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"Experience of Monitoring Oil Measurement System Performance" (and the most common errors)

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BP Exploration

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EXPERIENCE OF MONITORING OIL MEASUREMENT SYSTEM PERFORMANCE (AND THE MOST COMMON ERRORS)

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BP EXPLORATION

1. INTRODUCTION

There are several shared pipeline systems in the North Sea and they all operate allocation procedures to ensure that the total pipeline output is equitably distributed to the Fields who originally produced it. The raw input data for these procedures is the quantity and quality measurements made at the point where users of the shared systems deliver their material and the points where products are sold from, or used by, the system. How this raw data is used is governed by commercial agreements signed by the participants in any given system. This paper looks at the ways the operator of a shared pipeline system can monitor the performance of the measuring systems producing the raw data and hence establish confidence that the final allocation of sales products from the shared pipeline system is equitable. In discussing the procedures and techniques employed the paper also highlights those areas where the authors have most commonly identified errors.

The paper is written from the perspective of the operator of a pipeline transportation and onshore processing system. The activity of monitoring is carried out to ensure that the system is within control. The paper therefore describes how a new platform is brought into a pipeline system which is already operating, in a way that ensures that overall control is maintained.

The word "control" is used in its widest sense as applied to measurement. That is every aspect of control from control charts at the meter station to overall management control.

2. INPUT MEASUREMENT LOCATIONS AND RESPONSIBILITIES

There are two options, either each input Field measures on its own platform, or the Pipeline Operator measures at some central collection point. As the Pipeline Operator has the responsibility to maintain equitable treatment for all, it is obvious that one way of achieving this is for him to take the measurements himself. Unfortunately, this has some technical drawbacks, particularly on liquid systems. The turbine meters would be downstream of a line on the sea bed which may require frequent pigging. The meters could therefore see cold fluids, wax and water slugs. This can cause severe problems with sensitive measurement equipment. It is more normal, therefore, for Field Operators themselves to make the necessary measurements. The Pipeline Operators responsibility for equity to all users still exists and therefore he must ensure full compliance with agreements as they affect standards of design, maintenance and operation of the measurement equipment. The maintenance of high operating standards is achieved by a combination of the Field Operators professional integrity, comprehensive procedures manuals, routine inspection visits by Pipeline Operator staff, routine reporting of performance parameters to the Pipeline Operator; often audits by independent Companies are used as an additional control. In addition to these activities the Department of Energy or Norwegian Petroleum Directorate inspectors will be conducting checks.

The one area of measurement which is invariably put into the hands of independent people is hydrocarbon analysis. This is because skilled chemists and sophisticated laboratory equipment are required, making it a difficult task to perform offshore. It is also more difficult to audit most laboratory measurements after the event unlike metering stations where automatic records are kept.

3. WHY MASS MEASUREMENT AND WHAT ABOUT COMMERCIAL UNITS OF SALE?

3.1 All systems start by dealing with input quantities in mass terms. This is for three reasons:

3.1.1 A metering station can measure mass by multiplying volume by density at operating conditions (provided both are measured at the same temperature and pressure). This avoids the introduction of uncertainties from correcting to a standard temperature and pressure using generalised relationships. Accounting in volume requires all measurements to be corrected to standard conditions of temperature and pressure because, unlike mass, volume varies with temperature and pressure.

3.1.2 When liquid streams of markedly different molecular weight (e.g. NGL and crude oil) are mixed, their volumes are not additive. This phenomenon is known as shrinkage. Working in mass avoids the need to specify the magnitude of volume shrinkage in any given mixing situation thus avoiding additional uncertainty.

3.1.3 When high vapour pressure crude is processed to produce usable and saleable products changes of state occur. The terminal will receive a single phase liquid stream, separate off a gaseous phase by reducing pressure and possibly re-liquify some of the gaseous phase for onward transportation. To effectively reconcile inputs and outputs across such systems, mass must be used. Reconciliation is required to identify, control and allocate losses. Mass measurement allows useful loss control techniques to be established as described later, because mass cannot be created or destroyed.

3.2 Mass cannot, however, be carried right through to the end of the allocation process because very few products are sold in units of mass. Normally units of sale are:

Crude Oil - barrels @ 60^{o}F and 14.73 psia.
LPG - weight in air. Tonnes.
Natural Gas - mass, tonnes or energy, megajoules, therms,etc

4. SEQUENCE OF CONTROL ACTIVITIES WHEN BRINGING ON A NEW PLATFORM

The Pipeline Operators responsibility to ensure common standards are employed, thus giving each user a fair deal, mean that something like the following steps need to be taken every time a new entrant joins the system.

4.1 The first essential is that a commercial Transportation Agreement is agreed and signed. This commits the new user to compliance with Pipeline Operators measurement and accounting standards.

4.2 The Pipeline Operator should then supply the Field Operator with a statement of requirements for the measurement system. The output from the accounts and allocation procedures used by the pipeline operator is only as good as the quality of the input data used. It is therefore essential that all inputs to the system are measured to a similar standard to avoid bias between users.

The statement of requirements should specify:-

- Standards to be complied with.
- Data required by the Pipeline Operator from the measurement system.
- Procedures to be provided by the Field Operator.
- In limited cases equipment vendors that must be used.
- Pipeline Operator approval procedures for from design through to commissioning and use.
- Requirements for on-stream and off-line analysis.
- Form and frequency of data transmissions via the telemetry system.

