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MULTI-PHASE FLOW METERING USING TWIN HELICOIDAL ROTORS - THE ´MULTI-STREAM´ METER

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1. INTRODUCTION

Multi-phase flow meters development present different principles with different associated technologies. Some systems are designed to separate gas, oil and water fractions before measuring each one separately. Others are able to measure the three fractions together, using supplementary devices to obtain gas, oil and water cuts

Positive displacement meters have the advantage of having its accuracy not affected by different, complex flow patterns. Helicoidal positive displacement meters design provide toughness and accuracy, in both high and low gas fraction flows.

The multi-phase flow meters produced by ISA Controls Ltd. are based on a technology developed originally by British Petroleum Exploration (BPX). ISA is exclusively licensed of this technology.

BP built and it tested comprehensively a meter of 4 " in Witch Farm (GB) and in Prudhoe Bay, Alaska. The ISA built and it tested, in 1996, a second meter. The tests were accomplished in a plant of tests in Porsgrunne, Norway and subsequently, in a platform in Qatar operated by Occidental Oil of Qatar Ltd.

Based on the information obtained with these tests, it was reached a trust level in the technology and more two meters, of this time of 8 ", they were built and delivered to Casanare (Colombia).

The construction of larger meters was good to expose small flaws in the original project, which were solved assisting the demands and specifications of BP-Amoco Colombia.

The results of the test, accomplished for 14 months, in summary, pointed as result:

- The meters produced consistent measures of oil flow and gas with uncertainty smaller than 5% against reference meters;
- The reference meters were three different test separators operated by the teams of tests of well of Geoservices, PTS and BPX. The results obtained by the meters of ISA didn't vary in function of the use of one or other measure system;
- The tests demonstrated the importance of usual state equations in the multi-phase meters and of reference.
- In the initial tests, where the multi-phase meters didn't operate simultaneously in series with the reference meters they presented low correlation, with the multi-phase meter presenting a total flow (gas + liquid) from 10% to 20% larger than the reference meters. It was demonstrated that that installation of the reference separator test resulted of the great pressure fall in the test separator and in the unit " Wellcomp " and its effect in the production rate in the well. Other possible influences were leaks in the" SCARF " area valves and also in by-pass valves in the multi-phase meter skid. That period of test demonstrated the importance of testing of the multi-phase meter in series with the reference system. It also pointed previously that a multi-phase meter imposes smaller losses in the production when compared with a test separator;
- Multi-phase meter is not based on levels of fluids in pressure vases, so that, its readings are inherently stable. In numerous tests accomplished in Cusiana and Cupiagua (Colombia), tests were generally accomplished 10 minutes after the flow passage by the meter. A well test can be obtained satisfactorily after one hour, and, longer tests (more than one hour) don't produce any more exact result.
- The water-cut " measures for the multi-phase meter were obtained in field through sampling and centrifugation, technique similar to used her for Geoservices and for the PTS, larger vendors of tests of wells;
- The influence of slugs didn't alter in a significant way the accuracy of the meter nor it damaged its mechanical components; also during the test, the formation of it stains it didn't harm the performance of the meter;
- Operating teams of wells in test considered meters of easy operation. A team of PTS operated the meter for two months without any aid of ISA Control's team, after training of four days;

- The specifications of BP requested that the meter that operated in a continuous way to 3.500 rpm in 1.000 hours. After 1.200 hours the meter was disconnected of the line, disassembled and its components were measured. No waste was detected in any of the mobile parts;

The tests had duration from November of 1997 to February of 1999, with some intervals due to logistic and custom problems in Colombia also contributed to delay stops, since the pieces should go and to return of ISA going by the Custom control in Colombia.

In the total, 57 tests were accomplished in 16 different wells in Cusiana and Cupiagua.

2. HISTORICAL OF HELICOIDAL ROTORS MULTI-PHASE METER TECHNOLOGY

The prototype of the multi-phase meter was developed firstly by BP in 1986. Meter was designed to avoid sliding between liquid and gaseous phase between upstream and downstream pairs of positive displacement screws. The meter prototype was tested firstly in Witch Farm (1989/1990) and later at Shell's (KSEPL) three phases plant in Hague (1990).

