Intercomparison between multiphase flow test facilities

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Abstract

Currently a reference network consisting of test and calibration facilities for multiphase flow meter testing does not exist, in contrast to the broad network of accredited laboratories for calibration of single phase liquid or gas flow meters. In order to improve this situation DNV GL, NEL, OneSubsea and Shell are harmonizing their uncertainty budgets and conducting an intercomparison to validate these uncertainty budgets. This paper describes the test protocol and the performed test matrix. Special attention is given to testing at comparable dimensionless numbers, namely Froude and Reynolds numbers. Further, the harmonisation process of the uncertainty budgets is described. The paper concludes with an outlook describing anticipated outcomes from the project and essential further work in subsequent projects.

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1. Introduction

Currently a reference network consisting of test and calibration facilities for multiphase flow meter testing does not exist, in contrast to the broad network of accredited laboratories for calibration of single phase liquid and gas flow meters. In the context of the European research project “Multiphase flow metrology in oil and gas production” (EMRP ENG 58 MultiFlowMet) [2] it is planned to amend this situation. Project partners DNV GL, NEL, OneSubsea and Shell are aligning their uncertainty budgets and intercomparison tests are being conducted to validate the claimed uncertainties.

In section 2 the harmonization work on the uncertainty budgets is described. Section 3 presents the transfer standard. In section 4 the test protocol and test matrix are introduced. Special attention is given to testing at comparable dimensionless numbers (namely Froude and Reynolds numbers). The paper concludes with an outlook describing anticipated outcomes from this project and essential further work in subsequent projects.

2. Uncertainty calculation for multiphase test facilities

2.1 Current situation

At this moment no multiphase flow meter test and calibration facility has a validated uncertainty budget. Here, validation implies the ultimate validation through an intercomparison, which has not been performed as of yet. There is, however, one lab that has been accredited for multiphase flow where the reference is through the individual single phase flow meters. Despite this the partners of the research project have a solid understanding on their respective measurement uncertainties and do possess an uncertainty budget. In the next section the harmonisation approach will be described and more detail will be reported when the harmonisation process is complete.

2.2 Methodology and harmonization

Each of the partners DNV GL, NEL, OneSubsea and Shell were requested to present their uncertainty budgets to VSL. VSL reviewed the documents received and raised additional questions to the partners.

It was found that the uncertainty budgets vary in terms of potential sources contributing to the overall uncertainty and how these are accounted for. For example, in some cases the mass transfer between gas and liquid phase was accounted for while in other cases it has been assumed insignificant and therefore ignored. Note that as the various facilities have different operating principles, varying uncertainty budgets were to be expected. For example, the gas flow is circulated at DNV GL, whereas this is not the case at Shell and NEL. Another observation is that at some facilities the temperature difference between gas and liquid phase at the meter under test is (assumed to be) small, whereas in other facilities this difference can be much larger due to a much shorter upstream pipe length in which the single phases can equalize in temperature after mixing. Some facilities have ample calibration history for their instrumentation, whereas this is missing for others. VSL analysed and reviewed all presented sources of uncertainty, supplemented it with some other possible sources, and is currently drafting a ‘Guide to the Expression of Uncertainty in Multiphase Flow Meter Testing’. This should provide a general and detailed guidance for multiphase laboratories setting up an uncertainty budget. Typical sources of uncertainty are those related to instrumentation (temperature, pressure, density, and reference flow rates measurements), single phase contamination estimates, and calculation models for fluid densities, phase interactions and equilibriums. This guidance should eventually lead to more harmonized and comparable uncertainty budgets between the different test facilities. Upon completion this Guide will be shared on the project website.

3. Intercomparison transfer standard

Performing multiphase flow meter tests is a costly exercise. Therefore great care was taken in the design and selection of the intercomparison transfer package. For this purpose Schlumberger has made available a multiphase flow meter. Following the operating envelopes of the participating test rigs, the PhaseTester Vx52 has been selected. The complete transfer standard consists of this multiphase flow meter, 10 meter of straight pipe length upstream of the meter and a transparent spool piece that is used to capture the flow regime by means of a video camera.

The multiphase flow meter is based on the principle of gamma ray attenuation in the production fluid passing through a Venturi tube. Measurements of flow stream pressure, temperature, differential pressure over the Venturi tube and transmitted gamma photons at different energies from the Ba-133 radioactive source provide enough information to determine oil, gas and water volume fractions and flow rates. The meter has an inlet pipe diameter of 4” and the Venturi throat diameter is 52 mm. A picture of the flow meter while being tested at NEL is shown in Figure 1.

The 10 meter (4” schedule 80, hence more than 100 D) straight inlet pipe length should facilitate comparable flow regime/ pattern at the meter location in each test facility. Additionally the transfer meter has an upstream T-piece to redistribute the inlet flow so that it is independent of the upstream flow conditions. This is important as it is known that (multiphase) flow meters can perform differently if tested under different flow regimes although the average flow rates of oil, water and gas and other conditions may be the same.

