BAKER HUGHES
a GE company

Distributed Flow Metering

SUT Down Under

October 25, 2018

Agenda

- Why Distributed Flow Metering?
- What is Virtual Flow Metering, and how it works?
- What is the distributed flow metering solution?
- Concept Validation

BHGE Roadmap to Distributed Flow Metering

Existing Technology

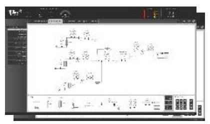
MPFM / WGFM
Mechanical footprints,
Expensive Solution…

Virtual Flow-Metering
Cheap, Reduced footprints,
limited calculations…

New Technology

Distributed Flow-Metering
Intermidiate solution, with limited
footprints Cheaper than MPFM / WGFM…

- Detail system design and component selection
- Solution benchmark against simulated and/or historic field data


+

=

The idea of a hybrid solution to provide the same results a the MPFM but cheaper…

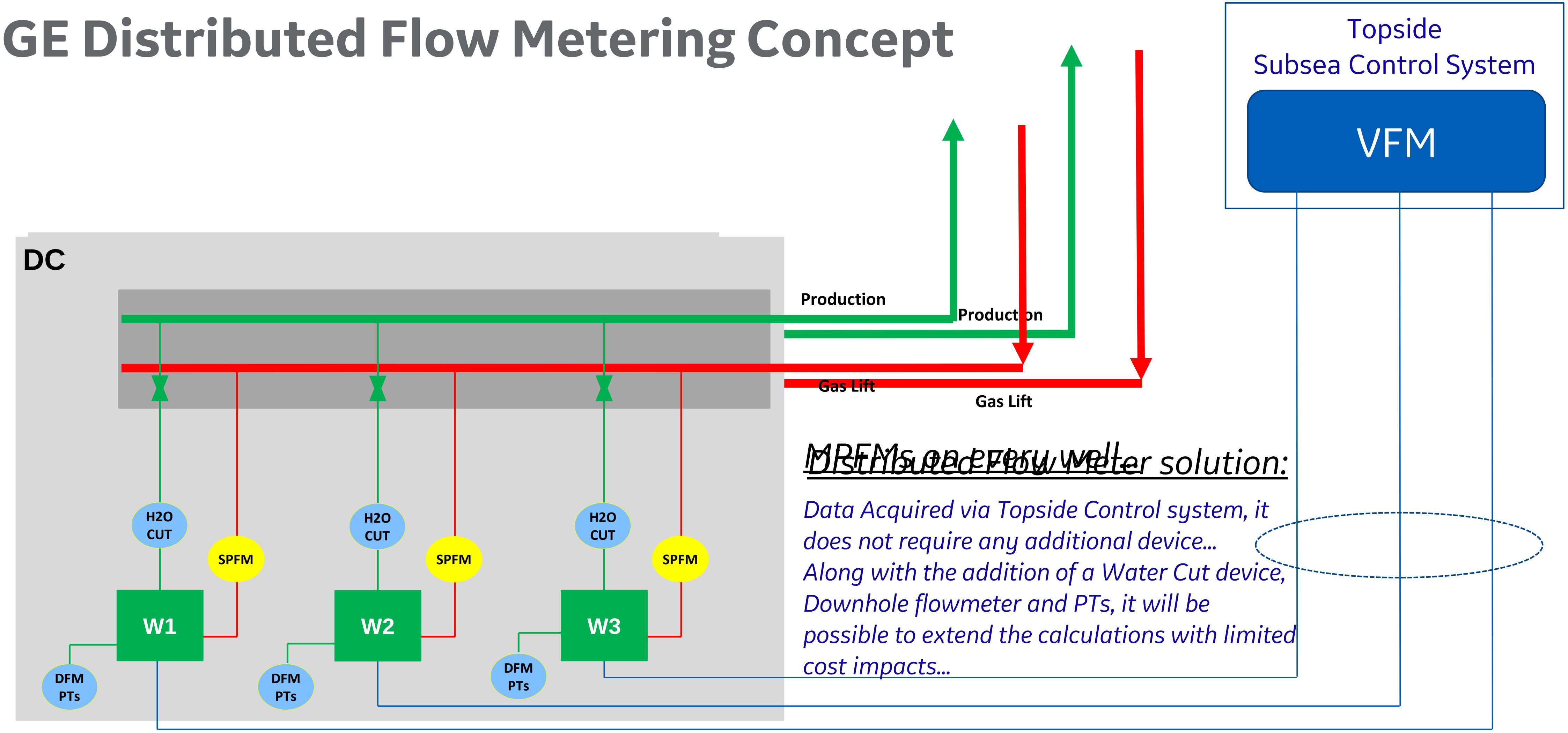
2019
Distributed Flow Metering Specification

- Detail system design and component selection
- Solution benchmark against simulated and/or historic field data

2020
Distributed Flow Metering

- Pilot Testing and qualification

BHGE Distributed Flow Metering Concept



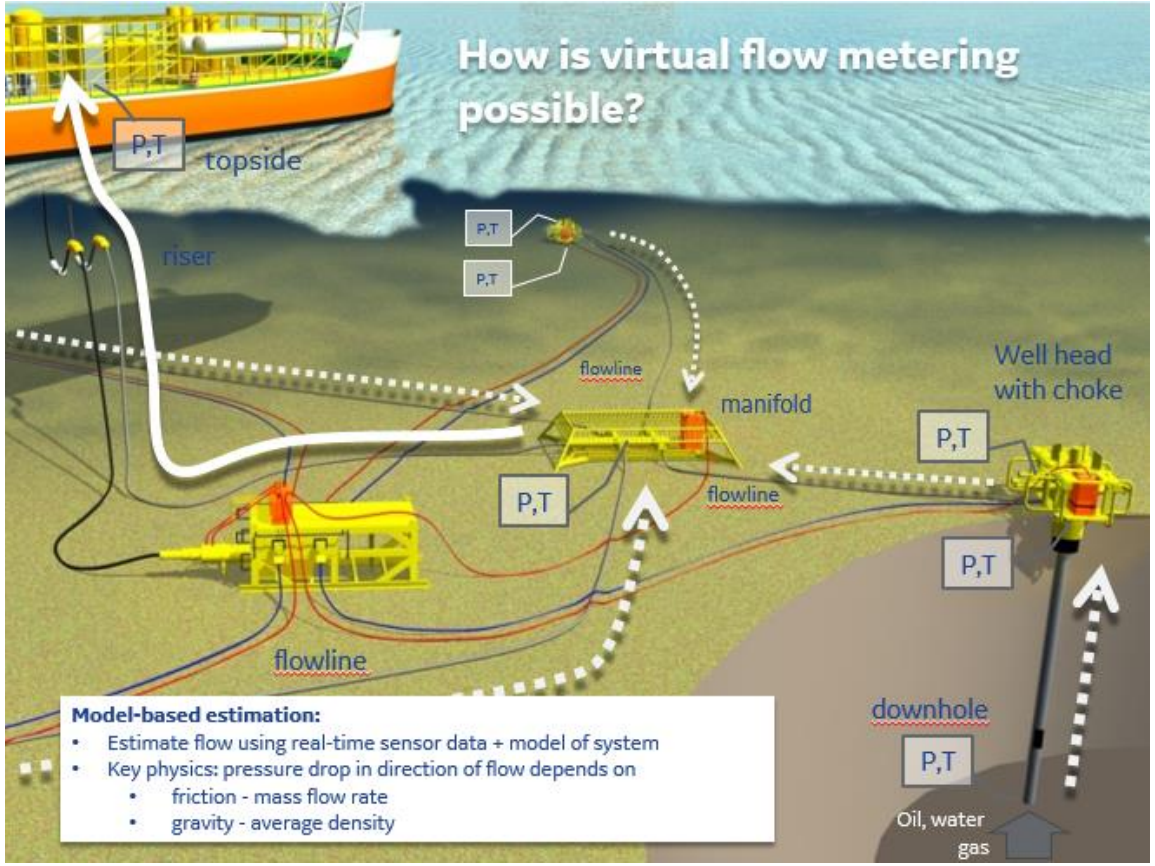
MPFMs on every well

Distributed Flow Meter solution:

Data Acquired via Topside Control system, it does not require any additional device… Along with the addition of a Water Cut device, Downhole flowmeter and PTs, it will be possible to extend the calculations with limited cost impacts…

Virtual Flow Meter Application (VMF)

Concept Definition

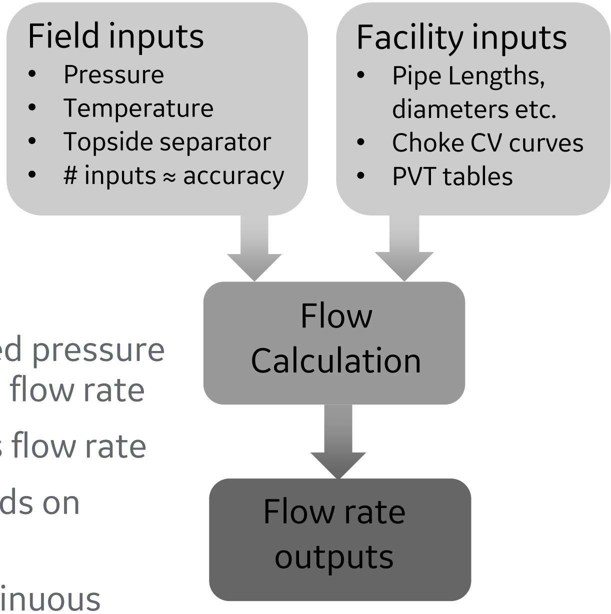


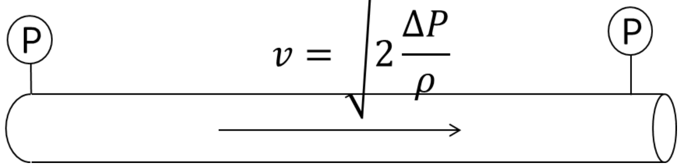
What is virtual flow metering?

- A software application that process subsea pressure and temperature measurements to estimate flow throughout the production system.

How is this possible?

- Correlations exist that relate the measured pressure and temperature drop to the (multiphase) flow rate
- Frictional pressure drop depends on mass flow rate
- Hydrostatic pressure drop (gravity) depends on density
- The mass flow through the system is continuous





$$v = \sqrt{2\frac{\Delta P}{\rho}}$$

Virtual Multi-phase Flow Metering

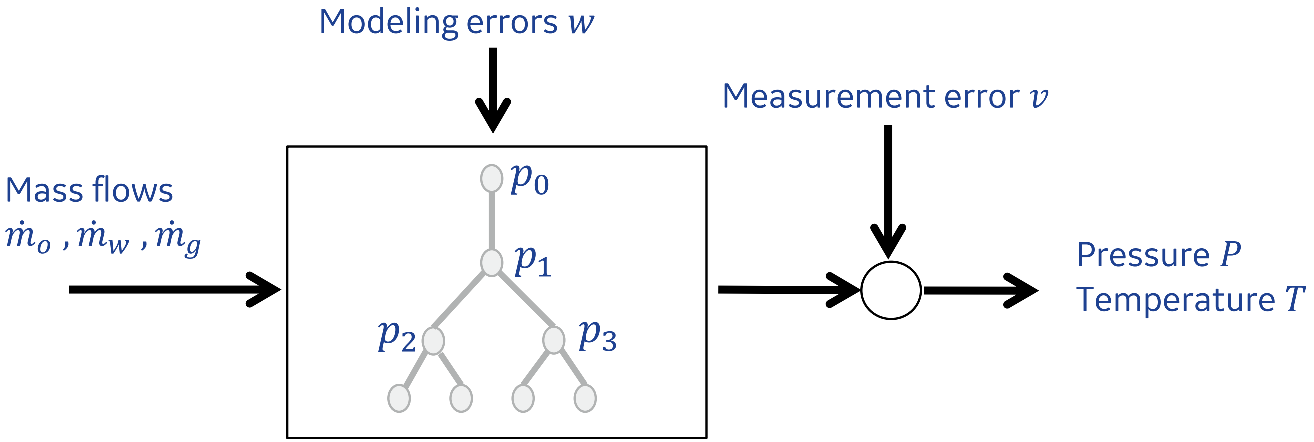
Problem Definition

Problem Statement:

> *"Given measured pressures, temperatures and other known inputs (e.g. chemical injection flows), estimate the value of flows on each well"*

Approach: Model-based estimation

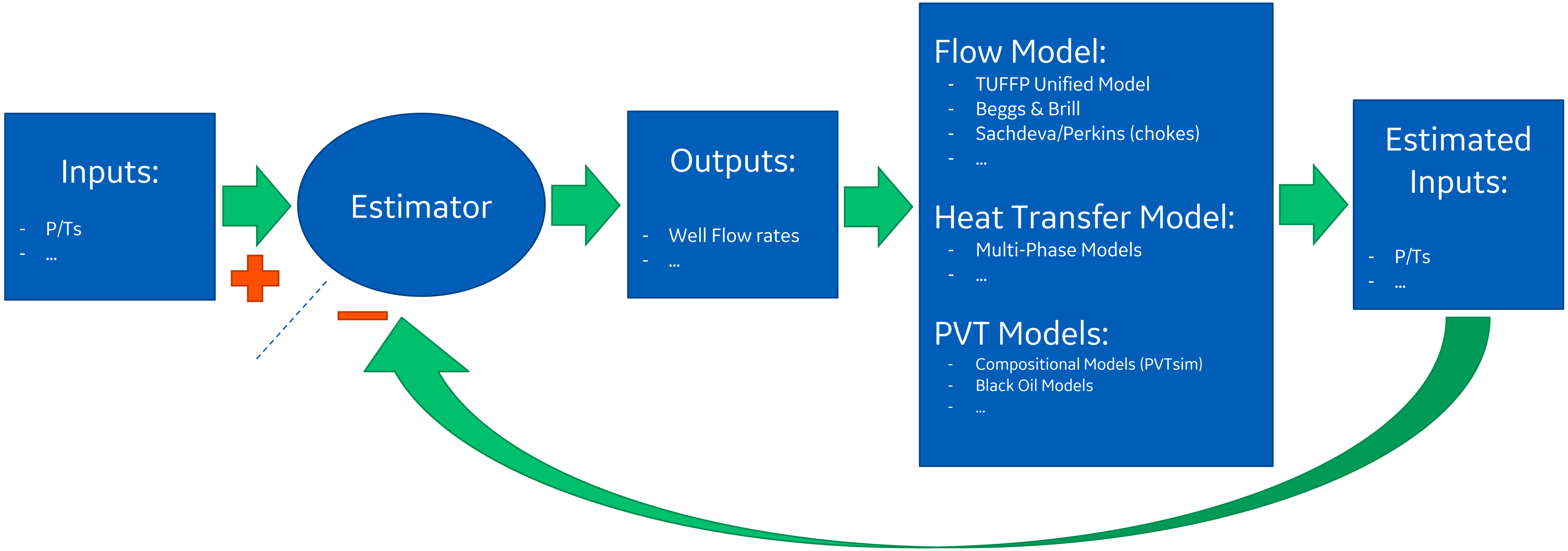
- Physics-based „*forward*" modeling of the production field, same inputs/outputs as data generating system:



