complex systems.

Monte Carlo simulation can be helpful in understanding the effects of various kinds of errors on the allocation process, including those due to measurement bias.

Proportional and Uncertainty-Based Allocation Model has been Created and Used to verify their Relative Performance.

Mean-Square-Error

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Mean-Square-Error is a Measure of How Well the Imbalance has been Distributed among the Allocation Meters. Where

$$\tilde{Q}_i = Q_i + a_i \cdot I$$

the Mean-Square-Error (MSE) is

$$MSE = E\left\{\sum_1^N (\tilde{Q}_j - Q_j)^2\right\}$$

Some MCS Results

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Ratio of Flows Q1/Q2	Q1	E1	Q2	E2	Qz	Ez	Avg ImB	Qa1	Eqa1	Qa2	Eqa2	Qb1	Eqb1	Qb2	Eqb2	MSE Ratio
10.00	**500**	**5.0%**	**5000**	**1.0%**	5500	**1.0%**	0.0	500.2	4.8%	5000.2	1.0%	500.2	4.7%	5000.2	1.1%	1.10
7.50	500	5.0%	3750	1.0%	4250	1.0%	0.0	500.0	4.6%	3750.3	1.0%	499.9	4.6%	3750.3	1.2%	1.17
5.63	500	5.0%	2812.5	1.0%	3312.5	1.0%	0.0	500.0	4.4%	2812.5	1.0%	500.0	4.4%	2812.5	1.2%	1.28
4.22	500	5.0%	2109.4	1.0%	2609.4	1.0%	0.0	500.1	4.0%	2109.5	1.1%	500.0	4.2%	2109.6	1.4%	1.43
3.16	500	5.0%	1582	1.0%	2082	1.0%	0.0	500.1	3.6%	1582.0	1.1%	500.2	4.0%	1581.9	1.6%	1.65
2.37	500	5.0%	1186.5	1.0%	1686.5	1.0%	0.0	500.0	3.2%	1186.5	1.1%	499.9	3.7%	1186.6	1.8%	1.93
1.78	500	5.0%	889.89	1.0%	1389.9	1.0%	0.0	499.9	2.8%	889.9	1.1%	499.8	3.4%	890.0	2.1%	2.24
1.33	500	5.0%	667.42	1.0%	1167.4	1.0%	0.0	499.9	2.4%	667.4	1.1%	499.8	3.1%	667.5	2.4%	2.59
1.00	500	5.0%	500.56	1.0%	1000.6	1.0%	0.0	499.9	2.1%	500.6	1.0%	499.8	2.7%	500.7	2.7%	2.76
0.75	500	5.0%	375.42	1.0%	875.42	1.0%	0.0	499.9	1.8%	375.4	1.0%	499.9	2.4%	375.4	3.1%	2.82
0.56	500	5.0%	281.57	1.0%	781.57	1.0%	0.0	499.9	1.6%	281.6	1.0%	499.9	2.1%	281.7	3.4%	2.78
0.42	500	5.0%	211.18	1.0%	711.18	1.0%	0.0	500.0	1.4%	211.2	1.0%	499.9	1.8%	211.2	3.7%	2.51
0.32	500	5.0%	158.38	1.0%	658.38	1.0%	0.0	500.0	1.3%	158.4	1.0%	500.0	1.6%	158.5	4.0%	2.22
0.24	500	5.0%	118.79	1.0%	618.79	1.0%	0.0	500.0	1.2%	118.8	1.0%	500.0	1.4%	118.8	4.2%	1.86
0.18	500	5.0%	89.09	1.0%	589.09	1.0%	0.0	500.0	1.2%	89.1	1.0%	500.0	1.3%	89.1	4.4%	1.56
0.13	500	5.0%	66.817	1.0%	566.82	1.0%	0.0	500.0	1.1%	66.8	1.0%	500.0	1.2%	66.9	4.6%	1.34
0.10	500	5.0%	50.113	1.0%	550.11	1.0%	0.0	500.0	1.1%	50.1	1.0%	500.0	1.1%	50.1	4.8%	1.18
0.08	500	5.0%	37.585	1.0%	537.58	1.0%	0.0	500.0	1.1%	37.6	1.0%	500.0	1.1%	37.6	4.9%	1.09
0.06	500	5.0%	28.189	1.0%	528.19	1.0%	0.0	500.0	1.1%	28.2	1.0%	500.0	1.0%	28.2	4.9%	1.03
0.04	500	5.0%	21.141	1.0%	521.14	1.0%	0.0	500.0	1.0%	21.1	1.0%	500.0	1.0%	21.1	5.0%	1.00

