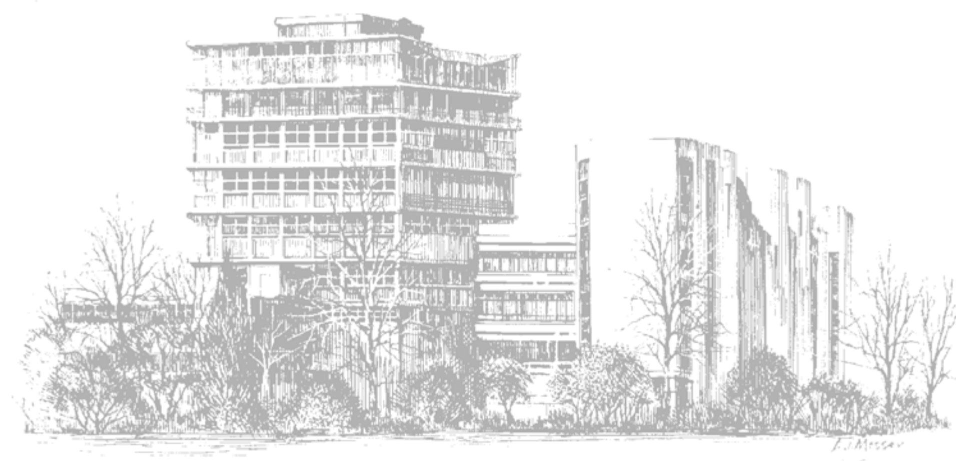
Coriolis or Mass Flow Meter Development and Uses in the Oil and Gas Industry

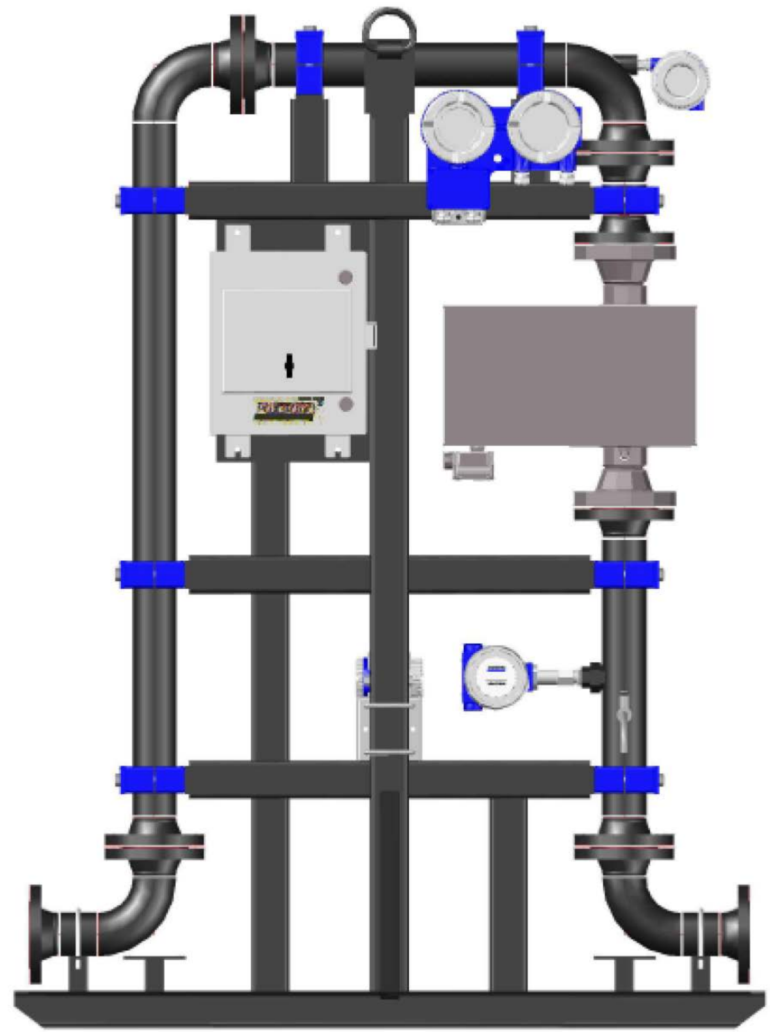
Prof. Manus Henry

Department of Engineering Science
University of Oxford



Overview

- Introduction: Coriolis mass flow metering
- Three-phase flow well testing
- Field experience with well testing
- New results for heavy oil with gas entrainment
- Future work

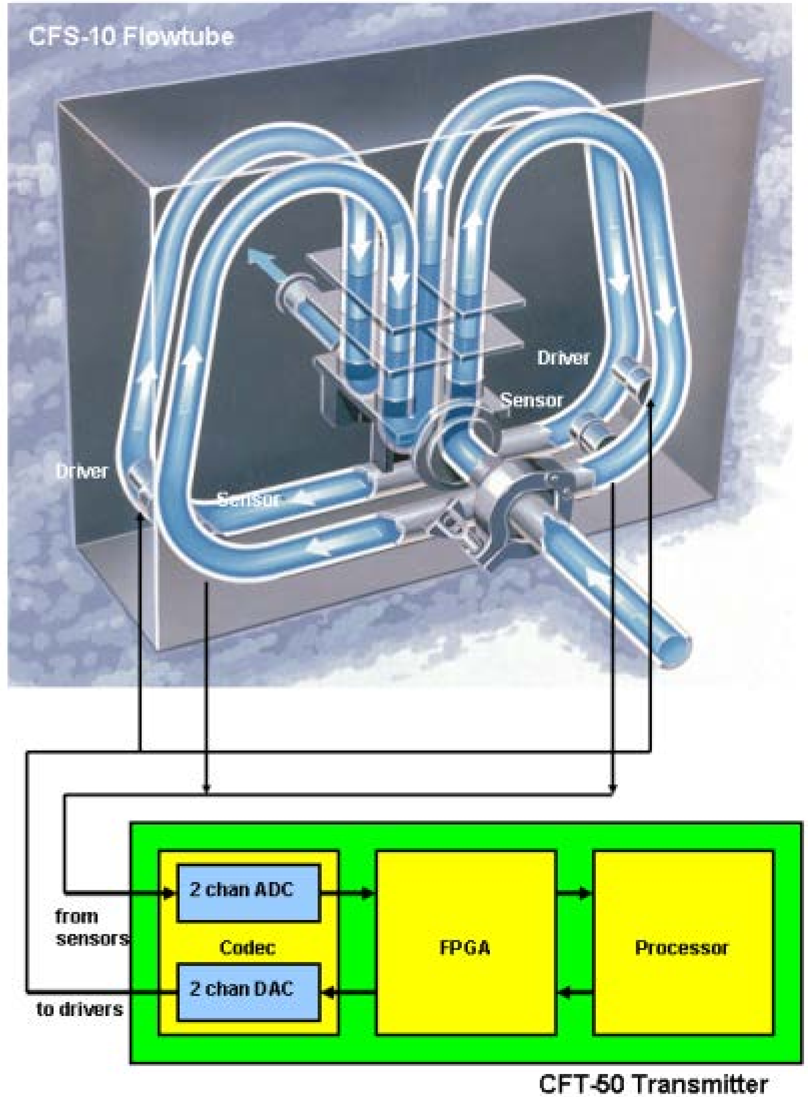


Prof Manus Henry

- 28 years full-time research at Oxford University
- Long term partnership with Foxboro / Invensys / Schneider Electric now ended
- Pioneered digital Coriolis flow metering, especially for two-phase flow
- 102 granted patents
- Associate Editor of “Flow Measurement and Instrumentation” Journal
- UK National Physics Laboratory Measurement Prize 2007
- BIS Flow Programme Expert Group
- Team: 3 senior post-docs + 1 DPhil student

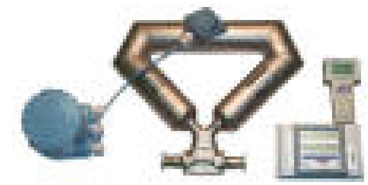
Coriolis Mass Flow Metering

- Flow metering is an essential commercial, industrial and fiscal activity
    - Goods transfer e.g. bunkers, filling lines
    - Recipes e.g. blending, adding catalysts
    - Accounting e.g. tax on oil and gas products
- Coriolis meters are high value, accurate (0.1%) flow meters.
- Coriolis meters have two parts
    - The **flow tube,** a mechanical device, through which the fluid flows
    - The **transmitter,** an electronic device, which makes the flowtube vibrate, and which does the flow calculation



Different flowtube designs

- There are many different flowtube designs.
- However the basic operation is the same.
- Flowtube diameters: 0.7mm … 300mm
- Flowrates: 1g/hour … 0.8 tonne/second



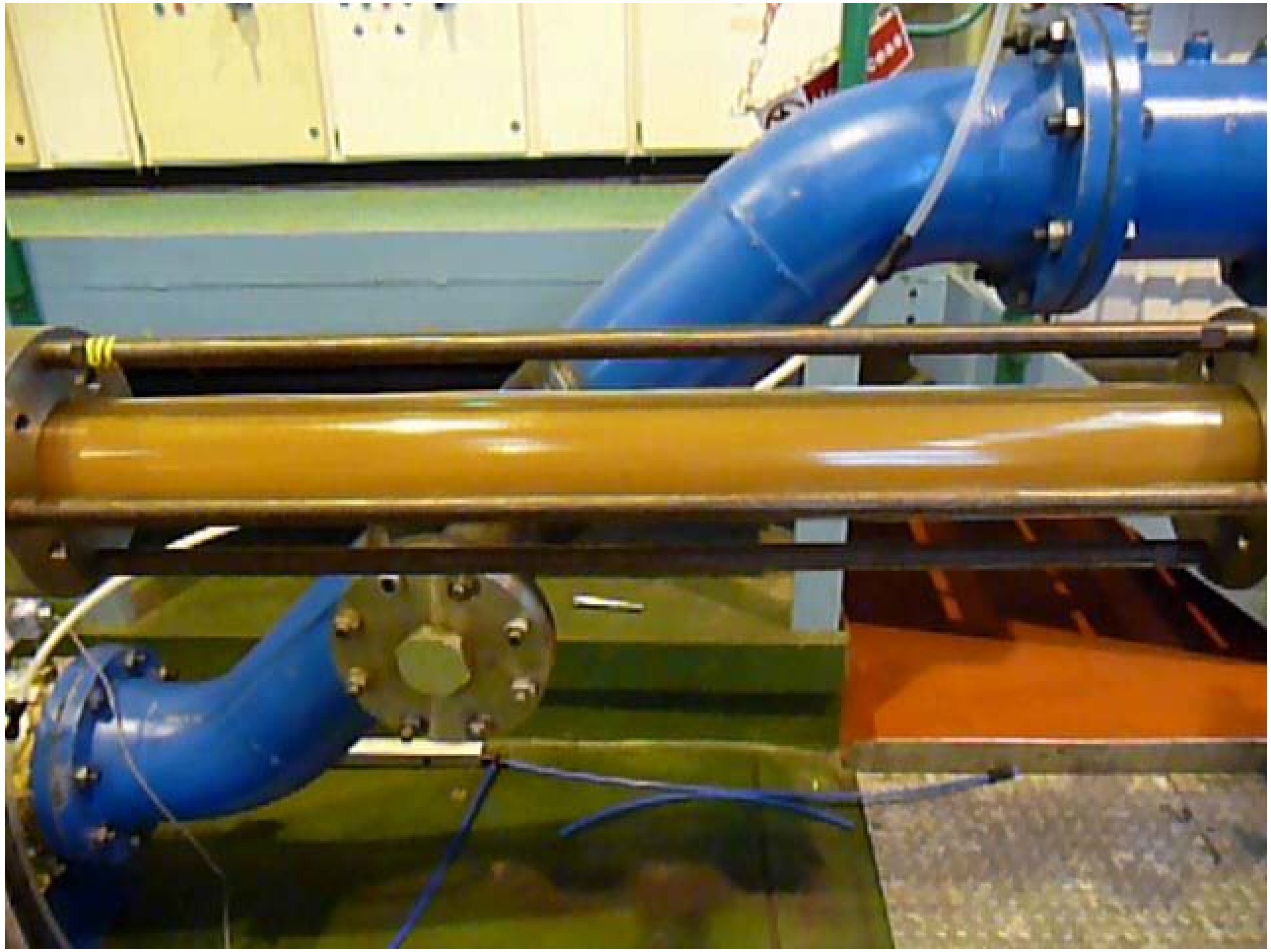
Recent Coriolis Meter Market Report (MarketsandMarkets, Jan 2015)

- Market size
  - 2014: $1,145 million
  - 2019: $1.932 million, 11% CAGR
- Application areas: **Oil & Gas**, Chemical, Petrochemical, Food and Beverage, Pulp and Paper, Textiles, Water, Waste Water Treatment
- North America is main market
- Typical price per unit $5k - $50k

Coriolis and two-phase (gas/liquid) flow

In the past, Coriolis meters responded poorly to two-phase flow:

- It is difficult to maintain flowtube vibration
- Large errors in mass flow and density measurements



Oxford/Foxboro pioneered Coriolis for two-phase flow:

- Maintaining flowtube operation by digital drive
- On-line signal processing to correct measurements

Coriolis Metering for the Bunkering Industry

- We began work on Coriolis for Bunkering in 2005
- Key issues: high viscosity and air entrainment
- We carried out trials on a Singapore barge
  - Monitored 78 commercial bunkers using Coriolis
- Results reported to the industry at SIBCON 2008
- 2014: Singapore make Coriolis metering mandatory

MPA SINGAPORE

Port of Singapore is First in the World to Mandate the Adoption of Mass Flow Metering System for Bunkering

Singapore, 8 April 2014

Port of Singapore is First in the World to Mandate the Adoption of Mass Flow Metering System for Bunkering

The Port of Singapore is the first in the world to mandate the use of mass flow metering (MFM) system for bunkering. This was announced by Mr Lui Tuck Yew, Minister for Transport, at the Singapore Bunkering Symposium

2008 article in 'Bunkerspot' journal, co-authored with IBIA President Don Gregory

Technical Issues

Air today, gone tomorrow

Manus Henry and Don Gregory reveal the initial test results on metering technology that may soon change the face of bunkering forever

One of the most critical aspects of the bunker transfer – the actual measurement of the quantity of delivered fuel – has remained unchanged over decades, despite the continuous advances in technology in so many other areas. But now a solution has been developed utilising a new type of Coriolis mass flowmeter from Invensys Process Systems (IPS), working with the University of Oxford on a project for BP Marine.

Currently tank dipping is the most common method of measurement, a process whereby the depth of fuel is measured in every tank on the bunker barge. Each depth measurement is converted into a fuel volume using a tank-specific table. Corrections are applied for the temperature of the fuel and the list of the ship. Finally, the weight of the fuel is calculated based on its temperature and certified density, because bunkers are sold by weight (in tonnes), not by volume.

While automated level measurement is used in some large modern barges, by far the most common technique is the tried and trusted method of dipping by hand, using a weighted tape measure. When properly applied, as set out in the industry

Enter the air entrainment problem

There are a number of structural issues within the bunkering industry that are relevant here. A low-cost fuel supplied at a low profit margin, and with a large number of small operators, is undoubtedly a recipe for staying low-tech. However, the rapid rise in fuel prices and the onward march of environmental legislation both suggest that low-tech may no longer be optimal, and perhaps eventually may no longer be permissible. In any case, the key issues with introducing more sophisticated alternatives to tank dipping are actually technical, and can be summed up in two phrases: high viscosity and entrained air.

The typical metering station in an oil and gas custody transfer application will consist of a flowmeter generating on-line data. The traditional mechanical metering technologies – positive displacement and turbine meters – have relatively high maintenance requirements and are steadily being replaced by electronic devices such as ultrasonic and Coriolis flowmeters.

A metering station is subject to regular calibration checks, typically somewhere between once per month and once per year. Usually this is achieved by using a portable 'prover' to check the meter. Alternatively,

'The key issues with introducing more sophisticated alternatives to tank dipping are actually technical, and can be summed up in two phrases: high viscosity and entrained air'

achieved through proving. However, such levels of performance are achieved only when pure liquid is being metered. Should air or gas entrainment occur in the fuel, it is likely to cause systematic errors in the measurement, and in some cases the meter will stop working entirely.

Thus, with two-phase (oil/air) flow, most conventional flowmeters are not reliable. This problem rarely arises in practice because these applications are engineered so that air is never passed through the meter. Where the fuel has a low viscosity, for example, a few minutes standing in a storage tank is sufficient for any entrained air to rise and break the surface of the oil.

