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THE TEXACO SUBSEA THREE PHASE METERING SYSTEM

ASC90\REPORTS\TLD-2

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SUMMARY

For several years the world's oil industry has been aware of the economic and technical benefits of metering subsea wells on the seabed rather than at the surface on production platforms. Texaco's research and development activities directed toward defining and developing multiphase metering technologies began in earnest in the late 1970's.

Since 1988, Texaco and Jiskoot Autocontrol have been working together in the fabrication and testing of a prototype Subsea Metering System (SMS) whose conceptual design evolved from Texaco's research and development efforts. This prototype development project is receiving financial support from the European Commission, Directorate for Energy, DG-XVII.

This paper describes the SMS design basis, identifies noteworthy problems intrinsic to the design concept and reviews solutions that were developed. The evolution of the SMS is tracked from its original design concept to its present configuration. The results of extensive model testing, both in steel and perspex, and results to date of prototype tests performed on Texaco's Tartan 'A' platform are discussed.

1 HISTORY

The conceptual design of the Texaco Subsea Metering System (SMS) evolved from research and development efforts initiated by Texaco Exploration and Producing Technology Division (EPTD) in the late 1970's, early 1980's. Of particular significance was EPTD's study of water fraction measurement techniques through a project supported in part by Aramco. The objective was to develop an instrument for measuring at the wellhead the relative fractions of oil and water in multiphase production streams. The instrument was to be capable of accurately measuring watercuts ranging from 0 to 100 percent in both oil continuous and water continuous media with gas fractions ranging from 10 to 90 percent of the total volumetric flow.

The results of capacitance probe tests at various field locations early in the project led Texaco to select microwave technology for this instrument. Entrained gas affects watercut measurements of both capacitance and microwave based instruments so use of either type of instrument requires essentially a gas free fluid. However, a microwave system has no inherent limit on the watercut which it can measure whereas a water continuous emulsion will cause a capacitance probe to short out. Microwave signal strength considerations limit the microwave unit to much lower flow rates than can be handled by capacitance probes. To obtain a practical range of flow rates or "turn-down" using microwave technology, a technique had to be developed for "feeding" the microwave unit with a representative, yet gas free, liquid sample from the production stream.

The extraction of a continuous representative side stream sample from the multiphase production stream was achieved by using a concept first developed by EPTD in work on two phase liquid and gas metering. A downwardly inclined section of flowline is used to stratify and hence separate the bulk gas and liquid. This design evolved into an inclined separator/extractor system and now is a key component of the SMS (see Fig. 1).

2 DESIGN CONCEPT EXPANSION

After developing the microwave watercut monitor sampling system, it became clear that the technology could be extended to give a novel three phase

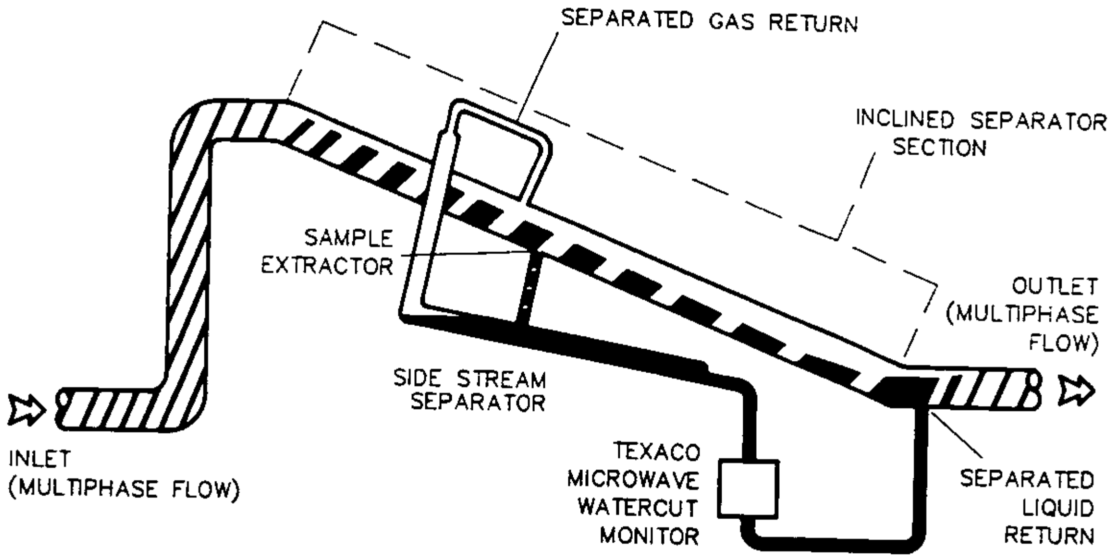

Fig. 1: Microwave Watercut Monitor Sampling System

metering system. The bulk separation of the gas and liquid achieved in the inclined separator presents the opportunity to measure the volumetric flow rates of both the liquid and gas with commercially available meters. The microwave watercut monitor then provides the means to determine oil and water flow rates from the bulk liquid flow rate measurement. The three rates, gas, oil and water, thus determined are refined by incorporating a density measurement of the bulk liquid which enables corrections to be made for gas entrained in the liquid. This then is the functional basis for the SMS (see Fig. 2).