Some MCS Results

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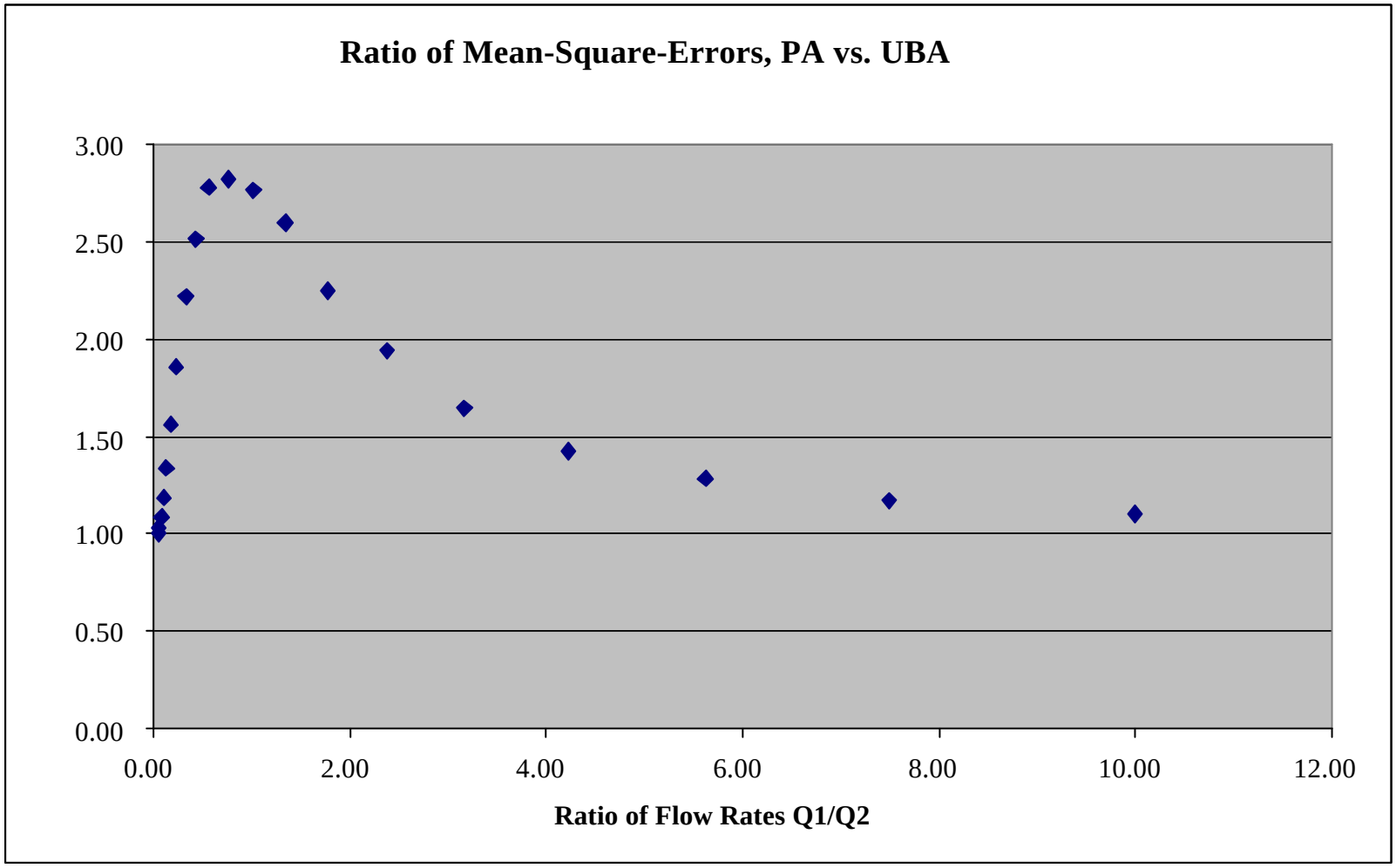