By witnessing the flow regime on site and recording it with a video camera through a transparent pipe section (see Figure 1), the assumption of similar flow regimes at each facility can be verified. If it turns out that flow regimes are significantly different, other pipe geometries and mixing configurations can be considered in future comparisons. This could possibly include the installation of a mixer or flow conditioner upstream. The flow regimes are also being predicted by means of Computational Fluid Dynamics (CFD) modelling in another work package of the project, and subsequently compared with the video material.

The measurement uncertainty of the transfer standard, once properly setup, is specified to be 3 % for liquid volume flow rate and 12 % for gas volume flow rate, both for a Gas Volume Fraction (GVF) below 90 % and line pressure above 5 bar. For higher GVFs these uncertainties can be higher. However the repeatability and reproducibility of the meter is typically better than 1 % for most measurements. This latter number is the most important value for the intercomparison. This will be verified in this work by including repeatability and reproducibility points in the test matrix. In addition, the transfer meter is tested twice at one of the participating laboratories. The experimentally established reproducibility value will however reflect a combination of the reproducibilities of the flow meter itself and of the test laboratories. The reproducibility will set a limit on the level of agreement that can be claimed by the laboratories at the end of the comparison, or can be used to partially explain possible discrepancies between results from these labs.

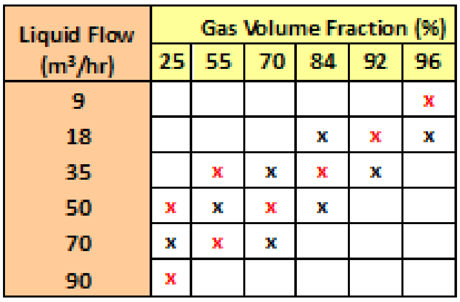
Figure 1: Intercomparison transfer standard and transparent pipe section used for flow visualization, as installed at NEL.

4. Test protocol and test matrix

A test protocol was written explaining the required meter set-up and procedures to be followed. The key requirements are to test under the same conditions and meter configuration. A flow meter expert from the manufacturer configured the meter at the start of each test. An important part of this configuration is the reference measurement of each component of the three-phase flow in order to reach the best possible accuracy. VSL verified that only fluid specific parameters were configured, and that the other parameters were kept constant throughout the complete intercomparison. The focus was on performing a fair intercomparison under similar test conditions as far as possible including consistent meter setup. Subsequently the flow meter was operated by a flow metrologist from VSL, who also witnessed the tests as independent observer.

The test matrix, containing all the points (flow rates, pressures, temperatures) is given in Table 1, whereas the anticipated flow regimes are given in Figure 2. It should be noted that there is a debate on the prediction of flow regimes, however this is not discussed in this paper (see [3] for a critical review on this and other flow pattern predictions). In WP2 of this project flow regime prediction is extensively studied, which should also lead to an improvement of Figure 2. The constraints on this matrix were dictated by the operation envelop of the flow meter and of the participating multiphase laboratories. Liquid flow rates were varied between 9 and 90 m^3/h, Gas Volume Fraction between 25 and 96 % and Water Cut between 0 and 100 %. Also some test points with single phase flows were taken for each of the three fluids. The values for the flow rates were the same at each facility.

Table 1: Liquid flow rates and gas volume fractions. Matrix to be carried out at water cuts of 0, 25, 50, 75 and 100%. A water cut of 0% and 100% represents two phase flow. Test points in red (‘x’) are carried out at water cuts: 0%, 25%, 45%, 70%, 90% and 100%, whereas test points in black (‘x’) are carried out at 25%, 45%, 70% and 90% water cuts.



Liquid Flow (m^3/hr)	Gas Volume Fraction (%)					
	25	55	70	84	92	96
9						x
18				x	x	x
35		x	x	x	x	
50	x	x	x	x		
70	x	x	x			
90	x					

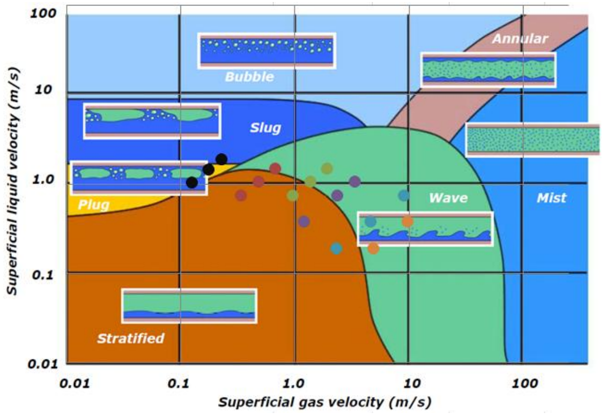


Figure 2 Test points plotted on a flow regime map, taken from [3]. . The different colors represent different GVF’s, from left to right: 10%, 30%, 55%, 75%, 92% and 96%.