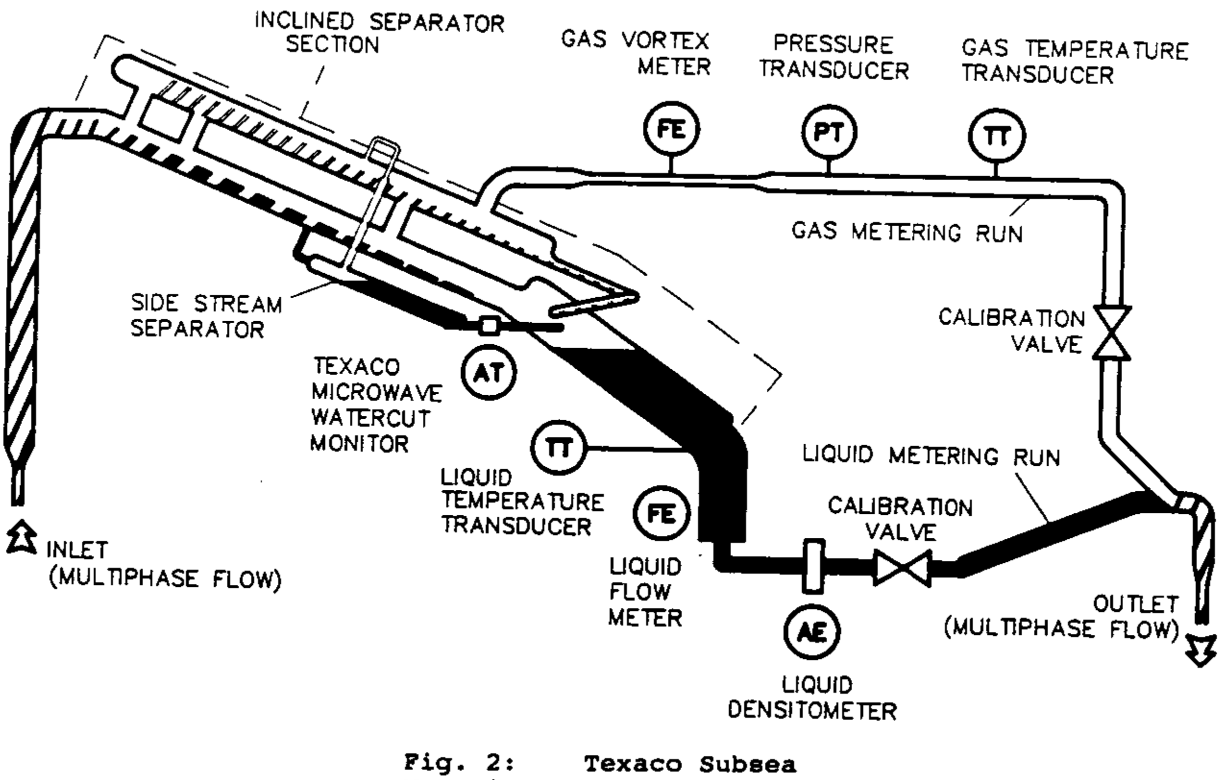

Fig. 2: Texaco Subsea Metering System Schematic

It is convenient to describe the SMS in terms of its gas/liquid separation concept, instrumentation and data acquisition system. This is done in the following sections.

3 GAS/LIQUID SEPARATION DESIGN

The design of the SMS depends on the bulk gas and liquid separating by gravity induced stratification in an inclined piping spool. The stratified liquid flowing along the bottom of the inclined pipe and containing some entrained gas has the characteristics of an open channel flow and is highly turbulent. This allows extraction of a representative sample from any point along the incline for the watercut measurement.

The liquid flows to the bottom of the incline section and back fills to form the necessary head to overcome dynamic pressure losses in liquid metering run piping. The liquid then flows through the liquid meter, the densitometer and an inclined riser leg to recombine with the gas stream.

The gas manifold, which is essentially an integral part of the inclined separator section, feeds a single piping run containing the gas meter. The gas flows through the meter to a downcomer and recombines with the liquid stream.

Passive self regulation is achieved for the entire range of flows by balancing the pressure losses in the liquid and gas metering runs through the careful selection of pipe diameters and lengths. The prototype SMS is designed to handle 3,000 to 18,000 BLPD with gas fractions ranging from 10 to 90 percent.

The microwave monitor side stream loop is itself provided with an inclined separator section and the static head developed in that separator provides the pressure required for the gas free liquid to flow through the microwave monitor and return to the main stream piping.

The system's two dimensional conceptual design was modified to give a three dimensional arrangement for the prototype SMS which fits over two adjacent Highlander template well slots for subsea testing. Initial layouts were developed by folding the two dimensional concept into parallel planes to create a more compact three dimensional design to suit the space available. Cameron-Atkins Technology performed the final detailed piping and structural design work. The three dimensional nature of the piping, numerous inclined lines and multiple fittings made it a difficult piping design problem (see Fig. 3).

The SMS is equipped with an enhanced support structure to protect it against side impacts from trawl boards, etc because its height exceeds that of the template protective structure. Future configurations of the SMS integrated into subsea installations would not require this extensive support structure.

All piping was manufactured in duplex stainless steel to provide corrosion resistance to carbon dioxide gas expected in the subsea trials.

4 INSTRUMENTATION

Priority was given to selecting passive devices with high reliabilities with the objective of developing a three phase metering system suitable for subsea service. Recognising that few instruments were designed for subsea use, vendors willing to package their instruments for this service were sought. A design depth of 300 metres and line pressure of 3640 psia were specified to assure the SMS would be capable of wide spread utilisation in the North Sea and other offshore fields. The design pressure requirement, in particular, severely limited the choice of instruments which could potentially be used.

