

Multiphase Flow Measurements using Coriolis Meters

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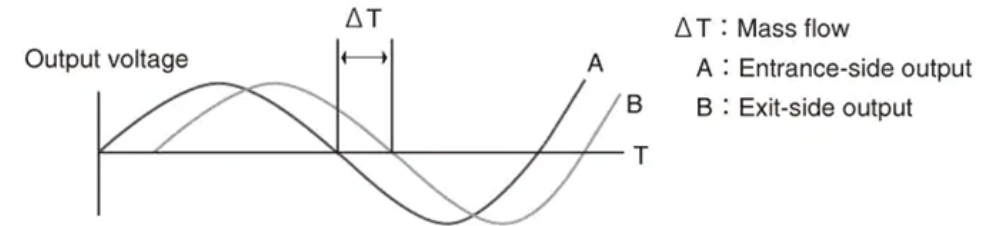
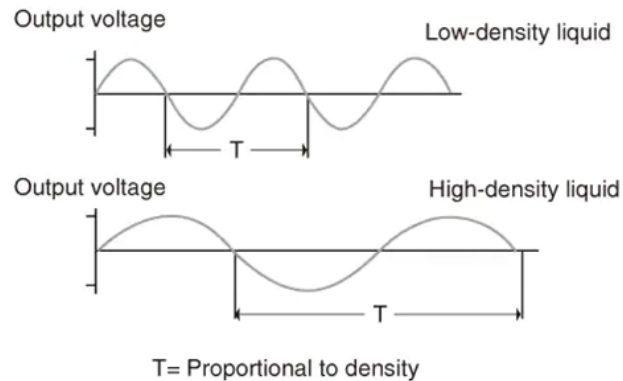
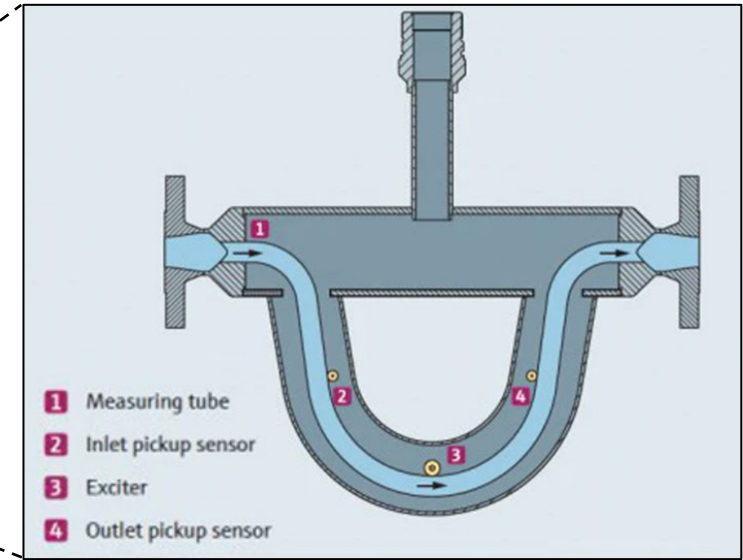
Saudi Aramco

Agenda

- Introduction
- Coriolis Meters in Multiphase Flow
- Aramco Efforts
- Multiphase Coriolis Meter Design
- Field Trial Results

Coriolis Metering Principle

- Pair of 'U' shaped flow tubes in meter
- Exciter vibrates the flow tubes
- Two pickup sensors - at inlet and exit



