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SUBSEA MULTIPHASE FLOW METERING OFFSHORE BRAZIL

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Abstract: Monitoring of the multiphase flow at the wellhead eliminates the need for dedicated testlines from remote wellhead completions, and the need for a dedicated test separator at the processing facility. A multiphase flowmeter at the wellhead will also allow improved well control, and hence better reservoir control. For remote or deep subsea wellhead completions the savings and operational benefits offered by this new technology are quite extensive.

In summer of 1997, Petrobras installed a Fluenta multiphase meter in a subsea production manifold, at 450 meter water depth at the Albacora field offshore Brazil. 20 months later, at the end of January 1999, the meter was powered up, signal communication was established, and calibrations were checked and verified. First oil through the meter was in early May 1999. The paper reports the operational experiences from first year of operation, and providse evaulation of measurement performance, compared to the conventional test separator.

Since the development of the subsea multiphase meter for Petrobras, the technology has been further developed to a new, compact design for ROV installation at water depth down to 2500 meters. Design and intervention concept for this new version is presented.

1. INTRODUCTION

Monitoring of the multiphase flow at the wellhead eliminates the need for dedicated testlines from remote wellhead completions, and the need for a dedicated test separator at the processing facility. A multiphase flowmeter at the wellhead will also allow improved well control, and hence better reservoir control. For remote or deep subsea wellhead completions the savings and operational benefits offered by this new technology are quite extensive.

PETROBRAS, for more than one decade, has been supportive to the development of the multiphase metering technology. It has come from internal R&D educational investigations to a point in which strong technological co-operations have been celebrated with the main conception holders and manufacturers of the most promising concepts of multiphase meters. Its supportive posture is aiming for the acceleration of the mature availability of such technology and its immediate introduction in the production practices - such effort has been considered as a Technology Implementation Project (TIP) when considering its ultimate nature. In addition, by considering the enhanced chances of success of such TIP when allowing the participation of other petroleum companies, as well as the benefits of a sooner spread out of the technology following a qualification success, PETROBRAS decided to offer such participation through the modality of a Joint Industry Project (JIP). Such decision received full support of the Company non-exclusive Partner, FLUENTA, which also accepted the responsibility of leading such JIP that since the first moment has counted with the strong support of eight petroleum companies - AMERADA HESS, AMOCO, CHEVRON, CONOCO, ELF, EXXON, SHELL and TEXACO.

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2. MULTIPHASE METERING - MAIN PURPOSE AND TYPICAL APPLICATION NICHES

The main purpose of this multiphase flow metering technological route when applied to the untreated usually produced fluids (e.g., oil, gas, water and occurring solids), without the need to separate them first, is to determine the fluid-phase fractions and their associated actual flow rates. In the E&P

segment of the petroleum industry, the multiphase metering has the following typical application niches.

Reservoir management; Such application has a direct contribution to the Reservoir Engineering discipline where, one of the most required aspects in terms of metrology performance resides in the low level of uncertainty in the phase flow measurements. In addition, such measurements shall have a high representation, shall be materialised through simplified logistics and producing results in very short time periods. It is clear that produced rates and produced volumes are key information in this area of the E&P set of activities.

Production management ; Here in the measurement of the usually present oil, gas and water phases, in terms of metrology performance seems that the repeatability in the measurements is the main characteristic sought for the multiphase metering. Such belief comes from the fact that such management has more a comparative approach and bases its correctional actions (e.g. the well work-over ones) on such monitoring of the production behaviour. The production management of subsea deep water wells systems, artificially producing by gas-lift, are seen here as a good example for what has been required for the metering in this niche.

Production allocation; Here either driven by the fluids share right determination or by transferring production among different production sites and particularly when a commingled production results from these actions, seems that, in addition to all aspects already required for the multiphase metering, it is particularly important that its (1) almost real time type of measurement and, its (2) non-required phase separation for each measurement.

Fiscal Quality Measurement; Here, as usual in this niche of application for almost all kind of measurements, the levels of required uncertainty, repeatability and even reproducibility are among the most stringent ones for this technology of multiphase metering. Consequently it constitutes the most difficult niche of application of multiphase metering, particularly in terms of meteorological performance. Interesting to notice that most of the written in the literature is sceptical about the ability of the present generation of meters to cope with the typical requirements in such niche. However, some oil-water and water-oil monitors, that compose some of the present multiphase meter conceptions, are already having their results fiscally accepted.