- Solving the inverse problem, we use field data and the network model to find the input value

Virtual Multi-phase Flow Metering

Estimation Algorithm

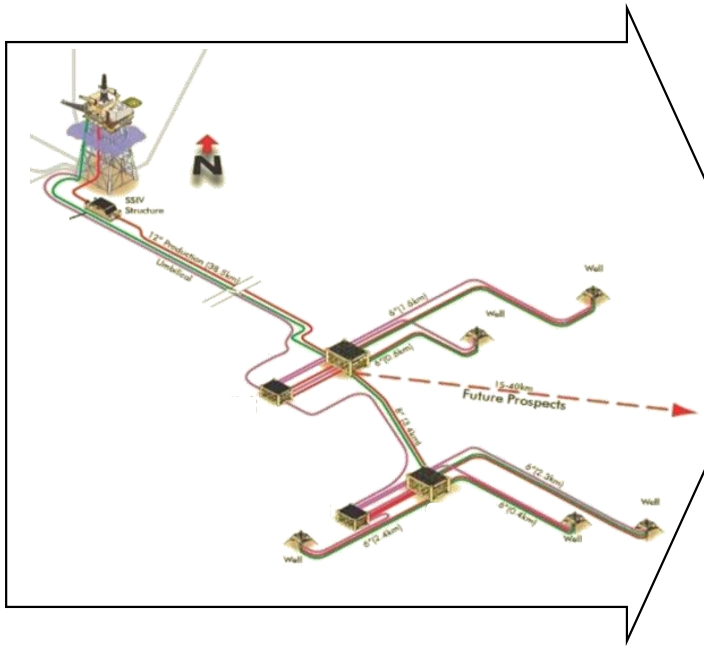


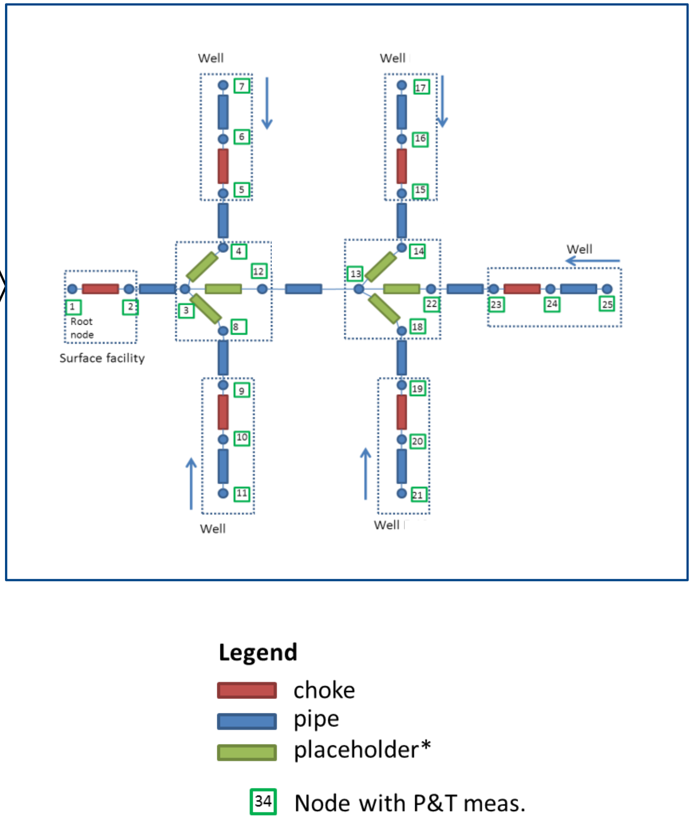
The VFM estimator optimises the relationship between P/T Drop Vs. Flow rate

Virtual Multi-phase Flow Metering

Network Model Analytics

- Network model consists of **‘pressure loss segments’ (PLS)**
    - eg. pipes, chokes, venturi etc.
- Industry standard flow correlations are used on all pressure loss segments
- Flow rates are calculated for each well. Calculation engine minimises the error between measured pressures & temperatures
- Implemented as Recursive Estimator

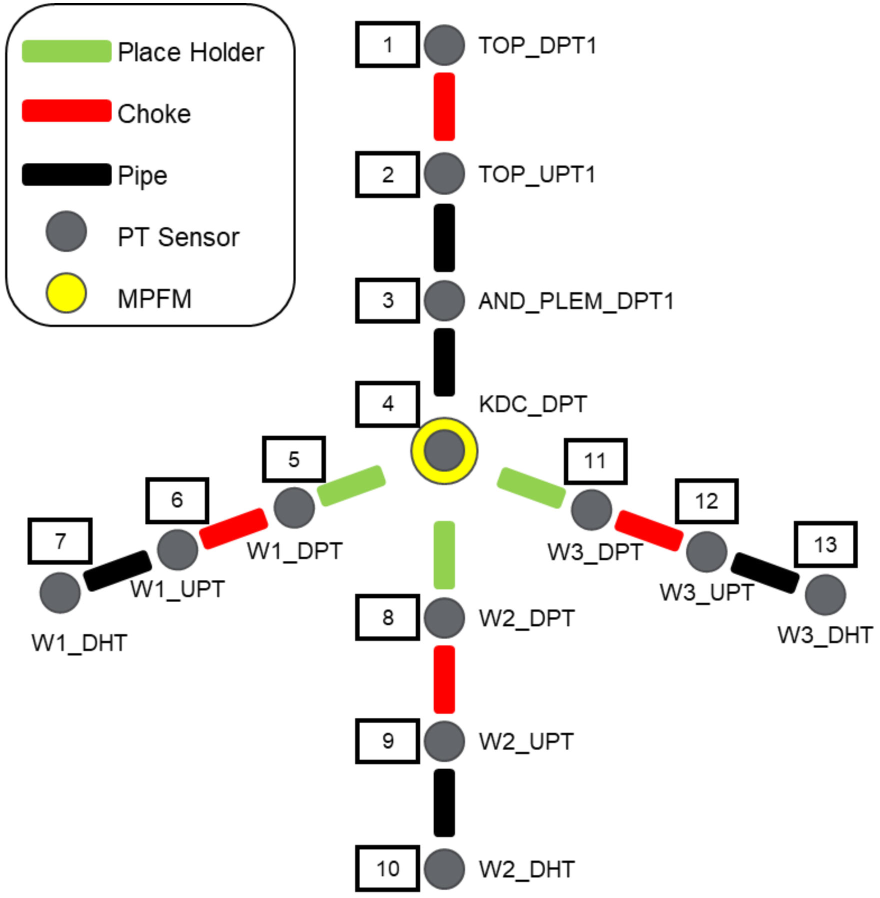




BAKER HUGHES a GE company

Virtual Flow Meter Application (VMF)