By contrast, given the viscosities of the

before the supply is switched to another. A

Two Phase Flow

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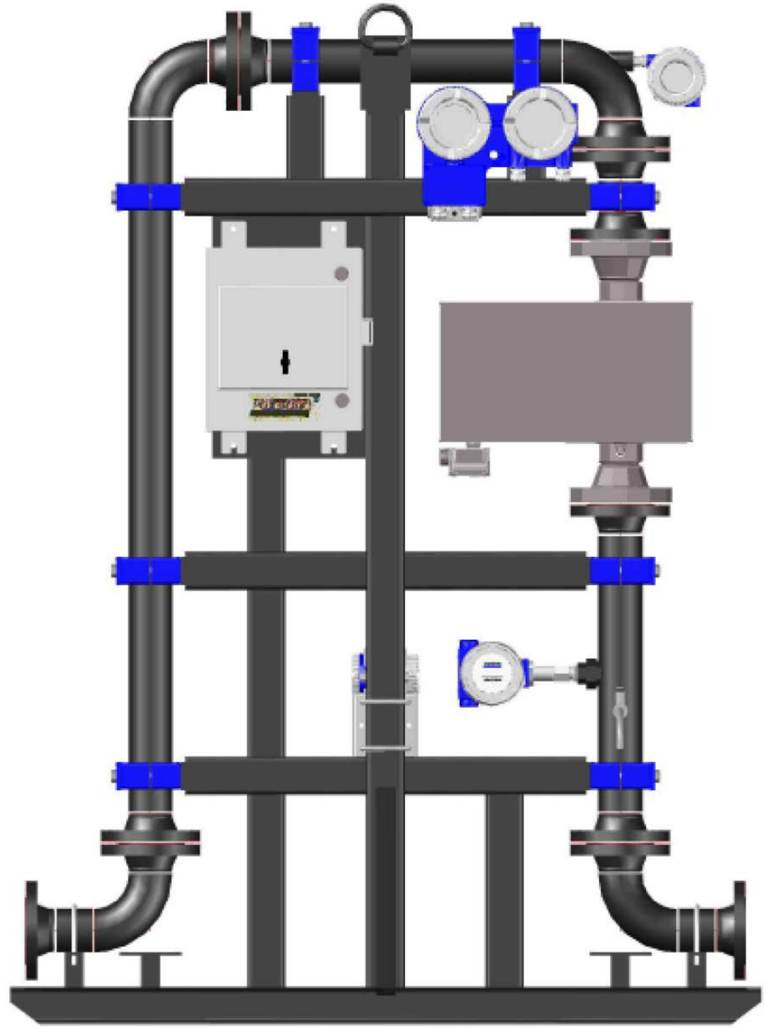


Three-phase flow metering

Benefits

- Real-time flow profile
- Lower cost than current multi-phase technologies
- No radiation source

However

- New technology
- Much to learn in field applications

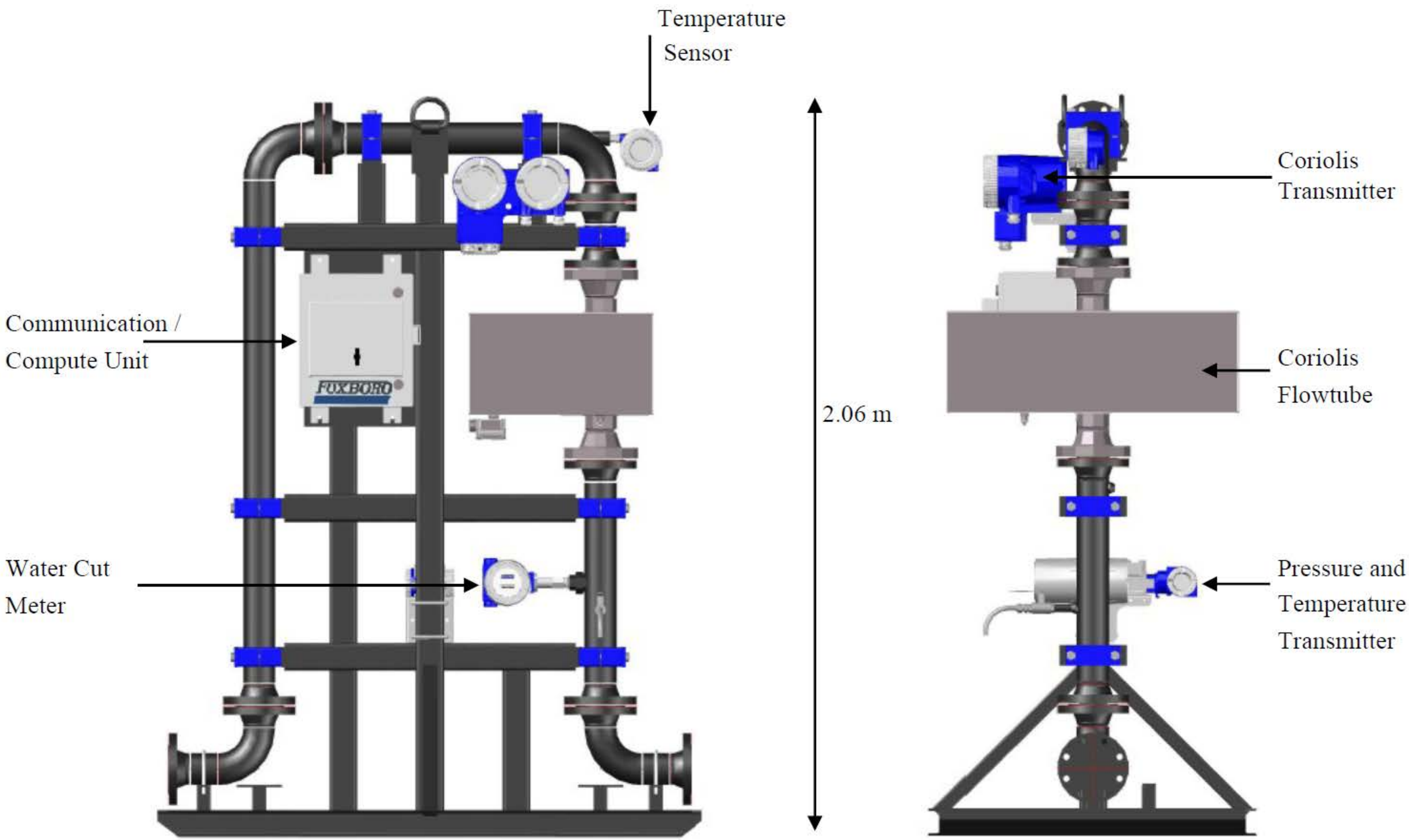
Application Know-how

Water Cut Meter

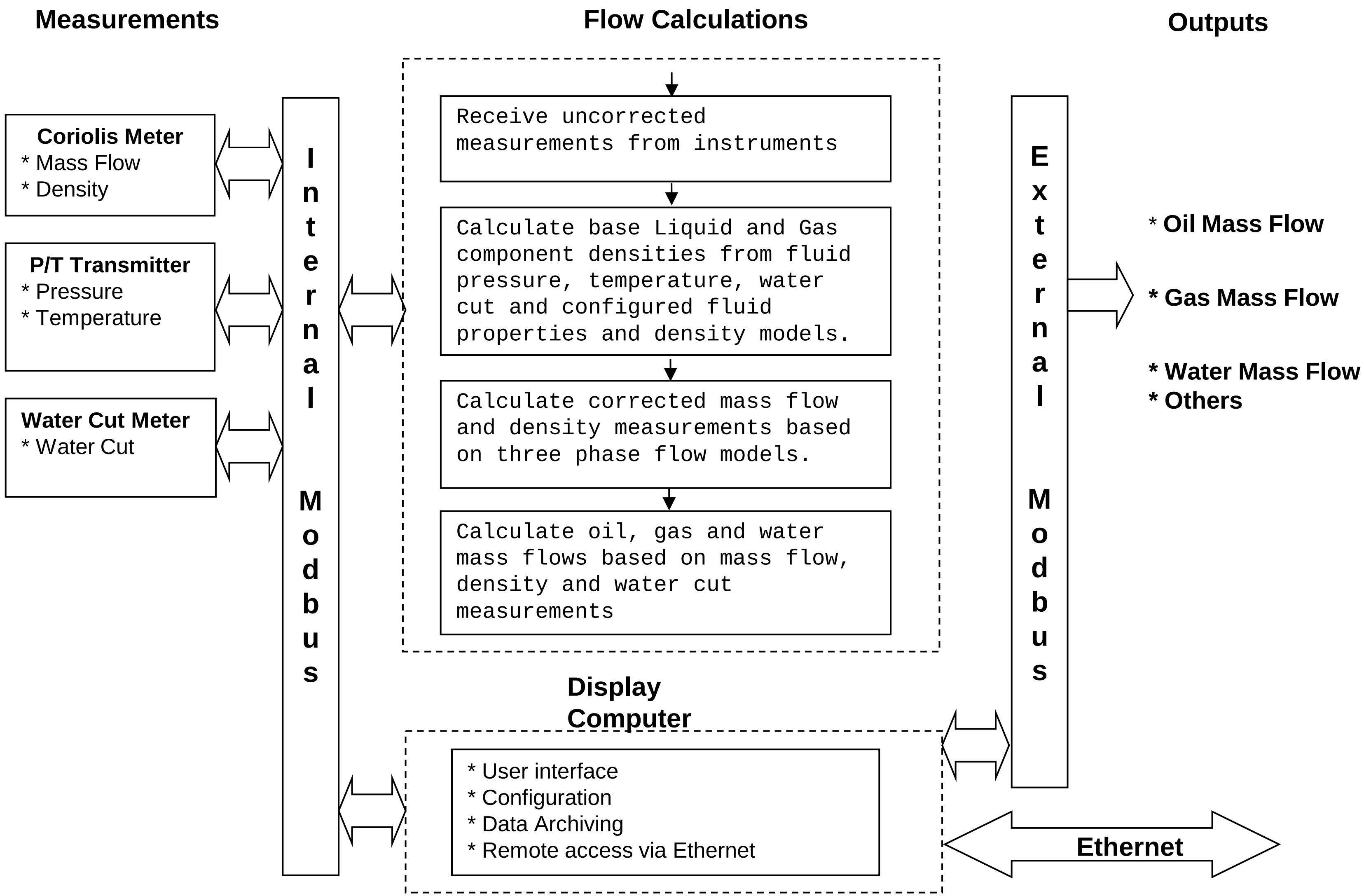
2-phase flow Coriolis meter

Gas /Oil / Liquid mass flow rates

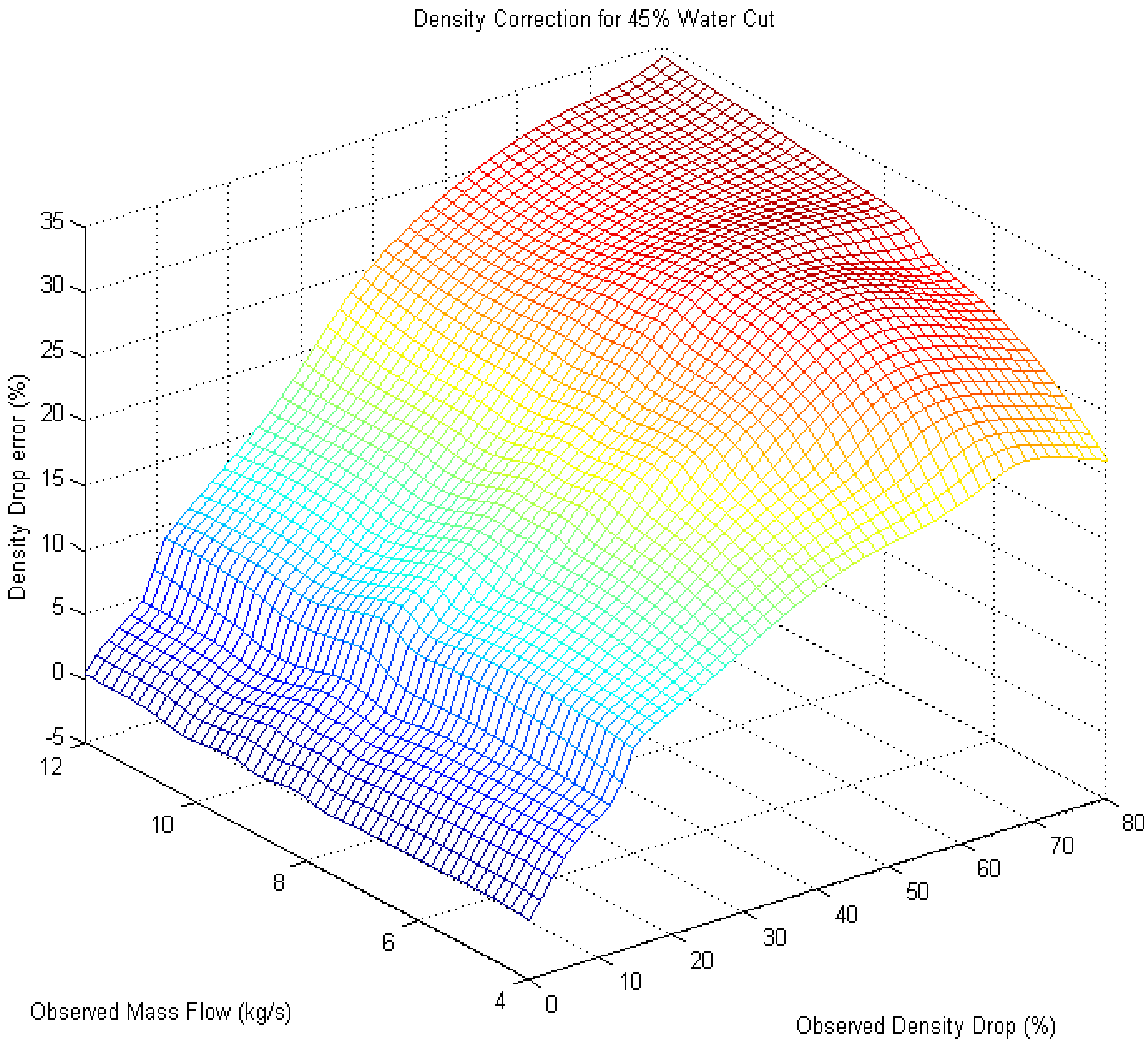
Net Oil & Gas Solution – Skid Design



Net Oil & Gas Solution – Architecture



Three Phase Flow Correction - Density



Russian Standard GOST 8.165 (amended 2008)

- Measurement of quantity of oil and petroleum gas extracted from subsoil

- Allowable limits of relative measurement error:

Total Liquid:	±2.5% error mass flow
Net Oil:	±6% error mass flow up to 70% water cut ±15% error mass flow at 70% – 95% water cut
Gas:	±5% error volume flow


ФЕДЕРАЛЬНОЕ АГЕНТСТВО

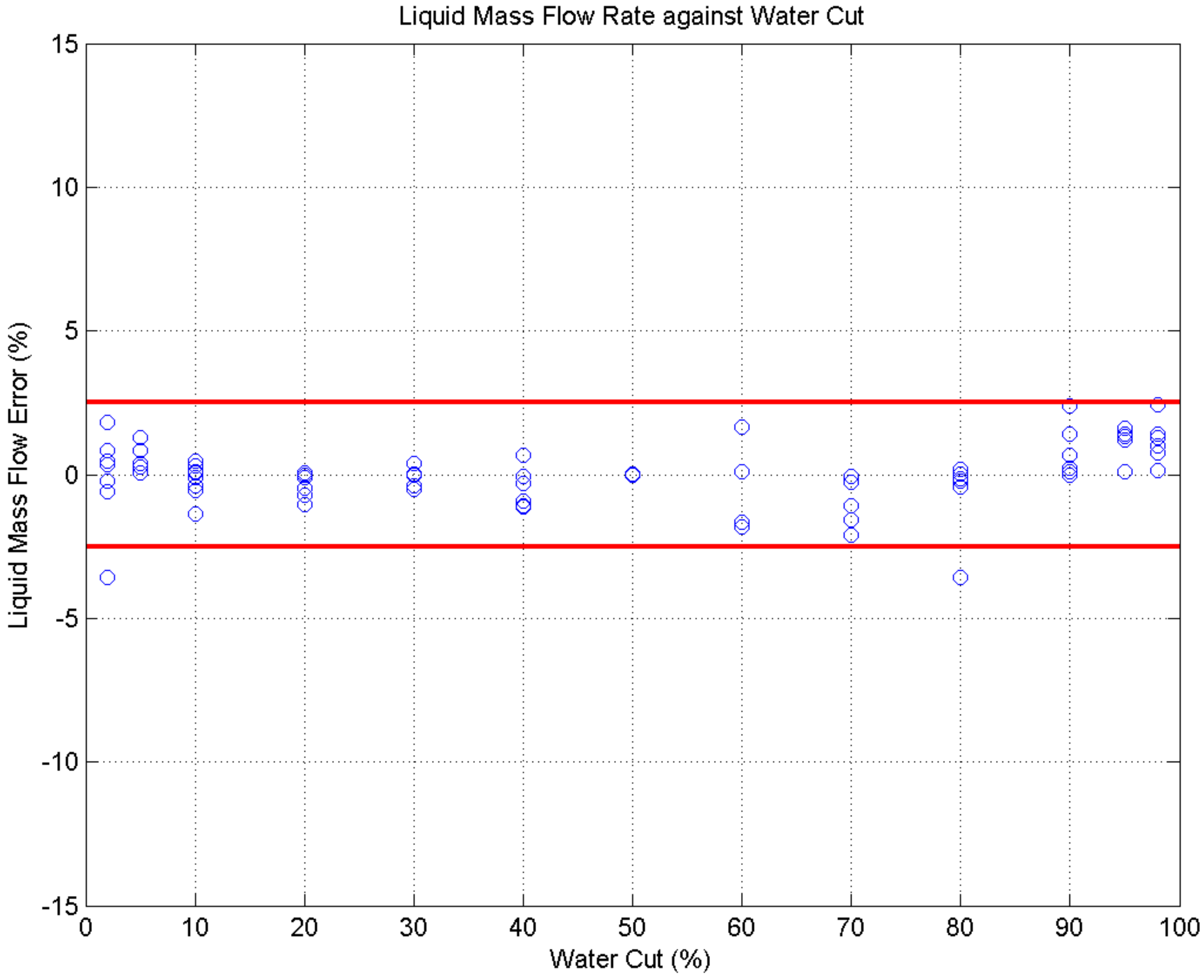
ПО ТЕХНИЧЕСКОМУ РЕГУЛИРОВАНИЮ И МЕТРОЛОГИИ