3. MULTIPHASE METERING - COST AND QUALITY IMPACTS

In general, function of the almost direct, partially or completely non invasive and non-intrusive characteristic to the flow, this present technology of multiphase metering when compared with the traditional multiphase metering way shows:

- shorter duration measurements,
- higher degree of representation of the measurement, particularly for manifold wells that were previously been measured through test lines
- comparable or better levels of uncertainty in the measurement
- less material (area, load, equipment, lines, instrument etc.) and human (test oversight, maintenance etc) resources are required,
- less disturbing practice to the non stopping production practices found in any production site
- comparable or lower, specially in the offshore subsea application, capital costs and
- lower operational costs.

Naturally by allowing a better, more frequent, less process disturbing and lower cost measurement practice, particularly when applied to the niche of reservoir monitoring, shall allow a better monitoring, which ultimately may allow an increase in the reservoir recovery factor, prompt detection of water and/or gas invasion fronts or even aggregate new exploitable reserve volumes.

The overall expectance, with the continuous maturation and spread out of this technology, is to reach an associated delivery cost that could even allow a complete retrofitting of the existent installations by substituting/abandoning the conventional way of doing multiphase metering in the entire set of activities of the E&P segment.

4. THE FLUENTA MPFM 1900VI MEASUREMENT TECHNOLOGY

The Fluenta multiphase meters are specifically designed to handle the various, and often complex, flow regimes that must be expected, without introducing mixing or separation of the flow. This has been achieved by developing a unique method for interpretation of sensor signals, the Dual Velocity method. This method is capable of handling complex flow regimes, including severe slugging, inhomogeneous phase distribution and interphasial slip.

4.1. Measurement principle

The MPFM 1900VI measurement system consists of a capacitance sensor, an inductive sensor, a gamma densitometer, a venturimeter and a system computer. The mean dielectric constant of the flow

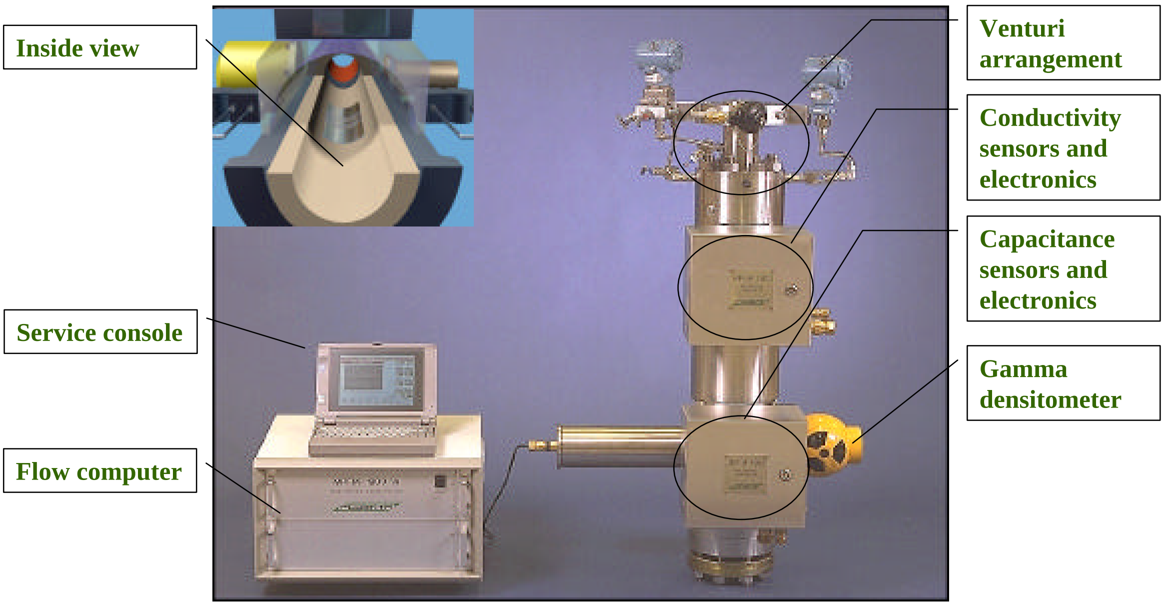

Figure 4.1 The Fluenta MPFM 1900VI; Block diagram

is measured using a non-intrusive, surface plate, capacitance sensor. The mean density of the flow is measured using a clamp-on gamma densitometer. Together these two measurements provide the instantaneous composition of the flow at the measurement location. At high water cut, when water is the continuous liquid phase, the mixture conductivity is measured using an inductive type sensor. This then replaces the capacitance measurement in the composition calculation. Velocity of the flow is determined by cross-correlation between different electrode pairs in the capacitance sensor. A venturi meter extends the range of the multiphase meter to cover single phase liquid and annular flow, and add redundancy to the velocity measurement. By combining both the compositional and the velocity information of the flow, the actual flowrates of oil, gas and water are determined by mathematical models hosted in a PC system.