Density $\propto 1/\text{resonant frequency}$

Mass flow $\propto$ Phase shift between pickups

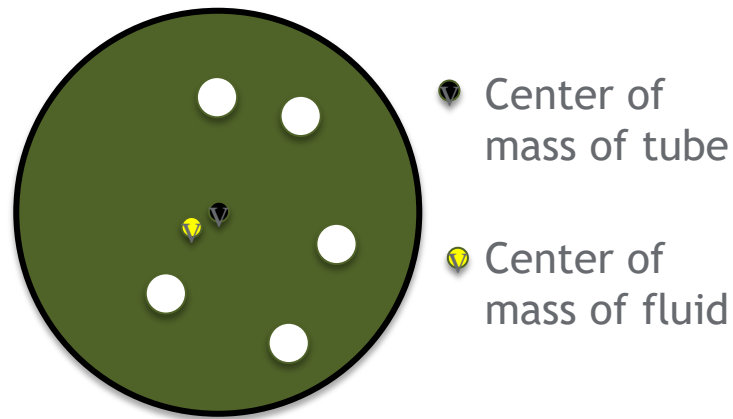
Phase Shift Caused by Coriolis Force

Very Good for Single Phase Flow Metering

Coriolis Meters: Effect of Gas Entrainment

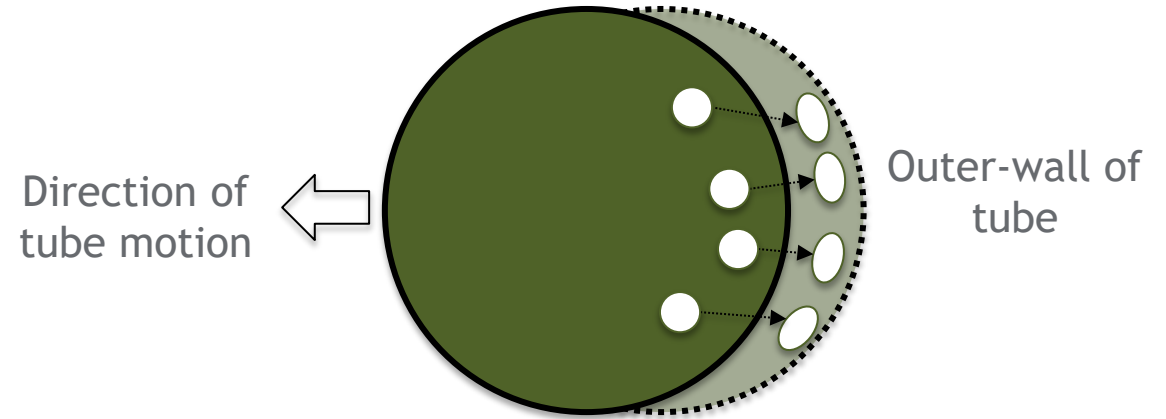
Gas entrainment issues^{1,2,3}

- Phase decoupling $\Rightarrow$ gas phase and liquid vibration response decoupled
- Gas compressibility² $\Rightarrow$ larger reaction by compressed fluid on outside wall



Phase Decoupling

Always causes a negative error^{1,3}



Gas Compressibility

Always causes a positive error^{1,3}

¹ - Basse, N., "A review of the theory of Coriolis flowmeter measurement errors due to entrained particles", Flow Measurement and Instrumentation, 2014, Vol. 37, pp.107-118

² - Weinstein, J., "Multiphase Flow in Coriolis Mass Flow Meters - Error Sources and Best Practices", Proceedings of the North Sea Flow Measurement Workshop, 2010

³ - Hemp, J., and Kutin, J., "Theory of errors in Coriolis flowmeter readings due to compressibility of the fluid being metered", Flow Measurement and Instrumentation, 2006, Vol. 17, pp. 359-369

Multiphase Coriolis: Efforts at Aramco - Part 1

- **2020: Yokogawa meter**
 - 3-inch Rotamass meter
 - Tested in Cranfield University flow loop
 - Published results in North Sea Flow Workshop 2020
 - Meter worked well up to 40% GVF

https://nfogm.no/wp-content/uploads/2022/01/D2_04-Saketh_Mahalingam-Aramco.pdf



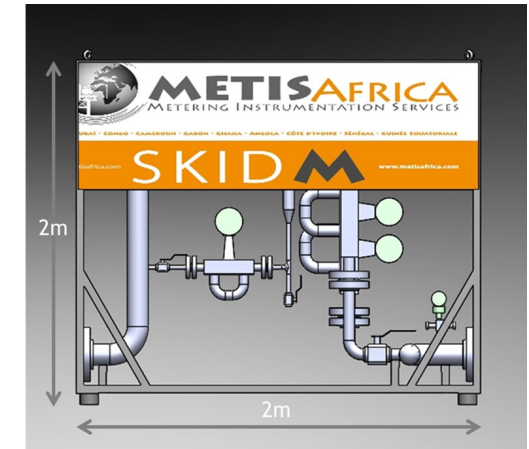
- **2021: Endress & Hauser meter**
 - 2-inch Dual Frequency Promass Q
 - Tested in Cranfield University flow loop
 - Published results in North Sea Flow Workshop 2021
 - Meter worked up to 50% GVF

https://nfogm.no/wp-content/uploads/2023/08/17-Multiphase-Metering-Using-a-Dual-Frequency-Coriolis-Mass-Flow-Meter_Aramco_-Mahalingam.pdf



