Oil & Gas Measurement Limited

Oil-Water Flow Measurement (or Sampling) for Custody Transfer Application

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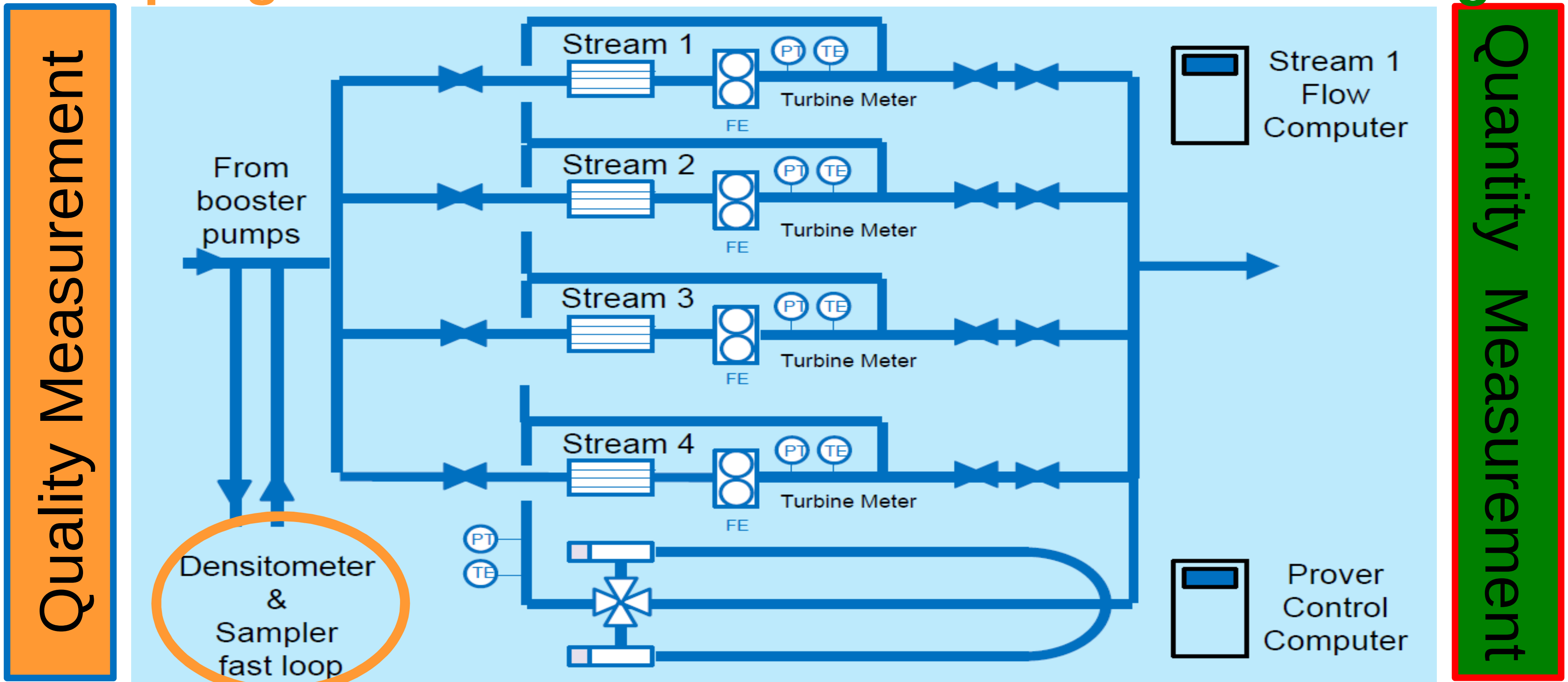
Oil & Gas Measurement (OGM) Limited

What does Custody (Ownership) Transfer involve?

Sampling **Metering**



ISO 3171 and API 8.2:

Homogeneity for a maximum of 5% WC

0.9 < C1/C2 < 1.0 ➔ ±5% Error

> 90% homogeneity

Meter Linearity: ±0.15%

Repeatability: 0.05% (5 runs)

Uncertainty : (overall ??)

Target: By consensus, the overall uncertainty is **±0.25%** (UK)

The FIVE Stages of Sampling : ISO 3171, API 8.2

What is really at the heart of Sampling?

Mixing

The aim is to achieve homogeneity for representative sampling

Mixing of oil and water → Two fluids that don’t like to mix / Two fluids that naturally co-exist → Challenging

Key Factors in Mixing

- **Turbulence → Mixing (chaos)**
- **Small droplet → Emulsification (delicate)**
- **Large droplet → Stratification (balance)**
- **Grab Size → low uncertainty (consistency)**
- **Sample handling → Evaporation (delicate)**
- **Sample Analysis → 1:300,000,000 (delicate)**

It may be easier to keep a man and a woman in a perfect relationship rather than keeping Oil and Water mixed homogeneously.

Presentation Outline

1. Introduction

If I managed to convince you that this is a difficult job, I will now take you through the efforts we made to achieve ~97% mixing efficiency and hence superior sampling .

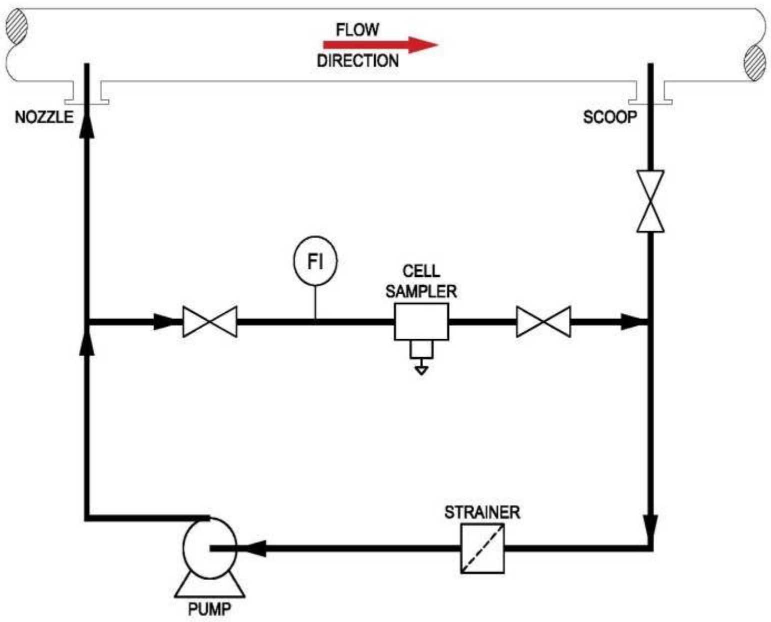
2. OGM's Approach to Automatic Pipeline Sampling
   - Development of OGM's Flow Testing & Calibration Facilities (FTCF)
   - Development of the SmartMix® Sampling System Concept
3. Testing and Validation of the SmartMix® Sampling System
   - Mixing quantification using Magnetic Resonance Imaging (MRI)
   - Mixing quantification and Proving by Water Injection (PWI) using the MPP™ device
   - Mixing quantification using Multiphase Computational Fluid Dynamics (MCFD) Model
4. Conclusion

