# Hybrid Machine Learning Virtual Flow Metering

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# Agenda

- Importance of well flow metering
- Multiphase flow metering methods
- Virtual Flow Metering (VFM)
- Hybrid Machine Learning (ML) VFM
- Project case study
- Summary
- Q & A

# Importance of Well Flow Metering

- Production allocation and revenue
  – How much is produced from which well
- Reservoir characterization
  – Reservoir depletion and remaining life, improved oil recovery options
- Flow assurance
  – Slugging, corrosion/erosion, chemical injection, hydrates
- Operations
  – Daily production goals, well control, safe operations

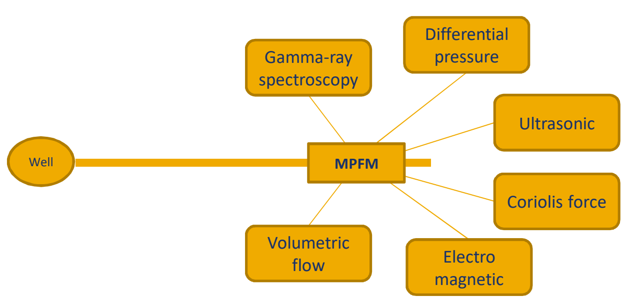
# Multiphase Flow Metering

- In-line flow meters
- Separation flow meters
- Virtual flow meters

NFOGM: Norwegian Society for Oil and Gas Measurement

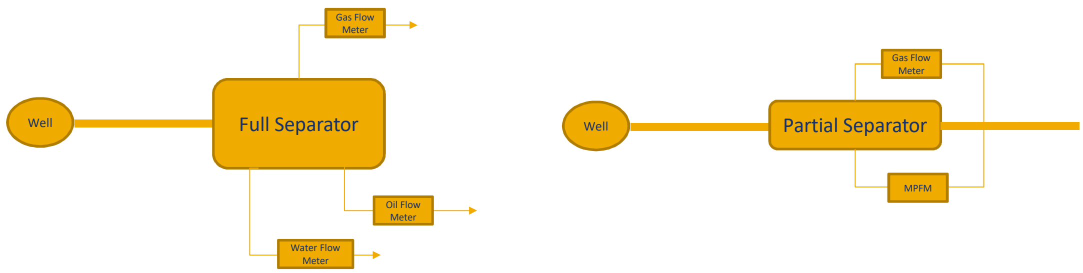
# In-line Flow Meters

- Direct measurement in the multiphase line without sampling or phase separation
- Measure gas volume fraction (GVF), volumetric flowrate, water-cut, density
- Require pressure and temperature measurements and some fluid properties
- Correlate raw measurements to standard phase flow rates



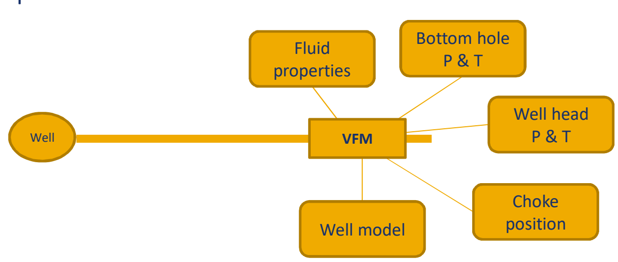
## Separation Flow Meters

- Full or partial separation of phases before direct measurement using single-phase or multiphase flow meters
- Test separator is common example of full separation flow metering of wells




## Virtual Flow Meters

- Use existing sensors to infer phase flow rates
- No direct measurements are performed
- Can be classified into two groups:
  - **Signal processing systems**: estimate flow based on statistical processing or pattern recognition
  - **Process simulation (or model-based) systems**: estimate flow using process models with estimated or measured fluid properties.



