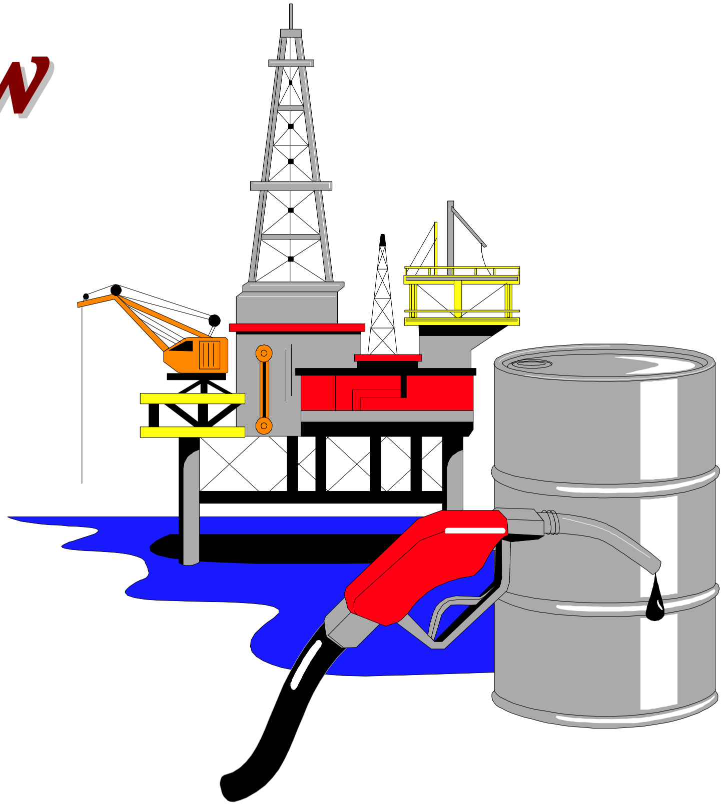
Caledonian Flow Systems Limited

EnSys Yocum

Are Fluid Properties Important for Multiphase Flow Measurement ?



By

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The Contentions of This Paper

1. Good PVT properties are essential to accurate multiphase metering

2. Good PVT properties plus good PTQ simulation expand the power of - or replace - mpms

Definitions

- Focus is produced gas, oil & water before separation
- Measurement goals:
  - phase volume fractions - gas, oil, water (saline) & sand?
  - volume rates: phase or bulk if flow homogenized
  - mass rates by phase (densities)
  - translation of rates to standard, downhole or other conditions

Incentives for Using Multiphase Measurement

- **Primary justifications:**
  - Compact size
  - Ability to operate at high pressures & temperatures
  - Eliminate need for test separators, test lines, deck space offshore
  - At least match test separator accuracy
  - Provide continuous not intermittent measurement
- **Typical meter locations:**
  - wellhead: offshore, onshore difficult/remote areas
  - sub-sea
  - downhole

Types of Multiphase Metering System

- Traditional 3 phase gravity separator plus single phase meters (total separation)
- Straight through multiphase meters (no separation)
- Partial separation systems
- “Neural network” meters
- Virtual meters - multiphase simulation software
- Apply to wet gas as well as black oil systems

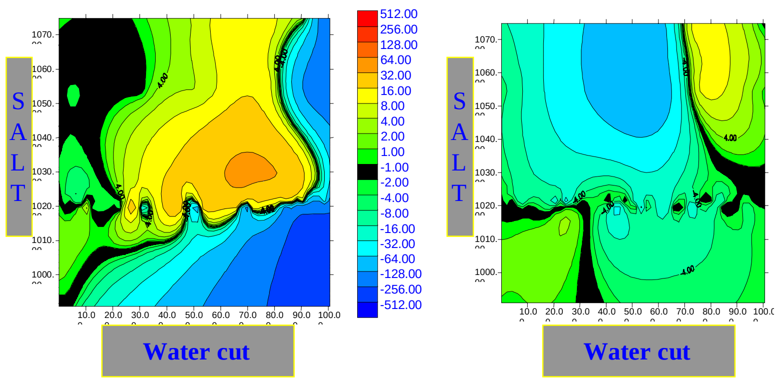
Current Multiphase Meters

- Use exotic technologies, e.g.:
  - Fluenta (Inductance / capacitance & sand)
  - Agar (Capacitance / low frequency Microwave)
  - Framo, Kvaerner, Mixmeter (Dual gamma densitometer)
  - Roxar (Microwave - Low Frequency plus densitometer)
  - Starcut (Microwave - High frequency)
  - fiber optics (CiDra)
- Resulting high cost
  - $150,000 - $300,000 topside
  - $250,000+ subsea

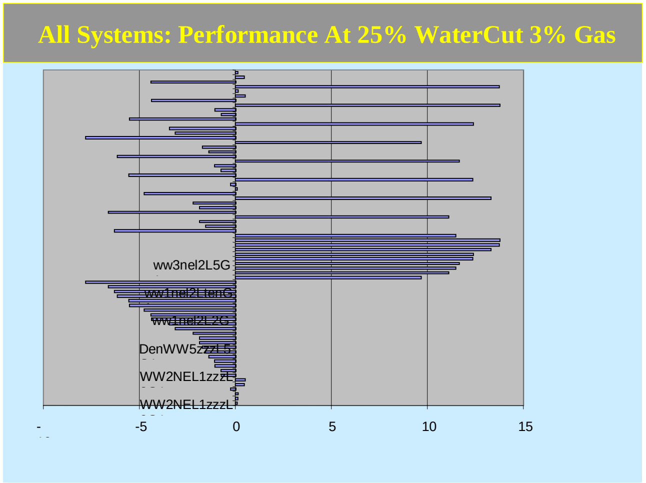
Current Multiphase Meters

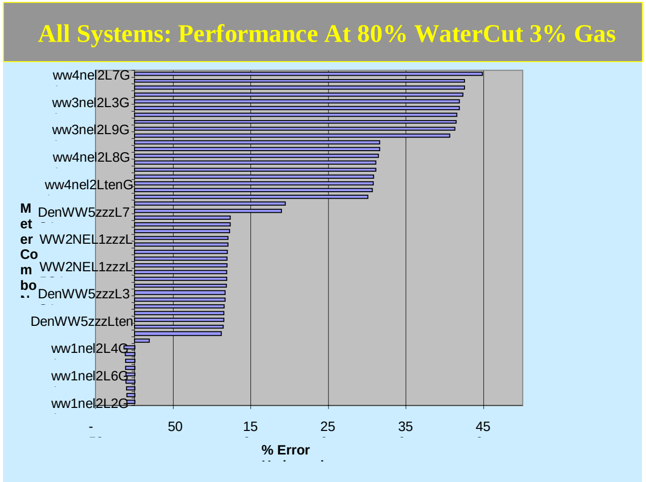
- Have variable accuracies

Dealing With True Complexity Forces Computer Modeling



Both Meters Claim 10% Uncertainty in WaterCut
But Performance is a Very Strong Non-Linear Function of Production



