Publishable Summary for 16ENG07 MultiFlowMet II
Multiphase flow reference metrology

Overview

Europe, and the world, will be dependent for many decades to come on the production of oil and gas for its underpinning energy needs. Multiphase flow measurement is a fundamental enabling metrology in subsea oil and gas production. However, field measurements exhibit high measurement uncertainty, costing industry billions of euros in financial exposure and production inefficiencies. To improve this situation requires a reference measurement capability that is consistent and comparable across different test laboratories that offer this service. This project will address this need by establishing harmonisation of measurements between multiphase flow reference laboratories.

Need

Over half of the world's energy demand is satisfied from oil and gas. The world economic value of oil and gas production is vast – around $3,000bn p.a. for oil (2014) and $1,000bn p.a. for gas (2013). When fluid is extracted from a well it typically comprises time-varying ratios of oil, water and gas. Multiphase flow measurement, where each component is individually metered, is a key enabling metrology that is vital for operational decision-making as well a prerequisite for allocation and fiscal measurement. However, currently field-based multiphase flow measurement is subject to high levels of uncertainty (up to c. 20 %, greater in some conditions), which has serious ongoing financial implications in all these areas of application. The lack of standardised facilities (and procedures) for testing multiphase flow meters (MPFMs) leads to variances in test results between laboratories which erodes confidence in the measurement system, and hence confidence in the meters themselves. Which in turn leads to a need for harmonisation of multiphase flow measurement methods and data.

The preceding EMRP project ENG58 MultiFlowMet developed and piloted an approach for such harmonisation. However, this approach now needs trialling and applying across an enlarged network of laboratories and a wider range of different multiphase meter types, which the current project will address. To achieve harmonisation, existing measurement comparability first has to be quantified through an extended intercomparison testing programme, which the current project will conduct involving six multiphase laboratories. This, in turn, requires the design and provision of a mobile suite of instrumentation that can be moved around different laboratories in order to enable comparison measurements to be taken. To understand any variances in the laboratory datasets this project will gain an understanding of the factors that influence the measurements, such as the geometrical features of each laboratory and the structure of the flow that develops in each set of flow conditions. Finally, this project will apply these findings to the intercomparison data, to see what insights can be developed in order to provide the maximum possible level of harmonisation between laboratories.

Objectives

The overall goal of the project is to establish an enduring multiphase flow measurement capability to end users.

1. To optimise, and fully prepare for, the intercomparison testing programme by building a measurement transfer package whilst taking into account leading-edge methods of flow pattern visualisation and producing a comprehensive set of test matrices and protocols.

2. To carry out intercomparison testing across a network of laboratories with appropriate facilities in order to significantly extend the test envelope, in terms of flow rates (4 to 100 m^3/hr for liquid and 3 to 300 m^3/hr for gas), pressure (4.5 to 9 bar; extended to >24 bar in complimentary research tests), and fluid properties (oil viscosity including the range of 5 cSt to 8.5 cSt). The intercomparison testing will include appropriate leading-edge methods of flow pattern visualisation and will be done with a meter that incorporates a Venturi, cross-correlation, gamma ray absorption and electrical impedance sensing.

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

3. To further develop modelling (e.g. computational fluid dynamics (CFD) techniques) for significantly improving the metrological characterisation of multiphase flows, using small and full-scale experimental testing. Improvements will come from new data that will allow flow regime map(s) to be extended and/or new one(s) created. This will include additional research to understand geometrical influences and the influence of gas phase activity.
4. To make statistical cross-comparisons between the measurements undertaken in each intercomparison laboratory with a view to establishing comparability of measurement between test laboratories. The analysis will compare findings, identify anomalies, deduce their method of investigation and state the resolutions achieved.

Progress beyond the state of the art

Reference infrastructure (Objectives 1, 2 and 4)

In the preceding EMRP project ENG58, a small reference network (of two laboratories) was established based on a single multiphase metering technology. This project will expand the reference network itself by one additional laboratory and will use a different mode of MPFM from the previous project. This will provide an enduring measurement capability. The project will also incorporate a wider range of industrially-relevant flow conditions that are proven across a more representative range of field-deployed MPFM technologies.