Some MCS Results

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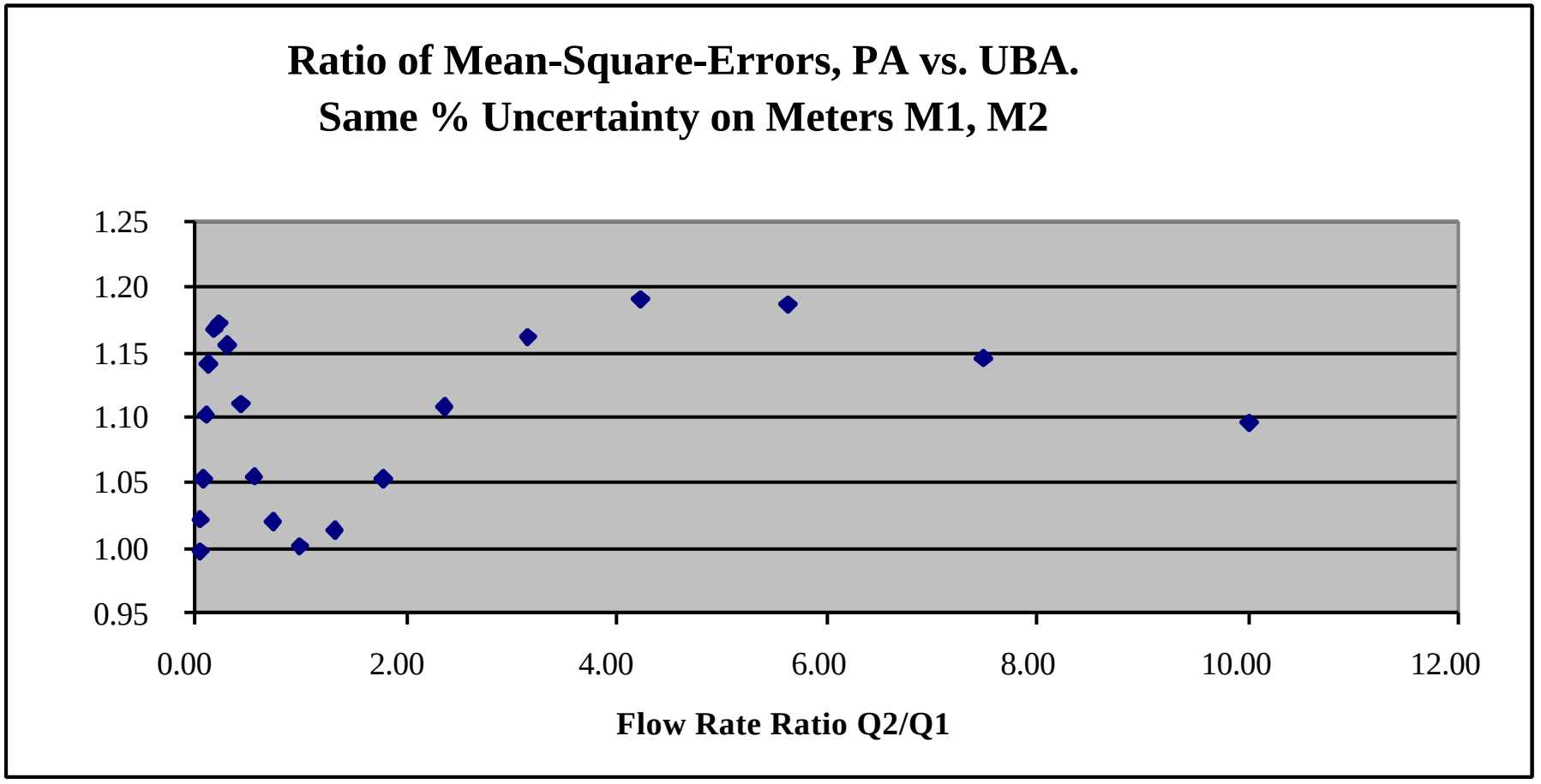