While temperature and pressure measurement techniques are by nature passive, velocity or mass flow measurements traditionally are not. A program of testing was undertaken at EPTD's multiphase flow facility in the USA to evaluate alternative passive meters suitable for determining the gas and liquid flow rates of the separated streams. A half scale model of the conceptual SMS was used for evaluating the performance of the various instruments.

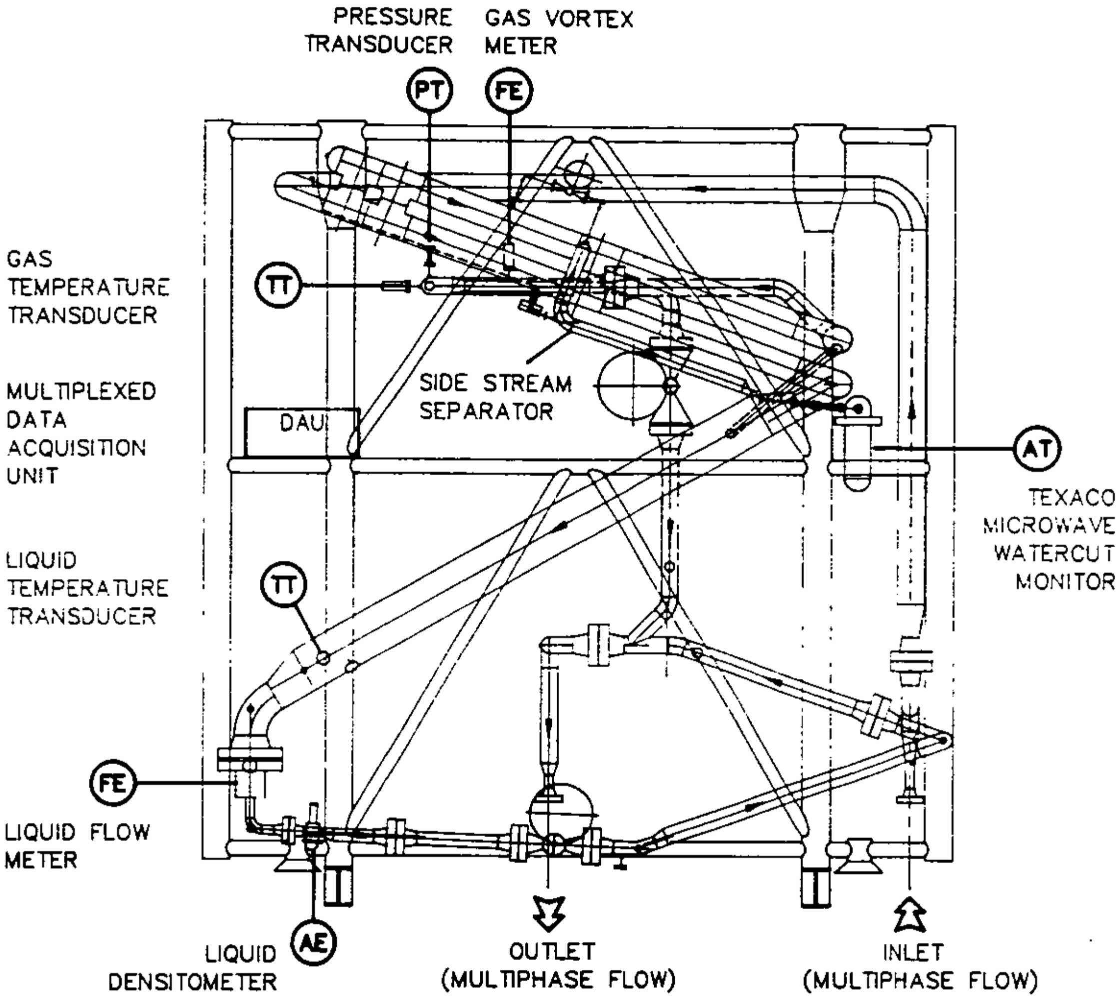

Fig 3: Elevation View of Subsea Metering System

Several vortex and time-of-flight gas meters were tested. Of these, only two were found which were actually capable of meeting the design pressure requirement, one was a vortex meter, the other a time-of-flight meter. Ultimately the vortex meter was selected as testing indicated this meter was insensitive to liquid drops entrained in the gas stream.

Finding a meter suitable for liquid flow measurement proved to be more difficult than the gas measurement. Time-of-flight, Doppler, vortex, Coriolis, and cross-correlation meters were all tested. All of these failed to perform acceptably due to the relatively high level of entrained gas in the liquid stream. Consequently EPTD developed a proprietary constriction meter to measure the bulk liquid flow. A variable orifice meter was also selected as a possible alternative for testing with the prototype SMS.

As described earlier, the Texaco microwave watercut monitor developed by EPTD provides the means of determining oil and water flow rates from the measured bulk liquid rate.

A densitometer is used to determine the bulk density of the liquid stream so the flow rates of gas, oil and water can be appropriately adjusted for the volume of gas entrained in the bulk liquid flow. A gamma ray densitometer was selected for this measurement.

Each general type of instrument will be considered individually to present some items the authors believe are worthy of note.

4.1 Pressure Measurement

The pressure transmitter is designed to meet the high specified design pressure but is spanned to give 4-20ma for 0 to 1250 psi to minimise measurement errors over the operating range of the SMS. The TransInstruments subsea transmitter was developed specifically for this application from an off the shelf topsides unit. It uses a thin film sensor which reduces the possibility of drift over time. The stated accuracy is +/- 0.5% full scale. The unit is flanged and of an all welded construction with a short flying lead to a subsea electrical connector. All external parts are manufactured from 316 stainless steel (see Fig. 4).