Multiphase Coriolis: Efforts at Aramco - Part 2

- 2025-Present: COMETS meter with METIS (Yokogawa)
 - 2-inch Yokogawa meters in parallel
 - Increase total flow range & reduce dP
 - Works in full range 0 to 90% GVF
 - Qualification test planned Q4/2026, field trial Q1/2027
- 2026-Present: Novel Coriolis meter planned project
 - Low pressure drop using straight tube design
 - Novel driver mechanism
 - Built-in dP, water-cut sensing



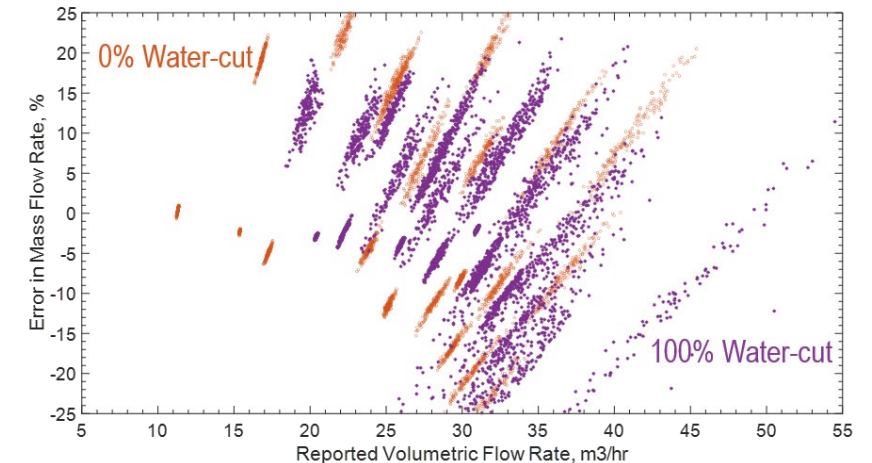
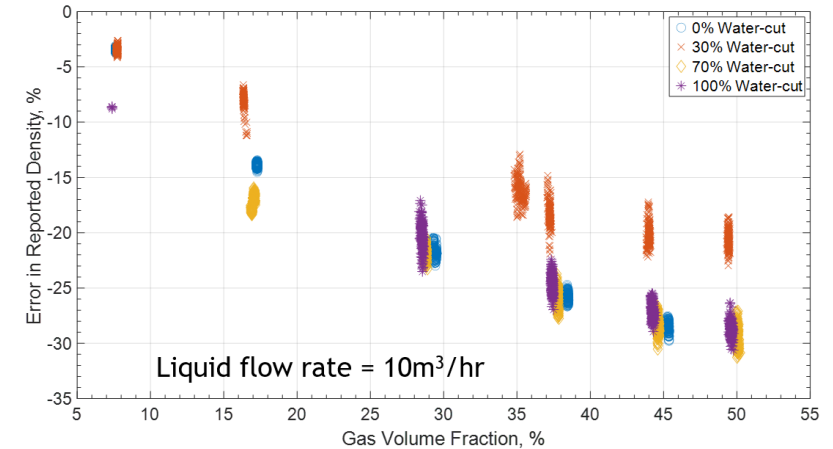
Coming soon

Projects part of a structured roadmap

Goal is to make Coriolis meters widely used in multiphase flow

Coriolis Meter Under Multiphase Flow

- Multiphase flow causes vibration control issues
 - Increasing gas $\Rightarrow$ increased damping
 - Increased damping $\Rightarrow$ increased drive gain
 - Increased drive gain $\Rightarrow$ meter readings **wrong**
- Modern Coriolis meters can handle GVF of up to 50%
- Density & Mass flow errors are repeatable
 - Need water-cut to know liquid density
 - Corrected density $\propto$ GVF
 - Corrected Mass Flow $\propto$ Mixture mass flow