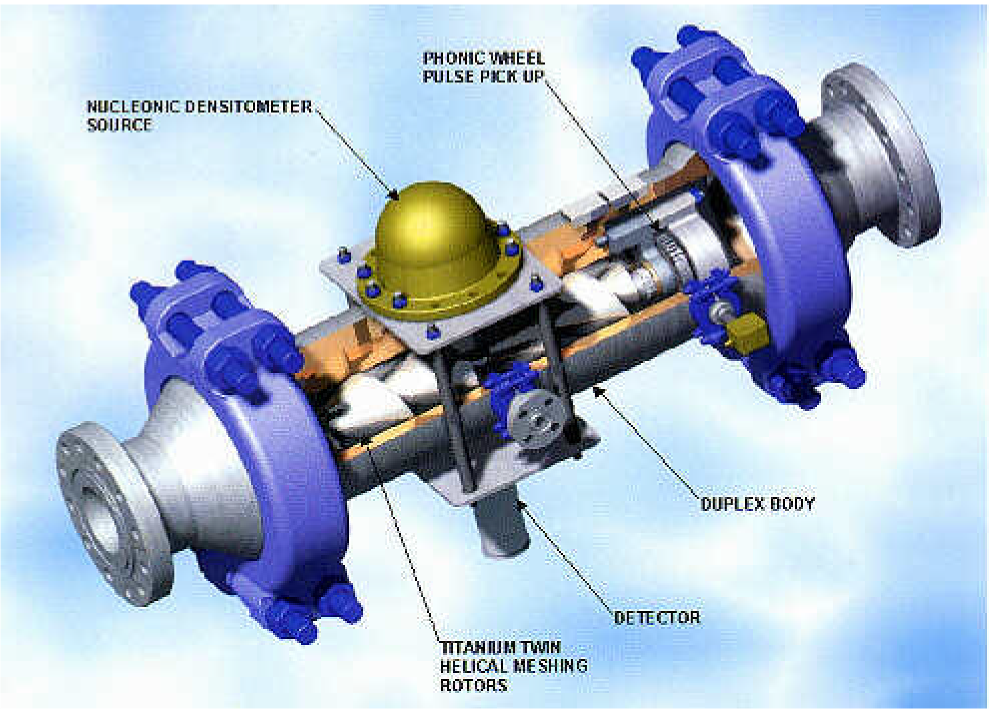

Figure 0 - Overview of the meter

BP defined as goal an uncertainty of 5%. Already in the initial tests that goal was reached. Modifications were executed in the internal part of the meter and, in a second version of 4 ", the equipment was tested again in Alaska (Prudhoe Bay) during the years 1992 and 1993. The tests covered pressures of 200 to 2.300 psig and fractions of gas among 62% to 95%. An uncertainty of 5% was reached in relation to test separators used as reference meters. A 2.000 hour durability test was made in 1993 and it was demonstrated the reliability and the robustness of the meter.

Based on that experience, BP sought a partnership for the conclusion of meter development, its data acquisition system and also for the commercial production. In 1995 a licensing contract was firm between BP and ISA Controls Ltd. The meter of 4 " was reconditioned and sent to Porgsrunn, a multi-phase circuit test operated by Norske Hydro in Norway, to participate of a series of tests in 1996.

During the year of 1996, it began the discussions with BPX - Colombia. Based on the good experience in the tests accomplished previously, both ISA and BPX had trust the meter presented the necessary technical characteristics so that the patterns specified by BPX - Colombia in operations of tests of wells were reached. Finally, in December of 1996, BPX - Colombia ordered two 8 " multi-phase mobile meters for delivery in July of 1997

Two challenges were imposed: meters of 8 " had not still been built by ISA, being necessary " to enlarge " the project of the 4 " meter, and also to increase transport " skid "; second: the ISA personnel didn't have field experience with the meter, since the process of tests accomplished previously were all accomplished by BP personnel.