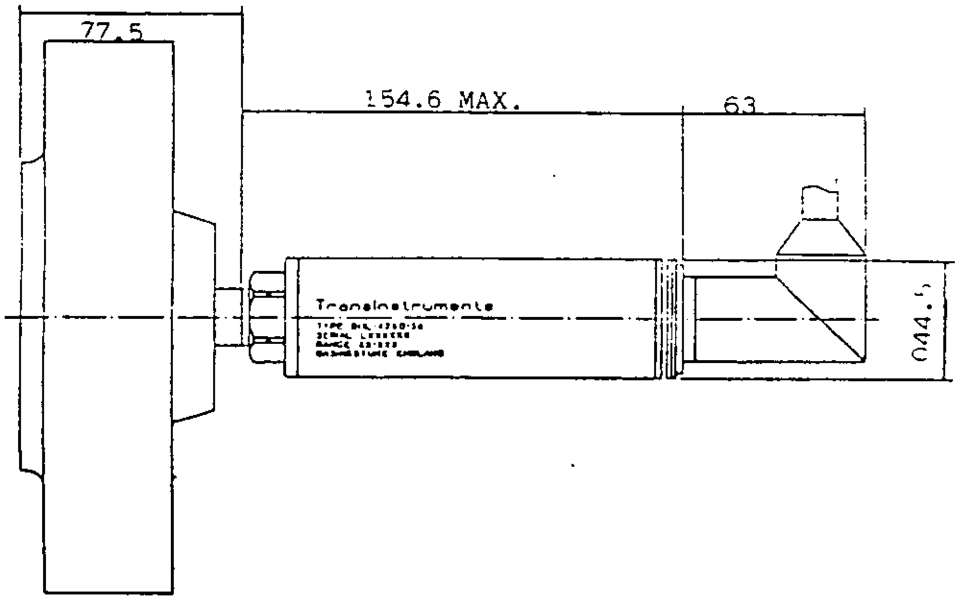

Fig. 4: TransInstruments Pressure Transmitter

4.2 Temperature Measurement

Two Bush Beach Engineering temperature transmitters are used, one in the liquid and one in the gas metering run. Each are fitted into thermowells isolating them from the process fluid. The transmitters are spanned to give 4-20 ma for the range 0 to 100° Celsius. Electrical elements are housed

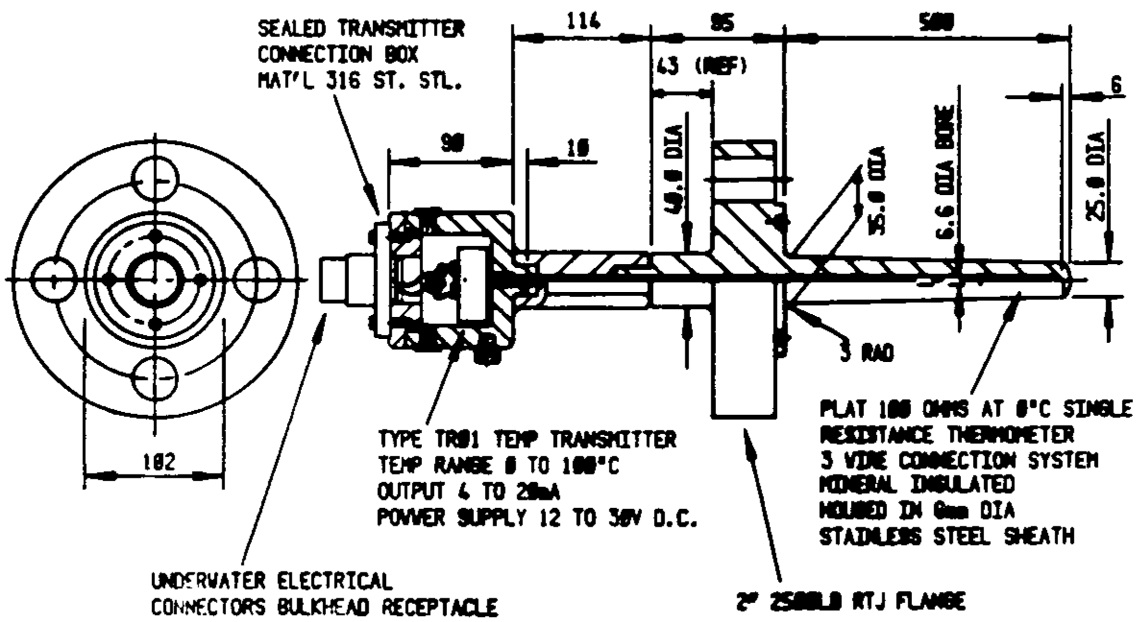

Fig. 5: Bush Beach Engineering Temperature Transmitter

in an oil filled housing which is not pressure compensated but which can withstand the full external hydrostatic pressure. A bulkhead subsea electrical connector is provided integral with the unit. All external parts are 316 stainless steel (see Fig. 5).

4.3 Densitometer

The ICI-Tracerco gamma ray densitometer is non-intrusive and designed for fast response. It consists of a small radioactive source housed in a shielded container, a detector unit and a mounting arrangement to allow the instrument to be clamped to the outside of the process piping. The densitometer contains a sensitive scintillator/photomultiplier system which produces voltages pulses in proportion to the density of the contents in the radiation beam. The output from the densitometer is an RS-232 digital message giving the number of radiation counts (see Fig. 6).

