Field Use of a Composite Phase Fraction Meter

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Abstract

M-Flow Technologies have developed a phase fraction meter for oil and gas applications based on a unique carbon fibre reinforced thermoplastic pipe technology. The phase fractions measured are the volumetric fractions of oil, water and gas in 3 phase fluids and the volumetric fraction of water in a 2 phase mixture of water in oil.

Composite construction allows the sensor elements to lie outside of the flow path, without obstruction or contact with the flow line fluids, and the sensing is capable of measuring the full flow line diameter. This gives significant advantages in terms of meter reliability and performance compared with conventional meter designs. The sensor device is monolithic, suitable for high line pressures and has good sour service performance as standard.

The technology is field ready and has been deployed in several 2 phase oil and gas applications. A number of three phase deployments are imminent.

Two phase field applications include the installation of a two phase low water cut meter on a custody transfer skid at the inlet to a major refinery. Water cut data from the meter was compared with data obtained from an API 8.2 compliant auto sampler on the skid. Data will be presented from between 50 and 100 off loads over a 6 month period. A wide variety of oils were tested with API gravities between 17 and 35. Comparison data will be given between the two water cut measurement methods and the use of the meter to measure dynamic events during off loads in real time will be illustrated.

Data will also be presented from a 3 phase well head meter to illustrate the applicability of the meter to a wide range of oil field measurement scenarios.

Introduction

M-Flow Technologies are developing a novel range of phase fraction meters for oil and gas applications. The underlying technology for these meters is a carbon fibre reinforced thermoplastic pipe forming technique used to manufacture deep water risers for oil and gas applications[1]. The pipe consists of a PEEK matrix with long continuous lengths of carbon fibre embedded into it to enhance the mechanical strength. It is manufactured by a laser welding process and its main attributes are a very high strength to weight ratio and a high chemical resistance to acid gases which makes it ideal for high pressure sour service applications in the oil and gas industry.

M-Flow is using the same manufacturing technology to develop a range of fraction meters for oil and gas applications. As well as the strength and chemical resistance advantages discussed earlier the composite materials have low absorption of many types of energy used for sensing. This means that the sensing elements of the meter can be either embedded in the pipe wall or located external to the pipe. There are a number of advantages to this approach:

- The sensing elements of the meter are not in contact with the fluid and are therefore not subject to erosion or corrosion. In meters with intrusive elements these processes can cause measurement drift and a degradation of meter performance which can significantly increase the need for meter servicing and re-calibration.

- Sensing elements within a pipe can alter flow regimes and also lead to plugging and other events that may require removal of the meter from the piping system to rectify. M-Flow meters have a solid state spool piece with no active components and are designed for minimal intervention of this type.

- Intrusive meters often have significant pressure drops across the meter. There is no pressure drop across an M-Flow meter.

Apart from the non-intrusive nature of the sensing technology, the low absorption of the composite material enables sensing systems to be designed that take whole pipe measurements with little bias to different regions within the pipe. This makes the measurements robust to flow regime changes in the pipe and removes the need for complicated flow models in the data analysis process of the meter.

Metering Principles

The M-Flow phase fraction meters are based on two technologies:

Figure 1: Field Installed Microwave Water Cut Meter

Two phase oil continuous water cut meters are based on microwave resonator technology. A resonant structure is built into the composite wall of the pipe to create a resonant cavity that includes the fluid within the pipe. The resonator has a number of resonant modes and the resonant frequencies of these modes are a function of the electrical permittivity of the fluid within the pipe. In two phase mixtures of water in oil the electrical permittivity of the fluid is primarily sensitive to the amount of water in the fluid and the meter response can be calibrated against the water cut of the fluid.

Figure 2: M-Flow Multiphase Fraction Meter Under Test at NEL Flow Loop

In the presence of gas an additional parameter is required to measure all three phase fractions. For M-Flow meters the parameter used is the line density of the pipe contents. The line density of the contents of a pipe containing a 3 phase mixture is primarily sensitive to the gas fraction within the pipe. In combination with data from the microwave resonator, which is primarily sensitive to the water fraction in the pipe, the line density data can be used to extract the water cut and gas void fractions in a 3 phase mixture within the pipe. These two parameters can then be used to generate the volume fractions of oil, water and gas.