In February of 1997, a program of tests with Occidental Oil of Qatar LTD, was negotiated. The program consisted of a limited series of tests in an offshore platform at the field of " North Dome". To the accomplishment of these tests the same meter used in Porgsrunn in 1996 was used. The tests in Qatar were fundamental since the characteristics that were found there would be similar to the expected ones in Cusiana. The resulting uncertainties of the test accomplished by the partnership Qatar/ISA were about 5% of the reference meter.

The ISA team acquired experience in meter operation as well as with the data acquisition system.

3. OPERATIONAL PRINCIPLES

3.1 GENERALITIES

The multi-phase meter developed together by BP and ISA Controls uses a very well known and studied mechanic principle. The meter is based on a pair of synchronized helical rotors. Being used a set up deflector in the front of the rotors; the flow enters tangentially to the inclined contours of the helix, following a parallel direction to the axes of screws rotation. The shocks and transients effects of flow are absorbed by special bearings.

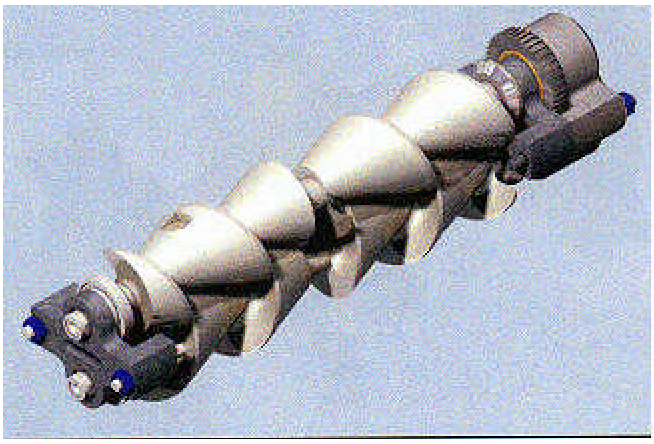

Figure 2 - Complex design rotors

The flow is confined in incremental portions in the cavities of the rotor during its passage through the meter, avoiding, this way, sliding effects. The density of each portion is measured in an intermediary point of the rotor where each portion is still controlled and restricted.

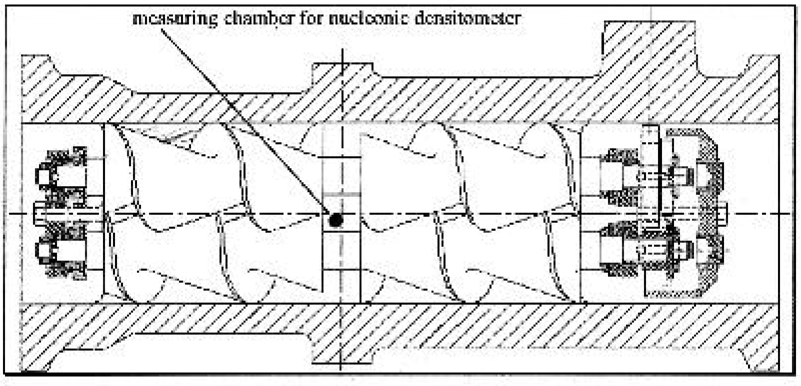

Figure 3 - Measuring point

In that intermediary point, called of Density Measuring Point, a nucleonic densitometer is installed. In that local, fluid that emerges of the first pair of rotors is homogeneous. The speeds of each phase stay the same to each other, since there is a restriction imposed by the downstream rotors.

Due to the geometry of the rotors, flow volume is proportional to its rotation. A conventional rotation sensor coupled to the axes of the rotor is used for flow volume computation.

The global mass flow can be obtained through the multiplication of the volume flow by density. The individual mass flow can be obtained being known the density of the oil; the density of the gas and the " water-cut ", being used the following equations:

The information is captured by transducers in the interval of 0,1 second. Those measures are integrated during the period of duration of the test so that it is obtained the well flow. Pressure and temperature transducers located the Point of Measure of Density are used for the flow correction to mass and standard conditions.

The meter is set up in the vertical position in order to alleviate efforts in bearings. The upstream bearings are the requested pair, having a special construction, in order to support the dynamic efforts caused by flow and weight of rotors, and also to guarantee the alignment of rotors. The superior bearings are simple, without the need of any special design.