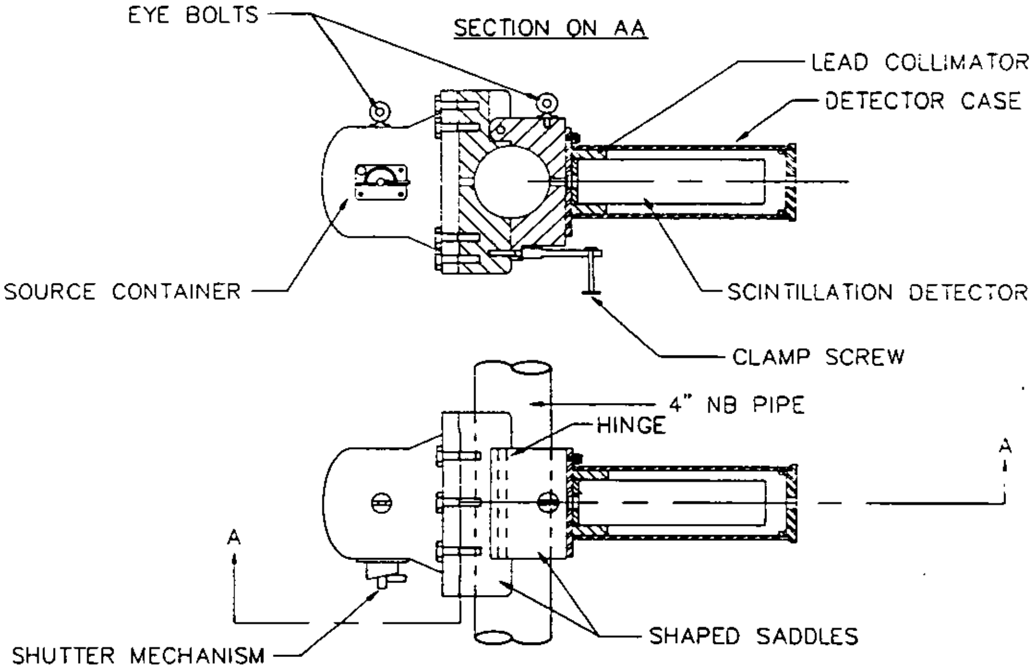

Fig. 6: ICI-Tracerco Densitometer

4.4 Gas Vortex Meter

The FSSL/Scheme gas vortex meter measures the rate of vortex shedding downstream of a shedder bar or strut using an ultrasonic beam modulated to the vortex frequency. The shedding frequency is related to fluid velocity through the fluids Strouhal number. The meter design was enhanced with pressure compensation within the sensor area using an oil filled housing and diaphragm. Meter readings are given on a 4-20 ma current loop (see Fig. 7).

It proved difficult to achieve the required gas metering accuracy over the specified range. Considerable development work was required before acceptable and repeatable onshore calibration results were obtained for high prssure gas (see Fig. 8).

4.5 Liquid Meters

The Texaco constriction meter, used to measure the bulk liquid rate, consists of a vertical piping spool with a stepped change in pipe diameter fitted with static pressure taps on either side of the abrupt transition. The taps are located nominally 0.5 upstream diameter above the transition and 1.0 downstream diameter below the transition. Two subsea differential pressure transmitters with fluid filled impulse lines are installed across the pressure taps. One transmitter is used for low range measurements and the other for high range measurements. Knowledge of the bulk liquid density