4.2. The Dual Velocity method for handling of interphasial slip.

The sensor system has been configured to measure the distribution of velocities present in the flow, and interphasial slip is directly measured and compensated for using the unique “Dual Velocity method”. This is achieved by measuring the two most predominant velocities in the multiphase velocity distribution; the velocity of the pseudo-homogenous dispersed phase, and the average velocity of larger gas bubbles.

By combining these velocities with measured cross-sectional area fractions of dispersed phase and “large bubbles”, flowrates of oil, gas and water can be calculated, irrespective of flow regime (restricted to vertical upwards flow). In a somewhat simplified way, one can explain the Dual Velocity method to treat the flow as a “two-phase” mixture in terms of velocity: a pseudo-homogeneous mixture of oil, water and small gas bubbles; and a "free" phase consisting of larger gas bubbles travelling with an average velocity significantly higher than that of the "dispersed phase".

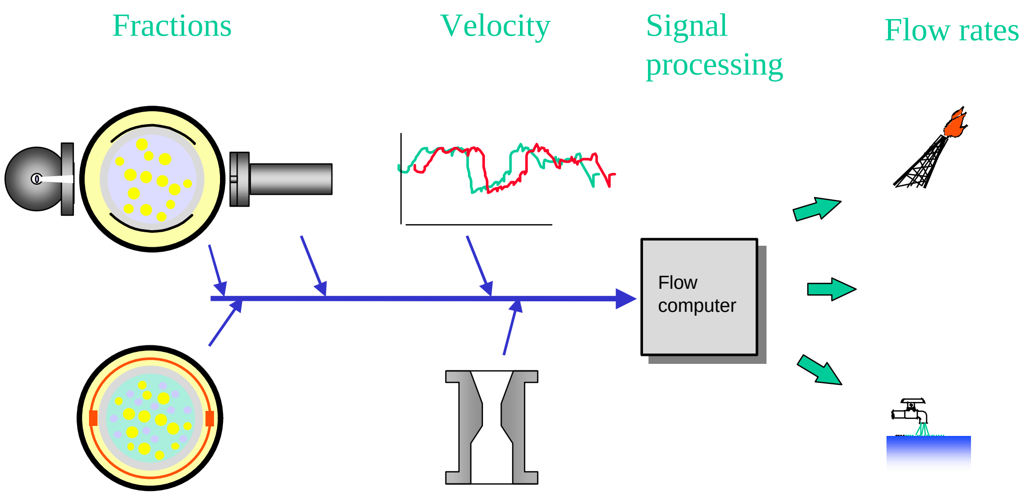

Figure 4.2 The Fluenta MPFM 1900VI; Measurement principle

The non-intrusive design, together with the Dual Velocity method for handling of phase slip, means the Fluenta multiphase meters do not require mixers to homogenise the flow, or separator to split the flow, before measurement. This gives the meter a wide operating range, which is not limited by the efficiency of the upstream flow conditioner or splitter. Interaction with the flow is kept to a minimum, avoiding pressure drop, erosion, or creation of emulsions that may otherwise seriously affect the downstream process.

5. THE FLUENTA SUBSEA MULTIPHASE METER SMFM 1000

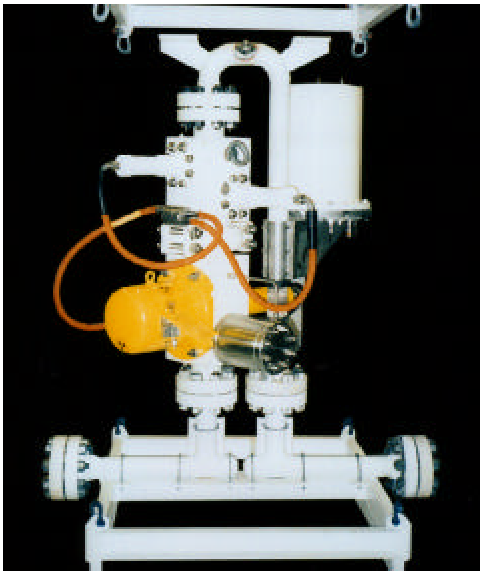

Figure 5.1 The Fluenta SMFM 1000, mounted on test skid.