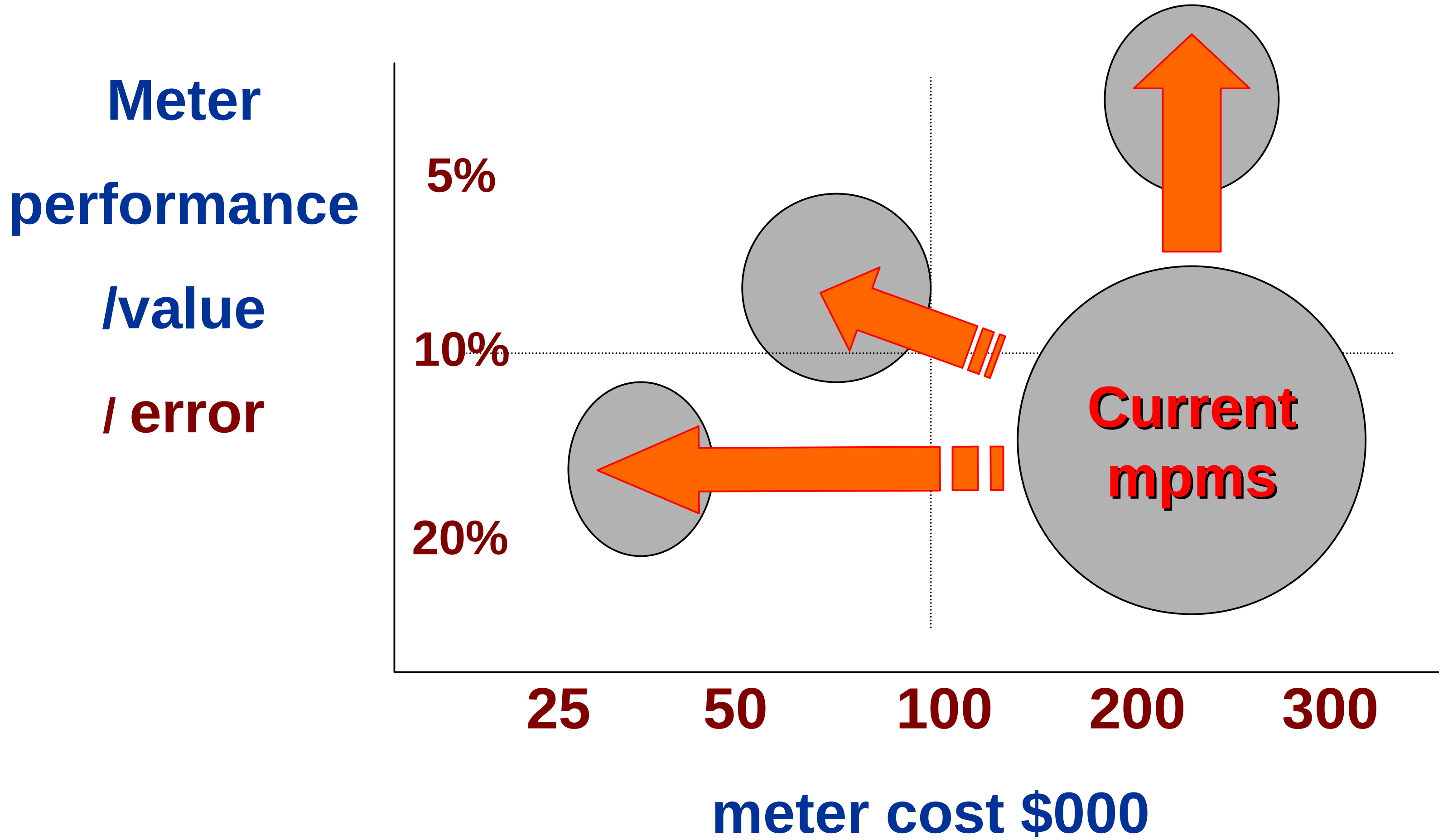


Courtesy of

Texaco Humble Flow Facility

Current Multiphase Meters

Price / performance does not always match market needs



Issue: Cost - Limits Widespread Use

- Three markets perceived:
- $150,000 - $350,000
  - limited/niche market
  - difficult/extreme conditions, e.g. sub sea
- $75,000 - $100,000
  - potential for wide application on medium to high rate wells
  - including retrofitting
  - e.g. offshore platforms, Alaska
- $30,000
  - widespread onshore replacement of test separators
  - lower rate wells/lines, onshore, existing/new fields

Issues: Reliability & Accuracy

- Typical current MPM error/uncertainty ranges:
  - favorable conditions / operating range < +/- 10%
  - unfavorable conditions / operating range > +/- 50%
  - compared against test separator +/- 1-5% at best to +/- 30%
- Desired MPM error ranges:
  - allocation: +/-10% higher error acceptable provided no bias
  - reservoir management: +/- 5-10%
  - process management +/- 5-10%
  - fiscal +/- 1%

Issues: Reliability & Accuracy

- Focus on Mean Time Between Failures (MTBF) reliability for extreme conditions
- Susceptibility to conditions, e.g.
  - low ambient temperatures
  - scaling
- Error susceptibility to:
  - high GVF (> 90%)
  - high water cut
  - salinity (StarCut, MEGRA technologies measure salinity)
  - viscosity

Current Multiphase Meters

the role of fluid properties

Are Fluid Properties Important for Multiphase Flow Measurement ?

Errors in input physical properties cause errors in fractions & total flow rates:

- MPM P,T operating conditions change every day, hour, minute
- Produced fluid properties drift over months
  - GOR and Watercut
  - due to differential zone depletion and gas coning

Errors in input physical properties cause errors in fractions & total flow rates:

Mpms require fluid properties as inputs

e.g. dual energy gamma densitometer equations require 9 input physical property items as function of meter P,T

$$N = N_o e^{-x\left[\left(\mu_o \rho_o OVF\right)+\left(\mu_w \rho_w WVF\right)+\left(\mu_g \rho_g GVF\right)\right]}$$

Where:

N = count rate from the gamma detector **(2 readings)**
N_o = "empty pipe" count rate (2 known)
x = gamma path length (constant)
ρ = density of the penetrated phase **(3 inputs)**
µ = mass attenuation coefficients of penetrated phases **(6 inputs)**

Vary with meter P and T

OVF = Oil Volume Fraction **) three**
WVF = Water Volume Fraction **) unknowns**
GVF = Gas Volume Fraction **)**

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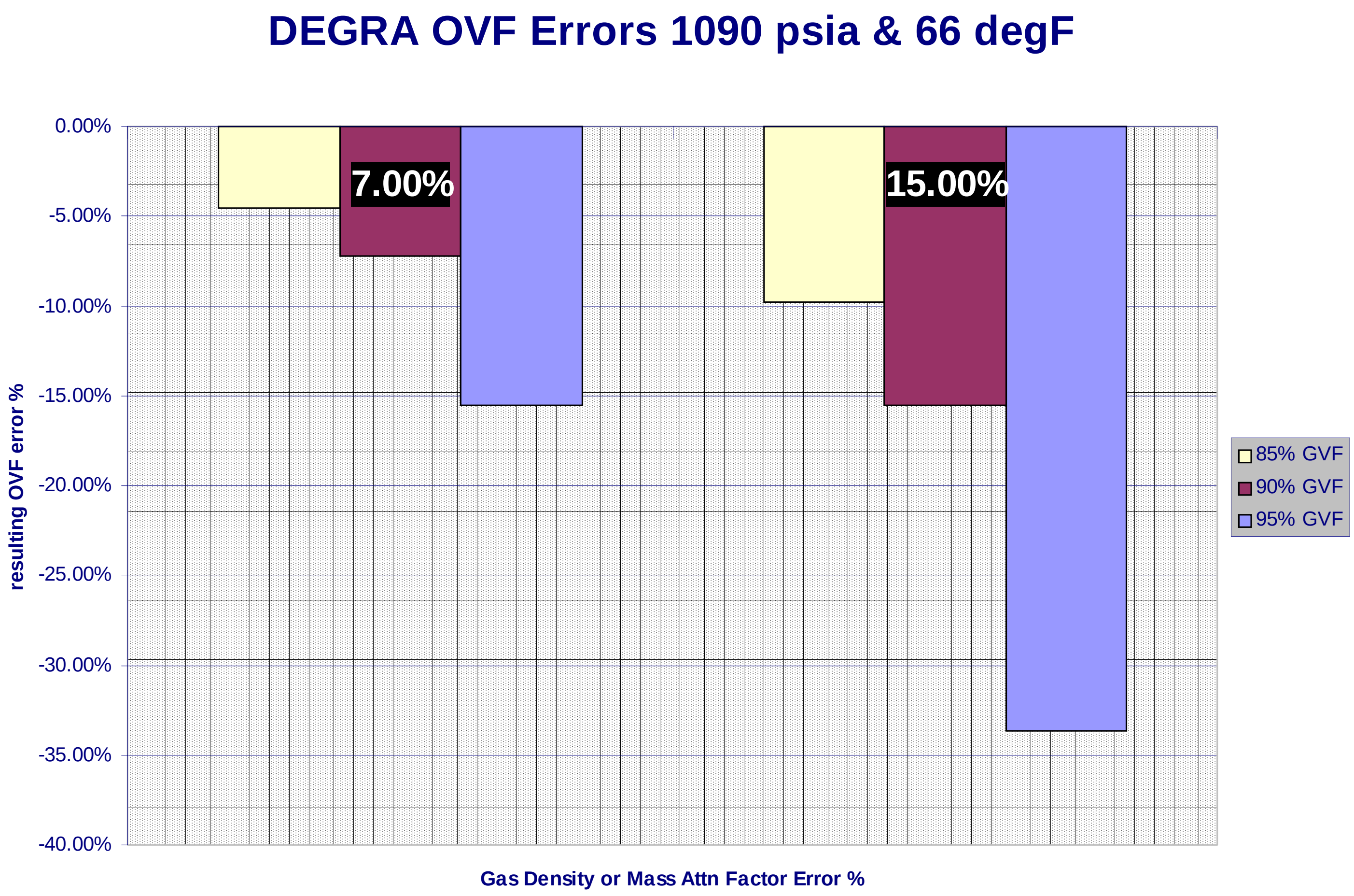
Errors in input physical properties cause errors in fractions & total flow rates:



Errors in input physical properties cause errors in fractions & total flow rates:

- With low GVF fluids, both phases are appreciably affected
- With wet gas / high GVF fluids (80%+ GVF), significant errors in input properties have only limited effect on calculated GVF – errors generally less than +/-2% - but substantial impact on calculated oil VF and rate
- As meter pressure increases so does resulting error in oil or gas VF and rate
- Similarly, oil or gas VF error increases with gas volume fraction

Are Fluid Properties Important for Multiphase Flow Measurement ?

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Errors in input physical properties cause errors in fractions & total flow rates:

- Errors in multiple input properties may partially offset each other but create the risk of very high total errors
- A resulting error in total bulk density (computed from the phase fractions and densities) leads to errors in calculated total flow rate as well as phase rates

90% GVF Fluid	*Gas density error*		*oil density error*	
	7%	15%	7%	15%
Mass flow rate error	+ 3%	+6.5%	+ 0.3%	+0.7%

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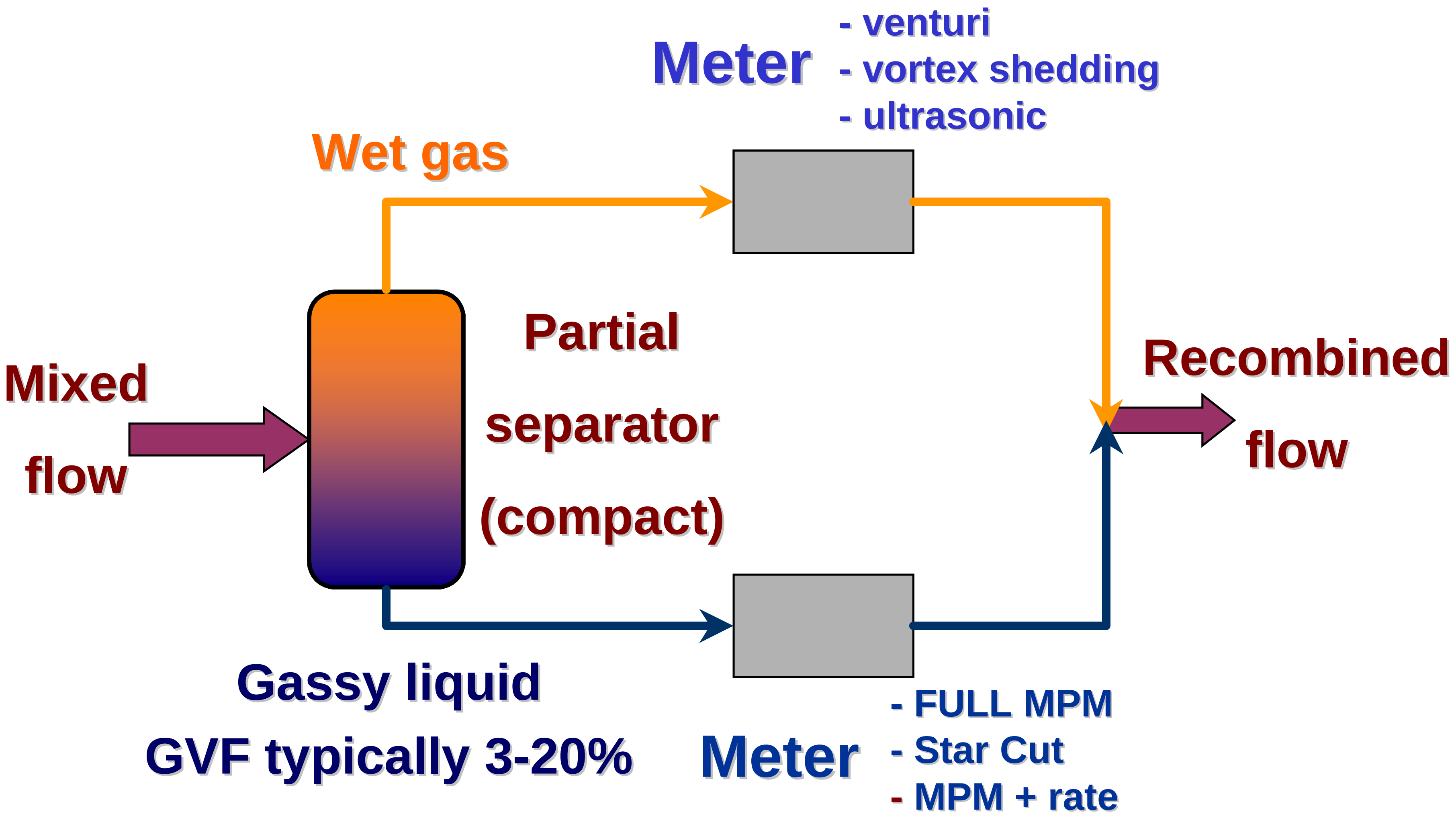
Partial Separation Metering - Sensitive to PVT Data