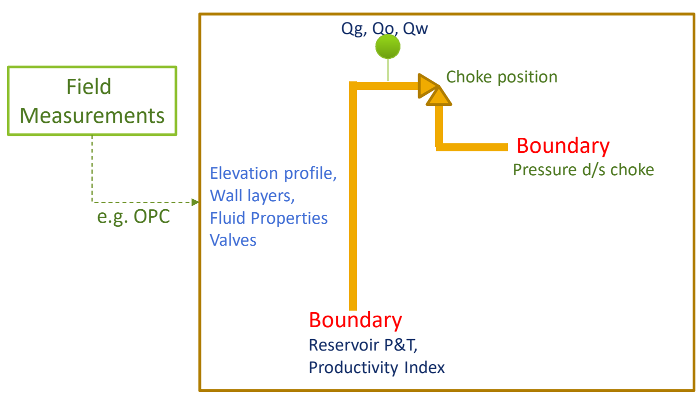
# Model-based VFM

Simulate multiphase flow in pipes to determine phase flow rates

- Steady State models
  - First-principle based models that provide steady state multiphase flow results
- Dynamic models
  - First-principle based models that provide dynamic or transient multiphase flow results

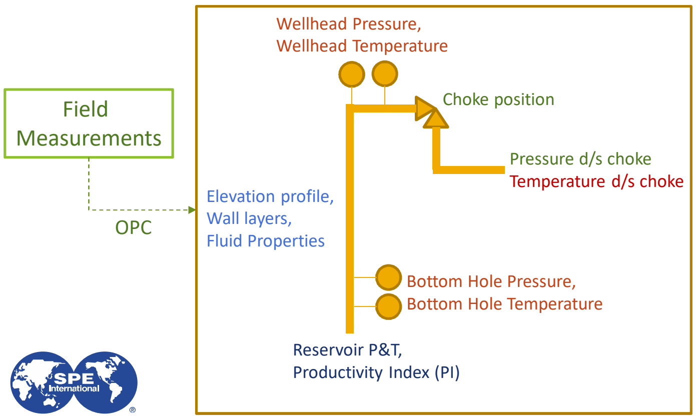
# Dynamic Model-based VFM: Basics

Simulate well hydrodynamics in real-time using available field measurements to set boundary conditions and valve positions



# Dynamic Model-based VFM: Calibration

Model must be maintained true to field and calibrated.



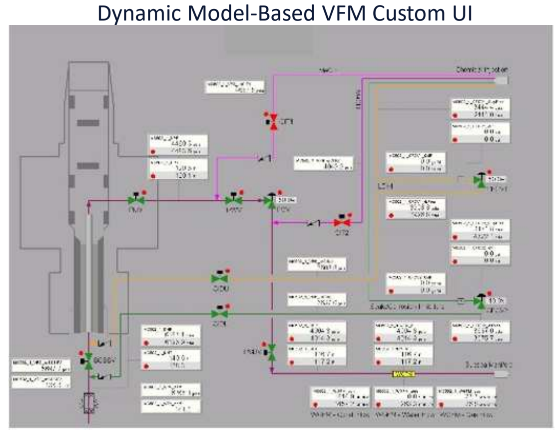

- Fluid properties are important!
- Commonly calibrated:
  - Choke bias
  - Ambient temperature
  - Heat Transfer Coefficients
  - Wall roughness
  - Reservoir P&T / PI
- Difficult to estimate:
  - Gas-to-Oil Ratio (GOR)
  - Water-Cut (WC)

# Dynamic Model-based VFM: Basics

Simulate well hydrodynamics in real-time using available field measurements to set boundary conditions and valve positions

- Provide real-time window into the process
- Provide planning and predictive capability
- High fidelity dynamic models of flow process
- Synchronized with the field process

Dynamic Model-Based VFM Custom UI



# Dynamic Model-based Production Management Systems

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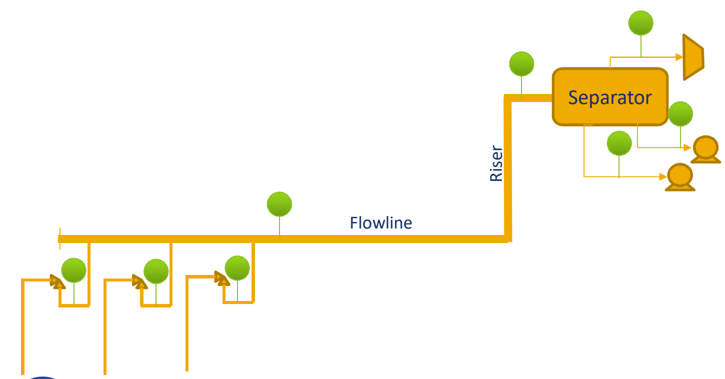
VFM as part of a production management system




