FRAMO MULTIPHASE FLOWMETER - PROTOTYPE TEST

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SUMMARY

A prototype test of the FRAMO Multiphase Flow Meter has been performed under flow conditions typical for North Sea oil and gas production systems.

The prototype includes a combination of the FRAMO flow mixer, a multi-energy gamma meter and a venturi meter built together with a barrier fluid arrangement and electronic processing equipment in a vertical stack.

The results show that the multiphase flow meter can be used to measure volume fractions and flow rates of oil, water and gas over the entire range of gas volume fractions 0 - 100% and water cuts 0 - 100%.

Most of the test points measure liquid volumetric and total mass flow rates well within +/- 10% relative error.

CONTENTS

1.0 INTRODUCTION

Multiphase metering has recently been subject to increasing interest due to its potential to enhance reservoir management and reduce capital expenditure and operating costs by eliminating the need for test separators and dedicated test lines. These advantages are particularly important for marginal fields and subsea satellite developments.

Several different methods can be used to distinguish between oil, water and gas in a production stream. One technique based on the attenuation of gamma rays at two energy levels was developed by Mitsubishi Electric Corporation (MELCO) in 1984/85. A prototype gamma ray compositional meter was built and extensively tested by MELCO, Petro-Canada Inc. (PCI) and Alberta Research Council (ARC), including a field test in 1987 and a subsequent flow loop test of a modified version in 1988, ref. /1/.

The meters capability of measuring volume fractions of oil, water and gas was demonstrated, and the results were excellent for homogeneous flow. However, due to flow effects such as phase slip and slugging, practical applications of the meter were limited to conditions with very low gas contents.

A static flow mixer was developed and tested by Framo Engineering AS in 1988, as part of the Subsea Multiphase Booster Station (SMUBS) programme for boosting of unprocessed well stream. It was demonstrated that the flow mixer significantly improves booster performance at multiphase conditions, and particularly at slugging conditions, use of the flow mixer is mandatory.

During the last five years this mixer has been extensively tested, and its performance has been demonstrated in flow loops and during several field tests. Today, the mixer is an integrated part of several multiphase booster concepts, including a version of the SMUBS which will be installed for subsea duty at the Draugen field in 1993, and the POSEIDON pump which will be installed on the Gullfaks B platform the same year.

In 1990 a joint industry project was established to qualify the combination of the FRAMO mixer, the MELCO compositional meter and a standard venturi meter for measuring oil, water and gas flow rates under flow conditions typical for North Sea oil and gas productions systems.

A successful test was performed in a high-rate oil, water and gas test facility. Tests with and without the mixer showed that the mixer was able to eliminate upstream flow effects well enough to obtain accurate and repeatable estimates of oil, water and gas flow rates. The test results was presented in ref. /2/.

Encouraged by the results we started the development of a subsea version of the tested metering system. A functional prototype for dry testing was designed and manufactured with some of the subsea parameters and equipment configuration aspects included. The subsea elements are based on the available SMUBS technology. The subsea flow meter was presented in ref. /3/.

This paper presents the test results from the prototype test of the FRAMO multiphase flow meter performed at the FRAMO test facility at Fusa, Bergen this year.

2.0 MULTIPHASE METERING

Multiphase flow metering without first applying phase separation is difficult due to the different flow effects resulting from the interminable variety of phase distribution which can occur in such flow.

The most important flow effects which can affect meter performance are:

- Uneven phase distribution
- Locally unsteady flow
- Phase slip

These effects are closely connected to various flow regimes. However, since flow regime description to some degree is arbitrary and the transitions between different flow regimes is a gradual process, the impact on flow meter performance can not be sufficiently predicted.

The implications of this are twofolds. Primary sensor response will obviously be sensitive to the flow effects, which not necessarily correlates with the quantities to be measured. Sensor integration and interpretation are therefore difficult and critical.

However, more seriously is the lack of reproducability, and the need for in-line calibration at various flow conditions. Since flow conditions will not only change from field to field, but also during time for a given field, such calibration will neither be practical nor will it normally be possible.

The flow conditions will also depend on the actual physical location in the process relative to risers, manifolds, bends, etc. Conveying the performance of a multiphase flow meter from one system to another will therefore always be questionable.

Generally two approaches exist to these problems. One method is to measure the individual phase fractions and related phase velocities. To establish the mass flow rates of the three phases, oil, water and gas, five measurements are required; three velocities and two phase fractions (the third being reduced since the sum of the three phase fractions equals unity).

The other method, which is applied in the FRAMO multiphase flow meter, makes use of a flow mixer and measures the individual phase fractions and the velocity of the mixture. In this case the required number of measurements are reduced from five to three.

The application of an effective flow mixer to eliminate or reduce the influence of flow effects, is in this case essential in order to obtain accurate, repeatable and reproducable estimates of the individual oil, water and gas flow rates.

Multiphase flow metering in general is further complicated by the fact that it is utmost difficult to measure small components of a large system with high relative accuracy. This can be illustrated by the production composed by 90% gas volume fraction and 90% water cut. In this case the oil volume fraction is only 1% to the total production. A typical uncertainty in the fraction measurement for such conditions might be in the range 1-5%, resulting in 100-500% relative error in the measured oil fraction, 11-56% relative error in the measured water fraction and 1.1-5.6% relative error in the measured gas fraction. This fundamental problem will probably impede the use of multiphase metering for fiscal applications yet for a long time.

3.0 MULTIPHASE FLOW METER - PROTOTYPE

The multiphase flow meter prototype was originally designed to meet some of the requirements to a subsea retrievable installation, refer to figures 3.0.1-3.0.2.

The technology forming the basis for a subsea flow meter 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 which totally protects it from the environments. The cartridge requires no orientation, and hence the crude inlet and outlet enter and leave the barrel through ring volumes sealed axially by pressure energized resilient seals.

Key elements such as:

- running tool
- lock-down mechanism
- receiver barrel
- cartridge seal system
- barrier fluid arrangement

have all reached a commercial level through the SMUBS project. In addition, an integrated wet mateable electric/signal connector has been developed and tested by Framo.

The multiphase flow meter prototype includes some of these elements such as the receiver barrel, cartridge seal system and the barrier fluid arrangement. The retrievable flow meter cartridge consists of these elements:

- Flow Mixer
- Multi-energy Gamma-Meter
- Venturi Meter
- Cartridge Seal System
- Barrier Fluid Arrangement
- Electric/Signal Connector
- Monitoring/Control System

3.1 Flow Mixer

The functional schematic of the flow mixer is shown in figure 3.1.1. The purpose of the mixing unit is to provide always identical homogeneous flow conditions in the measuring section, independent on upstream conditions.

Turbulent mixing is efficiently utilized in a turbulent shear layer, resulting in minimum pressure loss. The feature of axial mixing incorporated in the unit makes it possible for efficient operation also during intermittent and slug flow conditions.

The flow mixer is a purely static device comprising a tank into which the multiphase flow is fed. The most dense part of the fluid is drained from the bottom of the tank through an ejector, while the least dense part is drained from the top and directed via a pipe back to the ejector, where it is mixed with the dense part of the fluid, according to the ejection ratio.

Operation of the flow mixer can be described by grouping the various multiphase flow regimes into Dispersed, Separated and Intermittent flows.

DISPERSED or distributed flow regimes such as bubbles in the liquid or droplets in the gas:

This flow is by its nature already well mixed. The same mixture will therefore be drained from the top and the bottom of the tank, and mixed together in the ejector. Due to the very short residence time, there is no phase separation occurring in the tank.

SEPARATED flow regimes, such as stratified or annular flow with low entrainment rates:

In this case each phase is continuously distributed in the axial direction, resulting in a steady feed of both liquid and gas into the tank. Since the phases are already separated, the gravity force will result in the formation of a liquid pool in the lower part of the tank with a body of gas above it. The liquid flow from the pool creates a suction in the ejector. This draws gas from the top of the tank via a pipe into the liquid flow. The resulting gas volume fraction is in accordance to the ejection ratio. In the ejector where the gas and liquid meet, a strong shear layer is created. Consequently an effective turbulent phase mixing takes place in the downstream section.

INTERMITTENT flow regimes, such as slug flow and elongated bubble flow:

In this case the performance of the mixer is similar to the separated flow case, except that the gas and liquid are not continuously fed into the tank. Instead, gas bubbles and liquid slugs are entering the tank in a successive manner, causing the liquid level in the tank to vary. However, the perforations in the interior pipe acts as an integral regulator, ensuring that there is always both liquid and gas present in the tank. As the liquid level in the tank decrease and more gas flows through the perforations, the gas volume fraction drawn from the mixer will increase and consequently the liquid level will stabilize. If on the other hand, the liquid level increases, more liquid will flow through the perforations. This liquid will also partly choke the gas flow. As a result, the gas volume fraction drawn from the mixer will decrease, and consequently the increase in liquid level will be reduced. This system is stable and the liquid level will always find its equilibrium position.

3.2 Multi-Energy Gamma Meter

The multi-energy gamma meter provides the fractions of oil, water and gas in the flow, which can be considered as volume fractions since the gamma meter is located immediately downstream the flow mixer.

Calculation of the oil, water and gas fractions is based on the attenuation of different gamma energy levels. The prototype meter consists of two gamma isotopes, Americium 241 and Barium 133 with collimators and two independent NaI (Tl) scintillation detectors of ruggedized design, which can accept rapid temperature changes and sustain shocks and vibrations.

The energy levels which can be used for determining the fractions are 18 keV and 60 keV from the Am 241 source and 30 keV, 80 keV and 350 keV for the Ba133 source. The combination of two different energy levels is sufficient to determine three fractions, since the third fraction can be deducted from continuity.

The use of a low energy level 18 keV or 30 keV is essential in order to distinguish between oil and water. It is, however, important that the pipe wall is transparent to the low energy gamma rays, since these absorb very quickly. A Boron Carbide cylinder is used as a gamma ray window material. Independent tests have shown that this material is very transparent for low energy gamma rays, and yet strong and hard enough to sustain the design pressure of 345 bara and any practical erosional load.

3.3 Venturi Meter

A venturi meter arrangement is used in combination with the gamma fraction meter to obtain the flow rates of oil, water and gas. This is possible since the venturi meter is located immediately downstream the flow mixer. Here the multiphase mixture can be treated as a single-phase fluid with an equivalent mixture density, and the single-phase venturi relation can be applied. Defining the equivalent mixture density as:

$$\rho_m = OVF \cdot \rho_{OIL} + WVF \cdot \rho_{WATER} + GVF \cdot \rho_{GAS} \tag{3.3.1}$$

the relation between venturi differential pressure (DP) and total mass flow rate (m_T), can be written as:

$$m_T = C_F \cdot C_G \cdot Y_{am} \cdot \sqrt{\rho_m \cdot DP} \tag{3.3.2}$$

where;

$$Y_{am} = GVF \cdot Y_a + (1 - GVF) \tag{3.3.3}$$

Y_a is the gas expansion factor, C_G is a geometry constant and C_F is the venturi flow coefficient. The venturi differential pressure is the measured differential pressure corrected for the static height between the pressure ports. Similar to the practice in single-phase measurements, the venturi flow coefficient must be found by calibration. This is possible since the total mass flow rate and the mixture density are known from the reference measurements.