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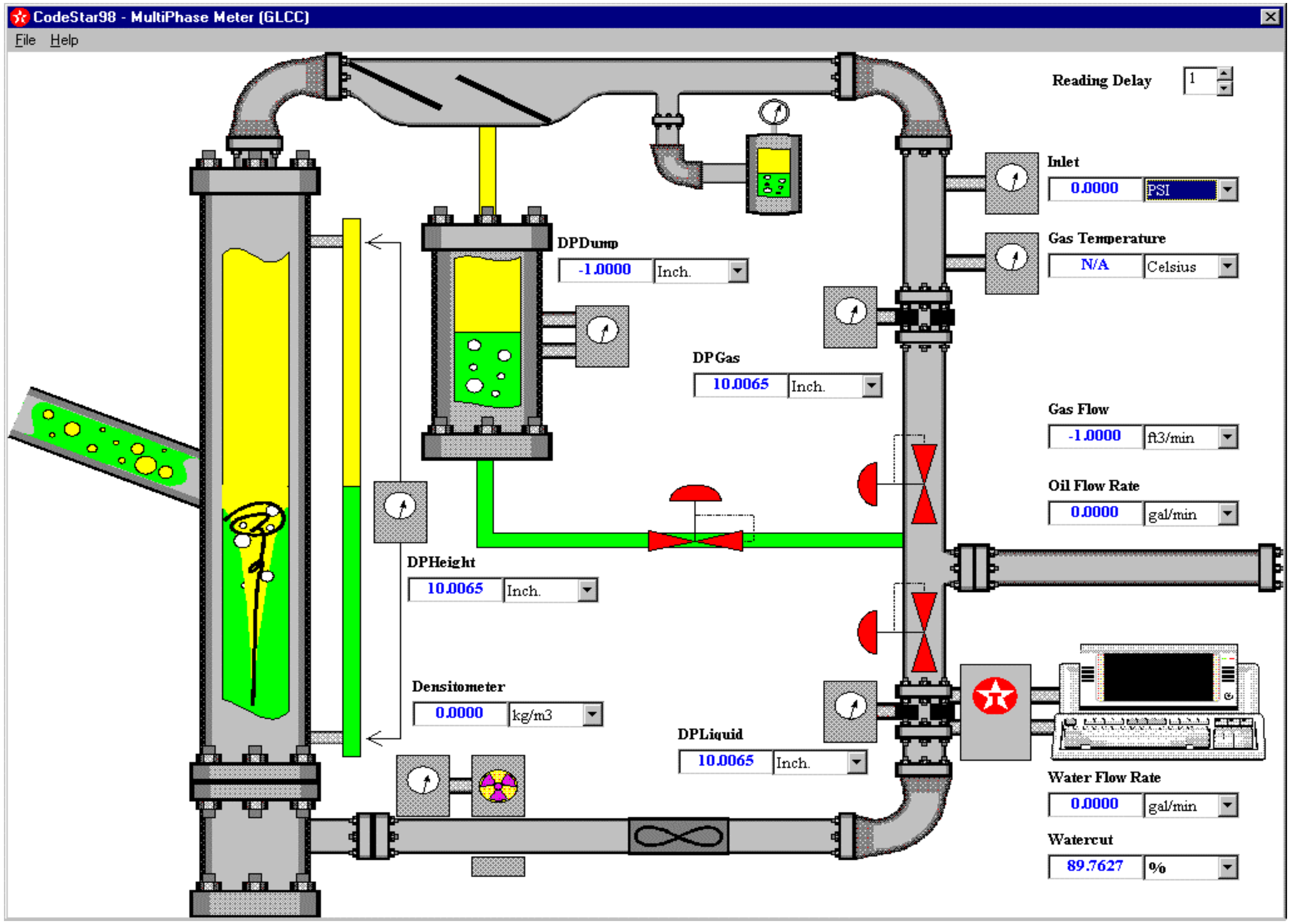
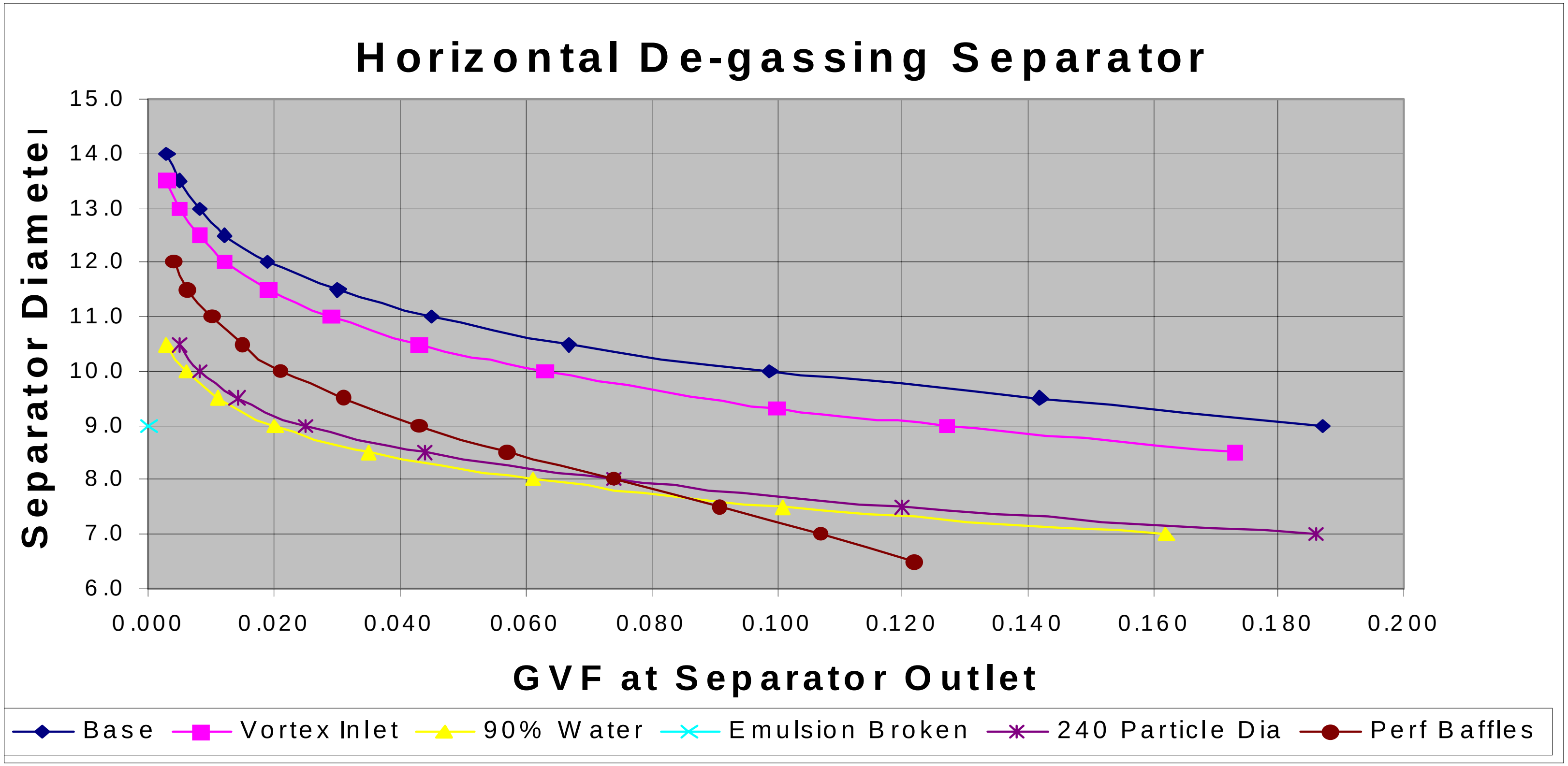
Partial Separation Metering Example

