FIELD EXPERIENCE WITH THE CMI MULTI-PHASE FRACTION METER

by

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SUMMARY

In a project sponsored by British Petroleum and Saga Petroleum, CMI has now developed a non-intrusive multiphase fraction meter based on the combination of a capacitance sensor and a gamma radiation density meter. Laboratory tests have shown that this measurement system is capable of determining the composition of a well mixed oil/gas/water flow to an uncertainty of better than± 3% for each of the components.

The first industrial prototype meter has recently completed a 5 months field test on a UK land based oil-field. During the field trials the instrument have experienced 4 months of continuous flow through the sensor. Measurements and experiences from these tests are presented.

ACKNOWLEDGEMENT

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BP Norway Limited, UA
Saga Petroleum

The field trials of the multiphase fraction meter have been a close cooperation between the different parties involved. The authors express their sincere appreciation to:

J.S.S.Miller, BP Engineering
Dr. Tom Knox and Dr. Bill Priddy, BP Research

for their good cooperation during the test period and for review of this paper. Special thanks is also expressed to the operational staff at BP Exploration who have been very positive and given us the opportunity to install and operate the equipment at a live production site.

NOTATION

α – Gas fraction

β – Water fraction

γ – Oil fraction

β_f - Watercut

1 INTRODUCTION

For development of the many small oil fields in the Northern Sea, multiphase transport of unprocessed crude oil is a key factor to make a development profitable. Within multiphase transport there are numerous challenges. One of them is to manage multiphase metering. Until now there has not been any device available which in a reliable way could give the operators the necessary information of flow rates and fractions of the produced multiphase mixture. With the research and development done at CMI, the operators will have the opportunity to get on-line measurements of the produced fractions of gas water and oil.

British Petroleum and **Saga Petroleum** have since 1985 run a research programme at CMI, "The Three-component Ratio Measurement Research Programme". The initial studies leading up to this project were sponsored by the **Norwegian Research Council, NTNF**. The objective of the programme has been to develop a non-intrusive meter for on-line monitoring of the composition of a multiphase flow in a pipeline. In 1989 the industrial prototype of a fraction meter based on the capacitance /gamma technique was ready. During the autumn 1989 this instrument has been tested at the crude oil flow rig at CMI. The measurement principle and the results from the laboratory tests at CMI has previously been presented and can be found in reference 5.

To assess the reliability of the instrument, and to get experience under realistic operating conditions, the instrument have during the first 6 months of 1990 undergone an extensive field trial at UK land based oil field. The primary aim of this paper is to update the reader with the results and experiences from the field tests. For readers unfamiliar with the previously presented paper, the measurement principle and lab test results are described briefly.

During the first six months in 1990, the system has been installed and tested at a BP operated landbased field in UK. During the testing period there has been a close cooperation between BP Engineering, BP Research and CMI. Although most of the tests have been run with BP and CMI personnel present, a substantial amount of the tests have been performed completely by BP personnel..

2 AN INDUSTRIAL PROTOTYPE MULTIPHASE FRACTION METER

2.1 "The 3C-project"

During the 3C project, three different measurement concepts have been evaluated:

- In the "Impedance measurement system", a carefully designed surface plate capacitance sensor is driven at a medium high frequency (~ 500 kHz), and both the capacitance of the sensor, and the dielectric loss, are measured. These two measurements are in turn related to the composition of the flow through mathematical models.

-The "Capacitance/gamma measurement system" utilizes a conventional surface plate capacitance sensor, together with a gamma radiation density meter, in order to derive at the flow composition.

-The third alternative evaluated is a combination of the two above ("Impedance/gamma measurement system").

These three measurement concepts were thoroughly analyzed through extensive testing of laboratory prototypes, and through sensitivity studies based on detailed simulation models of the measurement systems. On the basis of conclusions from this work, it was decided that an industrial prototype "Capacitance/gamma measurement system" should be built and tested. At this stage a collaboration with the Norwegian instrumentation company **Fluenta a/s** was also initiated.

The time-schedules for this prototype development project have been very tight: From project kick-off in February 1989, a measurement system ready for laboratory testing was completed by July. Following the lab-tests scheduled for August and September, final modifications of the measurement system have now been done. The electronics is intrinsically safe, and has been Baseefa certified for use in hazardous areas. The measurement section has been pressure tested and certified for use as Class 600 equipment.

The measurement system has been installed on a BP operated UK land based site for a 5 month period, where it has been tested in the pipeline upstream of the first stage separator.

2.2 The measurement principle

The basic concept behind the measurement system developed at CMI is, in simplistic terms, the solution of three equations with three unknown parameters, namely the fractions of oil, water and gas respectively.

The first equation is derived from the simple fact that the sum of all the fractions will always be equal to 1, i.e. the pipe is always full of oil, gas or water or a mixture of two or three of them. This gives the equation

$$\alpha + \beta + \gamma = 1 \tag{1}$$

In order to derive at the two remaining equations we will therefore now only need two independent measurements which are correlated to the composition of the flow.

In this measurement system the two independently correlated measurements are the permittivity of the flow, and the density of the flow. Schematically, the principle is shown in Figure 1. A theoretical description can be found in Reference 5.

Non-intrusive measurement of the mean permittivity of a well mixed flow can be done using a capacitance sensor as shown in Figure 2.

The density of the flow is measured by means of a gamma density gauge. This is a well developed technique, and a standard single beam, clamp on device is used.

3 DESCRIPTION OF THE SYSTEM

The measurement system is schematically shown in Figure 3. It consists of a 4" capacitance sensor (2), a capacitance transmitter (3), a gamma densitometer (4) and a control room read out unit (6).

3.1 The capacitance sensor

A cross-section of the capacitance sensor is shown in Figure 4. It is designed as a spool-piece with 6" flanges, with a 4" ID ceramic liner.

The electrodes are metallised on the outside of this ceramic liner. The electrode layout is shown in Figure 4. Two rectangular electrodes are situated opposite each other on the outer surface of the ceramic liner. In addition there is a guard electrode around the circumference of one of these electrodes in order to minimize the parallel capacitance between the electrode plates.

In addition to acting as an electrical screen, the outside steel housing of the sensor has been designed as a pressure container to Class 1500 specifications. Electrical connections to the electrodes are done via high-pressure cable glands mounted in the steel wall.

The ceramic liner, which is in direct contact with the fluid, is a zirconia-reinforced alumina tube. This material was chosen because of its good electrical properties, in combination with its high strength and extreme toughness against corrosion and erosion.

The volume between the steel housing and the inner ceramic liner is filled with an insulating material.

3.2 The capacitance measurement electronics

To measure the small capacitances of the sensor accurately, and with a long term stability of the measurement system, the electronic circuit design has been very important. The measuring principle used in this instrument is optimized with respect to temperature stability and it has also proved a very high degree of long term stability. Special care had to be taken to prevent stray capacitances in connectors and printed circuit board from influencing the measurement accuracy.

A block diagram of the capacitance measurement electronics is shown in Figure 5. This is in principle a resonance circuit, in which the sensor capacitance determines the charge or discharge rate of an integrator. The resulting resonance frequency is thus inversely proportional with the sensor capacitance. With the components chosen for the resonance circuit, the operating frequency band is 10-40 kHz. This frequency is divided by 64 before transmission as a current-frequency signal.

The sensor head electronics is enclosed in a gas-proof polycarbonate box inside an IP-65-certified enclosure, together with three temperature transmitters. Two of which measures the temperature within the sensor (Pt-100 elements), and one which measures the temperature within the electronics enclosure. The sensor electronics is intrinsically safe, and Baseefa certified for use in explosive atmospheres (EExia IIc T4, -40 - 70°C).