НАЦИОНАЛЬНЫЙ СТАНДАРТ РОССИЙСКОЙ ФЕДЕРАЦИИ

ГОСТ Р 8.615—2005

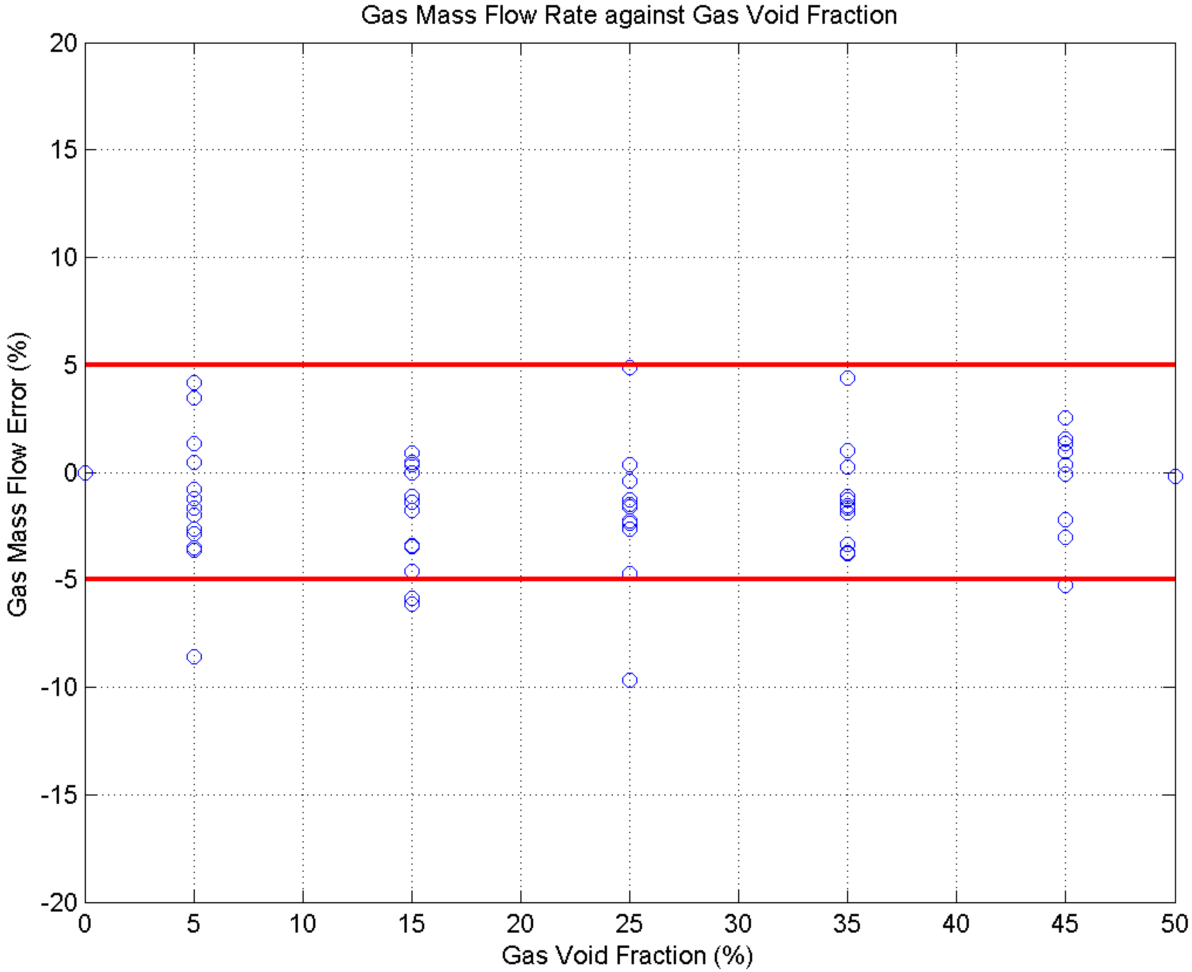
NEL Liquid Results

- Total Liquid errors mostly within ± 2.5%



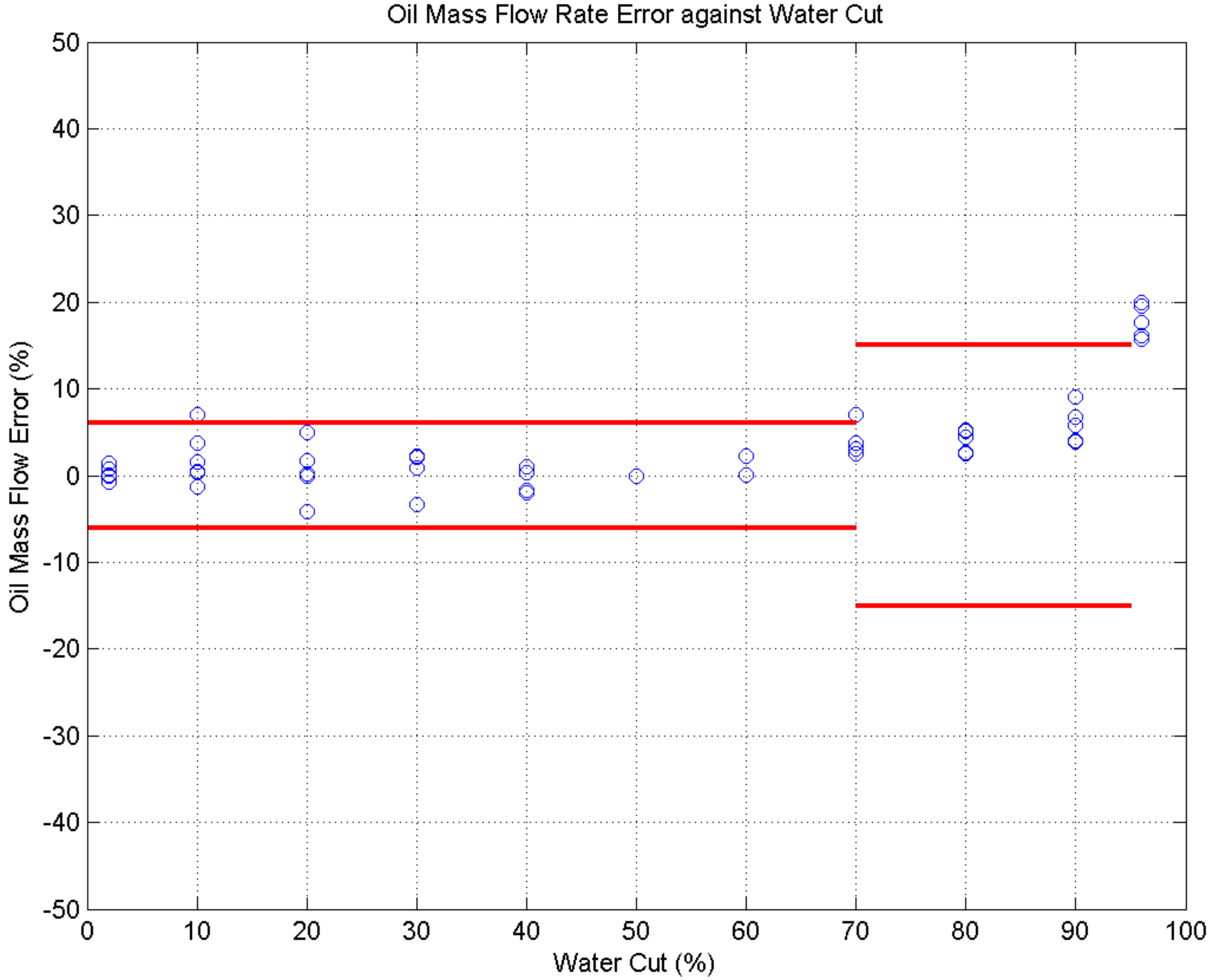
NEL Gas Results

- Gas errors mostly within ± 5.0%



NEL Oil Results

- Oil errors mostly within spec



Certified to Russian Standard GOST 8.165

ФЕДЕРАЛЬНАЯ СЛУЖБА
ПО ЭКОЛОГИЧЕСКОМУ, ТЕХНОЛОГИЧЕСКОМУ И АТОМНОМУ НАДЗОРУ

РАЗРЕШЕНИЕ

№ РРС 00-048471

На применение

Оборудование (техническое устройство, материал):
Расходомеры многофазные "NetOil & Gas" с комплектующим взрывозащищенным электрооборудованием согласно перечню в приложении к настоящему разрешению.

Код ОКП (ТН ВЭД): 42 1300 (9026 80 200 9)

Изготовитель (поставщик): Изготовитель: фирма "Invensys Systems, Inc." (США); поставщик: Общество с ограниченной ответственностью "Инвенсис Проусесс Системс" (г. Москва, Звенигородское шоссе, 18/20, корп. 1).

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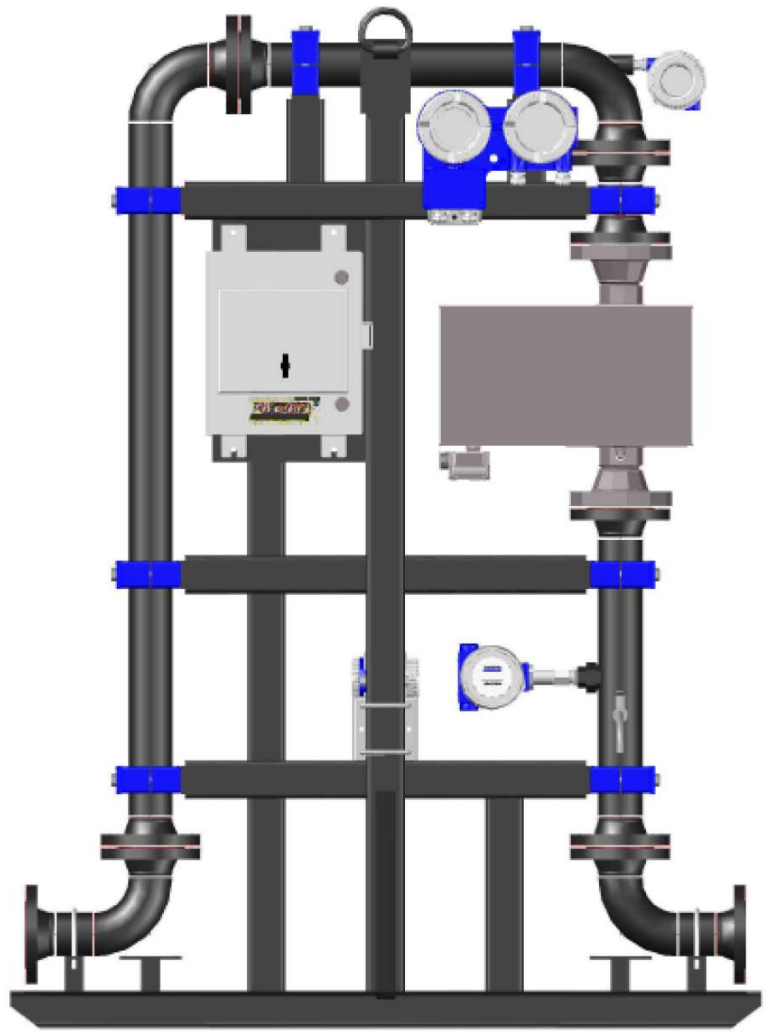


Net Oil and Gas Solution - Basic Function

- Designed as a separator substitute
- Totalized liquid flows:
  - Oil
  - Water
- Totalized gas flow
- Real-time flow profiles
- Historical record
- Alarms
- Configuration
- Valve control and scheduling
- Network interface

Russian Field Trials of Commercial Product

Mobile NOG with Test Separator

Mobile NOG testing well directly

Automatic Report Generation (English and/or Russian)

Отчет по тесту скважины системой Invensys NOG

Author

6 Окт 2014

Месторождение	*Well Location*
Идентификатор скважины	*Re Host Setup (Well slot 01)*
Инженер	*Engineer's Name*
Начало теста	15 Июл 2014 13:47
Продолжительность теста (чч:мм:сс)	6:23:38