OGM

OGM's approach to Automatic Pipeline Sampling

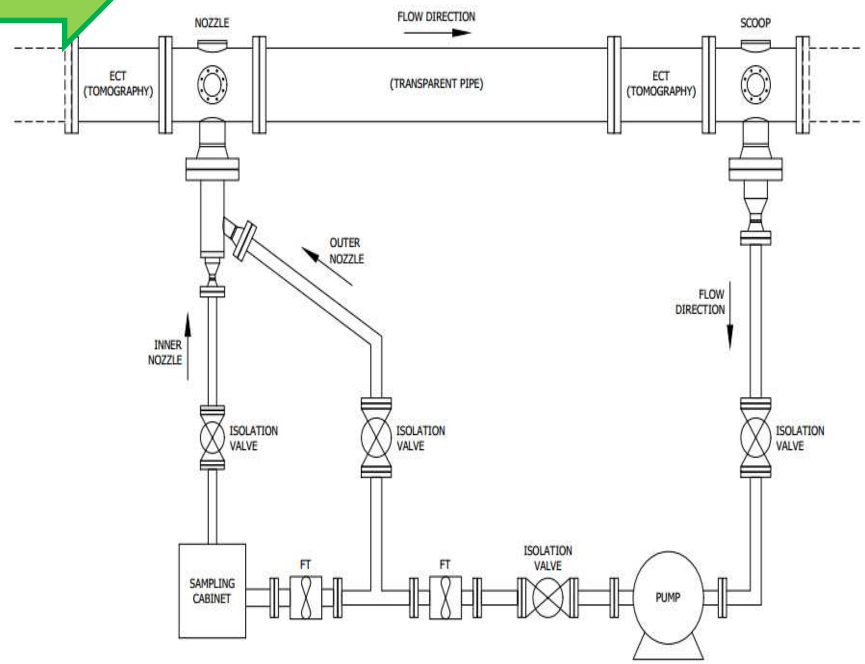
Limitations of Current Best in Class Mixing or Sampling systems:

- Repeated Sampling because sample re-circulation
- High Power Requirement due Agitation Mixing



Our Design Improvements

- Twin-Nozzle (**no repeat sampling**)
- Jet-Jet Vortex Interaction (**Entrainment-Atomisation Mixing**)

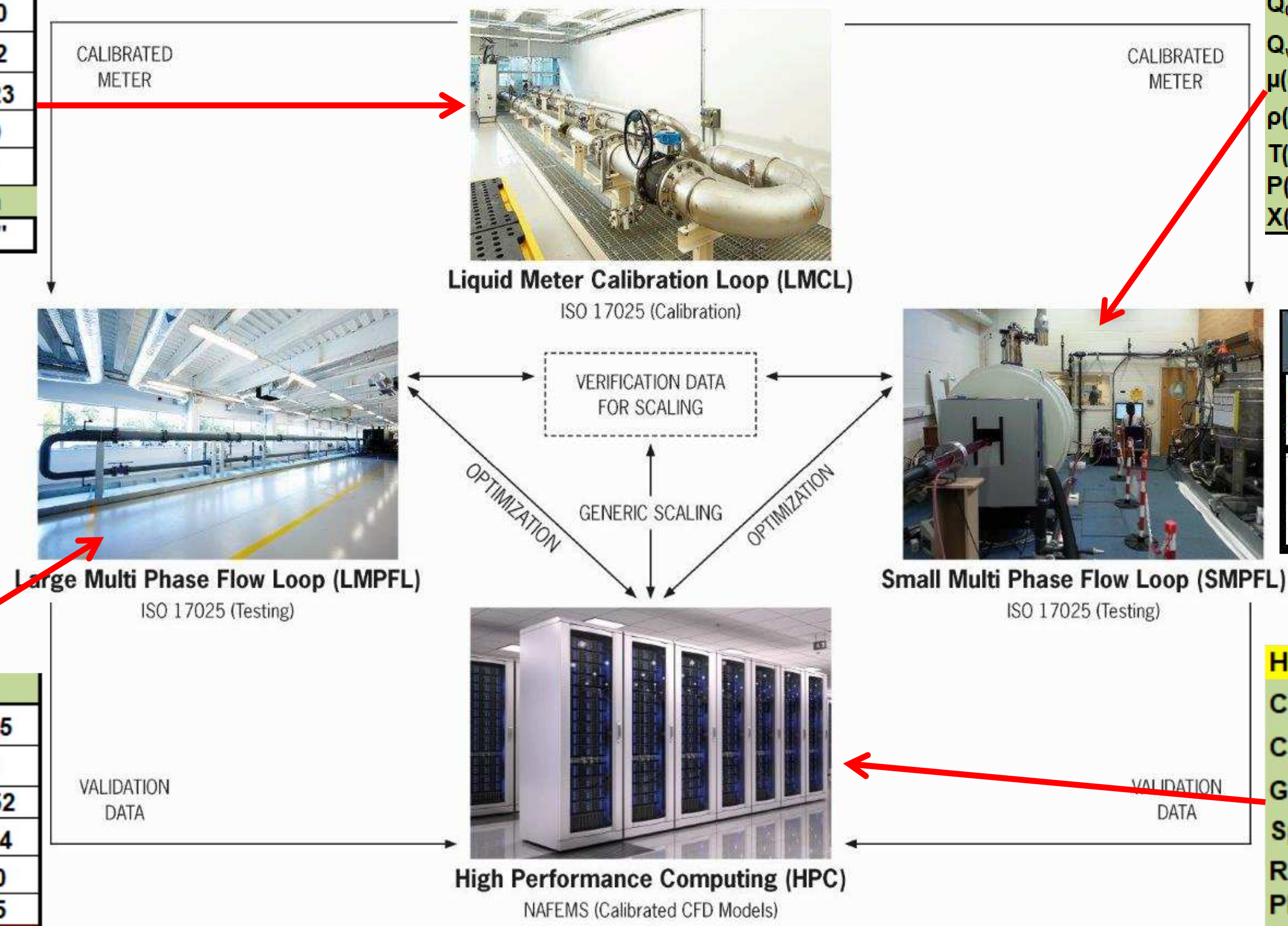


OGM Flow Testing & Calibration Facilities (FTCF)

- Extensive Investment on **facilities** = SMPFL + LMPFL + LMCL + HPC
- Government R&D funding and collaboration with the **University of Cambridge**
- **Synergy** between Physical Experiment (Loops) and Numerical Experiment (HPC)
- Validated MCFD Model to **scale up design** for Large Pipe Mixing/Sampling

LMCL	Min	Max
Q_w(m^3/hr)	0.6	800
μ(cSt)	1	112
ρ(kg/m^3)	998	1123
T(^{0}C)	20	40
P(barg)	0	8
	Calibration	
Diam	1"	12"