3.3 The gamma densitometer

The gamma-meter is an important part of the system, but there are very few requirements to the meter. The most important need is a fast response time of the meter. Of mechanical design reasons, a clamp-on device was preferred.

The unit chosen is a standard type Krohne NDM 1000, with a Krohne NDC 2000 read out unit. The radioactive source is Caesium 137. With activity 2.5 mCi, the response time of this meter is 1 second. This unit is certified for use in hazardous areas.

3.4 The control room read-out unit

The two primary sensors, i.e. the capacitance sensor and the gamma density meter, are connected to a readout unit located in safe area. The control room read out unit is designed as a 19" rack system, which includes a micro-controller based data acquisition unit, the gamma meter readout unit and a rack mounted PC, in addition to power supplies, safety barriers, and transmitters.

All the field measurements are handled by the data acquisition unit, which in turn communicates with the PC. All the mathematical models and calibration constants are implemented on this PC, which therefore takes care of all calculations, presentation of measurements and storage of data.

4 LABORATORY TESTS

Following construction and calibration, the measurement system went through a test period using the 4" crude oil flow rig at CMI. This rig is designed for low pressures and for a temperature range of 15 - 40°C. The rig is a closed loop, and generates a well mixed bubble flow through the vertical test section. Water and oil fraction in the range 0 - 100 % and gas fractions up to 50 - 60 % can be circulated. The rig is shown in Figure 6.

The tests were done by initially filling the closed loop rig completely with a mixture of oil and water with a known water/oil ratio. Then, while circulating the mixture, some of the liquid was drained off and substituted with nitrogen. This was done in steps of 10 % up to at least 50 % gas/liquid ratio, and for a series of different water/oil ratios in the range of 0 - 75 %. All the tests were done using Statfjord stabilized crude oil and salt water.

The water/oil ratio and the gas fraction in the rig is determined volumetrically. The water/ oil ratio is checked by centrifugal BS&W analysis of samples from the rig. The gas fraction is checked by use of gamma density meters.

The water/oil ratio in the flow is known to an uncertainty better than ± 1% and the gas /liquid ratio is known within ± 2 %.

4.1 Lab test results

In Figure 7 are presented typical samples of the test results. The solid lines represent the "true" values, i.e. the reference measurements, while the fractions measured by the CMI multiphase fraction meter are plotted as discrete measurement points. Each of the plots represent one test series, i.e. a fixed water/oil ratio, and varying gas/liquid ratio.

In Figure 8 these measurements are presented in a slightly different way. Here the difference between the measured component fractions and the reference fractions have been plotted with respect to gas reference fraction. These deviation plots contain all data from all of the fraction tests.

By analyzing these data it is found that for the oil fraction measurements more than 95% of all the measurements are within a ±3% error band of the reference oil fractions. For the water measurements even better results are achieved in that more than 97% of all the measurements within the ±3% error band. The gas measurements are exceptionally good in that 100% are within the 3% error band, and that 97% of the measurements are within ±1% of the reference.

5 FIELD TRIALS

In order to gain some operational experience with the CMI multiphase fraction meter, the meter has recently completed a five month test period at a land based BP-operated oil field. The aim of these trials was to gain operational experience with the instrument, rather than a test of system accuracy. The installation was not instrumented specifically for this purpose. Due to restrictions on use of nucleonic sources, the equipment could not run unattended. As this was a production plant, we had no possibility to change flowrates or compositions at the installation point.

During this five month period, the meter has experienced four months of continuous flow through the sensor head, the system has been powered up more than 250 hrs (whenever key personnel has been present), and a total of 70 hours worth of test data has been logged and analyzed.

5.1 Installation

The multiphase meter was installed in a vertical up-flow section of a 4" flowline upstream of the 1st stage separator. This installation is schematically shown in Figure 9. Additionally there was a possibility to switch between two different reservoirs with different characteristics; Reservoir "A" with a medium gas to liquid ratio (~30%) and high water cut (~30%), and Reservoir "B" with a high gas fraction (~60%) and low water cut (norminally 0).

Before the installation, water and crude samples from both reservoirs were analyzed. The densities of water and oil was measured, and the oil permittivities was determined.

Although it is important to emphasize that the purpose of the field tests has been to assess the reliability of the measurement system, rather than a test of the systems accuracy under operational conditions, it is seen from Figure 9 that the particular installation provided some means of reference measurement data. In addition to these single-phase flow measurements downstream of the 1st stage separator, well test data and samples analysis has been used for comparisons.

5.2 Some field test results

5.2.1 Reservoir "A"

This reservoir, which has appr. 30 % gas, has a flowrate which gives a flow velocity through the sensor of approximately 1.5 m/s. Measurements over a 1 minute period can be seen in Figure 10. The gas fraction varies between 10 and 50 with a periodicity of appr. 10 sec. In Figure 10, we can also observe how the water and oil fractions follow each other quite closely. This means that, at least over shorter periods of time, the water cut is fairly constant.

In Figure 11 is presented a sample test run with the measurement system connected to reservoir "A". In this figure the fractions of the three different components are individually plotted with respect to time. Although the flow appears to be very stable over this one hour test period, it may be observed that the gas fraction curve varies slowly with a time constant of several minutes.

Upstream of the 3C meter installation point there is a pig receiver station. In Figure 12, it is shown how the flow pattern changes during the last hour before the pig is received. As early as 30 minutes before the pig arrives, the gas fraction starts to be unsteady, and get increasing oscillations as the pig approaches. Immediately after the pig arrived, there is very little gas, and a much lower water cut. Approximately 10 minutes later, the flow is back to the normal conditions.

5.2.2 Reservoir "B"

This reservoir has a high gas fraction and a very low water fraction, nominally 0. The flowrate is higher than the other reservoir, and the velocity through the meter is approximately 5 m/s. The gas fraction varies with rapid changes from 30 % and up to 90 %.

The flow rig at CMI,which was used for the lab test of the meter, was restricted to maximum 50 - 60 % gas. These tests go beyond what is tested earlier on this meter,a s the gas fraction for these test are for short periods as high as 90 %, with an average higher than 60 %. The tests shows that the meter is capable of operating also in the upper region of gas fraction.

The fluctuations of the gas fraction over a 1 minute period is shown in Figure 13. The measurements during a 1 hour test run can be seen in Figure 14. The water cut is stable and very low.

5.3 Field test experience

The system was installed and connected at the field by BP personnel and it was commissioned by CMI. Most of the tests have been run with both BP and CMI personnel present, but a substantial amount of the tests have also been performed completely by BP personnel. During commissioning the only problem was a software error in the gamma meter readout unit. Once that was fixed, the meter was up and running.

Many of the problems early version of electronic instruments encounter during the first installations, have been avoided. There has not been observed any influence on the measurements from wind, rain, electrical noise, vibration, earth potentials etc.

During the period of testing several trivial problems occurred. Among them was:
- Temperature transmitters failed
- Broken electrical leads.
- Hard disk of the PC crashed.
- Bugs in software.

Most of the problems were corrected as they appeared and was reported so that the design could be improved for later systems. Also several mechanical details will be reviewed and improved after this field test.

The most important design change will solve much of the problems related to the PC. During the development phase the PC has been used for running the mathematical models, due to its flexibility. These field test confirms that the PC is a weak point in an industrial system. To reduce the need for the PC in the measurement system, the mathematical models will be implemented in the data acquisition unit which already is present in the system and has the necessary computing power. The PC will then only be used for configuration, and if wanted for data presentation and logging purposes.

The sensor electronics proved to work very satisfactory. The calibration of the electronics has been checked regularly during the test period and the drift has been so small that recalibration has not been necessary. There was also no need for temperature compensation.

