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STATUS OF THE FRAMO SUBSEA MULTIPHASE FLOW METER

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ABSTRACT

Multiphase Flow Meters have the last years become a fully accepted tool for well testing, well management and allocation metering. Significant experience has been gained in field installations and tests in topside applications. Another interesting area for use of multiphase flow meters is subsea installations where significant cost savings can be achieved if test lines and test separators can be avoided.

This paper summarizes the latest developments with the FRAMO Subsea Multiphase Flow Meter. It describes the measuring principle, the subsea packaging together with the intervention options which are based on diverless intervention. Procedures for remote calibration of the meter have also been developed and these are also explained herein.

Framo Engineering AS has been awarded commercial contracts for Subsea Flow Meters which will undergo full verification programs this Winter. The program includes both hydraulic verification in a multiphase flow loop and subsea intervention verifications at FRAMO's test facilities outside Bergen.

1.0 Introduction

The FRAMO Multiphase Flow Meter has already for several years been marketed and sold to various commercial offshore topside applications. The meter has been received by the market as a robust, simple and versatile principle, features which are of great importance to the environments where it is to be used.

Through several test installations, the FRAMO meter has proven its capability to consistently measure multiphase flow fully independent of upstream flow regimes, Gas Volume Fractions and Water Liquid Ratios. The Framo multiphase flow meter is also characterized by the extended use of standard off the shelf instrumentation, standard commercial programming tools and standard computers.

Through the commercial applications, in-house and third party testing the accuracy have been consistently improved primarily through improved gamma technology and the application of it. The FRAMO meter is today installed in several commercial installations where the meter will be used for allocation metering in addition to well testing (Martin, Woiceshyn, Torkildsen, 1992 /2/ and Olsen, Hansen 1994 /6/).

2.0 Functional Description

The FRAMO Multiphase Flow Meter (MPFM) is designed for measuring the individual flow rates of oil, water and gas as well as the pressure and temperature of a well stream.

An integrated Flow Mixer enables accurate and repeatable measurements independent of the upstream flow regime. It provides homogeneous flow conditions to the downstream metering section such that a Dual Energy Gamma Fraction Meter and a Venturi Momentum Meter can be applied.

The Dual Energy Gamma Fraction Meter features the ability to measure all combinations of oil, water and gas fractions, including 0 - 100% water in liquid ratio independent of the fluid being oil continuous or water continuous (Rafa, Tomoda, Ridley 1989 /1/).

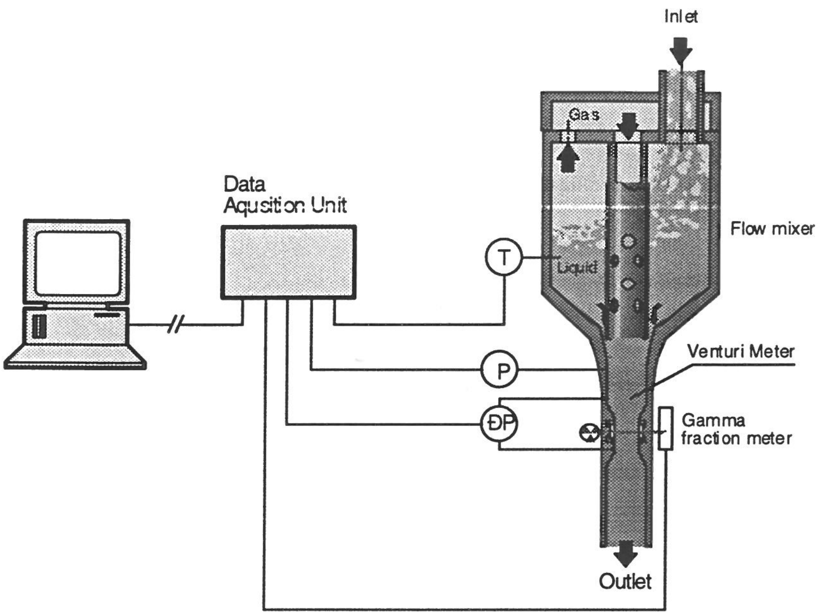


Figure 1. Principle of operation.