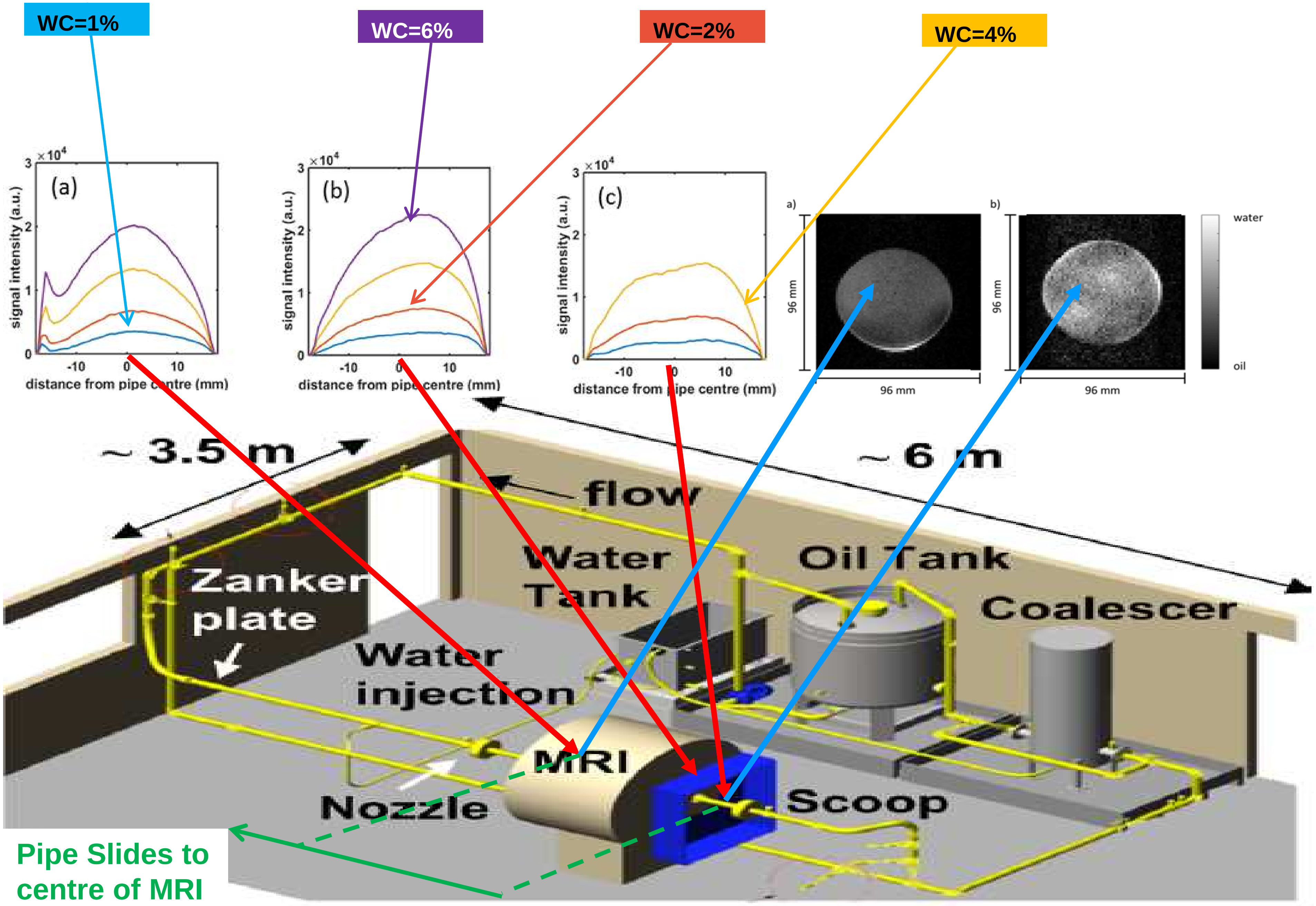
SMPFL	Min	Max
Q_O(l/m)	0	245
Q_w(l/m)	0	245
μ(cSt)	2.7	4.52
ρ(kg/m^3)	792	804
T(^{0}C)	20	40
P(barg)	0	5
X(%)	0	100



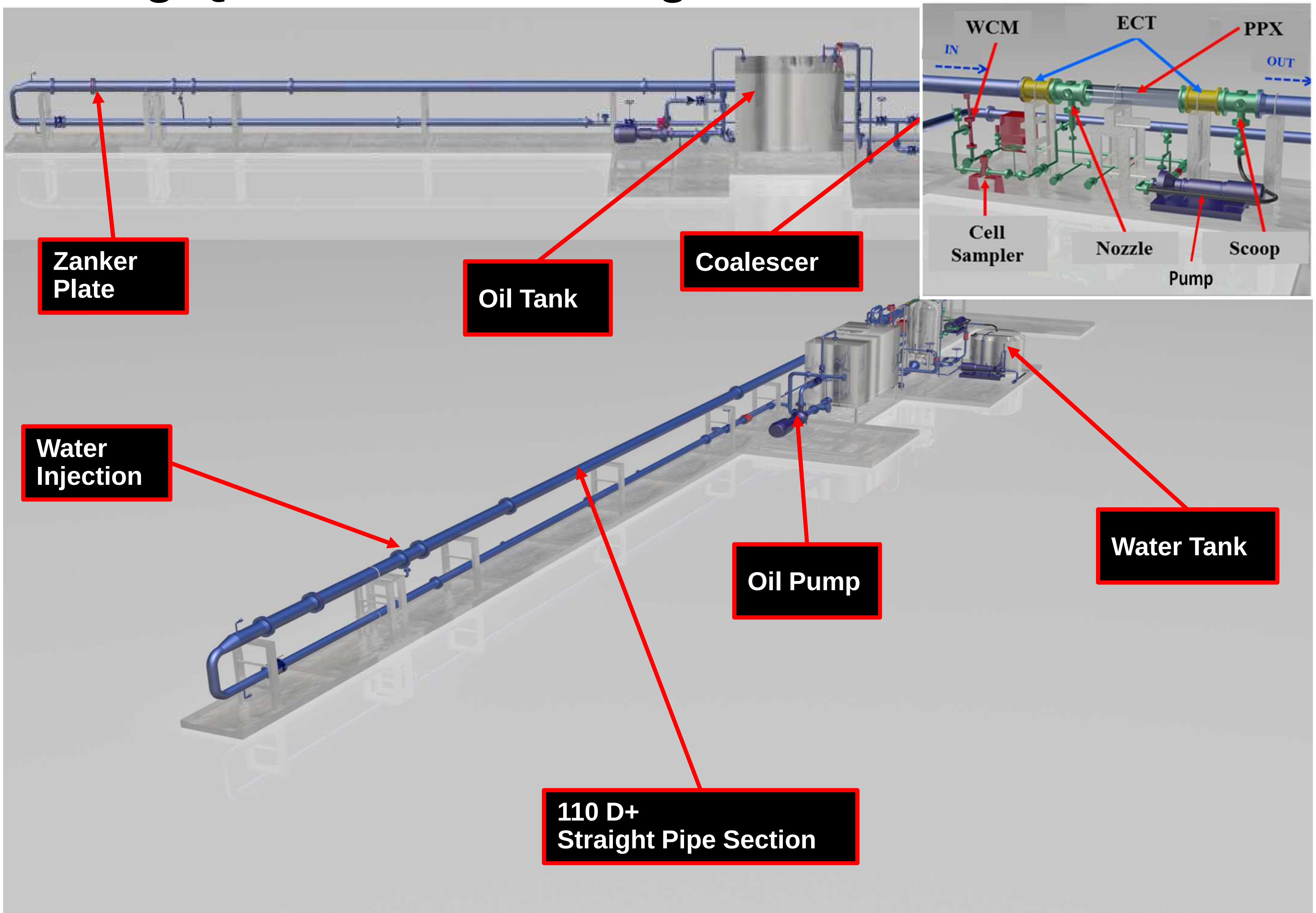
LMPFL	Min	Max
Q_O(m^3/hr)	0	145
Q_w(m^3/hr)	0	8
μ(cSt)	2.7	4.52
ρ(kg/m^3)	792	804
T(^{0}C)	20	40
P(barg)	0	15
X(%)	0	10

HPC	Min
CPU-GPU	16 Node
CPU /Node	Dual 8 Core
GPU/Node	4*K-20
Speed/CPU	2.6Hz
RAM/Core	32GB
Platform	OpenFOAM
Performance	32 Teraflop