This is the first time the CMI developed data acquisition unit has been used in an industrial environment. The unit, which consist of an Intel 80C196 microcontroller chip, with A/D , D/A and data communication ports, plays an important role in the measurement system. During the test period, there has not been seen any fails in operations, which confirms that the software and hardware worked very well.

The only serious problem experienced during the field test period, has been a leaking internal seal (No part of the pressure integrity of the measurement system!). This caused an overreading of the water cut, but was discovered and repaired.

The unit was designed for use in a class 1500 system. Due to the above mentioned problems with the internal sealings, the sealing was replaced with a more standard solution, which is applicable for lower pressures (up to class 600). In the future there will be a need for higher pressure classification of the system. For use in higher pressure systems a new sealing system is therefore being designed.

By studying the fast response measurement data, it may observed that there is a time lag in the gas measurement due to the slow response time (1 sec.) of the gamma densitometer. Therefore, particularly for flow regimes like plug- and churn-flow, improved performance may be achieved by utilizing a faster response gamma densitometer.

6. CONCLUSIONS AND FURTHER DEVELOPMENT

The viability of a number of development schemes for marginal fields in deep waters depend on multiphase transport of the unprocessed well-stream over long distances. A key element in such a development scheme is the availability of a meter capable of measuring the individual flowrates of oil, gas and water without separation.

During the project sponsored by British Petroleum and Saga Petroleum, CMI has now developed a non-intrusive multiphase fraction meter based on the combination of a capacitance sensor and a gamma radiation density meter. Laboratory tests have shown that this measurement system is capable of determining the composition of a well mixed oil/gas/water flow to an uncertainty of better than ± 3% of total volume for each of the components.

During the field test, the multiphase fraction meter has experienced higher gas fractions, and flow patterns than could be simulated in the CMI flow rig. The measurement system has shown good performance under these flow conditions. The test have confirmed that the instrument is capable of operating in an industrial environment.

The experiences from the field test are very satisfactory, but can not be used for evaluation of absolute accuracy of the meter. Further test are planned in order to get an independent calibration test run of the meter. During the autumn 1990, it will therefore undergo an extensive test programme at an independently operated multiphase test facility. There are also plans for further field tests.

Fluenta will produce and provide this meter for the market. One unit for test purpose has already been built. The contract is signed for another unit which will be installed for an offshore field installation in near future.

The CMI multiphase fraction meter will in itself provide the offshore oil industry with a quite unique and useful instrument for well monitoring and reservoir management. However, in most cases, and in particular when the total multiphase flow from satellites are to be measured for production allocation purposes, a composition monitor alone will not solve the measurement problem. The requirement is here for a meter that online measures the individual flowrates of oil, gas and water.

During the field test, the CMI multiphase fraction meter has been running in series with a BP developed positive displacement meter. This special design PD meter measures the total multiphase flowrate, and thus, in combination with the fraction meter, the individual flowrates of oil, gas and water may be found.

As this solution will involve an intrusive flowmeter with moving parts, for remote, and in particular subsea, installations, a rugged, non-intrusive measurement system will be preferred. We have therefore at CMI investigated the possibility of complementing the CMI multiphase fraction meter with a flow velocity measurement. This flow velocity measurement is proposed to be done by signal processing of the signals from a multiple electrode capacitance sensor.

Recently a new development programme has been launched at CMI. The overall objective for this new programme is to develop a multiphase meter for measurement of the individual flowrates of oil, water and gas. This will be achieved by complementing the CMI multiphase fraction meter with a flow velocity meter. In phase 1 a laboratory prototype of a capacitance correlation velocity meter will be developed and tested. In Phase 2 this meter will be integrated with the fraction meter to provide an industrial prototype of a non intrusive flowrate meter. Phase 3 of the programme will extend the capability of the meter for measurement also under conditions with slip between the phases. In addition to BP and Saga, two other oil companies and The Norwegian Petroleum Directorate are now supporting the project.

To service this programme, and other activities at CMI within multiphase metering, a completely new multiphase test rig is being built at CMI. The test facility will make it possible to generate flowrates up to 150 m^3/h with a mixture 0 - 100 % of gas, water and oil known to a high degree of accuracy. This test facility is partly financed by The Norwegian Research Council, NTNF, and partly by internal CMI fundings.

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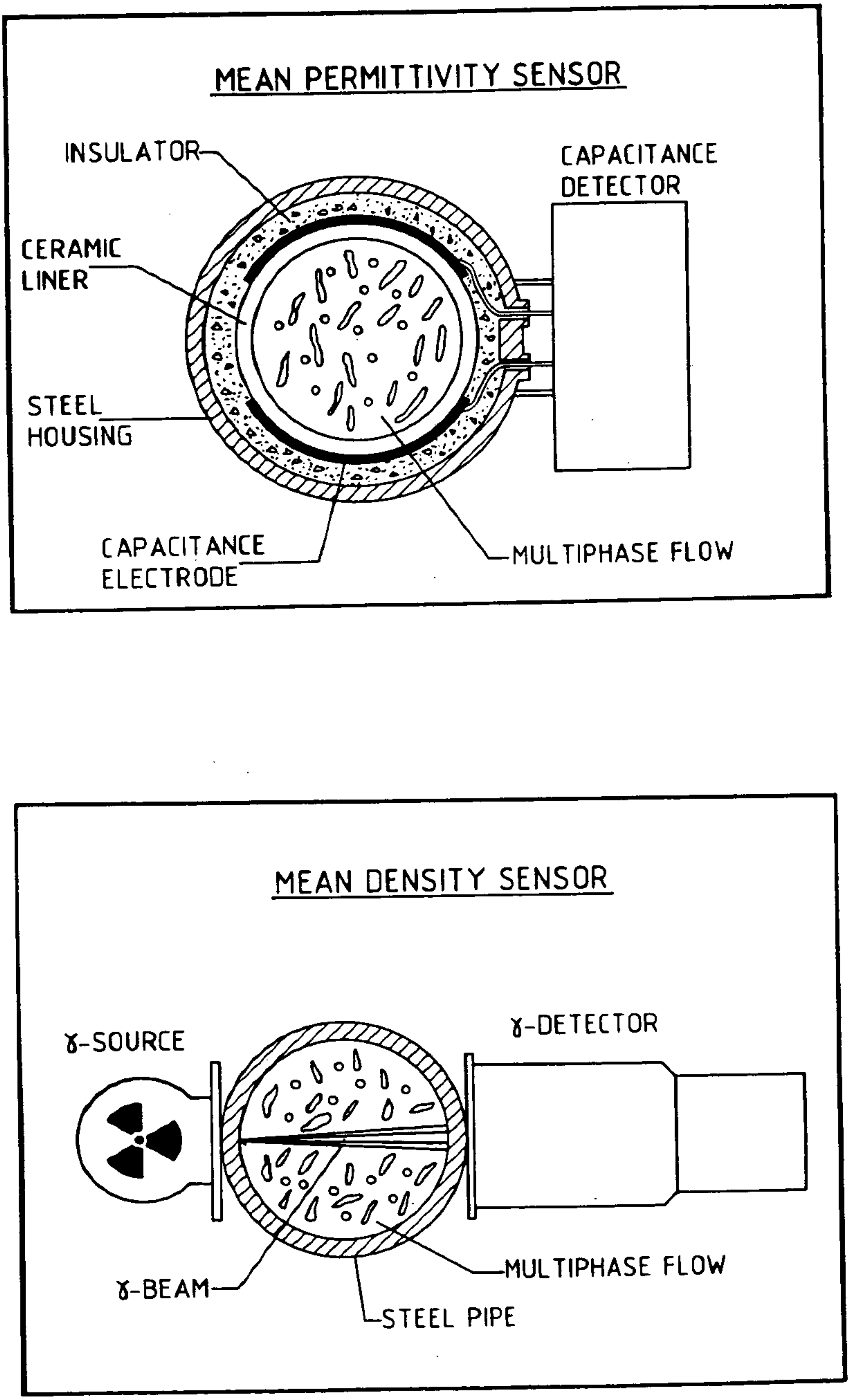

Figure 1. Measurement principle of the capacitance/gamma system.