	1689.8	кг
	3652.7	кг
	16.014	нм3
…OR)	9.477	нм3/т
…ность	53.7	%

Well Test Report for Invensys NOG Metering System

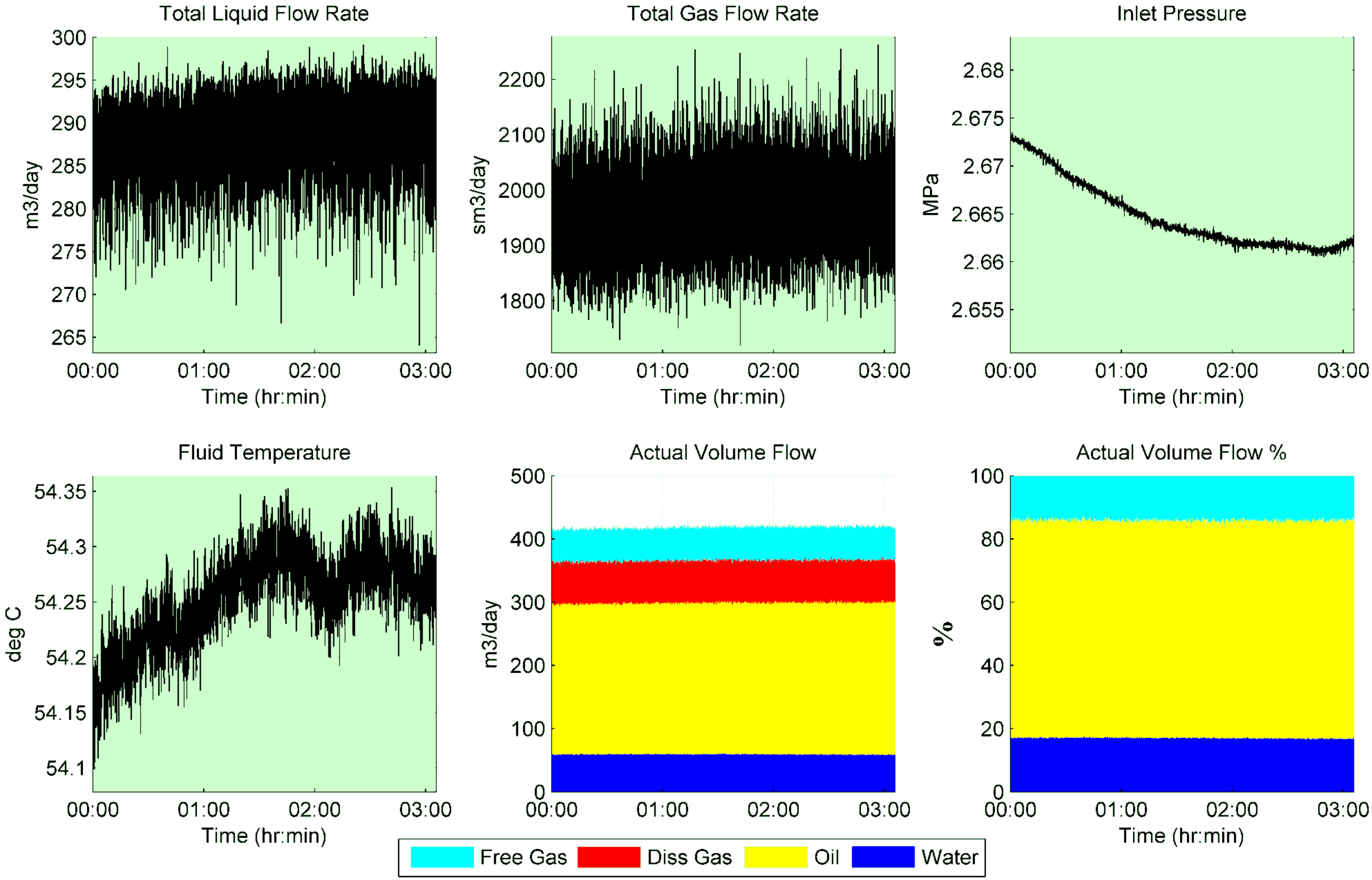
Author

04 October 2014

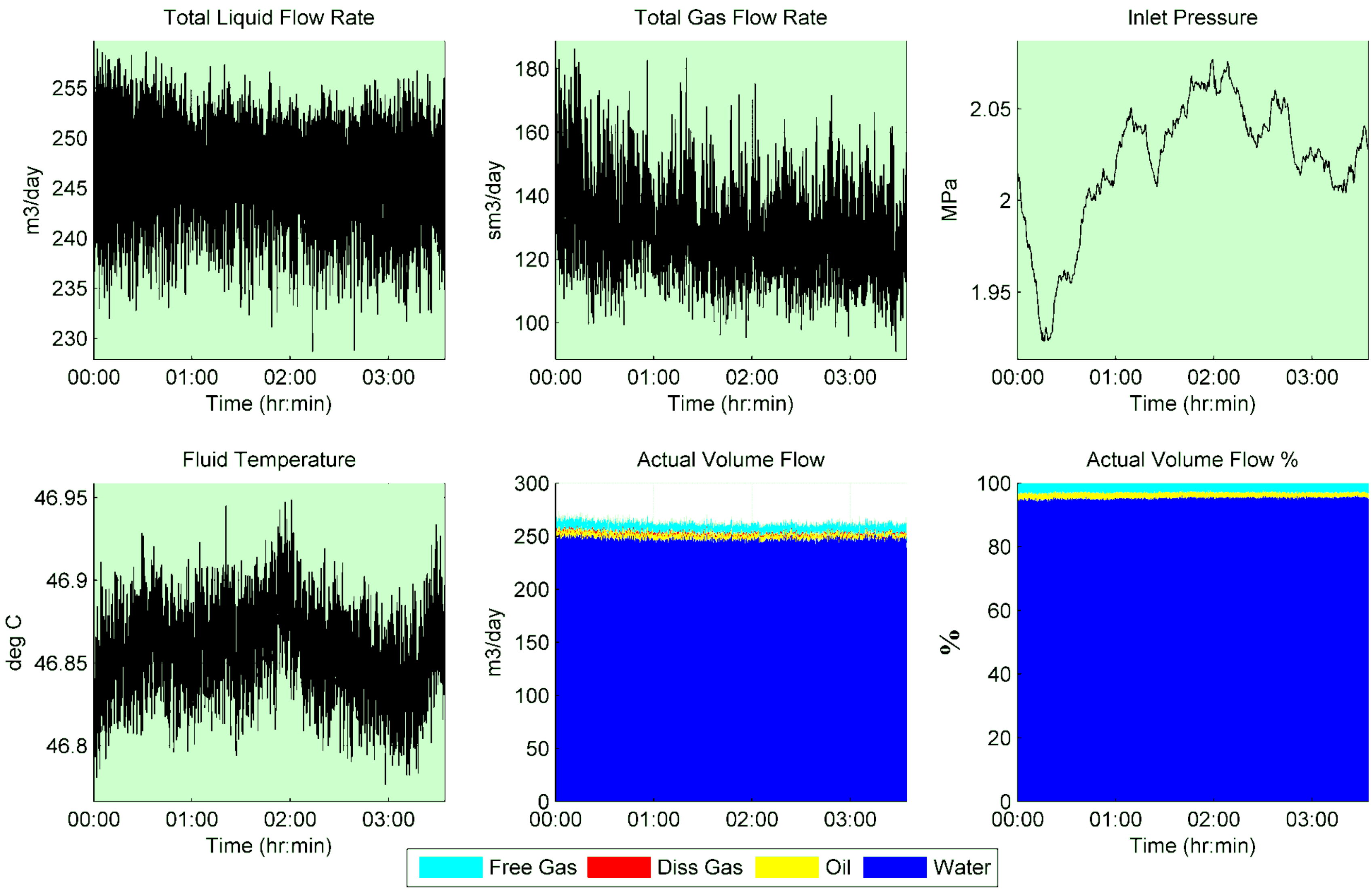
Well Location	*Well Location*
Well Identification	*Re Host Setup (Well slot 01)*
Engineer	*Engineer's Name*
Test Start Time	15 July 2014 13:47
Test Duration (hr:min:sec)	6:23:38

Total Oil	1689.8	kg
Total Water	3652.7	kg
Total Gas	16.014	sm3
Gas/Oil Ratio (GOR)	9.477	sm3/tonne
Average Water Cut	53.7	%

Steady well test flow profile – low water cut



Steady well test flow profile – high water cut



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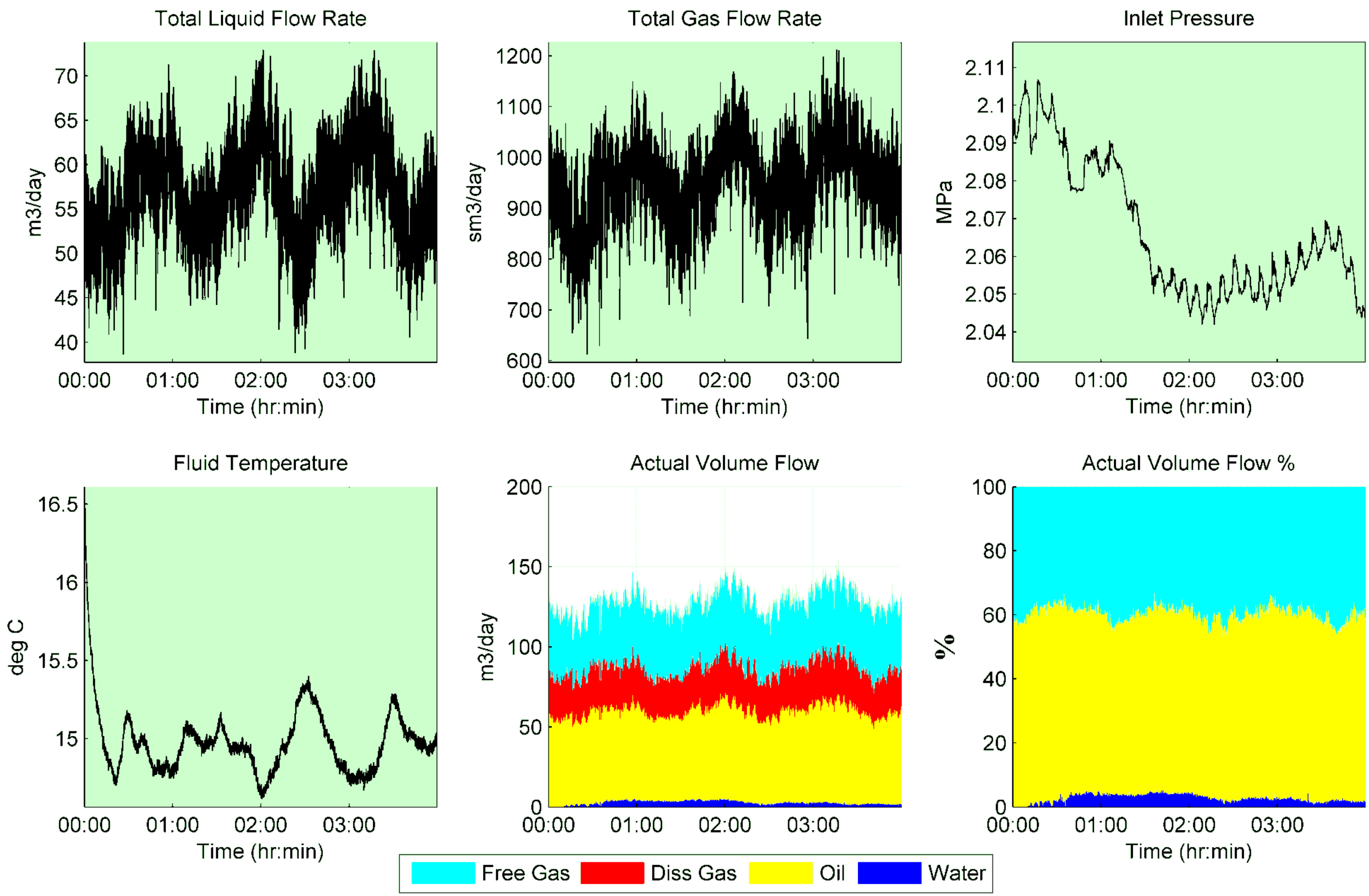
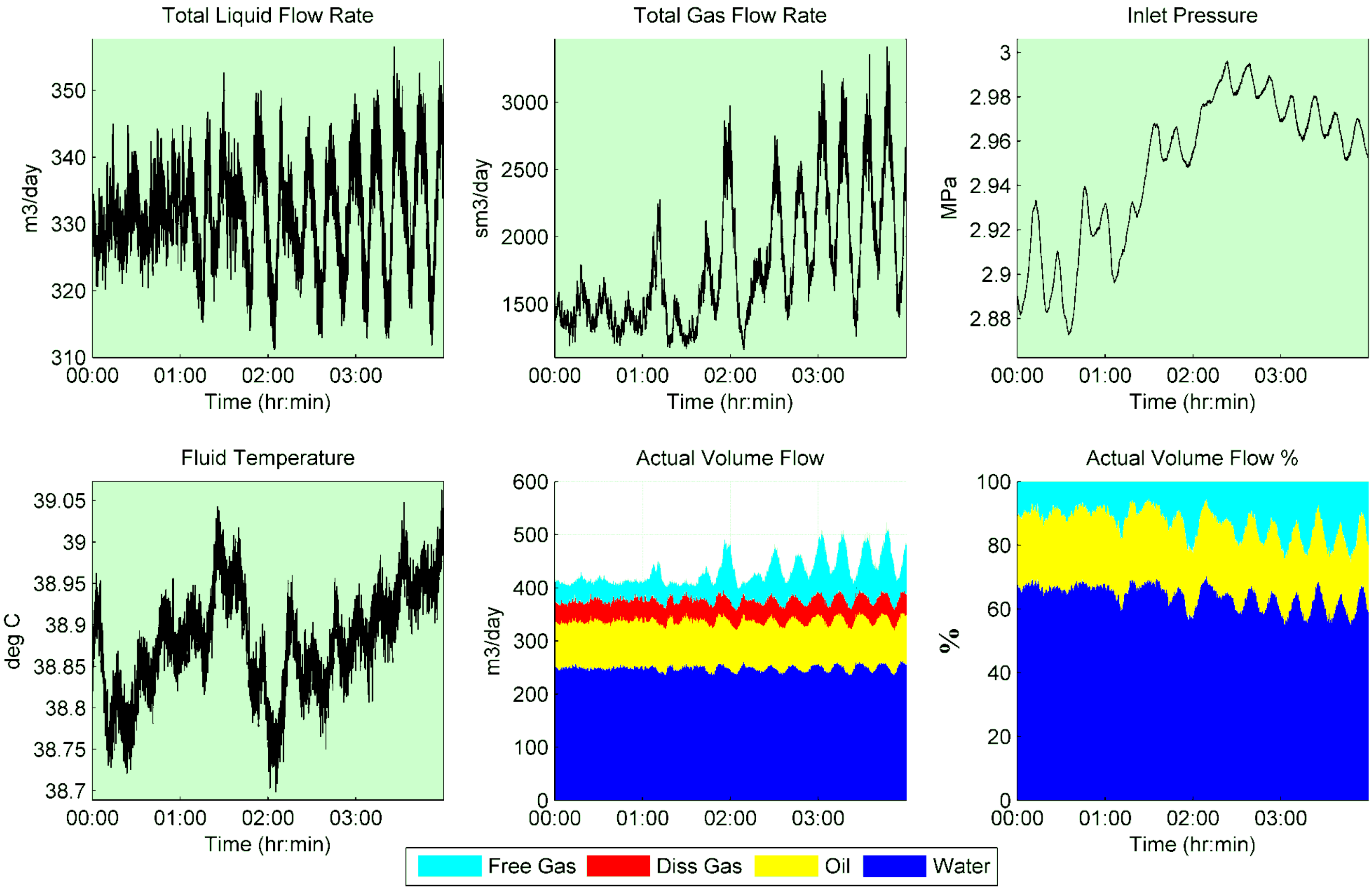
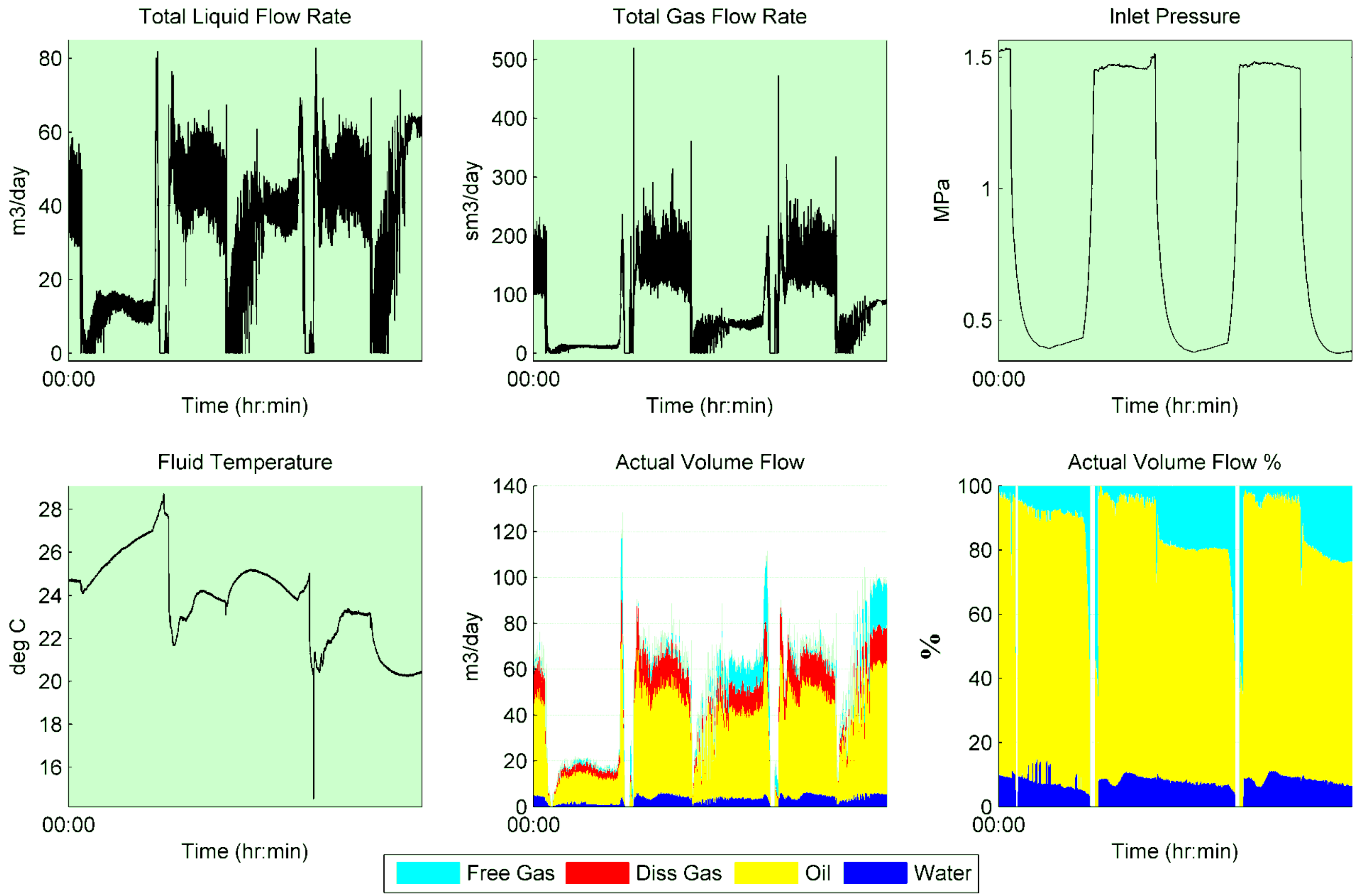
Cycling well test flow profile



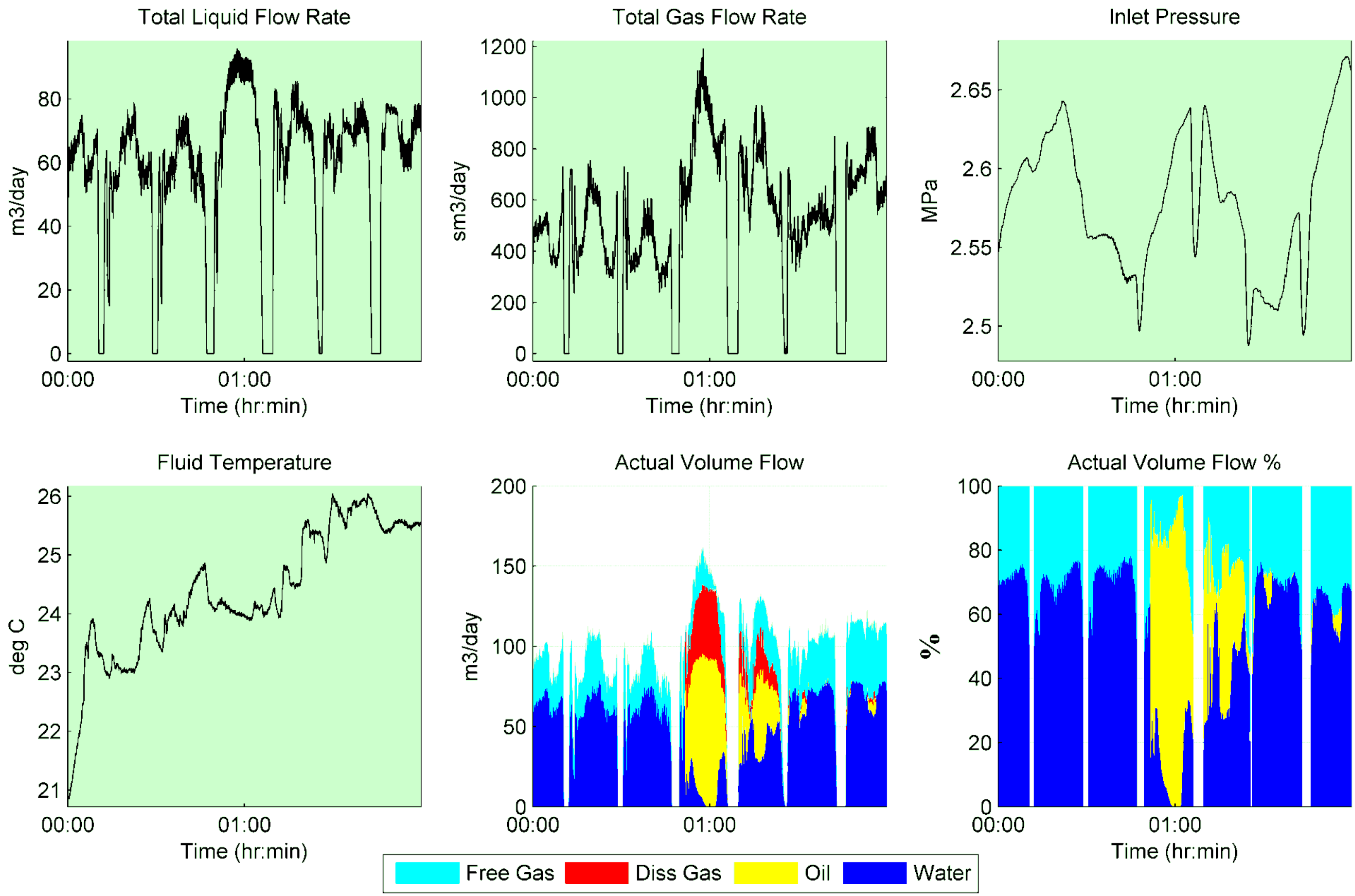
Well test flow – cycling pattern develops during the test