An advantage to be presented is the possibility of meter calibration in a single-phase calibration system, with water, being preserved, however, the necessary precision for operation. Usually, it is not necessary posterior calibration.

The multi-phase flow meter is the only measure system in which, due to the action of the helicoidal rotors, constrains the inter-phases sliding. It is not necessary, therefore, the use of correction algorithms. The meter can be used in any operation condition (flow with bubbles, for example) from until 95% of gas fraction to water cuts of up to 100%, without accuracy loss.

3.2 " SKID " FOR TRANSPORT (MOBILE VERSION)

The mobile version of the meter is set up in a " skid " on a transport base. The base has an articulation system that allows tumbling the group in 90 degrees for the passage under bridges, viaducts, etc.

Three valves that allow the connection of the meter and its by-pass to the test manifold. The electronics is set up in a box of reinforced plastic, which in operation is placed in safe area. The data acquisition system is coupled to the " skid " through a control umbilical. Flanges 8 " - pressure class 900 # allow the connection to the process. The exit flange can be used to connect a reference meter in calibration processes.

The whole group of the meter and " skid " for class of pressure 900# weighs about 9.500 kgf. The " skid " is drawn to be suspended of the transport base and to be used as an equipment " stand-alone ".

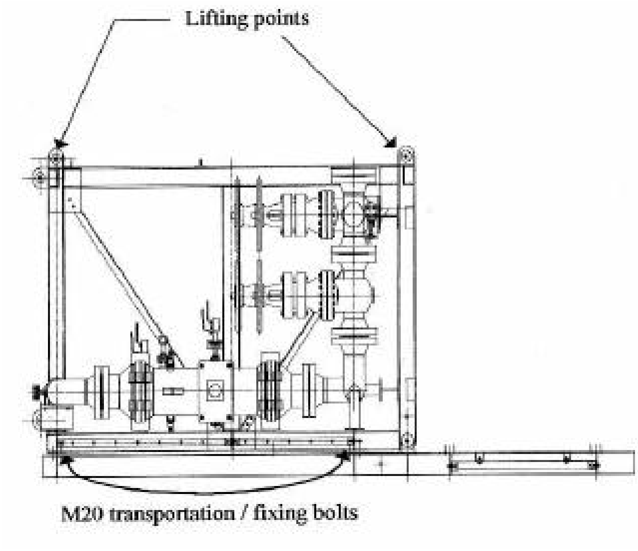

Figure 4 - Skid - Mobile Version

4. CALIBRATION OF THE METER

BPX - Colombia ordered, in January of 1997, two multi-phase meters set up in " skids " for transport. Those were the built first two 8 " multi-phase commercial meters. They were based in the previous project 4 "meter that suffered a geometric scale.

The first meter was set up and calibrated in a single-phase calibration system using water as working fluid, still in the facilities of ISA before being sent to NEL - National Engineering Laboratory in August of 1997. NEL is one of the few world laboratories with capacity of measure of multi-phase flow and the only with reference meters traced to national patterns.