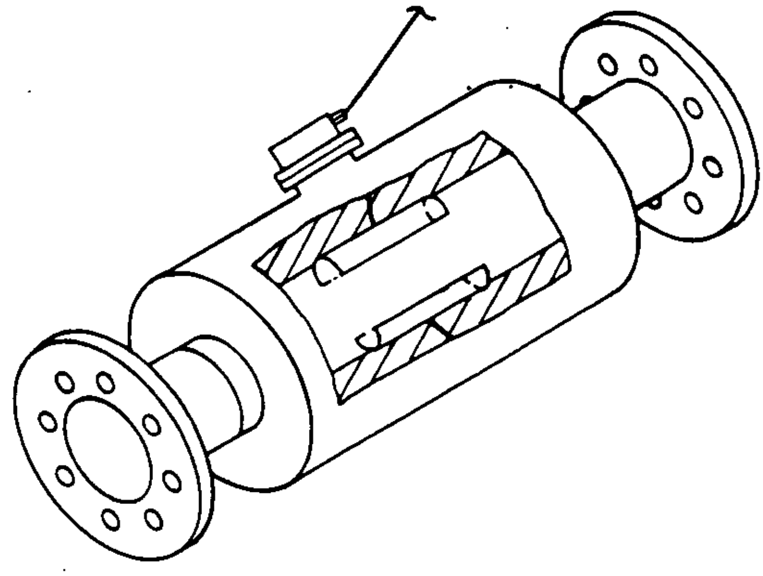

Figure 2. Surface plate capacitance sensor.

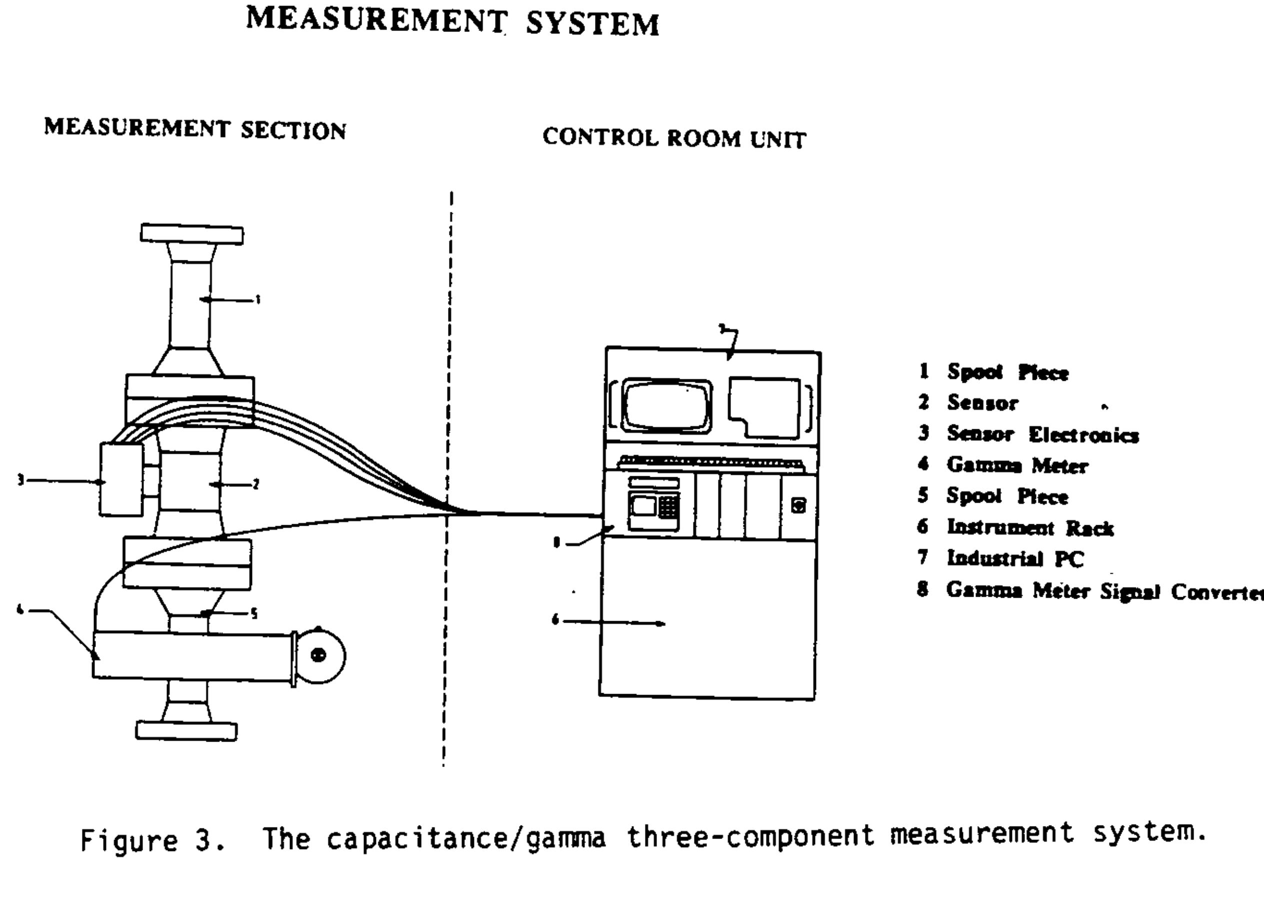

Figure 3. The capacitance/gamma three-component measurement system.

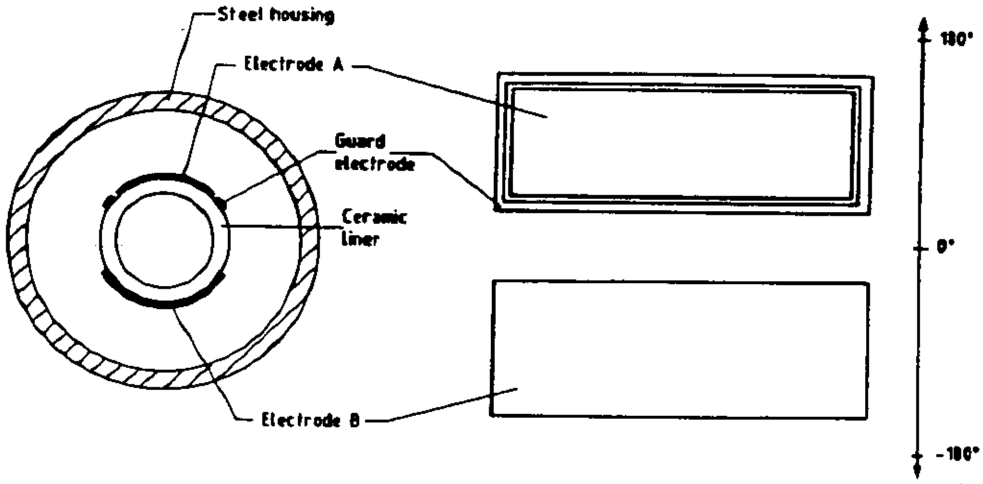

Figure 4. Cross section and electrode layout of the capacitance sensor.