courtesy Texaco Humble Flow Facility



Partial Separation Metering Introduces Separator/Meter Cost Trade-offs



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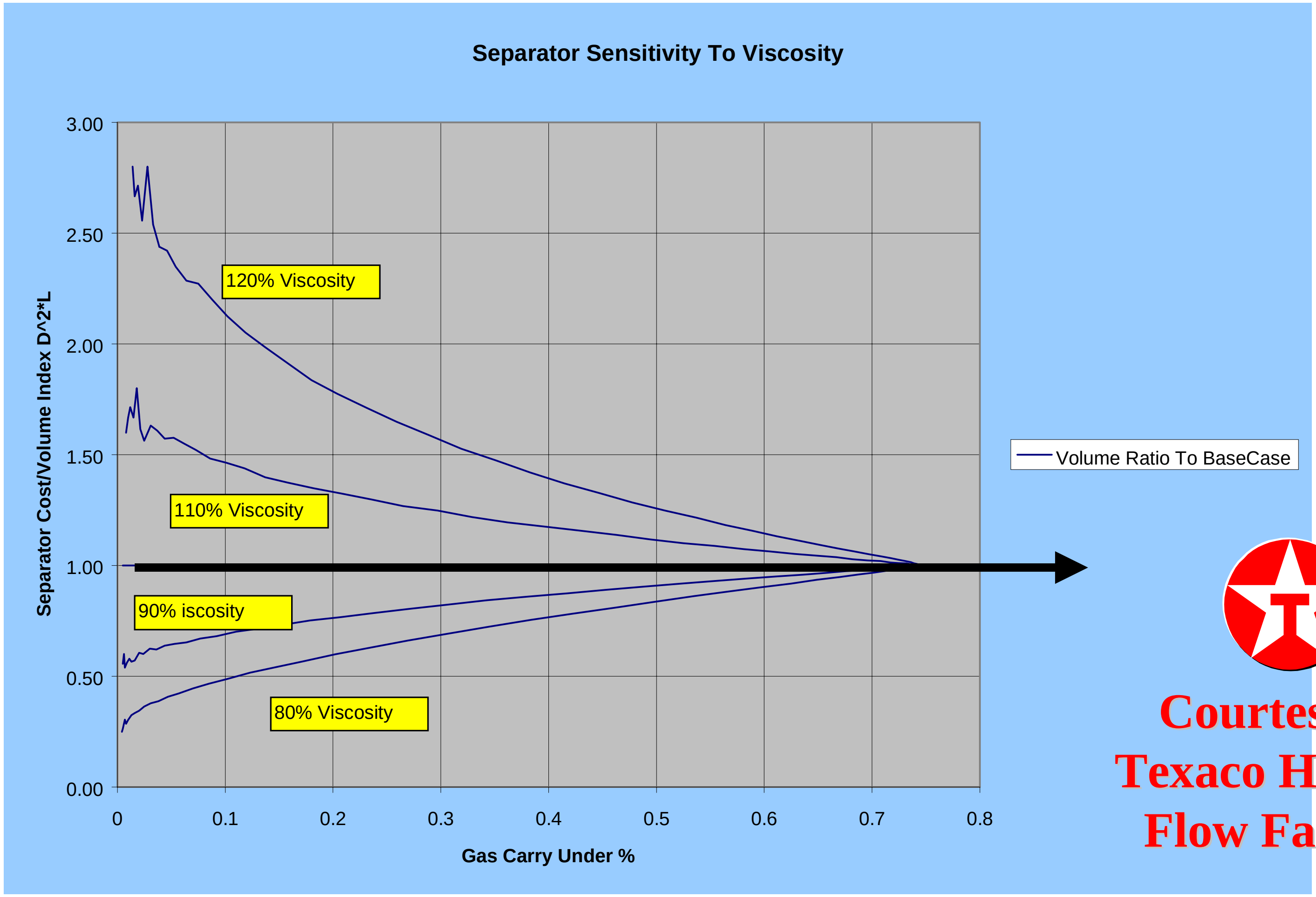
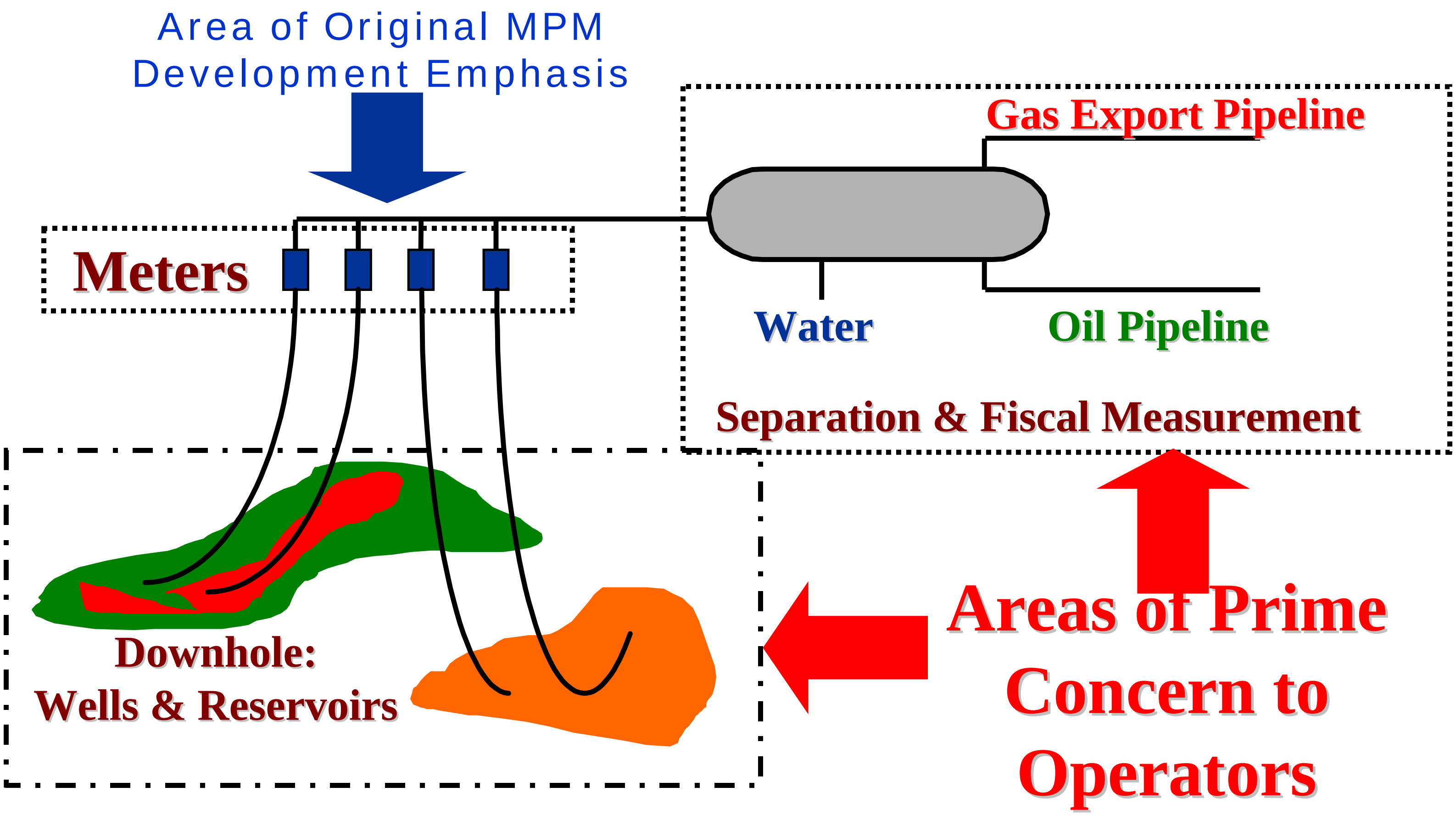
Separator/meter Costs Are Especially Sensitive to Fluid Properties/conditions



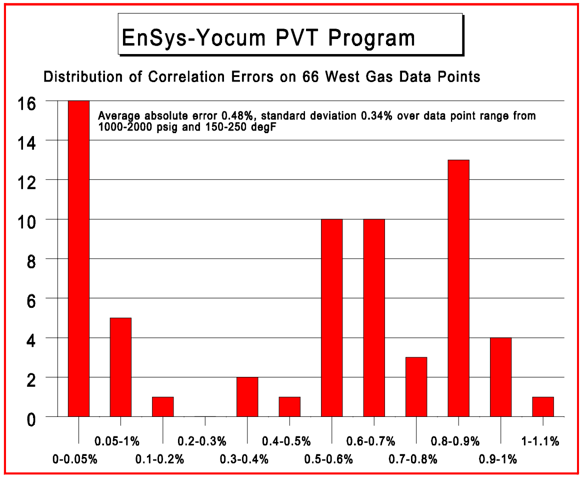
Courtesy of Texaco Humble Flow Facility

Operators Need Flow Rates at Different Conditions



PVT data - critical but sources of uncertainty

- Reservoir fluid laboratory PVT “assay”
  - the most accurate source of fluid property data
  - uncertainty +/- 1% to +/- 5%
- Compositional analyses plus Equation of State modeling or incomplete assay
  - uncertainties on phase densities
  - go to 10-15%
  - limited improvements since 1970’s
- Produced fluid properties
  - drift over months
  - GOR, Watercut
- Curve fitting / regression of properties against P,T
  - typical errors (EYI regression model method)
    - +/- 0.5-2 %