Data Structure



Sensor Data

- Pressure and Temperature sensors
- Choke Position Sensors
- MPFM sensors (if available)
- Separator flows and pressure / temperatures (if available)

Legend:

1) TOP_DPT1 = Sensor downstream of topside choke
2) TOP_UTP1 = Sensor upstream of topside choke
3) AND_PLEM_DPT1 = Sensor at bottom of riser
4) KDC_DPT = Manifold header sensor
5) W1_DPT = Sensor downstream choke @ W1
6) W1_UPT = Sensor upstream choke @ W1
7) W1_DHT = Downhole sensor @ W1
8) W2_DPT = Sensor downstream choke @ W2
9) W2_UPT = Sensor upstream choke @ W2
10) W2_DHT = Downhole sensor @ W2
11) W3_DPT = Sensor downstream choke @ W3
12) W3_UPT = Sensor upstream choke @ W3
13) W3_DHT = Downhole sensor @ W3

Field/Geometry Data:

In addition to sensor data, the following data is also required for each simulation:

Pipe Data:

- Pipe Profile: measurement depths Vs. true vertical depths
- Pipe Diameter (for all segments along the pipe)
- Relative roughness (for all segments along the pipe)
- Ambient Temperature (for all segments along the pipe)
- Heat transfer boundary condition (for all segments along the pipe)

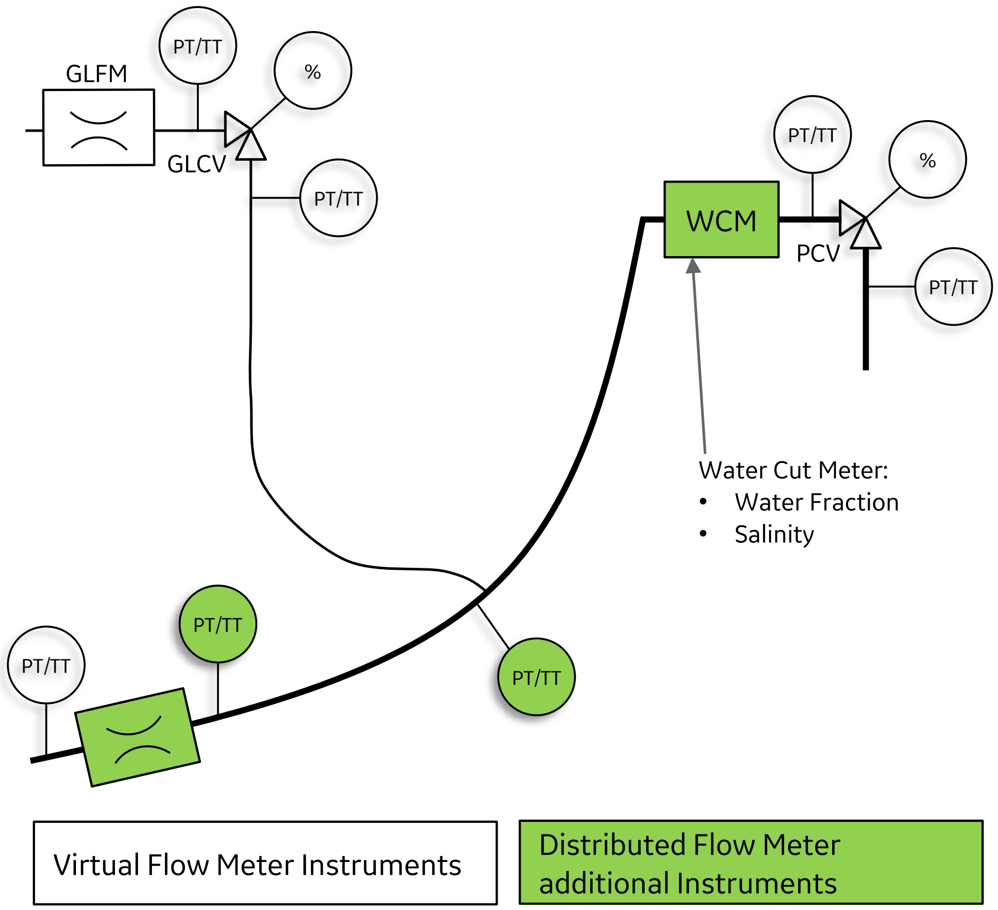
Choke Data:

- Choke CV curve

PVT data:

- Fluid properties, phase envelope, etc (e.g. PVT tab file)

Distributed Multi-phase Flow Metering

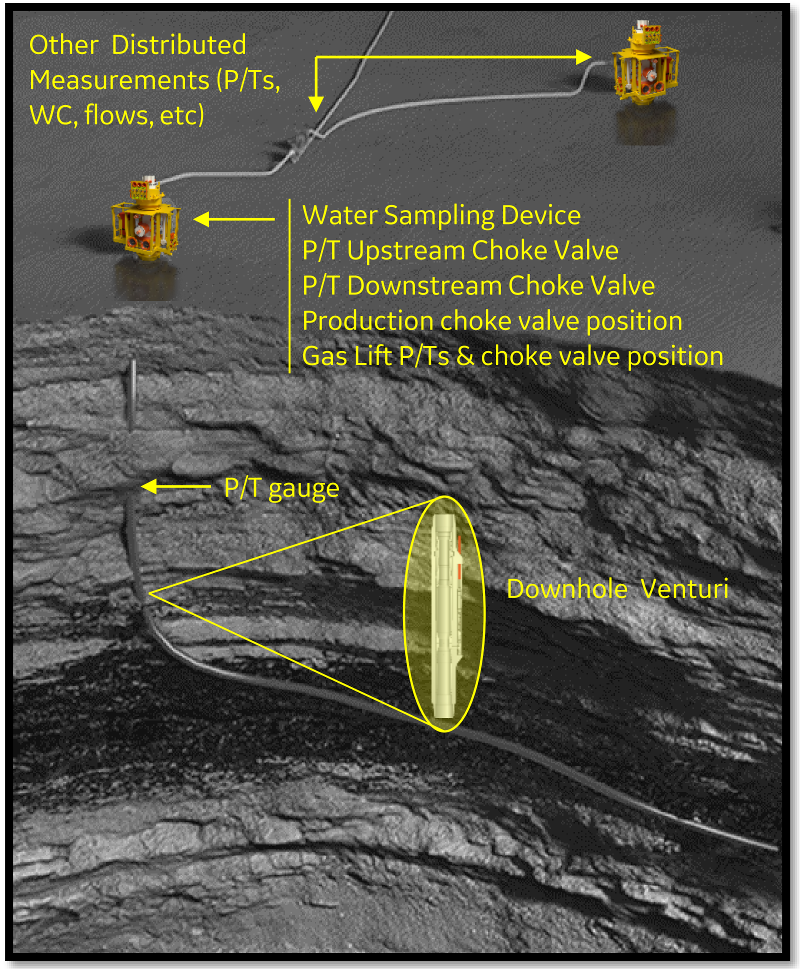


The main benefits of this solution are:

- **Removal of MPFM/WGFM**
  (Reduced cost & weight of subsea structures)
- **Improved lead times**
  (compared to WGFMs/MPFMs)

Other benefits include:

- Matching outputs to MPFM/WGFM technology (including water fraction and salinity measurements),
- Zonal allocation capabilities
- Reduced HSE exposure (e.g. avoidance of radioactive sources used in other technologies).