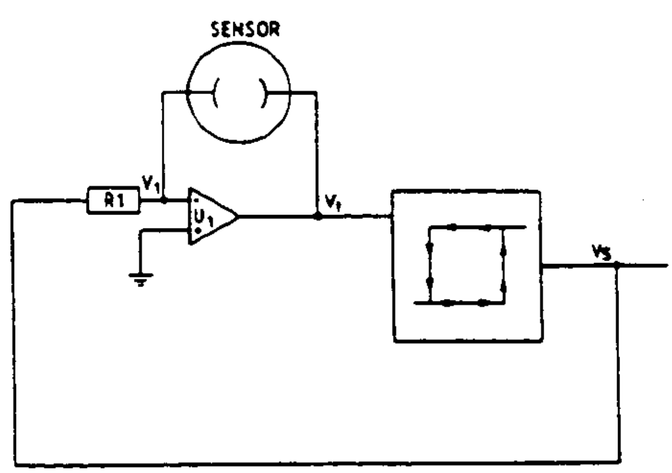

Figure 5. Block diagram of the capacitance measurement electronics.

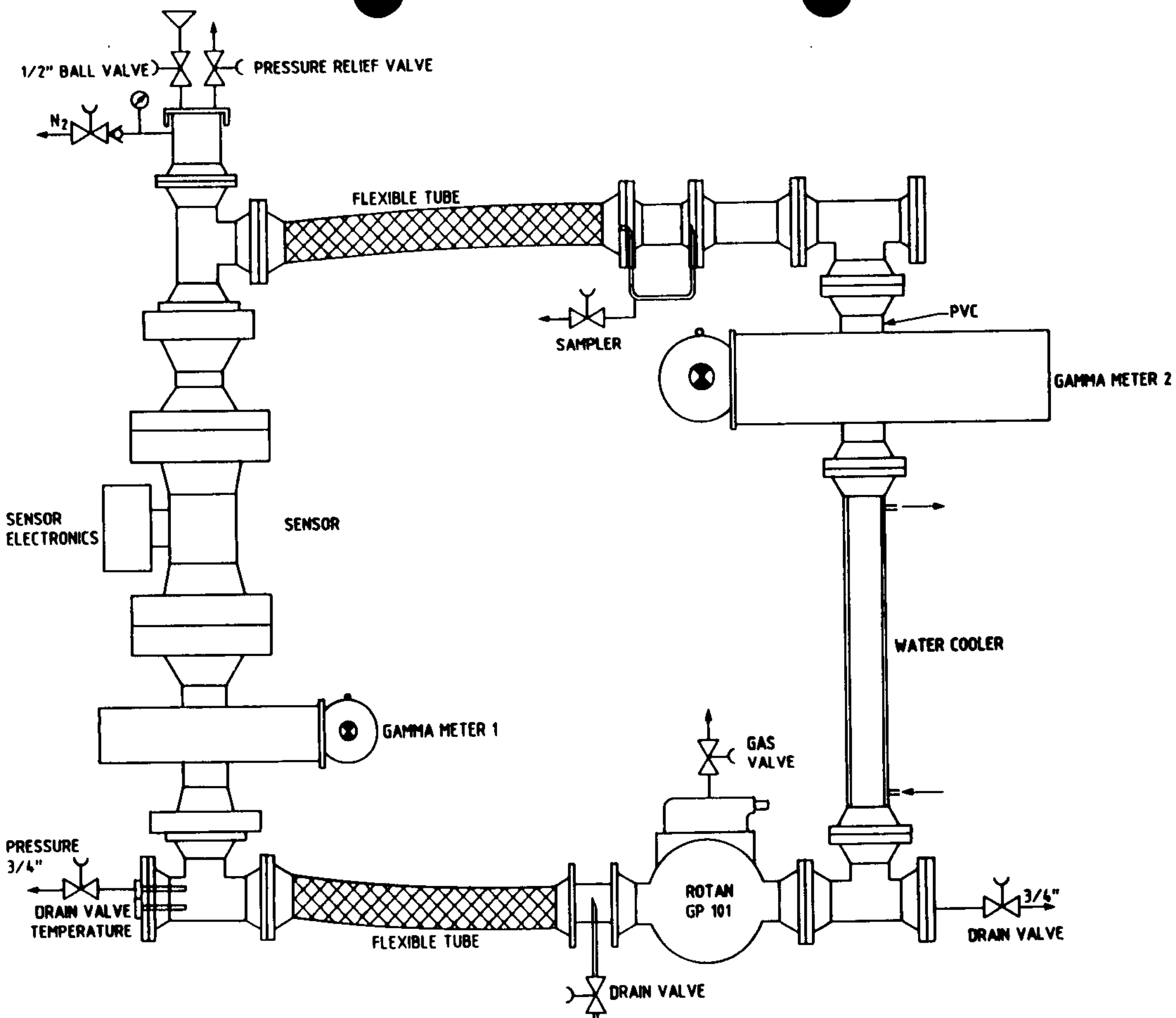

Figure 6. The 4" crude oil flowrig at CMI.

