Publishable JRP Summary Report for ENG58 MultiFlowMet
Multiphase Flow Metrology in the Oil and Gas Sector

Background

Europe, and the world, will be dependent for many decades to come on the production of oil and gas for its underpinning energy needs. Currently, well 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 $3,500bn p.a. for oil and $500bn p.a. for gas. When oil is extracted from a well it typically exists as a multiphase flow, comprising time-varying ratios of oil, water and gas. As larger reserves dwindle in number, the new reserves being exploited year on year are smaller in size, larger in number, more remote and in deeper water. This has necessitated the development of subsea production, where new wells are increasingly produced and metered, on the seabed, prior to comingling into shared pipelines leading to the nearest processing facility. Measuring the flow rate of each component is an underpinning metrology requirement that is key to operational resource efficiency, as well a prerequisite for custodial and fiscal measurement.

Need for the project

Typical multiphase flow measurement systems can have an uncertainty on component flow rate of 20 % or greater under field conditions. These figures are cause for concern by themselves but the implication in financial exposure is staggering in the context of the global production values above. Despite this, the industry has struggled to improve upon these levels of uncertainty. Part of this is due to the intrinsic complexity of the fluids but another contributing factor is the lack of a proven reference network for independent evaluation of multiphase meters themselves.

This is in stark contrast to *single phase* flow metrology, where there is a well-established metrology reference network with mutually supporting programmes of inter-comparison, harmonisation of test methods and uncertainty quantification. Thus, one of the project objectives is to develop a metrological reference network for multiphase flow measurement. No such network, norms or standards exist for multiphase flow metrology. The project will advance state-of-the art in multiphase referencing by undertaking the world's first comprehensive inter-comparison study on multiphase flow measurement, the basis of a sustainable reference network.

Any reference network relies on comparability of measurements across different facilities within the network. Fundamental to being able to make such comparisons is the determination of uncertainty of measurement in a consistent way. The project is therefore looking at ways of improving methodology for the calculation of uncertainty budgets for multiphase measurements. Multiphase flow patterns are one of the most indeterminate aspects of multiphase flow metrology, hence major parts of the work have the objective of improving upon current methods for determining flow patterns, both experimentally, using flow visualisation technology and numerically, using CFD modelling.

Scientific and technical objectives

- *To develop an accurate and validated metrological reference network*, using existing test and calibration facilities for multiphase flow. The objective is to achieve comparability between labs, using agreed test devices that is consistent with the respective uncertainty budgets. This agreement will establish, and take account of, cause and effect regarding variances in physical measurement methods, as well as in test, analysis and reporting procedures.

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- *To improve upon current theoretical and experimental determination of flow pattern*s (bubble, finely dispersed bubble, slug, churn, annular, stratified or wave) as a function of field variables such as pressure, temperature and component fluid properties and velocities. In particular, to extend the flow pattern data for the high pressure regime (at least up to 25 bar) that characterises many of today's multiphase measurement applications in oil and gas. A related objective is the development of synergistic modelling and experimental techniques that will allow flow patterns to be mapped using fewer experimental data points.
- *To provide an improved basis for determining uncertainties*, by combining state-of-the art computational fluid dynamics modelling techniques with polynomial chaos method. The scientific objective is to develop a method that enables closer comparison between modelling and experiment by quantifying the uncertainties associated with the former. Furthermore, this will allow modelling techniques to be developed for simulation of field conditions, where deterministic data are of only limited value without knowledge of the associated uncertainties. As a result an improvement by a factor of two in modelling uncertainty will be strived for, but should be regarded as an arbitrary target in the absence of prior data.
- *To evaluate and improve experimental methods of flow visualisation* using dual modality electrical tomography for vertical multiphase flow pattern determination. In particular, we aim to develop this technique as a tool that can be used in multi-phase flow loops for investigation and verification of flow patterns. Measurement methods will be developed to help quantify the flow pattern(s) observed (currently methods are partly-subjective). A specific objective is for real-time cross and through-sectional imaging with flow pattern recognition to be developed for mixtures and flow velocities appropriate to multiphase production. Flow pattern recognition and quantification is the objective. Improvements in spatial and time-domain resolution are regarded as strong contributing factors and a 'factor of two' improvement will be sought in each, unless a more optimal way is identified