Flow Pattern Visualisation by Tomography (Objectives 1 and 2)

In the preceding project ENG58, an experimental, multiphase visualisation and characterisation platform was developed with realistic and necessary spatial and temporal resolutions for multiphase flow metrology. This project will migrate software implementations of the appropriate advancements from an offline to an online (real-time) platform. Also, in this project the tomography platform will be deployed for the first time ever in live intercomparison testing, which will greatly enhance the experimental capability.

CFD Modelling (Objective 3)

Multiphase flow modelling using CFD is extremely challenging. In the preceding project ENG58, key advancements in techniques were made and a number of insightful simulations performed in both OpenFOAM and ANSYS Fluent software. Further advancements will be made in this project, by defining and applying more exact inflow (boundary) conditions, which have a big influence on the resulting flow pattern.

Data analysis & conclusions (Objective 4)

The proven methods from the preceding project ENG58 will be adapted and extended to cope with the much greater number of test laboratory variants and metering technologies. The analysis in this project will draw upon the theoretical background of multiphase flow in terms of dimensionless numbers.

Results

Objective 1 – Preparation for the intercomparison testing programme

Results to date include:

- Specification of the transfer packages. This consists of common instrumentation and other physical elements that will be deployed alongside the MPFM. The transfer packages include flow pattern observation and will be supplemented with tomographic visualisation technology. Assembly of said packages was completed in Q1 2019.
- Test matrix and protocols. A test matrix defining the test points, in terms of laboratory flow conditions, for optimally selected permutations of test laboratories and MPFMs has been developed for each transfer package. A set of intercomparison testing protocols (methods) has been agreed.
- Logistics plan. This was completed in Q1 2019 and included testing schedules, shipping details, detailing of customs requirements by country and definition of special licensing and/or certification requirements and the means of obtaining them.

Objective 2 – Execution of the intercomparison testing programme across the laboratories

Results to date include:

- Test laboratory data. Component flow rates have been measured for each test matrix point from each test laboratory in turn. Reference meter outputs, pressure and temperature have also been measured.

- MPFM data. Component flow rates and appropriate raw data outputs e.g. differential pressure have been measured for the MPFM.
- Two sets of data (laboratory reference meters and the MPFM) from the NEL facility have been taken under identical conditions, at the start and end of the test programme, to rule-out (or detect) drift in any of the instrumentation.
- Flow pattern experimental evidence - tomography and viewing section video footage. These data will require subsequent analysis before yielding numerical or other results e.g. flow pattern categorisation.

Objective 3 - Further development of modelling techniques

Results to date include:

- Full scale experimental research. Using the NEL and DNV GL facilities further experimental research have been carried out at full scale, to assist with intercomparison data rationalisation directly as well as to provide additional verification data for the modelling processes.

Results anticipated are:

- Inter-laboratory analysis. An analysis of the inter-laboratory differences will be carried out, including the geometrical variances, as a focus for the modelling work.
- Small-scale modelling. Results from small-scale experimental modelling will be compared to better quantify the key inter-laboratory influences, such as those above.
- CFD simulations. A number of CFD simulations will be produced that can be validated against small-scale and full-scale experimental data and, thereby, support data rationalisation in the intercomparison test programme.

Objective 4 - Cross-comparisons between measurements undertaken in each laboratory

Results anticipated are:

- Intercomparison analysis. A full analysis of intercomparison data is currently being undertaken, to compare findings, identify anomalies, deduce their method of investigation and the resolutions achieved.
- Intercomparison conclusions. A set of conclusions will be produced, summarising where good measurement agreement has been obtained between laboratories across a range of MPFM technologies.
- Intercomparison comparison. A case-by-case summary will be written covering any areas where good measurement agreement is not obtained, detailing the analysis carried out to rationalise any measurement variances together with the results.