4.3 The Field Operator should then provide Pipeline Operator with the following for approval (in chronological order):-

- design specification and drawings prior to tender.
- design specification, equipment specification, and computer calculation routines and data transmission routines prior to placement of order.
- procedures for factory calibration testing and inspection.
- pre-commissioning and commissioning procedures.
- operating procedure.
- calibration and maintenance procedure.

All of this documentation forms the bed rock for the provision of sound measurement equipment and control procedures. It is essential that adequate time is spent by the Pipeline Operator thoroughly reviewing this information and agreeing it with the Field Operator, to avoid misunderstandings and problems occurring in the future.

4.4 Pipeline Operator should then witness selected activities in the factory testing through to commissioning phases. It is essential that the third party equipment is completed to the required standard before start up of production is allowed. The Pipeline Operator has a responsibility to protect the existing users of the system. The Pipeline Operator should therefore issue a letter of authorisation to the Field Operator to use the system.

4.5 As soon as possible after start up the Pipeline Operator should visit the measurement system to check that the agreed operating, calibration and maintenance procedures are being adhered to.

4.6 The above describes the controls exercised by the Pipeline Operator. Additional approvals must be given by regulating authorities like the Department of Energy or the Norwegian Petroleum Directorate. Endorsement may also be required by the end customer.

5. ONGOING MONITORING POST START UP

Our experience suggests that the following frequency of visits is required:-

Initially monthly to review progress against check lists of outstanding items from previous audits/reviews. During these monthly visits experience and confidence builds up within both Pipeline and Field Operator.

Sometime within the first 6 months of operation, visiting frequency can be reduced to quarterly. We find that this is a frequency that is consistent with allowing a single inspector to review the measurement system operation within the reasonable time scale of a 1 to 2 day visit. By the time visiting is reduced from monthly to quarterly a bank of operating and monitoring information has been built up by the Pipeline Operator which allows the remote identification of potential measurement problems. These will either take the form of obvious errors or deviations from normal that can be immediately referred to the Field Operator for action, or less definite trends that provide guidance on where effort should be concentrated during the next quarterly inspection. In some circumatances, as the level of confidence and operating experience increases, Pipeline Operator visiting frequency can be further reduced, with the need to visit controlled by the results of the remote monitoring.

Up until this point all dealings have been directly between Pipeline Operator and Field Operator. We believe that measurement is so important that it is necessary to bring in independent auditors from time to time who are external to the two companies operating the field and the pipeline. It is important that such audits are carried out to the same terms of reference on all measurement systems feeding the pipeline. It is particularly important that measurement system performance is subjected to independent review when the operator of the Pipeline and the Field are the same company. Large oil companies organise themselves in such a way that the Pipeline and Field Operator functions are separate, however to satisfy other companies using the pipeline, independent review is the only answer. Currently we are using a frequency of annual independent audits in the Forties Pipeline System.

6. REMOTE MONITORING TECHNIQUES

We have talked about monitoring the performance of a Field Operators measurement system by visits; what can be done from a remote office location? Experience shows that the earlier a problem is identified the easier it is for Pipeline and Field Operators to agree a correction. Daily information must therefore be monitored by the Pipeline Operator.

6.1 Meter Control Charts

Meter K factors can be reported to the beach and plotted on the same control charts as available to the offshore operator. These types of control charts are in common use throughout the North Sea and are therefore not considered in detail in this paper. Their value cannot be overstated. Examples are provided in Figures 1 & 2.

6.2 Density Control Charts

We have found that one of the most powerful control charts that a Pipeline Operator can keep is dry density at standard conditions plotted against time. Examples of such a control chart are given in Figures 3 & 4. The dry oil density is calculated from the following daily information reported to Pipeline Operator from Field Operator:-

- mass produced.
- standard volume produced.
- average water content.

The successful use of this control chart does depend on reasonable stability in the quality of the oil passing through the metering system; with most North Sea fields this is generally the case. The primary requirement of a control mechanism is that it alerts you to a problem.

This particular control chart will show deviations if:-

- densitometers begin to drift.
- meters begin to collect deposits. (Meter control chart should also detect this).
- water content incorrectly measured.
- conversion from operating to standard conditions incorrectly calculated (e.g through incorrect temperature input or change in constants in the flow computer).
- transcription errors occur on information sent to pipeline operator. This is a useful check before data is input to the hydrocarbon allocation and accounting programs.

It is therefore necessary to refer to other monitoring mechanisms to home in on the most likely cause of the error. Our experience does show that densitometer drift due to deposition is quite a common cause of measurement error.

When this occurs both master and tracking densitometer usually drift together so that the discrepancy alarm on the difference between them is never activated.

6.3 Gross Mass Balance Information

Unlike volumes, masses are additive. Mass is a fundamental measurement and mass cannot be destroyed. Comparing mass in against mass out from a system is therefore a powerful monitoring tool. An example of a total system mass balance is given in Figure 5. This particular example quotes the deviation in the mass balance as the "Pipeline Loss". This is convention and does not mean that the pipeline is leaking; it is mainly made up of measurement errors with very little real loss. Usually the only real losses in a system will be the escape of volatile hydrocarbon components to the atmosphere during tankage and loading operations and the loss of hydrocarbon in the liquid effluent disposal. Both of these sources of real loss are carefully controlled for environmental reasons and in terms of relative magnitude are insignificant.