The measured differential pressure across the venturi momentum meter is combined with the fraction measurements to obtain the individual flow rates of oil, water and gas.

Turndown in total flow rate is governed by the maximum acceptable pressure loss through the MPFM and the minimum venturi differential pressure which can be measured with the adequate accuracy. Figure 2 below shows operating envelopes for three venturi diameters, 50 mm, 75 mm and 95 mm. In this diagram it is assumed that the maximum pressure drop that can be accepted across the meter is 2 bar.

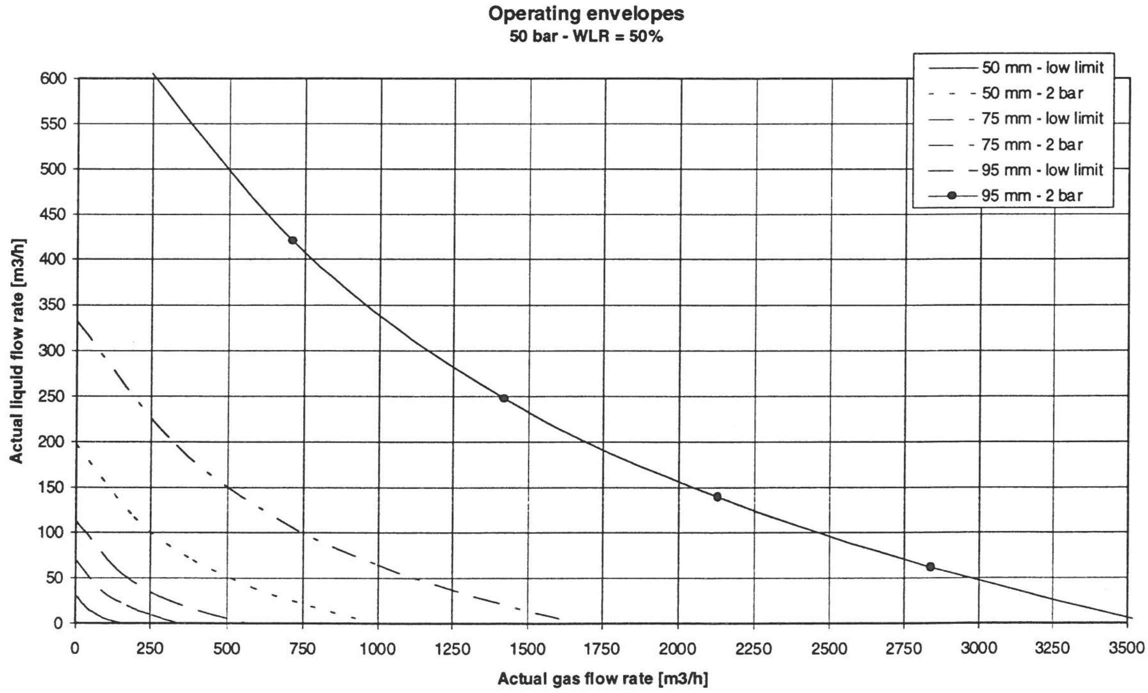


Figure 2. Operating envelopes for 50 mm, 75 mm and 95 mm at 50 bar, 70°C and 50% WLR.

The Gamma Detector System, Differential Pressure transmitter, Pressure transmitter and Temperature transmitters, which are all located in the measuring section of the MPFM, are wired to a Data Acquisition Unit which transmits raw data to a PC based computer which performs all calculations.

2.1 Flow Mixer

The purpose of the in-line mixer is to provide stable homogeneous multiphase flow conditions into the measuring section, independent on upstream conditions.

The Framo Flow Mixer (patented) is a static device and comprises a cylindrical compartment with a gas/liquid diverter, an injection pipe and a gas/liquid ejector.

When arriving the flow mixer, the most dense part of the fluid (i.e. the liquid phase) is continuously drained to the bottom of the compartment and through the ejector. The gas phase is diverted to the top section of the compartment and via the injection pipe to the ejector. In the ejector nozzle, a turbulent shear layer is generated. The operating principle may be compared to the operation of a carburettor. Minimum associated pressure loss is achieved by utilising this turbulent shear layer mixing process.

