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"Measurement and Allocation for Production through Ekofisk"

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INTRODUCTION

The planning and development of the Ekofisk allocation system in the early 1970's was a remarkable challenge that required a wide range of innovations and new developments to solve a number of problems.

A basic requirement considered during the planning phase, was that each field's contribution of the finished products in Emden and Teesside, was to be determined with a high degree of accuracy. The ownership of the Ekofisk fields are not all the same and the composition of produced hydrocarbon vary substantially from field to field. It was therefore important that each field's production of light components could be tracked through the system, to be able to allocate the Natural Gas Liquid (NGL) products to the owners of each of the fields.

It was decided early that weight rather volume was to be used as the standard for measurement of flowing streams. The problem with volumetric measurements was that the tables available for liquid volume corrections, were not applicable for the pressures and stream compositions present at Ekofisk.

The complexity and size of the operation made it obvious from an early date, that extensive use of computers would be required. A system was necessary to capture, integrate, store and retrieve operational data, metered flows and laboratory analysis. This data is required for several purposes: for production monitoring, for reporting on a day-to-day basis and for product allocation purposes.

It was probably not appreciated at the time of planning, that the system installed would later be expanded, using very much the same computer hardware and allocation principles, to meter and allocate third party fields discovered later and tied-in with Ekofisk production.

The solutions chosen for Ekofisk have served as an example for others and to some extent has been used as basis for NPD's regulations for fiscal measurements of oil and gas.

DEVELOPMENT HISTORY

At the time of discovery in 1969, Ekofisk was the largest oil field in Western Europe, and the first commercial oil field in the North Sea. The Ekofisk Area development encompassed seven fields: Ekofisk, West Ekofisk, Cod, Tor, Eldfisk, Albuskjell and Edda, of which four are oil fields and three are categorized as condensate fields.

The construction of the Ekofisk facilities was one of the largest offshore development projects that has ever been undertaken. The project was conducted in several phases. During the first phase, four subsea Ekofisk wells were produced through separation facilities located on a converted jackup rig. Oil was loaded to tankers through single-point mooring buoys and associated gas was flared.

In the second phase the Ekofisk field was developed, which included setting of three drilling platforms (two for production and one for gas injection), one field terminal platform and one million barrel concrete storage tank (figure 1).

The subsequent phases included installation of drilling and production platforms on all fields. A central processing facility was located at the Ekofisk Center on top of the underwater storage tank. Pipelines were laid from all the "outlying platforms" to feed oil and gas to the central processing facility. The central processing facility was designed to produce a 100 Reid Vapor Pressure crude consisting of a mixture Natural Gas Liquid and crude for delivery to Teesside, England, and a low dew point pressure residue gas to be delivered to a treating plant in Emden, Germany.

A 36" pipeline 441 km long was constructed, to transport gas to Emden and a 34" pipeline 354 km long was constructed to transport oil to Teesside. At Teesside a terminal was built to extract the NGL products (ethane, propane, isobutane and normal butane) and to stabilize crude before loading into tankers.

Ekofisk is important not only for its own production of oil and gas, but also for its role as transportation hub. Almost all of the gas and much of the oil produced in the Norwegian sector of the North Sea is transported to market through the Ekofisk Complex (figures 2 and 3).

MEASUREMENTS AND SAMPLING

Measured mass of oil and gas, and component analysis are the important input parameters to allocate the finished products of gas in Emden, and NGL and crude in Teesside. The finished products consists of a blend of the various streams feeding into Ekofisk Center. One objective of the allocation system is to determine a fair and equitable split of finished products based upon results of measurements and tests of the various input and output streams to Ekofisk Center. Another objective, is that the metering and allocation system shall be automatic, in the sense that the gathering of measurement data, data transfer, data storage and allocation calculations shall be automatic, with a minimum influence of operator's judgement and intervention.

The oil and gas streams are metered and sampled at several points during the flow from wellhead to Emden and Teesside terminals. At Ekofisk oil and gas is separated in a three stage separation process. The gas is dehydrated and dew point controlled before delivered to the export pipeline. Extracted NGL is "spiked" into the oil stream before pumped to Teesside.

The first point of measurement is after the first stage of separation, before the fields production is delivered into the central processing facilities at Ekofisk center. The streams measured after the first stage of separation are termed as "Ekofisk Input Streams" (figure 4).

The second point of measurement is at Ekofisk Center as the production of oil and gas leaves Ekofisk and is delivered into the export pipelines after processing. The export streams are termed as "Ekofisk Center Output Streams" (figure 5).

The third and final point is at the sales metering points, for gas the gas sales meters in Emden and for crude and NGL products the sales meters before the finished products are loaded on board ships (figure 6) at Teesside.

All measurements and testing at the various metering points at Ekofisk are done according to the same principles, codes and standards.

Total weight of oil is measured continuously by turbine meters and densitometers. Total weight of gas is measured continuously by orifice meters and densitometers. All accounting gas flow measurements were originally done according to AGA 3. The formula to compute mass flow is now being modified according to ISO 5167.

Automatic flow proportionate samplers are installed at all oil and gas meter stations.

ANALYSIS

Composite samples are obtained monthly at the measurement stations. Spot samples are taken with sufficient frequency to serve as back-up, if the composite sample should fail.

Located at Ekofisk Center is an allocation laboratory, where analysis of oil and gas samples are performed. The samples are analyzed by fractional distillation (according to ASTM D-2892), gas chromatography (NGPA-2261, NGPA-2162 and ASTM-1945) to determine the content of nitrogen, carbon dioxide, methane, ethane, propane, isobutane, normal butane, pentanes, hexanes and heptanes and heavier hydrocarbons.