Regular flow surges driven by artificial pressure step changes



Regular surges of flow with substantially varying water cut



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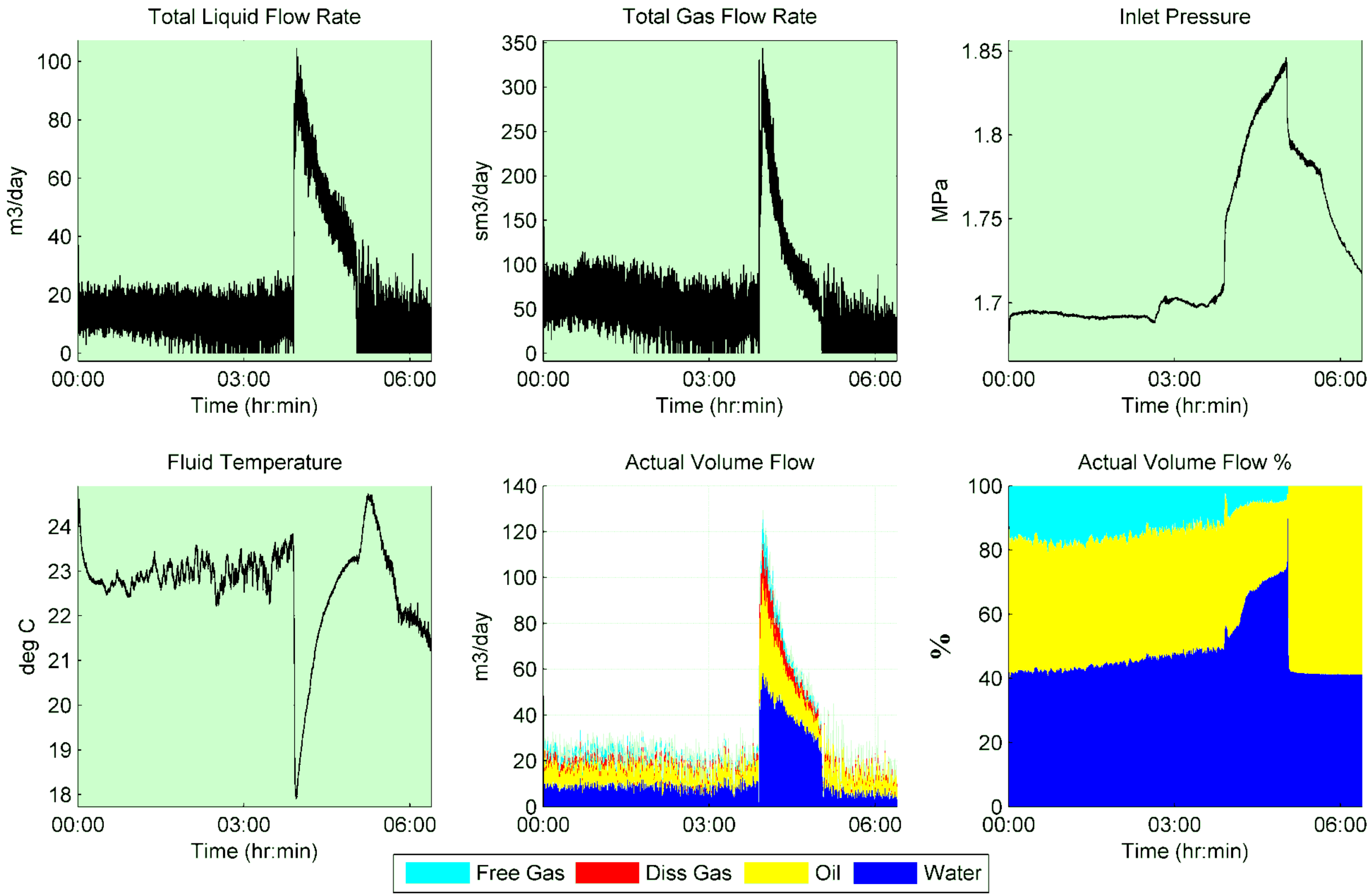
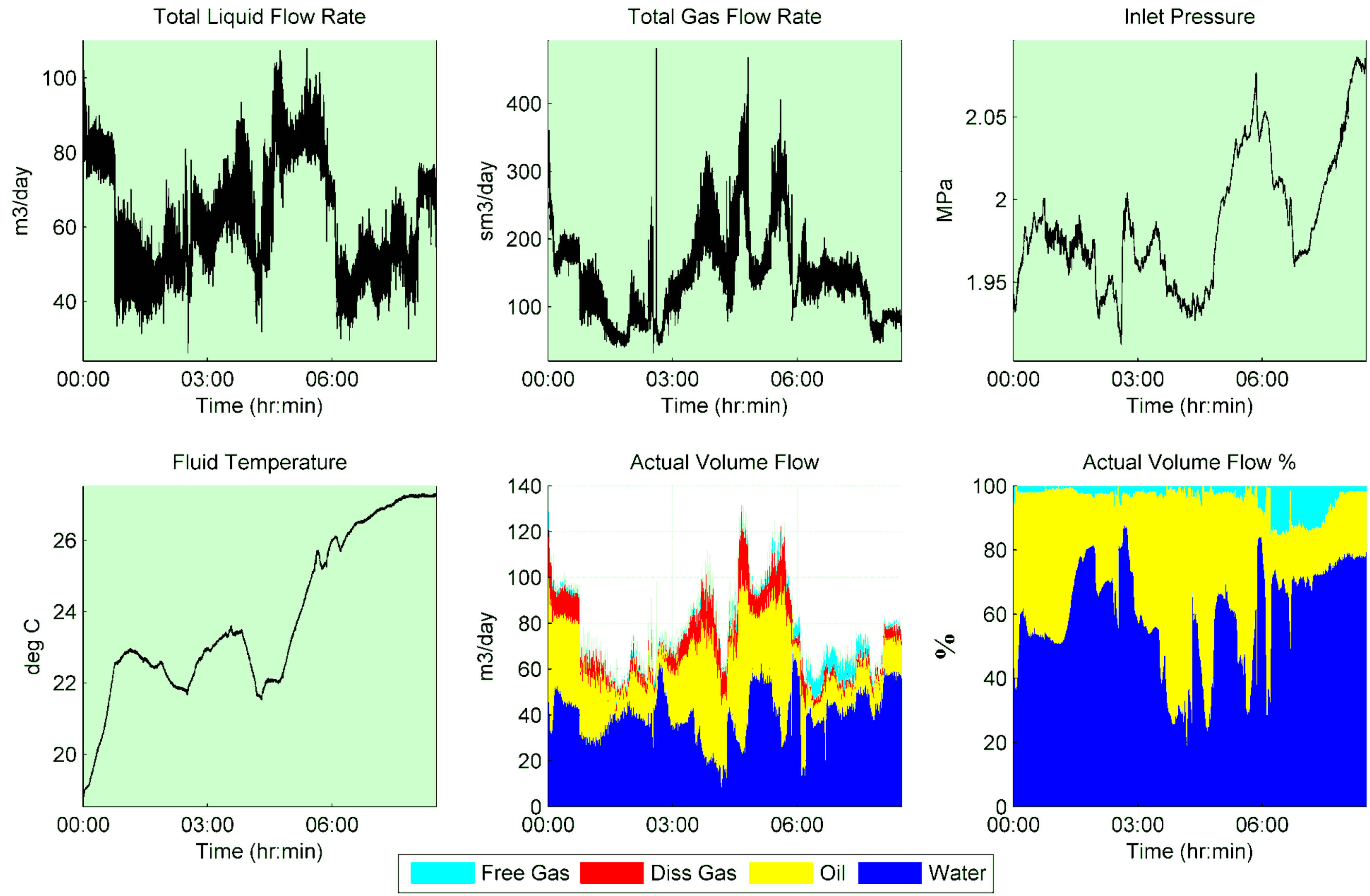
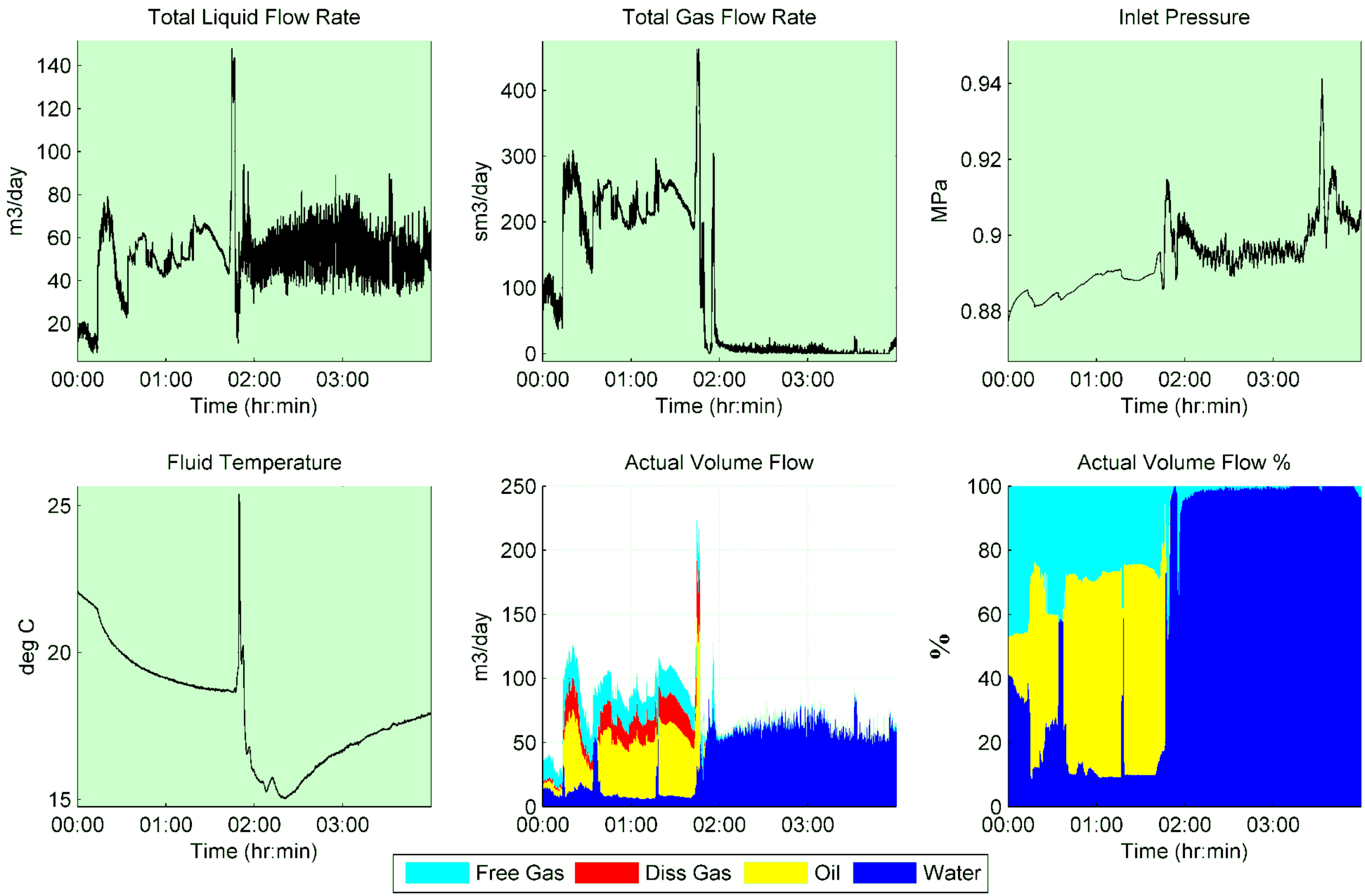
Well test profile: steady flow with surge



Erratic well test profile



Erratic well test profile



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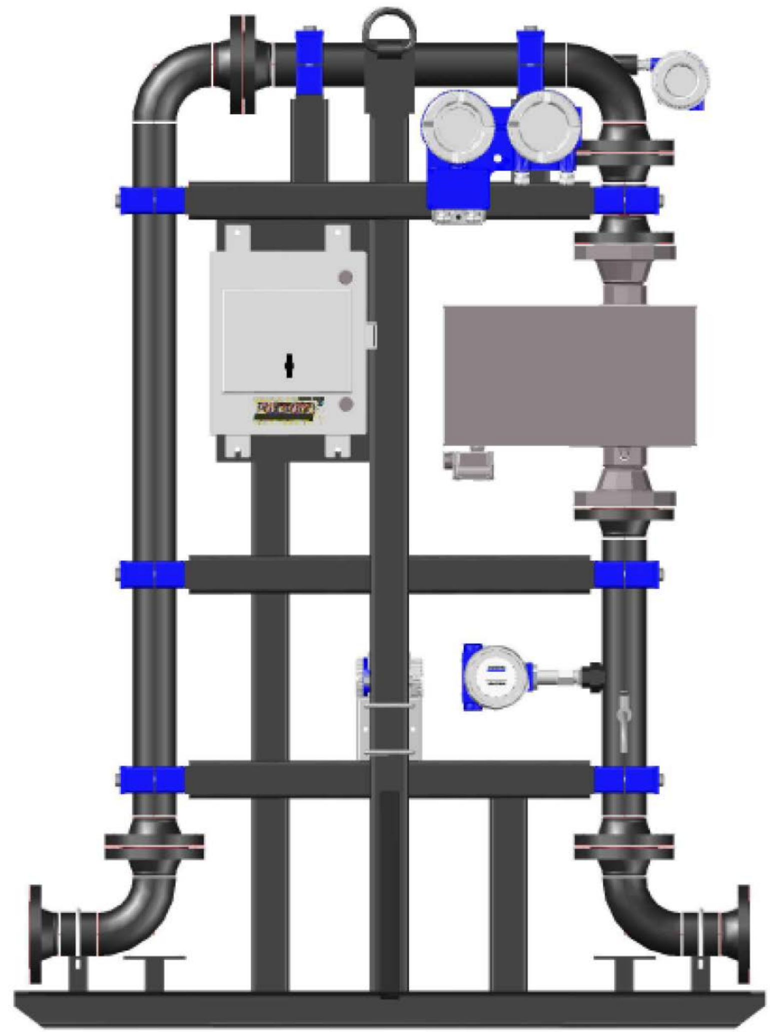
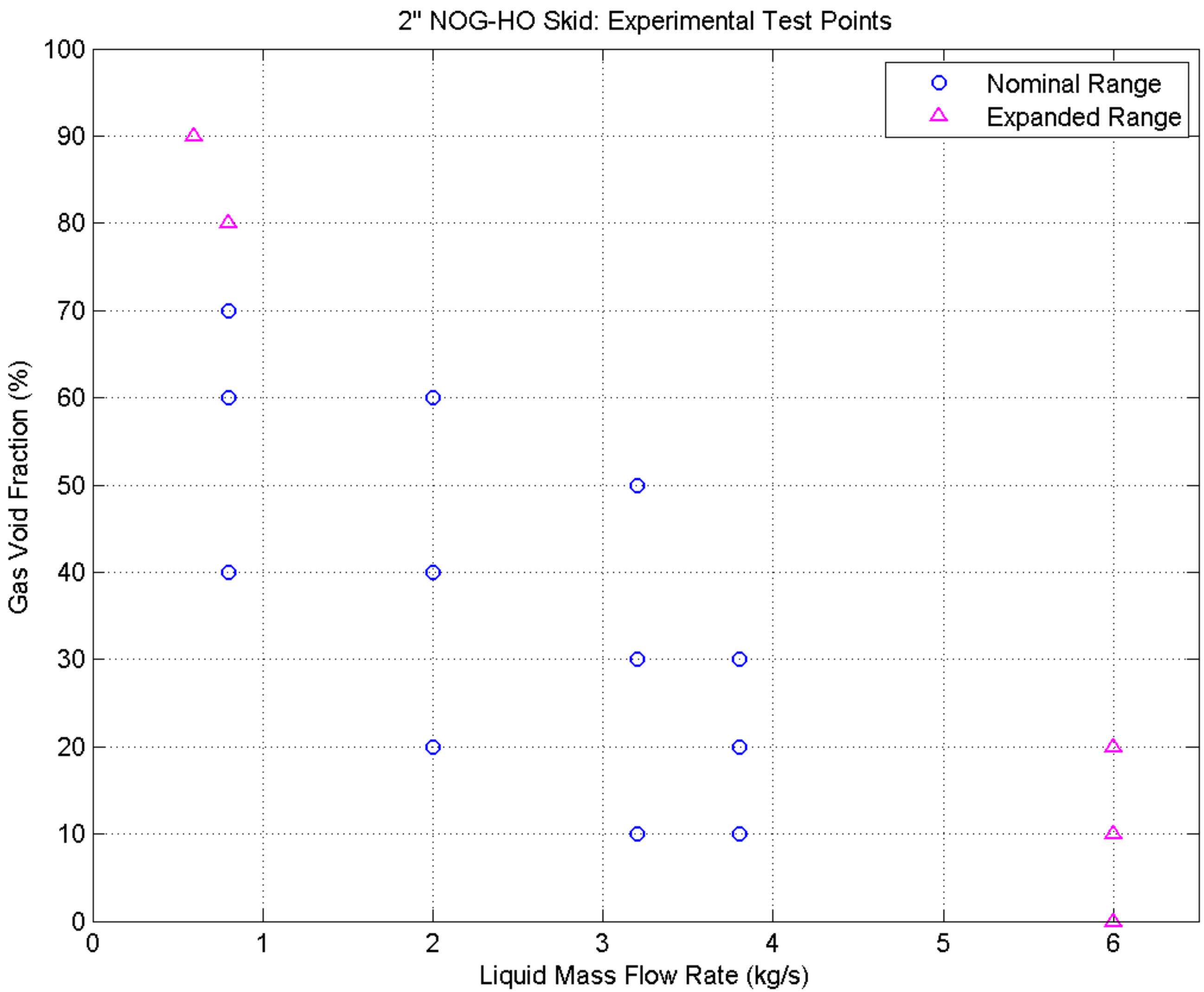
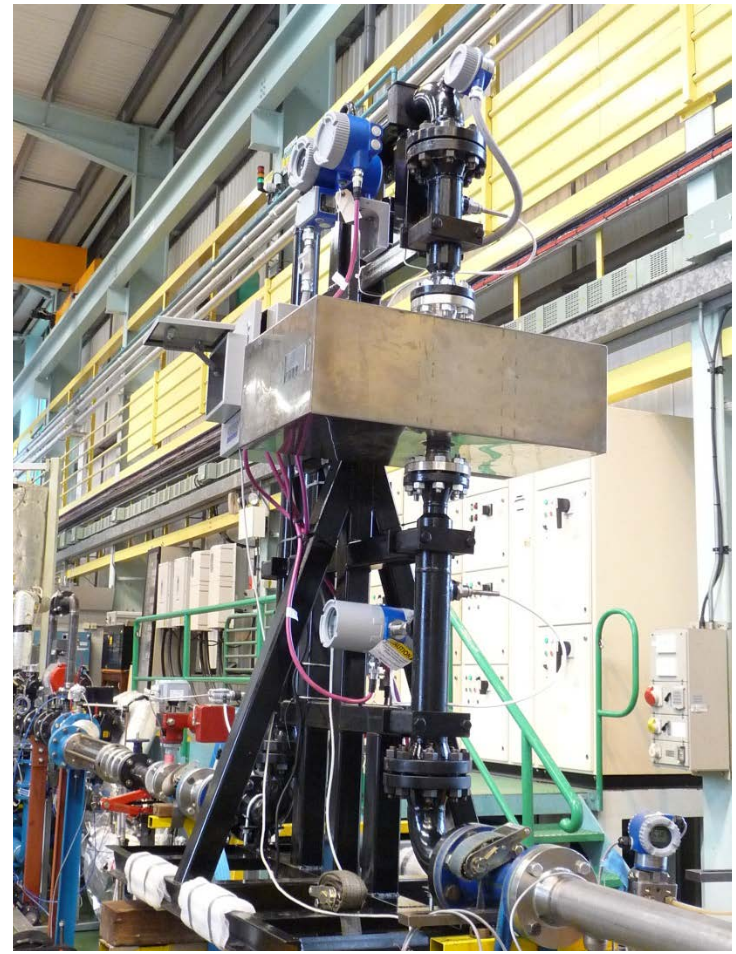