It is an increase in dynamic pressure rather than the fluid velocity which is measured with a venturi meter. The fluid velocity as calculated from the venturi meter is therefore dependent on the mixture density obtained from the gamma meter. This is of great advantage when the flow rates of the liquid components are sought, because an error in the liquid fraction will be partly compensated by a resulting opposite error in the calculated fluid velocity.

The prototype venturi meter has a β ratio of 0.71, and is configurated with high precession quartz crystal absolute pressure sensors, (Digiquartz 46K). These sensors are temperature compensated. By using absolute pressure sensors, the measured venturi differential pressure is not influenced by the density of the fluid in the wet legs. Included in the venturi meter is an arrangement which allow a continuous or intermittent flushing of the wet legs. This way any contamination in the wet legs is prevented, which otherwise could lead to a blockage of the pressure ports. Flushing becomes particularly important for subsea and long term applications.

3.4 Cartridge Seal System

The seal system provides the sealing of the inlet and outlet ring volumes. Double pressure energized lip seals above and below the ring volumes ensure proper sealing against the environment.

In a subsea installation, the seals are set and pressure tested via the running tool during installation and a pressure higher than wellhead pressure is maintained during operation of the flow meter. This pressure is fed through the barrier fluid arrangement.

3.5 Barrier Fluid Arrangement

The barrier fluid arrangement provides for cleaning and protection of vital elements in the flow meter cartridge. Important features are:

- Flushing of venturi wet legs to prevent contamination
- Flushing of electric/signal connector (for subsea applications)
- Cartridge seal setting pressure

3.6 Electric/Signal Connector

The electric/signal connector used for subsea installations provides for transmission of low voltage power and signals to and from the cartridge and consist of two assemblies:

- A female part integrated in the flow meter receiver barrel lower end
- A male connector mounted at the lower end of the flow meter cartridge

The connector requires no orientation and is made up simultaneously with the installation of the flow meter cartridge. The connector allows supply of hydraulic fluid to the barrier fluid arrangement.

3.7 Monitoring/Controls System

Communication with the prototype flow meter is performed via the control system which is located in and forms an integrated part of the flow meter cartridge.

The control system which applies transputer technology, conditions the signals from gamma-meter detector and the sensors and transmits them to the topside control unit (host computer) for further processing. The topside control unit will typically provide data communication, power transmission to subsea flow meter and remote calibration of the multiphase flow meter.

4.0 PROTOTYPE TEST

4.1 Test rig arrangement

The multiphase flow meter has been tested in a closed loop, where individual measurements of single-phase oil, water and gas streams were compared with the multiphase flow meter measurements on the combined oil-water-gas stream. The fluids used are Exsol D80, fresh water and nitrogen gas. Schematic of the test rig arrangement is shown in figure 4.1.1.

Oil is taken from the oil outlets of four identical vertically installed three-phase separators and routed to a horizontally installed two-phase oil-water separator for removal of any remaining water. The oil from this two-phase separator is then routed through pumps, a single-phase oil reference metering section and a remotely operated control valve before it is combined with the water and gas streams. Oil saturation pressure and temperature is measured at the oil exit from the three-phase separators.

Water is taken from the water outlets both from the four three-phase separators and the two-phase oil-water separator and routed to a large low pressure water tank for removal of any remaining oil. The water from this water tank is then routed through pumps, a single-phase water reference metering section and a remotely operated control valve before it is combined with the oil and gas streams. Any oil from the water tank is routed through a pump back to the three-phase separators.

Gas is drawn from the top of the four three-phase separators and routed through a gas compressor, a single-phase gas reference metering section and a remotely operated control valve before it is combined with the oil and water streams. Strainers and scrubbers are located both at the suction and the discharge side of the compressor.

The combined oil-water-gas stream is routed through a 26 m long 3" flow loop to ensure that any three-phase flow regimes are fully developed. Part of the flow loop has been made of transparent material, allowing flow regime visualization and registration. The stream is then routed through the multiphase flow meter and back to the four three-phase separators. Pressure is measured upstream and downstream the multiphase flow meter, so that the total pressure loss through the multiphase flow meter can be calculated.

To enhance test rig operation, the oil and water pumps are ajustable by means of two independently and remotely operated frequency converters, while the gas compressor is equipped with a remotely operated flow control valve.

The oil and water streams can each be individually routed to an open tank with an accurate known volume. This way the respective flow rates instruments can be checked, or when necessary recalibrated. Samples of the single phase oil, water and gas streams are taken regularly during testing and analysed in order to monitor separator efficiency.

4.2 Test rig instrumentation

As a reference to the multiphase flow meter the flow rates of oil, water and gas through it are calculated based on measurements of the single-phase oil, water and gas streams and known PVT correlations for the different phases. Minimum, maximum and standard deviations of the single-phase measurements during the sampling time are obtained as well.

The single-phase measurements are corrected for any water in the oil caused by an incomplete oil-water separation, and for the difference in the amount of gas dissolved in the oil and the water between the multiphase flow meter station and the single-phase metering stations.

Dual instrumentations are used for critical measurements. The arrangement and specification of the test rig instruments are shown in figures 4.2.1-4.2.5. For each instrument an operating range has been defined to ensure an optimum overall accuracy.

All instruments has been factory calibrated with the actual fluids used in the test rig. PVT-data of the fluids has been obtained from specific laboratorium analysis.

4.3 Test conditions

It was aimed to simulate flow conditions typical for North Sea oil and gas production systems, and emphasis was given on creating realistic flow regimes. Most of the tests were run in the slug flow regime, which is believed to represent the most demanding conditions.

Initially several two-phase conditions was tested in order to verify the mixer performance and the ability of the gamma fraction meter to distinguish between the different phases. The gamma meter was calibrated on single-phase oil, water and gas.

The following four test series have been performed, and are described in this paper:

TWO-PHASE OIL and GAS		
	Total flow rate:	20-230 m3/h
	Gas volume fraction:	30-95%
	Pressure:	9-14 bara
	No. of test points:	155
TWO-PHASE WATER and GAS		
	Total flow rate:	20-185 m3/h
	Gas volume fraction:	5-90%
	Pressure:	9-12 bara
	No. of test points:	68
TWO-PHASE OIL and WATER		
	Total flow rate:	20-135 m3/h
	Water cut:	5-85%
	Pressure:	3-11 bara
	No. of test points:	44
THREE-PHASE OIL, WATER and GAS		
	Total flow rate:	60-220 m3/h
	Gas volume fraction:	30-85%
	Water cut:	5-70%
	Pressure:	6-10 bara
	No. of test points:	140

5.0 RESULTS

Performance of the Multiphase Flow meter is evaluated by comparing measured and reference quantities. "Measured" refers to the measurements obtained with the Multiphase Flow meter. When the term "error" is used, it is assumed that the reference quantity is correct, and the error is then relative to this quantity.

Some of the results obtained by using 18 keV from the Americum 241 were hampered by drift in the gamma meter, so this option could not be fully explored. All the results presented were obtained by use of the Barium 133 source. The two-phase results were obtained from the 30 keV energy level, while the three-phase results from the combination of the 30 and 350 keV energy levels. The sampling time was always 1 minute.

The isolated performance of the venturi meter is expressed through the venturi flow coefficient as defined in section 3.3, equations 3.3.1-3.3.3. It should be noted that any error in the measured venturi differential pressure or in the reference flow rates will also affect the venturi flow coefficient the way it is defined here.

The flow rate measurement results, as presented in this paper, are obtained by using a venturi flow coefficient equal to unity.

5.1 Two-phase Oil and Gas

Measured and reference gas volume fractions are compared in figure 5.1.1, and the corresponding relative errors in the measured gas and oil volume fractions are shown in figures 5.1.2 and 5.1.3 respectively.

The venturi flow coefficient is shown in figure 5.1.4.

Figures 5.1.5-5.1.7 compare measured and reference oil volumetric flow rates, gas volumetric flow rates and total mass flow rates respectively, while figure 5.1.8 shows the corresponding relative errors in the measured total mass flow rates.

5.2 Two-phase Water and Gas

Measured and reference gas volume fractions and total mass flow rates are compared in figures 5.2.1 and 5.2.2.

5.3 Two-phase Oil and Water

Measured and reference water cuts and total mass flow rates are compared in figures 5.3.1 and 5.3.2.

5.4 Three-phase Oil, Water and Gas

Measured and reference gas volume fractions, oil volume fractions and water cuts are compared in figures 5.4.1-5.4.3 respectively.

The venturi flow coefficient is shown in figure 5.4.4.

Figures 5.4.5-5.4.8 compares measured and reference liquid, oil, water and gas volumetric flow rates respectively, while measured and reference total mass flow rates are compared in figure 5.4.9. The relative error in the total mass flow rates is shown in figure 5.4.10.

6.0 DISCUSSION

Results from the two-phase oil and gas tests show that the gas volume fraction is predicted with good accuracy and repeatability over the whole range tested.

This has been possible since flow regime effects have been eliminated by the flow mixer. Nevertheless, large relative errors are associated with small volume fractions.

Also the venturi meter shows good performance over the whole range tested, with an average flow coefficient of 0.96. This shows that a simple equivalent single-phase venturi equation is valid for a venturi meter located immediately downstream the flow mixer. All flow rate measurements have been obtained by using a venturi flow coefficient equal to unity.

The oil volumetric and total mass flow rates correlate well with the reference values, while some more scatter is observed in the gas volumetric flow rates. By replacing the applied venturi flow coefficient of unity with the calibrated flow coefficient of 0.96, all measured flow rates would have been reduced by 4%, resulting in additional improvement of the accuracy.

Observe that the relative errors in the total mass flow rates, as obtained by combining the volume fraction measurements with the venturi measurements are significantly less than the relative error in the volume fractions. This is a favourable feature of applying a venturi meter.

The two-phase water gas tests (100% WC) and the two-phase oil water tests (5 - 85% WC) show similar performance to the two-phase oil gas tests.

Results from the three-phase oil water gas tests show that the gas volume fraction is predicted with good accuracy over the whole range tested. The predictions of water cuts are more scattered, however, some of the scattering can be explained by a slight drift in the gamma meter, and the fact that the gamma meter needed a longer warm-up period to stabilise than initially anticipated.

It is possible that these results could have been improved by an increased sampling time beyond one minute.

The venturi meter shows acceptable performance with an average flow coefficient equal to 0.96 for the range up to 60% gas volume fraction.