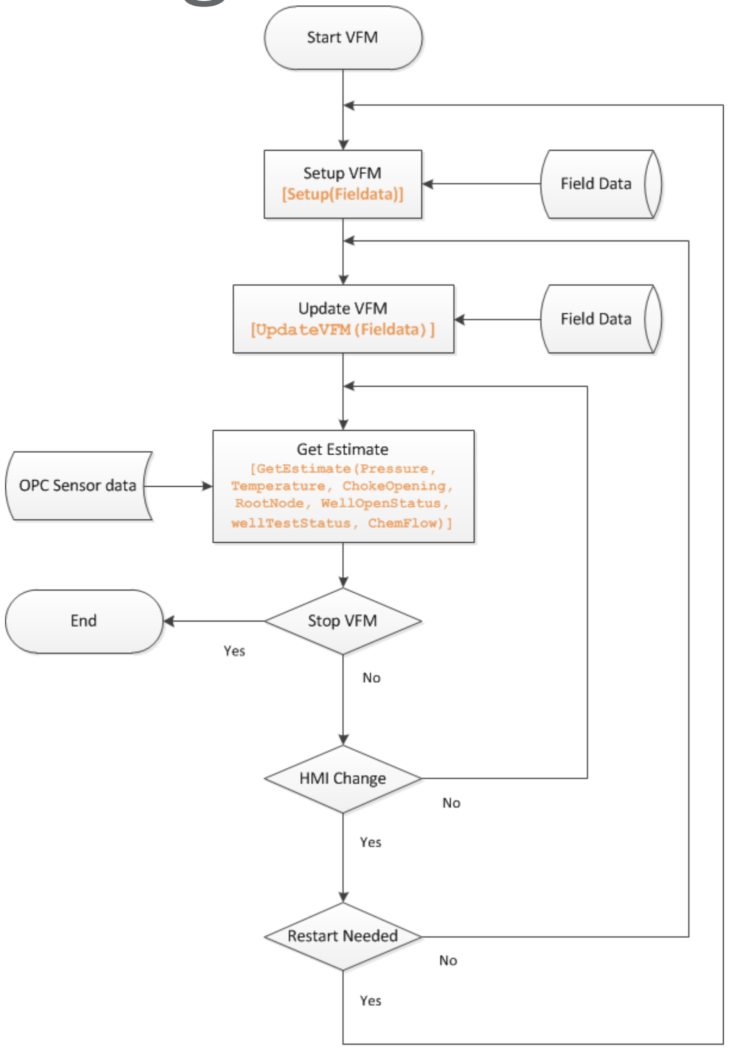
Distributed Multi-phase Flow Metering

Key Features

Key features

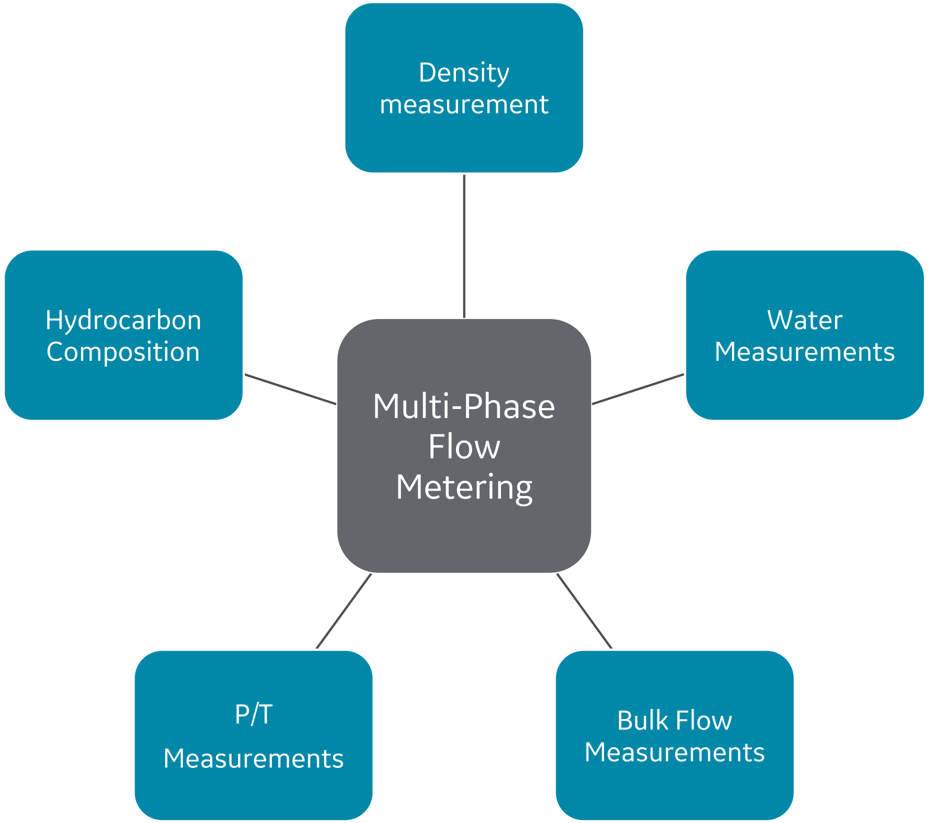
- Flow assurance & well performance tool
  - ✓ Steady-state 3 phase estimator
- Flow & phase fraction estimate *at any point* in production gathering network
- Integrated into Topside Control System
- Uses University of Tulsa TUFFP Flow Correlations
- Automatic reconcilliation of subsea flow to match topside separator measurements
- Offline maintenance and tuning
  - ✓ Remote connectivity to GE operative
  - ✓ Access to authorised users

- Low cost metering solution for well performance
- Straightforward Calibration/Tuning
- Robust to instrumentation failure – "Graceful Degradation"
  - ✓ as sensors fail, the VFM tolerance increases but will still provide distributed field measurements.
- Advanced Trending & Reporting using PROFICY®/CIMPLICITY