Expected results and potential impact

Intercomparison testing using an agreed standard metering arrangement, test matrix and testing procedure, has been completed between three industrial-scale multiphase flow laboratories in UK, Netherlands and Norway. The results from the intercomparison tests forms the basis of comparability between the laboratories. Analysis is now underway. Early indications are that there are no widespread differences of significance in measurements taken at the different labs. However, detailed analysis is still ongoing and any differences that are detected under similar flow conditions will be highlighted for further investigation using a range of modelling and experimental techniques that are also being developed as part of the project. This includes experimental investigations into the individual influence of parameters that are known to differ between laboratories, as well as the complementary application of computational fluid dynamics (CFD). The former include geometrical variables (such as injection geometry and test section length) and fluid variables (such as liquid and gas properties). Experimental work also includes the development and use of electrical tomography (capacitative, resistive and dual-modality) in quantifying the influence of key parameters on flow pattern.

Following establishment of a metrological reference network for multiphase flow testing, end-users will then be able to test with much greater confidence, knowing that test results obtained in any of the participating labs are backed up by robust intercomparison testing and analysis against the other labs in the network. Increased confidence in the lab-based testing environment will facilitate a step-change improvement in the evaluative process that end-users go through to optimise meter selection and configuration. This will lead, eventually, to corresponding step-changes in field measurement uncertainty. In end-user terms, reduced uncertainty of flow measurement reduces financial exposure and risk. This occurs at two levels; operational decision-making and allocation (and fiscal) exposure. This will also lead to more efficient exploitation of finite natural resources. Further, the project will be widely disseminated through numerous publication and training routes and bodies responsible for standards and norms.

As of February 2017, the following progress has been made against objectives:-

To develop an accurate and validated metrological reference network

The programme of intercomparison tests that will underpin this objective, together with the multiphase transfer device, test procedures and test matrices to be used for common testing in the three participating labs has all now been completed..

The first round of intercomparison testing was carried out at NEL (United Kingdom) in July 2015. The testing was very successful, all instrumentation working as planned and all the planned data being logged successfully. The multiphase flowmeter was supplemented by a flow-pattern observation viewing section with video capture and a 10m 'test section' along which pressure tappings were logged to enable slugging and other low-frequency flow patterns to be tracked. Data analysis is ongoing. The second round of intercomparison testing was completed at DNV GL (Netherlands) in July 2016 (the time gap between the 1st two test rounds was due to licensing issues and facility schedules). The DNV GL tests were also very successful as regards the acquisition of data and instrumentation performance.

Repeatability testing of selected test points was undertaken at NEL in August 2016. Data appear to confirm good repeatability with no evidence of instrumentation drift in the 12 months + since the initial Round 1 testing at NEL.

Based on a 'first pass' of early experimental data from the first two labs (NEL and DNV GL), the results are highly encouraging, with good levels of measurement comparability being demonstrated. This has been established for an intercomparison transfer standard based on a single multiphase metering technology, which is a small but crucial first step in progressing harmonisation state-of-the-art for multiphase flow measurement.

Third and final round testing was carried out at OneSubsea (Norway) in November/December 2016. Analysis of these data are now being carried out.

A paper covering the approach taken to intercomparison testing was presented at FLOMEKO 2016 in September.

To improve upon current theoretical and experimental determination of flow patterns

A review of existing data and literature was been completed.

The CFD and reduced-scale physical modelling work being undertaken at Cranfield University (physical modelling and related CFD), PTB and CMI (CFD modelling of full-scale intercomparison transfer standard) has continued to make very good progress as regards understanding of flow through key geometrical features. More comprehensive comparisons can now be made between the various moving images obtained over a wide range of test conditions – those obtained both visually and tomographically – and the predictions made using CFD. Consortium members and those from the project Advisory Group have commented on the excellent insight afforded, even without analysis, from the various video images that accompany the different intercomparison test conditions. The fact that these now exist for such a wide range of test conditions represents a significant leap forward in subjectively understanding multiphase flow patterns. The moving images will be published online in due course to supplement the traditional publications. CFD simulations also continue to develop in terms of ranges of conditions covered. Good visual correlation has been obtained between CFD predictions and visual images.