The venturi flow coefficient appears to increase slightly for higher gas volume fractions. However, it should be kept in mind that the flow coefficient as defined here, is affected by the accuracy and repeatability in the pressure sensors which, despite their high quality specifications, were no better than 0.02 bar. This influence can be particularly significant at high gas volume fraction.

The average value of the venturi flow coefficient for all the three-phase test points is equal to 1.0.

All flow rate measurements have been obtained by using a venturi flow coefficient equal to unity over the entire range. The liquid volumetric and total mass flow rates correlates well with the reference values while more scatters are observed in the individual components' flow rates. 90% of all the three-phase test points are measured within +/- 10% relative error in the total mass flow rates.

7.0 CONCLUSIONS

The results presented show that the FRAMO Multiphase Flow Meter can be used for measuring oil, water and gas volume fractions and flow rates over the entire range of gas volume fractions from 0 - 100% and water cuts from 0 - 100%, and under flow conditions typical for the North Sea oil and gas production systems.

The use of 30 keV and 350 keV energy levels from the Barium 133 source enabled accurate estimates of gas volume fractions and reasonable estimates of water cuts.

The venturi meter shows good performance over the entire range tested, with an average flow coefficient close to unity. This demonstrates that a simple equivalent single-phase venturi equation holds for a venturi meter located immediately downstream the flow mixer.

For most of the test points, liquid volumetric and total mass flow rates are measured well within +/- 10% relative error.

ACKNOWLEDGEMENTS

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30 March - 1 April 1992 in Bergen, Norway.