The subsea version of the MPFM 1900 series multiphase meters, the SMFM 1000, incorporates the same basic primary sensor elements and measurements principles as the topside version. One exception for the meter delivered for the Albacora field application, is that it does not contain the inductive sensor module, limiting the operational range to low water cut (below ~ 60 - 80% water cut).

In Figure 5.1, the meter is pictured mounted on a test skid. When installed subsea, this test skid was replaced by a dual bore flange arrangement. The detector electronics and flow computer is installed in an atmospheric chamber next to the flow meter itself, and connected to the meter through oil-filled cables. This complete sensor assembly is installed in a subsea retrievable module, guidelineless and cable deployed, the MMS 1200 designed by Petrobras.

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6. THE ALBACORA FIELD APPLICATION

The project for developing the Albacora Field - Phase II utilizes an FPSO vessel (P-31, Vidal de Negreiros) to receive the produced fluid from four production manifolds and to provide water to an additional manifold for injection. The four subsea production manifolds, MSPDL-3, 4, 5, and 6, are designed to accept a multiphase meter in a retrievable module (see Figure 6.2). The first production manifold fitted with a multiphase meter was the MSPDL-3. In May 1997, the Fluenta Subsea Multiphase Meter SMFM 1000 was integrated into the host manifold (constructed by CBV). In June 1997, this manifold was installed on the sea floor, at 450 water depth, in the Albacora field. The location of the Albacora Field in the Campos Basin is shown in Figure 6.1.

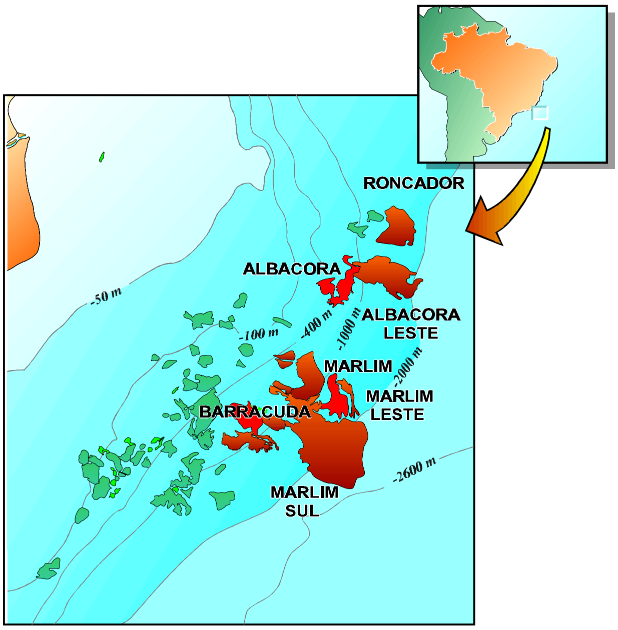
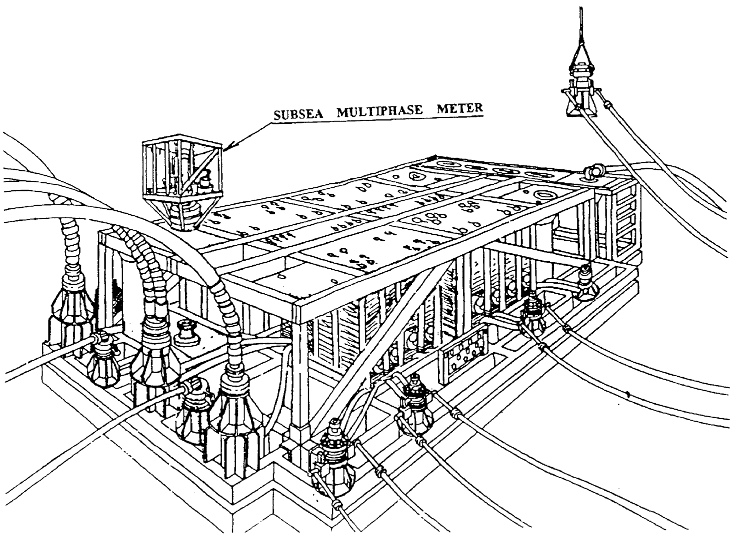


Figure 6.1 Campos Basin offshore Brazil

The main purpose of this measurement system is to allow more accurate and continuous reservoir monitoring (well testing). In addition, the subsea multiphase flow measurement system is expected to provide economic benefits, such as the elimination of subsea testing lines and simplification of subsea production systems. The use of this technology is also part of the developed concept of a “Remote Operated Platform.”