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Bias Errors in Measurement

Bias Errors in Measurement

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Bias errors can be analyzed by writing the measurement as

$$Q_i = \overline{Q}_i + e_i + d_i$$

where

$e_i =$ random measurement error

$d_i =$ systematic (bias) measurement error

Bias Errors in Measurement

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It can be shown that

$$E[I] = d_z - \sum_1^N d_j$$

and

$$E\left[(I - \bar{I})^2\right] = s_z^2 + \sum_1^N s_j^2$$

Bias Errors in Measurement
A Few Sources

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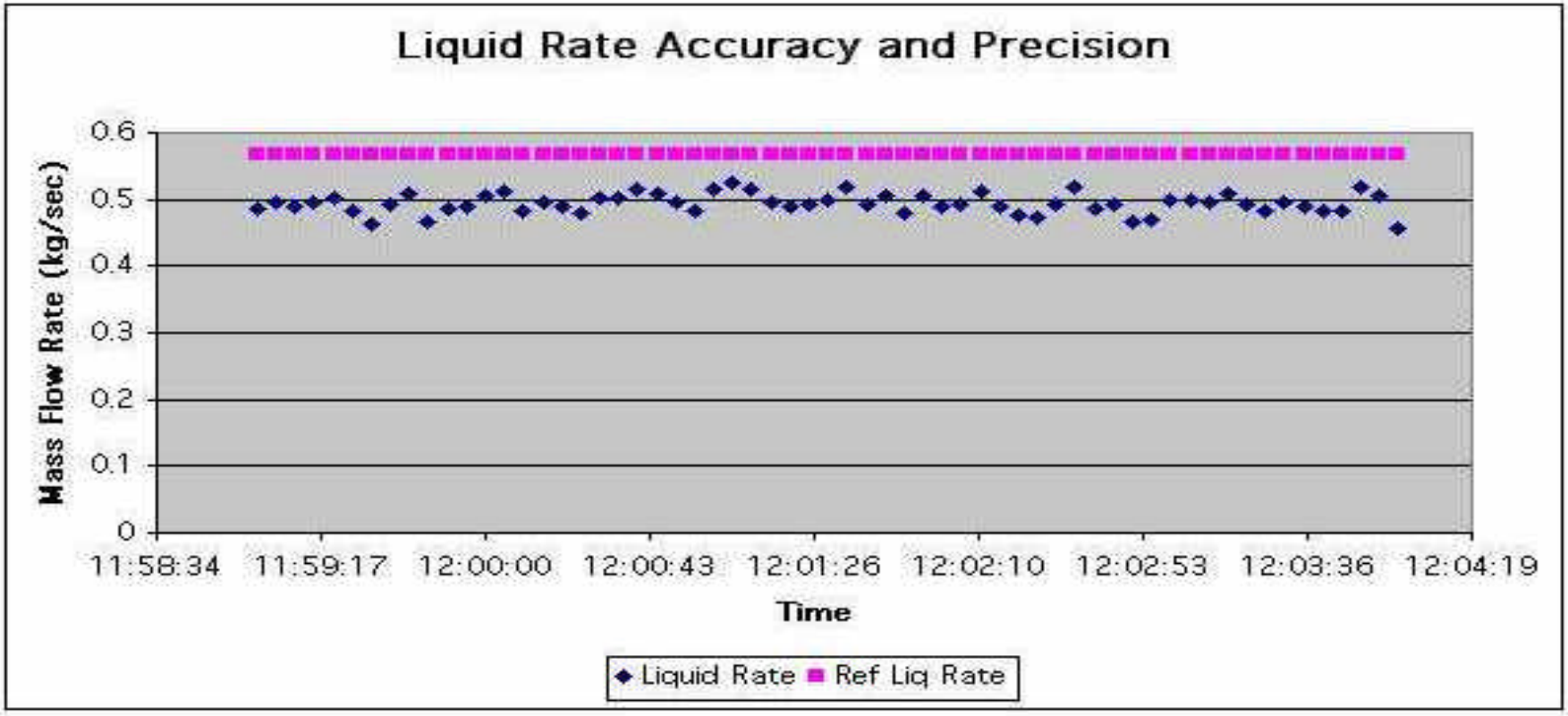
1. Sensor Drift (e.g. P, DP, T)	Bipolar
2. Geometric Alteration (e.g. Deposits)	Unipolar
3. Installation Effects (Pipework)	Bipolar
4. Composition, PVT Errors	Bipolar
5. Meter Model Errors	Bipolar