Heavy Oil

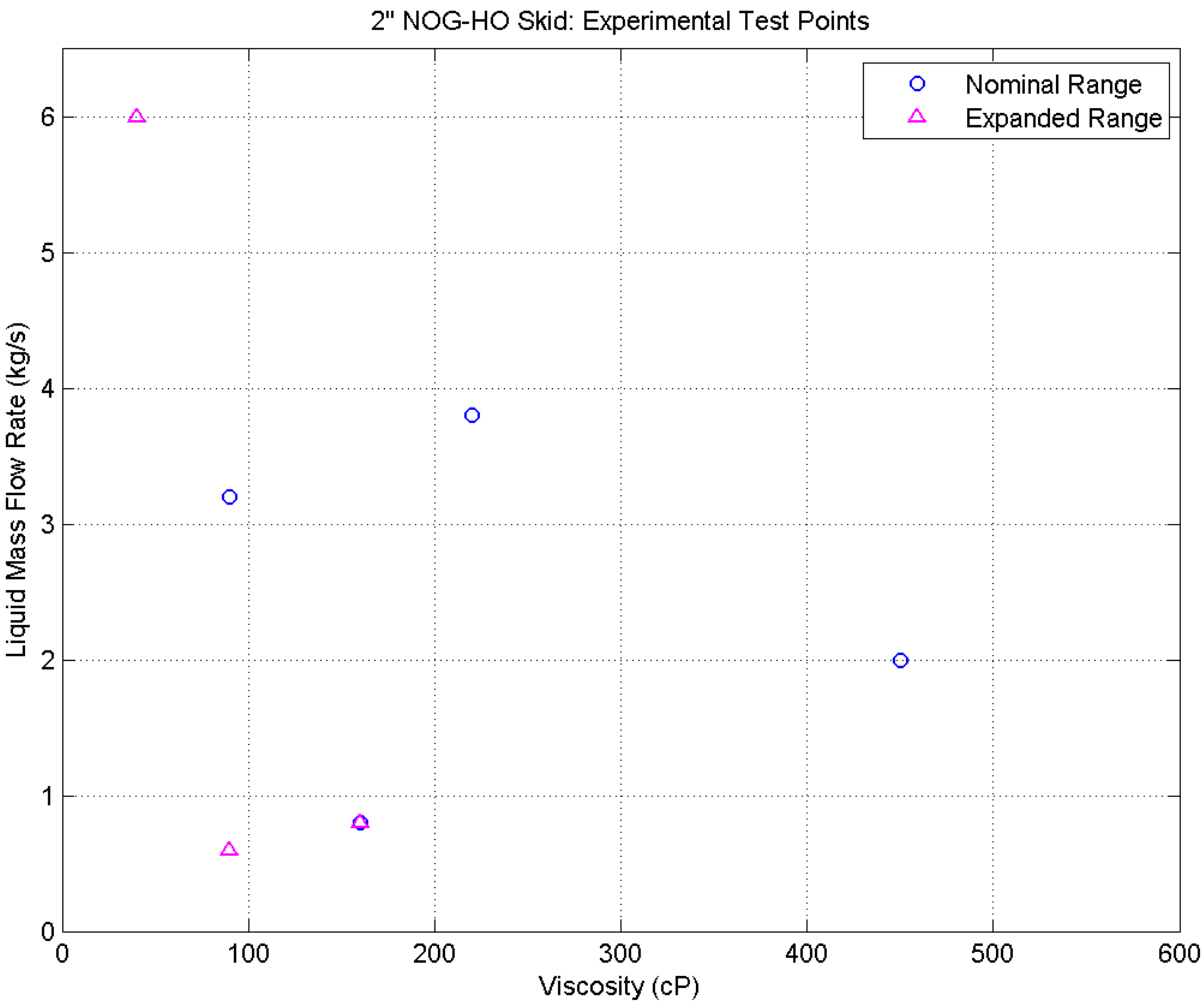
- Remaining oil reserves are increasingly 'heavy'
  - High viscosity/density
- Conventional well test equipment e.g. separators unsuited for heavy oil
- Test laboratory facilities for heavy oil are limited
- We have recently carried out trials at NEL (oil and air only)
  - GOST certification for high viscosity oil approved
- Coriolis meters are well suited to heavy oil and air
  - Better turn-down ratio
  - Higher GVF range – to 90% +

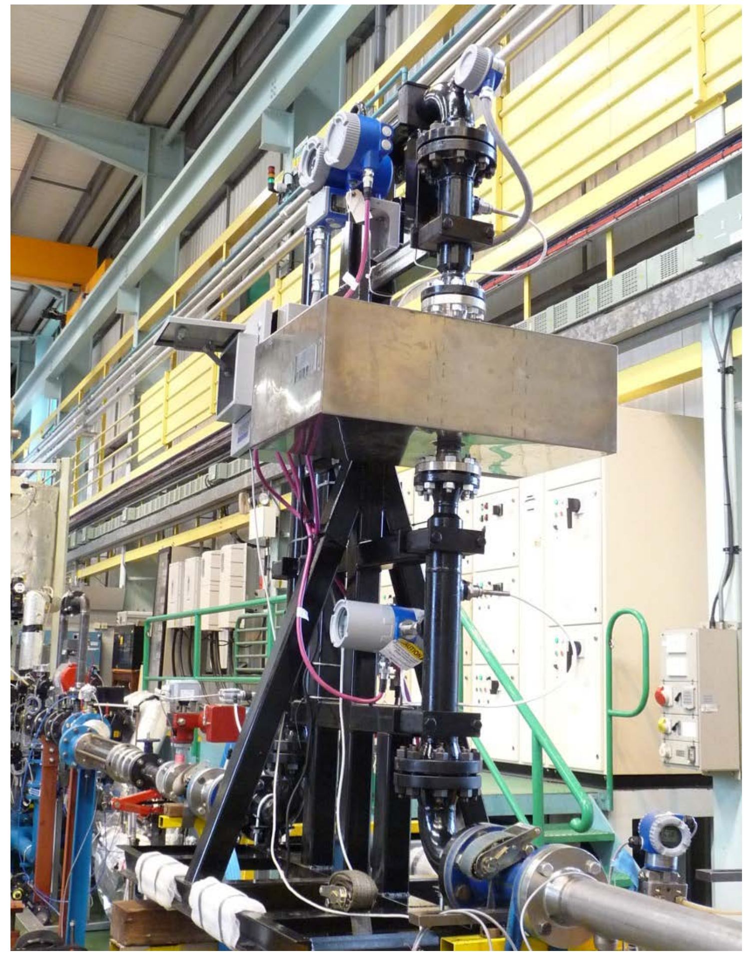
NEL Heavy Oil Test Matrix



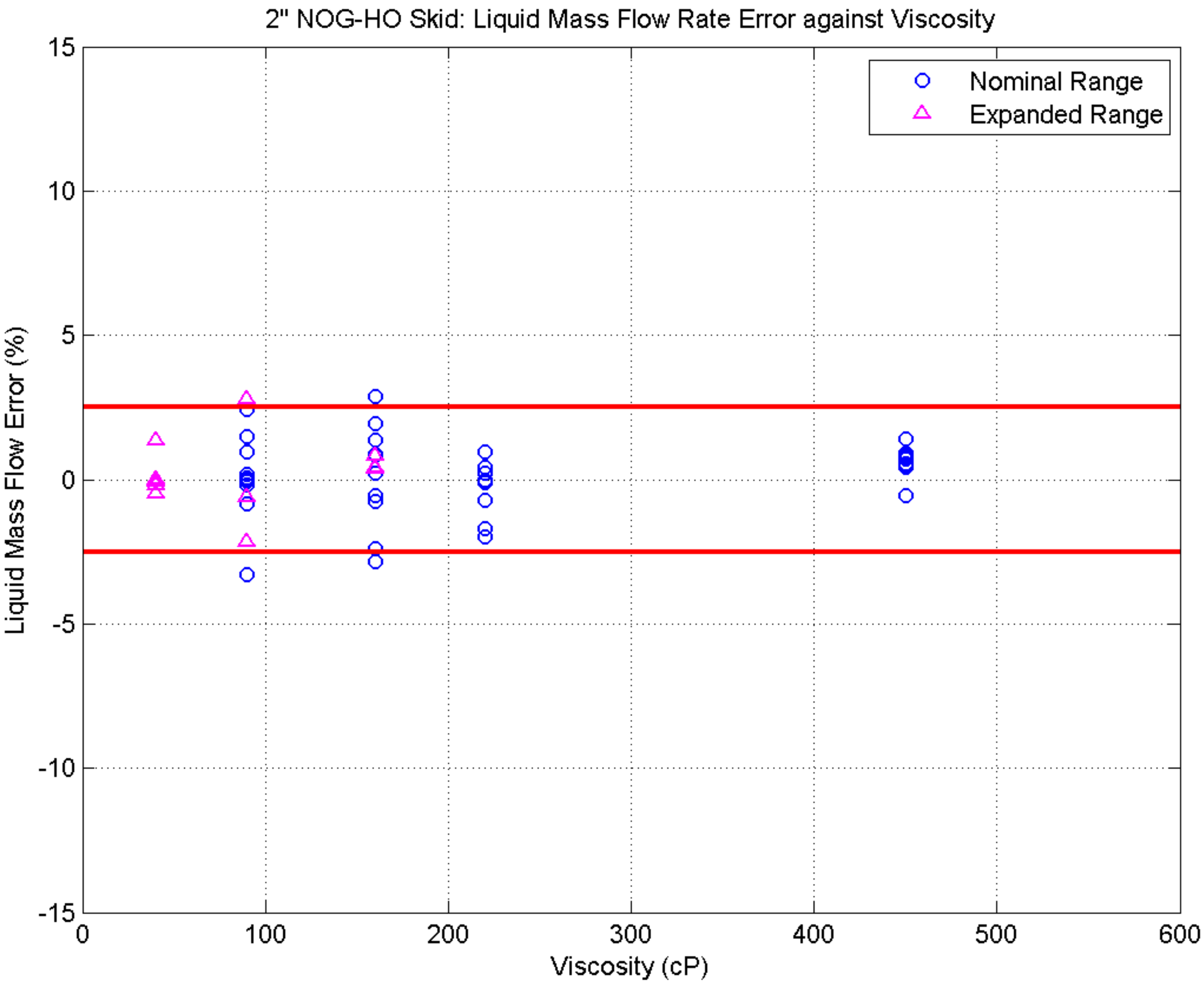


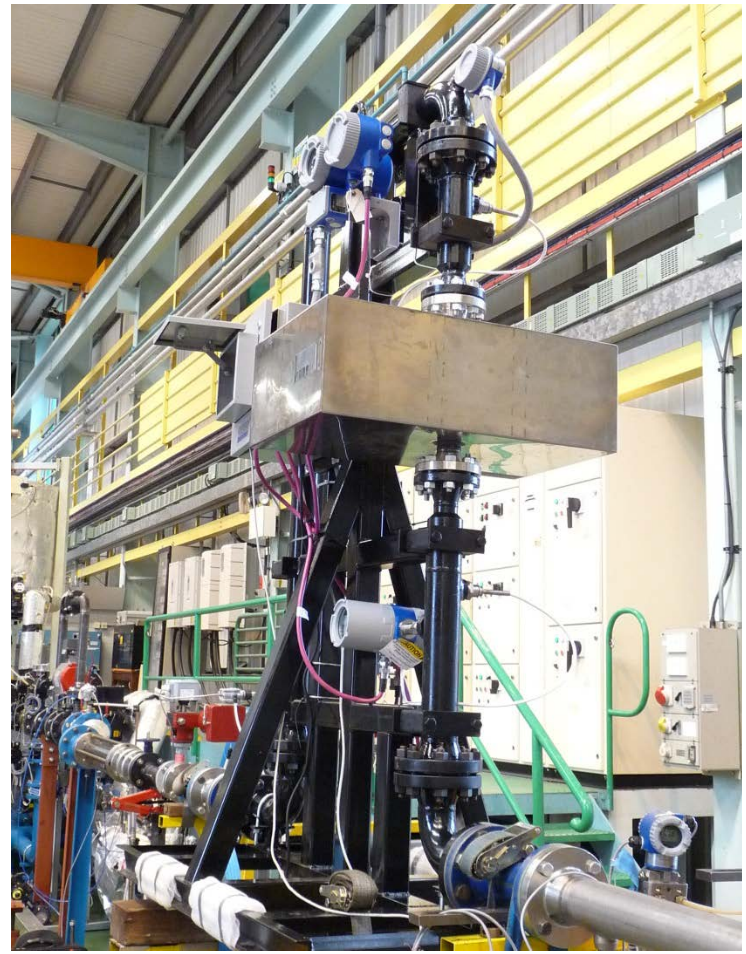
NEL Heavy Oil Test Matrix (continued)