The actual concept of the project utilizes guidelineless installation and recovery of such a flow meter without production interference. This is accomplished by installing the multiphase meter in a retrievable module, the MMS 1200, designed by Petrobras. The manifold piping arrangement allows well production to be routed:

- Through the SMFM 1000 to the test line and a test separator on the FPSO.
- Through the SMFM 1000 to the production line.
- Directly to the production line or test line without passing through the SMFM 1000.



Data from the Fluenta subsea multiphase meter is compared with data reported by the test separator system on the Vidal de Negreiros FPSO. This is a conventional reference system, and being composed by a three-phase separator vessel, hydro-cyclone device at the water-outgoing stream, BS&W analyser and related instrumentation.

Figure 6.2 The subsea production manifold MSPDL-3, with retrievable multiphase meter module.

7. OPERATIONAL EXPERIENCE

The SMFM 1000 Subsea Multiphase Meter embarked on the PETROBRAS MMS-1200 module that ultimately was installed in the production manifold MSP-DL3 (Albacora field). Basic operating conditions are translated by 20x10-3 Pa.s oil viscosity @ 38 ºC, 300-1000 m3/d oil flow rate, 60-80 % GVF, 0-50 % WCUT and 60 bar in pressure. The following qualification program has been executed for this meter:

- performance testing (Jan/Feb./Mar. 1997) at the Atalaia Test Site;
- functionality testing (Mar 1997) following assembly in the MMS-1200 and integration in the MSP-DL-3 manifold (CBV-CANECO Shipyard, Brazil);
- subsea installation in the Albacora field (Jun. 1997);
- functionality test from an offshore rig (May 1998);
- performance testing (May 1999) subsea; and,
- endurance testing (May. 1999-2000) subsea.

7.1. Performance testing at the Atalaia test site

The results of the performance testing conducted at Atalaia Test were found within the manufacturer's uncertainty bands. These tests reflected most of the conditions foreseen for the Albacora field host subsea manifold, except for the pressure; the Test Site was set to run at 15 bar, while the manifold's pressure will be under 60 bar. During the tests GVF ranged from 60 to 80 % and water-cut from 0 to 50 %, besides a slug flow pattern condition very close to that expected at the subsea site.

7.2. Functionality testing at CBV-CANECO Shipyard, Brazil

At the CBV-CANECO shipyard in Rio de Janeiro, Brazil, the SMFM 1000 was functionally tested after its assembly in the MMS-1200 module and the module installation ("dry deployment") in the manifold. Such test checked the meter-module transmission system communications and power supply (using an electric cable in order to simulate the control umbilical line, right connected to the clamp ring connector/jump); inside of the meter, initially we had just air flowing and later water based hydraulic fluid. Besides that, a hydrostatic test at 50 bar was performed in the Control Pod's dual ring sealing system, in order to assure its proper operation when in the deep sea.

7.3. Subsea deployment and functionality test

After the subsea deployment (Jun. 1997) a functionality test, by means of connecting the control umbilical to the host MSP-DL-3 manifold, energising all electronics and checking out their operational trends and diagnosis, was executed in May 1998 from a service rig. No signal from the meter was received in the surface console. However, after taking the topside console to CENPES, it was found a malfunction on it. A proper repair was executed but no other opportunity was given for a second functionality testing using this rig (rig availability).

In January 1999, the meter was connected to the the FPSO (Floating, Production, Storage and Offloading, P-31), and the functionality was successfully tested. At this time the multiphase meter was filled with diesel oil, which also allowed a one-point check of meter calibrations. No drift since deployment 18 months earlier was observed.

7.4. Subsea performance testing

The first oil was routed through the meter in May 1999. The subsea meter measurements are compared with the results of the topside separation/measurement system (taken as a conventional reference and being composed by a three-phase separator vessel, hydro-cyclone device at the water-outgoing stream, BS&W analyser and related instrumentation.

Figures 7.1 and 7.2 show the flow rate and accumulated volume, respectively, as measured by the Fluenta meter and the test separator as a function of time, on May 15 & 16, 1999, with a test duration time of ~40 hours. The relative deviation for the accumulated volume in the test period was –5.6 %.