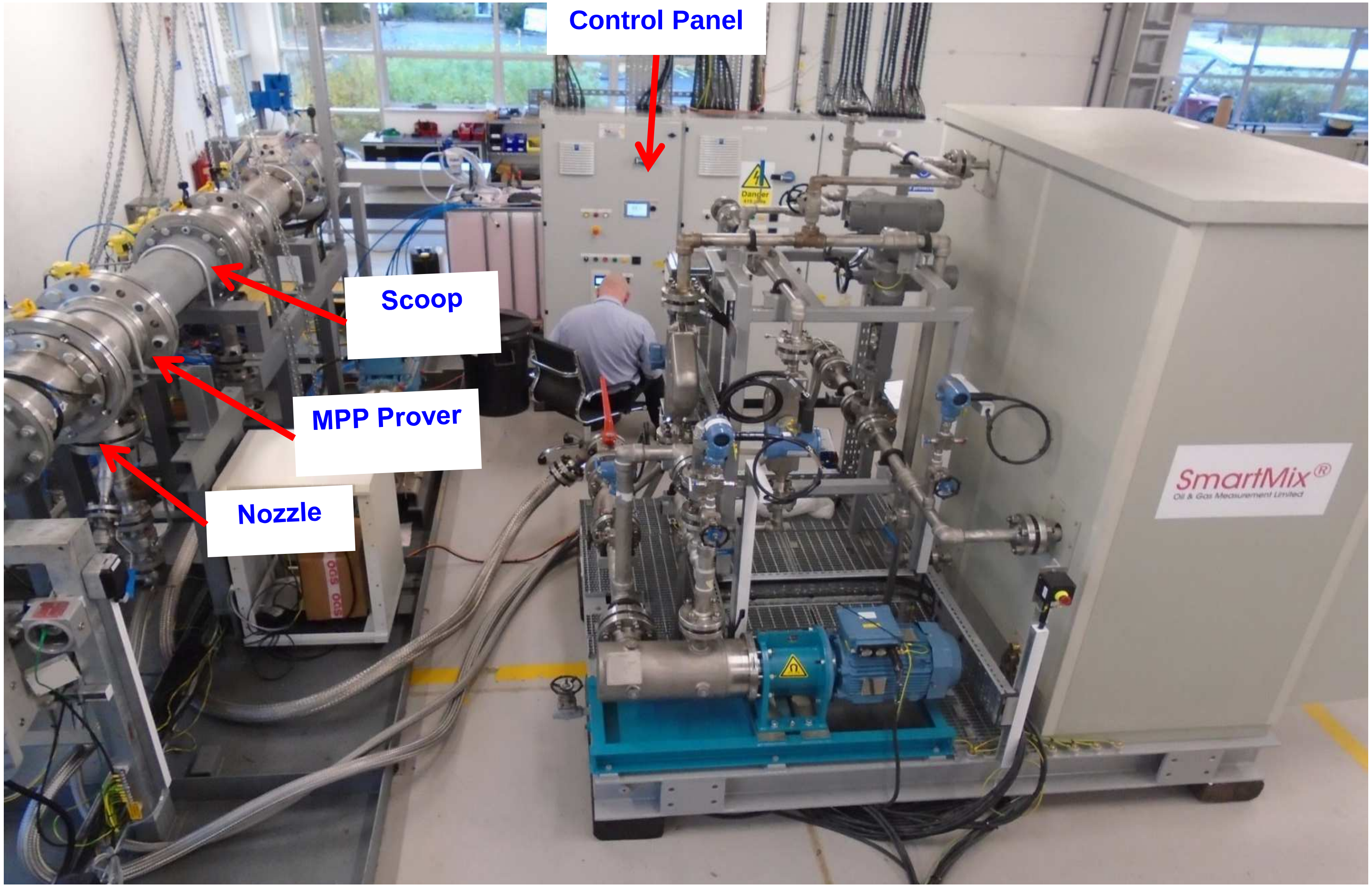
Results: Mixing Quantification using MRI on the SMPFL



Mixing Quantification using PWI on the LMPFL



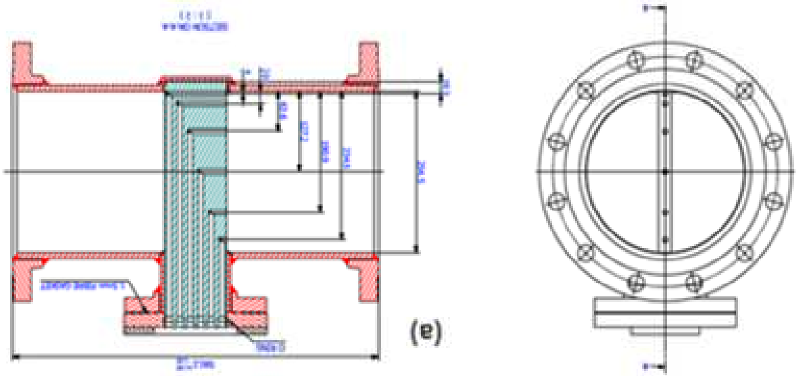
SmartMix® Sampling System SKID



- **Nozzle : mixing via Twin Jet-Jet Interaction**
- **Scoop : Iso-Kinetic Sample Extraction**
- **MPP : Multiport Profile Proving via Water Injection**

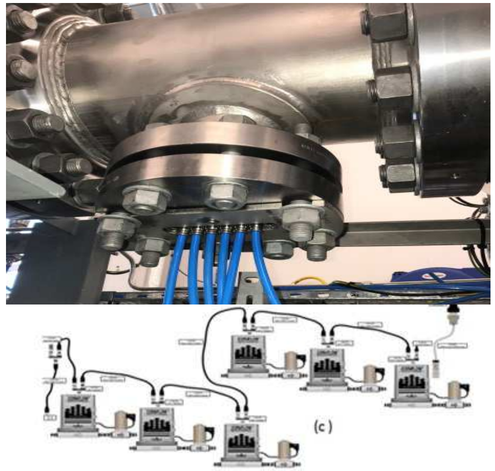
Result: Isokinetic Sampling using MPP^{TM} Device

- **MPP = Multiport Profile Proving** for water injection testing
- Two stage "Mix and Measure" approach versus Current 5-stages



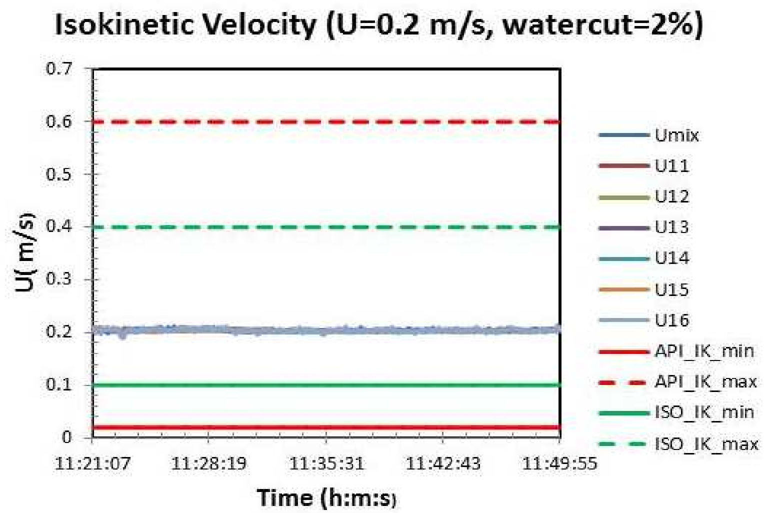
MPP Structure

MPP spool



M55 Coriolis Meter (Bronkhorst UK)

- Aims to capture mixing distribution across the pipe diameter using 6-probes,
- One probe is placed directly at the pipe base and one at the pipe axis/centre while the other four probes are positioned symmetrically according to ISO 3171
- True ISOKINETIC Sampling was achieved



Mixing Homogeneity at Challenging Conditions

ISO 3171 and API 8.2 both recommend the C1/C2 ratio to lie within 0.9 < C1/C2 < 1

- Where C1 is the mixture component concentration measured from upper half of the pipe while C2 is from the lower half of the pipe

Challenging conditions:

- Low density
- Low flow rates
- Horizontal orientation

LMPFL	Min	Max
$Q_O(m^3/hr)$	0	145
$Q_w(m^3/hr)$	0	8
μ(cSt)	2.7	4.52
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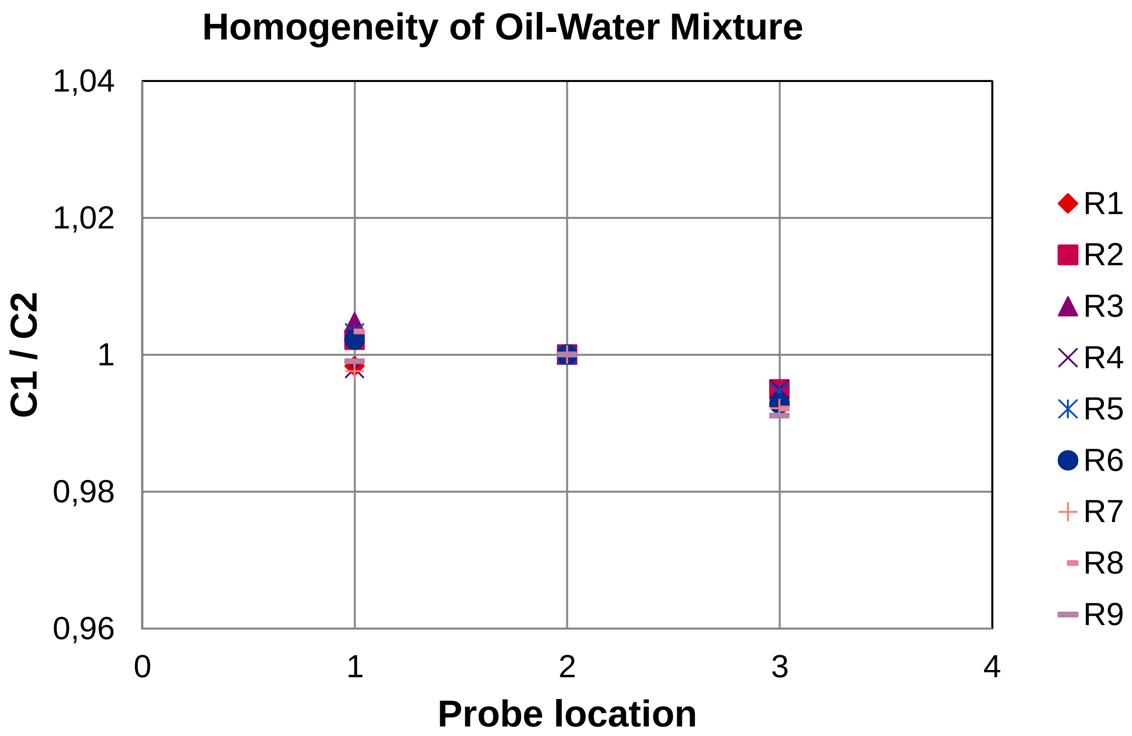
$T(^0C)$	20	40
P(barg)	0	15
X(%)	0	10

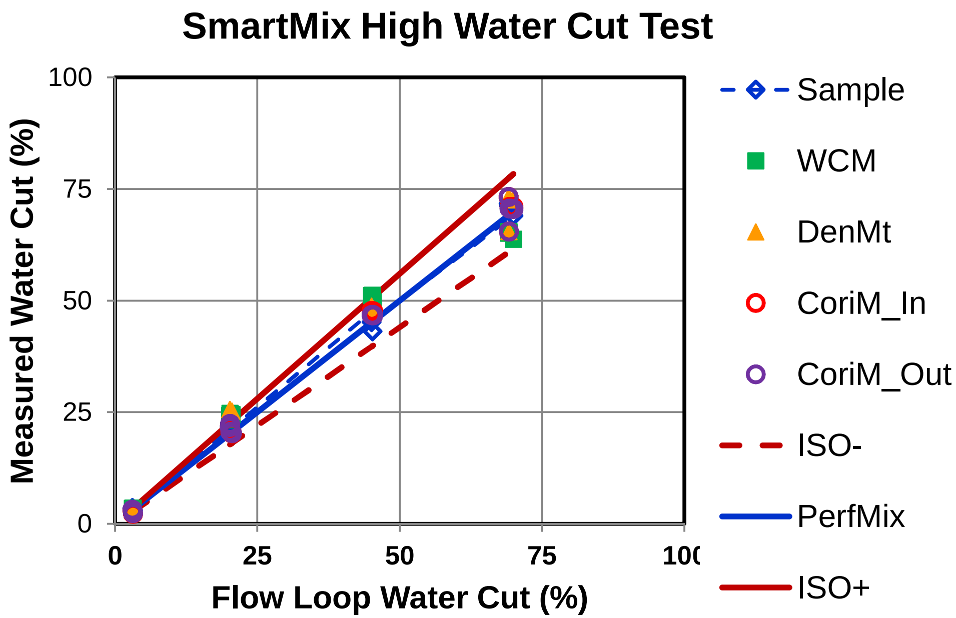


	R1	R2	R3	R4	R5	R6	R7	R8	R9
U(m/s)	0.2	0.4	0.6	0.2	0.4	0.6	0.2	0.4	0.6
WC(%)	1	1	1	2	2	2	4	4	4

Mixing Homogeneity at Challenging Conditions

SmartMix® Sampling System High Water Cut Mixing Test Matrix & Results

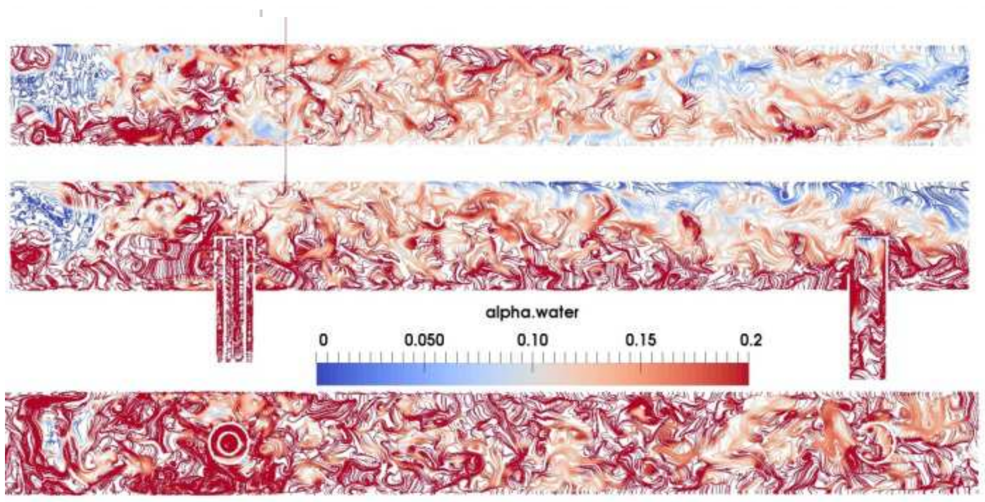
- Results from high water cut (3% ≤ X ≤ 75%) mixing test results show exceptional mixing efficiency of > 96.7%



	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12
U(m/s)	0.45	0.65	0.85	0.45	0.65	0.85	0.45	0.65	0.85	0.45	0.65	0.85
WC(%)	3	3	3	20	20	20	45	45	45	70	70	70

CFD Simulation of High Water Cut Test (R4)

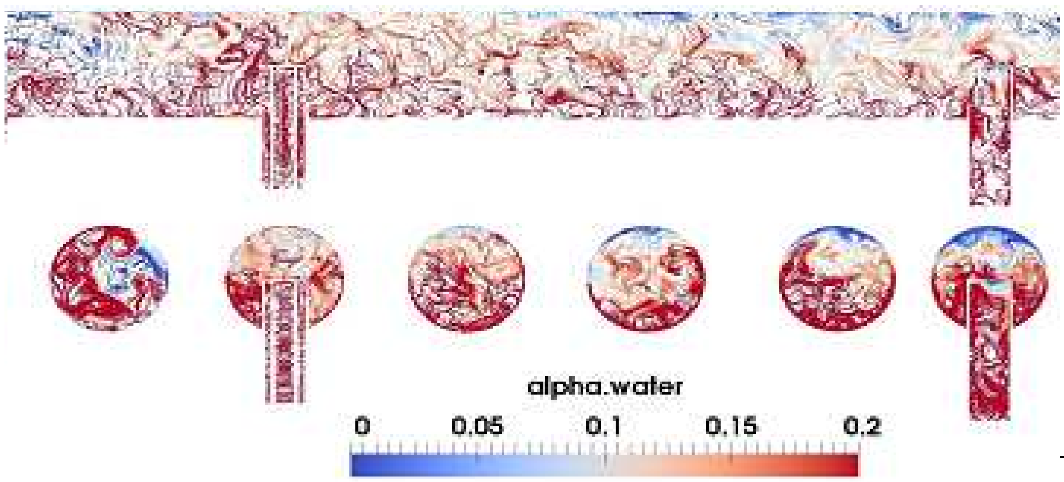
2D View of mixing evolution
- Top Profile
- Front Profile
- Bottom Profile



Water

Oil

2D view of the mixing evolution
- Front Profile
- Slice of Axial Profile



Conclusion

Sampling is the elephant in the room in Oil-Water flow measurement mainly due to poor mixing.