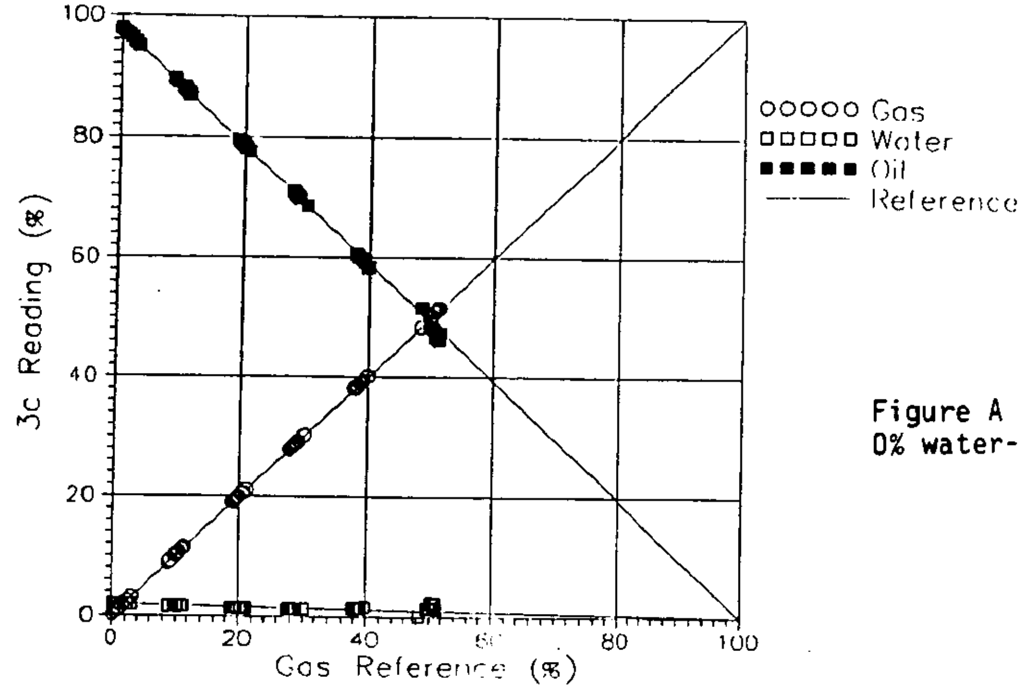

Figure A
0% water-in-oil

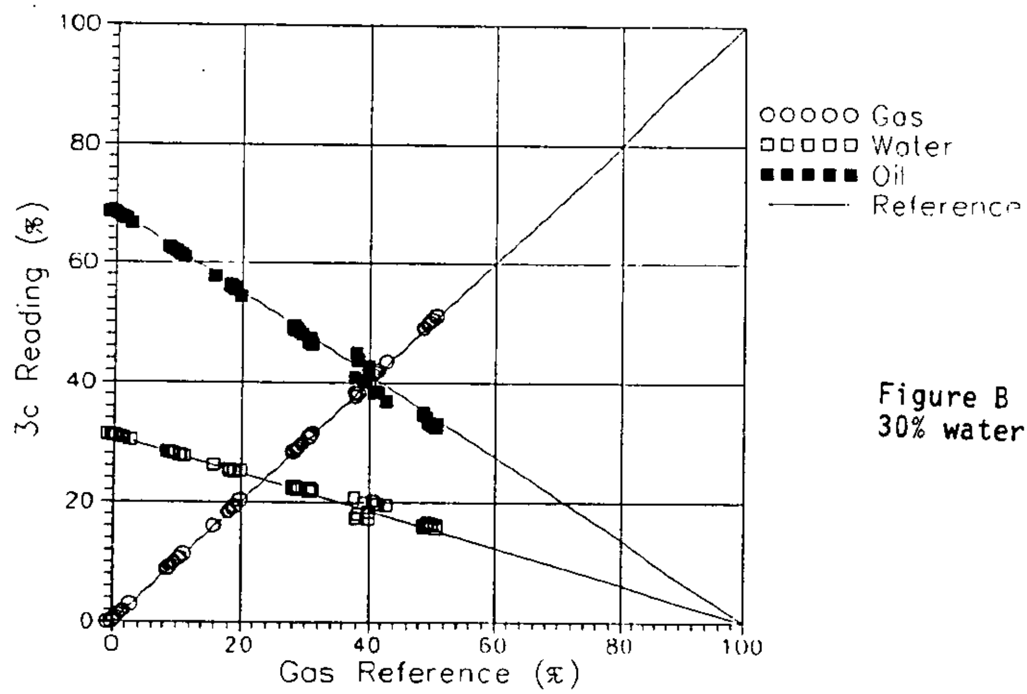

Figure B
30% water-in-oil

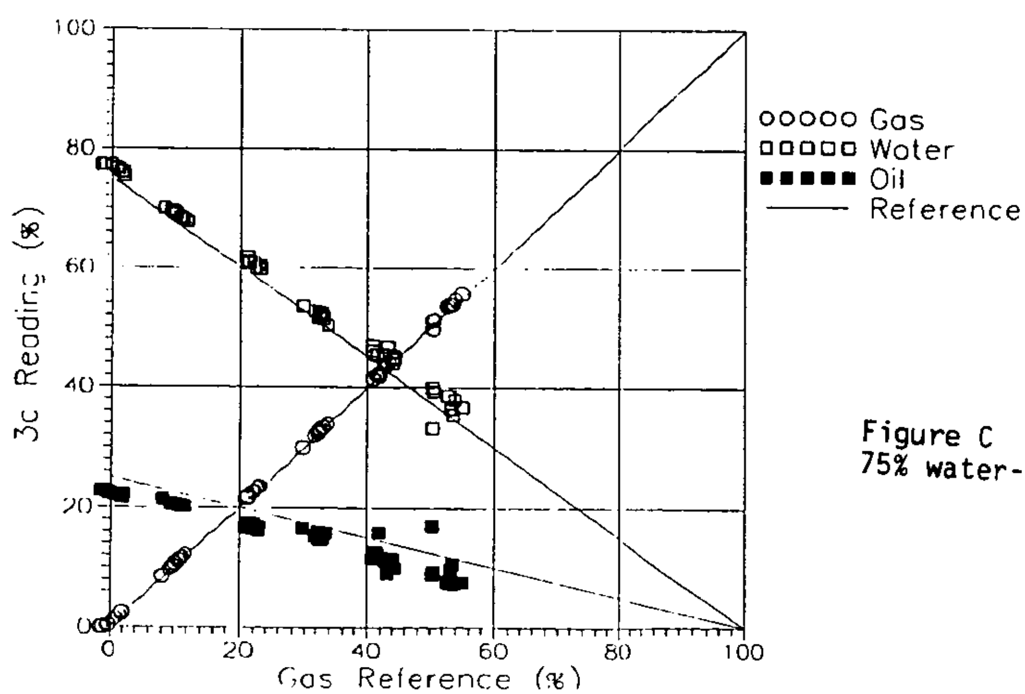

Figure C
75% water-in-oil

Figure 7. Results from lab tests at CMI

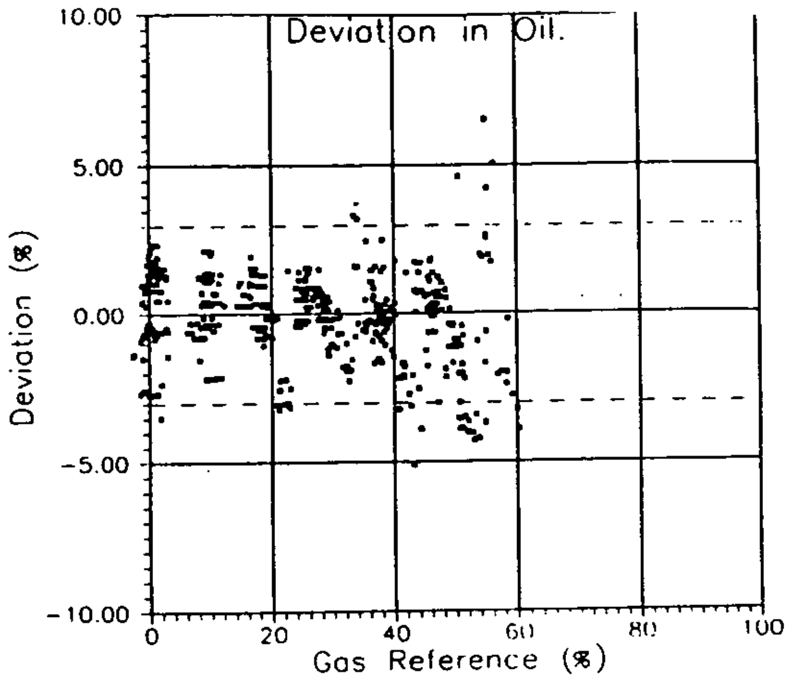

Figure A.
Deviations in oil
fractions.

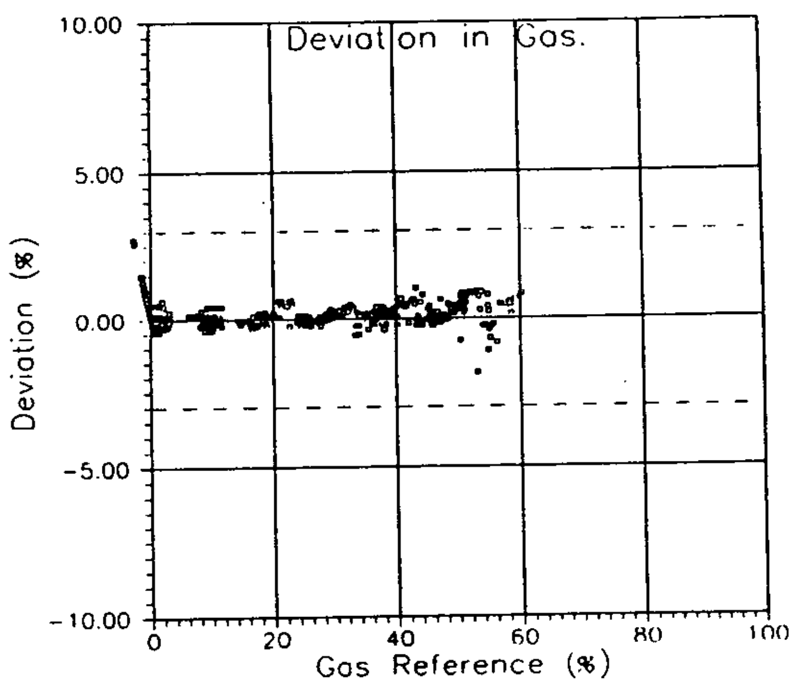

Figure B.
Deviations in gas
fractions.