Because the oil type and salinity of the water was not the same at each facility, the fluid density and viscosity and therefore Froude and Reynolds numbers were not equal at the facilities. Additionally, the range of available temperature and pressure did not overlap. In order to match these dimensionless numbers as much as possible, temperature and pressure settings at each facility were adjusted.

The variables that feed into the calculation of the Reynolds, Froude and Weber numbers are given below:

- Diameter and gravitational constant;
- Superficial velocities of the three phases;
- Density of the three phases;
- Viscosity of the three phases.

It should be noted that use of different test liquids to match the forth-mentioned dimensionless numbers is not considered in this work.

Obviously, the diameter and the gravitational constant cannot be changed. Furthermore, because of the operating envelope of the transfer meter, alterations to the superficial liquid velocities are restricted. Consequently, only the following parameters can be modified to achieve matching Froude and Reynolds numbers:

- Oil density and viscosity (via the temperature);
- Water density and viscosity (via the temperature and salinity);
- Gas density and viscosity (via temperature and pressure);
- Superficial gas velocity (within ‘acceptable’ limits).

In this research, it has been decided to prioritize matching the Froude numbers over the Reynolds number and over the Weber number (since the expected flow patterns do not include bubble, annular or mist flow). Nevertheless, the Reynolds number is considered important because it has a significant impact on the discharge coefficient of the Venturi. The following procedure has been used:

Temperature

- Within the available limits, reduce the operating temperature at DNV GL. This increases the oil density to best match the Froude numbers. Furthermore, it increases the oil kinematic viscosity to best match the oil Reynolds number.
- Set the operating temperate at Shell to 40 degrees Celsius. Compared to ambient temperature this gives a fair match for the oil Reynolds number. Further increase of the temperature would yield a slightly better match in the Reynolds number, however it would also result in a weaker match of the Froude number.
- Set the operating temperature at NEL to 40 degrees Celsius for a best match of Reynolds number.

Pressure

- Within the available limits, minimize the operating pressure at DNV GL (to 8 bar plus safety margin) and at Horsøy[1] (20 bar). This will change the nitrogen density to best match the gas Froude numbers.
- Set the operating pressure at Shell to 6 bar. This will change the air density to best match the gas Froude number. Furthermore, it will change the kinematic viscosity to best match the gas Reynolds number
- Set the operating pressure at NEL to 10 bar to match the nitrogen density and thus gas Froude number.

Gas velocity
In order to match the gas Froude number at Shell and Horsøy, the superficial gas velocity can be multiplied by factors of 1.25 and 0.65 respectively. In aerodynamics it is common practice to scale the velocity to match a certain characteristic number. This scaling criterion will be explored in this project to investigate if it can be applied to multiphase flow meter testing. Note that with the multiplication of the gas velocities the test points remain within the operating envelope of the multiphase meter and that the predicted flow patterns, as per Figure 2, hardly change. Nevertheless, the measurements are firstly performed with exactly the same phase flow rates and then possibly repeated with scaled gas velocities.

Salinity
The salinity is not varied for the intercomparison tests, i.e. each facility uses its own default salinity, because modifying the salinity is quite labor intensive and has only a relatively small influence on the dimensionless numbers (Froude and Reynolds). As density and therefore salinity does influence the multiphase flow meter sensing, the flow meter is configured using single phase water at each facility before the actual test takes place.

At the end of the intercomparison a best practice guide for multiphase flow meter intercomparisons will be produced, which will be a generalization of the protocol used in this project, enhanced with the lessons learnt during the tests.

5. Outlook

Due to unforeseen circumstances the intercomparison work was delayed considerably. In the summer of 2015 the first test was completed at NEL and in July 2016 the second test was completed at DNV GL. The remaining testing is planned in the last quarter of 2016 and therefore it is too early to report the results. Once results from all testing are available more can be reported on the consistency of the uncertainty claims of the multiphase flow meter test and calibration facilities, together with the uncertainty of the transfer standard itself.

If consistency is established, this will be the start of a reference network for testing multiphase flow meters. By using a harmonized method for uncertainty calculation it is expected that the uncertainty claims from the different facilities will be consistent. Any differences in test results between facilities should be explainable by referring to the harmonized uncertainty budgets, and the reproducibility of the flow meter under test.

A follow-up project is being planned for the years 2017 – 2020. If this new project goes ahead, it is envisaged to extend the number of participating laboratories and involve more multiphase metering technologies to achieve a more comprehensive outcome. It will hopefully standardise the test protocol and the uncertainty budget for multiphase flow facilities as well. Both the Uncertainty Guide and the Test Protocol developed in this project will feed into the next ones.

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References

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[1] Horsøy is the test and research facility of OneSubsea near Bergen, Norway.