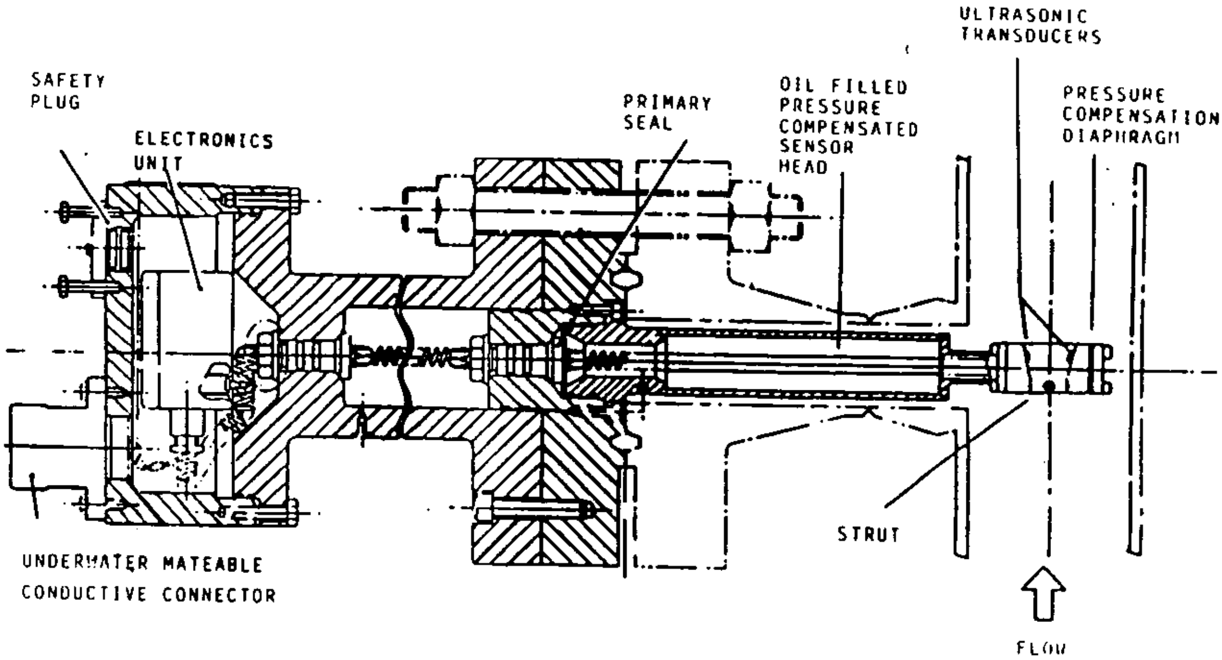

Fig. 7: FSSL/Scheme Gas Vortex Meter

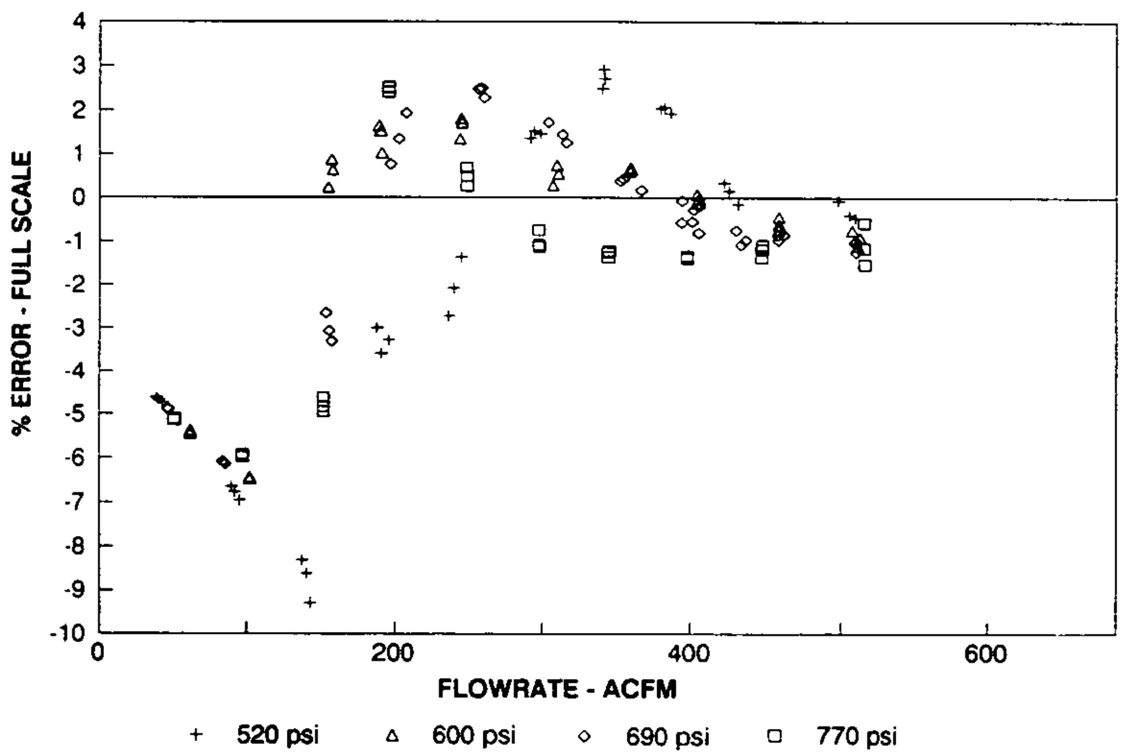

Fig. 8: Vortex Meter Single Phase Onshore Calibration

and the constriction spool coefficient of discharge allows repeatable and accurate calculation of the liquid volumetric flow rate (see Fig. 9). The geometry of the constriction meter gives a linear relationship between flow rate and the square root of differential pressure for Reynolds Numbers on the order of 10000 or higher. However, because of entrained gas in the bulk liquid stream, it is important that the constriction spool be mounted vertically to eliminate the formation of gas pockets near the abrupt transition. The differential pressure transducers give the measurements via 4-20 ma current loops.