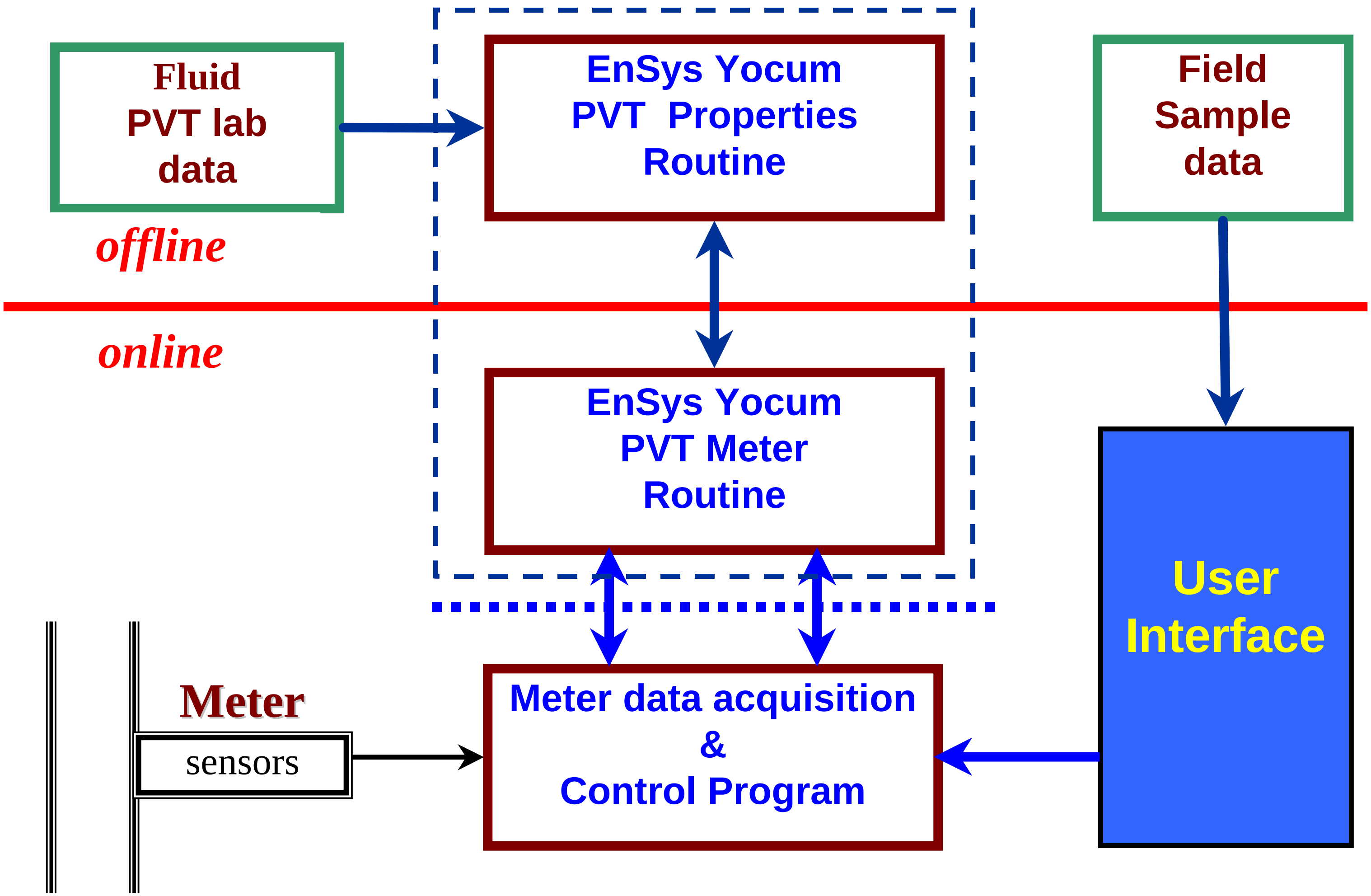
Methods to reduce PVT data uncertainty

- Reservoir fluid assays
  - multiple samples, repeat sampling - costly ($$$)
- Partial data / EOS modeling
  - field sampling to update and anchor base PVT data ($$)
  - on-line compositional analyses linked to fluid assay ($$)
- Gap filling
  - use of EYI reservoir fluid database (65+) to cross check and fill data gaps
- Corroboration through:
  - PTQ simulation across total field:
    - rate accuracy +/_ 2-3% for wells
    - 4-10% for surface facilities including flow lines and separators
  - Reconciliation against fiscal meters

PVT Meter Software

- Addresses many mpm accuracy and utility issues:
  - accuracy of phase densities etc. at meter P,T
  - maintaining accuracy as P,T alter
  - updating for changes in other conditions, e.g. gas lift rate
  - updating properties over time
  - converting rates to standard, downhole and alternative conditions

Scope of EYI PVT Software



PVT Meter Software

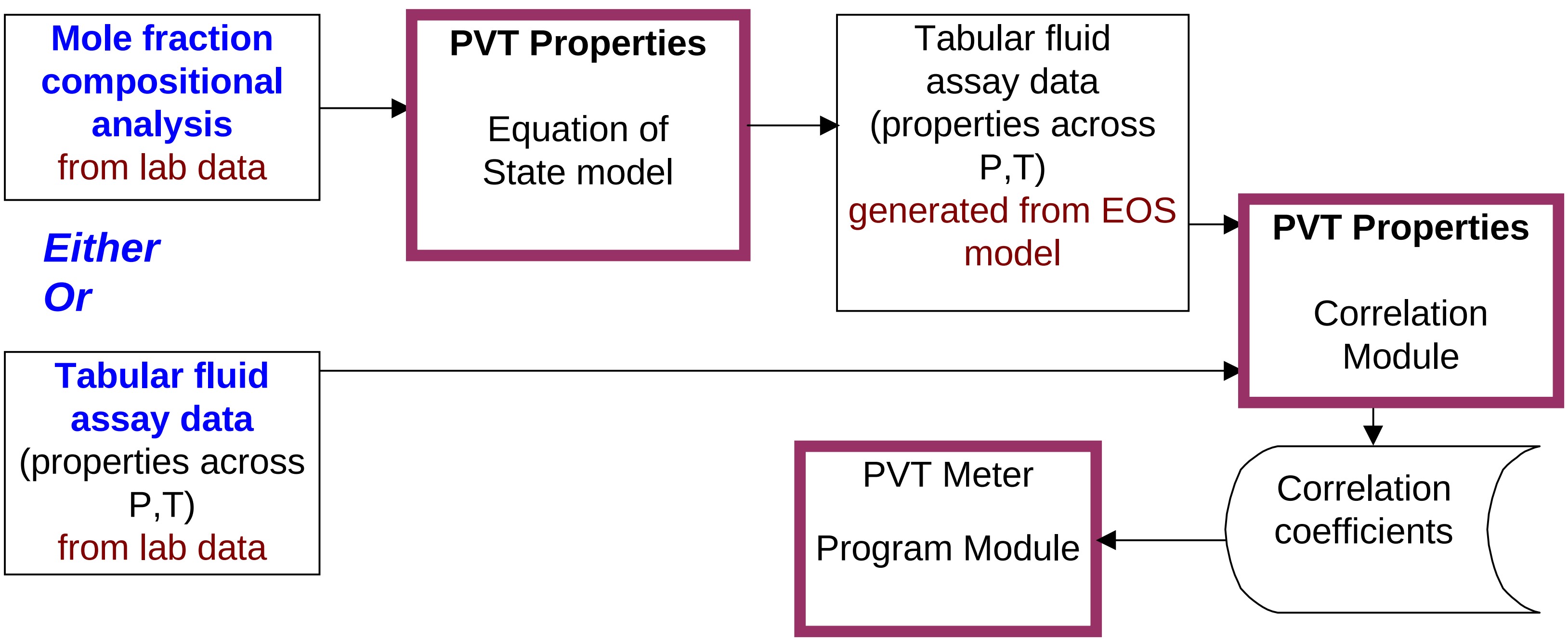
- The PVT Meter routine:
  - Takes in meter conditions data
  - PVT coefficient data, as produced by EYI PVT properties routine and representative of a particular fluid assay
  - Outputs corrected fluid phase densities
    - At meter conditions
    - Flow correction factors to standard
    - Other conditions e.g. Reservoir, stock tank
- The PVT Properties routine:
  - Processes reservoir fluid assay data to produce properties correlation equations against temperature and pressure
  - Interfaces resultant PVT coefficient data sets for input to the PVT meter routine