NEL Heavy Oil - Liquid error results





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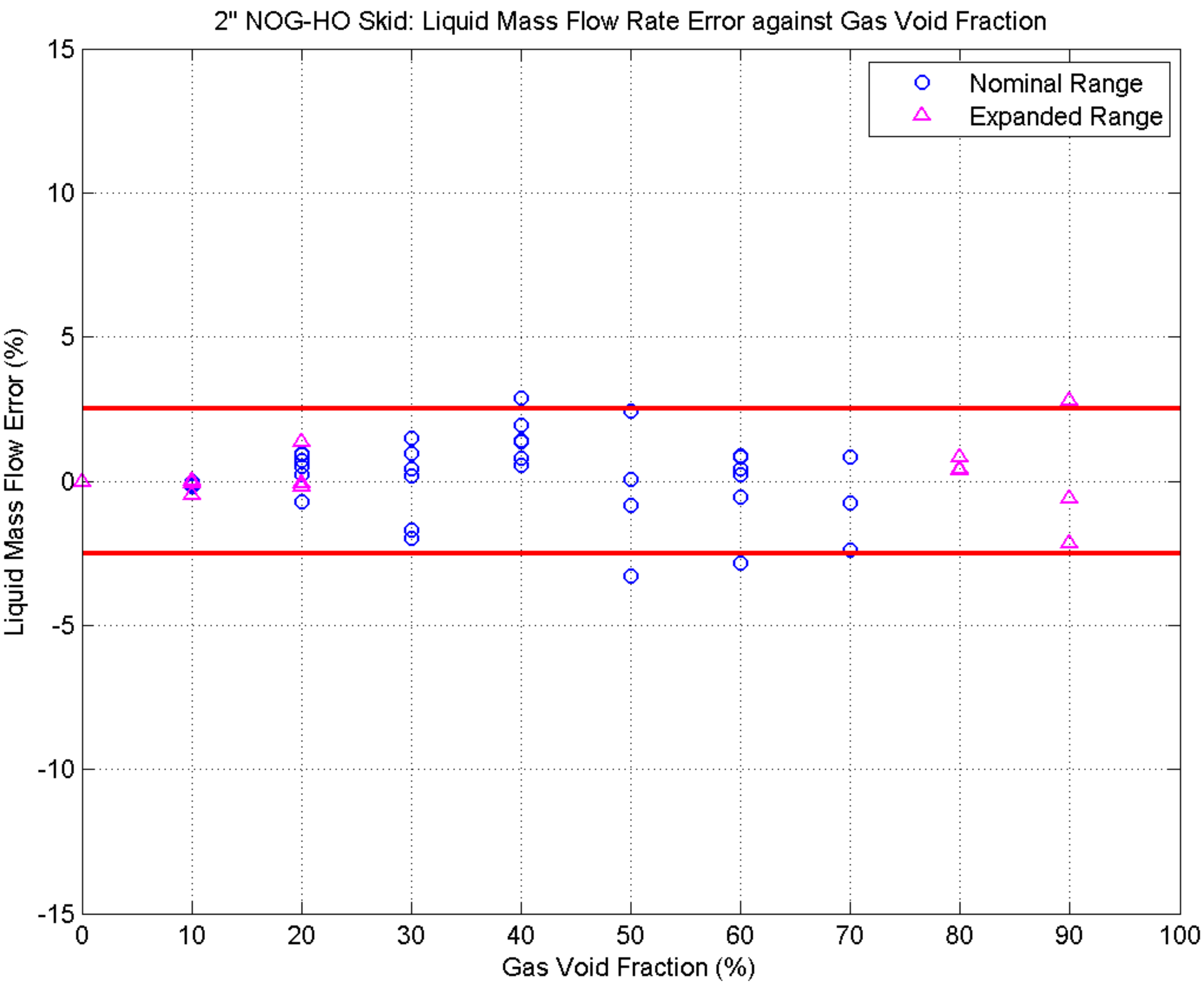
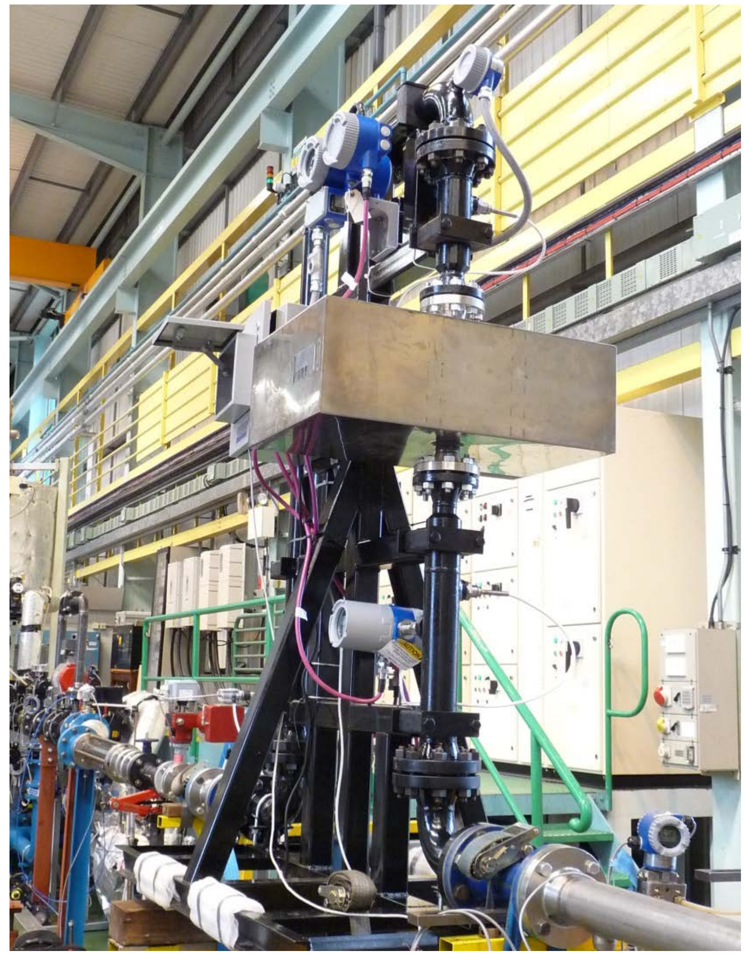
NEL Heavy Oil - Liquid error results (continued)





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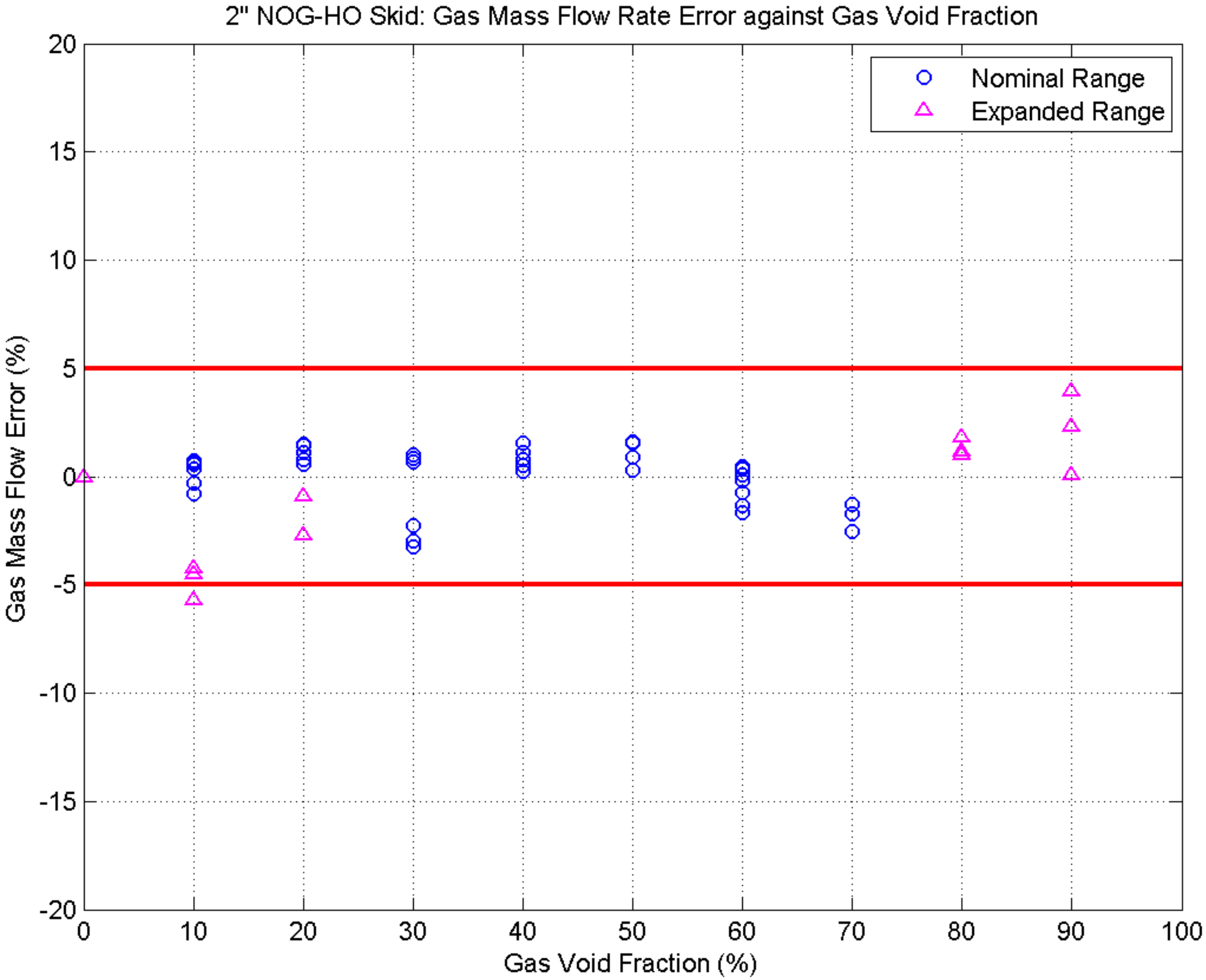
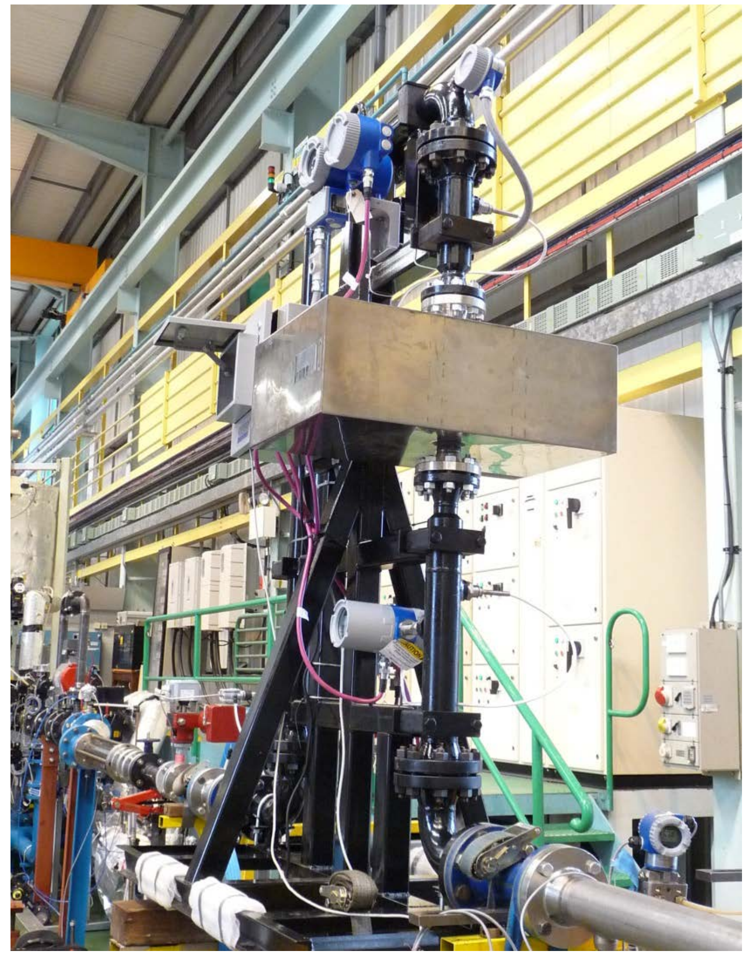
NEL Heavy Oil – Gas flow error results





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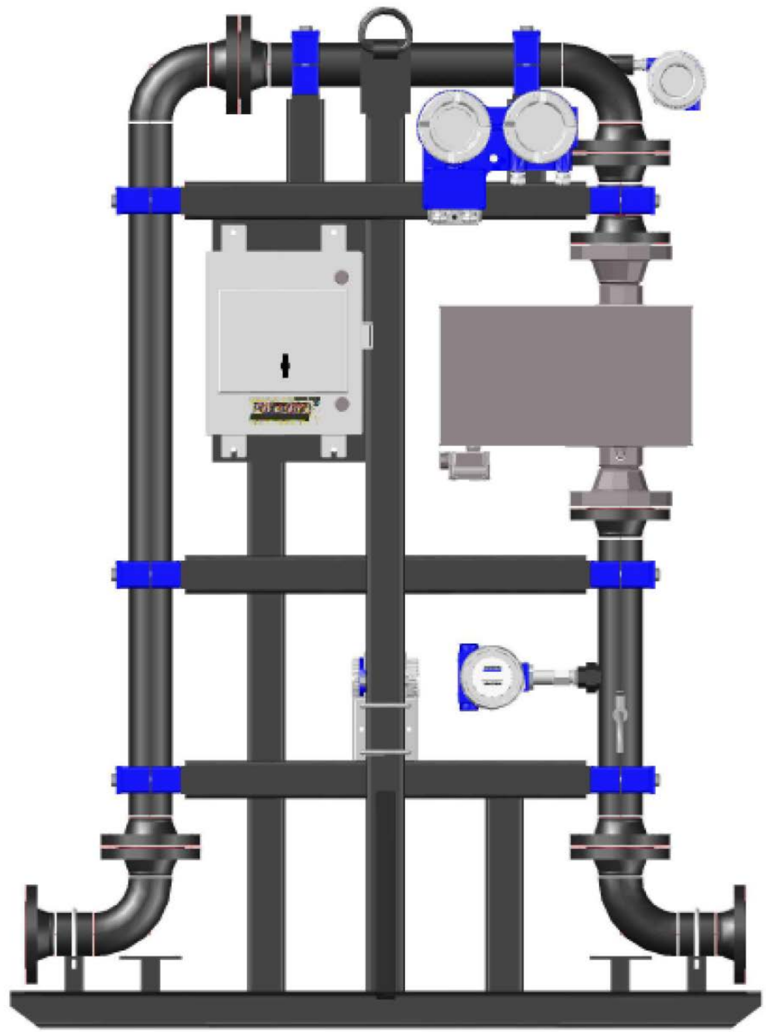
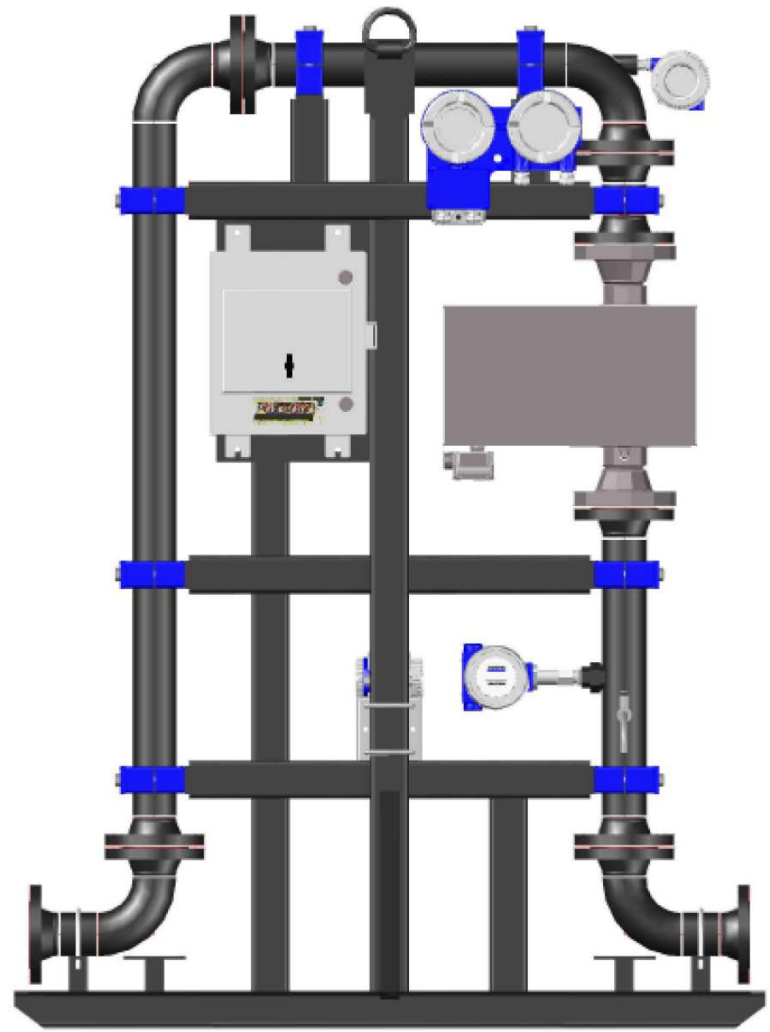


Future Work

- The Oxford group is now independent of Schneider, after 20+ years
- We are developing a next generation Coriolis transmitter architecture
  - Improved base technology for:
    - Short batches
    - Multi-phase flow
- We are looking for new partners and projects to share in the development of the next generation Coriolis meter
- Coriolis metering is becoming firmly established as one of the metering technologies to be used with multiphase flow
- We will continue to develop Coriolis technology, alone and in combination with other measurement types, to provide enhanced metering solutions, especially for the oil and gas industry