The work at Cranfield University was completed in February 2017. Taken together, these are not only giving us improved understanding of the way that flow patterns develop and evolve, but in some cases are challenging some historically-held 'rules of thumb' about geometrical influences on flow pattern. Such observations could have implications not only for inter-comparability of test results between laboratories but also for the manner in which flowmeters are deployed in some field situations. A paper covering some of the experimental work was presented at the International Conference on Flow Measurement 2016 and one on CFD modelling of flow patterns was given at FLOMEKO 2016 in September.

To provide an improved basis for determining uncertainties

The CFD modelling work being undertaken jointly by PTB and CMI on Venturi multiphase flow has provided some significant general findings as regards the application of CFD to multiphase flow modelling. A common technical issue encountered by CMI, PTB and Cranfield University has been the impact of computational power requirements on the 3D CFD modelling of various multiphase scenarios. However, subsequent rationalisation and focusing of the CFD development work has yielded results that exhibit good agreement with experimental data obtained to date. A paper covering CFD modelling of Venturi pressure drop was given at FLOMEKO 2016 in September.

To evaluate and improve experimental methods of flow visualisation

The development work on the use of electrical tomography for flow visualisation has been very successful in moving the technology forward with regard to its application to oil and gas flows. There has been significant hardware and software development of combined ERT and ECT tomographic methods and of the application of high-speed ECT. A particular highlight was the completion of the tomography evaluation work at the NEL facility involving the collaboration of two research organisations and two instrument developers, whose instrumentation was installed in tandem with an optical viewing section and gamma-densitometer. A previously unrecognised flow pattern was identified (designated *gas core slugging*) which had not been previously reported at this scale. The new flow pattern could be significant not only for laboratory intercomparisons but, potentially, for multiphase flowmeter design and development. More generally, important advances have been made in image resolution & interpretation and optimisation for oil and gas flow environments.

Regarding exploitation potential, the consortium comprises

- three industrial-scale European multiphase flow metrology laboratories,
- four National Measurement Institutes/Designated Institutes and
- three device manufacturers/developers

There is therefore strong potential in the consortium for post-project commercial impact in the form of new calibration and evaluation services as well as potential for future instrumentation product development. A project advisory group has also been set up. This comprises, in addition to the delivery partners themselves; three oil & gas operators, two industry regulators, three multiphase meter developers and one CFD software vendor.

A new working group has been set up for the purpose of developing an ISO Technical Report on Multiphase Flow Measurement within ISO TC/28 (Petroleum Measurement), chaired by Dr. Michael Reader-Harris of NEL. TC/28 (Petroleum products) is the specific Technical Committee dealing with petroleum measurements and covers specifically the oil and gas industry. The chairman of the TR working group is anticipating input from the project in early-mid 2017. The project's objectives have also been informally communicated within ISO TC/30 (Flow Measurement in Closed Conduits) and its subcommittees. TC/30's scope is the Standardisation of rules and methods covering installation, operation, measurement conditions, evaluation and interpretation of measurement data.

Follow-on project, MutiFlowMet II, which will build upon the findings of ENG58 will start in the summer of 2017. This involves 7 test laboratories and 6 multiphase meter vendors and will take multiphase laboratory harmonisation to the next level in key areas like inter-comparison testing, flow visualisation and modelling. It will also seek to formalise the enlarged reference network, which will represent a new business offering in metrology services.

A depressed oil-price continues to de-prioritise, for the time-being, initiatives of a longer-term nature, such as this project, amongst oil & gas producers. This, in turn, is affecting the ability of the oil & gas sector, such as our advisory group members, to engage actively with the project.

JRP start date and duration:	June 2014; 36 months
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