- Process state at all locations
- P & T Profiles along flowlines
- Liquid holdup in flowlines
- Phase flow in flowlines & wells
- Inhibitor rates and holdup
- Hydrate monitoring
- Leak detection
- Corrosion & erosion
- Equipment performance

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# KDI Dynamic Model-based Production Management Systems

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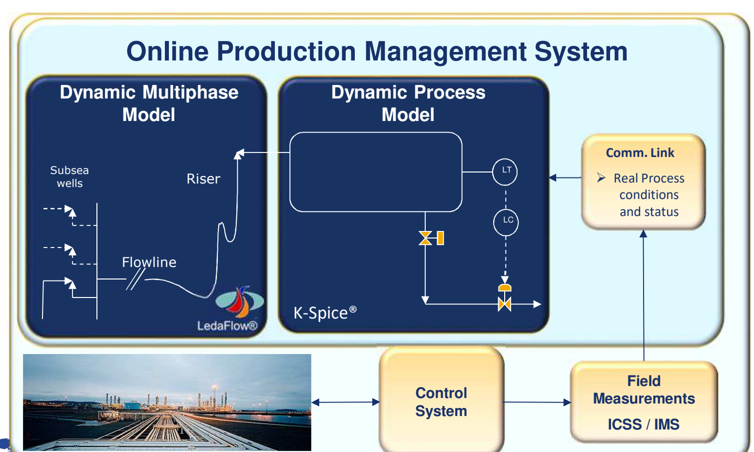


- Real-time Simulator
- Planning/What-if Simulator
- Predictive/LookAhead Simulator
- Performance Monitoring
- Virtual Flow Metering
- Hydrate monitoring
- Leak/Blockage detection
- Corrosion & erosion Monitoring
- Process Optimization

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# Multiphase Flow Metering Methods Pros & Cons

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**In-line Metering**
- Best direct flow measurement option available currently
- 2% to 20% error

- Costly
- Must be kept calibrated
- May fail over time

**Separator Metering**
- Conventional
- 1% to 5% error

- Production deferment
- May not be practical for some wells (low flow or flow assurance issues)
- Operational disruption

**Virtual Metering**
- Cost-effective
- 2% to 20% error

- Model must be maintained and calibrated
- Uncertainty in model inputs (GOR/WC)
- Simulator downtime

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# Machine Learning VFM Drivers

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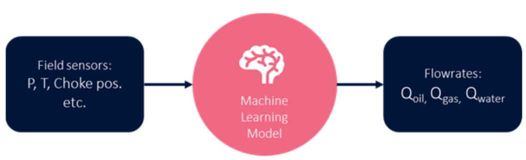
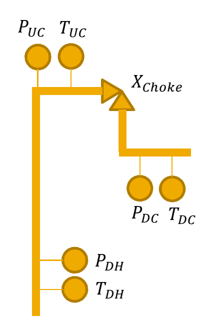
Machine Learning is very good at finding relationships between inputs and outputs




$$Q_{Gas}, Q_{Oil}, Q_{Water} = f(P_{DH}, P_{UC}, P_{DC}, T_{DH}, T_{UC}, T_{DC}, X_{Choke})$$




- Robust → no model convergence issues
- Simple and fast calculation → no high-end hardware required; model speed is a non-issue
- Easy to deploy → No need for frequent model monitoring or calibration
- Scalability → No issues going from 10 to 1,000 ML models on the same hardware
- Can estimate GOR or Water-cut

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Machine Learning requires large **quantities** of **quality** data

# Machine Learning VFM Challenges

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Challenges for ML Flow Metering using field data:

- **Quantity** of field data is not always available
  - Green field; little historical data
  - Faulty/missing measurements
- **Quality** field of data is not always available
  - Data at all possible choke openings, flow rates, expected GORs and water-cuts