The example in Figure 5 is derived by comparing the mass at a common point in the system calculated from 2 independent sets of data. The common point chosen is often the shore interface between the pipeline and the processing terminal. The two sets of data used to calculate the mass passing this point in the month are:-

i) Sum of offshore metered mass from each platform +/- change in pipeline stock.

ii) Sum of sales from the terminal +/- changes in tank and process equipment stocks.

A common question is "what is a typical loss for a system?". There is no simple answer. Experience must be gained to define an acceptable loss for any given system. The complexity of the system will have a bearing, as will the standards of measurement employed. The example given is for a North Sea Pipeline system that has been in operation for over a decade where the measurements are well understood. Ideally one would hope to see the "pipeline loss" oscillating from month to month about the zero line. This is not usually the case, in our experience. Using the conventions described above often leads to there being a bias in favour of "loss". In our experience there are many reasons for this but the predominant one is due to water. The higher the water content the more likely it is that any measurement of it will be an understatement. System input measurements are made at pipeline input qualities whereas measurements at the terminal are usually made after significant water has been removed from the oil.

6.4 Subset mass balance information

6.4.1 Balances over parts of the equipment

The mass balance concept can be used throughout the system on any part where measurements in can be compared with measurements out. Examples would be comparing production measurements of LPG as the material leaves the fractionation unit with final point of sale measurements. This could be used, for example, to monitor and control the losses around an LPG refrigeration plant.

Figure 6 shows an example of comparing measurements into a stabilised crude oil pipeline with quantities coming out of the line computed from quantities sold +/- stock changes. This example is particularly interesting because totally different types of measurement are used for the input and the output. Input is measured by full fiscal quality turbine meters with on-line densitometers and a flow proportional sampler. Output measurements are made by tank dips, laboratory density (IP160) and tank samples. As this is a simple system with no opportunity for shrinkage to be caused by adding volumes a volume balance is also carried out. As can be seen from Figure 6 the system typically shows a volume loss and a mass gain. The graphs are plotted on a dry hydrocarbon basis and water is drained after metered measurements in but before tank measurements out; this probably accounts for the small loss.

The mass gain is caused by the small increase in density that occurs as light hydrocarbons are lost from the tank samples during collection, transportation and laboratory application of IP 160. This example also shows what happened to the normal trends when the sphere in the prover developed a split. This was picked up earlier on the meter control charts.

6.4.2 Balances over parts of the material

Many allocation procedures used in the North Sea require that the total hydrocarbon streams in and out are analysed by component. Typically the components analysed for are:-

methane
ethane
propane
iso butane
normal butane
the rest (often called C5+)

Mass balances over these individual components can give important indications regarding the accuracy of sampling and analytical measurements made. Errors in components will manifest themselves by producing mis-allocations of sales products, particularly gases, to the rightful owners. As the different products attract different prices in the market place this could lead to financial losses and gains to the individual users of a shared system even if the overall system mass balance is entirely acceptable. Experience shows that the lighter the hydrocarbon the larger the discrepancy in the mass balance is likely to be.

Looking at component balances across a gas plant can give valuable information about which streams have been mis-measured, sampled or analysed when investigating an overall mass balance discrepancy. In Figure 7 a hypothetical gas processing plant is shown with an overall mass balance gain of 1 percent. Examination of the mass balances by component shows that a large discrepancy is present for condensate (C5+). There must therefore be an error in either the C5+ output meter or the analysis of the input. These specific points can therefore be investigated.

6.4.3 Theory compared to Actuals

The allocation system used in the Forties Pipeline system is unique in the North Sea and produces some very useful control information. The heart of the allocation procedure is a chemical engineering model of the process equipment. The total input to the terminal, as determined by offshore mass measurements and analysis of offshore samples, is fed into the model and this is used to predict the quantities and qualities of products made. These predictions are compared with the actual measurements and deviations investigated, thus providing another level of control.

7. MONITORING QUALITY

Quantity is not the only important measurement required to enable equitable allocation of sales products, fuel and flare, quality must also be measured. Hydrocarbon quality is also used for the important function of giving each user a quantity of crude oil which is consistent in value terms with the material put into the pipeline system. An example of analytical information monitoring is given in Figure 8. The reasonableness of the information can be monitored by following trends; for example if two components from the group show a different trend then an error may be present. Once sufficient data has been collected it can be subjected to statistical analysis and control limits placed on the trend graph.

8. MOST COMMON ERRORS

Time only permits a few examples to be explained in more detail in the text above. In summary the most common errors in our experience are:-

- Densitometer fouling.
- Temperature differences which are not compensated for.
- Flow computer constants incorrectly entered. Particularly common examples are densitometer constants and the constant for the thermal expansion of steel.
- Data transposition errors at points of manual intervention in transferring the data from the meter station to the hydrocarbon accounting computer program.
- Sampling & analytical errors. Water is the biggest problem and has a direct effect on dry mass.
- Line clearing operations. This causes an accounting problem when one quality of product is replaced by another or ownership changes.
- Any operation that has no dedicated automatic logging equipment and therefore relies on manual logging.
- Flaring measurement and/or estimation.

9. CONCLUSIONS

The general conclusions we have drawn from our experience in monitoring measurements as a Pipeline and Terminal operator are:-

9.1 To be successful, a control procedure must have a simple output and preferably be based on data already collected for other reasons.

9.2 Control procedures that either, produce a single number that can be used as a target, or produce a graphical trend against a target can be used as an effective senior management tool by individuals who do not understand the technical detail.

9.3 A large quantity of useful control information can be obtained by analysing the output of Pipeline and Terminal system hydrocarbon accounts. This should be borne in mind when designing computer systems to produce such accounts.

9.4 Successful "loss control" depends on closing the loop back to senior management to provide the required levels of commitment and motivation.

10. ACKNOWLEDGEMENT

We thank BP Exploration for permission to publish this paper and express our gratitude to the many colleagues in BP who have helped us prepare this presentation.

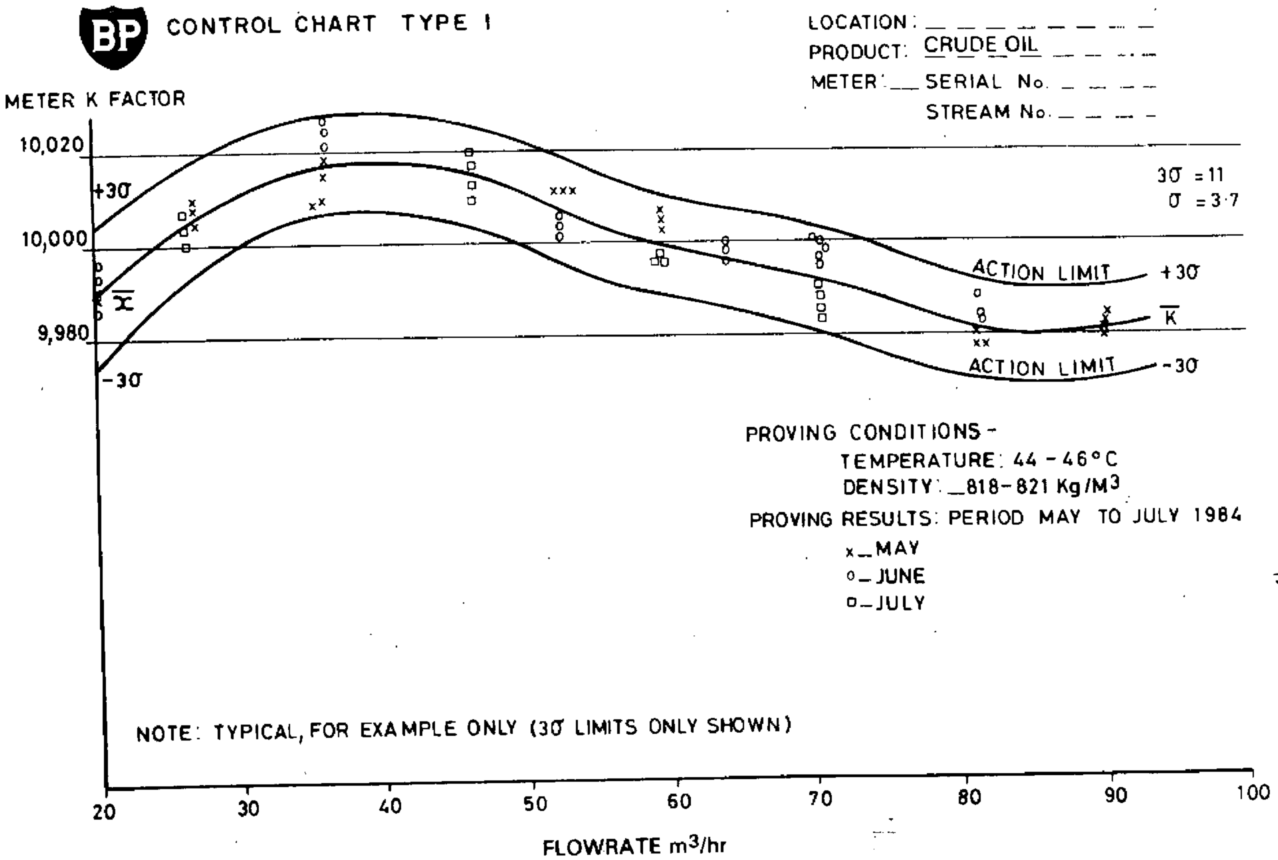
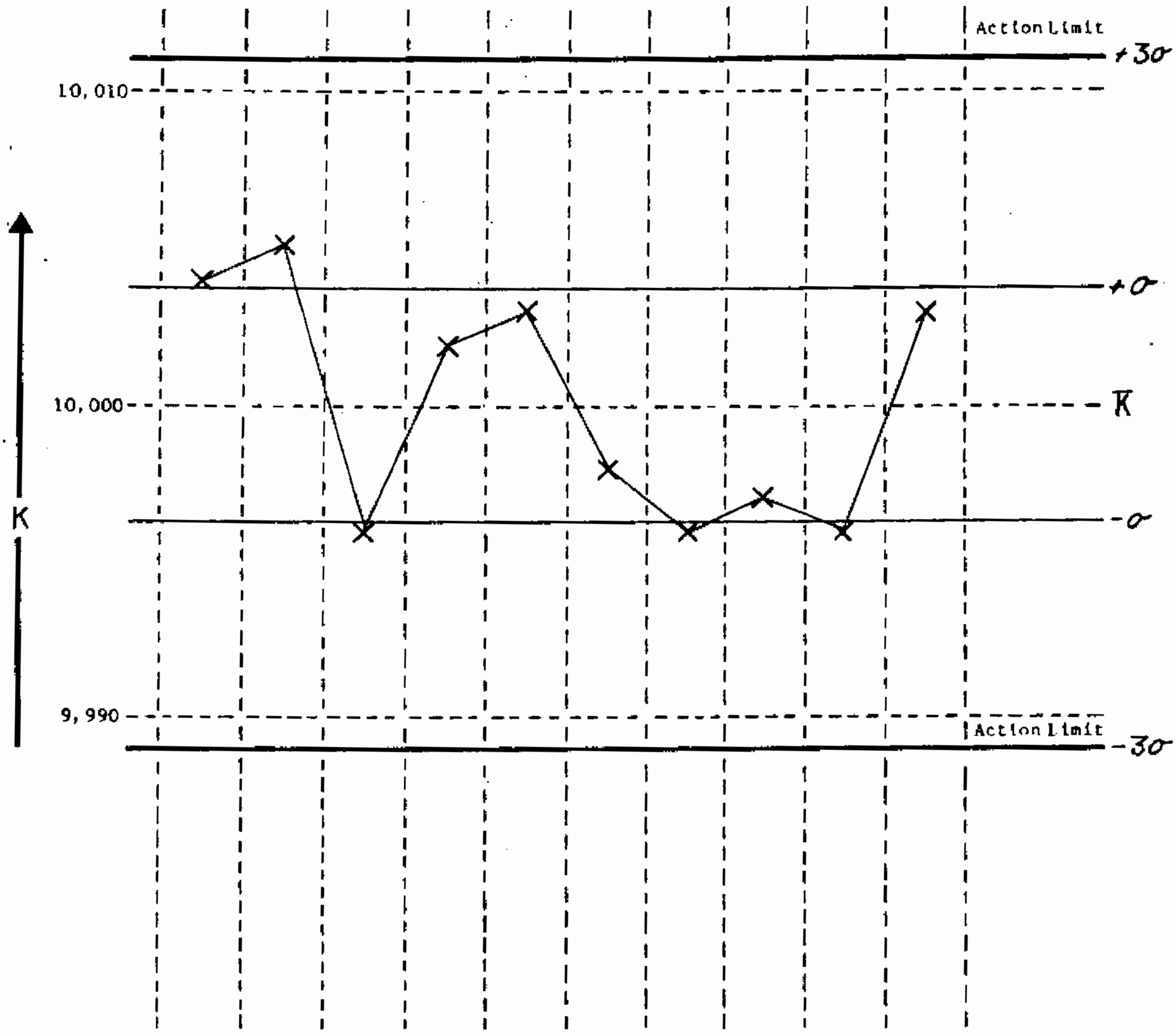


