KUWAIT FLOW MEASUREMENT TECHNOLOGY FOR OIL & GAS CONFERENCE
GE Safire* Multiphase Program

GE Oil & Gas
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Global Commercial Leader – Multiphase, R&D Alliance Manager
GE Oil & Gas

✧ 29+ years of flow measurement experience and product management background focused on latest technology and innovation
✧ Active member of flow measurement standards committees at API, AGA, ISO, ASME
✧ Active member of measurement committees at PRCI (Pipeline Research Council Institute) and RPSEA (Research Partnership to Secure Energy for America)
✧ Authored technical papers and lectured at conferences and training schools including: AGA, ASGMT, ISHM, AGMSC, NSFMW, WGMSC, FLOMEKO, CSHM, CGA, ISFFM, CEESI, ASCOPE, IDEA, APPA, AEE, EPRI, ASME, ISA, etc.
✧ Bachelor of Science (BS) in Mechanical Engineering from Marquette University-Milwaukee, WI USA
✧ US Navy Military Veteran
Agenda

• Overview of Multiphase Measurement challenges
• Review GE Technology Solution Approaches
• Co-Development program and technology roadmap
• Discuss unique Swept Frequency Acoustic Interferometry impact on performance
• Describe Insights into Multiphase flow through Ultrasound Doppler
• Test Results from NEL, SWRI and large scale pilot of onshore oil wells for validation
• Conclusions and Next Steps

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Why Multiphase metering is a challenge?

Wide operating range
- Measuring cross section sees varying fluid mixtures
- Fluid composition changes over the well life
- Temperature depended fluid properties (Electrical/physical)

- One technology cannot address the whole operating environment of Multiphase Flow
• Oil-water-gas flow measurement needs 6 parameters (3 velocities and 3 phase fractions)
• Measuring all 3 velocities is a challenge → Models are used to fill in missing information
• Premise of slip models: Velocity components are dependent and the relationship can be defined for all flow conditions
• Slip model assumptions:
  • Assume that slip is a function of measurable flow conditions (Eg. Pressure, Temperature, fluid density, viscosity etc)
  • Average slip captures the effect of variations in space and time

Use of models and assumptions affect the accuracy and reliability
What are the parameters needed for measurement?

Component fraction:
- Ratio of liquid to gas phase
- Ratio of amount of water in liquid

Component Velocity:
- Velocity of each phase

Component density:
- Density of oil, water & gas

\[
\text{Mass flow rate} = \left(1-(\beta+\gamma)\right) V_o \rho_o + \beta V_w \rho_w + \gamma V_g \rho_g
\]
Velocity measurement challenges

Commonly used velocity measurements for gas-oil-water flow:

**Venturi dP**
- Provides mixture velocity if mixture density is available
- Estimation of and needs a model that accounts for slip between phases

**Cross correlation**
- Measures disturbance velocity, needs a model to estimate gas/liquid velocity
- Translating disturbance velocity to liquid velocity needs a slip model

*Current methods not directly measuring liquid velocity ➔ Need models to transform measured velocity to liquid velocity/flow rate*
• Combination of Sensors: Absolutely necessary for Performance Reliability
GE Subsea Version

Sensors

Electrical Impedance
- Phase fraction
- Gas velocity
- Water-cut
- Flow regime

Microwave
- Water-cut
- Phase fraction
- Salinity
- Flow regime
- Gas velocity

Ultrasound: Transit time & Doppler
- Liquid velocity
- Bubble velocity/profile
- Speed of sound – water cut

SFAI – Swept Frequency Acoustic Interferometry
- Dif.Pressure, press & temp
- Mixture density
- Mixture velocity

DP/P&T across venturi
- Liquid density
- Liquid viscosity

Ultrasound Torsional
- Mixture density

Gamma (Optional – subsea only?)
- Mixture density

Sensors integrated through Intelligent data fusion algorithm

Higher accuracy & performance reliability
As challenges increase more measurement modes are required

- **Land Wells**: Accessible, Calibration ‘OK’, Low fluid variety
- **Offshore**: Less accessible, Calibration not OK, Sampling possible, Higher fluid variety
- **Subsea**: Not accessible, Calibration not OK, No sampling, High fluid variety
- **Down-hole**: Un-accessible, Calibration not OK, No sampling, High fluid variety

- **Safire 2.0**: Ultrasound +Microwave option
- **Subsea**: Ultrasound, Microwave, EIS, Venturi, Gamma (optional)

- Leverage GRC & other GE technologies – i.e. Healthcare, etc
Partnering with Industry
A world-class partnership

- Industry leaders
- Innovative collaborators
- Understanding industry needs
- Domain expertise

Resulting in cutting-edge award winning technology

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Co-development, combining patented award winning technology

Frequency-sweep measurements in liquid through a container wall.