BAKER HUGHES a GE company

Distributed Multi-phase Flow Metering

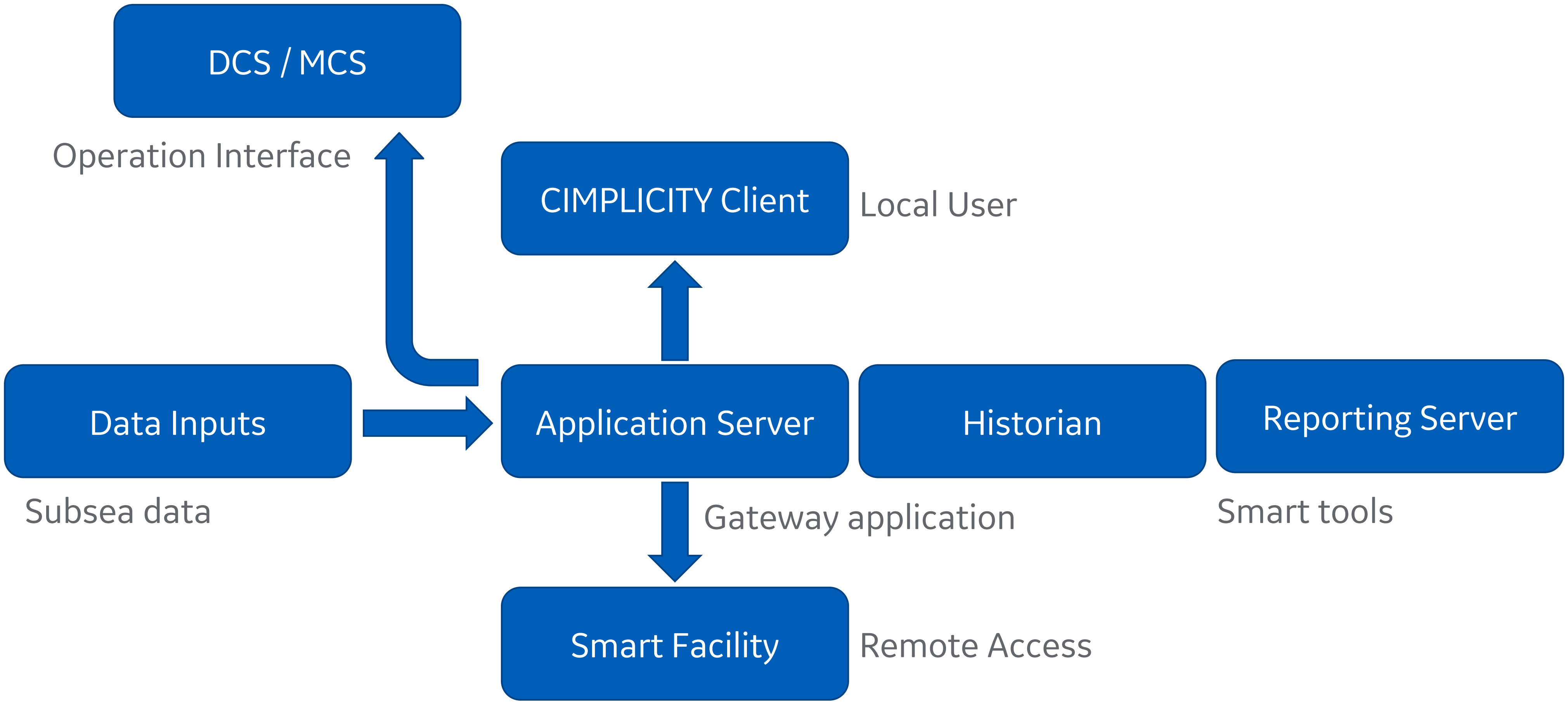


Typical WGFM/MPFM Measurements

Calculation inputs:	Typical MPFM/WGFM	Typical Virtual Metering System	Distributed Flow Metering Solution
Density	Gamma densitometers, etc	Calculated from P/T measurements at different TVDs (e.g. wellhead & DHPT)	Calculated from **multiple** P/T measurements at different TVDs (e.g. wellhead & DHPT).
Water	Infrared, microwave, capacitance, etc	Calculated using continuity and P/T drop measurements (particularly the temp drop across well)	**Includes direct water sampling (e.g. infrared, microwave, capacitance, etc)**
Bulk Flow	Venturi deltaP flow meters, etc	Calculated from pressure drops across choke valves and wells	**Downhole flow meter** complemented with pressure drops across chokes and wells
P/T	P/T measured at meter	P/T measured at various locations (DHPT, upstream / downstream choke, etc)	P/T measured at various locations, **including multiple P/T at well as required**
Hydrocarbon Composition	Used as input	Used as input	Used as input
Calculation Outputs:	**Oil, gas, and water rates + water conductivity/salinity**	**Oil, gas, and water rates**	**Oil, gas, and water rates + water conductivity/salinity**