Operating Environment

- PVT Meter Software (PVT Properties and PVT Meter) can be offline or integrated as routines into the MPM Data Acquisition & Control (DAC) system
- PVT Software routines passes information internally to and from the main DAC routines and externally via user interfaces to and from the operator
- MPM DAC system performs flow and fractions calculations at approximately once per second cycle, calling the PVT Meter Software each cycle - or when P,T change
- PVT Meter routine may therefore optionally not pass back calculations on fluid property slopes versus P and T since phase fluid properties will be considered constant for each one second (or selected) interval

PVT Meter Software

Works with alternative sources of fluid properties data



Primary Features of PVT Meter Software

- PVT Properties routine can:
  - accept tabular data against pressure and temperature
  - interface with Equation of State systems enabling users to input compositional data (although less accurate)
  - EYI Reservoir Fluid Properties Database of Reservoir fluids analysis is available to match fluid properties
  - other approaches to maximize accuracy with compositional data / EOS based approaches to fill assay gaps.
  - convert phase densities, GOR and mixture viscosity against P,T into compact, accurate regression equation correlations, coefficients for which will be fed to the PVT Meter routine

Primary Features of PVT Meter Software

- PVT Properties and Meter routines are capable of handling multiple fluid "assays" for MPMs cycling across several streams/wells with MPM DAC program will need to identify the relevant assay/well to the PVT Meter routine
- PVT Meter routine will:
  - Calculate phase densities, bulk density, GOR (mass fraction gas and mass fraction liquid), mixture viscosity all at meter P,T (one second interval) for use in MPM phase fraction computation equations
  - Re-anchor phase properties correlations based on input gas and liquid field sample data

Primary Features of PVT Meter Software

- **PVT Meter routine will:**
  - Adjust assay GOR and hence re-anchor phase properties given user input of change (up or down) in GOR versus assay plus related gas density
  - Given gas, oil and water phase mass flow rates at meter P,T calculated by the DAC program using the EYI one second phase densities, convert these meter conditions rates to standard conditions and to alternative conditions as specified (input) by the operator
  - Given input lift gas rate and density, account for the effect of lift gas on produced gas phase density and rate at meter, standard and alternative conditions
  - Given an input user flag, accommodate for retrograde condensation fluid characteristics

Primary Features of PVT Meter Software

* PVT Meter routine will:
  - Provide a comparison of bulk density from the MPM with bulk density from the assay so significant differences can be used as a flag to potential problems reading and can provide a "takeover" function in the event of the failure of the MPM unit
  - Calculate the split of H_2S and CO_2 between gas and liquid phases for meter, standard and alternative conditions
  - Optionally report flow rates on an H_2S and CO_2 free basis
  - Compute the calorific value of the gas phase at standard conditions
  - Perform a back-up Venturi total mass flow rate calculation given input Venturi characteristics and one second P,T, delta P

Primary Features of PVT Meter software

- PVT Meter routine will:
  - Calculate the fraction of liquid at meter conditions remaining as liquid at standard conditions. (This feature is valuable if the presence of a liquid slug causes instantaneous MPM phase fraction computation to be lost.)
  - potentially calculate phase mass attenuation coefficients or other properties as a function of P,T
  - Separator stages may be user specified. The PVT Meter Program will calculate the oil, gas and water flows at each stage, along with the calorific values and H_2S, CO_2 and water contents.

Primary Features of PVT Meter Software: Partial Separation Configuration

- From the total fluid properties at partial separator input conditions, calculates:
  - The fluid properties of the overhead gas phase to enable computation of the gas leg mass rate from the gas leg meter's computation of gas velocity/volume rate
  - The fluid properties (as above) of the gassy liquid leg for the MPM
- Achieving accuracy in these computed gas and liquid leg properties can employ simulation of the partial separator to capture gas carry-under and liquid carry-over (if any).

Primary Features of PVT Meter Software

- Has the following features designed to ensure robustness:
  - Handles complete range of gas and liquid flow ratios, from 0%-100% liquid
  - Handles from zero to high rate flow to capture both, the laminar flow (where the venturi coefficient of discharge decreases) to homogeneous flow, up to sonic flow regions
  - Performs over a range of test loop runs intended for meter calibration, to establish accuracy and to define the operating envelope of the meter
  - Performs over a wide range from low pressure environments to the 10,000 psi plus conditions associated with high pressure gas condensate reservoirs
  - Continues to compute if incomplete input screening allows corrupted data to pass through as input to the program

PVT Meter Software - Field Experience

- The PVT Meter program was tested against actual flow data covering six readings/time periods during Summer 1998.
- The PVT Meter Program densities for gas and condensate were applied to convert to input mass flow rates.
- The comparison of database values versus program predictions is given below:

	Database	PVT Meter Program	Difference
Meter condition flow rates			
Gas flow rate, m^3 per hour	709.30	666.4	-6%
Condensate, m^3 per hour	62.15	64.1	+3%
Standard Condition flow rates			
Gas flow rate scf per day	39.85	38.65	-3%
Condensate stock tank bbls/day	7701	7553	-2%

PVT-PTQ

- Combining PVT modelling with multiphase pressure, temperature, flow (PTQ) simulation builds on the benefits of employing sound PVT software

- PTQ in this context combines:
  - multiphase PTQ simulation software
  - facilities configuration data: line profiles, valves etc.
  - PVT data & modelling - exactly as used for mpm
  - P,T sensing - minimally at start and end of flow system
  - optional low cost orifice or venturi meters (e.g. at well head)
  - initial/infrequent tuning/calibration against fiscal meters

PVT-PTQ

- New developments e.g. dependable downhole P,T sensing are enhancing potential
- Benefits:
  - low cost method for multiphase flow measurement
  - brings redundancy and comparison with conventional meters/mpms
  - can replace high cost mpms with simpler hardware
  - provides mass balance across entire flow system
  - maintains accuracy over wide range of flow conditions - no major error regions
  - flags sensor/meter malfunctions
  - integrated simulation is basis for production facilities trouble-shooting & optimization