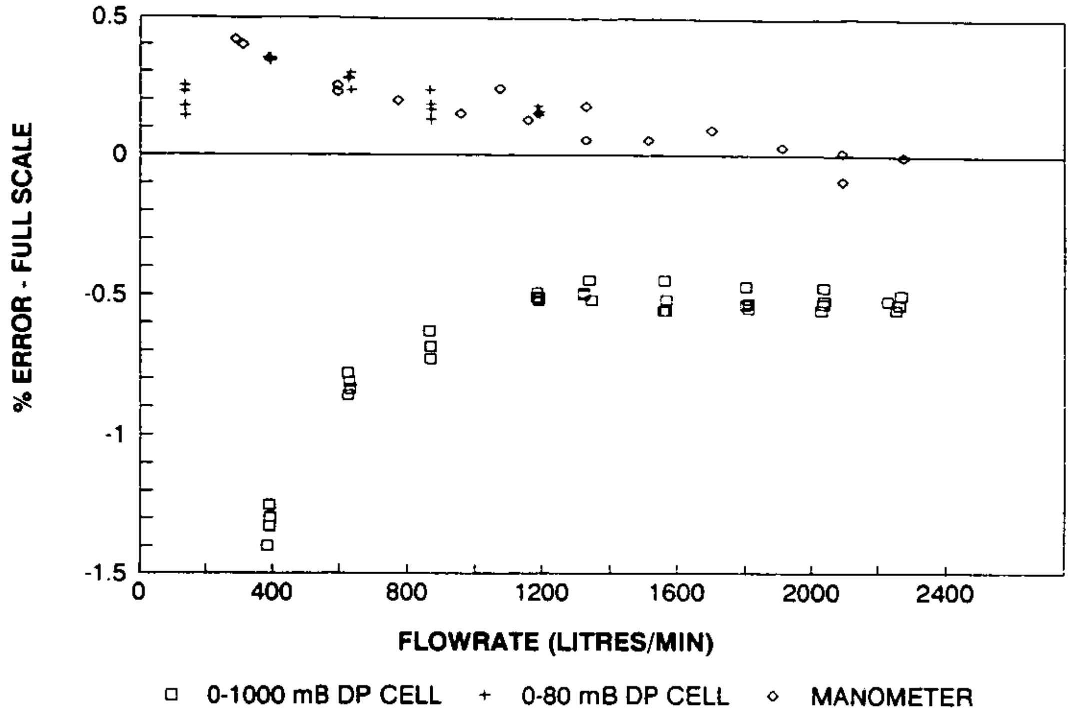

Fig. 9: Constriction Meter
Single Phase Onshore Calibration

A Gervase variable orifice meter was selected as a possible alternative to the constriction meter. Unfortunately, the configuration of the SMS restricted installation of this meter to the horizontal to provide the requisite upstream and downstream piping. Testing indicates that gas pockets will form in the meter in this orientation under certain flow conditions and these will significantly reduce the meter's accuracy. Meter readings are given by a subsea differential pressure transmitter via a 4-20 ma current loop.

Both meters use variations of the Statham Schlumberger subsea differential pressure transmitter and were supplied with bulkhead mounted subsea electrical connectors. These are accurate to +/- 0.25% full scale. All external parts are 316 stainless steel. One interesting feature is that zero and span adjustments are made externally to the hermetically sealed electronics housing via magnetically coupled links allowing re-calibration without opening the enclosure.

4.6 Texaco Microwave Watercut Monitor

The Texaco microwave watercut monitor utilises the dielectric properties of water and oil to determine the percentage of water present in the sample stream. The instrument transmits microwave signals through the liquid. The difference in the dielectric properties of oil and water enables the relative amounts of each to be determined from the change in the amplitude and phase of the microwave signals received. The microwave monitor is equipped with its own micro-processor which performs the necessary analysis to transform the measured signals into meaningful output. The watercut measurement is transmitted as a 4-20 ma signal. An RS-232 link through the Data Acquisition System allows modifications to be made to microwave monitor software from a topsides computer. The link permits software updates, calibration checks and general troubleshooting.

5 DATA ACQUISITION SYSTEM

This system, supplied by N L Shaffer/Liebnitz-Lann, consists of two parts, the Surface Computer Unit (SCU) and the subsea Data Acquisition Unit (DAU). The DAU is of greater interest as it controls power to and transmits signals from SMS instruments.