Impact

Several dissemination activities have already taken place. A press release was issued to the media to announce the start of the project. This was picked up by papers by the University of Leeds, which also produced a master‘s thesis. So far there have been five open access papers published or submitted for publishing, and four posters and seven presentations related to the project presented at international conferences. Five training sessions have taken place within the consortium as well as a workshop on multiphase flow visualisation.

Impact on industrial and other user communities

The results of this project will impact the oil and gas community that is becoming increasingly reliant on multiphase metrology as part of subsea engineering allowing lower-cost exploitation of new fields. It will do so by creating an enlarged, comparable network of multiphase flow measurement reference facilities with an enduring measurement capability. This will provide oil and gas operators (the instrumentation end-users) and instrumentation developers with a renewed confidence in the testing and reference measurement infrastructure. In turn, this will lead to lower uncertainty of measurement and greater confidence in the deployment of multiphase metering technology.

Increased confidence and lower uncertainties of measurement associated with multiphase metering reduces both financial exposure and risk, as well as enabling better operational efficiency. This occurs at two levels;

- Operational decision-making – multiphase flow measurement data are key to deciding if (at the assessment stage), when and how a particular field will be exploited, balancing capital investment against revenue potential at set-up, then optimising conditions when the well is in production.
- Allocation (and fiscal) exposure – arising from uncertainty regarding how much of each operators production is being commingled into common networked flowlines. There is also significant financial exposure related to uncertainty of measurement for the application of taxation.

Further to this, the project will produce a case study for demonstrating to end users how the outputs of the project could be used, to reduce uncertainty and increase end-user confidence in the metering technology being evaluated. The partners will work with the end user advisory group to develop a case-study that is realistic, to maximise impact. The case study will then be advertised through the end user advisory group and on the project website.

Impact on the metrology and scientific communities

A key benefit for the European flow metrology community is that it is the first step in establishing a long-term Key Comparisons programme for NMIs and other commercial and non-commercial laboratories. Key elements will be harmonised uncertainty budgets, intercomparisons, auditing and accreditation, as has existed for single phase flow metrology activity for some decades. For multiphase flow metrology, the preceding EMRP project ENG58 has already made significant progress in the former two and this project will build on these as well as producing three Good Practice guides for practitioners from end-user groups. The Good Practice guides will be on 1) Good Practice guide on general preparation and approach to multiphase intercomparison testing, 2) Good Practice guide on the acquisition of experimental data for the determination of multiphase flow patterns and 3) Good Practice guide for minimising uncertainty of laboratory flow reference measurement. The Good Practice guides will be published on the project webpage and will also be disseminated to the metrology community and end users through the end- user advisory group and project partners.

Impact on relevant standards

There exists an extremely timely and unique opportunity for this project to influence standardisation in a major way, as ISO TC/28 (Petroleum products) is working on a new ISO standard on Multiphase Flow Measurement and has circulated ISO/TR 21354 Multiphase Flow Measurement draft 6 in May 2019. The project team meets on a regular basis with the drafting committee to both influence, and be influenced by, the new standard as it develops. Other standards committees through whom the project outputs may also be exploited include ISO TC/30 (Flow measurement in Closed Conduits), ISO TC/193 (Natural gas), the Energy Institute's Hydrocarbon Management Committee, EURAMET TC Flow and the American Petroleum Institute Manual of Petroleum Measurement Standards (API MPMS) Chapter 20.3 - Measurement of Multiphase Flow.

Longer-term economic, social and environmental impacts

In end-user terms, including both industry and government, the potential economic impact of reduced uncertainty of flow measurement is huge. In allocation and fiscal metering, certainty of measurement is an enabler of 'fair-trade' – which in turn underpins economic prosperity in Europe. It has been shown that the development of multiphase flow measurement over the last few decades has facilitated the development of marginal oil and gas fields previously considered uneconomic to produce. As future field development becomes more technically and economically challenging, the ability to squeeze those additional few percentages out of the available resource will be paramount to energy resource efficiency.