The heptanes and heavier fraction of the oil samples are further tested to determine specific gravity at 60°F/60°F (ASTM D-4052), salt content and water content (according to Karl Fischer).

DATA ACQUISITION, DATA TRANSMITTAL, DATA STORAGE

The data acquisition, data transmittal and data storage system was designed to provide a flexible and automatic system to transfer metering and process data to a mainframe computer located at the onshore base without the need to keypunch data. Data from "outlying platforms" are transferred to Ekofisk Center via microwave and further from Ekofisk Center on to onshore via satellite communication. Data from 45 gas metering stations, 17 oil meter stations, numerous valve statuses and process readings are continuously being transmitted from offshore and received by the onshore computer.

Each measurement system on the field producing platform and on the Ekofisk Center is tied in to a dedicated on-line computer to monitor and control station operations, perform all flow calculations and prepare various reports. Pressure, temperature, density, flow and mass data are sent from the measurement computers to the Telemetry Computer System (TCS) located at Ekofisk Center. The TCS calculates 2-hour averages for the pressure, temperature and density as well as mass flow data. The 2-hour information is sent every second hour to onshore (figure 7). The TCS also communicates with Emden, Teesside and Ula measurement systems.

Onshore, the 2-hour data is collected and stored by the TIS (Technical Information System). The TIS is a major computer system for organizing, storing and reporting of operational data. It is implemented on an IBM mainframe computer (IBM 4381) and consists of a total of 250,000 lines of source code, 140 programs, 100 library routines and 55 data files. The work to develop TIS started in 1974. To date a continued effort has been done to expand and maintain the system. From 1974 to date at least 100,000 manhours have been spent on the TIS development.

The described computerized system has proved highly successful. The only human intervention is for quality control purposes and possible corrections of data received in the TIS files. Corrections done in TIS data are tracked in a separate file available for third party audits. Included in this file is a reason given for each correction. All manual corrections to measured data are to be documented with a reason given for the correction.

ALLOCATION OF EKOFISK INPUT STREAMS

The data collected from the measurements and tests are used to determine the ownership of products in a stepwise fashion following the direction of flow. The first step is to determine the ownership of the input streams to Ekofisk Center, the next step is to determine the ownership of the output streams from Ekofisk Center, and the final step is to allocate the finished products at Teesside and Emden amongst the owners of the production, based upon ownership calculated in the preceding steps.

Measured masses are accumulated during the accounting period, which at Ekofisk is a month. The results of the sample analysis yields the stream composition as weight fraction of each component. The weight of the components produced from the various fields are calculated as the accumulated measured mass during a month times weight percent of each component.

By considering the component ownership in all input streams to Ekofisk Center, the fractional weight shares and the fractional volume shares are calculated. Each owner's fractional weight share of each component in all input streams is that owner's input weight of each component divided by the total weight of that component in the input streams.

The fractional volume shares are calculated by converting the accumulated masses of pentanes, hexanes, heptanes and heavier to volume by using component mass to volume conversion factors generally accepted in the oil industry. The measured C7+ specific gravity of the oil samples is used to convert weight to volume of C7+ in oil. Each owner's fractional volume share, is that owner's input volume of pentanes and heavier divided by the total volume of pentanes and heavier in the input streams.

The fractional shares so calculated are used as split keys in the following steps of the allocation procedure.

ALLOCATION OF EKOFISK CENTER OUTPUT STREAMS

The component weight in the export oil and gas pipelines are determined similarly as described for the input streams. The ownership of the output oil and gas export streams from Ekofisk Center are allocated component by component in accordance with the input streams:

1) Each component in the gas output stream is allocated in accordance to each owner's fractional weight share of that component in the input stream. All components other than pentanes and heavier in the oil output stream are allocated in accordance with each owner's fractional weight share of that component in the input stream.

2) The pentanes and heavier components in oil output stream are allocated in accordance with each owner's fractional volume share of pentanes and heavier in the input streams.

The allocation of the output streams are done in two steps. The first step is to calculate ownership in the oil and gas that has been processed at central processing facilities at Ekofisk as described above. The second step is to reallocate ownership in the export pipelines to 1) account for gas injected into Ekofisk field owned by others than the owners of the Ekofisk field, 2) to include the production of third party fields tied-in to Ekofisk Center (Ula oil, Valhall oil and gas, and the gas from Statfjord, Gullfaks, and Heimdal fields delivered through Statpipe) and 3) to reflect adjustments in ownership in gas due to fuel and purge gas arrangements at

Ekofisk Center. Figure 8 shows the metering at Ekofisk Center of the streams to be reallocated. The final results after the reallocation is the component weight ownership in oil and gas pipelines, and thereby are the split keys to allocate production in Teesside and Emden calculated (figure 9).

FUELS

Fuel gas streams are measured and sampled similarly to the gas stream accounted for in the ownership allocations. However, all fuel gas streams are deemed as lost for the purposes of product ownership. As a loss, the fuel quantities are not considered and do not appear in the allocation reports. An exception is the fuel gas consumed by oil pipeline pumps and gas pipeline compressors at Ekofisk Center, which is allocated to the owners of products shipped.