In M-Flow meters the line density usually comes from either a gamma densitometer measurement or density data from a Coriolis meter. The former method is more developed and has been tested over a large range of void fractions and flow regimes. The Coriolis method is more focussed on low GVF's (up to 20%) and bubble type flow regimes.

The gamma based method is different from other implementations of gamma meters in multiphase meters in that no window in the pipe is required nor is the measurement is not limited to a chordal measurement. Composite material has a relatively low gamma absorption compared to steel due to the light molecular weights of the component materials and the absorption of a composite pipe is typically less than 10% of that expected from a steel pipe of an equivalent pressure rating. Thus the gamma source can be "shone" directly through the pipe wall without the requirement for a window. This also enables gamma configurations different from the standard chordal configuration which makes measurements using either the whole pipe or a significant section of it feasible. This in turn significantly reduces the effect of flow regime on this measurement and reduces the need for flow models.

2 Phase Water Cut Meter

A 1” meter has been tested on the multiphase flow loop at NEL in a conventional fast loop configuration with a prototype commercial jet mixer in the main line. The meter was laboratory calibrated prior to installation and the only adjustment made to this calibration was to baseline the meter to the oil in the NEL loop by taking a manual sample from the fast loop and performing Karl Fischer analysis on it.

The system was run over a variety of main line and fast loop flow rate conditions. The main line flow rate varied between 32 and 128 m^3 per hour and the fast loop flow rate varied between 4 and 16 m^3 per hour. The water cut varied between 2% and 32%. The water cut data from the meter was compared with water cut data from manual samples taken from the fast loop and analysed in the NEL laboratory.

The standard deviation of the differences between the NEL laboratory reference data and the water cut meter data was 0.12% which is equivalent to a 95% confidence limit of +/- 0.24% and the bias between the two data sets was 0.09%.

A zone 1 hazardous area certified version of this meter was then installed on a measurement skid at the inlet to a major North American refinery. This was installed in series with an API 8.2 compliant auto sampler and the skid also provided density and temperature compensation data to the meter. The meter provided instantaneous water cut data to the skid which was then flow weight averaged by the skid flow computer according to the equation:

$$WC_{FW} = (1/V_{Tot}) \times \sum_i \Delta V_i \times WC_i \qquad (1)$$

Where WC_{FW} is the flow weight averaged water cut for the offload, V_{TOT} is the total volume of liquid that has been off loaded, ΔV_i is the change in the volume between samples i and i-1 and WC_i is the instantaneous water cut measurement at sample point i.

The flow weight averaged water cut was then compared with off load water cut obtained from the auto sampler. The grab frequency of the auto sampler was flow weighted in accordance with API 8.2 and the water cut was obtained from laboratory analysis of the off load composite sample in accordance with ASTM D4928 (Karl Fischer).

The auto sampler data was used as a reference water cut to evaluate the accuracy of the water cut meter.

The meter was supplied to site with a laboratory calibration for water cut, temperature and density. It was initially baselined by using the first month’s data to adjust the water cut & density calibrations. The meter was then left to run for a further 7 months in this state. In this period roughly 50 off loads were undertaken with flow-weighted water cuts between 0 and 1%, instantaneous water cuts to 25%, and an oil API range from 17 to 35.

Field Results

The statistics of the differences between the flow weight averaged water cut values obtained from the auto sampler and the water cut meter are shown in Table 1 below:

uncertainty* in water cut meter data vs auto-sampler data	+/- 0.14%
average difference between water cut meter data and auto sampler data	+0.04%
largest discrepancy between water cut meter and auto sampler data	+0.18%

Table 1: summary of comparative statistics between flow-weighted water cut meter and auto sampler data

*uncertainty quoted here is to 95% confidence, i.e. +/- two standard deviations in the difference data.

Discussion

The flow weight averaged meter data showed a very good correlation with data obtained from the auto-sampler over the period of the trial. In addition the field data obtained showed similar uncertainties to that obtained in the flow loop trials which indicates that the laboratory performance can be maintained under field conditions

The meter also proved to be very stable showing very little drift across the 7 month testing period. As can be seen in figure 3 below the difference between the two flow weight averaged water cut measurements showed a drift of less than 0.1% water cut over the trial period. This drift was a combination of drift in both the water cut meter and the inline densitometer measurements. Further investigation attributed approximately 50% of the drift to the densitometer so the actual meter drift was equivalent to less than 0.05% water cut over the whole trial. This drift is included in the overall uncertainty data quoted in Table 1. Apart from the initial baselining of the water cut meter in the first month discussed earlier no other adjustment was made to the meter during this period.