Industries, hence employment and economic prosperity, are dependent on an energy mix that is fully optimised, not only in terms of cost, but in terms of adequacy and continuity of supply. Measurement of production is key for this and greater accuracy leads to better optimisation. Vital services such as health, emergency services and defence are all directly dependent on continuity, as well as economic optimisation of energy supply.

It is an undisputed fact that Europe needs energy and that no other, more environmentally friendly, sources of energy are ready as yet in sufficient volume to replace fossil fuels - nor will they be for decades to come. If we therefore accept our oil and gas dependency for the time being as a given, it is useful then to focus on what can be done to minimise environmental impact in its production. From this point of view, reduced uncertainty of measurement of multiphase flow will lead to optimal operational decisions, hence more efficient exploitation of a finite natural resource. Resource efficiency, should then in turn, underpin environmental sustainability.

With the establishment of the enduring multiphase flow measurement capability, end users will be able to confidently verify manufacturers' uncertainty claims for new meters as well as carry out periodic meter calibrations to confirm or correct their output. In addition, manufacturers will be able to commission independent test data to verify their marketing claims as well as benchmark the benefits of meter upgrades. This transparency in meter performance is likely to lead to progressive improvements in the metering technology driven by end users as well as by increased competition between MPFM manufacturers.

List of publications

Qiang Wang, Xiaodong Jia, Mi Wang, Bubble Mapping: a three-dimensional visualisation approach for gas-liquid pipeline flow using electrical tomography, Measurement Science and Technology, Volume 30, Number 4, https://doi.org/10.1088/1361-6501/ab06a9

Qiang Wang, Xiaodong Jia, Mi Wang, Fuzzy Logic based Multi-Dimensional Image Fusion for Gas-Oil-Water Flows with Dual-Modality Electrical Tomography, IEEE Transactions on Instrumentation and Measurement, https://doi.org/10.1109/TIM.2019.2923864; http://eprints.whiterose.ac.uk/149072

Wang, Q., Wang, M, Thresholding Values and Fuzzy Logic Fusion in Visualisation of Gas-Oil-Water Horizontal Flow using Dual-Modality Electrical Tomography. Proceedings of 9th World Congress on Industrial Process Tomography. WC-IPT-9, 02-06 Sep 2018 http://eprints.whiterose.ac.uk/140300/

M Olbrich, E Schmeyer, L Riazy, K Oberleithner, M Bär and S Schmelter, Validation of simulations in multiphase flow metrology by comparison with experimental video observations, Journal of Physics: Conference Series, Volume 1065, Flow Measurement, http://iopscience.iop.org/article/10.1088/1742-6596/1065/9/092015

Kun Li, Qiang Wang, Mi Wang, Three-dimensional visualisation of gas-water two-phase flow based on bubble mapping method and size projection algorithm, Flow Measurement and Instrumentation, Volume 69, October 2019, 101590, https://doi.org/10.1016/j.flowmeasinst.2019.101590

<table>
<tr><td colspan="2">Project start date and duration:</td><td>01 June 2017, 36 months</td></tr>
<tr><td colspan="3">Coordinator:
Anna Pieper, NEL Tel: +44 1355 593818 E-mail: Anna.Pieper@tuv-sud.co.uk
Project website address: https://www.tuv-sud.co.uk/uk-en/about-tuev-sued/tuev-sued-in-the-uk/nel/members-area/european-metrology-research-programme/multiflowmet-ii</td></tr>
<tr><td>Internal Funded Partners:
1 NEL, United Kingdom
2 CMI, Czech Republic
3 PTB, Germany
4 VTT, Finland</td><td>External Funded Partners:
5 NORCE, Norway
6 CU, United Kingdom
7 DNV GL, Netherlands
8 ITOMS, United Kingdom
9 OneSubsea, Norway (withdrawn from March 2018)
10 PSL, United Kingdom
11 Roxar, Norway
12 UCov, United Kingdom
13 ULE, United Kingdom
14 UofG, United Kingdom</td><td>Unfunded Partners:
15 Rosen, Germany</td></tr>
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