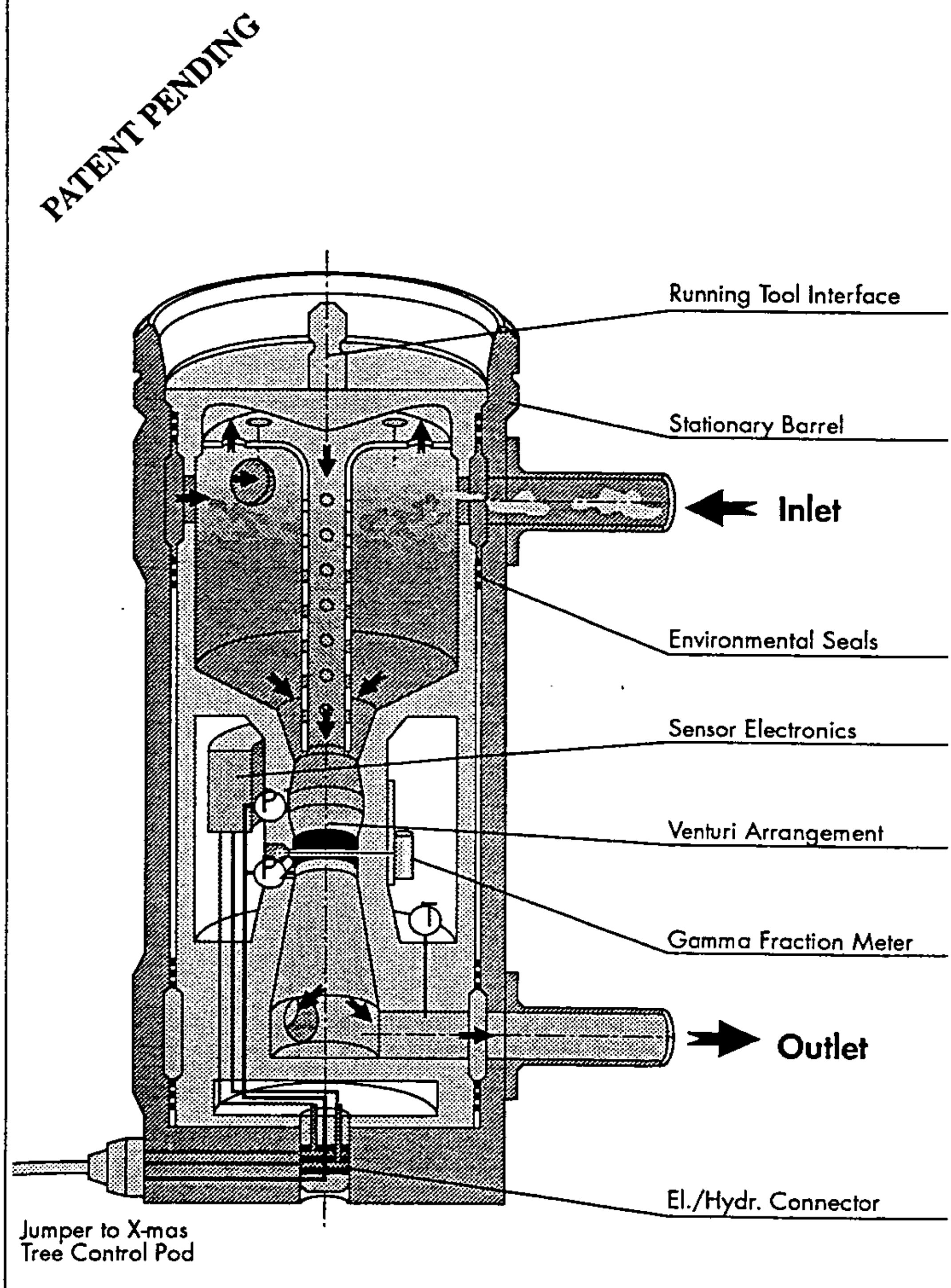


FIGURE 3.0.1: FRAMO SUBSEA MULTIPHASE FLOWMETER

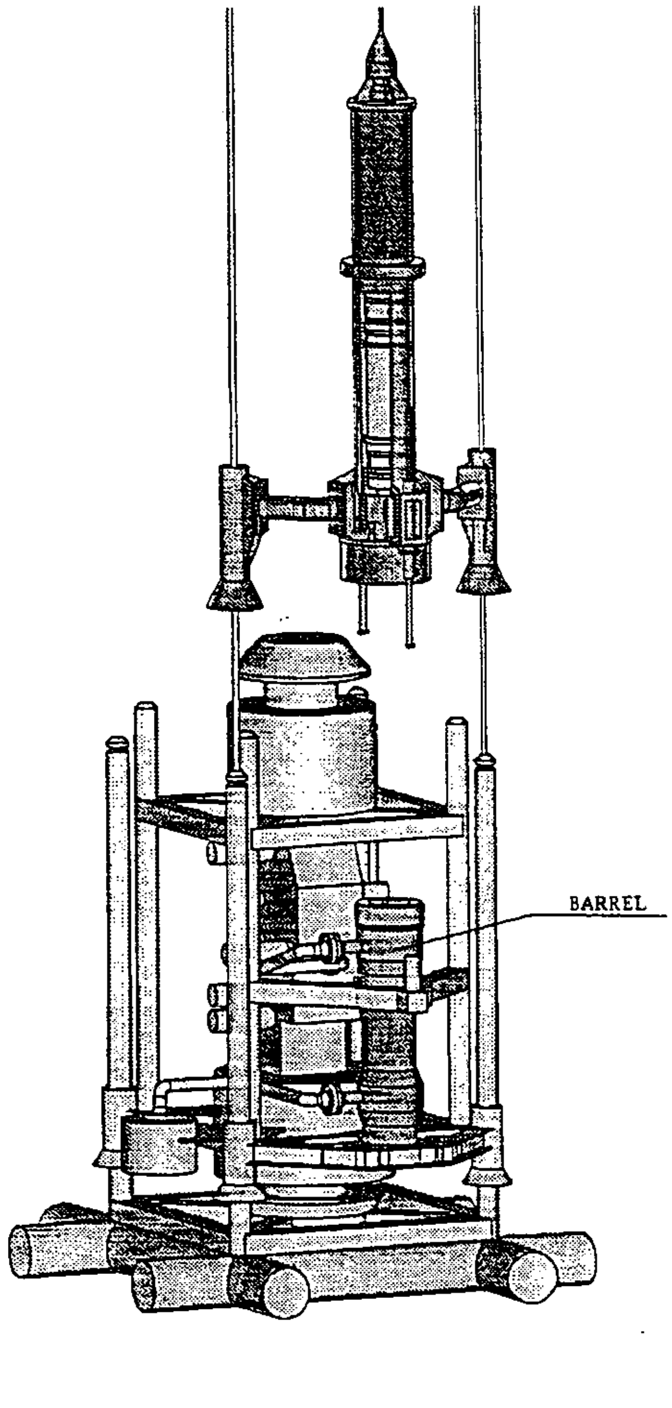


FIGURE 3.0.2: FRAMO SUBSEA MULTIPHASE FLOWMETER INSTALLATION

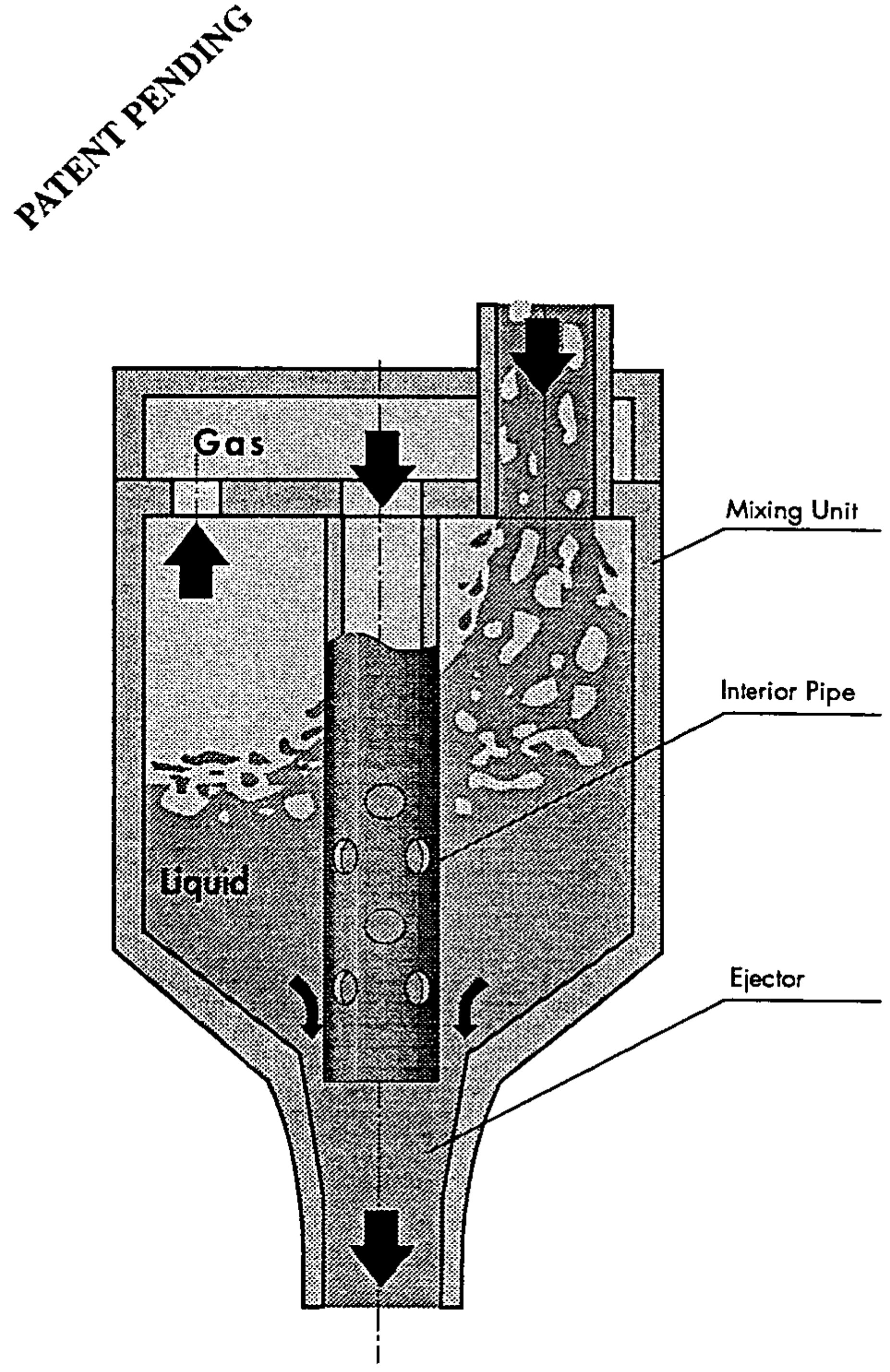


FIGURE 3.1.1: FLOW MIXER SCHEMATIC

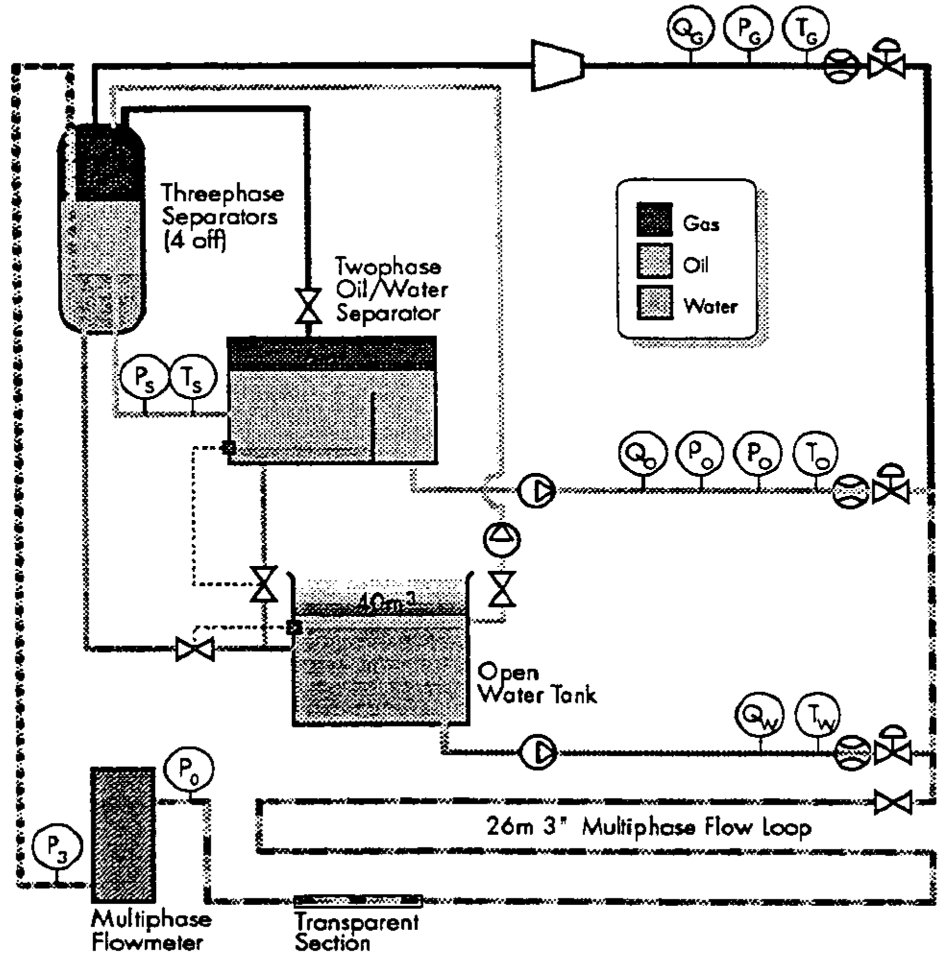
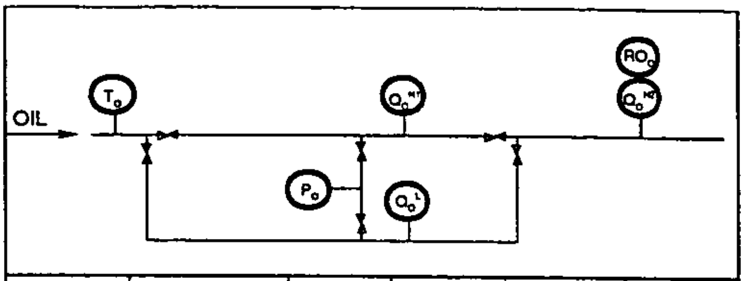
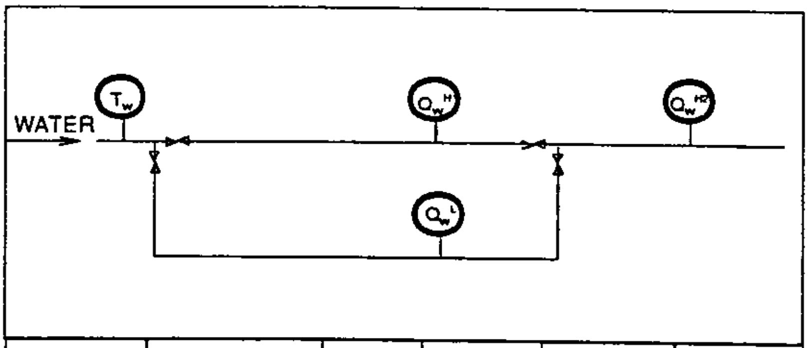


FIGURE 4.1.1: TEST RIG ARRANGEMENT



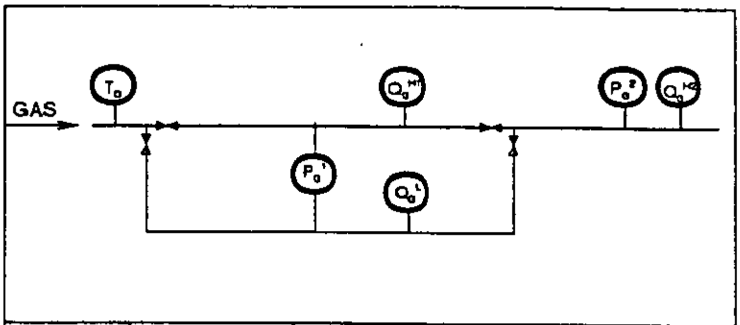
INSTRUMENT ID	INSTRUMENT DESCRIPTION	NORMAL RANGE	EXTENDED RANGE	OPERATING RANGE	ACCURACY (NORMAL RANGE) (±)
Q_O^L (m³/h)	FLOW TECHNOLOGY TURBINEMETER	5-51	0.6-57	0.6-35	0.0255
Q_O^{H1} (m³/h)	FLOW TECHNOLOGY TURBINEMETER	15-150	1.7-170	35-170	0.0750
Q_O^{H2} (m³/h)	MICRO MOTION DS300S CORIOLISMETER	9.6-192	9.6-192	9.6-170	0.0432 0.4032
RO_O (kg/m³)	MICRO MOTION DS300S CORIOLISMETER	200-1100	200-1100	700-1030	0.5000
P_O (bara)	PAROSCIENTIFIC DIGIQUARTZ 31K PRESS. TRANSDUCER	0-69	0-69	5-20	0.0069
T_O (°C)	ROSEMOUNT 244P RTD TEMP. TRANSMITTER	0-150	0-150	5-40	0.1200

FIGURE 4.2.1: SINGLE-PHASE OIL METERING SECTION.



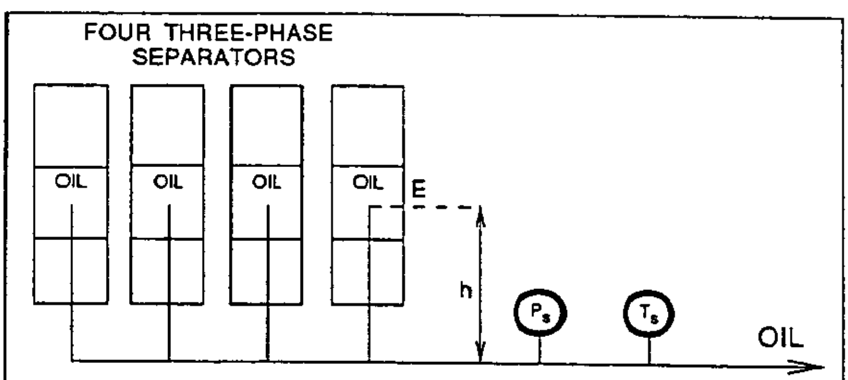
INSTRUMENT ID	INSTRUMENT DESCRIPTION	NORMAL RANGE	EXTENDED RANGE	OPERATING RANGE	ACCURACY (NORMAL RANGE) (±)
Q_W^L (m³/h)	FLOW TECHNOLOGY TURBINEMETER	5-51	0.6-57	0.6-35	0.0255
Q_W^{H1} (m³/h)	FLOW TECHNOLOGY TURBINEMETER	15-150	1.7-170	35-170	0.0750
Q_W^{H2} (m³/h)	FLOW TECHNOLOGY TURBINEMETER	15-150	1.7-170	1.7-170	0.0750
T_W (°C)	ROSEMOUNT 244P RTD TEMP. TRANSMITTER	0-150	0-150	5-40	0.1200

FIGURE 4.2.2: SINGLE-PHASE WATER METERING SECTION.