FIGURE 1 CHARACTERISTIC PERFORMANCE CURVE CONTROL CHART

CONTROL CHART TYPE 2

LOCATION:
PRODUCT: Crude Oil
METER: Serial No.
Stream No.



Flowrate	65.0	64.8	65.3	64.9	64.9	65.0	65.1	65.1	65.2	64.8	m^3/hr
Temp	45.25	44.5	46.0	45.0	43.75	46.25	44.9	45.1	45.8	44.5	°C
Density	820.2	819.7	820.8	820.4	819.2	820.2	820.0	820.1	820.7	819.7	Kg/m^3
Proving Report no.	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	
Date	8/5/84	15/5/84	22/5/84	29/5/84	5/6/84	12/6/84	19/6/84	26/6/84	3/7/84	10/7/84	

FIGURE 2 SINGLE POINT CONTROL CHART

FIGURE 3 : CRUDE OIL DENSITY

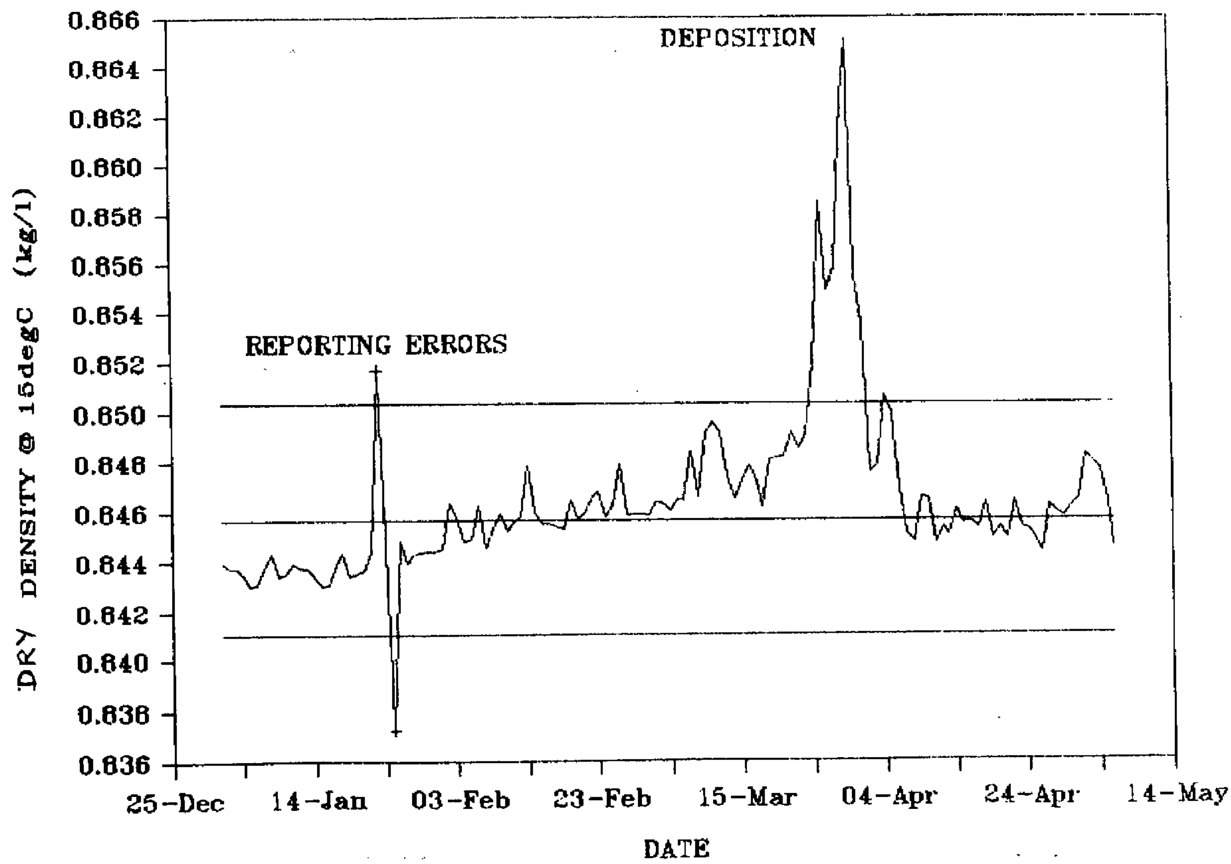


FIGURE 4 : CRUDE OIL DENSITY

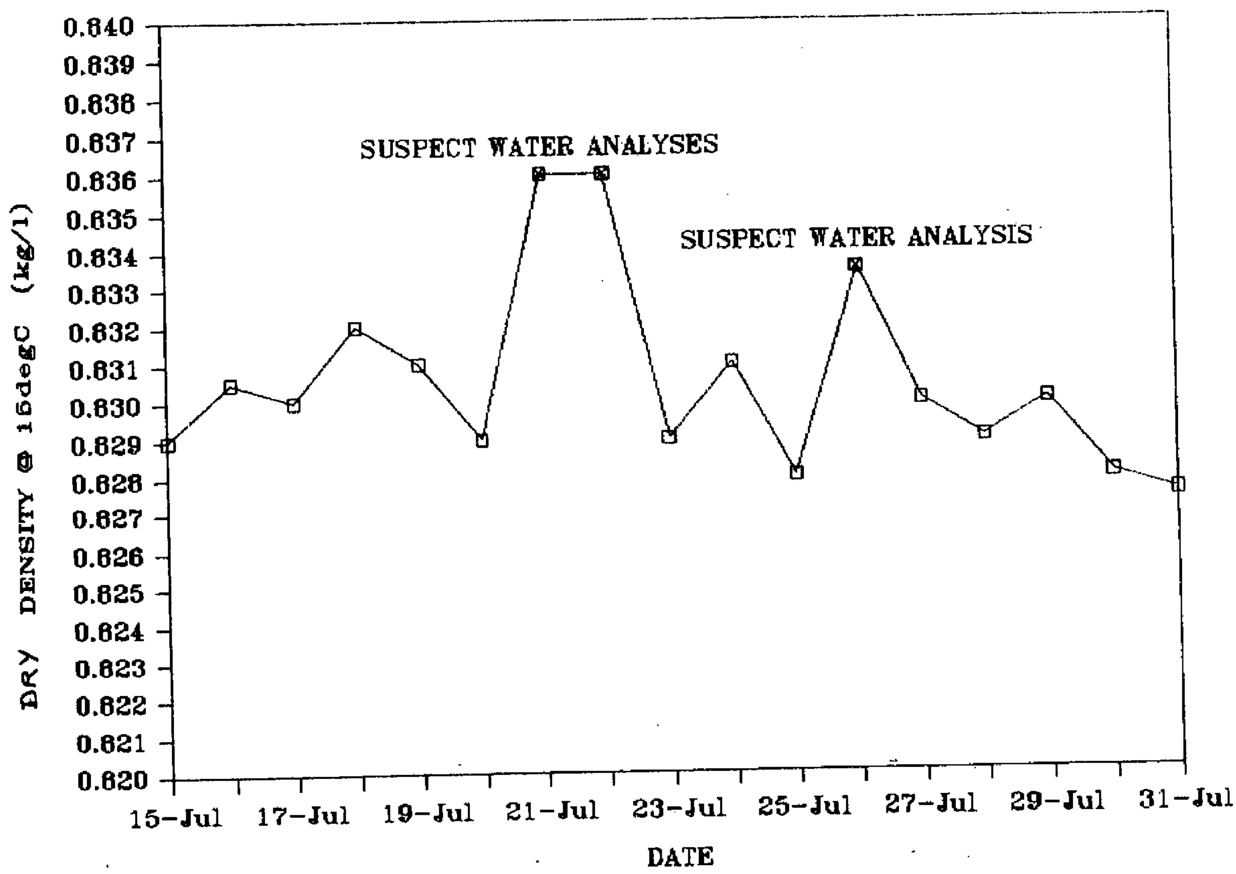


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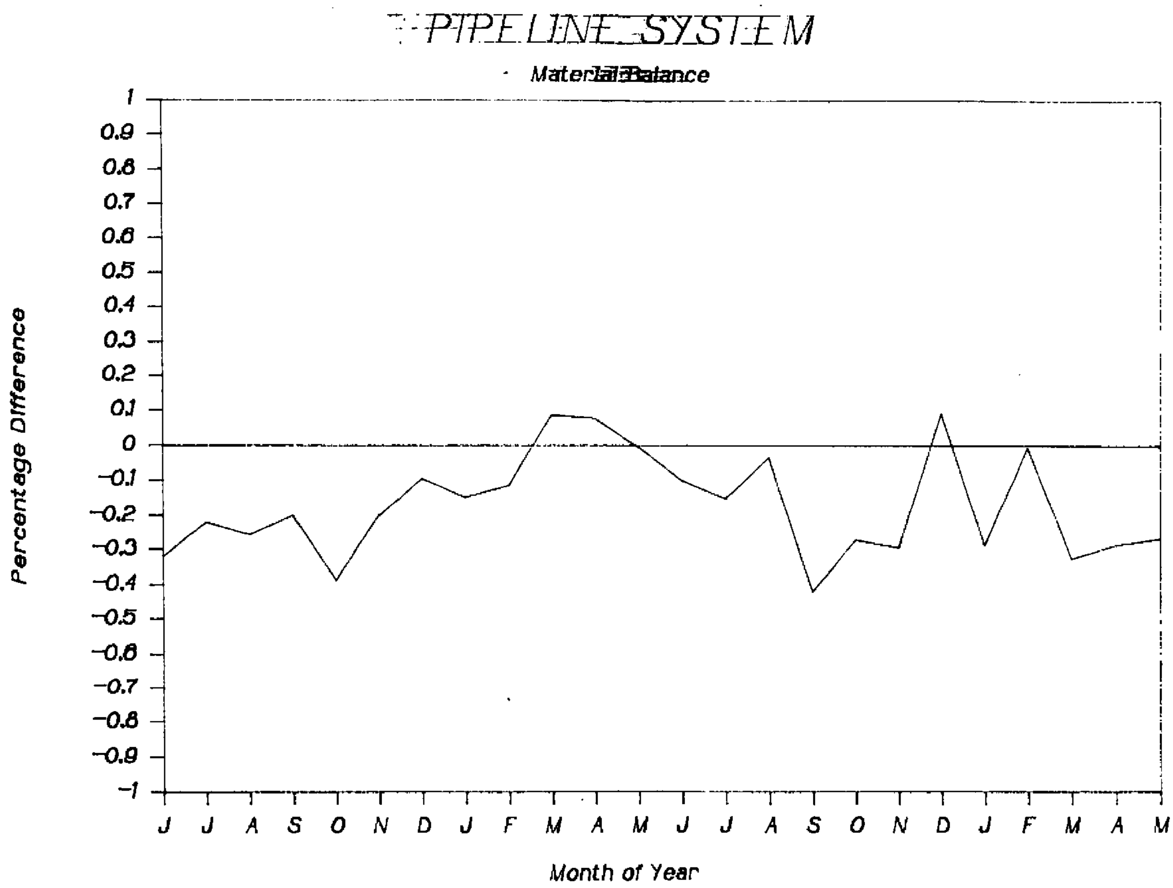
FIGURE 5



PIPELINE SYSTEM
Material Balance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
Percentage Difference
J J A S O N D J F M A M J J A S O N D J F M A M
Month of Year