In order to simplify the measuring requirement, the primary objectives are to achieve a homogeneous flow in the venturi cross section, and to eliminate phase slip through the measuring section. Secondly, the volume of the mixer is large enough to accommodate for sufficient fluid hold-up in order to smoothen out the transients in multiphase composition during intermittent and slug flow conditions. Thus axial mixing of the multiphase flow is achieved.

2.2 Venturi Momentum Meter

The fluid velocity is measured with a Venturi Meter arrangement in combination with the Gamma Fraction Meter. This is possible since the Venturi Meter is located immediately downstream of the Flow Mixer. Here, the multiphase mixture can be treated as a single-phase fluid with equivalent mixture properties, and a standard single-phase venturi relations can be applied.

The venturi differential pressure is measured by a differential pressure transmitter. The differential pressure transmitter and pressure transmitter are equipped with remote seal sensors of pancake type, bolted to the sides of the Venturi section.

2.3 Dual Energy Gamma Fraction Meter

The Dual Energy Gamma Fraction Meter provides the fractions of oil, water and gas in the flow, which represents volume fractions since the gamma meter is located immediately downstream of the flow mixer.

Calculations of oil, water and gas fractions are based on the attenuation of two different gamma energy levels of a Barium 133 isotope.

The Gamma Detector System comprises the following main elements :

- A NaI(Tl) scintillation detector of rugged design complete with photo multiplier tube which detects the gamma radiation not absorbed by the multiphase fluid.
- Cable Penetrators complete with special cables.
- A High Tension generator for operation of the photo multiplier tube.

- A preamplifier for signal conditioning prior to spectroscopy analyzing
- A Multi Channel Analyzer

The high tension generator, the preamplifier and the multi channel analyzer are all located in a data acquisition unit, separated from the sensors (ref. figure 1)

The Barium 133 isotope is encapsulated in a separate housing diametrically opposite to the detector housing at the venturi throat. The low intensity of the source in combination with the multiple levels of protection has for the FRAMO meter proven to be 100% safe against any radiation to the ambient.

3.0 Subsea packaging

The first prototype of a FRAMO Multiphase Flow Meter ever manufactured was a subsea prototype meter (Torkildsen, Olsen 1992 /4/). Although most of the metering experience with the FRAMO meter has been achieved from topside packaging, the principle of the meter is identical for the subsea and topside design.

The initial subsea design of the FRAMO meter has continuously been improved (Olsen, Torkildsen 1992 /3/ and Olsen 1993 /5/), and the meter which now has been commercially sold to a customer in Western Australia, offers several advantages compared to the first generation design:

- Full metal to metal seal philosophy applied
- Insert style gives reduced subsea handling weights
- Diverless running and retrieval with or without the use of guidewires.
- Subsea liquid sampling facilities included
- Up to 10.000 psi design available