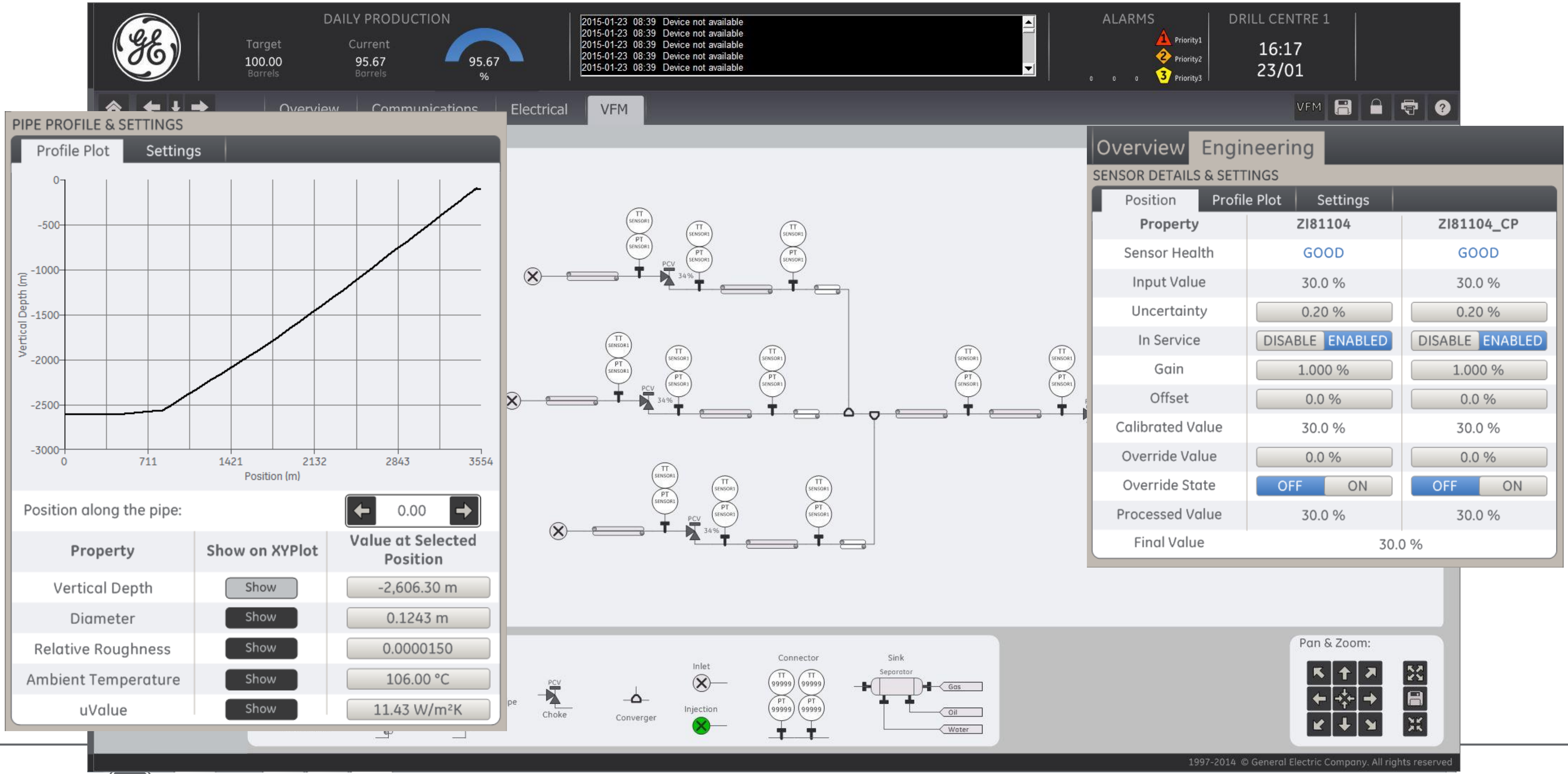
Software Architecture

On-Premise & Cloud Solutions



Smart Facilities

User Experience

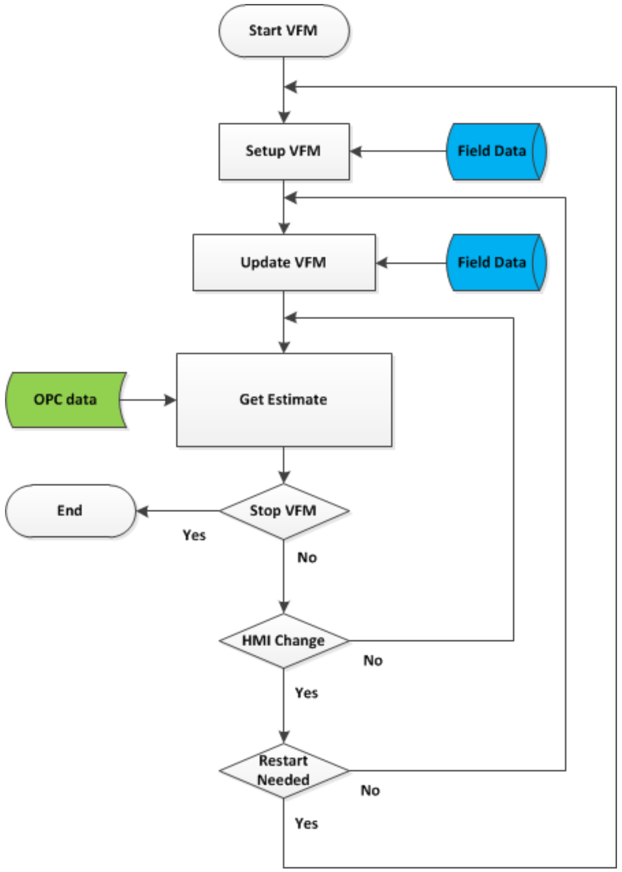


BAKER HUGHES
a GE company

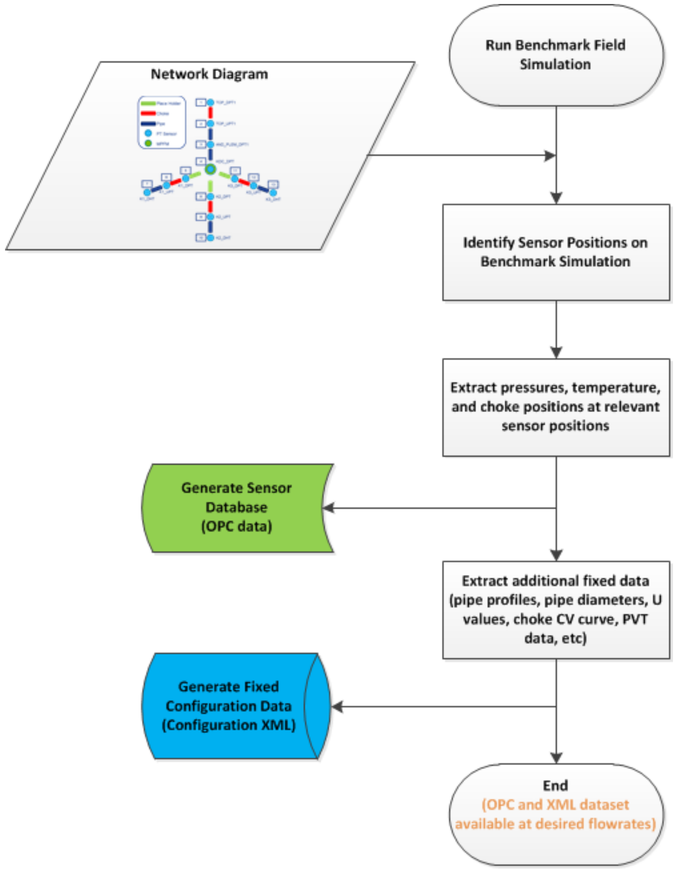
Concept Validation

Model Validation

Performance against 3rd Party transient simulations - Tests Flow Diagram



VFM Calculation Engine Flow Diagram



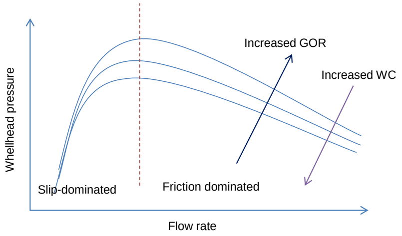
Flow Diagram for Fabrication of Transient Data

Model Validation

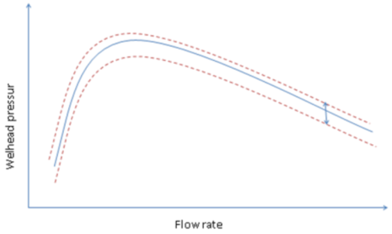
Performance against field data - Calibration Process

Calibration is required to account for modelling and sensor inaccuracies. The Calibration process includes:

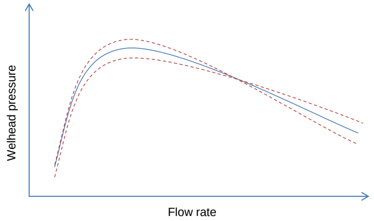
- PVT calibration (GOR, WLR, phase fractions)
- Forward model calibration (pressure and temperature drop models)
- Estimator Calibration