Current 5-Stages of Sampling Approach:

- **Chain of Increased Uncertainty**
- **Could be Laborious**
- **Could be Expensive**
- **Physical Sampling useful (composition/evidence)**

Proposed "Mix and Measure" Approach:

- **Achieves quoted measurement Uncertainty**
- **Competitive cost**
- **Automatic operation**
- **No physical evidence (so does other meters)**

How bad is the financial Exposure?

- Consider Half a Million BBL/day Capacity Station (0.5% water cut)
  - 61% (G>2) Mixing Efficiency ➔ Loss of ~$ 18 Million/year
  - **90% (G>10 or Grade A) Mixing Efficiency ➔ Loss of ~$4.8 Million/year**
  - 95% Mixing Efficiency ➔ Loss of ~$ 2.4 Million/year
  - **97% Mixing Efficiency ➔ Loss of ~$ 1.43 Million/year ($2.37M ➔ 70% gain)**
  - 99.8% Mixing Efficiency ➔ Loss of ~$ 95K/year

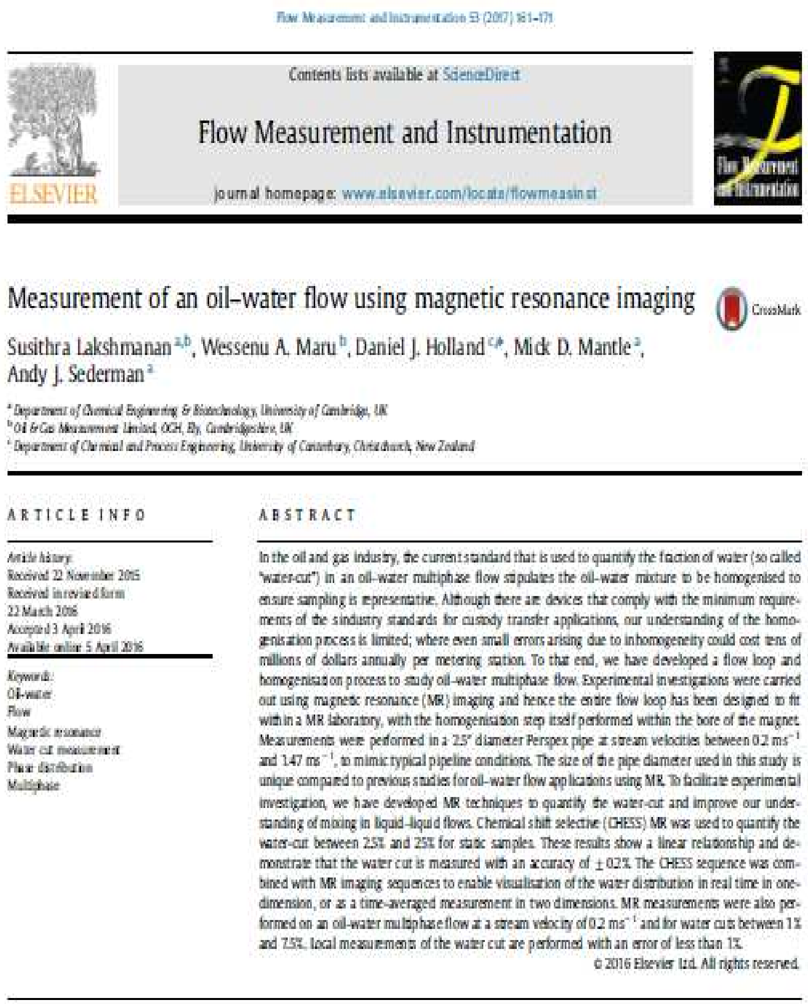
Selected Publications on SmartMix® Technology Development

- Maru, W. Holland, D. Lakshmanan, S , Thomas, A and Sederman, A. J. Multiphase Flow and Mixing Quantification using Computational Fluid Dynamics and Magnetic Resonance Imaging, Special Issue in Recent Global Developments in the Measurement of Oil and Gas Flows (2019) to appear

- Lakshmanan, S., Maru, W., Holland, D., Thomas, T. and Sederman, A. J., Quantifying Mixing Efficiency in automatic pipeline sampling, Northsea Flow Measurement Conference, Norway, 2017.

- Lakshmanan, S., Maru, W., Holland, D. J., Mantle, M, D., and Sederman, A. J., Measurement of a multiphase flow process using magnetic resonance imaging, J. Flow Measurement and Instrumentation, 53: 161-171, 2016.

- Lakshmanan, S., Maru, W., Holland, D.J., and Sederman A., Multiphase flow quantification using Computational Fluid Dynamics and Magnetic Resonance Imaging, North sea Flow measurement Conference, Norway, 2015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Measurement of an oil–water flow using magnetic resonance imaging

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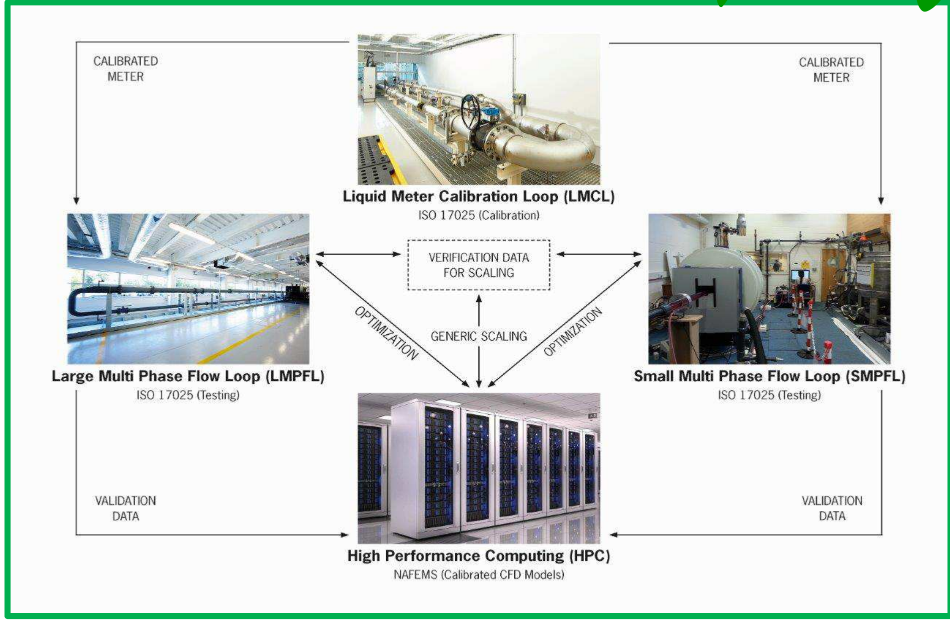
ABSTRACT