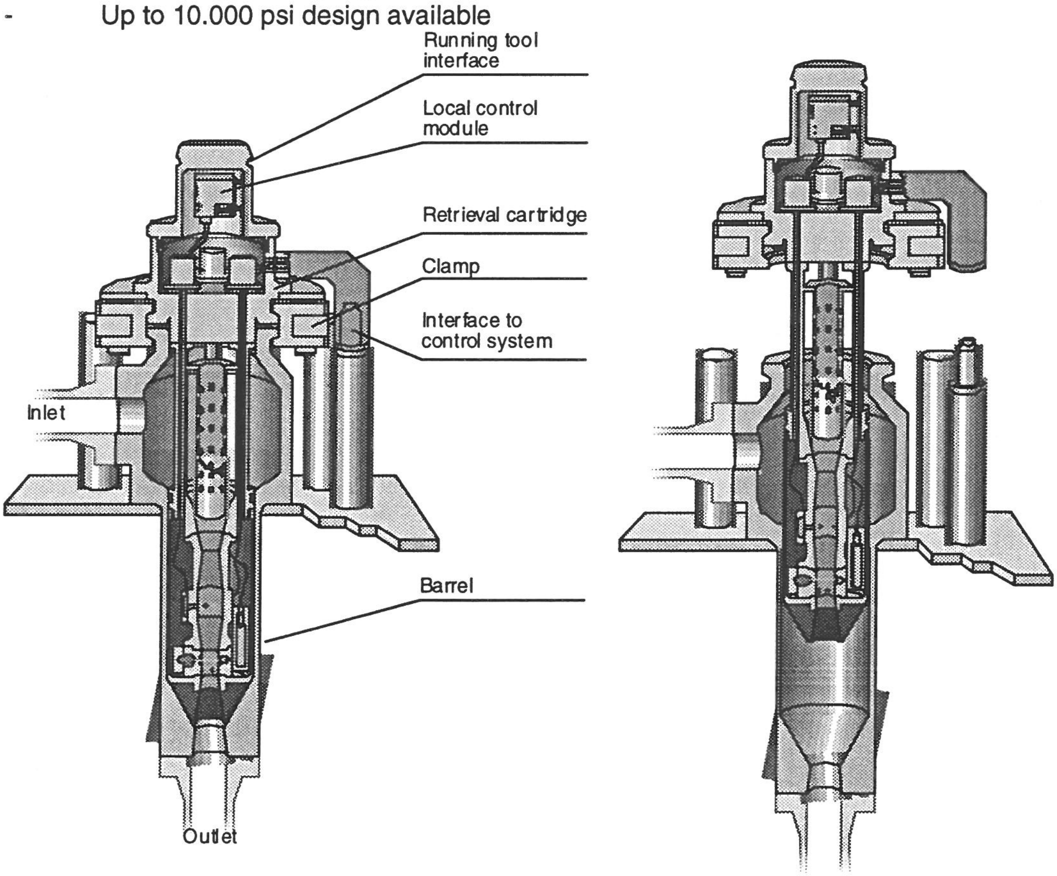


Figure 3. FRAMO Subsea Multiphase Flow Meter

Figure 3 shows a cross section of the FRAMO Subsea MPFM. The meter when being installed is shown at left and during installation or retrieval at the right.

In the following, the main components of the FRAMO subsea multiphase meter are described:

3.1 Receiver Barrel

The subsea MPFM design utilizes a barrel styled subsea configuration with an insert cartridge which carries all active MPFM elements. The cartridge is locked into a receiver barrel.

The receiver barrel is permanently installed on the subsea structure and includes no active elements. There are no requirements for straight pipe lengths upstream or downstream the FRAMO Multiphase Flow Meter.

The receiver barrel serves the function as inlet and outlet housing and as a guide and support during installation of the MPFM insert cartridge. In addition, it forms the outer housing of the flow mixer. Standard (surface mounted bolted) flange connections at the receiver barrel will be used for connection of the flow meter inlet and outlet to the subsea tree or manifold piping. It is designed to take the actual design pressure.

The technology forming the basis of the subsea flow meter design is to a large extent developed for other FRAMO products. All vital elements are maintained in a vertical stack-up configuration forming a retrievable cartridge. The cartridge is, when installed, located inside a receiver barrel with appropriate lock-down and sealing functions.

The flow meter barrel includes the lower tapered lip profile connection hub for pulling the insert Cartridge together with the barrel thus making a rigid connection , i.e. radial clamp movement is converted to axial hub face loading. To seal the two hub halves, a lined seal groove is provided in each hub half to accept a metal seal ring.

3.2 Insert Cartridge

The insert cartridge incorporates the following main elements :

- Cartridge body with metal-to-metal seals and mechanical clamp connector
- Flow Mixer internals
- Venturi Section
- Gamma Isotope / Detector, Pressure and Temperature Sensors
- Flow Meter Data Acquisition Unit
- Connectors for power / signal and flushing media

3.3 Data Acquisition Unit

All instruments at the MPFM are wired to the MPFM Data Acquisition Unit at the upper section of the MPFM insert cartridge for signal conditioning and transfer of raw data to the MPFM Flow Computer located topside.