Small meters (<=2-inch) can handle 0 to 100% GVF but lower overall flow

Larger meters GVF is limited to <=60% due to pressure drop

Multiphase Metering Approach

- Fit Hemp error model accounting for decoupling and compressibility

$$\text{Error in density} = E_d = -3\alpha + f(\alpha, \beta)$$

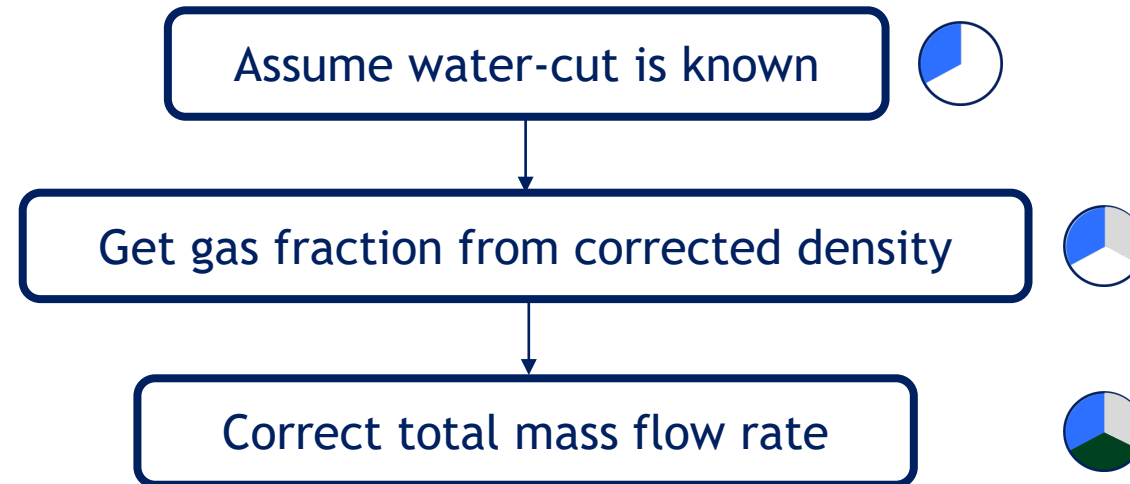
α = gas volume fraction

β = water cut

f = function of

$$\text{Error in mass flow} = E_m = -\frac{2\alpha}{1-\alpha} + f(\alpha, \beta)$$

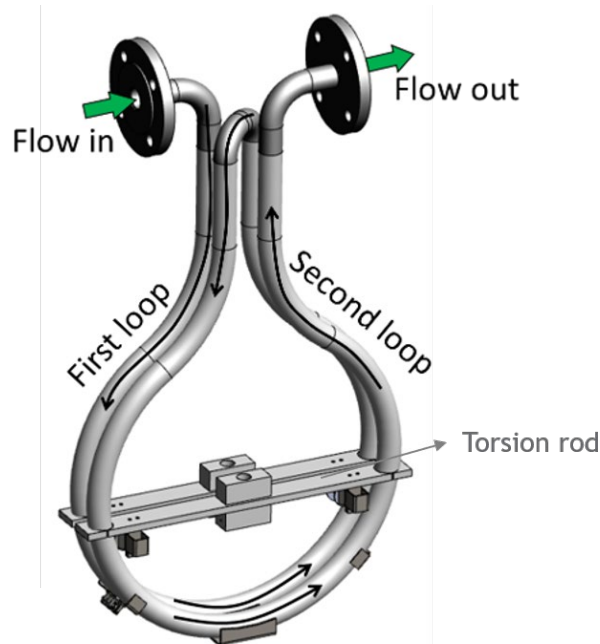
How do we achieve multiphase metering?