In the oil and gas industry, the current standard that is used to quantify the fraction of water (so called "water-cut") in an oil–water multiphase flow stipulates the oil–water mixture to be homogenised to ensure sampling is representative. Although there are devices that comply with the minimum requirements of the sindustry standards for custody transfer applications, our understanding of the homogenisation process is limited; where even small errors arising due to inhomogeneity could cost tens of millions of dollars annually per metering station. To that end, we have developed a flow loop and homogenisation process to study oil–water multiphase flow. Experimental investigations were carried out using magnetic resonance (MR) imaging and hence the entire flow loop has been designed to fit within a MR laboratory, with the homogenisation step itself performed within the bore of the magnet. Measurements were performed in a 2.5" diameter Perspex pipe at stream velocities between 0.2 ms^{-1} and 1.47 ms^{-1}, to mimic typical pipeline conditions. The size of the pipe diameter used in this study is unique compared to previous studies for oil–water flow applications using MR. To facilitate experimental investigation, we have developed MR techniques to quantify the water-cut and improve our understanding of mixing in liquid–liquid flows. Chemical shift selective (CHESS) MR was used to quantify the water-cut between 2.5% and 25% for static samples. These results show a linear relationship and demonstrate that the water cut is measured with an accuracy of $\pm$0.2%. The CHESS sequence was combined with MR imaging sequences to enable visualisation of the water distribution in real time in one-dimension, or as a time-averaged measurement in two dimensions. MR measurements were also performed on an oil-water multiphase flow at a stream velocity of 0.2 ms^{-1} and for water cuts between 1% and 7.5%. Local measurements of the water cut are performed with an error of less than 1%.

Ely, Cambridgeshire, UK

Thank you for listening



SmartMix® Sampling System

Benefits

- Greater than 97% mixing efficiency, typically saving ~US $1.4M/year
- Efficient horizontal mixing even at very low velocities
- Efficient mixing at the worst flow conditions (low velocities, low densities and/or low viscosities)
- Up to 80% shorter nozzle-scoop distance resulting in compact design
- Significantly (up to 50%) lower pump power requirement

Conclusions

- **SmartMix® Sampling System** heralds a new paradigm shift on-demand continuous mixing, in-line analysis, and automatically controlled high efficient mixing even at challenging conditions

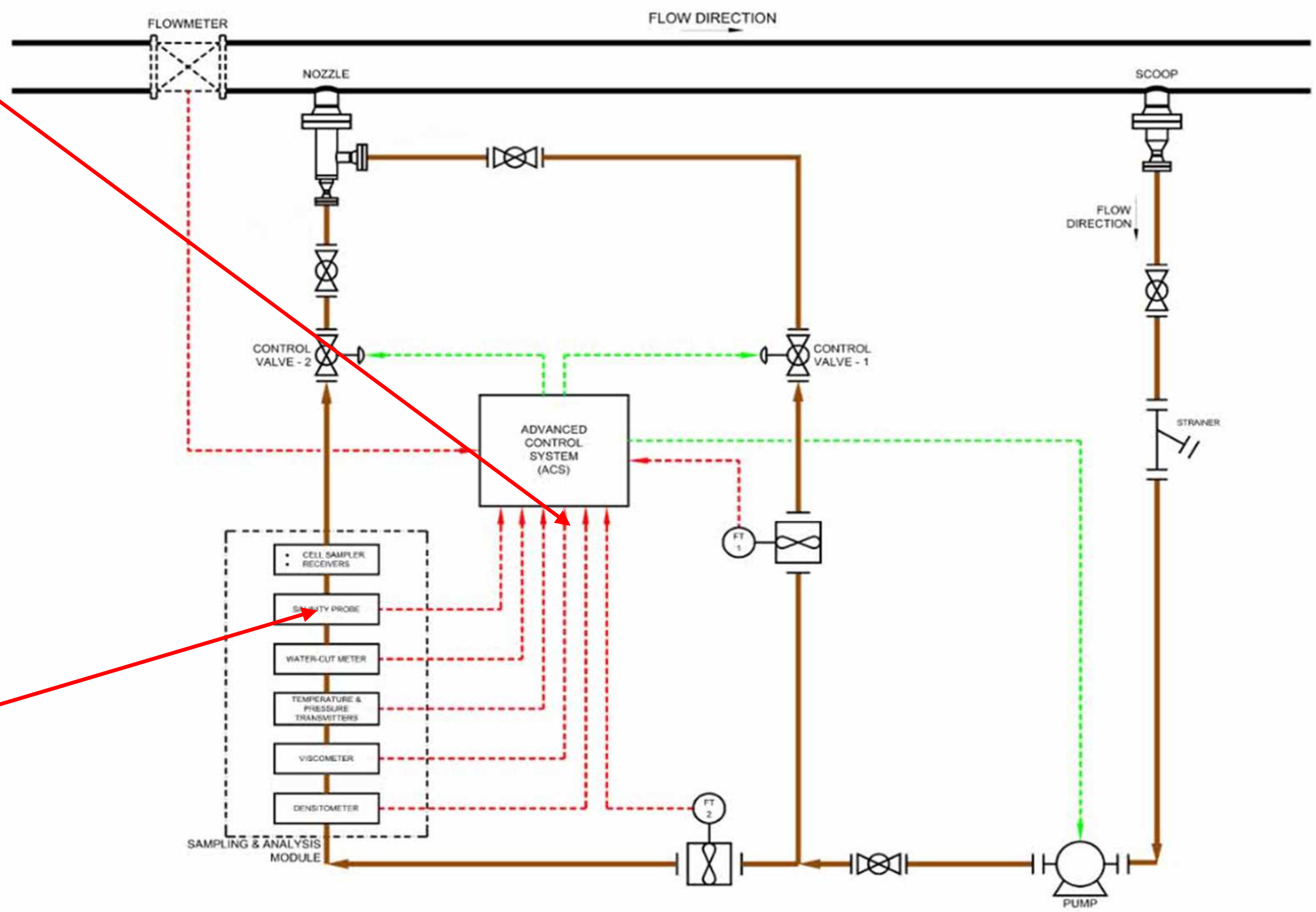
- Better than ~ 97% mixing efficiency, saving millions of dollars in financial exposure and/or lost revenue

- MPP provided a highly resolved spectrum indicating the presence of water droplet or globules in the pipe. It is a highly accurate quality measurement system to correct the Flow Metering (or quantity measurement) for its Oil-Cut

- The results are scalable for larger pipes using CFD Modelling

Advanced Control System (ACS)