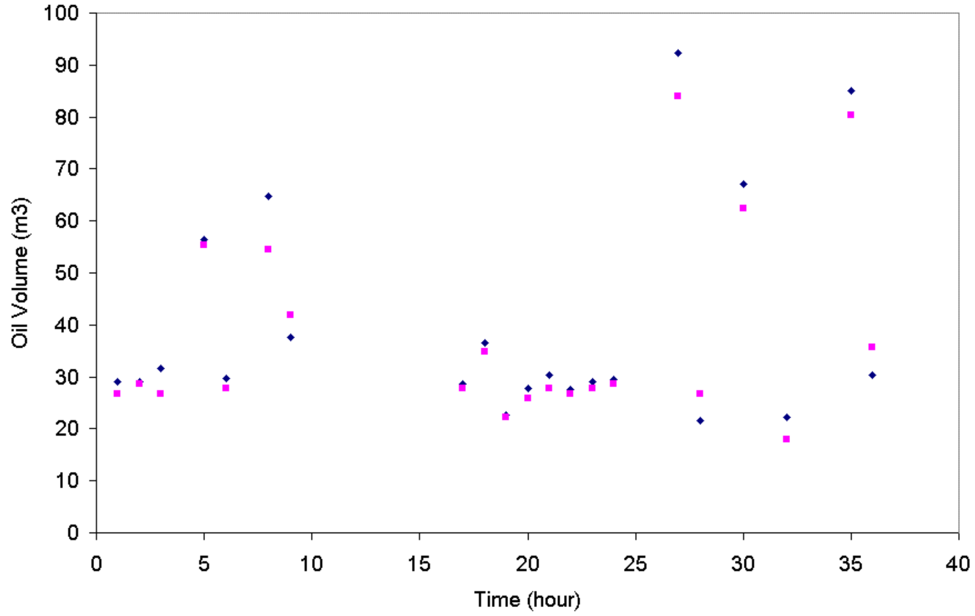


Figure 7.1 Relative deviation for measured oil flow rate, versus time.

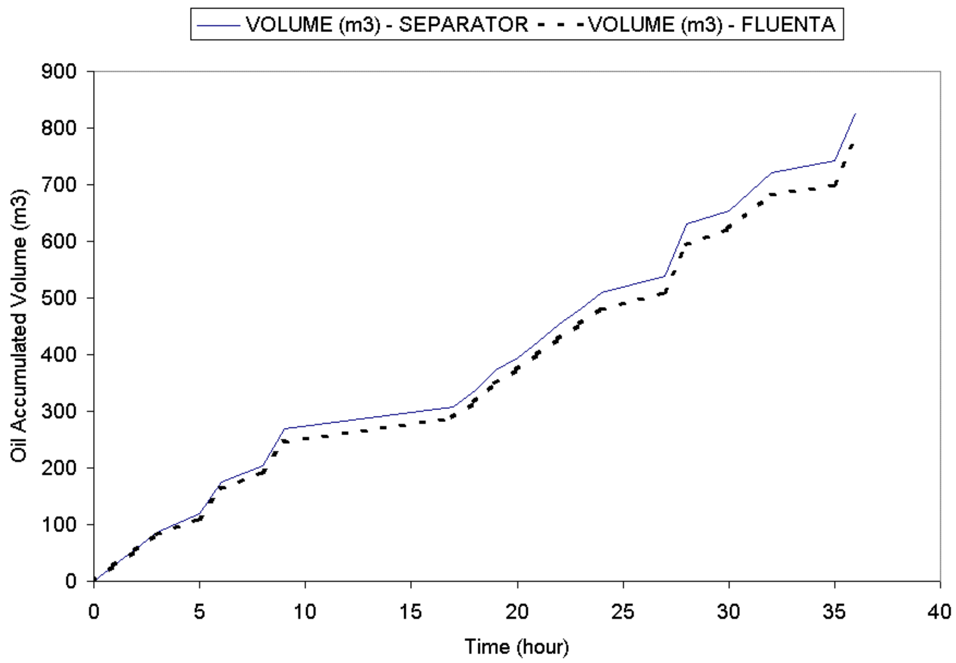


Figure 7.2 Accumulated oil volume versus time, measured by the Fluenta meter and the test separator.

Figures 7.3 and 7.4 show the accumulated gas volume by period and the accumulated gas volume over time, respectively measured by the Fluenta meter and the test separator, with a test duration time of ~40 hours. The relative error for the accumulated volume in the test period was –1.04 %.