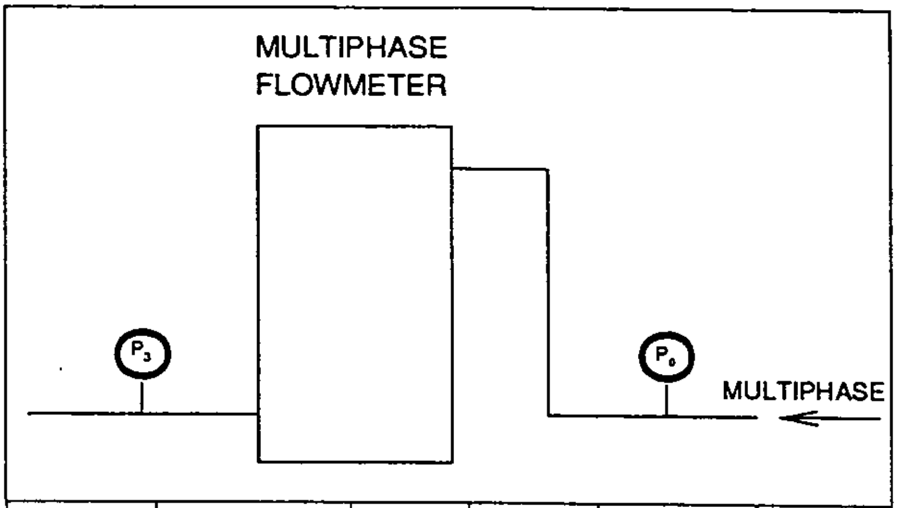
INSTRUMENT ID	INSTRUMENT DESCRIPTION	NORMAL RANGE	EXTENDED RANGE	OPERATING RANGE	ACCURACY (NORMAL RANGE) (±)
Q_G^L (m³/h)	FLOW TECHNOLOGY TURBINEMETER	3.4-34	1.7-42.5	1.7-35	0.0340
Q_G^{H1} (m³/h)	FLOW TECHNOLOGY TURBINEMETER	37-382	8.5-425	35-425	0.3820
Q_G^{H2} (m³/h)	KETEMA V-CONE METER (COMPLETE)	20-200	20-200	20-200	0.2-2.0
P_G^2 (bars)	PAROSCIENTIFIC DIGIQUARTZ 31K PRESS. TRANSDUCER	0-69	0-69	5-20	0.0069
P_G^1 (bars)	PAROSCIENTIFIC DIGIQUARTZ 31K PRESS. TRANSDUCER	0-69	0-69	5-20	0.0069
T_G (°C)	ROSEMOUNT 244P RTD TEMP. TRANSMITTER	0-150	0-150	5-40	0.1200

FIGURE 4.2.3: SINGLE-PHASE GAS METERING SECTION.



INSTRUMENT ID	INSTRUMENT DESCRIPTION	NORMAL RANGE	EXTENDED RANGE	OPERATING RANGE	ACCURACY (NORMAL RANGE) (±)
P_S (bars)	ROSEMOUNT 3051 PLUS PRESS. TRANSMITTER	1-21.6	1-21.6	5-20	0.0155
T_S (°C)	ROSEMOUNT 244D RTD TEMP. TRANSMITTER	0-150	0-150	5-40	0.1200

FIGURE 4.2.4: INSTRUMENTS LOCATED ON THE OIL STREAM DOWNSTREAM THE FOUR THREE-PHASE SEPARATORS.



INSTRUMENT ID	INSTRUMENT DESCRIPTION	NORMAL RANGE	EXTENDED RANGE	OPERATING RANGE	ACCURACY (NORMAL RANGE) (±)
P_0 (bara)	ROSEMOUNT 3051 PLUS PRESS. TRANSMITTER	1-21.6	1-21.6	5-20	0.0155
P_3 (bara)	ROSEMOUNT 3051 PLUS PRESS. TRANSMITTER	1-21.6	1-21.6	5-20	0.0155

FIGURE 4.2.5: INSTRUMENTS LOCATED UPSTREAM AND DOWNSTREAM THE MULTIPHASE FLOWMETER.