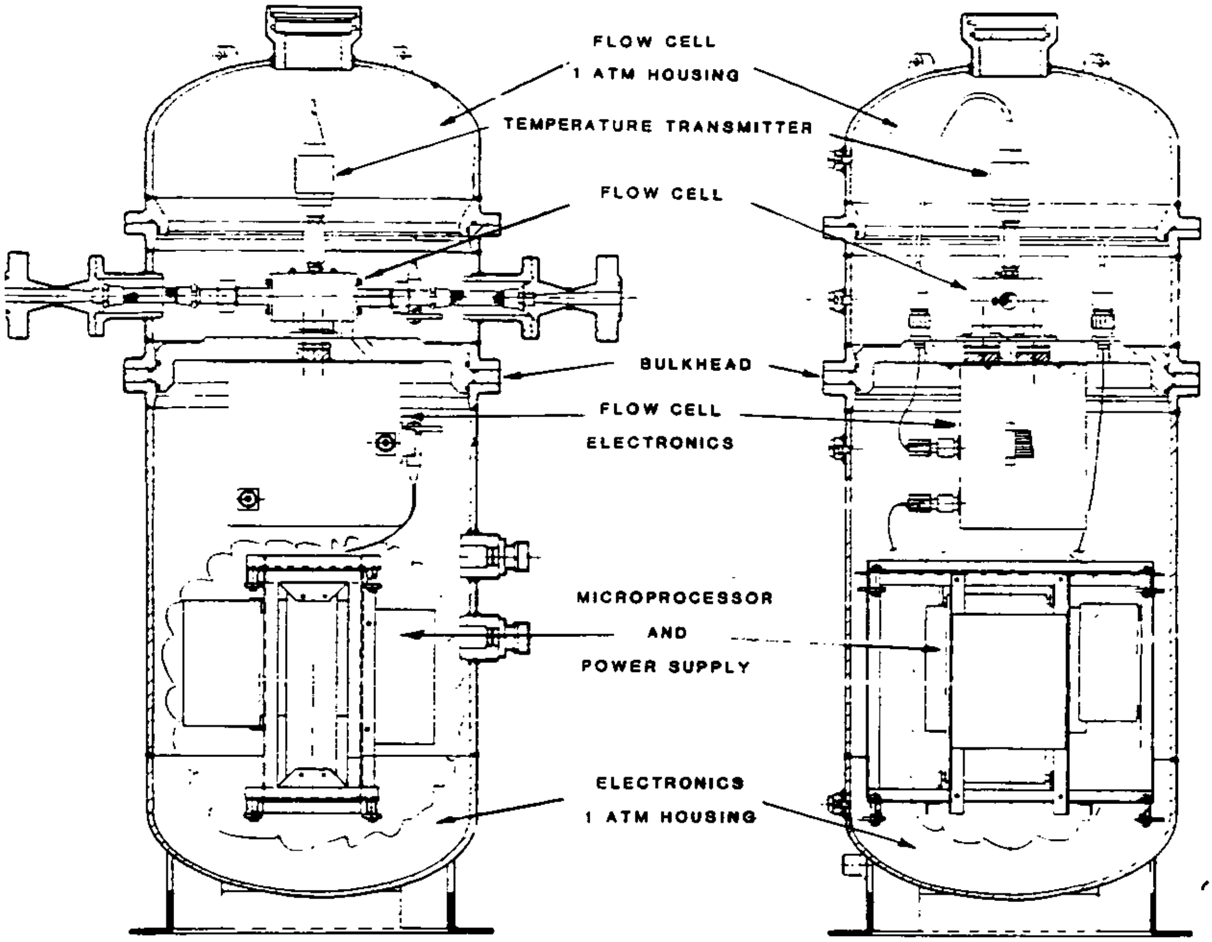

Fig 10: Texaco Subsea Microwave Watercut Monitor (N L Shaffer Enclosure)

To optimise reliability, the DAU was designed as a dual redundant system, the only common component between the dual sub-systems being a coupling transformer to the communications link. All components used are to industrial standard and the finished assembly was subjected to rigorous temperature cycling. Reliability is further enhanced by sending data from the DAU automatically, without prompting by the SCU, to avoid the risk of potential downlink faults.

The DAU has thirteen 12 bit analogue channels and five RS-232 ports to provide redundancy to SMS instruments should any of its subsea connectors become damaged. Connections are made via Tronic subsea pin-to-pin electrical connectors. Large pin sizes are used to minimise contact resistances for the analogue circuits. The DAU accepts downloaded configuration information from the SCU. The DAU multiplexes the raw data and transmits it topsides to the SCU via a Frequency Shift Keyed (FSK) modem link. Power to the SMS instruments can be switched on and off by the DAU.

For the subsea trials, the DAU will transmit its data to the SCU through an unused spare signal cable in the FSSL Highlander subsea control system via an inductive signal coupler. Power will be drawn from the electrical distribution system with FSSL inductive power couplers.

6 INSTALLATION AND TESTING ON THE TARTAN PLATFORM

The SMS was installed on the Tartan Platform during May and June 1989 and testing commenced soon thereafter. Over 150 runs were performed using production from several different wells with various production rates, gas/liquid ratios and watercuts. Difficulties with the gas vortex meter were experienced and it was later learned that it had an electrical fault. These tests confirmed the viability of the metering system although foaming of the crude limited the flow range which the system could handle.

The foaming was caused in part by small diameter piping used to transport the production stream from the test manifold to the SMS, which was mounted on the skid deck of the platform. The pipe size is however representative of flowline and manifold pipework the system will utilise in subsea installations. At the maximum design limit of the SMS, the velocity of the fluid in this piping exceeded 35 m/s. Foaming remained a problem because of the limited residence time available within the SMS. If the gas entrained in the liquid stream exceeds approximately 35 to 40 percent, the bulk liquid level will rise to the point where considerable liquid will be carried into the gas leg. This results from high pressure losses in the liquid leg due to the increased volumetric flow. Insufficient height is available in the inclined piping for this bulk liquid of relatively low density to develop the required head. Hence, the self regulating balance of pressure losses between the gas and liquid legs is lost and the system fails to function properly.

At the conclusion of the 1989 tests on Tartan, a program of enhancements was undertaken using further model studies. A half scale perspex model of the SMS was fabricated and tested using water and air. A small quantity of alcohol was added to the water to promote foaming.

Through testing of the perspex model several enhancements to the SMS design were made. These included a proprietary centrifugal device for suppressing foam, a vortex breaker for the constriction meter, flow straightening vanes before the gas vortex meter and minor changes to the liquid leg piping runs to eliminate gas pockets.

7 FUTURE

The final modifications of the SMS are currently being made in conjunction with continued testing on Tartan. The topsides testing is scheduled to be completed by the end of this year. The SMS will then be taken to shore to be equipped for installation on the Highlander subsea template in early 1991.

Much of the credit for this work goes to the specialist suppliers who have gone to great effort to develop key subsea instruments. It is believed many of these instruments will be used in other applications such as the subsea metering of lift gas and water injection.

Texaco and Jiskoot Autocontrol are excited that the project is nearing the point of proving this important new technology and believe its first commercial use on a new development could be as early as 1992.

REFERENCES

1. HATTON, G.J., HELMS, D.A., MARRELLI, J.D. and DURRETT, M.G. - A New Microwave-Based Water-Cut Monitor Technology. OTC 6426, OTC 1990.

2. ABRAHAM, K.S. and TERRELL, H.D. - Latest Technology Stresses Smarter, Quicker Operation. World Oil, July 1990.

3. HATTON, G.J. - Wellhead Metering of Gas/Oil/Water Production Streams. North Sea Flow Metering Workshop, October 1986.

4. DEAN, T.L., DOWTY, E.L. and JISKOOT, R.J.J. - The Development of a Subsea Three Phase Metering System. European Oil and Gas Conference, Palermo, October 1990.