Extra slides



Singapore Bunker Metering Project Phases

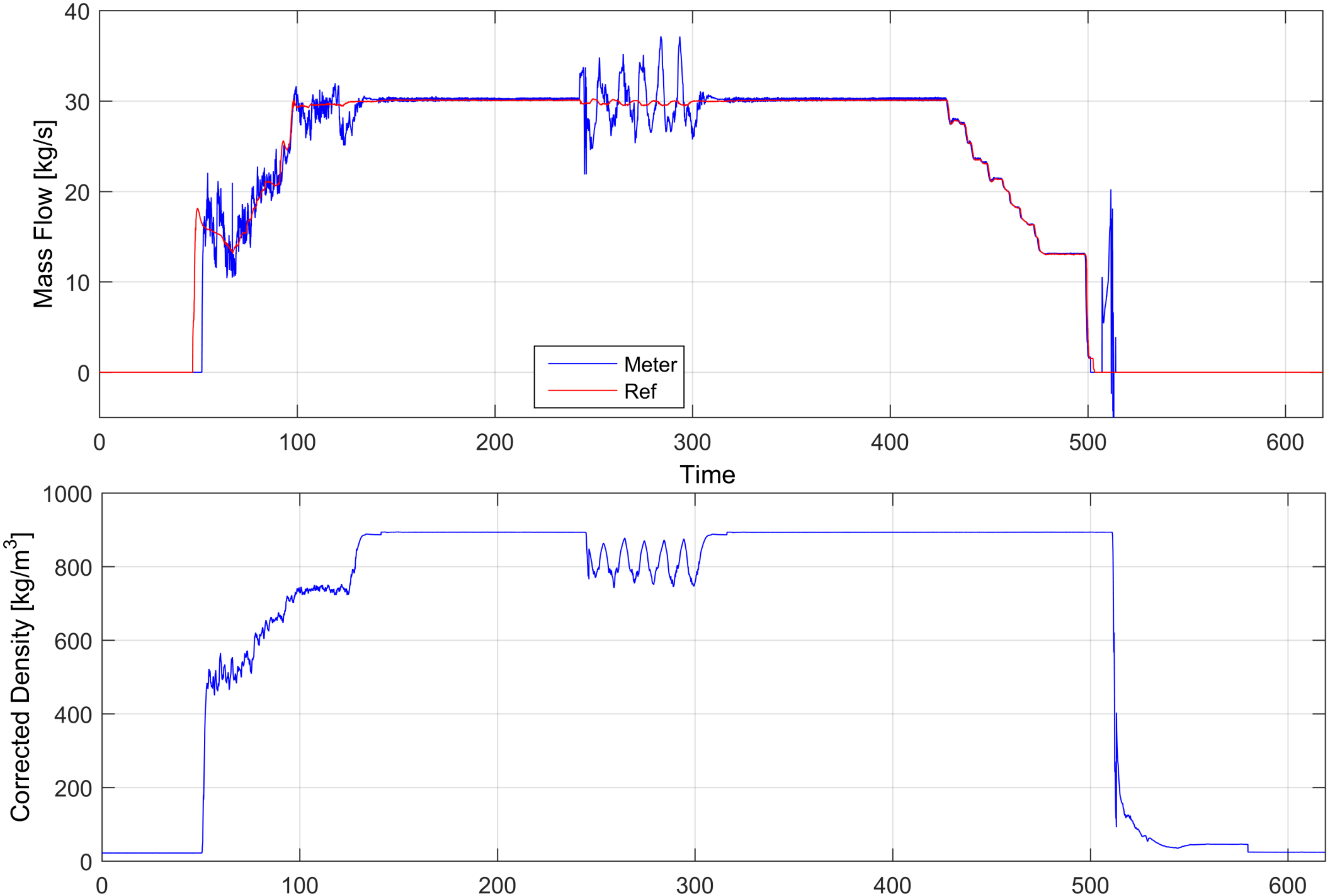
- **First Phase** - Mass meter testing at National Engineering Laboratory (TUV – NEL UK)
  - Purpose - accuracy of meter using single and two phase mixtures of oil and gas

- **Second Phase**
  - Road test of integrated meter skid on board bunker barge
  - Purpose
    - Mechanical and Operational Integrity and Impact

NELTrials

- Trials at NEL (UK National Flow Facility near Glasgow)
- Evaluation of single phase and two-phase (oil/gas) performance
- Simulation of bunkering operation to/from empty with tank stripping
- 8” flowtube
- Trials were formally witnessed by NEL and BP

Typical gas-entrained batch



NEL Witnessed Trials

MAX FLOW 33KG/S   120 TONNES/HOUR

			Meter error	
Run	**Ref total (kg)**	**Meter total (kg)**	**(kg)**	**(%)**
1	13679.86	13651.15	-28.71	**-0.21**
2	14300.85	14273.6	-27.25	**-0.19**
3	12444.67	12419.29	-25.38	**-0.20**
4	13092.49	13017.37	-75.12	**-0.57**
5	13356.9	13255.77	-101.13	**-0.76**
		Mean Error	-51.52	**-0.39**
		Spread (max - min)	75.75	**0.57**

Summary of Singapore Barge Trial, 2008

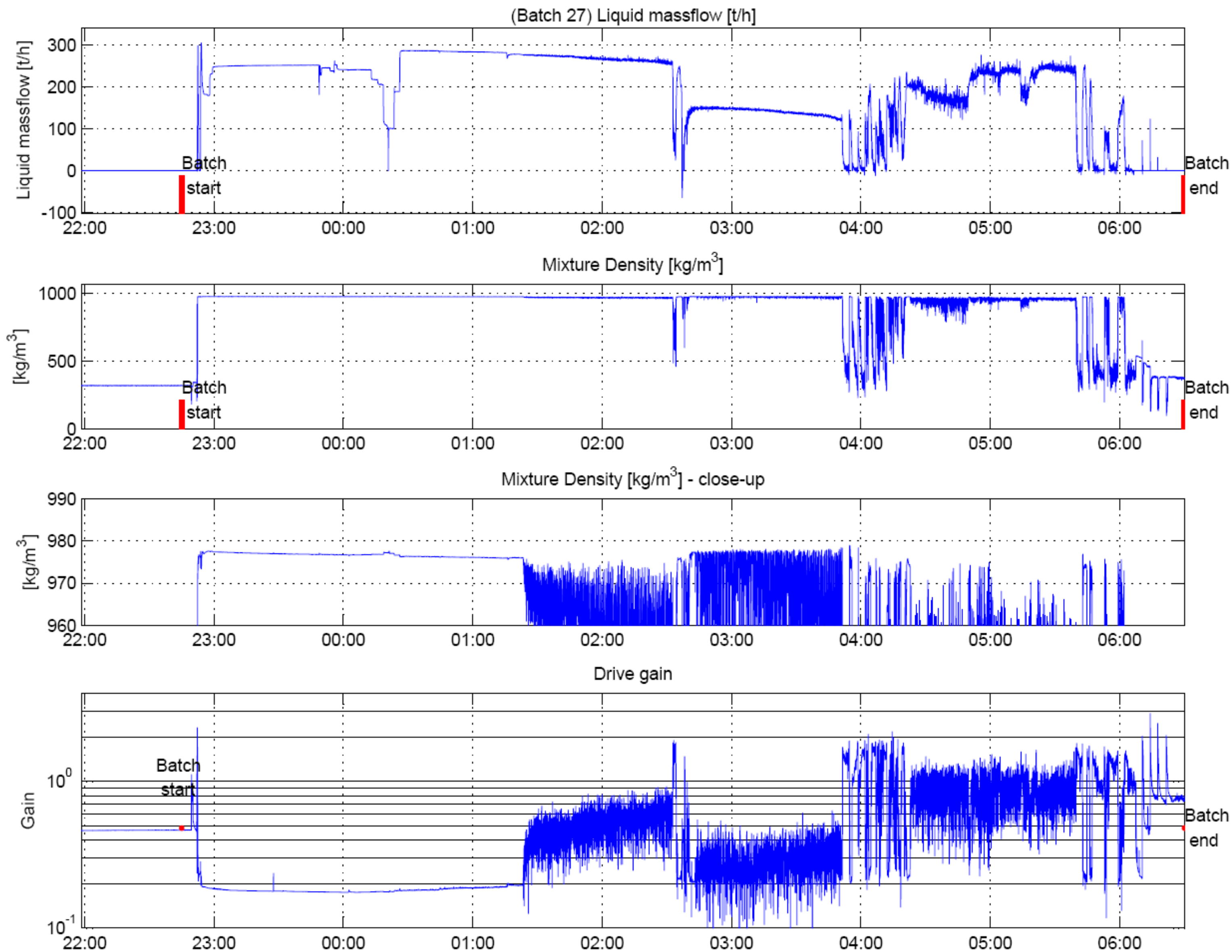
Basic Statistics

• Number of monitored bunkers with full data available	**78**
• Number of days covered	**71**
• Total fuel monitored by Coriolis meter	**75,608.420 t**
• Value of fuel (based on $300 per tonne)	**$30.2M**
• Estimated annual turnover (based on $300 per tonne)	**$120M**

Overall, good agreement between meter and dips, but many detailed findings

"How do we know it is entrained gas?"

- Meter is highly sensitive to gas
- Drive gain can indicate gas even at low levels (< 1% by volume)
- Meter has become a useful detector of low levels of gas entrainment
- Unambiguous gas detector



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Two-phase flow statistics

• Overall mass flow metered in two-phase conditions	45.60%
• Time-averaged Gas Void Fraction (including no flow)	29.38%
• Average mass-weighted Gas Void Fraction	**3.11%**
• Maximum mass-weighted GVF (Bunker 15)	**16.38%**
• Standard deviation	2.68%
• Estimated 95% probability bounds on GVF	**0.0 … + 8.5%**

➢ Examples – consecutive batches on Oct 13th, 2008

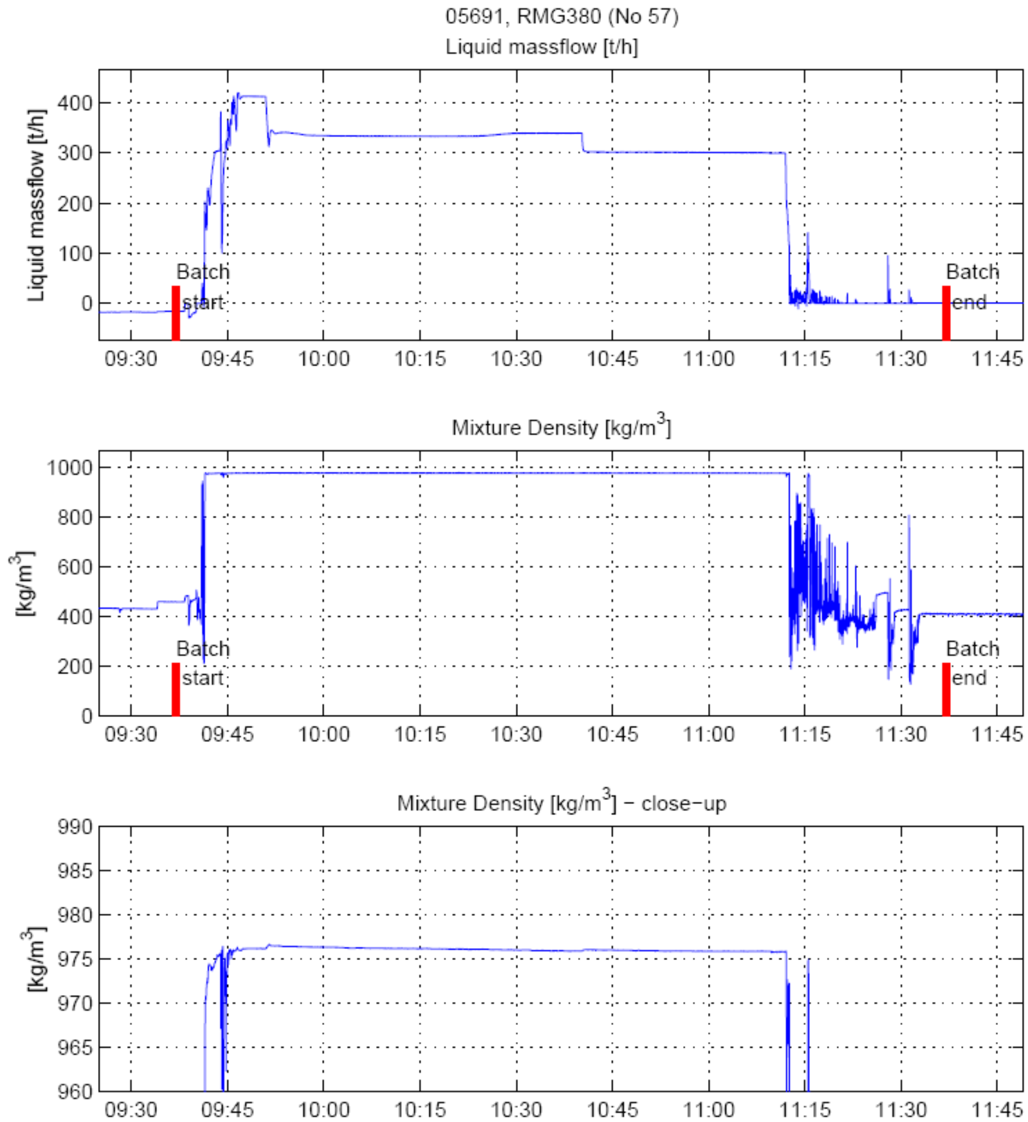
Batch 57

- Mass in two-phase conditions 2.4%
- Time-averaged GVF 55.2%
- Mass-weighted GVF 0.0%

➢ Very clean batch

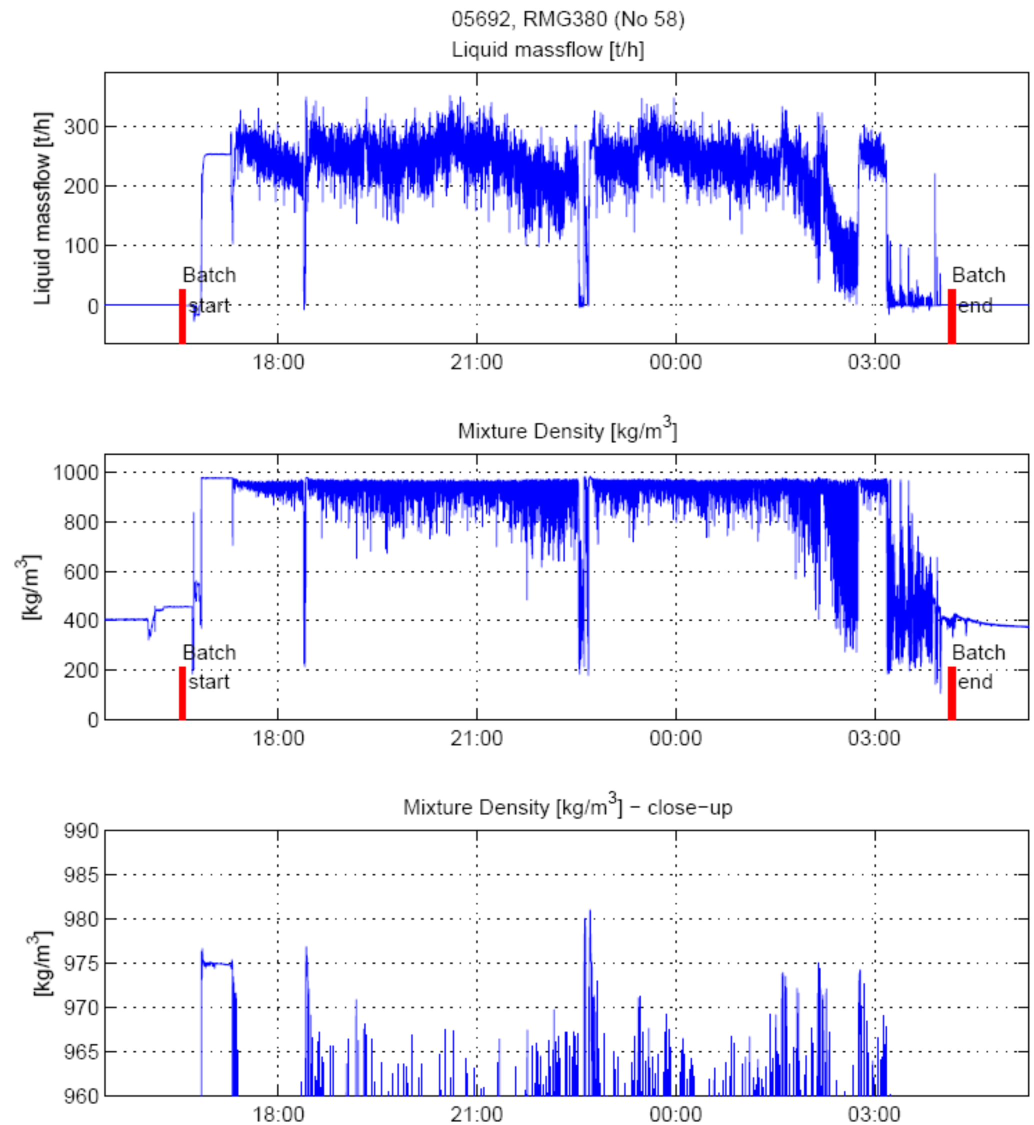
➢ Very steady density reading

➢ Good agreement between dip and meter – within 0.1%



Batch 58 – a few hours later

- Mass in two-phase conditions 95.5%
- Time-averaged GVF 17.1%
- Mass-weighted GVF 9.4%



- ➢ 10 minutes of clean flow
- ➢ Rest of bunker has high GVF
- ➢ Poor agreement between dips and meter (7%)
- ➢ Change from previous batch suggests operating procedure issue

UNIVERSITY OF OXFORD
Department of
Engineering Science