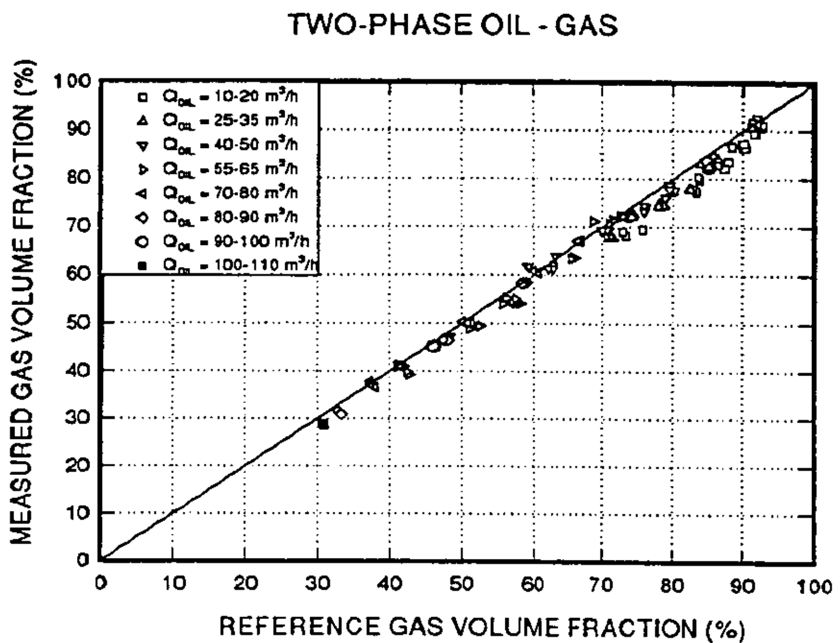


FIGURE 5.1.1

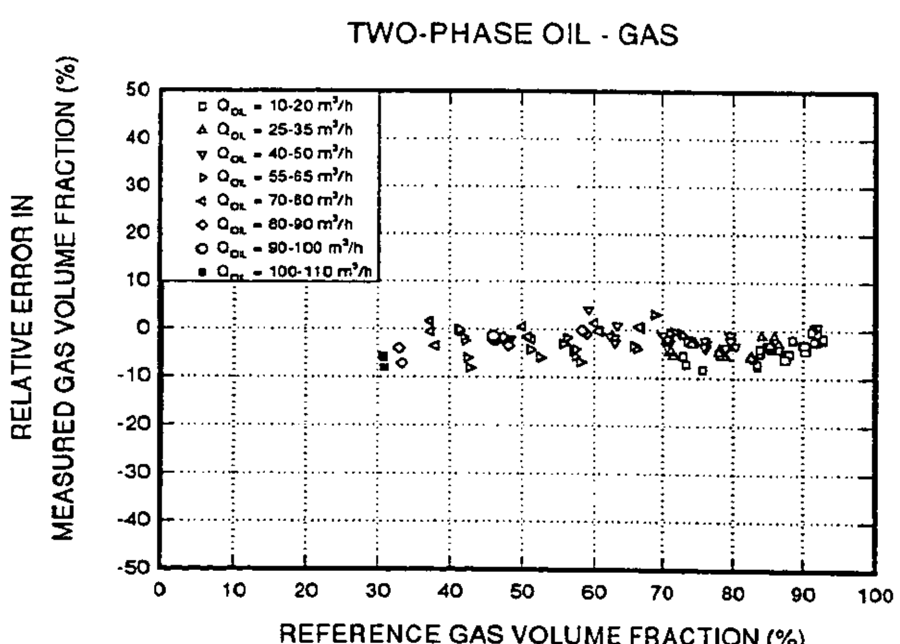


FIGURE 5.1.2

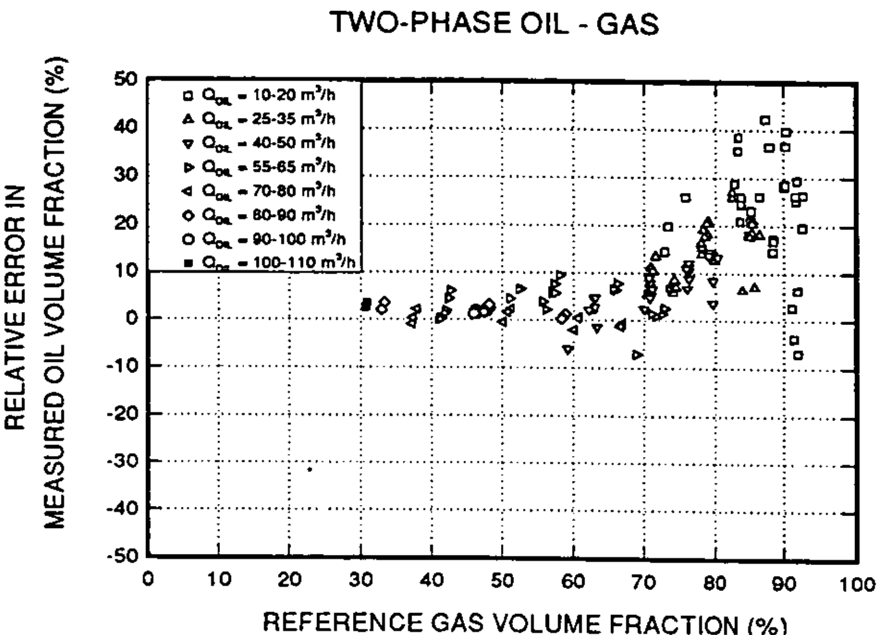


FIGURE 5.1.3

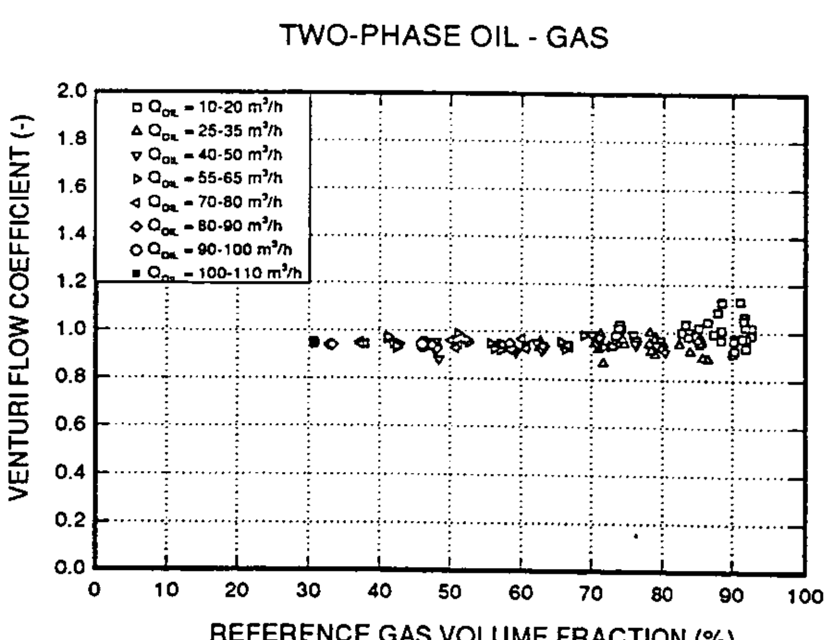


FIGURE 5.1.4

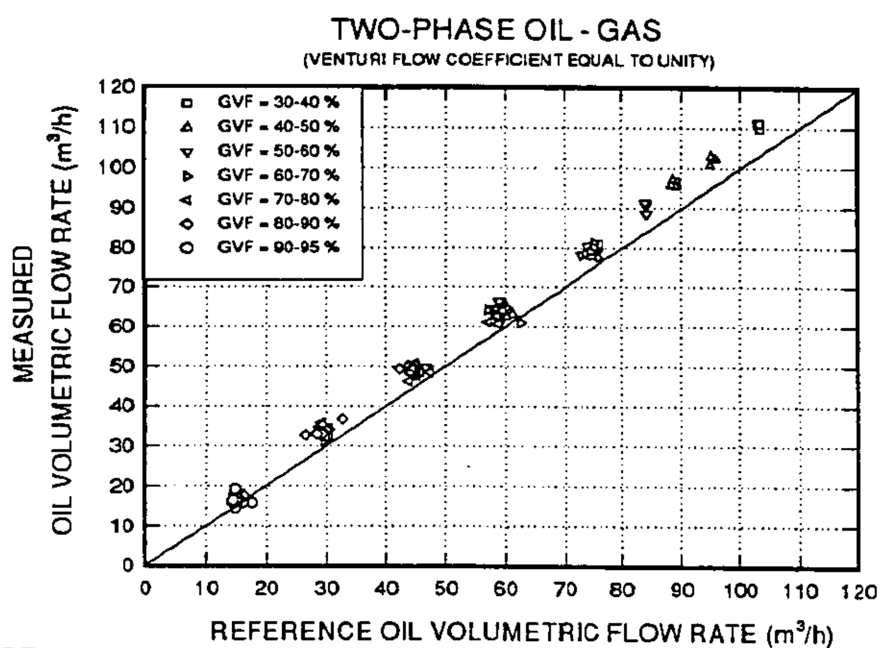


FIGURE 5.1.5

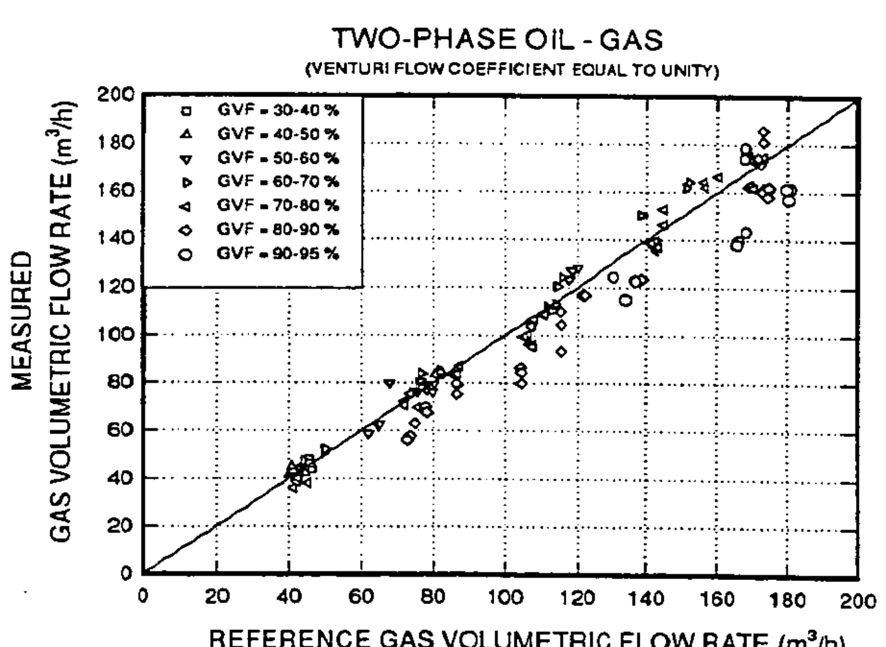


FIGURE 5.1.6

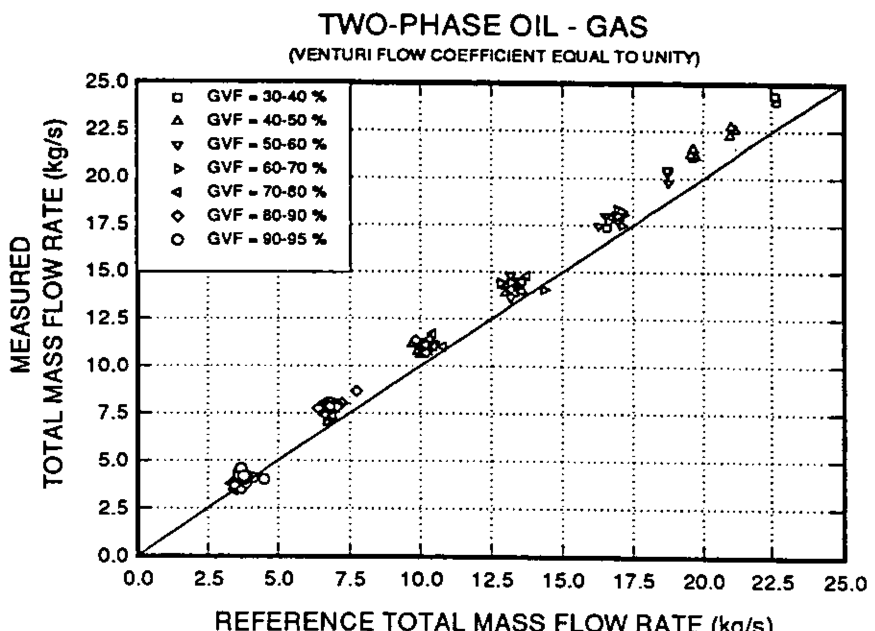


FIGURE 5.1.7