The MPFM Data Acquisition Unit comprises the following main elements:

- Power Input Switching Unit
- Power Supply and Solenoid Driver Module, 24 VDC
- CPU Module for signal conditioning and data communication as Modbus Slave
- MCA Module (Multi Channel Analyzer)
- Pre-amplifier Module for signal conditioning prior to spectroscopy analyzing

- Analog Input Module, 4-20mA
- High Voltage Module for operation of the photo multiplier tube.
- Back-up Communication Module

The application program running at the processor can if required be changed / downloaded from a Surface Control Unit.

Data to surface is via a RS-422, Modbus RTU link which during metering will transfer required data once every 60 second.

3.4 Control system interface

Electrically the MPFM can be interfaced directly to a Control Pod in a Subsea Production Control System with separate wires for power supply and a serial link for data transmission. Operationally, this interface with the Subsea Control System will require a minimum of interference with other Subsea Control System functions. Alternatively, the flow meter can receive power and transfer data through a dedicated single pair cable in a control umbilical.

A Flow meter Electronics Module, which is located on the multiphase flow meter unit, performs acquisition of data from the Gamma Detector, Pressure Transmitters and the Temperature Transmitter. A topside Flow meter Control Unit calculates, presents and stores all measurements and provides for transfer of desired data to the overall Platform Control System. Subsea processing is limited to acquisition of data and reporting the "health" status.

The Flow meter Electronics Module contains the following main elements :

* The Electronic Rack for acquisition of sensor data and transfer of data to the Surface MPFM Control Unit.
* Sensor Electronics for Pressure and Temperature Measurements.
* Penetrators for external connections

The Flow meter Electronics Module is located in a Nitrogen environment at a pressure of 1 atmosphere. External connections for electrical power supply to the flow meter and data transfer to surface is via an electrical penetration at the side of the Electronics Module wall. Penetrators for flow meter sensors are located at the bottom of the Flow meter Electronics Module.

Supply voltage and communication can to a large extent be adjusted to meet any specific requirements. Typical supply voltage will be 24 VDC. Estimated total power consumption is less than 40 W.

A total of 7 wires are required for operation of the MPFM. This includes both power supply and digital communication and they are all gathered in a single subsea electrical connector. The connector is mated either by using a common stab type connector at the insert/barrel interface (ref figure 3) or by using ROV.

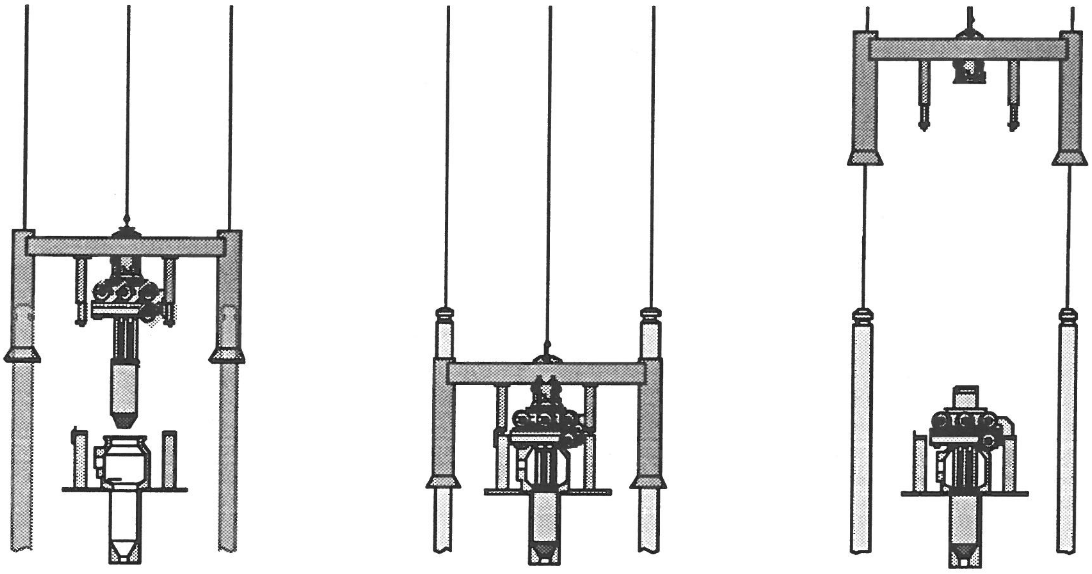
3.5 Design specifications

The FRAMO Subsea Multiphase Flow Meter is designed for the following conditions:

- Pressure - up to 10.000 psi
- Gas Volume Fraction - 0 to 100%
- Watercut - 0 to 100%
- Independent of flow regime
- Design life time - 20 years
- Intervention - with guidwires or ROV assisted

4.0 Insert Cartridge Retrieval and Re-installation

Normally, in new developments, the flow meter cartridge will be pre-installed inside the barrel and deployed as an assembly on the manifold structure. The Flow meter insert cartridge can then be retrieved and re-installed either guidewireless or guidewire supported. In both cases, a purpose built Running Tool will be utilized. If guidewires are used, guide posts will be run and guidewires established prior to deploying the Running Tool. Otherwise, the insert cartridge can be retrieved and installed simply by hanging the running tool in a wire, and use a ROV to guide the tool into position prior to retrieval or guide the insert cartridge into the barrel during installation.



Installation of flow meter unit with running tool

Flow meter unit in position and locked to stationary barrel. Electric, signal and hydraulic connection established

Retrieval of running tool. Flow meter ready to operate.

Figure 4. Installation procedure - guidewire assisted.

The following outline procedure applies for re-installation of the insert cartridge after maintenance retrieval. The intervention is in this example based on use of guidewires:

- The Insert Cartridge is picked up from a transportation skid by the running tool and positioned in the moonpool.
- All seals are checked / replaced
- The flow meter bleed valve is opened and stab connectors are checked
- The flow meter is lowered to the subsea structure.
- Initial guidance is provided by guide posts at the subsea manifold structure
- The Insert Cartridge is lowered into the barrel and the impact load is reduced by the cushion cylinders during the last phase prior to the cartridge seal lands out on its mating face at the top of the barrel.
- The ROV will then operate the clamp for locking and securing of the Flowmeter Insert Cartridge.
- The primary seal is now tested via the Running Tool / Subsea Power Unit.
- Finally the flow meter bleed valve is closed and the Running Tool is released from the Insert Cartridge running neck and retrieved to surface.
- The flow meter manifold isolation valves are now opened and metering can start.

4.1 Running tool

The running tool will be fitted with two cushion cylinders landing on either side of the flow meter receiver barrel It is proposed that the cushions are connected back to the surface by hose, or to the subsea hydraulic power pack, if the running tool is hydraulically operated. This allows the cushions to be used to jack the flow meter insert from its connected position at commencement of retrieval. This overcomes any strain energy effects from tensioned lift cables etc.

The running tool is mechanically or hydraulically operated. ROV hot lines can be connected up for cushion cylinder jack off, then removed for running tool retrieval.

Because of the length of the flow meter insert, initial interfacing of the insert to the receiver barrel will be provided from course guide funnel to guide post alignment, assuming that guide funnels will be used. Otherwise, the ROV would position the insert into the throat of the receiver barrel.

The insert nose at this point will have generous clearance with the receiver barrel throat in consequence there should be no contact. The nose will still have a substantial resilient sheath to ensure that no possible damage could occur. Once the insert has been located in the barrel it will be lowered until it lands out on the metal seal ring which is retained in the upper bonnet flange. To ensure that the receiver barrel metal sealing face is not damaged, its edge is set back to eliminate contact with the moving insert surface.

There are two alternatives of connecting the electrical signal and flushing lines. These can be made up using an ROV to interface the couplers on the side of the flow meter insert from flying controls leads, or the connectors can be arranged at a stab plate for automatic vertical stab connection as the insert is landed.

The flow meter insert is clamped and sealed to the barrel using an ROV operated clamp and is attached to the insert bonnet for surface retrieval.

The clamp is of standard oil field design, though with the addition of an upper guide plate to symmetrically open the clamp halves ensuring there is no interference foul at point of retrieval.

Once the clamp connector is made up, external pressure testing of the metal seal may be carried out using an ROV hot stab. A further docking cone is therefore provided on the upper clamp mounting plate.