# Hybrid Machine Learning VFM

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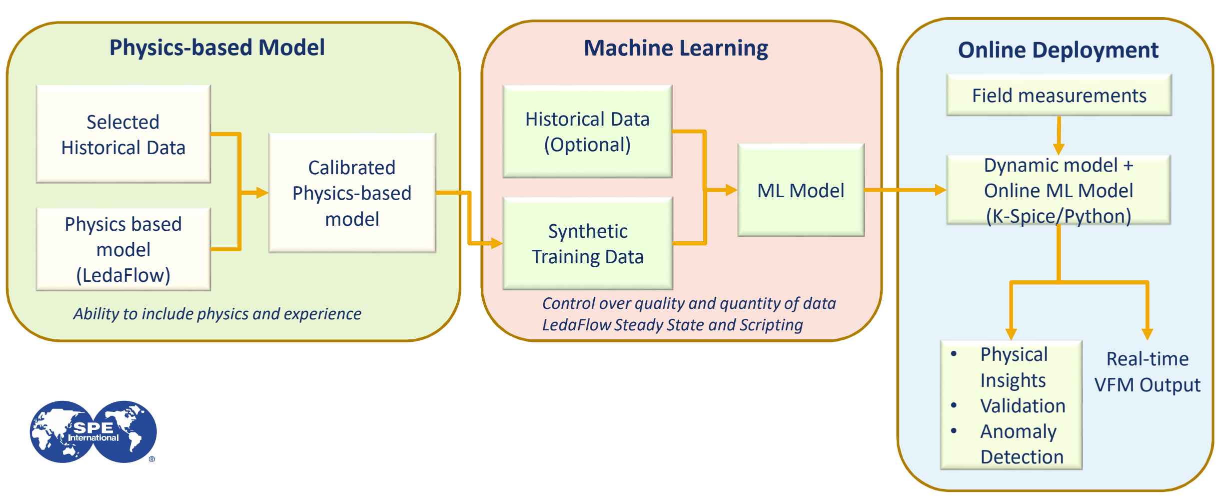
Physics-based models (Synthetic data) + Machine learning



# Case Study: Hybrid ML VFM

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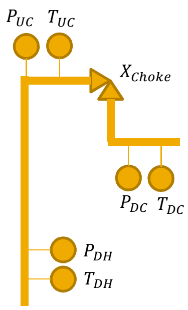
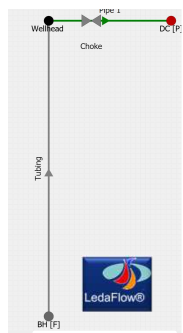
Hybrid ML VFM for Oil well; Measurement data available over 3 years

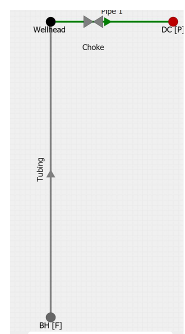



Model Build



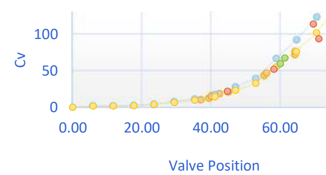

Base Model

Model calibration using selected historical data points




Calibrated Model

Choke CV Curve Validation/Calibration




- Choke Cv curve
- HTC
- Roughness/friction factors

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# Case Study: Hybrid ML VFM Synthetic Data Generation

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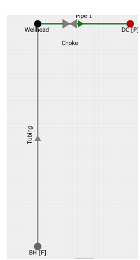
$$Q_{Gas}, Q_{Oil}, Q_{Water} = f(P_{DH}, P_{UC}, P_{DC}, T_{DH}, T_{UC}, T_{DC}, X_{Choke})$$

Input to LedaFlow model

$P_{DC} = \{1000\ \ldots 9000\}$ psig, Np
$Q_{Oil} = \{0\ \ldots 20{,}000\}$ sbpd, Nq
GOR = {400 … 800} scf/sbbl, Ng
WC = {0 … 100} %, Nw
$X_{Choke}$ = {0 … 100} %, Nx
$T_{DH}$ = {200 … 300} F, Nt

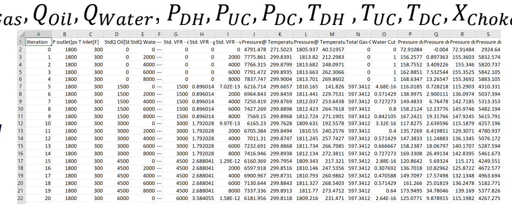



Calibrated Model

*Run LedaFlow Steady State using automated scripting*

Synthetic Data

$Q_{Gas}, Q_{Oil}, Q_{Water}, P_{DH}, P_{UC}, P_{DC}, T_{DH}, T_{UC}, T_{DC}, X_{Choke}$



Total number of data points = Np * Nq * Ng * Nw * Nx * Nt

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# Case Study: Hybrid ML VFM
# Machine Learning

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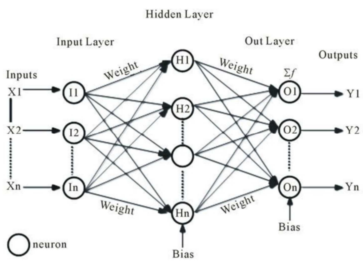
Machine learning

$P_{DH}, P_{UC}, P_{DC}, T_{DH}, T_{UC}, T_{DC}, X_{Choke}$




$Q_{Gas}, Q_{Oil}, Q_{Water}$

*Can apply physical insights by combining inputs; but not necessary*

$\sqrt{P_{UC} - P_{DC}}$

$\Delta P = P_{DH} - P_{UC}$

$\Delta T = T_{DH} - T_{UC}$

- Some details on ANN training
  - **Activation function = ReLU**
  - **Adam optimizer**
  - **Loss function = mean squared error**
- Available ML tuning parameters
  - **number of hidden layers**
  - **Number of nodes in a hidden layer**
  - **Learning rate**
  - **Batch size**
  - **Epochs**
- If expected accuracy against test data not achieved, then tune or generate more training data and re-train
- Select the best ML model

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# Case Study: Hybrid VFM
# ML VFM Accuracy

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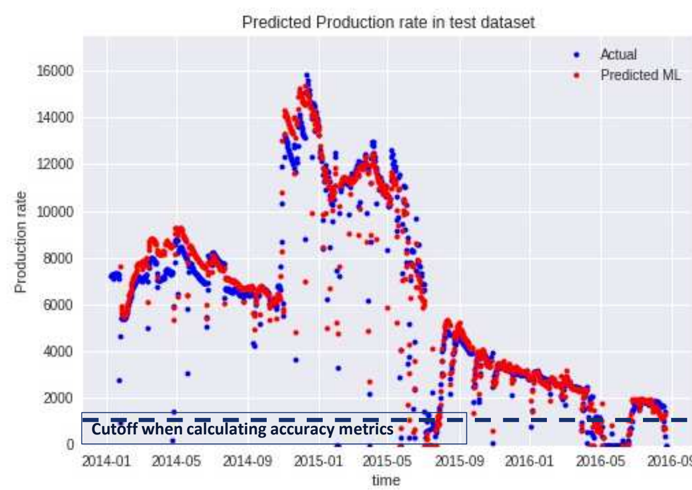
**Comparison against field measured data**

Red dots: ML-predictions
Blue dots: Real measurements

<u>Key accuracy metrics:</u>

| | |
|---|---|
| Mean absolute error: | 450 |
| Mean absolute %-error: | 5 % |
| Cumulative error: | 2 % |

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# Case Study: Hybrid VFM Online Deployment

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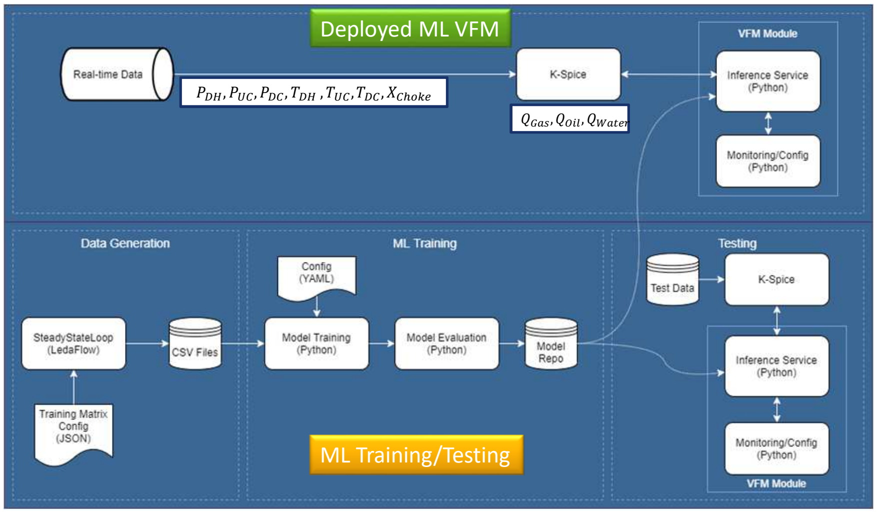


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# Case Study: Hybrid VFM

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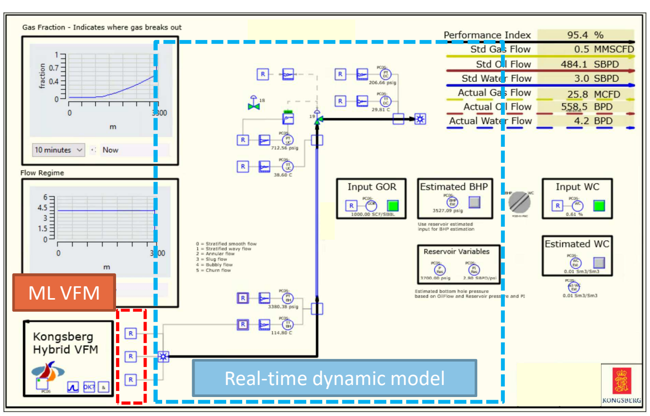


- **ML VFM + dynamic model**
  - ML VFM provides inlet flow boundary conditions; no need for manual input of GOR or Water-cut
  - Dynamic model provides flow assurance insights
  - VFM decoupled from dynamic model issues; always available
  - ML VFM can be used as inputs to pipeline management systems
  - Deviation from measurements indicate real issues: flowline blockage; choke erosion/blockage etc.

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# Case Study: Hybrid VFM Comparison & Insights

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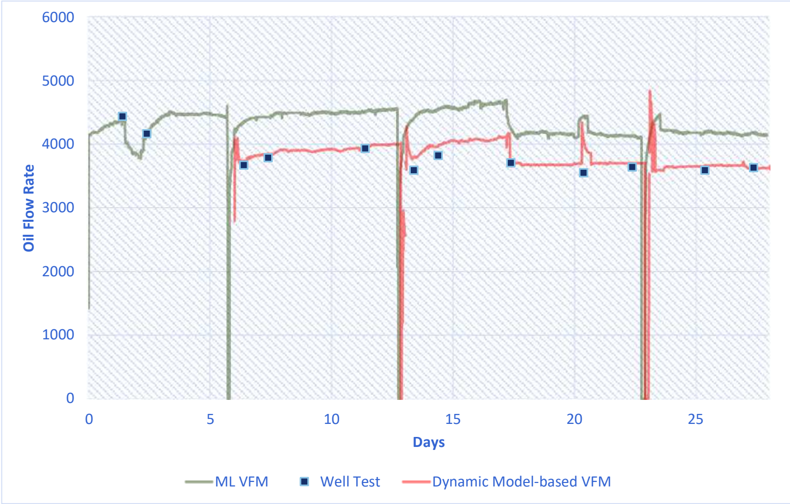


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# Summary

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- ML VFM is type of signal processing/pattern recognition virtual metering
- Hybrid ML VFM provides best of both worlds approach (ML + dynamic models)
- ML VFM computation effort is front-loaded; instant estimations
- Robust; no dynamic model convergence or calibration issues
- Confidence and accuracy by validating results in a physics-based model
- Increased knowledge about the wells to be monitored when combined with dynamic model; anomaly detection possible (flowline/choke blockage)
- Implements seamlessly into a production management system
- Subject matter expertise required to develop good hybrid ML models

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# Q & A

Thank you!