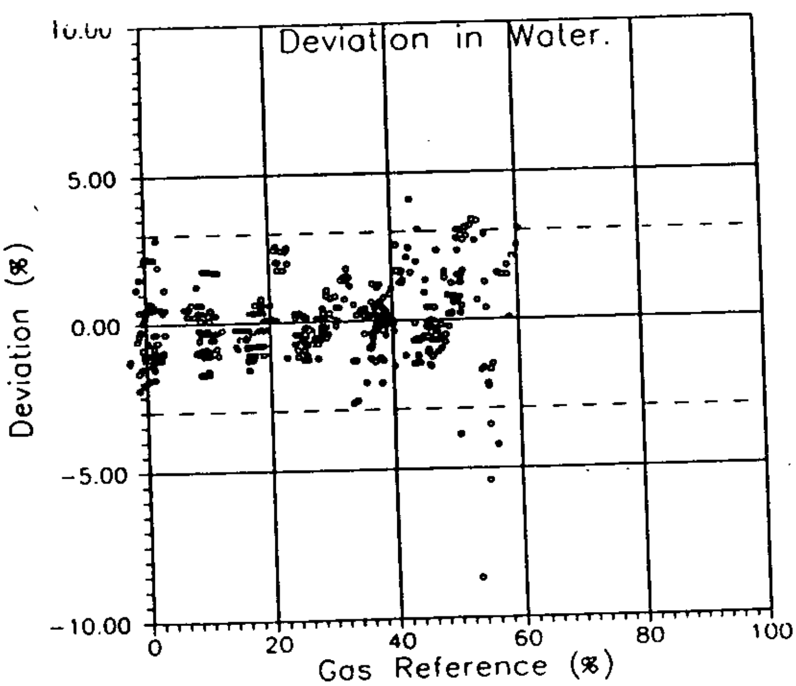

Figure C.
Deviations in wa
fractions.

Figure 8. Measurement errors in the tests at CMI.

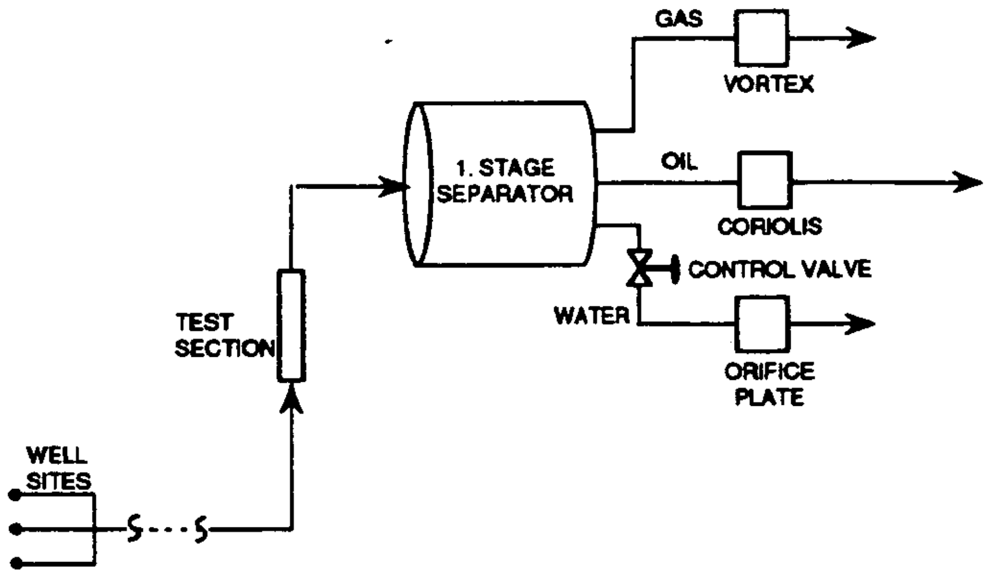

Figure 9. Field test installation.

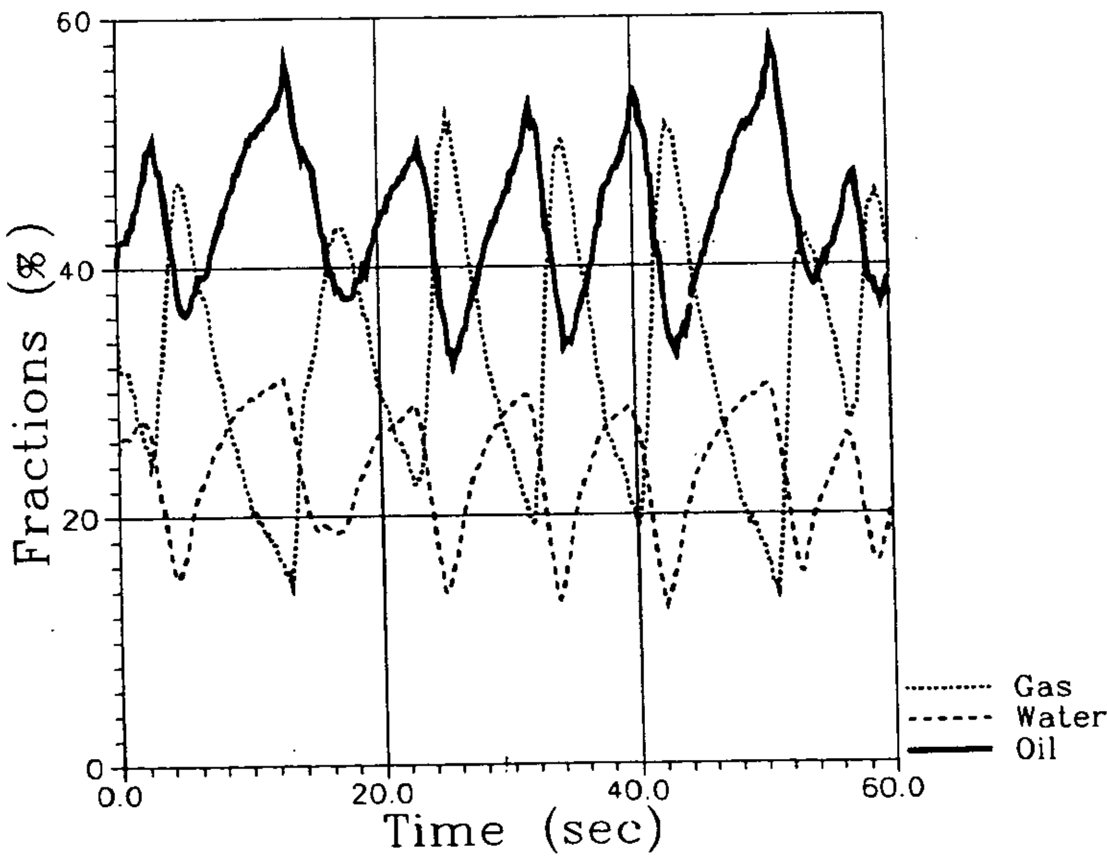

Figure 10. Sample test run from Reservoir "A". 1 minute.