Multiphase Coriolis Metering Projects

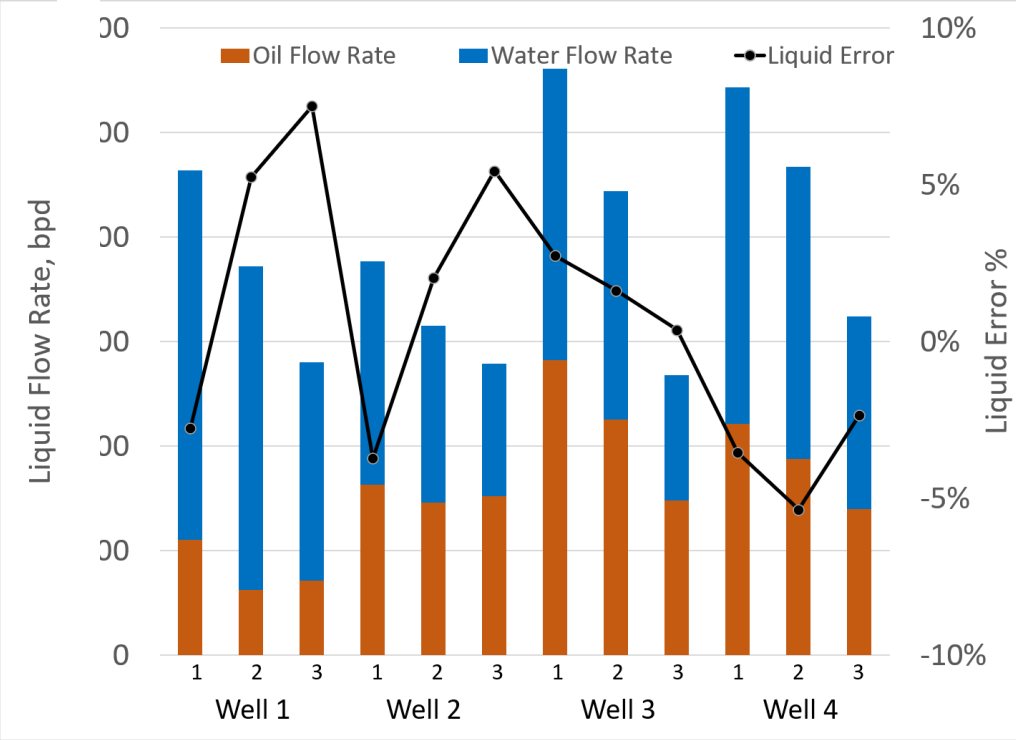
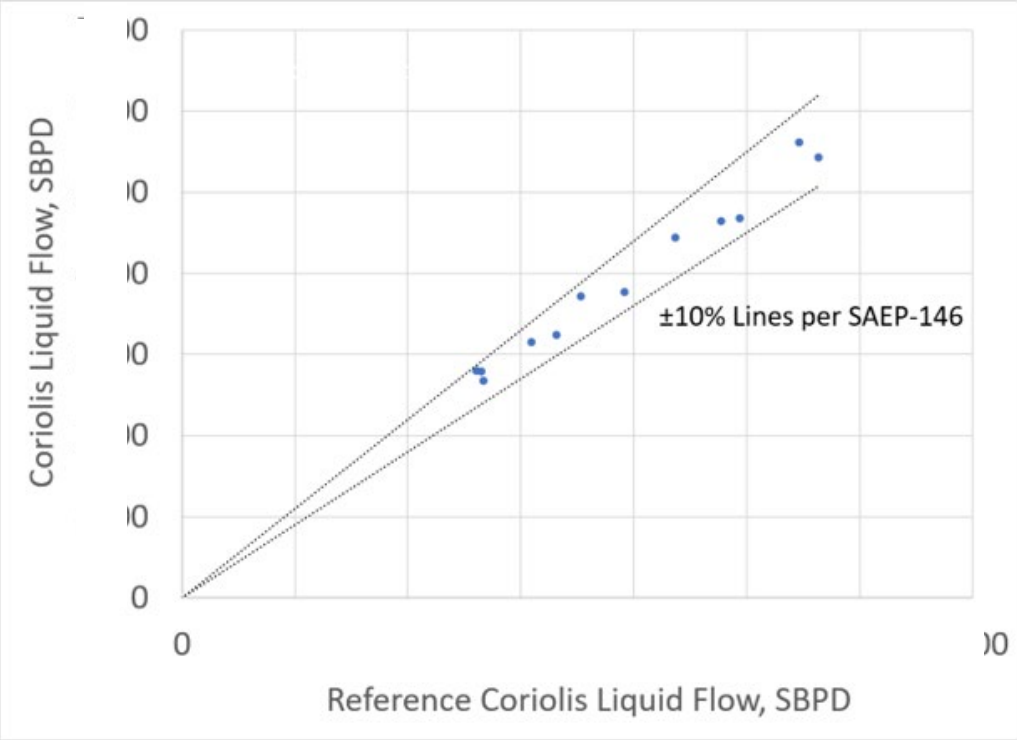
- 2021-Present: Oxford University + Rheonik meter
 - Single-path, dual frequency meter
 - Tested at NEL, Coventry flow loops, 0-50% GVF
 - PRISM signal processing from Oxford
 - Successful field trial completed May 2026 in Saudi Arabia

<https://nfogm.no/wp-content/uploads/2024/06/2-Operation-and-verification-of-a-dual-mode-Coriolis-meter-using-Prism-Signal-Processing-Oxford-Henry.pdf>



Meter Performance

- Excellent performance of meter within Aramco standard SAEP-146



Summary

- Coriolis meters offer a viable option for non-radioactive multiphase metering
- Technology successfully tested in the field
- Further development to develop a commercial solution planned

Questions?