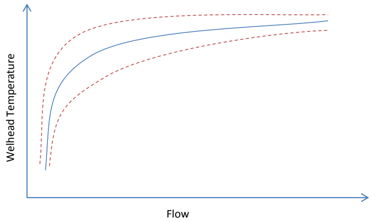
Well pressure drop



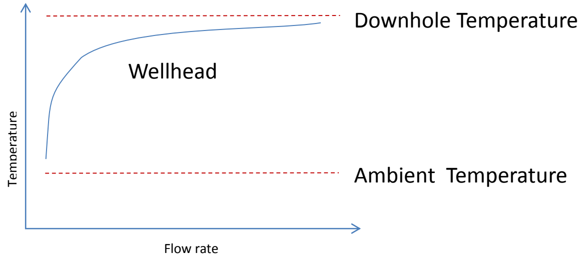
Gravity Calibration

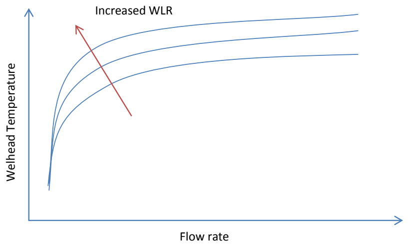


Friction Calibration

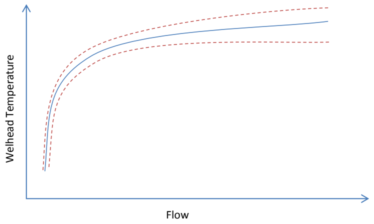


Radial heat transfer



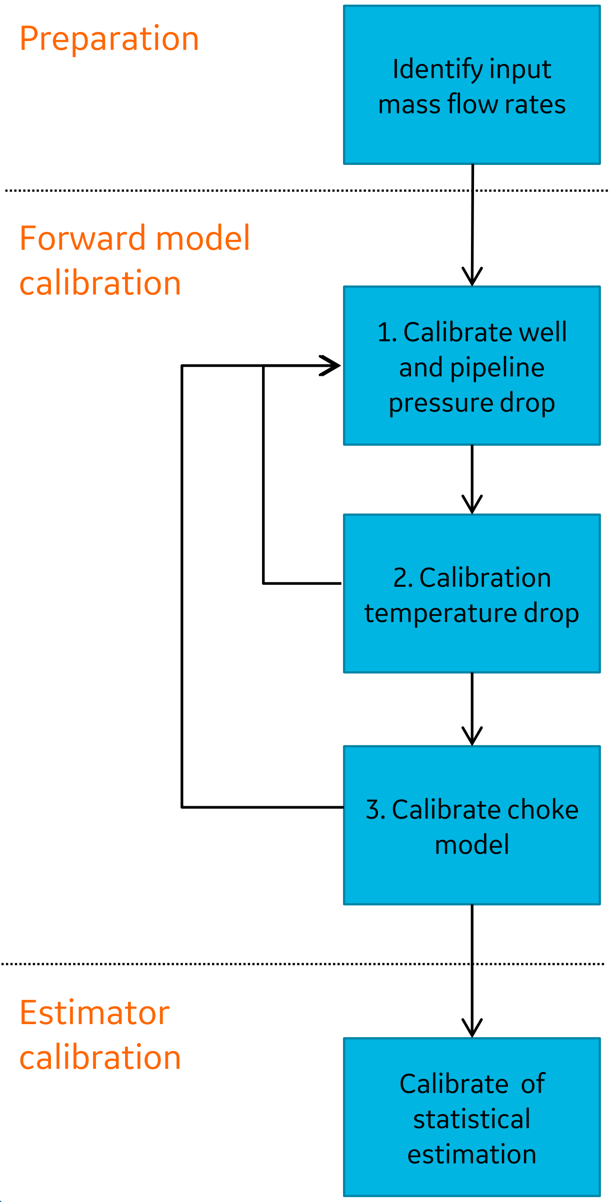


Well Temperature drop



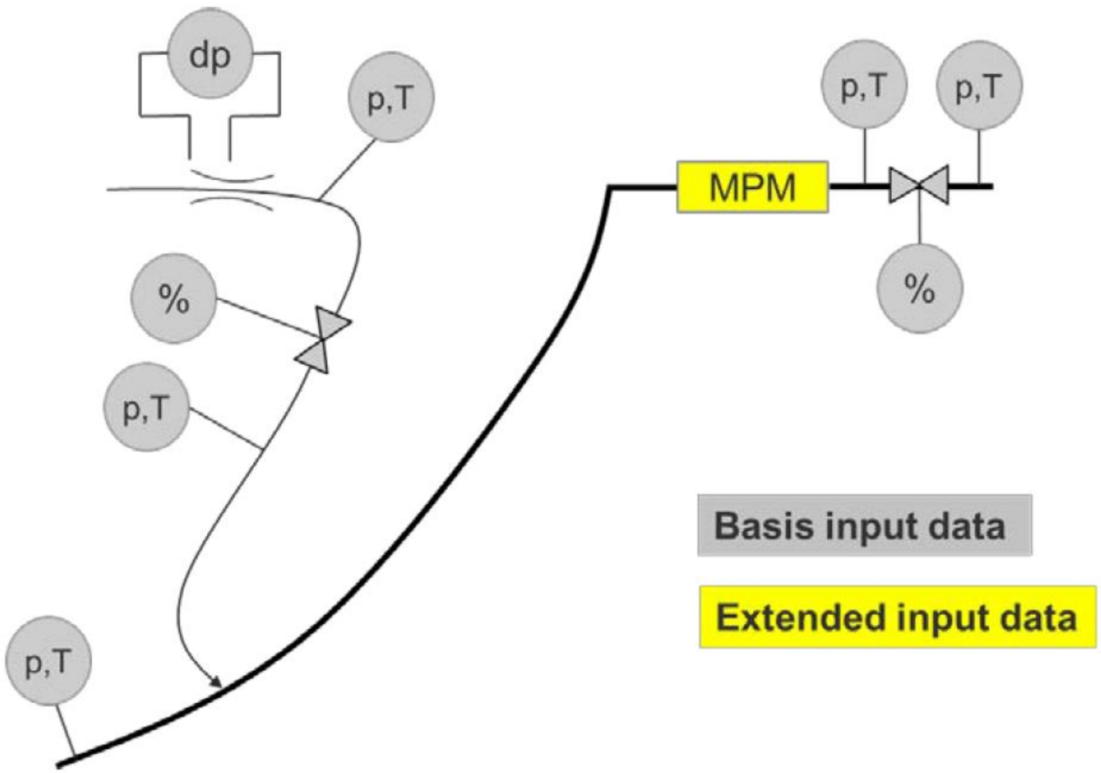
Flow dependent heat transfer

Typical Calibration Workflow



BAKER HUGHES a GE company

Virtual Flow Metering Test Campaign



	Available Meassurements		
VFM Study	P1 (without Gas Lift)	P4 (with Gas Lift)	S2 (with Gas Lift)
Phase 1	Choke DeltaP Choke DeltaT Well DeltaP Well DeltaT	Choke DeltaP (~100% open) Choke DeltaT (~100% open) Well DeltaP Well DeltaT Gas Lift Venturi DeltaP	Choke DeltaP (~100% open) Choke DeltaT (~100% open) Well DeltaP Well DeltaT Gas Lift Venturi DeltaP
Phase 2	+ MPFM Venturi DeltaP	+ MPFM Venturi DeltaP	+ MPFM Venturi DeltaP
Phase 3	+ Mixture Density + P/T at MPFM	+ Mixture Density + P/T at MPFM	+ Mixture Density + P/T at MPFM
Phase 4	+ Water Conductivity + Salt Content	+ Water Conductivity + Salt Content	+ Water Conductivity + Salt Content
Phase 5	+ Water Cut	+ Water Cut	+ Water Cut
Phase 6	+ MPFM volumetric flow rates for First Year ONLY (to be used for tuning, deliverable is to re-run full time window)	+ MPFM volumetric flow rates for First Year ONLY (to be used for tuning, deliverable is to re-run full time window)	+ MPFM volumetric flow rates for First Year ONLY (to be used for tuning, deliverable is to re-run full time window)
Verification Phase	+ MPFM volumetric flow rates from Full Time Window	+ MPFM volumetric flow rates from Full Time Window	+ MPFM volumetric flow rates from Full Time Window

TUFFP (Tulsa University Fluid Flow Program)

Multi-Phase Flow on Pipes

Industry-University research group supported by several oil & gas production, consulting, service member companies and government agencies. Researching on multiphase flows since 1973.

Test Facilities

- 6" High Pressure Large-Diameter Pipeline
- 6" Low Liquid Loading Large-Diameter Pipeline
- 3" High Pressure Large-Diameter Gas/Water/Oil Flow Loop
- 3" Gas/Oil/Water Flow Loop
- 2" Gas/Oil/Water Flow Loop
- 2" High Viscosity Oil/Gas Two-Phase Flow Loop

Advanced Instrumentations

- Flow Visualization Cameras
- Canty Flow Visualization Device
- Conductivity/Capacitance Probes
- Iso-Kinetic Sampling Probe
- Wire Mesh Sensor
- Particle Image Velocimetry

Other Facilities

- Single-Phase Paraffin Deposition Flow Loop
- Multiphase Paraffin Deposition Flow Loop

Member Companies: