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TOPSIDE AND SUBSEA EXPERIENCE WITH THE FRAMO MULTIPHASE FLOW METER

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TOPSIDE AND SUBSEA EXPERIENCE WITH THE FRAMO MULTIPHASE FLOW METER

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ABSTRACT

Multiphase flow meters have been in regular service onshore and offshore for several years, and operators are achieving some level of comfort with the technology. A significant amount of experience has been gained with the Framo Multiphase Flow Meter both topside and subsea. Typical applications are well testing, well management and allocation metering.

For topside applications, the principal advantage of the meter remains the elimination of the test separator and all it's associated hardware and maintenance. For subsea applications, the advantage is even greater as separate test lines and in some cases even entire platforms can be eliminated.

The Framo Multiphase Flow Meter concept which combines the Framo Flow Mixer with a Multi Energy Gamma Meter and a Venturi Meter offer the optimum in precise estimation of oil, water and gas flow rates and has at the same time proved to be a particular robust concept. True reproducibility and high accuracy combined with built-in features such as simple calibration and a separate gas and liquid sampling arrangement solve many of the operational problems that are encountered with alternative methods.

Operational experience with Framo Multiphase Flow Meters installed around the world, both topside and subsea, will be reviewed. Special attention will be paid to the difficult issues peculiar to subsea meters, such as their remote installation, retrieval, calibration, and maintenance.

Finally, future trends in multiphase metering will be explored, particular will the challenges of introducing this technology into more routine applications be addressed.

BENEFITS OF MULTIPHASE FLOW METERS

When the developments of multiphase flow meters started for more than twenty years ago, one of the main aims was to develop low cost flow metering systems, which could accurately measure the flow rates of oil, water and gas in difficult multiphase flow regimes including emulsing and foaming conditions, where conventional metering systems based on phase separation have great difficulties. With the Framo Multiphase Flow Meter this aim has been achieved, as the meter is capable of measuring the individual flow rates of oil, water and gas without being affected by any multiphase flow regime or whether the liquid is oil- or water- continuous.

Resent years experienced have however taught us that the benefits of multiphase flow meters reach fare beyond this. Even when conditions are present for efficient separation in conventional metering systems, (**Fig. 1a)** the advantage of being able to continuous or near-continuous monitor each well stream (**Fig. 1b and 1c**), is so great that although the multiphase measurement is fundamentally more difficult than a single phase measurement, the performance from multiphase flow meters is often comparable and even better than what is normally achieved with conventional metering systems. In addition, whereas a conventional testing system might take hours to become stable for measurement, a multiphase flow meter could yield good test results minutes after a well is switched in.

Elimination of test separator, manifold and/or flow lines is ordinarily the single most important reason for choosing to use a multiphase flow meter (**Fig. 1**). Not only are test separators and their associated metering equipment expensive, but their bulk requires also additional platform space in offshore topside installations. In the case of satellite fields, running a test line back to a test separator on a platform is also a non-negligible expense.

Because well-designed multiphase meters must be virtually maintenance-free it they are to be used subsea or on unmanned platforms, their application will significantly reduce operational expenditures (OPEX) over conventional test separation systems.

The reservoir engineers requirement for representative fluid samples is well accommodated by the Framo Multiphase Flow Meter as it has a built-in feature which allow individual sampling of gas and liquid in a very efficient manner. Numerous other advantages of multiphase measurement could be listed, but what is shown above should be sufficient to convince any potential user that they deserve consideration. Having crossed this threshold, whether through one's own experience or that of others, it is apparent that if one chooses to use a multiphase meter, then a test separator is no longer needed.

CHALLENGES OF MULTIPHASE FLOW MEASUREMENT

Multiphase flows exhibit many complex phenomena, and by its very nature, metering of it is extremely complex and fraught with subtle problems. Some of these will be explained here.

Flow Regime Effects
Different distributions of oil, water and gas in space and time within a pipe are classified in flow regimes, **Fig. 2**. However, flow regimes vary depending on operating conditions, fluid properties, flow rates and the orientation and geometry of the pipe through which the fluid flow. Characteristic for well streams is that flow regimes are changing, and dramatic changes can occur rapidly or as part of a more gradual process, however in most cases prediction of it is extremely difficult. Slijkerman *et al* 1995 /8/ showed several real-world examples of how wells can drastically change their production characteristics over their lifetime, changes that cause the flow to span three or four different flow regimes. For the same flow rates, different flow regimes will result in changes in phase hold-ups, in phase velocities (slip) and in local transient characteristics of the flow.

Since a flow regime can never be exactly simulated or reproduced, verification of multiphase flow meter performance in a laboratory is very difficult, and has only limited value unless the meter is insensitive to different flow regimes, a feature that however is essential for a true multiphase flow meter.

Sensor Dependence
Some sensors are more strongly dependent on the relative physical distribution of the oil, water, and gas in the pipe than others. Particularly sensitive are electromagnetic measurements. Fairly insensitive is gamma attenuation, so long as the attenuation path is through a representative sample.

Oil-Water emulsions can cause severe problems on certain electromagnetic sensors, especially when making the transition from oil-continuous to water-continuous, or the reverse. Gamma attenuation on the other hand is not influenced by whether the oil and gas has formed an emulsion or in that case whether the liquid is oil- or water- continuous (Rafa, Tomoda, Ridley 1989 /1/).

Both electromagnetic and nuclear sensors exhibit changes in their response when confronted with a change in water salinity. Slijkerman *et al* 1995 /8/ showed the relative watercut sensitivities to salinity for conductivity and gamma attenuation methods, **Fig. 3**. This sensitivity can be further reduced for the gamma attenuation method by careful selection of gamma energy levels.

FRAMO MULTIPHASE FLOW METER

The Framo Multiphase Flow Meter consists of three primary components: (1) a static Flow Mixer to homogenize the flow and eliminate flow regime effects; (2) a Venturi Meter to measure the composite or bulk flow through the meter; and (3) a Multi Energy Gamma Meter imbedded in the throat of the Venturi. Each of these will be discussed individually.

FRAMO Flow Mixer

The purpose of the Framo static in-line mixer is to provide stable, homogeneous multiphase flow conditions through the measuring section, independent of upstream conditions. It is the means whereby the Framo meter can make the claim of always having a common velocity through the device for all three component phases. It is comprised of a cylindrical compartment with a gas/liquid diverter, an injection pipe, and a gas/liquid ejector, as shown in **Fig. 4**.

When arriving in the flow mixer the liquid phase is continuously drained to the bottom of the compartment and through the ejector. The gas phase is diverted to the top section of the compartment and via the injection pipe to the ejector. In the ejector nozzle, a turbulent shear layer is generated. Minimum associated pressure loss is achieved by utilising this turbulent shear layer mixing process.

As shown in **Fig. 10**, parts for taking liquid and gas samples from the most advantageous points in the mixer are standard features of both topside and subsea designs. These will be discussed in more detail later.

The Framo Multiphase Flow Meter has three methods for addressing the problem of salinity variations over time. The first is by simply taking a liquid sample from the bottom of the mixer, as shown in **Fig. 10**, and analysing the separated water for salt content. The second is through a new method for salinity determination derived from an analysis of the gamma ray spectrum. This latter technique is obviously more attractive for meters in remote locations, and will be incorporated in future software releases. Finally, whenever practical a direct single-phase measurement can be performed on the water phase and the salinity can be derived thereof.

Multi Energy Gamma Meter

The Multi Energy Gamma Meter provides the volume fractions of oil, water and gas in the flow. Calculation of these fractions is based on the attenuation of gamma rays from two different gamma energy levels of a Barium 133 isotope, as explained earlier.

The system consists of the following main elements:

- Ba-133 source (10 milliCurie activity)
- A rugged NaI(Tl) scintillation detector with photomultiplier tube
- Cable Penetrators complete with special cables
- A High Voltage supply for the photomultiplier tube
- A pre-amplifier for signal conditioning
- A Multi Channel Analyzer for gamma spectroscopy

The Barium 133 isotope is encapsulated in a separate housing diametrically opposite the detector at the Venturi throat. The low intensity of the source in combination with multiple levels of protection has proven to completely prevent any radiation exposure outside the meter.

Venturi Meter
The bulk fluid flow is measured with a Venturi Meter immediately downstream of the Flow Mixer. Here the multiphase mixture can be treated as a single-phase fluid with equivalent mixture properties, and standard single-phase Venturi relations can be applied. The differential pressure transmitter and pressure transmitter are equipped with remote seal sensors of the pancake type, bolted to the sides of the Venturi section.

Subsea Package
Although most multiphase flow meters that have been installed to date have been for topside offshore service, their use on the sea floor is clearly of great importance. The Framo meter's subsea design is one of its greatest strengths. The first Framo Multiphase Flow Meter ever manufactured was a subsea prototype (Torkildsen, Olsen 1992 /4/), and although most experience with the Framo Multiphase Flow Meter has been achieved topside, the principle of the meter is identical for both subsea and topside designs. The subsea meters that were delivered in mid-1996 offer several advantages over the first generation design:

- Full metal to metal sealing
- Insert style reduces subsea handling weights
- Diverless running and retrieval, with or without the use of guidewires
- Subsea liquid sampling facilities included
- Design pressures up to 10,000 psi

Fig. 5 shows a cross section of the Framo Subsea Multiphase Flow Meter. The meter when in place is shown in **Fig. 5b** and during installation or retrieval in **Fig. 5a**.

The main components of the Framo Subsea Multiphase Flow Meter are described below.

Receiver Barrel
The subsea multiphase flow meter design utilizes a barrel style subsea configuration. An insert cartridge, which carries all active multiphase flow meter elements, is locked into the receiver barrel.

The receiver barrel is permanently installed on the subsea structure and includes no active elements. There are no requirements for straight pipe lengths upstream or downstream of the meter.

The receiver barrel serves the function as inlet and outlet housing and as a guide and support during installation of the insert cartridge. In addition, it forms the outer housing of the flow mixer. Standard flange connections at the receiver barrel are used for connection of the flow meter inlet and outlet to the subsea tree or manifold piping.

Insert Cartridge
The insert cartridge incorporates the following main elements:

- Cartridge body with metal-to-metal seals and mechanical clamp connector

- Flow Mixer internals
- Venturi Meter
- Gamma Source and Detector
- Pressure and Temperature Sensors
- Data Acquisition System
- Connectors for power / signal and flushing media

Data Acquisition System
All sensors of the subsea meter are connected to the Data Acquisition System at the upper section of the insert cartridge as shown in **Fig. 5(b)**. If required, the application software running in the processor can be changed or downloaded from the surface.

Supply voltage and communication can to a large extent be adjusted to meet any specific requirement. Typical supply voltage will be 24 VDC; typical power consumption is less than 20 W. Data to the surface is transmitted via an RS485 Modbus RTU link, which during metering will transfer data once every 60 seconds.

Control System Interface
The Framo Multiphase Flow Meter can be interfaced directly to a Control Pod in a Subsea Production Control System, with separate wires for power and data transmission. Operationally, this interface will present a minimum of interference with other Subsea Control System functions. Alternatively, the flow meter can receive power and transfer data through a dedicated single pair cable in a control umbilical.

MULTIPHASE FLOW METER PERFORMANCE

Table 1 shows the field locations and reference flow facilities where the Framo Multiphase Flow Meter has been tested. It should be emphasized that, in each of the cases shown, the meter was installed and calibrated by Framo personnel, then left for the user to operate and collect data without Framo in attendance.

To give the reader some idea of what can typically be achieved using a Framo Multiphase Flow Meter, results from the project Multiflow testing at NEL in 1996 are shown in **Figs. 6 and 7**. **Fig. 6** is a composite plot of the difference in watercut measurement, between the Framo meter and the NEL reference. The data shown represent 63 different measurements at gas volume fractions ranging from 0 up to 95%; the rms deviation is about 2%. **Fig. 7** plots the Framo measured oil flow rate versus the NEL reference; 171 points are shown, again at gas fractions ranging from 0 to 95%.

The data shown in **Fig. 8** are interesting because they demonstrate the stability and repeatability of the measurements as compared to those made with a test separator, on Gullfaks B in 1994. Two interesting points are worth noting. First, the oil production rate is quite constant during the testing periods, and returns to very nearly the same rate after a period of many hours between tests, as shown by the tests on Wells 1 and 5. Second, the variations in measured flow are smaller with the Framo meter than with the test separator.

FIELD EXPERIENCE

As shown in Tables 1 and 2, the Framo meter has been used in a variety of installations throughout the world. In the following, three typical, though very different, applications are considered in more detail with respect to operational considerations and experience.

BHP Liverpool Bay

The application is on three unmanned remotely operated wellhead platforms in the North Sea. This development has used the FRAMO Multiphase Flow Meter as its only means of well testing and allocation metering for the central combined process platform and two remote unmanned satellites. The field has a very high GOR, and the actual GVF are in the high end of the range originally designed for. The meters are designed for gas flow rates up to 80 MMscf/d with a maximum pressure loss of less than 1 bar. All three meters are installed on test manifolds, allowing individual wells to be tested locally at the wellhead platform, where the data are collected and transmitted to the central process facility over a serial link. The test headers on which the meters are installed are 8 and 10 inches, and the connections of the meters are made to match this.

Due to the phased development of the field, two of the meters have been in operation for more than two years and the third for about 6 months. Based on the feedback from the operator, the meters have been operating to his full satisfaction. Only one site visit has been made by Framo service personnel, this to verify the calibration and set up of one of the meters. No changes were made.

Petroleum Development Oman

This is a remotely-operated, solar-powered installation. The meter is located on a test manifold in a remote well cluster in the desert of Oman. The meter was originally installed as part of a test program for the operator to verify the meter performance at actual conditions. The installation was consequently rigged as a temporary system, with only local readout of the flow meter through a portable PC system. Power was derived from a small solar array, since the unit draws less than 20 watts. A schematic diagram of the operation is shown in **Fig. 9.**

The meter was operated in this mode for several months. As the meter has performed to the operator's satisfaction over the period (Mhos, Mar A and Al-Hindi, Ruqaiya, 1997 /10/), it is now being procured and the installation made permanent, including providing remote data collection through a radio link to the meter using standard Modbus RTU protocol. The use of Modbus protocol permits interface to all common control systems, including those used for subsea systems.

East Spar Development

The East Spar Development, offshore West Australia, was the first oil field in which subsea multiphase flow meters were used in commercial application. As of September 1997 the meters have been in operation subsea for twelve months. It is a two well subsea completion producing gas and gas condensate, and is located 62.5 km offshore. The wells are commingled into a single pipeline through a subsea manifold and are individually metered with dedicated multiphase flow meters. Communication with the meters is via a field- installed buoy, where the flow computer and all the other field control systems are located. Communication of the processed meter data from the field buoy to the shore terminal control room is via a telemetry link. The real-time operational data from these subsea multiphase meters are also available anywhere in the World via satellite telemodems.

The meters are of the insert retrievable design described earlier. The operating conditions are:

- GVF: 87-95%
- WC: 0-70%
- Design Pressure: 200 bar
- Operating Pressure: 100 bar

Calibration data were obtained for both meters immediately following the installation subsea. This was done on a routine basis without any problems. The calibration values were then remotely downloaded to one of the meters, which since has been operating to the full satisfaction of the operator.

Remote downloading of calibration data to the second meter was hampered, and downloading required access to the flow computer located in the unmanned buoy, which for a long time was not accomplished. However, also the second meter has been in full operation since field start-up and stable reading have been recorded, although slighly biased for the reason mentioned. Since the calibration values are known, the data can be corrected manually topside based on the recorded raw data.

Performance Verification

It is important for the user to be able to verify the correct operation of his multiphase meter throughout its life. Since the Framo Multiphase Flow Meter is based purely on gamma ray attenuation physics and Venturi flow measurement, there is no need to "tune" the meter to any reference. If all sensors are correctly calibrated and accurate input parameters are used, the meter will maintain its accuracy through its lifetime.

At various points in time the user will likely want to verify its correct operation. Some ways of doing this are listed.

Factory Testing

Prior to delivery, each meter should be put through a complete test matrix of flow conditions representative of what is anticipated at the field installation site. This should be the first time the user sees the meter in correct operation, and should raise his confidence level.

Calibration Checks

Once the Framo Multiphase Flow Meter has been installed in the field, by simply isolating and letting the trapped fluids settle, static conditions can be attained. At this point, calibration checks on each of the four sensors can be performed; if each is within an acceptable tolerance, the meter verification is complete and the user should be confident in its correct operation. This is a significant advantage over meters that depend on flow models and flowing calibrations. The details of these calibration checks are reported in greater detail elswhere (Hanssen, Torkildsen, 1995 /7/).

Sampling
With the built-in sampling capabilities of the Framo meter, as shown schematically in **Fig. 10**, the user can verify the correct operation of the meter or detect physical changes in water salinity, oil density, or the like.

Site-Specific Testing
In certain field operations, production trends from individual and commingled well streams can be used to check the meter's overall performance.

Service Company Proving
On an infrequent schedule, or whenever there is a question regarding the correct operation of the meter, production can be tested by a qualified service contractor to assess the performance of the meter

Operational Problems Experienced
Framo Multiphase Meters have been installed on more than 25 different locations to date, of which approximately 20 have been in actual operation. The first meters installed have been in operation for more that two years, and as a consequence the accumulated operational time for Framo Multiphase Meters is substantial, and increasing by more than 8000 hours each month.

As shown by Table 2 the breadth of experience gathered is quite extensive in terms of applications, flow rate, pressure, gas volume fraction, and watercut. Additional experience about to be gained through meters that are installed and will be commissioned in 1997 is highlighted by the shaded section.

During the operational life of the meters listed in Tables 1 and 2, only two significant problem areas have been experienced. On a meter that was installed on a North Sea platform, a mechanical problem leading to an oil leak and subsequent contamination of the gamma collimator was experienced. This problem was identified as an isolated mistake in the final assembly of the meter not detected by quality assurance procedures. Appropriate procedures have been put in place in the ISO 9001 certified QA program to avoid this kind of incident in the future.

Another problem area identified during the commercial introduction of the meter has been the gamma ray detector and certain of its associated nuclear electronics. Even though a rigorous QA screening process was in place, there have been cases of detector failures. Their incidence has been dramatically reduced by turning to detector vendors who specialize in the hostile environments of the oilfield. Improved performance from previously failure-prone nucleonics has been achieved by working with vendors to select high-temperature components, to perform chamber testing on completed assemblies, and so on. The 3-Phase Measurement partnership, described later in this article, should make this an area of strength, as two of the three partners specialize in instrumentation for difficult oilfield environments.

FUTURE TRENDS

The trend in multiphase metering which all users care most about in the *price trend.* At today's prices for the devices, often only high-volume, expensive production systems can justify their use. If this situation were to endure, multiphase metering would have only a minimal impact on the worldwide economics of production. Happily, this is not the case; in the coming years multiphase meters will come down in price and go up in usage, primarily due to the factors listed below.

Economies of Scale

Thus far no manufacturer of these meters has delivered enough quantity of product to bring their prices down substantially. However, as these manufacturers begin to see a strong market for their product, they will build to forecast rather than demand, they will achieve savings in both purchase and production of parts, and they will be able to pass these savings on to the user.

Cost Reduction Efforts

When it is clear that there is a solid market for multiphase meters, manufacturers will address every part of their manufacturing process to take cost out - and will do it over and over again. Some of these improvements will require re-design, some will necessitate new machines or tooling. However, when it is perceived that there will be a return on this investment by the manufacturers, they will surely make the changes, and the end user will be the beneficiary.

Alternate Less Expensive Technology

As with the manufacturing processes, manufacturers will invest in alternative designs - some of which may be radical - if they feel that these investments will pay off with increased meter sales and better margins. Thus, new technology and improved designs will produce even further reductions in prices.

The phenomena described here are certainly not unique to multiphase meters; on the contrary, they are typical of what happens in a competitive market where there is strong demand for products that are technology-laden. **Fig. 11** presents an interesting example of how the prices of non-volatile computer memories have come down during the past eight years as demand for this technology has gone up.

Another trend which will appear in coming years is that suppliers will offer a portfolio of multiphase meters rather than a "one size fits all" product. This will be a consequence of the natural market segmentation due to larger sales volumes and a richer variety of measurement methods. For example, certain land applications might accept a reduced-accuracy, low-cost unit, whereas deep subsea applications might demand the most accurate, reliable meters money can buy. Successful suppliers will recognize this diversity of requirements and offer the market a range of products.

A final trend worth mentioning is that of intelligent metering systems. Intelligent meters are those which are capable of providing more information than simply a measure of flow. Probably the most important ancillary information in most cases is the fitness of the meter. Given the power of imbedded processors used in today's instruments, it is mandatory that meters be able to diagnose both their own health and the quality of their measurements. This data should be reported to the user just as is the information on flow.

3-Phase Measurements AS

Daniel Industries, Framo Engineering, and Schlumberger Limited announced recently their intent to cooperate in the area of multiphase flow measurement. The vehicle for this cooperation will be a jointly owned technology center, to be called 3-Phase Measurements AS, located in Bergen, Norway. It will be staffed by specialist personnel from each of the three companies, and will be tasked with the design and manufacture of multiphase meters for use both topside and on the sea floor.

3-Phase Measurements will initially offer the latest version of the Framo meter as its standard product for both topside and subsea applications, since it is a fully commercial and proven concept. As new multiphase developments are brought forward from the three partners, these will be refined and offered commercially by 3-Phase Measurements.

CONCLUSIONS

1. Multiphase meters have the potential to provide significant savings in both capital and operational expenditures, and to provide continuous or near-continuous monitoring of production performance.

2. There are significant technical differences between metering technologies. The user should beware of those which he cannot understand or the details of which the supplier can't adequately explain.

3. Flow regime effects and salinity are the two most important environmental effects on these meters. The Framo mixer removes uncertainties due to flow regime. Salinity changes can be dealt with by direct sampling, by new methods of gamma ray spectral analysis or by direct single-phase measurements.

4. The Framo Multiphase meter has extensive operational experience on land, topside offshore, and subsea. In fact, the two East Spar subsea meters are unique as the only multiphase meters ever installed on the sea floor for any significant period of time.

5. There are, at every stage of installation and operation, verification methods that can be applied to assess the health of the meter.

6. These meters will continue to become more robust, more performant, and less expensive as the technology and the market mature.

ACKNOWLEDGEMENTS

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REFERENCES

/1/ Rafa K., Tomoda T., Ridley R. "Flow Loop and Field Testing of a Gamma Ray Compositional Meter". Energy-Sources Technology Conference and Exhibition, January 22-25, 1989, Houston Texas.

/2/ Martin W., Woiceshyn G. E., Torkildsen B. H. "A Proven Oil-Water-Gas Flow Meter for Subsea". The 23rd Annual Offshore Technology Conference, May 6-9, 1991, Houston, Texas.

/3/ Olsen A. B., Torkildsen B. H. "Subsea Multiphase Flowmeter System". Underwater Technology Conference, March 30 - April 1, 1992, Bergen, Norway.

/4/ Torkildsen B. H., Olsen A. B. "Framo Multiphase Flow Meter Prototype Test". 10th North Sea Flow Measurement Workshop, October 26-29, 1992, Scotland.

/5/ Olsen A. B., "Framo Subsea Multiphase Flow Meter System". Multiphase Meters and their Subsea Applications, April 13, 1993, London, UK.

/6/ Olsen A. B., Hanssen B. V., "Framo Multiphase Flow Meter - Field testing experience from Statoil Gullfaks A and B platforms and Texaco Humble test facilities." 12th North Sea Flow Measurement Workshop, October 24-27, 1994, Scotland.

/7/ Hanssen B.V., Torkildsen B.H., "Status of the Framo Subsea Multiphase Flow Meter", North Sea Flow Measurement Workshop, Lillehammer, October 1995.

/8/ Slijkerman W.F.J., Jamieson A.W., Priddy W.J., Økland O., Moestue H. "Oil companies needs in multiphase flow metering", North Sea Flow Measurement Workshop, Lillehammer, October 1995.

/9/ Hanssen B.V., Svaeren J.A. "Diverless subsea multiphase meter", Underwater Technology Conference, Bergen - March 1996.

/10/ Mohsen, Amr A. and Al-Hinai, Ruqaiya, "Experience with the Framo Multiphase Flowmeter in Petroleum Development Oman", 1997 Saudi Aramco Chapter SPE Technical Symposium, Dhahran, Saudi Arabia, 8-9 June 1997.

/11/ Torkildsen, Bernt H. and Hanssen, Birger V., "Practical considerations related to multiphase metering of a well stream", North Sea Flow Measurement Workshop, Scotland, October 1996.

Table 1. Test sites for the Framo Multiphase Flow Meter

User	Platform / Field	GVF at actual condition (%)	WC at actual condition (%)	Total flow rate (m^3/h)	Design pressure (bar)	Date
Statoil / JIP, Norway	Gullfaks B	20 – 50	0 - 90	250	96	1994
Statoil, Norway	Gullfaks A	40 – 60	0 - 80	120	250	1994
Texaco / JIP, USA	Humble, Texas	50 – 96	5 - 90	270	250	1994
Maersk Olie & Gas AS, Denmark	Dan F	89 - 92	0 - 40	200 - 750	20	1994
Statoil / Saga / Norsk Hydro, Norway	Porsgrunn Flow Loop Test	50 - 98	0 - 100	Up to 250	250	1995
Phillips Petroleum Co. Norway	2/4A, Ekofisk	83 - 98	0 - 76	1400	41	1995
Multiflow JIP, Scotland	National Engineering Laboratory, Glasgow	0 - 100	0 - 100	0 – 520	250	1996
Shell UK Exploration & Production	Gannet	75 - 86	0 - 90	60 – 200	25	1996
Petroleum Development Oman	Hazar	70 - 90	0 - 50	50 – 170	250	1996
Statoil / Saga / Norsk Hydro, Norway	Porsgrunn Flow Loop Test II	50 - 98	0 - 100	Up to 250	250	1996

Table 2. Operational conditions in which the Framo Multiphase Flow Meter has been commercially installed.

Meter Location	No. of Units	Design	GVF at actual Condition (%)	WC at actual Condition (%)	Total flow rate (m^3/h)	Installation
Offshore UK	1	Topside	90 - 99	0 - 90	200 - 5000	1994
Offshore UK	1	Topside	90 - 99	0 - 90	200 - 5000	1994
Offshore UK	1	Topside	85 - 99	0 - 90	200 - 5000	1994
North Sea	1	Topside	85 - 95	0 - 20	150 - 800	1995
North Sea	1	Topside	42 - 99	0 - 75	250 - 1370	1995
Gulf of Mexico	1	Topside	90 - 95	0 - 10	220 - 830	1996
Offshore Australia	2	Subsea	87 - 95	0 - 70	Up to 750	1996
North Sea	1	Subsea	Variable	Variable	---	1996
North Sea	6	Topside	85 - 95	0 - 63	Up to 1200	1996
North Sea	2+1	Subsea	41 - 99	0 - 90	Up to 1500	1997
North Sea	1	Topside	77 - 88	0 - 25	500 - 3000	1997
Mediterranean	1	Topside	30 - 50	0 - 10	10 - 200	1997
Mid East	1	Topside	27 - 97	0 - 84	20 - 1200	1997
North Sea	1	Subsea	60 - 80	0 - 92	100 - 550	1997
North Sea	1	Topside	47 – 87	0 – 86	Up to 3000	1997
North Sea	1	Topside	85 – 92	0 – 80	50 – 400	1997

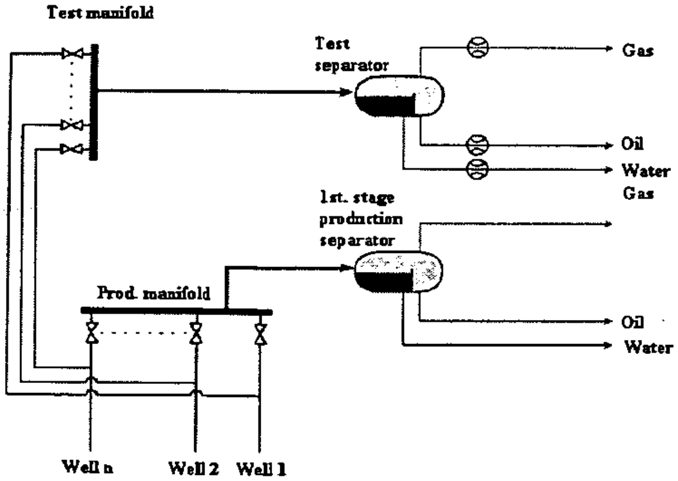


Fig. 1(a) Typical offshore arrangement of production and test manifolds and separators

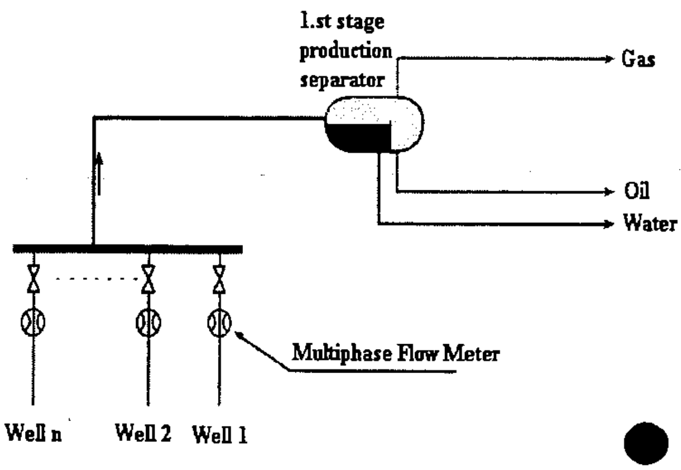


Fig. 1(b). Replacement of test manifold, test line, and test separato by use of a multiphase flow meter on each well stream.

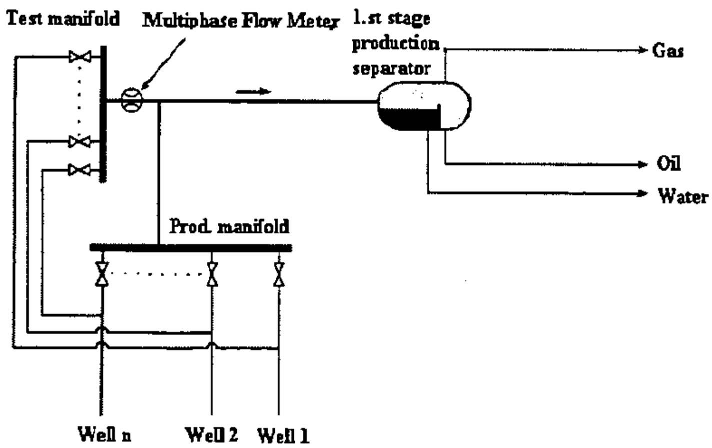
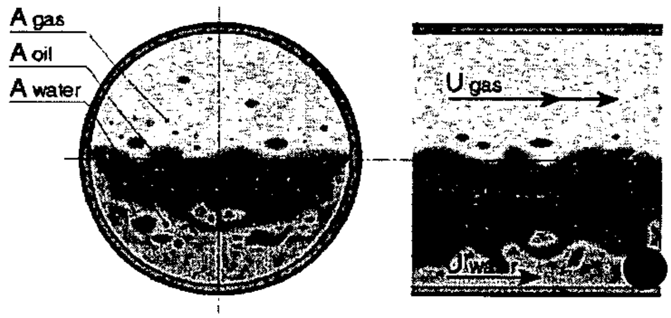


Fig. 1(c). Replacement of test line and test separator by use of one multiphase flow meter downstream of the test manifold.



Ug : Gas velocity
Uw : Water velocity
Uo : Oil velocity
Ag : Area occupied by gas
Ao : Area occupied by oil
Aw : Area occupied by water

Fig. 2. Schematic showing three-phase flow through a pipe.

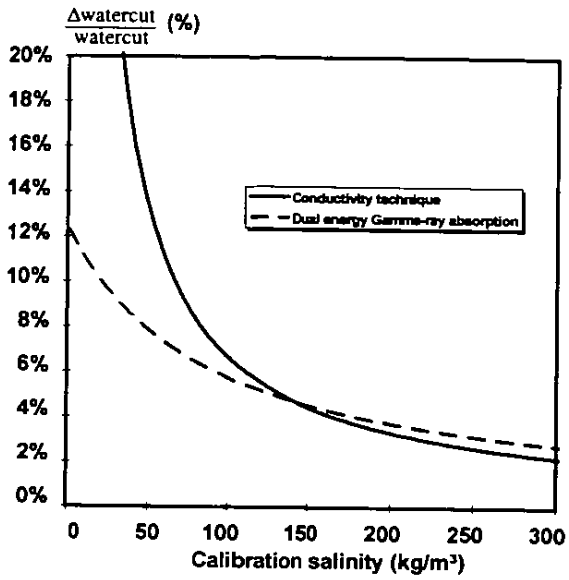


Fig. 3: The relative error in water cut, as a function of calibration salinity, due to a change in salinity of 10 kg/m^3.

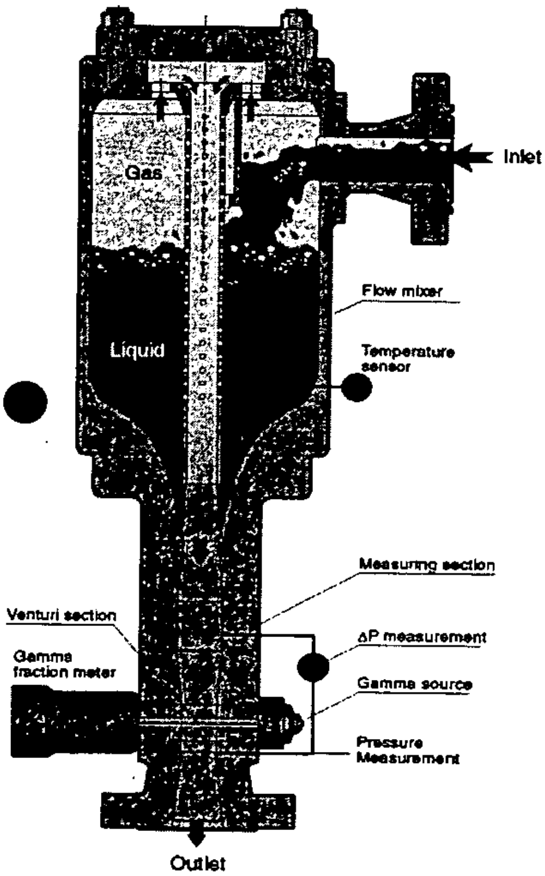


Fig. 4: Topside version of Framo Multiphase Flow Meter

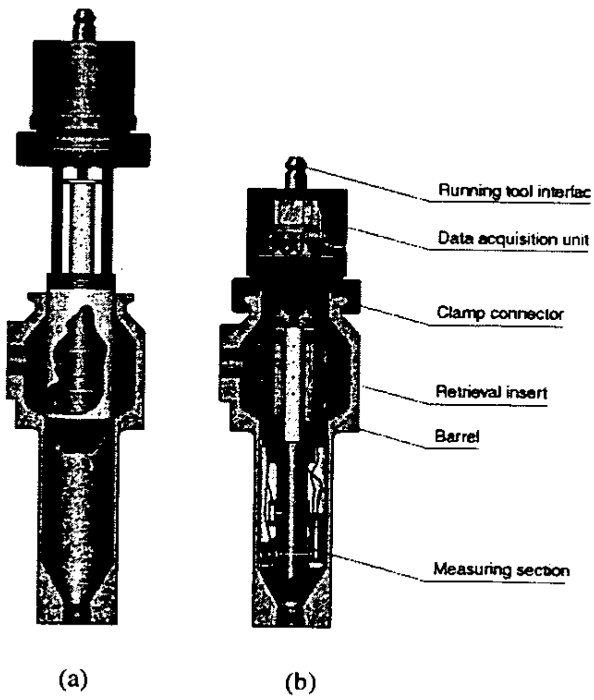


Fig. 5: Subsea version of Framo Multiphase Flow Meter. (a) During cartridge insertion. (b) With cartridge secured in receiver barrel.

Fig. 6: Absolute Framo meter watercut deviation from NEL reference (1996).

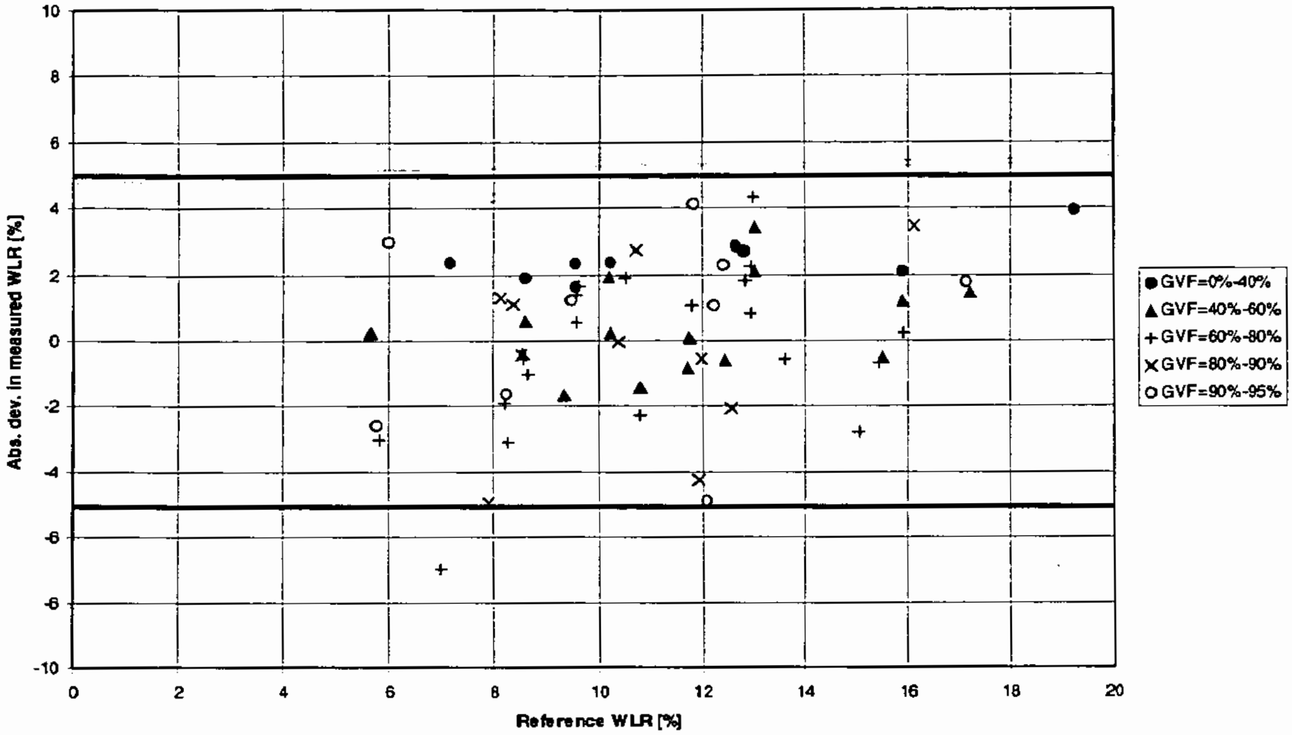
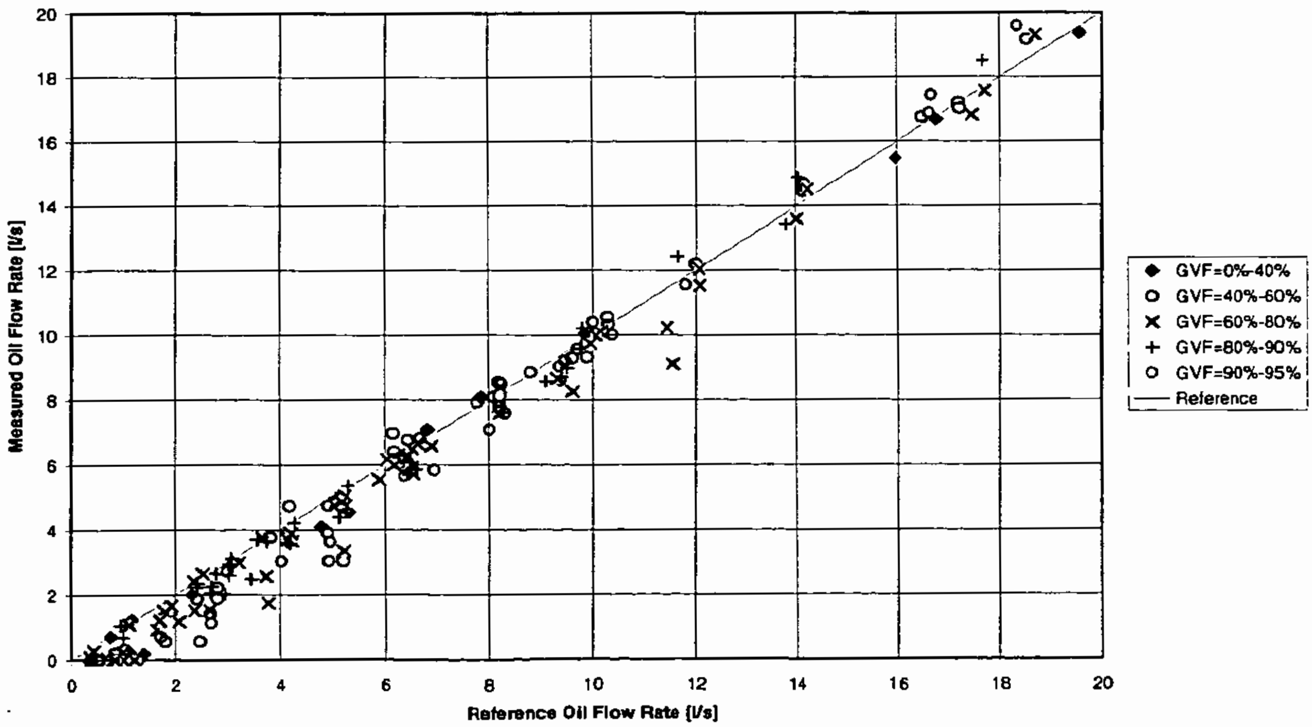


Fig. 7: Framo oil rate measurement versus NEL reference (1996) for gas volume fractions of 0 - 95%



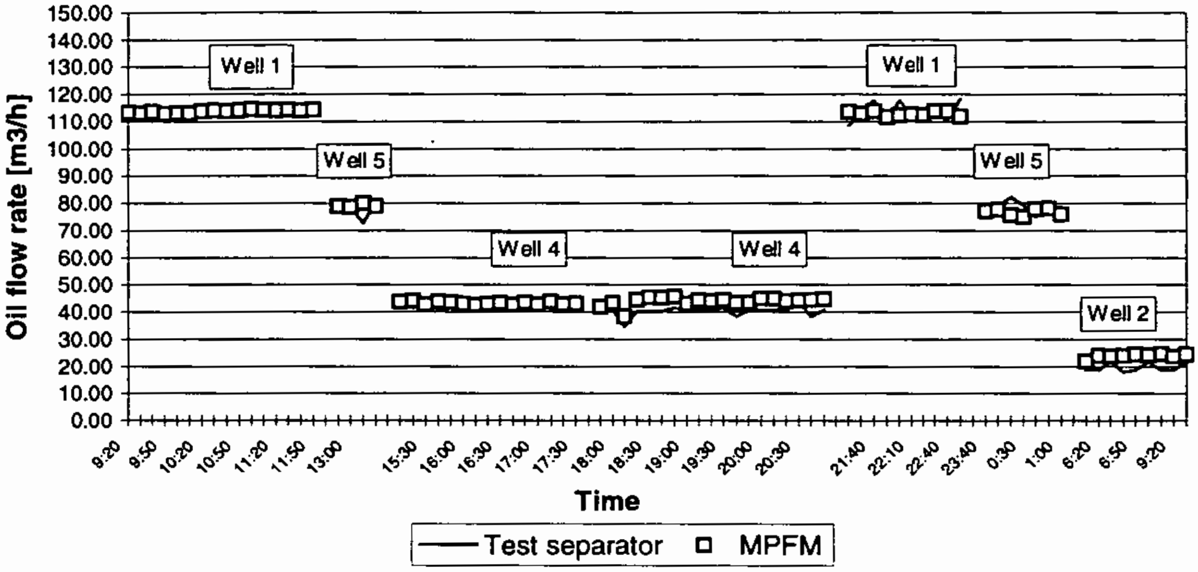


Fig. 8: Gullfaks B 24-hour well test results with Framo Multiphase Flow Meter and test separator.

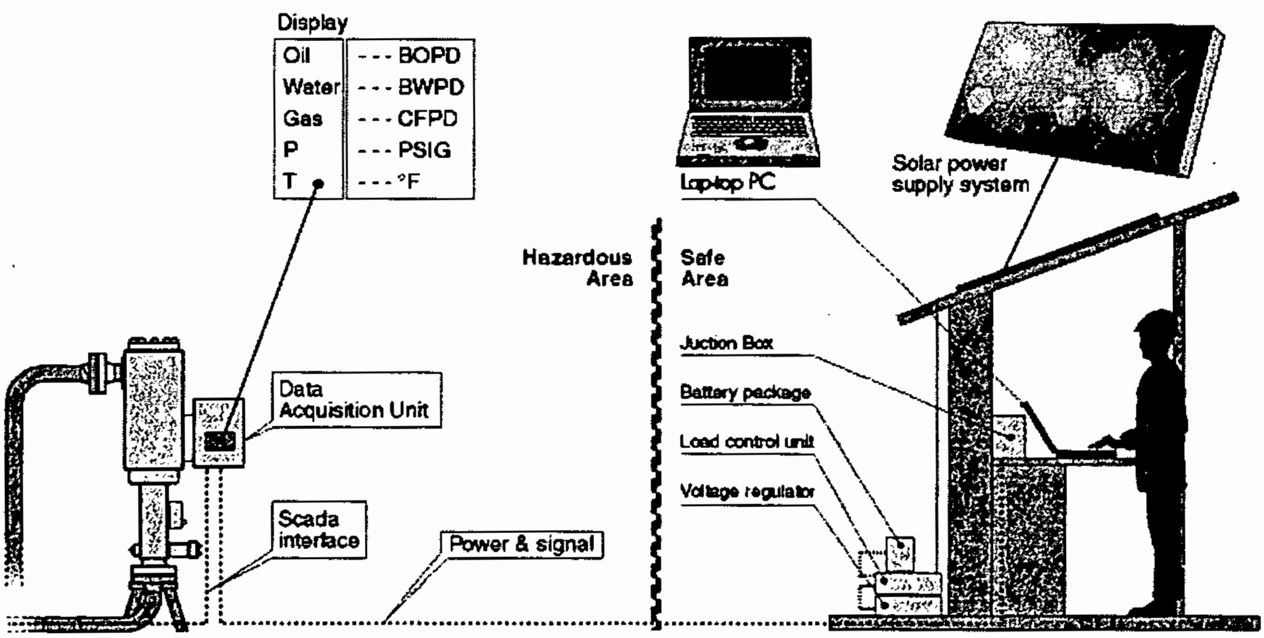


Fig. 9: Application of the Framo MPFM at a remote land location in Oman.

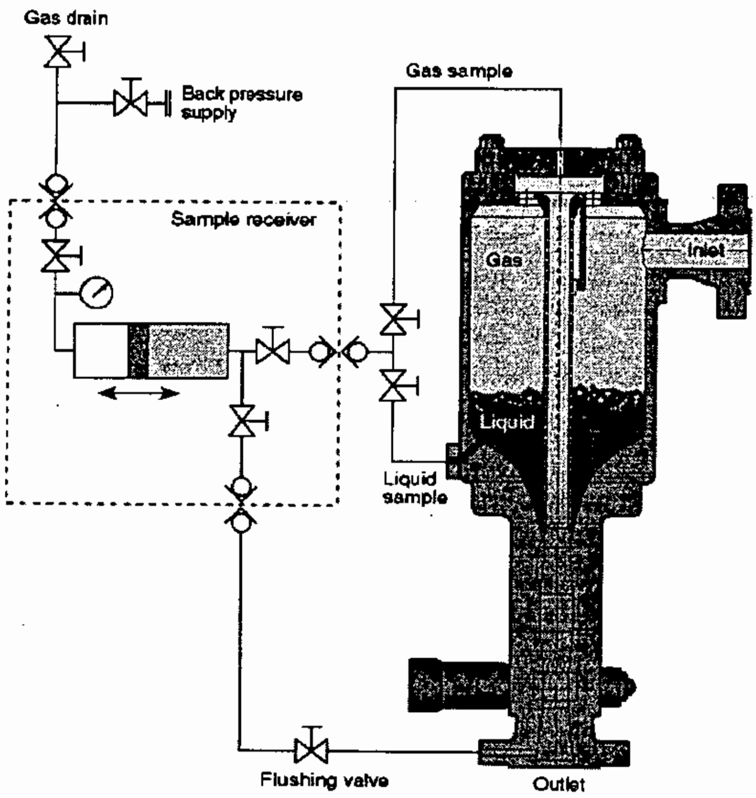


Fig. 10: Sampling capabilities with the Framo MPFM.

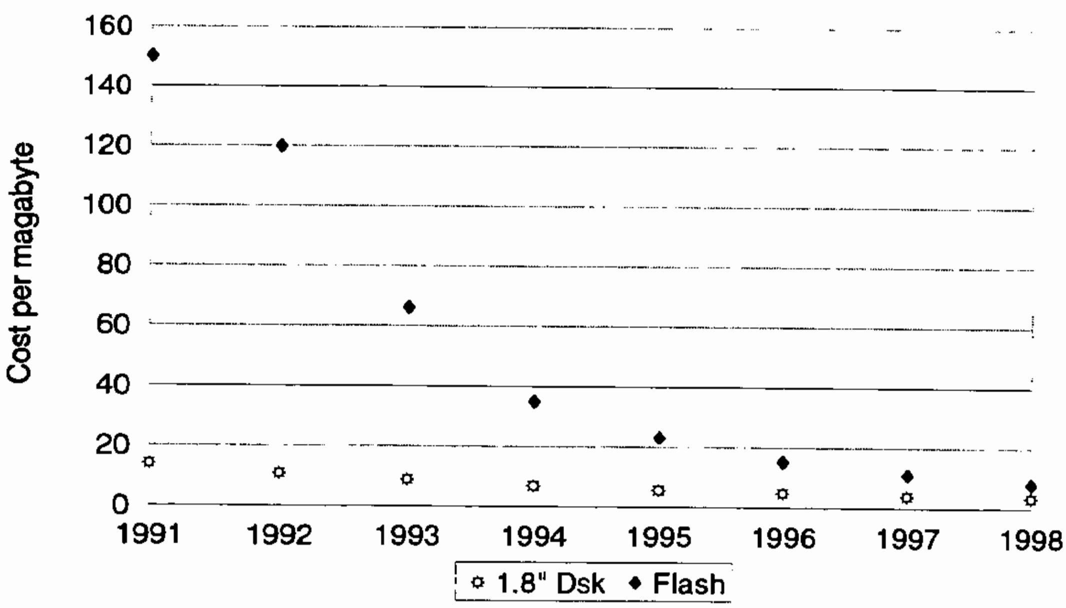


Fig. 11: Cost reduction of microdisk and flash memories, 1991-98.