SmartMix®

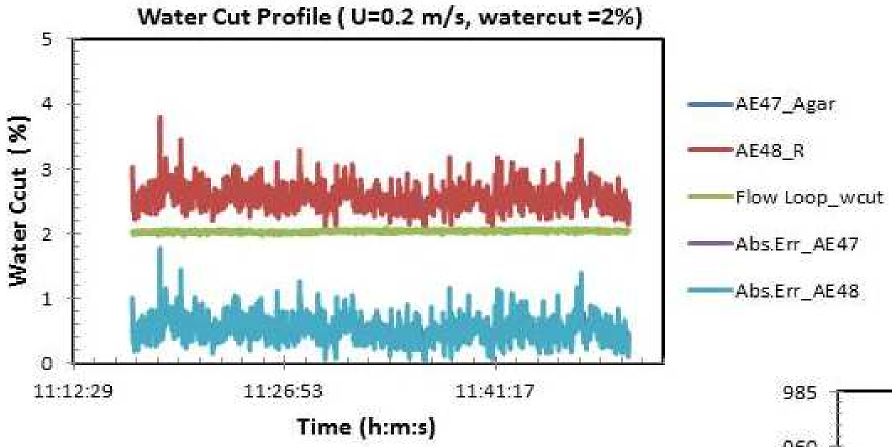


Integrated Analytical Instruments

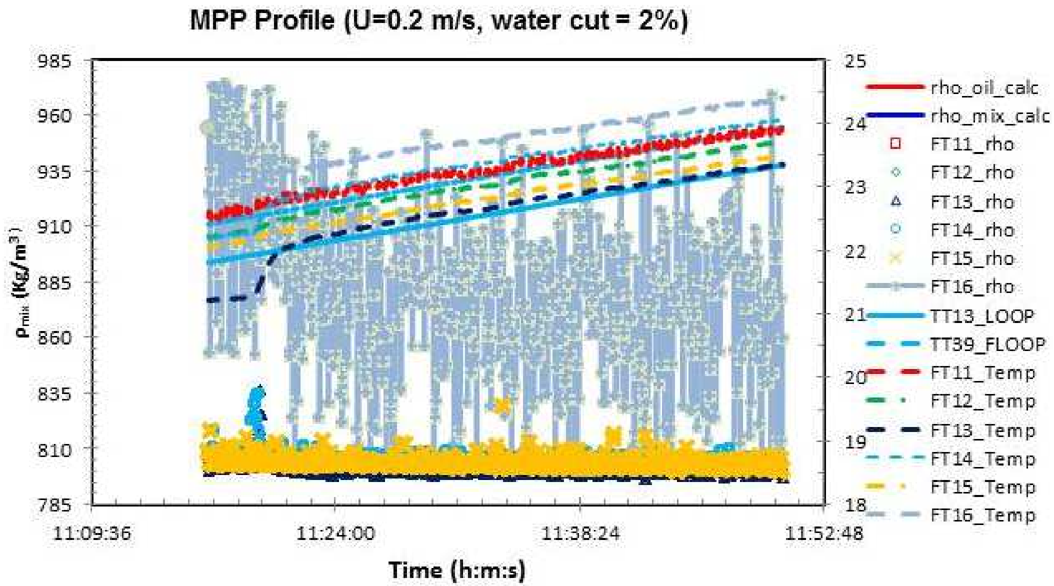
Paradigm Shift: On-demand Mixing using Advanced Control System (ACS)

Multiport Probe Profiling (MPP) Device for SmartMix®

Composition Measurement

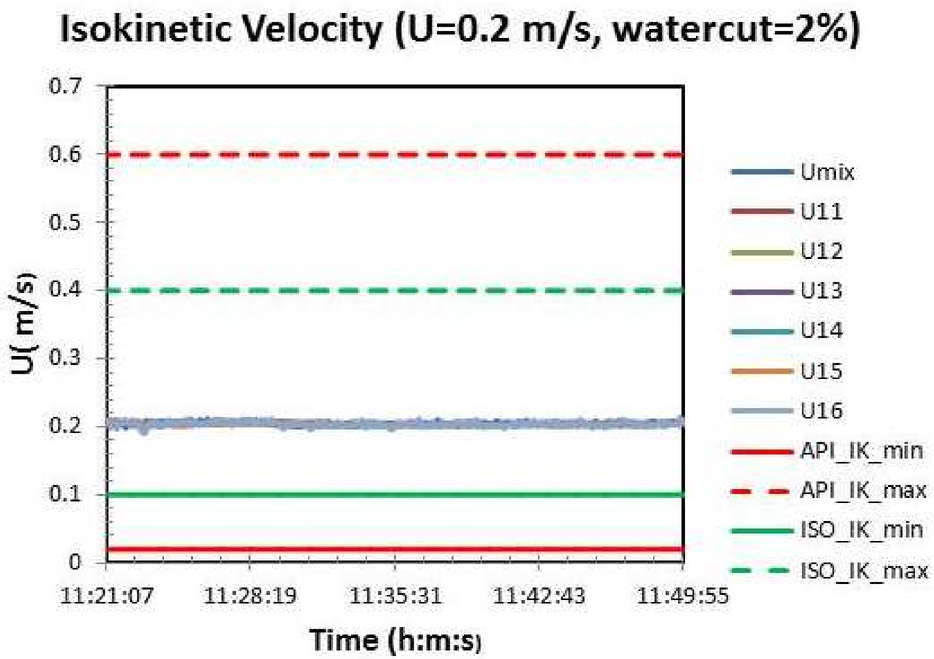


- MPP profiling using density measurement proved very effective to detect even small globules of water at the base of the pipe, which would have been undetected otherwise using water cut meters.



Multiport Probe Profiling (MPP) Device for SmartMix®

Composition Measurement



- We have achieved TRUE Isokinetic representative sample extraction
- Smartmix matching velocity is ~ 1:1 (100%)
- This ensures correct physical sampling and the continuous in-line measurement of flow rate and density profiles

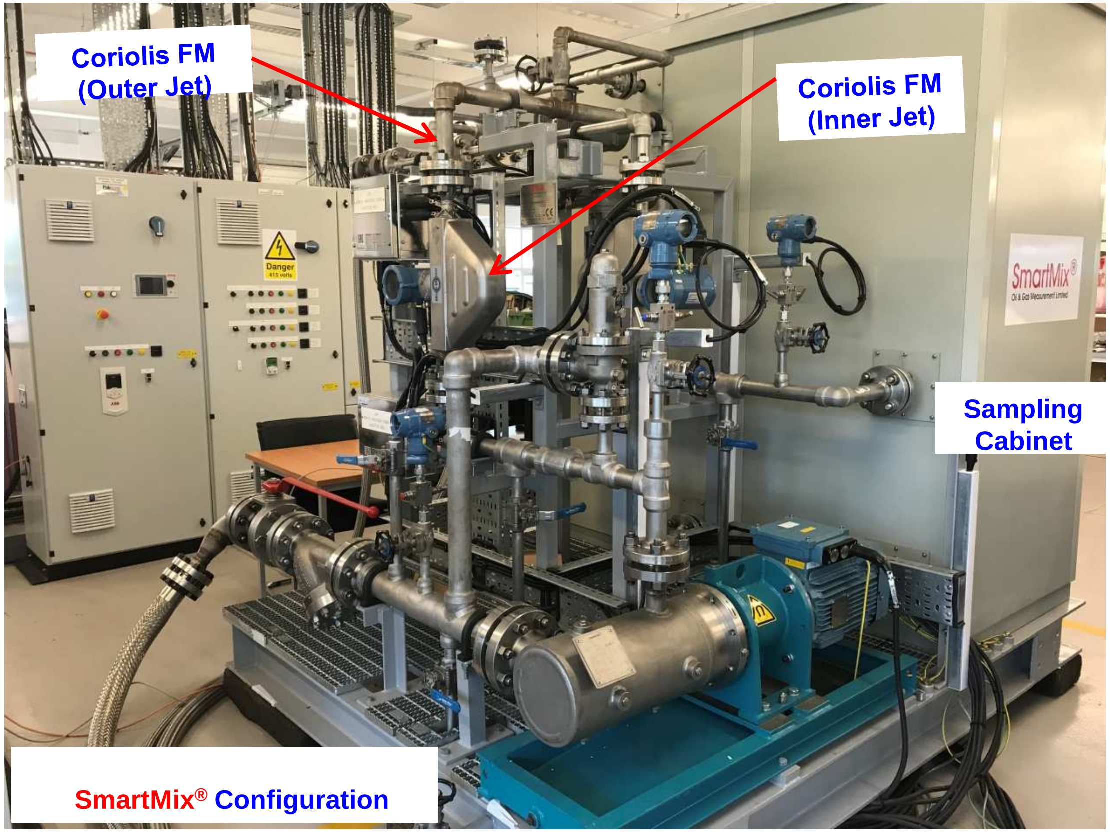
Development of SmartMix® Sampling System

- Initial Product Development
  - Government R&D funding
  - Research Facilities (MRI/HPC/Flow Loop)
  - Best Academics in Multiple subjects

- Product Verification & Validation
  - LMPFL designed and constructed for industrial mixing and sampling applications
  - LMPFL used in SmartMix® Validation

- North Sea Commissioning
  - SmartMix® Sampling Systems installation
  - Challenging high water cut mixing/sampling

SmartMix® Sampling System SKID



- Sampling System with Integrated Analytical Instruments