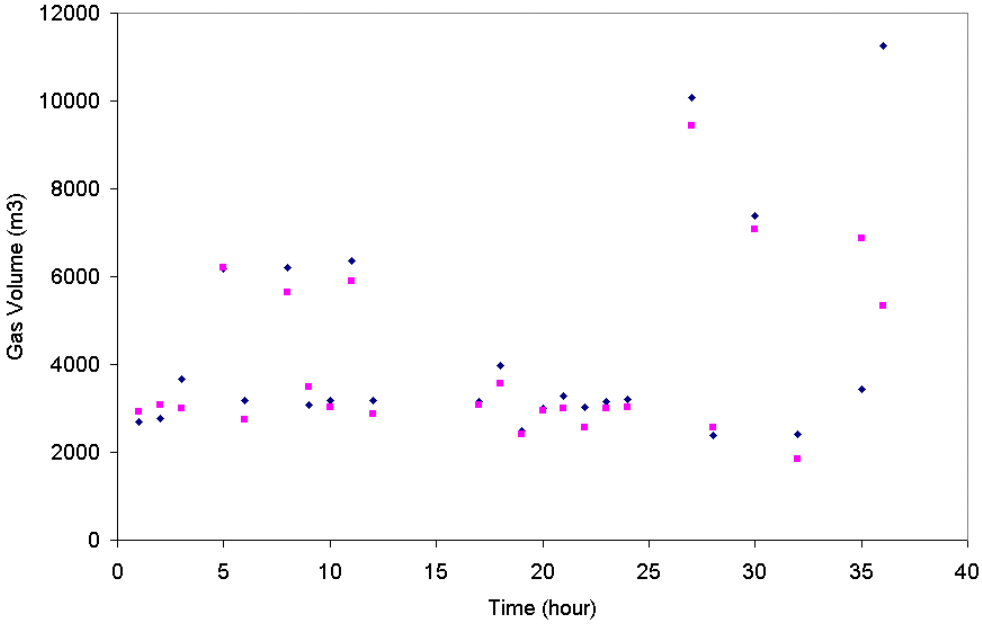


Figure 7.3 Relative deviation for measured gas flow rate, versus time.

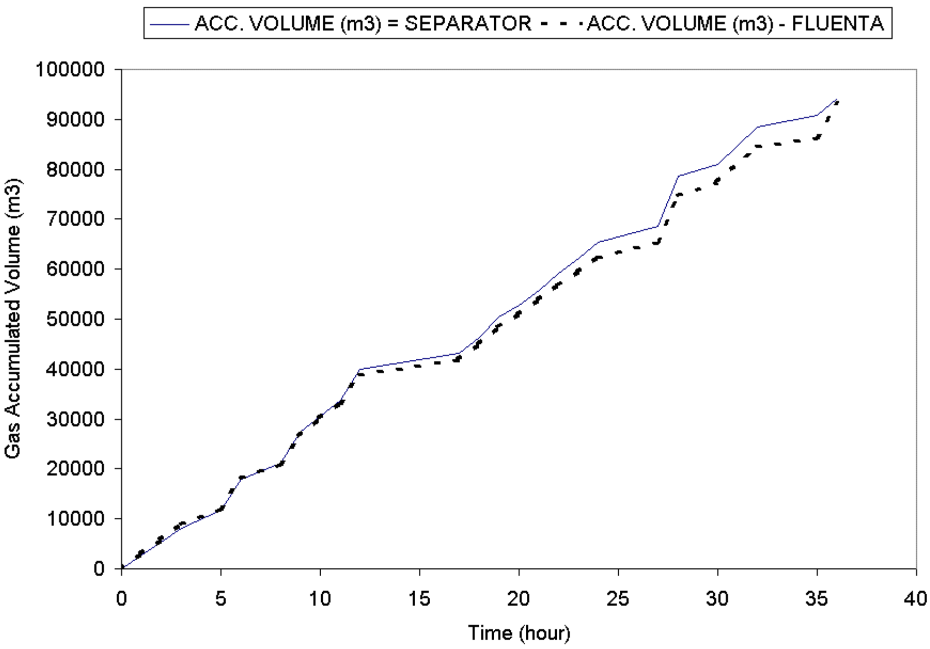
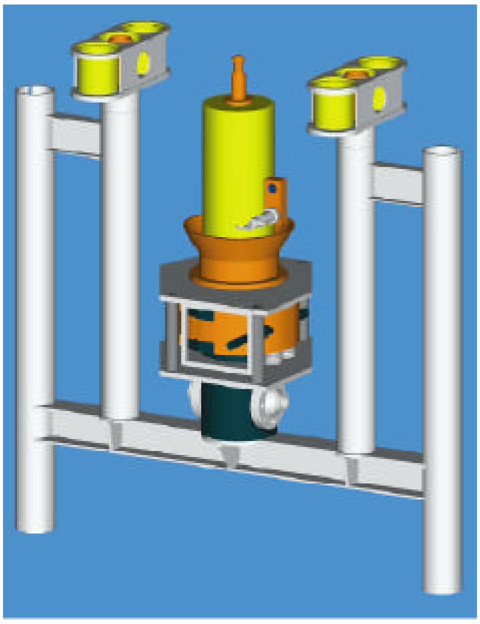