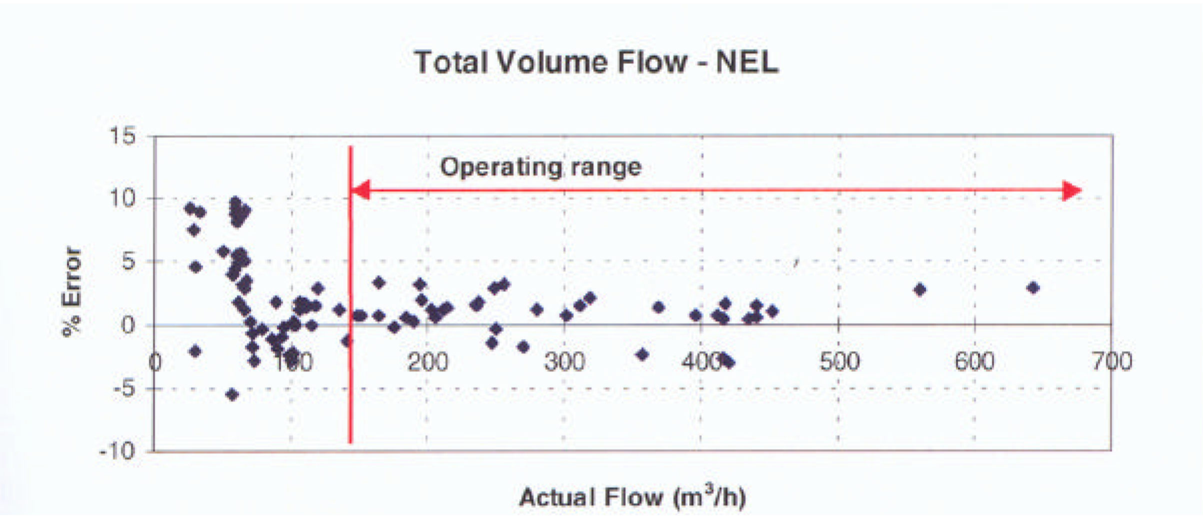

Figure 5 - Calibration at NEL facilities

The program of tests was made to coincide with the period of the BPXC personnel's training in England. This way, the meter can be seen in operation before yours it embarks to Colombia.

The base of the tests accomplished in NEL collects a range of flow from 30 m3/h to 600 m3/h (25.4 MACFD to 508 MACFD) what represents a range of intermediary flow of the meter with fractions of gas from 0% to 99% (from totally liquid to almost totally gas). The characteristics imposed by the test facilities limited the use of the meter in half inferior of its measure range. The operational conditions of NEL are low pressure (30 to 60 psi) and low temperature (104ºF). The used fluids were raw petroleum, nitrogen and synthetic salt-water. Those fluids in the pressure conditions and temperature of the tests don't present the ideal situation for the measure multi-phase, because the segregation and the sliding of the phases difficult the measure process.

The uncertainties in the facilities of test of NEL are estimated in 2,5%. The meter presented an uncertainty smaller than 3% in its operation range with error increasing with smaller flow rates, range where the drag and sliding effects are more significant.

The results obtained in the NEL encouraged ISA to begin the tests in field.

5. TESTS IN THE FIELD OF CUSIANA (COLOMBIA)

The tests in Colombia had beginning in October of 1997 in it SCARF (Slug Catcher and Related Facilities) plant of Cusiana CPF, where a test section was especially built so the meter could be set up in series with a test separator. The objective of the test was to compare the multi-phase meter against test separator of CPF, before moving it for several different wells.

A total of 34 tests was accomplished in the facilities of CPF between November 7, 1997 and February 7, 1998.

The relative deviations for gas and oil mentioned in that document were corrected to the temperature and pressure standard conditions. Equations of State supplied by BP exclusively pertinent to the wells of the fields of Cusiana and Cupiagua being used. During the tests, the Equations were reviewed so they reached the whole range tests pressures and temperature.

5.1 WELLS TESTS

In February of 1998 it decided to move the meter number two for the gas and oil wells. The first test lasted about four hours and soon it was noticed an over reading in the gas measures when compared with readings obtained through test separators (that simultaneous didn't operated with the multi-phase meter).

Firstly, the Equations of State form corrected so that they could cover the whole test pressures and temperature ranges. Nevertheless, there were differences of the order of 30% in the liquid measure and 20% in the gas measure. That difference didn't have clearly explained causes, but it was related of some form with the pressure drop and, for consequence, of the regime of production of the well caused by the test separator. Consequently, it is only possible the obtaining of correct reference values, when the test separator is mounted in series with the multi-phase meter

After 950 hours of test, operating in rotations of up to 2500 rpm, the multi-phase meter was dismounted and its inspected and mechanical components have been measured. Any damage was not observed, the rotors and the bearings were in perfect state.

To avoid the uncertainties presented in the first test period, it was installed in series with the multi-phase meter, a separator of portable test operated by Geoservices, for the accomplishment of a second phase of tests. Immediately, good results were obtained. An intense package of tests was accomplished, where the meter operated with a rotation of up to 3.500 rpm. It was necessary the use of two test separators to support the produced volume of gas and oil.