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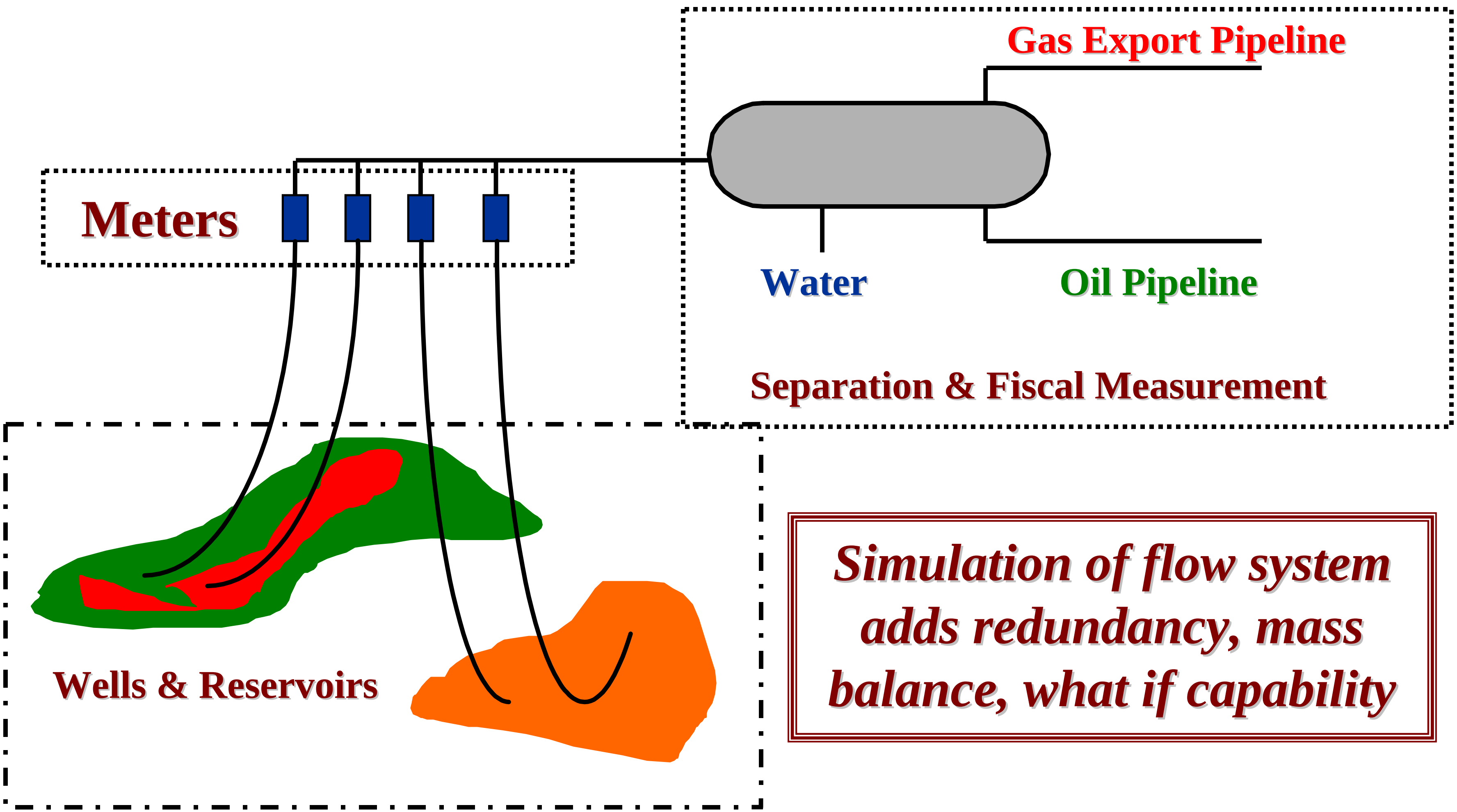
PVT-PTQ "Virtual" Metering



Simulation of flow system adds redundancy, mass balance, what if capability

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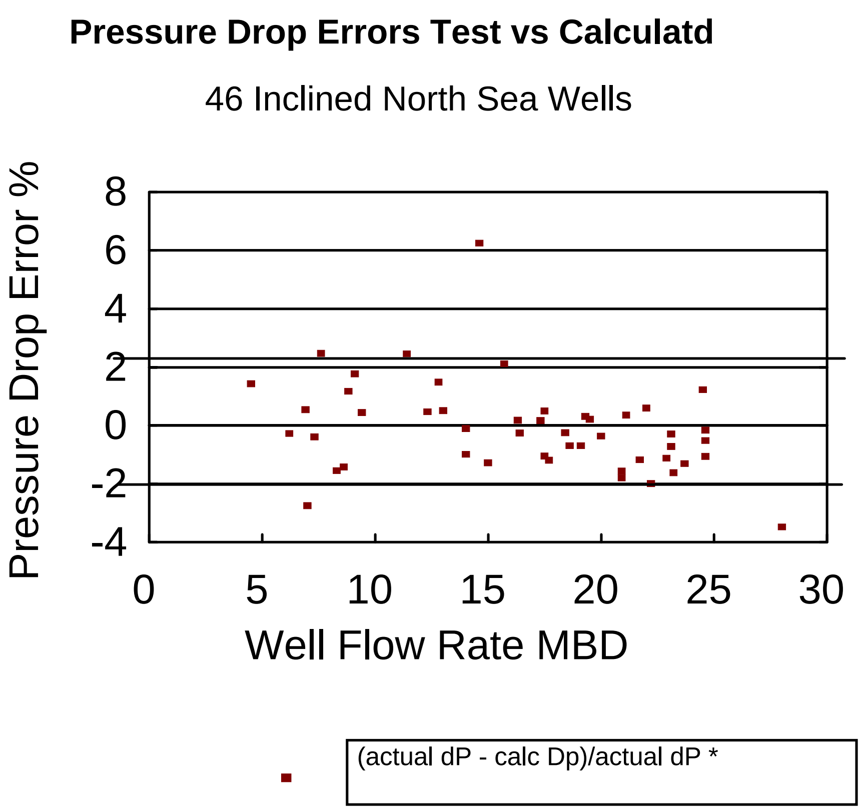
PTQ Simulator Performance is Critical

Validation against 46 North Sea Wells +/- 2-3%



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PTQ Simulator Performance is Critical

Validation against 367 Wells & Surface Facilities

OIL FIELD	OIL WELLS			SURFACE SYSTEMS		
	No.	Average Deviation (%)	Maximum Deviation (%)	No.	Average Deviation (%)	Maximum Deviation (%)
AGHA JARI	44	0.05	0.5	39	0.67	5.2
AHWAZ	31	0.28	0.77	30	0.16	5.1
GACH SARAN	29	0.08	0.57	25	0.78	2.6
RAG E SAFID	13	0.17	0.79	9	1.4	7.2
MARUN	31	0.08	0.95	29	0.6	4
PARIS	18	0.33	0.8	14	2	6.9
KARANJ	6	0.27	0.75	3	0.51	4.7
BIBI HAKEIMEH	11	0.05	0.55	11	0.45	4.2
NAFT E SAFID	9	0.04	0.96	9	INSUFFICIENT DATA	
PAZAN	3	INSUFFICIENT DATA		3	3.8	5.7
TOTAL	195	0.13	0.7	172	0.73	4.5
DATA ACCURACY	+/- 1-2%			+/- 3.7-10 %		

PTQ Simulator Performance is Critical

Validation - difficult systems

- **Agha Jari engineered field tests - pressure drop errors**

  11 runs above 10 sfgv 5.1%

  4 runs below 10 sfgv 11.8%

  - "tough" cases in hilly terrain
  - 16” flowlines up to 20,000 foot long
  - a GOSP case and a looped line case included
- The low rate cases are in slug flow and are extremely difficult to obtain accuracy for - these are characteristic of the low Froude Number flow in horizontally drilled laterals
- **Offshore Indonesia - 29 mile sub-sea line**

  calculated line pressure drop (without knowing P_{in}) to 15 psi

Conclusion

- Developing and maintaining accurate PVT data is essential to mpm fraction and rate performance
  - and to translating mpm rates to conditions needed by the operator
- PVT data production, application and updating need to be integral components of the mpm “system”
- Piggy-backing PTQ simulation onto the same PVT data
  - significantly enhances the power of a hardware mpm system
  - can provide an alternative low cost solution where hardware mpm’s not justified

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