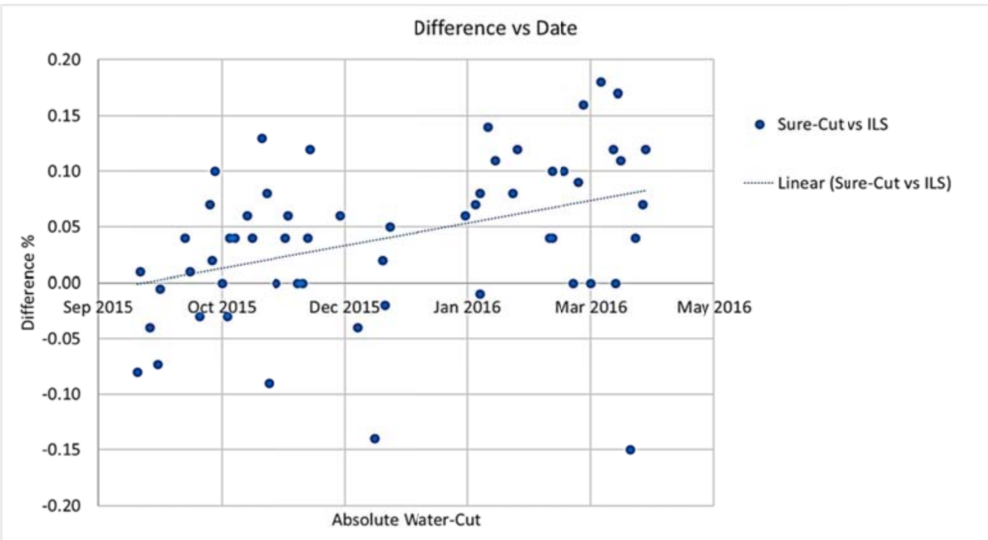

Figure 3: Drift in the differences between the flow weight averaged water cut meter and auto-sampler (ILS) data over the period of the trial.

As well as the headline water cut data the instantaneous real time data from meter was shown to be useful in monitoring a number of field conditions such as high water cut slugs arriving in the line, the presence of gas and changes in the mix state of the fluid.

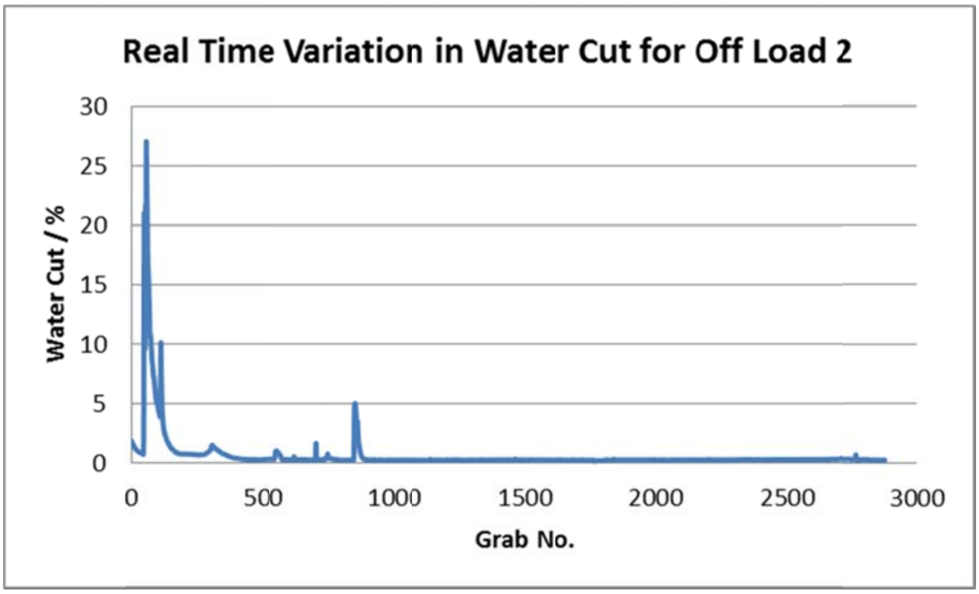

Figure 4: Illustration of high water cut slug in data from a single off load.