In a third phase of tests, it was verified the reliability, the accuracy and repeatability of the meter along a long operation period. More than a thousand hours of continuous operation close to the maximum nominal capacity of the meter was executed for five weeks reaffirming the high reliability of the multi-phase meter.

Test them in that last phase, they confirmed the good results obtained in the plant of " SCARF " and in the second phase of tests.

5.2 SUMMARY OF THE TESTS

57 tests in 16 different wells were accomplished, being used as reference meters of two portable test separators of the Geoservices and Production Testing Services (PTS) and a fixed separator of Central Cusiana Processing Facility (CPF). The multi-phase meters were calibrated firstly with water (flow volume) and later on with water and air in field (density). It is not necessary the calibration being used the product of the wells.

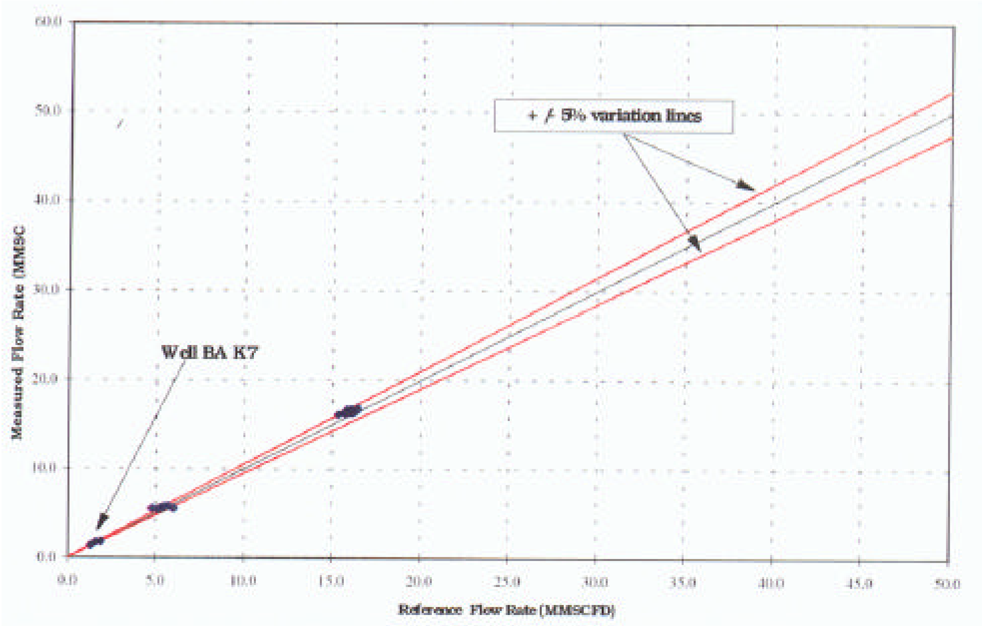

Figure 6 - Deviation of the multi-phase meter

The found uncertainties are a combination of the uncertainties of the multi-phase meters with the uncertainty of the reference meters (test separators). The tests show that the repeatability of the multi-phase meter is about f 5% and that the global uncertainty (multi-phase meter + test separator) is about 10%. The estimated uncertainty of the test separators is of 5%, resulting in an uncertainty of 5% in the measures realized for the multi-phase meter. During the duration of the tests (12 months) it was not made any additional calibration, that is, the only done calibration was that accomplished in the maker's facilities. Any error tendency in the measure was observed during the period of tests.

6. CONCLUSION

Numerous tests accomplished about in several production fields of the world and also in calibration laboratories they check the efficiency of the multi-phase meter.

Operating with two helical rotors that constrain the flow in small portions, through a nuclear densitometer is obtained the liquid portions and gas that compose the flow.

The uncertainty of the measure obtained in several tests is of the order of 5% and the repeatability, also of 5%. During the tests accomplished in field, it was observed that is necessary the installation of the test separator in line, when it wants himself to compare the multi-phase meter against other measure system.

After each battery of tests, the meters were dismounted and its analyzed parts and measures for waste verification in the components. There were not any sign of wearing, damage or deterioration of the mechanic components of the meter.

7. BIBLIOGRAPHY

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