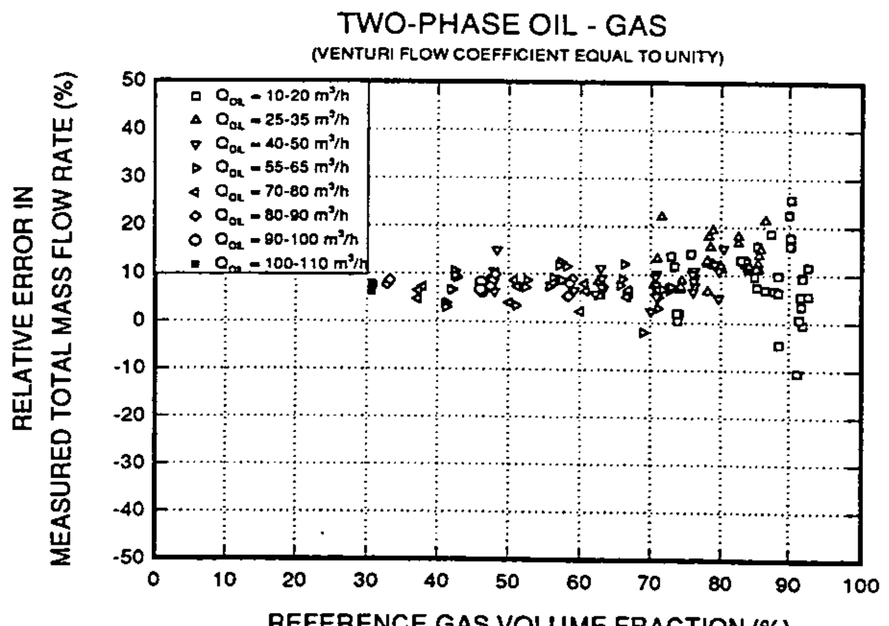


FIGURE 5.1.8

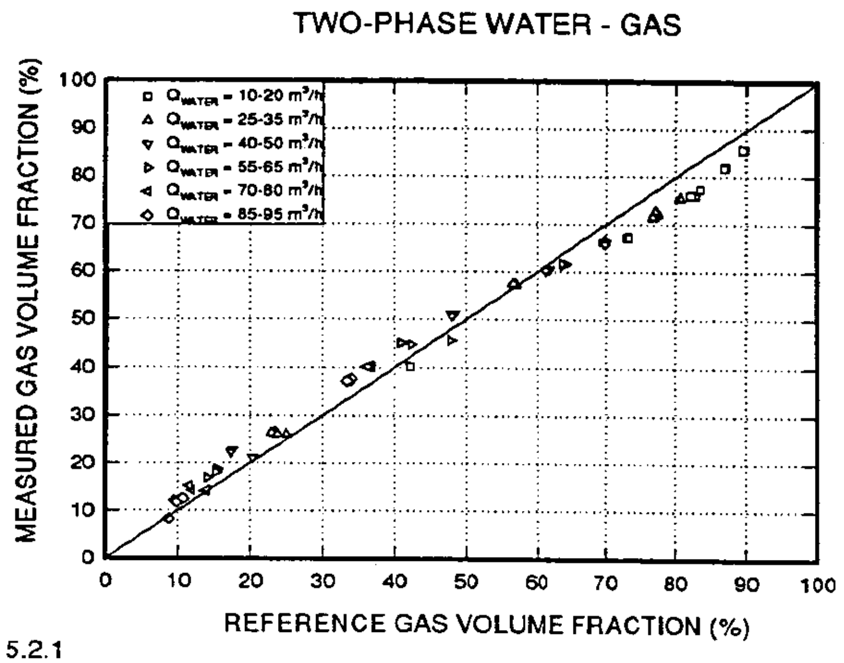


FIGURE 5.2.1

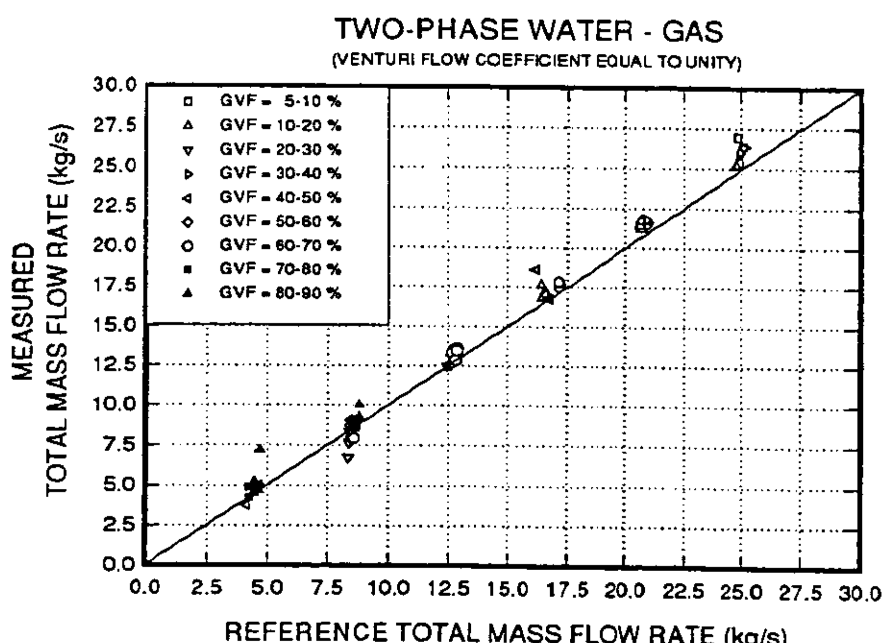


FIGURE 5.2.2

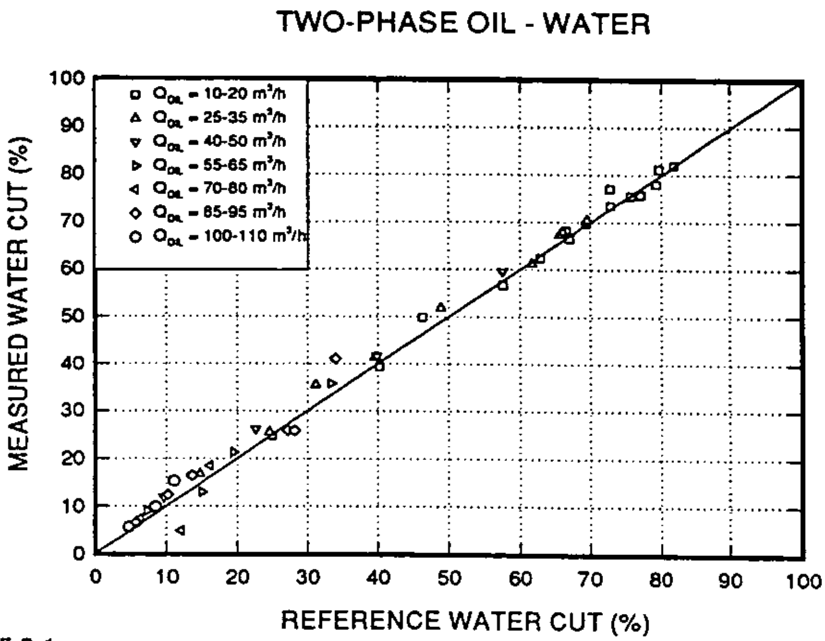


FIGURE 5.3.1

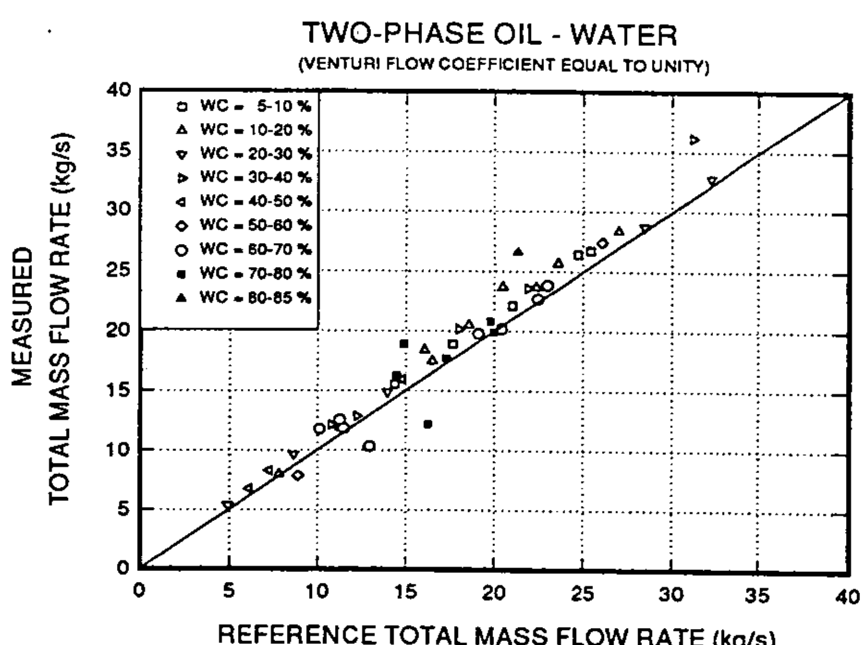


FIGURE 5.3.2

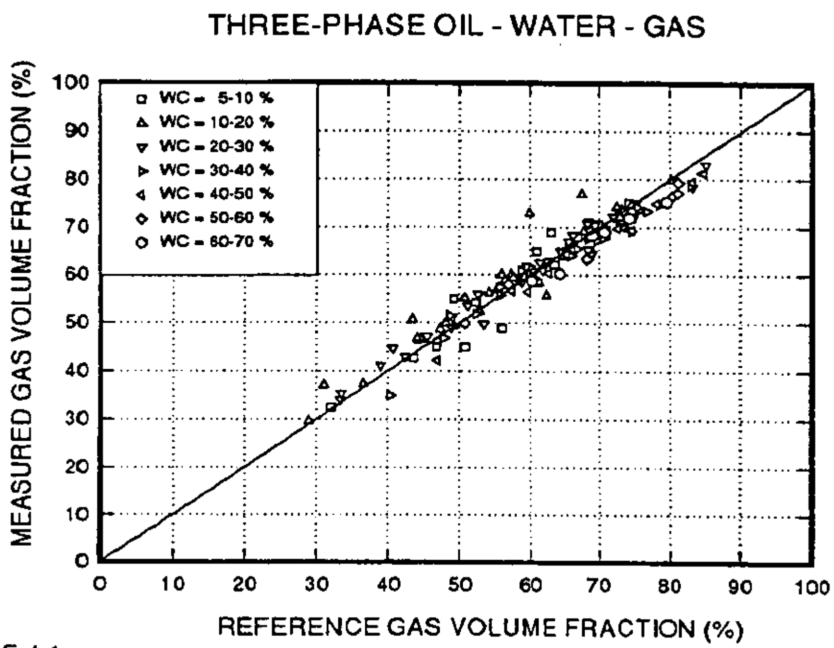


FIGURE 5.4.1

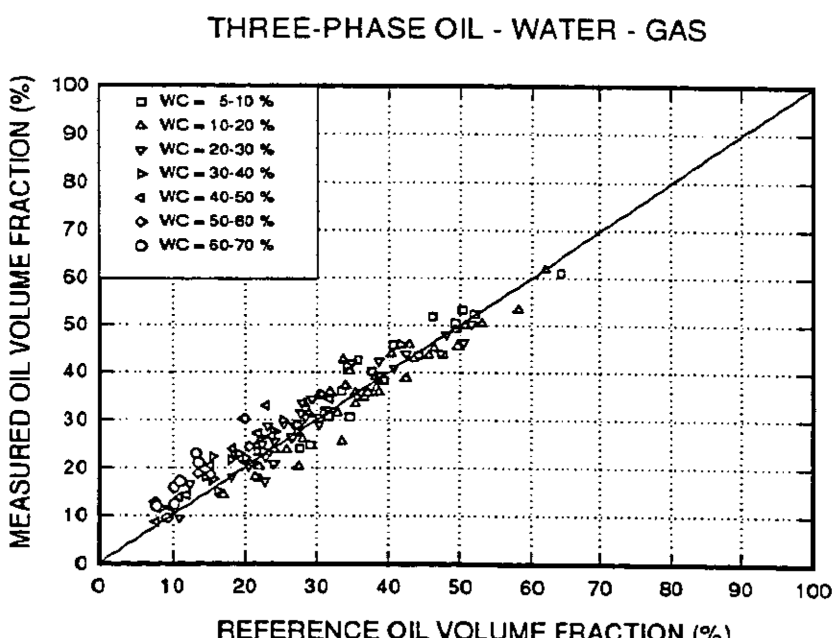


FIGURE 5.4.2

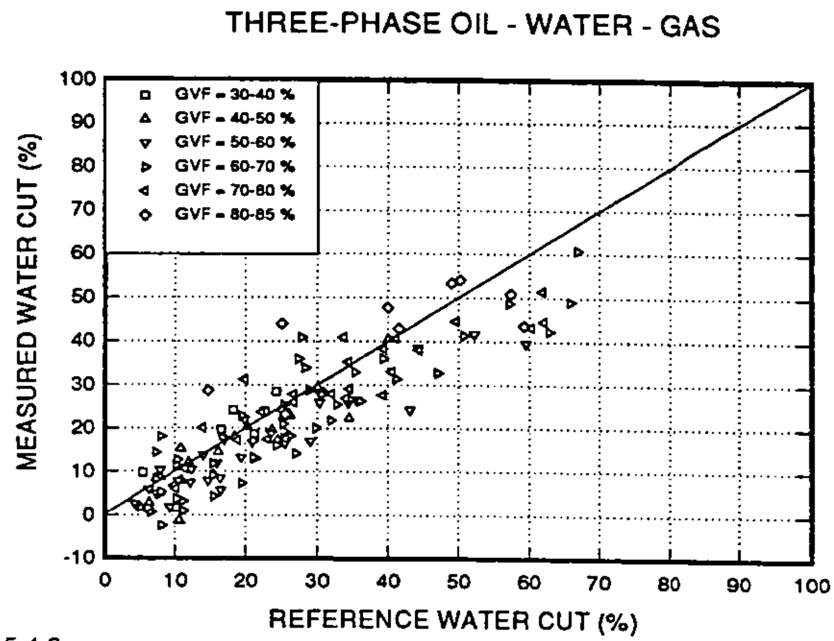