Previously applied to military applications.

Composite spectra of container wall and liquid.

GE O&G, Chevron, LANL Awarded 2014 R&D Magazine Award for 100 Most Innovative Technologies

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Swept Frequency Acoustic Interferometry (SFAI)
From Los Alamos National Laboratory (LANL)

Military Technology: Used to detect chemical agents inside warheads

Sensitivity: Can identify Coke versus Pepsi in a container

• If so, can we measure oil, gas, & water flowing in a pipe?
R&D Magazine’s Top 100 Worldwide Technologies

Previous award winners include fax machine, banking ATM, LCD display, medical MRI, and HDTV
Leveraging Ultrasound Doppler technology

Near Real time cross-sectional view with varying GVF

Liquid velocity profile observed through ultrasound transducer that are mounted diametrically opposite for 3” pipe with varying liquid and gas flow rates
• Doppler measurement based on principle of frequency shift of signals from moving objects

• Doppler measurement for flow: Scattered signals from inhomogeneities (small gas bubbles/droplets) exhibit Doppler shift related to velocity of scatterers

• Velocity is estimated from Doppler frequency shift $f_D$, carrier frequency $f_e$ in scattered signal, beam angle $\theta$ and speed of sound $c$

$$V = \frac{cf_D}{2f_e \cos \theta}$$

• Max, min velocities and resolution depend on carrier freq, beam angle and pulse repetition rate
Doppler data analysis

- Doppler velocity is a function of bubble velocity and amplitude is a function of number and size of bubbles.
- Larger bubbles reflect ultrasound signals and appear as blank spots.

**NEL test 2011**

**FFT peak velocity & amplitude**

@ 1250 frames/sec

**Pipe cross section**

- Doppler velocity is a function of bubble velocity and amplitude is a function of number and size of bubbles.
- Larger bubbles reflect ultrasound signals and appear as blank spots.
Doppler data
Flow regimes

• Tracking velocity and amplitude in time and space provides clear indication of flow regime

• As flow transitions from slug to churn to annular (NEL test 2011)
  – Gas bubbles get larger & liquid slugs are smaller and less frequent
  – Increased amplitude in the wake of large bubbles → smaller bubbles following the large Taylor bubble

• Doppler information (velocity and amplitude) is captured at instances of liquid slugs with embedded scatterers
Doppler data – Flow dynamics

• Negative flow (green) observed in slug-churn transition regime following the large gas bubble

• High sampling rate of Doppler DAQ captures acceleration and deceleration of flow

Pipe cross section
Ability to measure flow dynamics in complex flow regimes is key to reducing dependence on flow models and approximations
First Step: Onshore Liquid dominated Wells
Today’s well-by-well production data

- No cost-effective method of real-time measurement
- Wells are measured too infrequently (once every three weeks to six weeks)
- Measurements are unreliable and unrepeateable
- Complex measurement systems are expensive to maintain, build and operate
• It’s time for a solution to measure oil flow and water cut for new and mature topside oil field production.
Introducing the GE *Safire* meter

• Finally, a cost-effective topside multiphase flow meter for every well.

Enabling customers to make better decisions to produce more oil.
The vision: increasing oil production for industry

**TODAY**
Periodic data collection process

MONTHLY MEASUREMENT

Oil | Water | Gas

**TOMORROW**
Real-time data collection process with M&C sensors

HOURLY MEASUREMENT

Oil | Water | Gas

More frequent reliable data
Better decisions
Potential X...% production improvement

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About the Safire* meter
The topside **Safire*** meter today

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**FEATURES**

- Compact economical design
- Water (WLR) and oil (OLR) measurement
- Non-intrusive flow measurement
- Real-time measurement
- Available in 2, 3, 4 and 6-inch versions
- Multi-channel redundancy

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**BENEFITS**

The **Safire*** meter helps operators to make better decisions to reach their goals of:

- Optimizing oil production and recovery
- Reducing the cost and complexity of traditional gauging facilities, and
- Decreasing safety risks

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Empowering Customers

The *Safire* meter helps operators to make better decisions to reach their goals of:

**Optimizing oil production**
- Enabling accelerated oil production
  - Well level optimization
  - Identify underperforming wells
- Enabling increased reservoir recovery
  - Understand well-to-well interaction
  - Optimize injection points and locations
  - Enhance reservoir & drilling models

**Reducing costs & complexity**
- Eliminating the need to install traditional measurement systems (test separators, AWTs)
- Removing the need to maintain traditional measurement system (valves, manifolds)
- Decreasing the need for well testing services

**Decreasing safety risks**
- Reducing the amount and size of equipment in the field to maintain
- Minimizing the occurrence of field fabrication
- Reducing man-hours in the field

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Validation & Results
Bangalore GRC loop

Multiphase flow loop @ NEL UK

- Loop fluid: North-sea crude, water & nitrogen
- Pressure ~10bar, no salinity and viscosity variation
- Test carried out @ NEL: 2010, 2011 & 2012

Multiphase flow loop @ SWRI US

- Loop fluid: Mineral oil, saline water & nitrogen
- Representative pressure (~230bar), varying salinity & viscosity
- Representative flow rates, 2 months of detailed test 2012

Trailer Test Setup

More GE multiphase loops in Norway & Billerica, MA

Bakersfield oil wells

Chevron Loop – real fluids
Safire
Well Test Results

**PWT 11 WLR**

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<th>PIC</th>
<th>Inlet</th>
<th>Outlet</th>
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<td>59.6</td>
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<td>2:19</td>
<td>57.4</td>
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<td>Average</td>
<td>57.6</td>
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<td>58.1</td>
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**PWT 26 WLR**

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<tr>
<td>Average</td>
<td>56.8</td>
<td>55.9</td>
<td>53.4</td>
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</table>
Measuring Rod pump wells – New insights from Safire

Real-time data deals with flow transients
Unprecedented performance

FLUID TYPE: Crude oil <20% GVF; 0-100% WLR
API RANGE: 13 to 45
TEMP LIMITS: Up to 165°C (330°F)
FLOW RANGE: 0.1 to 20 ft/s (0.03 to 6.1 m/s) and higher velocities
PIPE SIZES: 2”, 3”, 4” & 6” pipe sizes (others upon request)
SWEET SPOT: Heavy oil; high water cut

• “This is outstanding! I finally got the rates and cuts from [AWT] and here is the comparison with the GE meter for the testing.”
• - Chevron Technology Advisor

<table>
<thead>
<tr>
<th></th>
<th>WLR (Cut by Volume) - %</th>
<th>Gross Flow Rate - BPD</th>
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<tbody>
<tr>
<td>Test Trailer</td>
<td>97.5%</td>
<td>623</td>
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<tr>
<td>GE Meter</td>
<td>97.1%</td>
<td>647</td>
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<tr>
<td>Difference</td>
<td>-0.4%</td>
<td>-3.9%</td>
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Smarter decisions faster

**Technology**
- Expand capability
  - SFAI
  - Doppler
  - Microwave
  - Global Research Center

**Software**
- Industrial Internet
  - Production optimization
  - Multiple data inputs
    - Safire, Lufkin, Artificial lift
  - GE Software COE

**Services**
- Establish foundation
  - Local support office
  - Domain expertise
  - Global development
Production Optimization Vision

- Integrated sensing & automation
- Smart & automated workflows
- Big data analytics & optimization

- Lufkin POC
- Safire* Meter
- Zenith

Maximize existing hardware & capabilities
Empowered decision making with scaled automated expertise
Analyze & optimize data to increase production efficiency

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Summary

• Exciting New Measurement Technology developments to help industry better manage and operate oil and gas wells
• Unique & truly revolutionary ultrasonic non-invasive technology
  – SFAI & time gated Doppler applications
• Great collaboration between GE and Industry partners/co-developers
• Continuous flow, water cut and GVF can provide real time dependable data to:
  – Optimize and accelerate production
  – Increase recovery through better reservoir management
  – Get More Oil Faster!
• Big Data: GE SW COE co-developing production optimization platform
  – Integrated Total Solution Package
Safire MPFM Deployment Examples