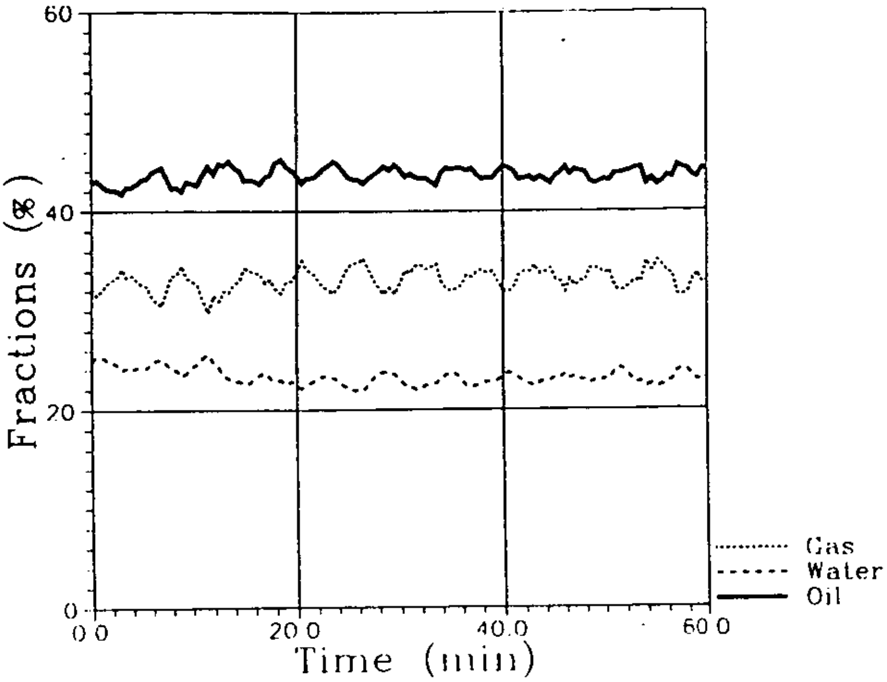

Figure 11. Sample test run from Reservoir "A". 1 hour.

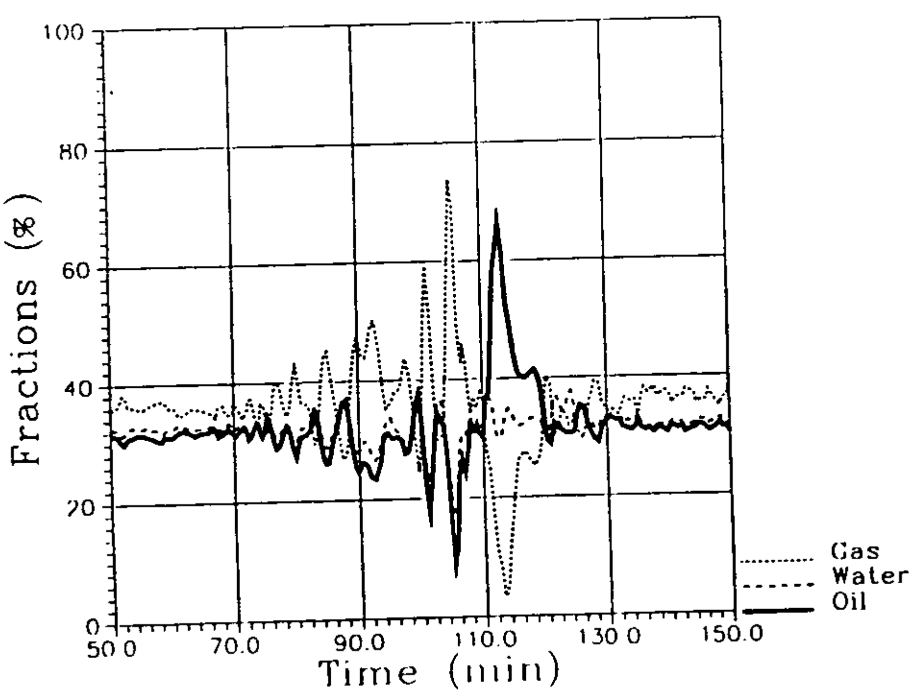

Figure 12. Slugging flow as a result of line pigging.

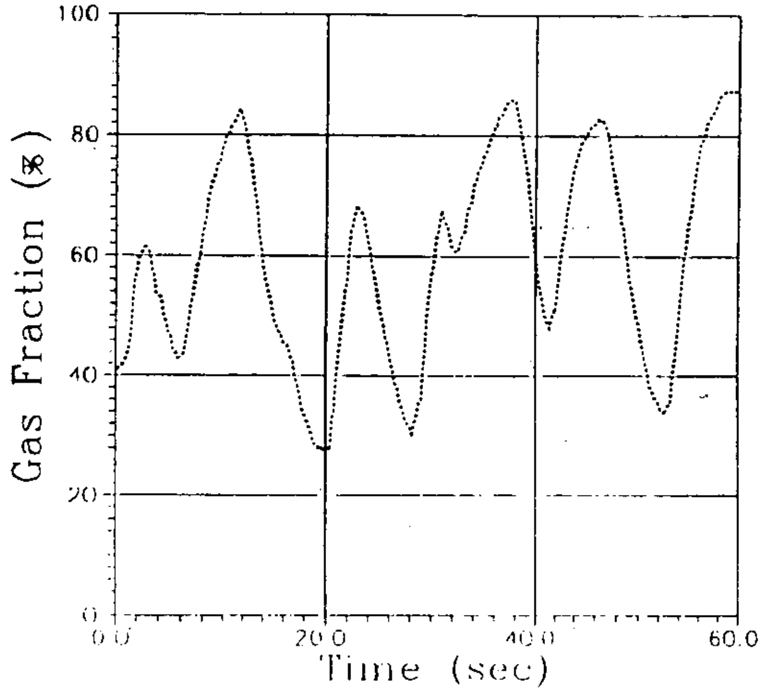

Figure 13. Gas fraction. Reservoir "B" over 1 minute.

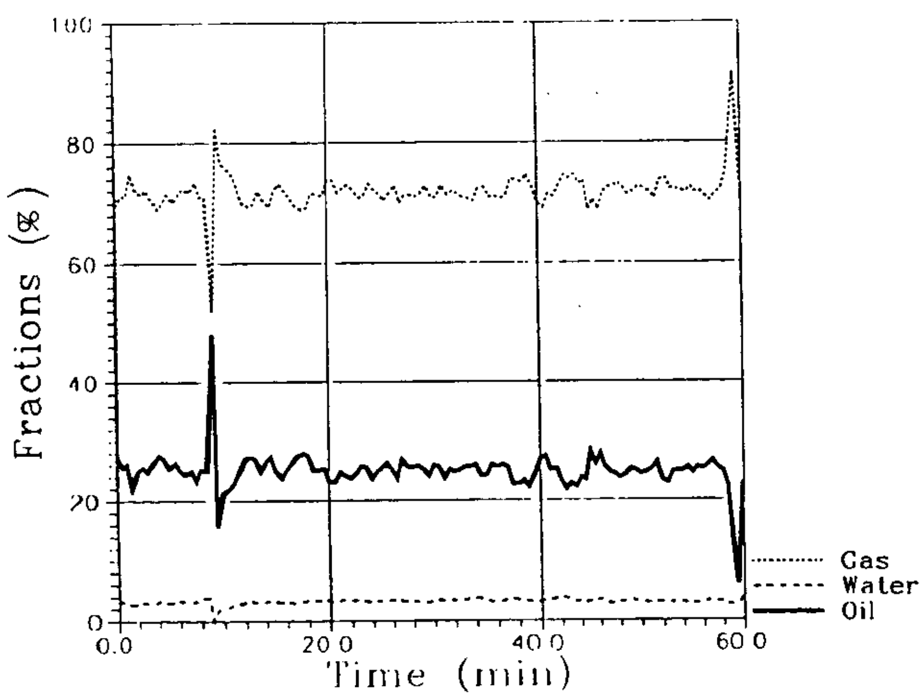

Figure 14. A 1 hour test run. Reservoir "B".