Bias Errors - Meter Model



Bias Errors - Meter Model

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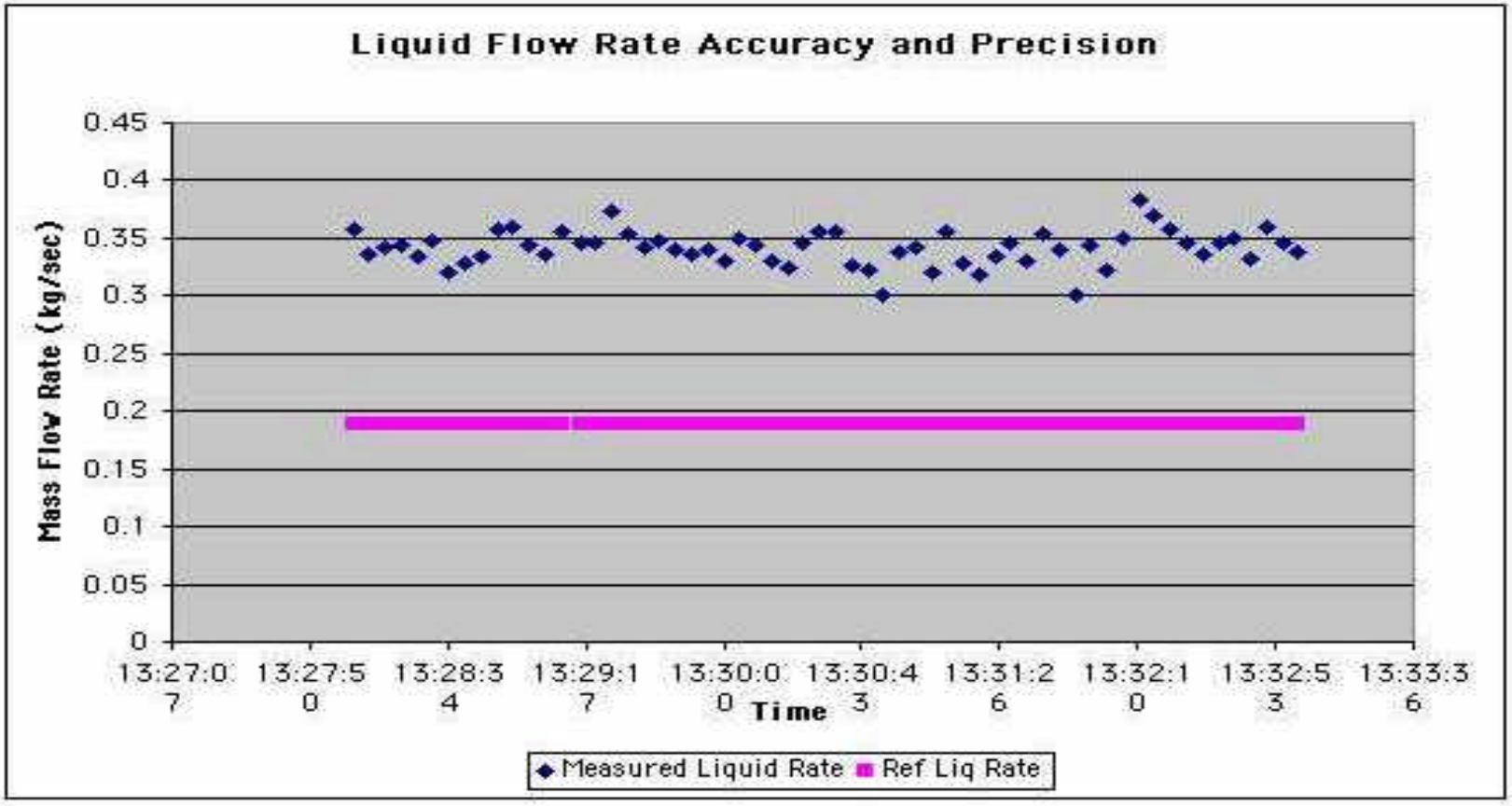

Conclusions

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1. Uncertainty-Based Allocation May Offer a More Equitable Method for Imbalance Distribution than Proportional.

2. Determination of the Various Uncertainties Required is a Non-Trivial Exercise.

3. To Fully Exploit the Potential of the Method, Large-Scale Simulations Can Prove Helpful. Monte Carlo Simulation Seems Particularly Well-Suited for this.

4. This is Just the Beginning.