51

FIGURE 6 : PIPELINE RECONCILIATION

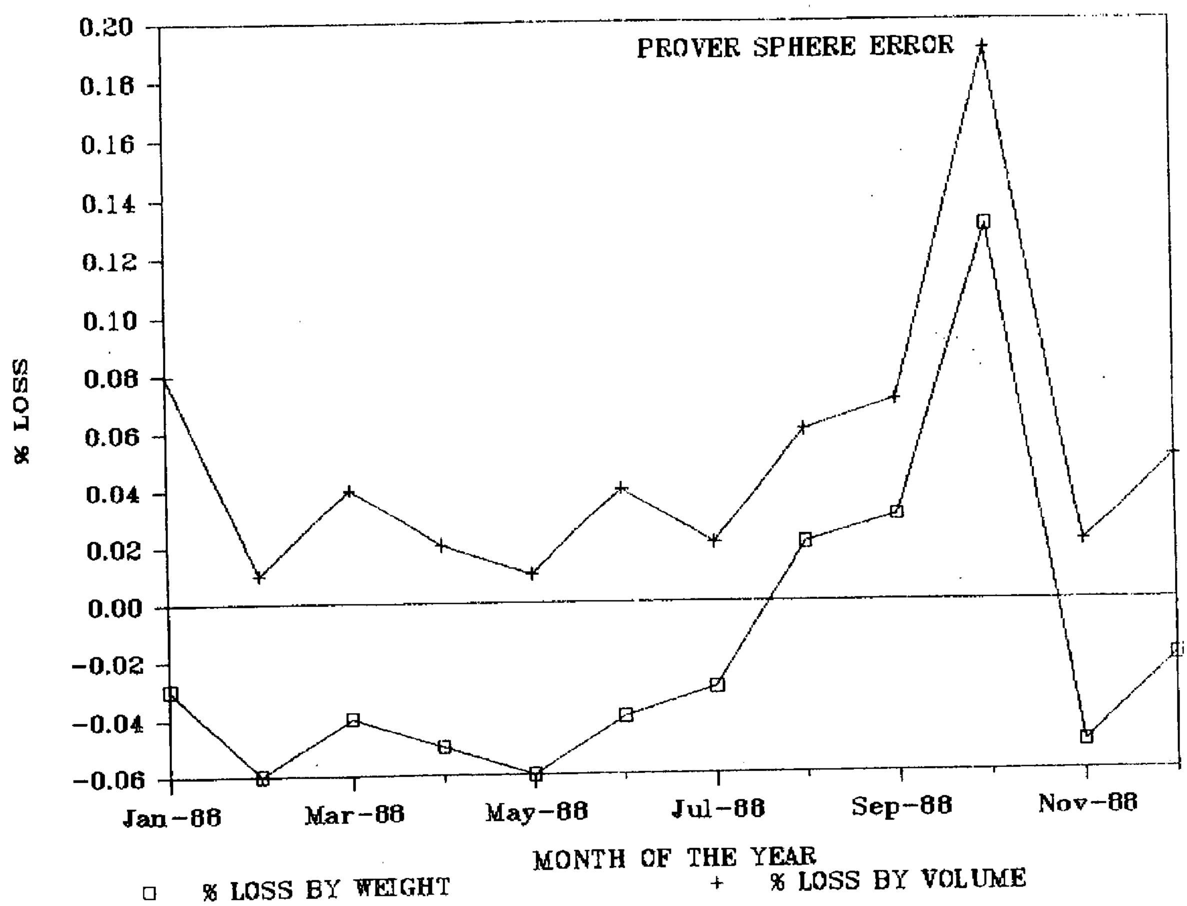


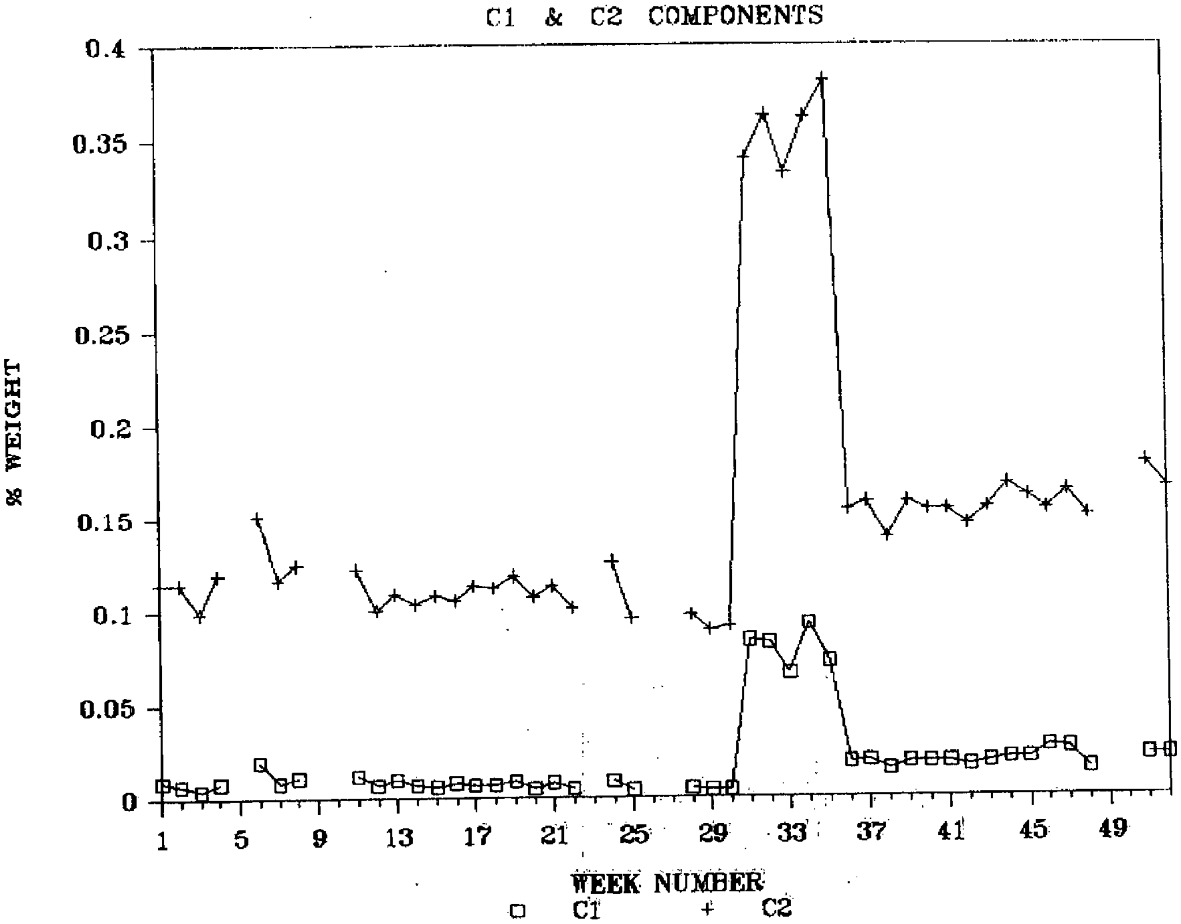
FIGURE 7

COMPONENT MASS BALANCE

COMPONENT	OUTPUT TONNES	INPUT TONNES	% GAIN/LOSS	
CONDENSATE (C5+)	110.00	98.91	1.11	*
BUTANE (C4)	300.00	300.36	-0.04	
PROPANE (C3)	300.00	300.36	-0.04	
ETHANE (C2)	200.00	200.24	-0.02	
METHANE (C1)	100.00	100.12	-0.01	
TOTAL	1010.00	1000.00	1.00	

* Conclusion: Potential measurement problem with condensate could explain overall mass balance discrepancy.

FIGURE 8 : ANALYSIS TREND CHART



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References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.