Figure 7.4 Accumulated gas volume versus time, measured by the Fluenta meter and the test separator.

8. FUTURE PLANS

The installation of multiphase meters on the subsea manifolds constructed for the Albacora field (Campos Basin), besides those under design and/or construction for Marlim, Marimba and Barracuda fields, all in the Campos Basin. PETROBRAS has instituted a design guideline by determining that all new production manifolds should allow the installation of a multiphase meter, which shall be immediately installed after the ongoing process of technology qualification has reached a successful end. Based on the present forecast, up to the year 2000, 27 new manifolds are planned to be built and deployed. In this scenario, the economical attractiveness of such usage is high and usually the application, especially in terms of measurement uncertainty, exhibits a better performance due to the fact that such measurements are usually done under high-pressure values. The subsea deployable and retrievable multiphase metering module (MMS 1200) has been installed in the most recently built manifolds - Albacora, Marimba and Marlim fields. The MMS is conceived to host any of the already mentioned as seen by PETROBRAS as the most promising conceptions to be used in such environment. After a meter conception has been qualified, such MMS shall be optimized and even abandoned by then adopting concepts of subsea stacking-up modules and serving only the most prone ones to failure, with extremely reduced infra-structure (e.g., ROV's). It shall also be mentioned, that the crucial meter characteristics in this scenario are believed to reside on its adequacy to the deep-water deployment and operation (i.e., RAM exhibited levels).

9. COMPACT ROV INSTALLED MULTIPHASE METER



For future applications of subsea multiphase metering, Fluenta has developed a new generation compact ROV retrievable version: The MPFM 2000 SR system design is based on the topside meter, MPFM 1900 VI and the previous Fluenta subsea flowmeter, the SMFM 1000. The basic elements are the same as for the previous subsea meters, with a number of improvements and re-packaging.

The mechanical interface is through a dual bore connector in the bottom. This allows simple installation by use of a well qualified and accepted locking mechanism. Electrical interface is over a ROV operable connector. This allows for connection to a subsea control module. The low power consumption of the meter allows for supply of 24VDC. The meter has redundant power supply and signal interface.

The MPFM 2000 SR is designed for 3000 meters water depth, and the design of the system is flexible with regard to selection of ROV and/or ROT interfaces as well as system components such as flowline connector(s), electrical connectors and corresponding intervention interfaces.

Figure 9.1 The MPFM 2000 SR; here pictured with a GSR type connector.

10. CONCLUSIONS

PETROBRAS and FLUENTA are conducting a non-exclusive Technological Co-operation Agreement (TCA) involving two different liquid-liquid monitors an three multiphase meters, which shall lead, among others results, to the first multiphase flow meter operation in a deep water environment. A FLUENTA SMFM 1000 assembled in a PETROBRAS subsea retrievable module, guidelineless and cable deployed, MMS 1200, was successfully installed (June 1997) in a host manifold (MSP-DL3) in the Albacora field. After several delays in the delivery of items composing the field exploitation scheme, the overall tiebacks and hook-ups are completed and the first oil has come in the 10th of May, 1999. The overall performance, including the measurement error has been considered as very good.

All the activities imbedded in the celebrated TCA with FLUENTA was offered to the industry under the modality of a Joint Industry Project (JIP) - eight petroleum companies are participating on it.

PETROBRAS has decided to equip all the production manifolds under design and construction with a MMS 1200 module. Considering the present and near future production portfolios at PETROBRAS, a mapping of the niche opportunities and the PETROBRAS views associated to this technology have been offered.

The number of meters and their diversity in conceptions installed or to be installed, not only confirms one of the PETROBRAS views for such technology but, also demonstrate how strong has been the support and decision of implementing such technology in the production practices. The impact resulting of the expected success of this venture has the potential of strongly modifying the current way of monitoring the production practices in the E&P segment of the petroleum industry.

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