5.0 Calibration

A typical cost effective installation scenario is the case where subsea multiphase flow meters are installed in a satellite field which is tied back to shore or to an existing process platform. The subsea satellite may have either one meter per well or one meter in a subsea test manifold configuration to accommodate individual well measurements. Hence the expensive test line can be avoided. This scenario provides continuous and accurate measurements without the need to shut-in wells during testing.

Since the cost of retrieving and re-installing a subsea multiphase flow meter in most cases will be more expensive than the meter itself, remote calibration has been raised as one of the most important issues that needs a practical solution.

Calibration of the subsea multiphase flow meter might be required in order to identify and compensate for off-sets or drift in sensor readings and changes in fluid component properties over time.

A complete calibration of the FRAMO Subsea Multiphase Flow meter is performed by separate calibration of the four individual sensors (gamma detector, differential pressure transmitter, pressure and temperature transmitters) based on simple static measurements being an important feature offered by the system.

5.1 Gamma detector

The Gamma Detector is completely calibrated by performing a single-point static measurement on any known fluid.

By simply isolating the subsea multiphase flow meter and letting the fluids being trapped inside the meter settle, static conditions are obtained, and the single-point calibration measurement can be performed. Even without being correctly calibrated the meter will be able to identify whether the fluid is oil, water or gas. This method has been verified from the topside installed flow meters.

5.2 Differential pressure transmitter

The differential pressure transmitter is calibrated by performing a single-point static measurement following the same procedure as for the gamma detector. Since a closed wet-leg arrangement with remote seals sensors is used, the differential pressure at static conditions should equal the hydrostatic height between the two sensor elements.

The pressure ports in the venturi section are arranged with a facility that allows flushing. The feature is built in to reduce the risk for clogging of pressure ports, and procedures for such flushing will be implemented in purchaser's operational routines. Flushing media will be high pressure fluid supplied through a dedicated hydraulic line which can also be used to fill the measuring section with the same fluid for calibration purpose. The high pressure flushing media can either be hydraulic control fluid, chemical injection fluid, methanol or similar.

5.3 Pressure and temperature transmitters

For typical subsea applications, the operating conditions are such that small deviations in temperature and pressure reading have little impact. A comparison of the pressure and temperature readings with the readings taken at a X-mas tree or a subsea manifold will in most cases be accurate enough.

The pressure transmitter can alternatively be calibrated by the pressure in the flushing fluid when the meter is isolated and pressurized through the flushing line.

5.4 Changes in fluid component properties

Changes in fluid component properties as a result of changing pressure and temperature are automatically accounted for in the flow meter software.

However at conditions when a significant amount of water is produced, large variations in the water salinity will influence the multiphase flow meter readings.

The FRAMO Multiphase Flow meter has been provided with facilities to take a liquid sample to a sampling bottle subsea if required. The liquid is taken out from the bottom of the flow mixer compartment, which always will be dominated by liquids. A sampling bottle can be coupled to an ROV panel mounted to the insert cartridge. The bottle is filled by opening an ROV operated valve. When the valve is closed, the bottle can be released and brought to the surface by an ROV, where the salinity of the water can be obtained with standard laboratory equipment.

An alternative, direct on-line method for determining the water salinity on-line has recently been developed. The method is based on an analysis of the entire gamma spectrum, and will reduce or

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eliminate the need for sampling. The method will be included as standard in future flow meter software both for topside and subsea applications.

6.0 Conclusion

As part of a commercial delivery, two FRAMO Subsea Multiphase Flow Meters are presently being built and tested. The following important features have been built into the design:

- Measures independently of multiphase flow regimes due to use of the FRAMO flow mixer.
- Measures in any water-liquid ratio and any gas volume fraction.
- Design up to 10.000 psi available.
- Remote calibration methods applied.
- Diverless installation end retrieval procedures.

Subsea multiphase flow meters are today commercially available and will significantly contribute more to cost effective subsea developments in the future.

7.0 Acknowledgments

The authors wish to thank the sponsors that have been involved in the development of the FRAMO Multiphase Flow Meter; Statoil, Norsk Hydro, British Petroleum, Conoco, Elf, Shell and Saga.

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Gas ± 5 %
Liquid ± 10%
Water ± 5%