FIGURE 5.4.3

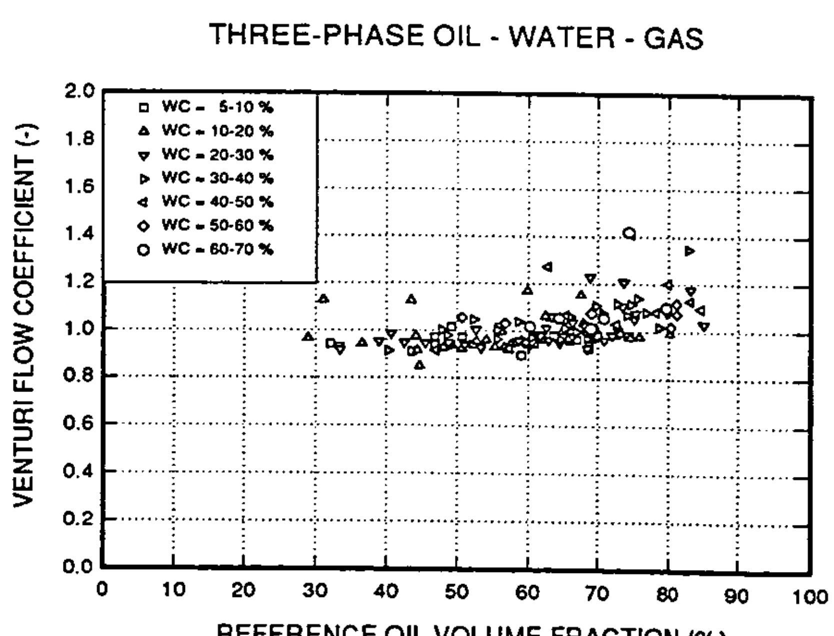


FIGURE 5.4.4

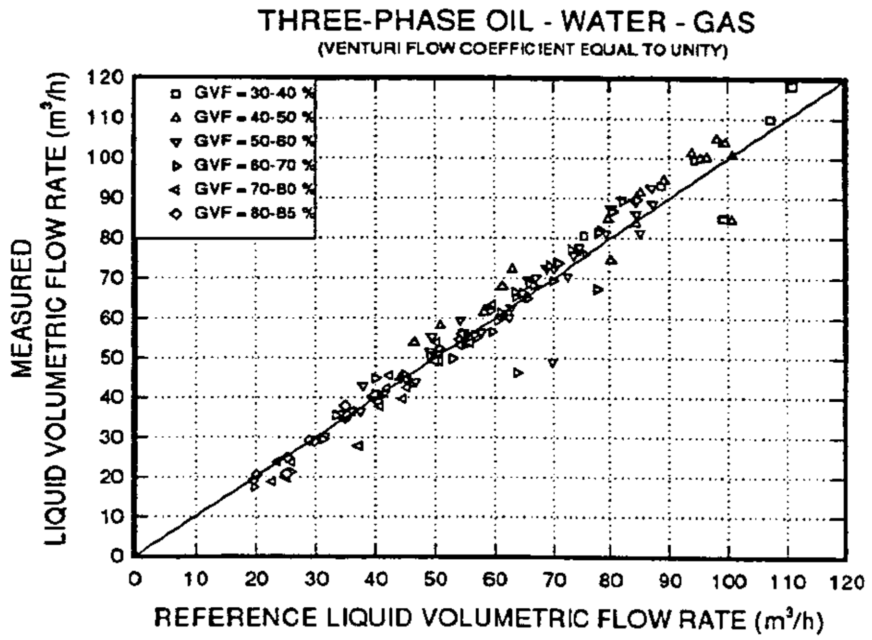


FIGURE 5.4.5

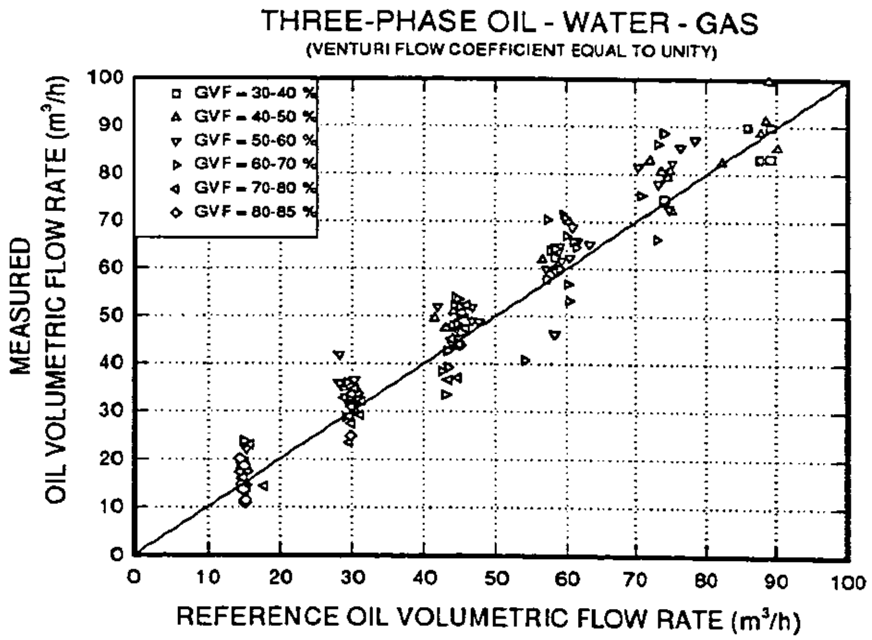


FIGURE 5.4.6

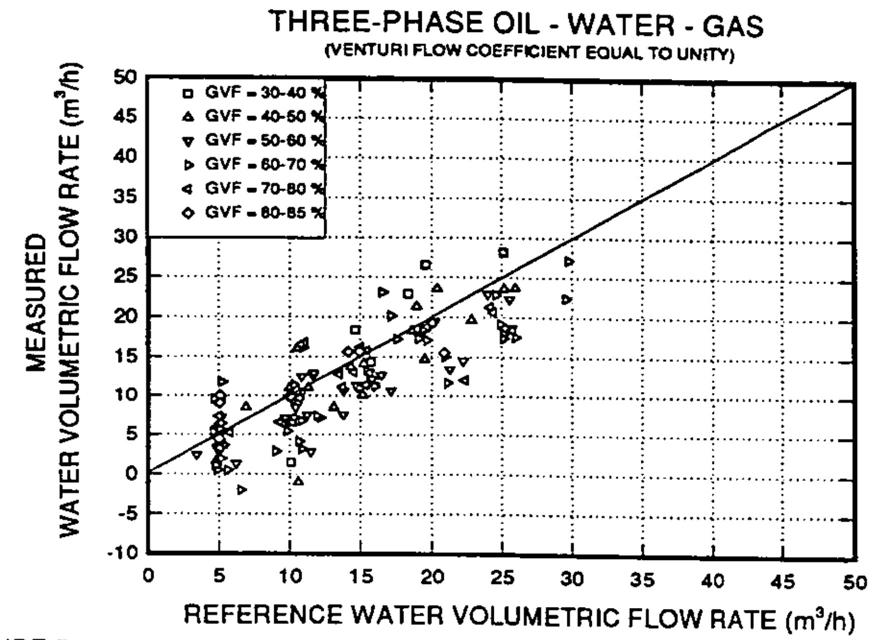


FIGURE 5.4.7

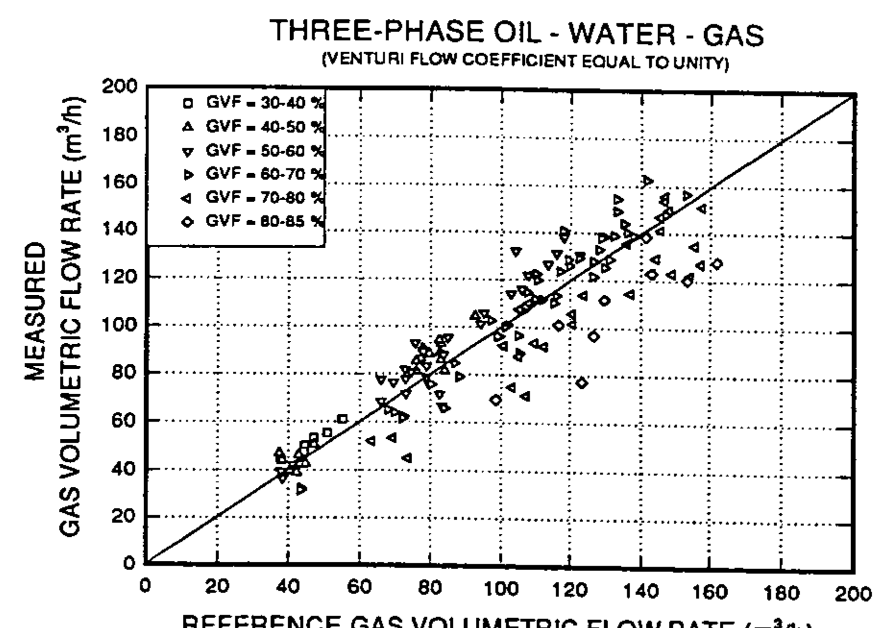


FIGURE 5.4.8

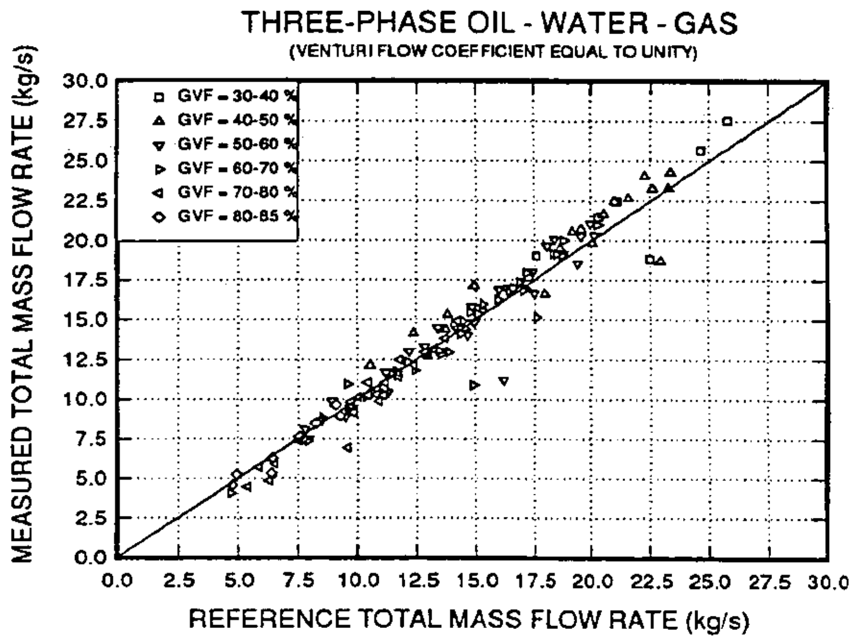


FIGURE 5.4.9

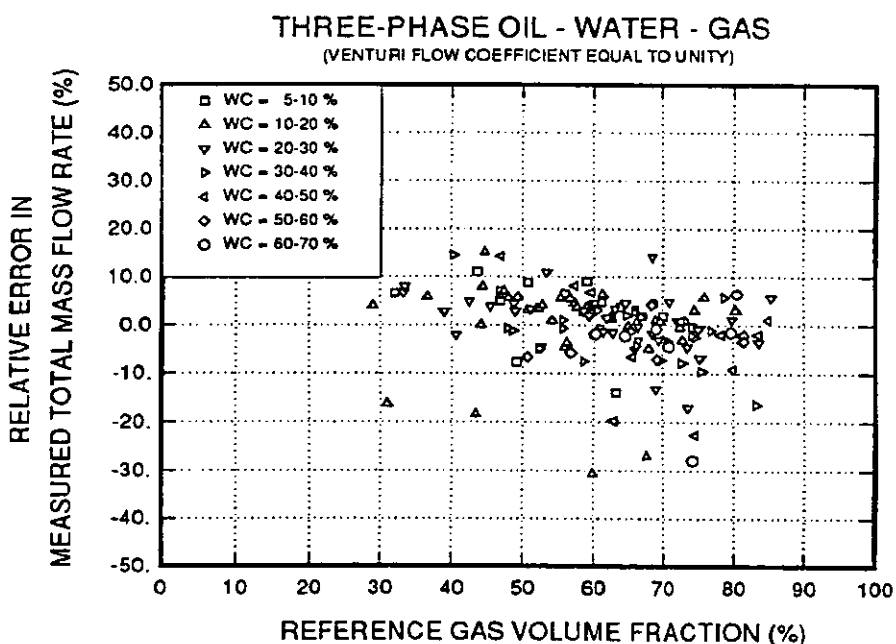


FIGURE 5.4.10