Multiphase Fraction Meter

Three phase meters suitable for 3 inch & 4 inch pipes have been developed and tested extensively on flow rigs. Field certified versions of these meters are now available and several of these will be deployed imminently.

The meter testing carried out has shown that the measurement technique using whole pipe measurement produced coherent results over the full GVF range from 0-99%, showing insensitivity to a broad range of flow regimes. As an illustration of this versatility, data from two flow loop trials will be discussed wher the two tests were carried out in close succession with the same meter hardware in slightly different software configurations. The meter in question is an ATEX Zone 1 certified multiphase fraction meter which uses a combination of microwave and gamma densitometer technologies. For both trials the meter was prepared as for a field installation in that a PVT model was generated from composition data provided by the flow loops and the only calibration steps taken at the rig were simple “baselining” procedures that are practical under field conditions for the application conditions.

Testing under Low GVF Conditions

The first test was performed as part of a JTP at the DNV Groningen flow loop in April of this year investigating meter performance under low GVF bubbly flow conditions. The water cut range the meter was used under was 0 to 30% and the GVF range for the test was 0 to 20%.

Testing was performed over a range of liquid flow rates. The meter was supplied with a laboratory calibration prior to installation and baseline measurements were made with an empty pipe and the pipe full of oil of a known water content.

Results

A statistical summary of the results of the test is given in Table 2 below and the results to 20% water cut are illustrated in figure 5

*uncertainty in M-Flow multiphase meter data versus DNV reference data to 20% WC	+/- 1%
average difference between M-Flow multiphase meter data versus DNV reference data to 20% WC	0.5%
*uncertainty in M-Flow multiphase data versus DNV reference data to 25% WC	+/- 2%
average difference between M-Flow multiphase meter data versus DNV reference data to 25% WC	0.5%

Table 2: summary of comparative statistics between M-Flow multiphase data and DNV reference data

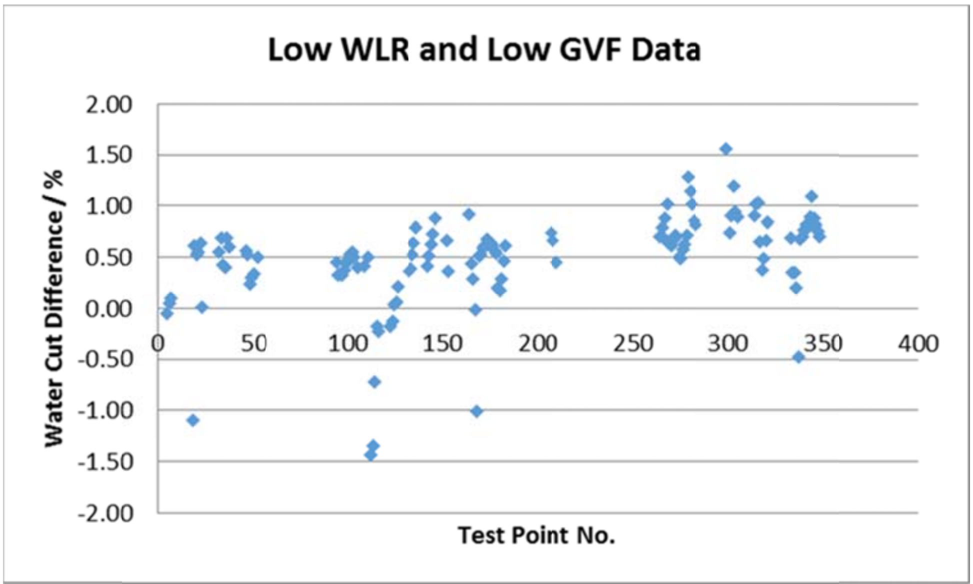

Figure 5: Difference between M-Flow Multiphase Fraction meter water cut data and DNV reference data for points to 20% water cut and 20% GVF.

Discussion

The water cut data from the M-Flow multiphase fraction meter showed good performance across its measurable water cut range during this test. Data to 20% water cut showed a very good correlation with the reference data from the flow rig and this degrade slightly at 25% water cut. The data taken at 30% water cut indicated that the flow loop inverted (i.e. went from oil continuous to water continuous) somewhere between 25% and 30% water cut during this testing which may explain some of this degradation in performance as the mix state of the fluid may not be stable under these conditions.