SALES GAS ALLOCATIONS

At the Emden terminal gas is conditioned to meet buyers specifications and thereafter metered at the sales point. Gas is sold and allocated in terms of energy. Each owner's fractional energy shares are calculated by converting component weight ownership of the reallocated Ekofisk Center Output Stream to energy, using factors to convert weight of components to heating value units.

At the end of each month an "over/short" account is prepared showing the balance between each owner's accumulated daily sales and monthly allocated deliveries. A payback schedule is then prepared for each owner group, considering possible substitution arrangement and operational flexibility agreements between the owners.

A matter of some controversy and discussion amongst certain third party shippers, is the fact that the final Emden allocations do not consider quantities of gas delivered from the pipelines inventory during a month. However, with the current high utilization of the pipeline, the linepack available is only 0.2-0.4% of the total monthly deliveries. The error introduced by not accounting correctly the split amongst the shippers of these 0.2-0.4% is not great. In addition, any error in one month, tends to be balanced out in the coming months, when the linefill volume is restored to the original state.

ALLOCATION OF TEESSIDE PRODUCTS

The high vapor pressure crude received at Teesside Plant is stabilized to provide a crude ready for shipment with vapor pressure of 3 to 8 RVP. The light components are fractionated to commercial grades of ethane, propane, iso- and normal butanes. Methane is used as plant fuel. Stabilized crude is sold and allocated in terms of volume (barrels). NGL products are sold and allocated in terms of weight (tonnes).

On the condition that the stabilized crude has a vapor pressure less than 7 RVP, the Teesside oil is allocated in accordance with each owner's fractional volume share in the oil to pipeline stream at Ekofisk Center. The NGL products are allocated in accordance with each owner's fractional weight share of the predominant component in the oil to pipeline stream.

At the end of each month an "over/under lift" account is prepared for each owner, showing the balance between allocated quantity of finished product and actual shipped quantity.

To avoid biases, the allocation contracts state that in the case that the NGL product has a content of less than 95% of the predominant component, then the product shall be allocated on a component by component basis. With the current hydrocarbon feed, the error introduced by allocating only by the predominant component is very small, typically less then 0.05%. The 7 RVP limit for the crude allocations is to limit possible problems occurring because not considering contents of NGL components in the crude in allocation of the crude (particular n-butane).

METERING ACCURACY

By comparing measured mass through the Ekofisk process and transportation system, it is possible to evaluate consistency in data from metering point to metering point. In Table I are given factors, calculated by dividing mass measured at the outlet point with measured mass at the inlet point.

Table I - Material Balance Factors

	Ekofisk Center		Oil Pipeline		Gas Pipeline	
Component	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
N_2	.894	.056	-	-	.805	.122
CO_2	.994	.014	.994	.068	1.013	.030
C_1	.987	.007	1.020	.066	1.001	.006
C_2	1.011	.009	.962	.058	1.017	.021
C_3	1.031	.011	1.025	.042	.980	.050
IC_4	1.055	.020	1.102	.049	1.051	.040
NC_4	1.035	.023	1.157	.061	1.048	.048
IC_5	1.080	.036	1.140	.053	1.068	.072
NC_5	1.093	.032	1.094	.066	1.097	.101
C_6	1.055	.037	1.026	.035	-	-
C_{7+}	1.005	.007	.986	.007	-	-
Total Mass	1.004	.003	1.000	.004	1.002	.001

The factors are calculated using monthly total metered masses and sample analysis over a twelve month period during 1988 and 1989. The factor for "total mass" is the ratio of total metered mass at outlet with total metered mass at inlet, and thus expresses the accuracy of the metering excluding the possible errors introduced by sampling and testing.

It is evident that there is a high degree of consistency of measured mass at the various metering installations through the Ekofisk processing and transportation system with a difference of less than ±0.4% total measured mass from metering point to metering point. However, for the individual components the difference and potential absolute error is greater. These errors may be explained by biases introduced by the sampling and gas chromatography methods.

W.J.Hines/3/ concludes that gas chromatography analysis is the limiting factor in the component mass measurement system. This seems also to be the case at Ekofisk. According to Hines, an error of ±0.25% of the total stream is to be expected for continuous integration of orifice flow data and of densitometer data into mass units. For measurement of NGL components by gas chromatography the error is given to be 1-3%.

THIRD PARTY SHIPPERS

From being a producer and transporter of its own production, the role of Phillips Petroleum Co. Norway, is changing more and more to be that of also being a transporter of third party oil and gas. The importance of third party oil and gas transportation has increased, as the number of third party fields tied in to Ekofisk facilities has increased, and third party share of production has progressively become greater. The effort to utilize spare capacity in the Ekofisk/Norpipe system has been successful as demonstrated by figure 10 and 11. In addition to the original 7 Ekofisk Area fields, the total production from Valhall, Ula and Tommeliten and the gas from Heimdal, Statfjord and Gullfaks are tied in to Ekofisk Center. Ekofisk Center is today the hub of transportation of gas from the Norwegian Sector to the Continent.

For the owners of the transportation network the third party production gives additional income and profits. For the operator there is not only income to be received, but also increased responsibilities. Each of the 26 oil companies that provide their production of oil and gas at Ekofisk, wants to be certain that they get their fair share of products sold in Teesside and Emden. For Phillips Petroleum it has been a challenge to refine procedures and routines to an extent and to a standard that can meet the third party audits. Comprehensive documentation, quality of data, unbiased metering and allocation, compatibility of design and calculation methods, and mode of operation at the various levels of metering are some of the key areas where efforts have been concentrated. Frequent third party and authority audits has been useful to pinpoint weaknesses and to identify improvements.

The incorporation of each new shipper group in the TIS database and allocation reports has proved to be a task on its own. The TIS database has been designed for flexibility, and can relatively easily be expanded to include data from new third party fields.

The allocation procedures applied for a new field is contingent upon to what extent the production is processed at Ekofisk. The Tommeliten Field, for instance, undergoes full 3-stage separation and dew point control after the unprocessed Tommeliten wellstream is received at the Edda platform. In the allocation procedures Tommeliten production is incorporated as an Ekofisk "Input Stream".

The Valhall case is an example of allocation of production where no processing occurs at Ekofisk. Valhall oil and gas is received at the 2/4 G platform at the Ekofisk Center processed to pipeline specifications. The oil and gas is metered and sampled on 2/4 G, before it is delivered directly to export oil and gas pipelines for shipment. In the allocation procedures Valhall production is incorporated as an Ekofisk "Output Stream".

The inclusion of new fields requires a careful effort by the program analysts to ensure that allocations are done according to agreements and that computer "bugs" are avoided.

For new fields it has been established as a principle, that the production shall be allocated according to the same procedures and standards as applied for the existing fields. One of the reasons behind this, is that amendment of the existing agreements to cater for changes will, at best, be a time consuming exercise, considering the many parties involved. Any change that will benefit certain shippers, will inherently be at the expense of others. Actually, the Appendix B "Allocation of Ownership of Production Ekofisk Facilities" has remained unchanged and unamended since first time signed in 1975.

CONCLUSIONS

The metering and allocation system designed for Ekofisk early in the 1970's has proven to be a reliable and a practical system. It is in use today using very much the same principles and hardware to incorporate new fields and new third party shipper groups. To improve the quality of the product allocations further, emphasize must be made to improve the accuracy of determination of component analysis of oil and gas samples.

ACKNOWLEDGEMENTS

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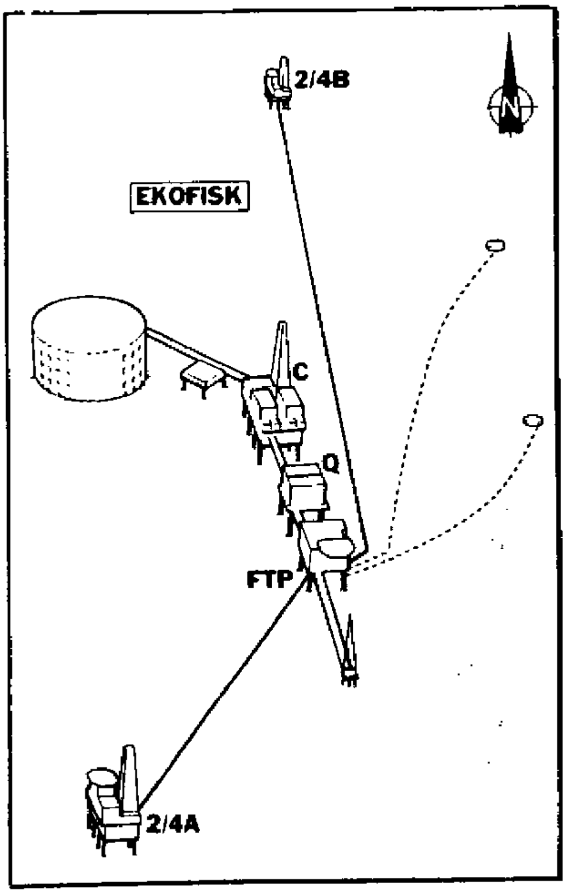

Figure 1 - Ekofisk Field development - Phase II.

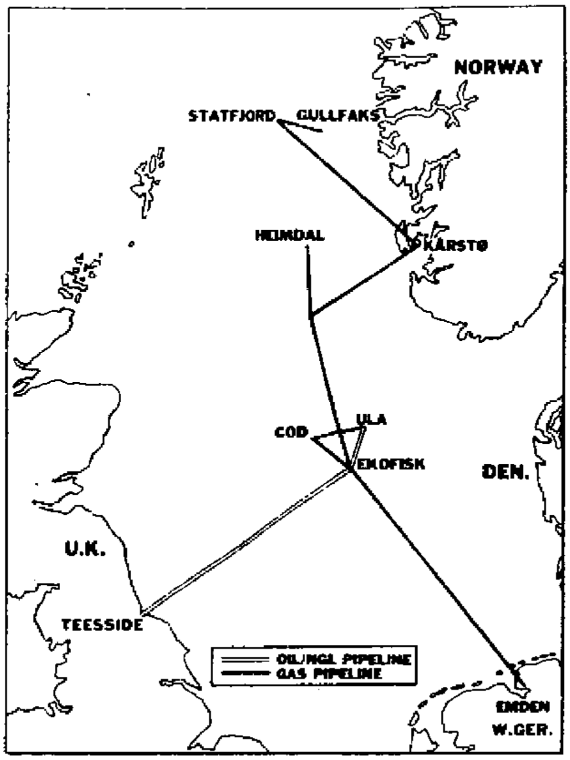

Figure 2 - Location of the Greater Ekofisk area and pipelines.

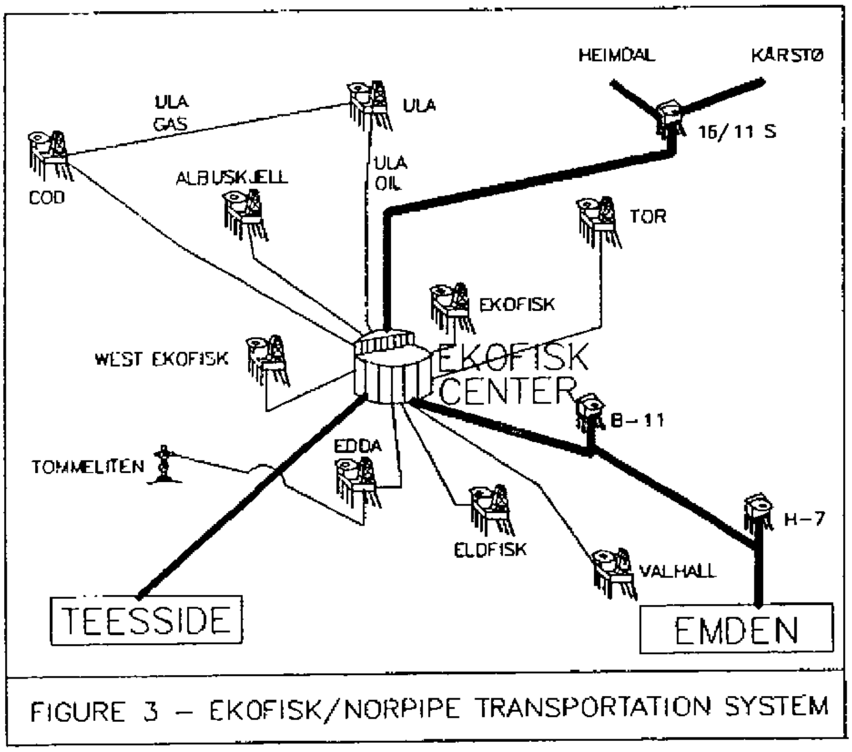

FIGURE 3 – EKOFISK/NORPIPE TRANSPORTATION SYSTEM

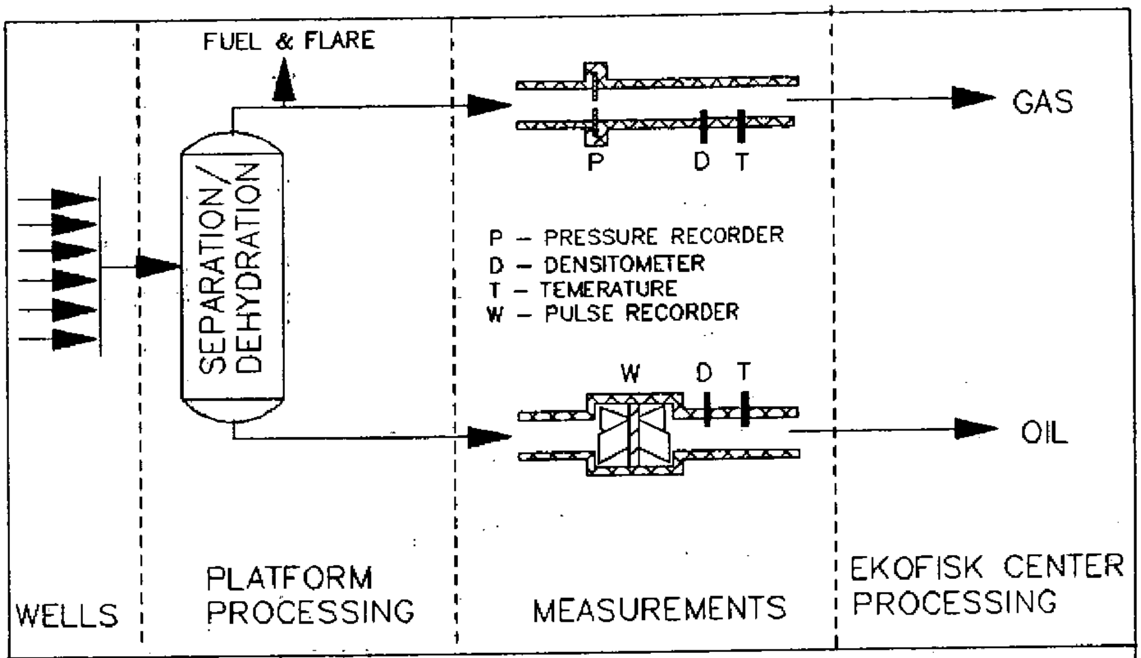

FIGURE 4 – EKOFISK INPUT STREAMS

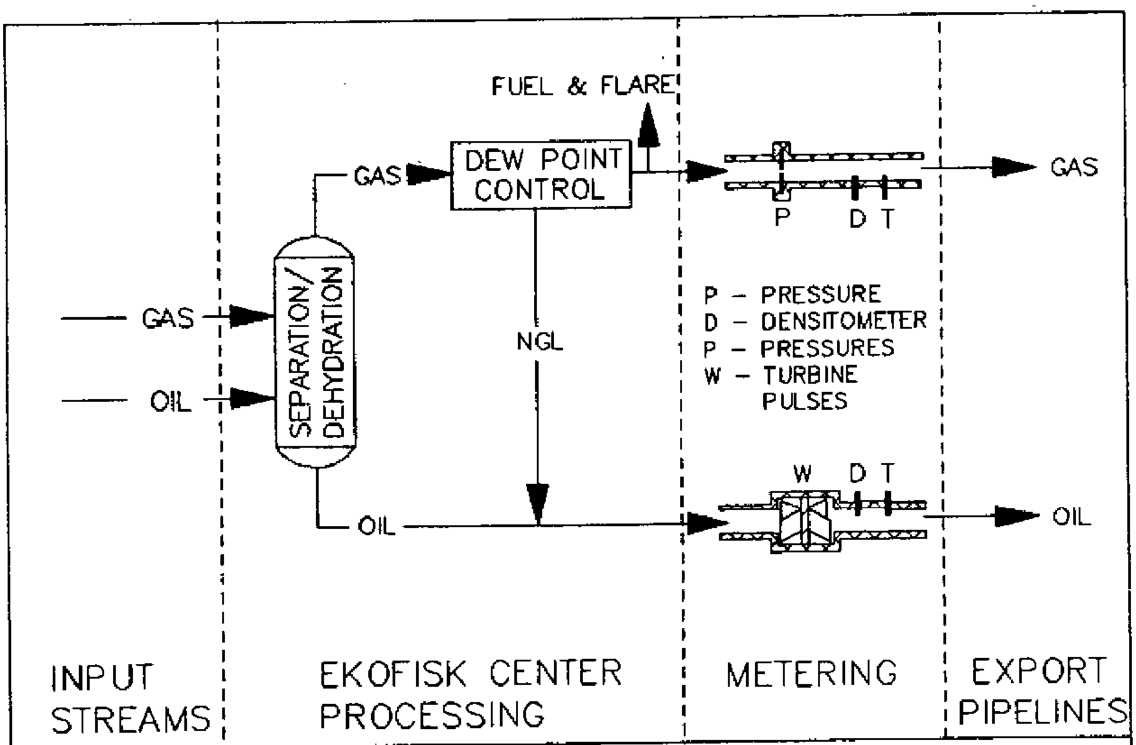

FIGURE 5 – EKOFISK CENTER OUTPUT STREAMS

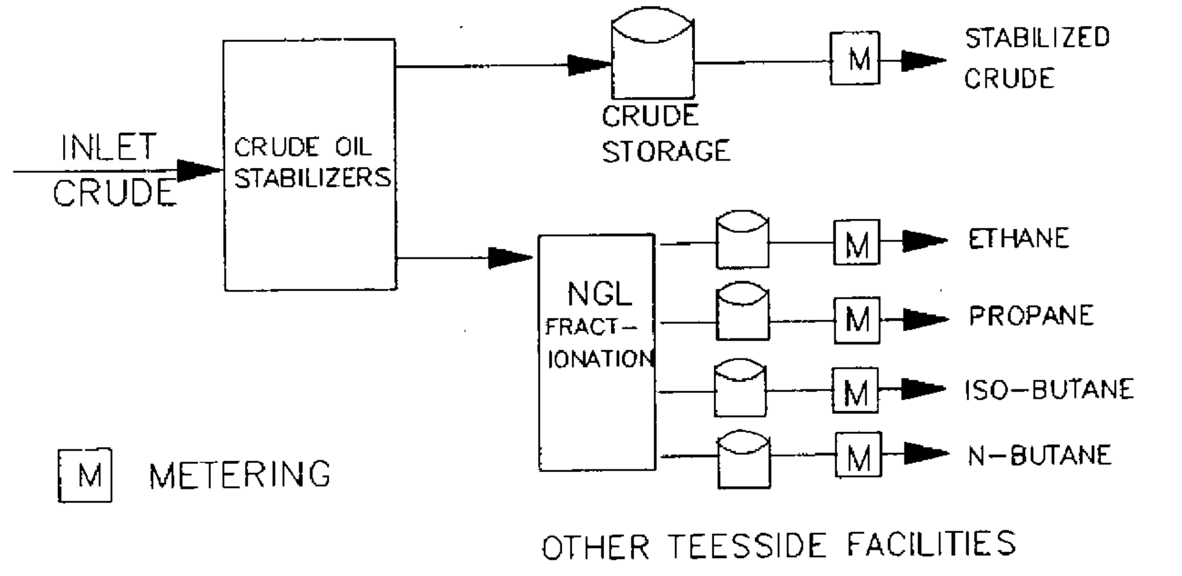

FIGURE 6 - TEESSIDE METERING

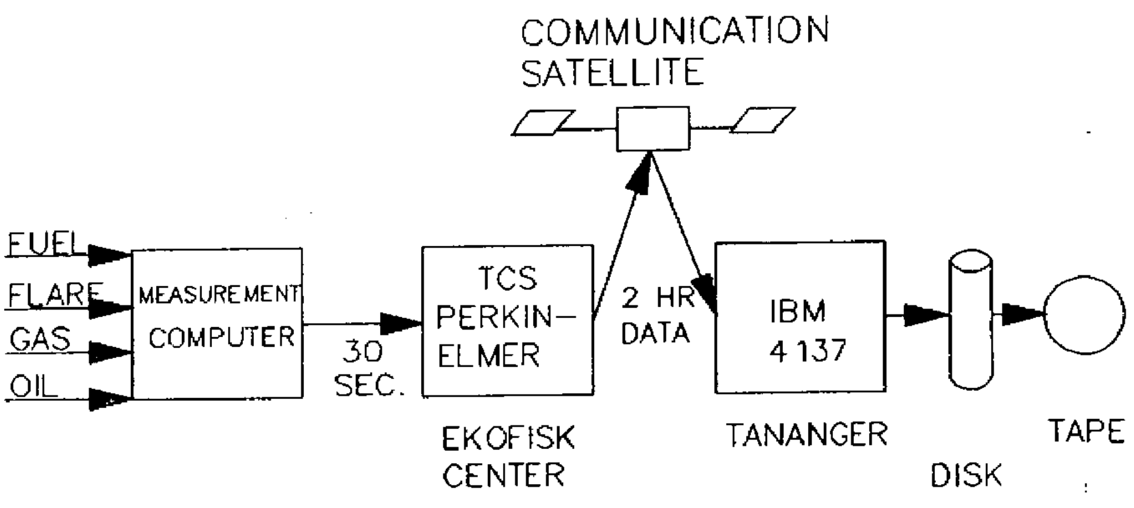

FIGURE 7 - TRANSFER/STORAGE OF METERING DATA

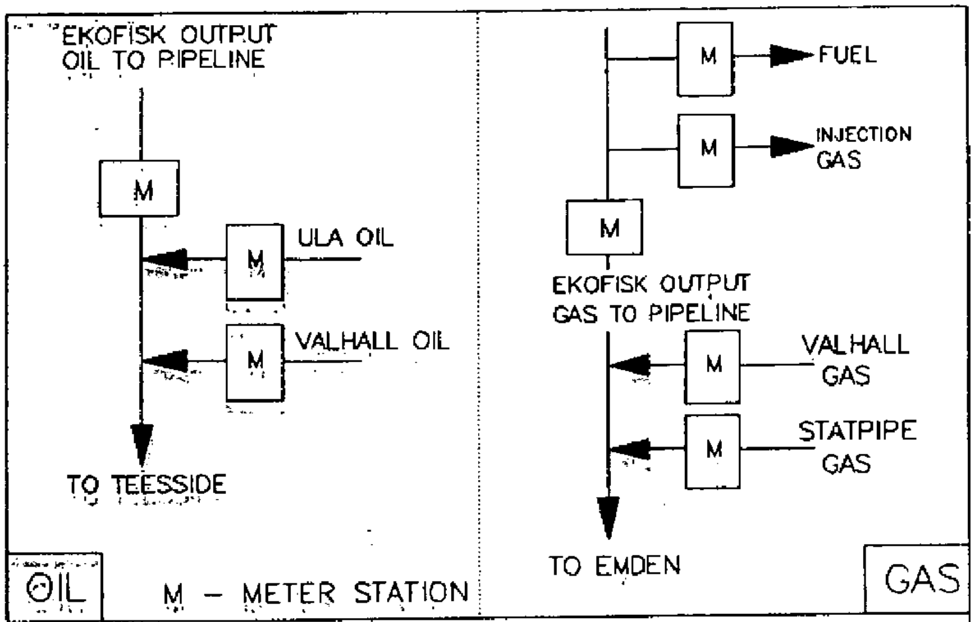

FIGURE 8 REALLOCATION OF EKOFISK CENTER OUTPUT STREAMS

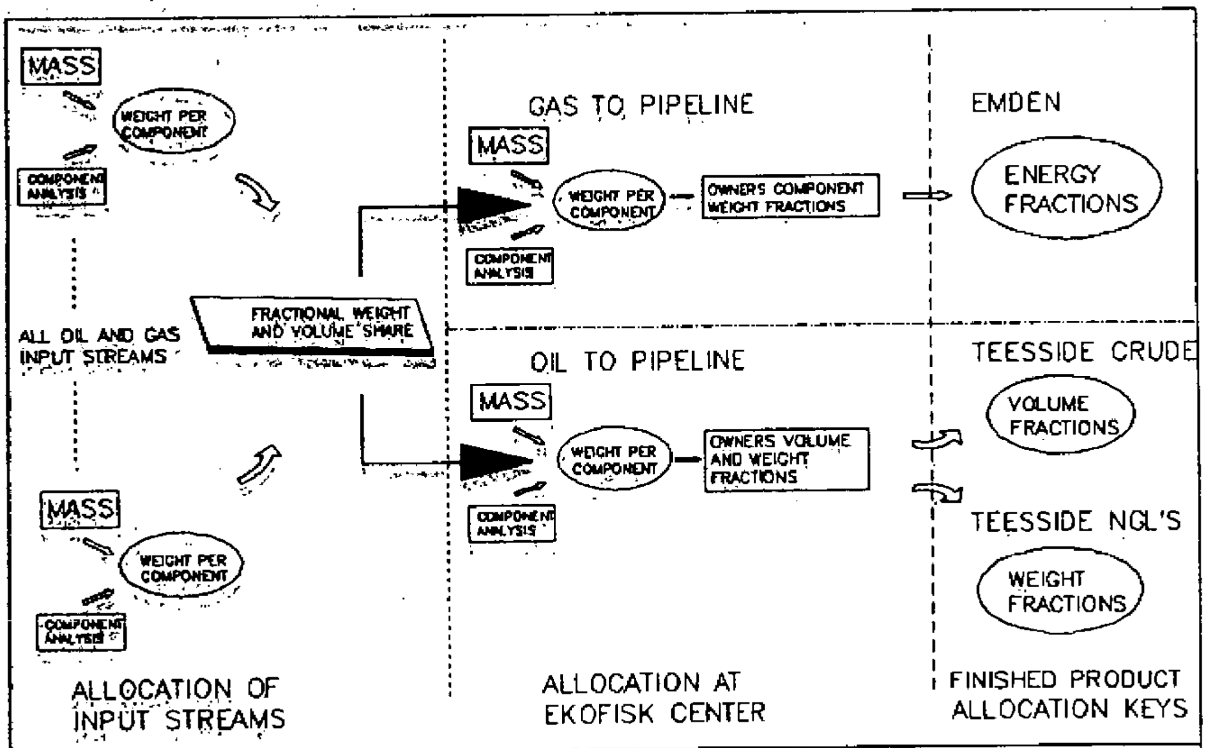

FIGURE 9 – ALLOCATION OF FINISHED PRODUCTS

OIL PRODUCTION 1979 - 1989

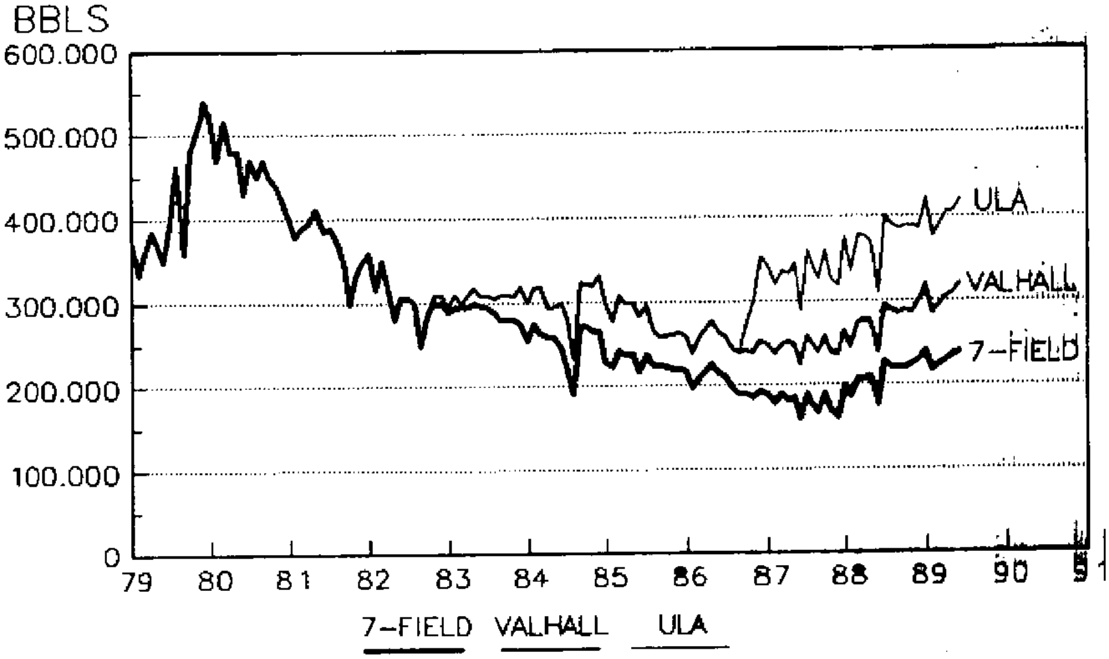

FIGURE 10

GAS PRODUCTION 1979-89

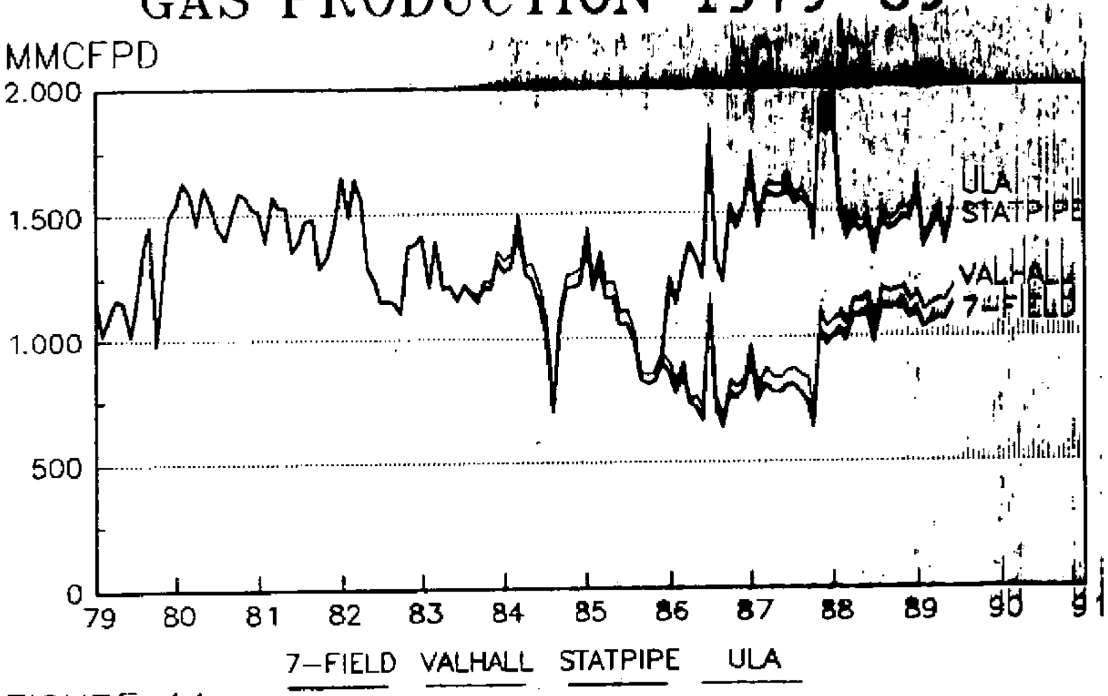

FIGURE 11