Testing Under High GVF (Wet Gas) Conditions

In May this year the same meter was tested with a different PVT model and minimal changes to the configuration on the wet gas loop at the NEL facility in East Kilbride. The water cut range tested was 0 to 25% and the GVF range was 90 to 95%, 97% and 99%. The meter was tested over a range of flow conditions with gas Froude numbers varying between 1 and 5.5. The only on-site calibration performed on the meter was an empty pipe calibration at the operating pressure. The other main change for this test was that the meter was installed horizontally. The default orientation for the meters is vertical but a horizontal orientation is often more appropriate for wet gas testing and so it was decided to investigate the performance in this orientation as part of this test.

Results

Data for the lower Froude numbers (less than 2.5) showed evidence of separation and stratification in the liquid flow and gave either large differences between the meter data and the NEL rig reference data or did not give a valid reading. This was almost certainly due to the horizontal orientation of the meter. Likewise data taken at 99% GVF also gave large difference between the meter data and the rig reference data. This was probably due to the small amount of liquid in the pipe. A comparison of the void fraction measured by the gamma section of the meter and the GVF data obtained from the rig showed that the liquid gas slip was close to 1 across most of the GVF range tested. A statistical summary of the data from the remaining test envelope (GVF range 90 to 95% and 97% and water cut range 0 to 25%, gas Froude number 2.5 to 5.5) is given in Table 3 below:

*uncertainty in M-Flow multiphase data vs rig reference data to 95% confidence (GVF 90 to 95%,WC 0 to 25% gas Froude number 2.5 to 5.5)	+/- 5%
average difference in M-Flow multiphase data vs rig reference data to 95% confidence (GVF 90 to 95%,WC 0 to 25% gas Froude number 2.5 to 5.5)	3%
*uncertainty in M-Flow multiphase data vs rig reference data to 95% confidence (GVF 90 to 97%,WC 0 to 25% gas Froude number 2.5 to 5.5)	+/- 10%
average difference in M-Flow multiphase data vs rig reference data to 95% confidence (GVF 90 to 97%,WC 0 to 25% gas Froude number 2.5 to 5.5)	5%

Table 3: summary of comparative statistics between M-Flow multiphase data and NEL Reference Data

Discussion

In the operating envelope where the meter gave good data (GVF 90 to 95%, water cut 0 to 25% and gas Froude number 2.5 to 5.5) the meter performed well. It should be pointed out that, to make the test as close to a field performance test as was practicable, the meter was installed & commissioned on the rig in a manner similar to a field commissioning in that a PVT model was generated from composition data and the only calibration measurement performed was an empty pipe gas calibration. All other calibration of the meter had been performed previously in the M-Flow factory in Abingdon.

The degradation in performance of the meter outside of the operating envelope discussed above can be explained as follows:

At the lower Froude numbers the degradation in meter performance was almost certainly due to stratification of the liquid part of the flow due to the horizontal orientation of the meter. Previous wet gas studies done with meters oriented vertically indicate that this situation would be considerable improved by installing the meter vertically.

At 99% GVF and a gas liquid slip of close to 1 this work indicates that there is not sufficient liquid in the flow to measure water cut to any accuracy and under these conditions it may be better to consider measuring water volume fraction in the pipe instead.

As discussed above these meters have also been tested in the GVF range 20-90% and the uncertainty results are continuous and coherent with the two tests set out above.

Conclusions

Data has been reported for two types of novel phase fraction meters:

Flow loop and field data are reported for a two phase water cut meter that demonstrates good performance across a range of crude oil in an extended trial under field conditions at a working refinery. It is also apparent that the flow loop performance was maintained under field conditions.

Flow loop data was presented for a field ready multiphase fraction meter from two loop trials under very different flow regime conditions. The meter was prepared in as close a manner as possible to mimic a field installation and the only calibrations procedures taken at the flow rigs were consistent with the type of procedure that is feasible in the field. In both cases the meter demonstrated good performance in terms of the water cut measurement compared to the flow loop reference data. The same meter hardware was used for both tests with minimal software changes to the meter configuration between the two tests. This demonstrates the versatility of the meter design and the relative insensitivity of the meter performance to changes in flow regime.

A number of 3 phase meters of similar design are currently in the process of being installed in the field.

References

1. For further information see https://www.magmaglobal.com/