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A comparison of the performance og in-line and bypass type sampling devices in the BP Rotterdam tests

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1. SUMMARY

Trials have been carried out on a 48 inch crude oil transfer line at BP's Rotterdam Refinery to assess the performance of two versions of a new type of automatic grab sampler. One was mounted directly in the pipeline and the other in a pumped bypass loop. Also on trial were a new trash-resistant insertion flow meter and a continuous water content monitor.

Most of the tests were made on tank to tank transfers with injected sea water mixed by natural turbulence. Good water distribution was achieved but the water droplet size may have been larger than would be expected with a pipeline mixer.

Our principal finding was that the bypass sampler takes a representative sample for water content whereas the in-line sampler water content was low by about 5% relative. Our finding probably represents the worst case situation for operational installations: with more efficient mixing the difference could be less than 5% relative.

Both samplers proved reliable over the relatively short test period, operating on viscous crudes without tracing or lagging and below 0°C ambient. The Maurer 'Cruflo', turbine meter was trash resistant and is suitable for pacing samplers. Testing the need for isokinetic flow into the bypass loop gave pointers to the best method of loop operation but more work is needed before drawing firm conclusions.

The paper includes a description of a complete crude oil sampling package, which we have recommended for BP Group applications.

2. INTRODUCTION

The economic importance of accurately determining the water content of crude oil transfers is now well accepted, both for tanker discharges and for platform exports. Because there is as yet no proven accredited method for on-line continuous water determination, the present universally accepted procedure is to use automatic flow proportioned sampling, followed by a laboratory analytical test. In this procedure the representativity of the sample is obviously of critical importance.

Two aspects of automatic sampler performance have seriously concerned operators in recent years.

1) the ability of the sampler to take a properly representative sample
2) the reliability of the sampling equipment

Because of BP's widespread involvement in commercial crude oil transactions our Central Engineering Department have played a leading role in the development of sampling equipment over recent years.

The culmination of our work has been the development of the BP Grab Sampler, which is now made under licence and marketed by Jiskoot Autocontrol Limited and by Maurer Instruments Limited.

In 1984, the results of work in a small bore pipework test rig using kerosine and water by the National Engineering Laboratory, suggested that there could be differences between the water content of samples taken by an "in the line" grab sampler and by one installed in a bypass loop. Prompted by this, we designed a programme of field trials to try to determine which sampling installation gave the most representative results. Our intention was to establish the optimum crude oil sampling package, to be recommended for use by BP associate companies worldwide. So that the specification would be complete the trials were extended to include an evaluation of alternative flow metering devices suitable for crude oil sampler pacing. Also included in the trial installation was a continuous capacitance cell water content monitor. Although part of a separate evaluation project, information from this proved to be useful in evaluating sampler performance.

This paper presents the trial results.

3. MAIN OBJECTIVES

The main objectives of the field trials were:

1. To compare the representativity of samples taken by a grab sampler in a bypass loop, with those taken by a grab sampler in the main pipeline.

2. To monitor the mechanical reliability of the new Maurer grab sampler. The reliability of the Jiskoot Series 200 sampler had already been proven through use at other BP locations

3. To investigate the accuracy and reliability on crude oil of a trash resistant insertion turbine meter. (Reliable flow measurement is essential for the purpose of pacing a flow proportional automatic sampler.)

4. To investigate the performance under process conditions of a low pressure capacitance monitor and to assess its potential for continuous measurement of the water content of crude oil.

5. To compare the results from the alternative methods of water determination listed above i.e. automatic in-line and bypass loop samplers and continuous measurement using a capacitance cell.

6. To test the representativity of the system measurements using the water injection procedures recommended in ISO/DIS 3171.

7. In addition, profile testing was to be carried out at the chosen location to test for homogeneity of the line contents at the test conditions. These tests were also used to assist in verifying the theoretical prediction techniques being developed for determining homogeneity.

The basis for these objectives was as follows:

Objective 1 Because of the poor reliability record of so called fast loop type samplers, BP has in recent years favoured the use of automatic grab samplers.

Since the original BP patent for the grab sampler was filed in 1979, several different models have evolved. In most cases the difference has been only in the driving mechanism i.e. pneumatic/electric. However an important fundamental difference with later models is between the in-line and bypass or cell sampler. The original in-line sampler is installed directly into the process pipeline, whereas the cell or bypass sampler is installed in a pumped bypass loop, typically of 1" N.B.

The bypass loop sampler evolved mainly because of early problems associated with installing a sampler directly into a high pressure line. To resolve this, the recommendation within BP before these trials was to fit an in-line sampler for low pressure applications, and a bypass sampler for high pressure duty. Because the sampler in a bypass loop is sub-sampling a great deal of design effort was put into ensuring the representativity of this operation. To help ensure representativity the sampler is always placed after the bypass loop pump to ensure good water dispersion. In addition the sampler is fitted with a long upstream entry port to ensure that the severe bluff body effects of the capture tube have no influence on the sample entering the capture chamber. The in-line sampler also has an extended entry port, but because of the necessity for live line insertion through a valve its length has to be restricted. In practice it is only about 25% of the bypass sampler entry tube. Despite these significant changes in design concept no direct tests had ever been made to confirm the efficiency/representativity of either type of sampler. Comparative trials were therefore decided upon. For these it was imperative that both sampler mechanisms were identical as far as practicable, and that their primary sample offtakes should be from the same general area of the main pipeline (to negate any small differences in homogeneity). They should also be powered from the same controller.

Objective 2 Following an agreement with Maurer Instruments to manufacture grab samplers based on the BP patent, it was decided to use the opportunity presented by these trials to test the performance and reliability of their first production models.

Objective 3 The provision of a simple, cheap and reliable flow meter for sampler pacing has always been a problem, particularly for tanker discharges. The problems arise because of the comparatively large diameter lines, the presence of trash, and the need to retrofit. Work had previously been carried out within BP using a clamp-on type Doppler ultrasonic flowmeter with gas injection to provide the necessary phase discontinuities. Also we were aware that an American company were offering a large diameter insertion turbine meter for this duty. At first sight, this seemed to offer an equally attractive solution to the problem. However, on closer investigation we identified potential problems with the removal of the turbine blade from the pipeline in the event of its jamming. This possibility, coupled with a general feeling that a suitably designed conventional insertion type turbine meter could give satisfactory performance, led us to specify our own improved design of turbine meter. We felt that our design concept could have significant advantages over the two other possibilities.

Objective 4 The potential advantages of direct water in oil measurement are obvious and the proposed work constituted the first BP field trials of the Endress and Hauser on-line monitoring device known as the 'Aquasyst'. The capacitance monitor trials are not yet complete but the results to date, which have a direct bearing on the trials of the sampling equipment, are reported in this paper.

Objective 5 It was planned to compare the three methods of water determination; samplers, both in-line and in the bypass loop, and the capacitance system, against the actual water content calculated from the flows during tank to tank transfers.

Objective 6 and 7 The new draft ISO/DIS (Petroleum Liquids Automatic Pipeline Sampling) describes a water injection procedure for proving sampling systems without the need for profile testing. The objective was to test the method for its effectiveness, but also to use profile testing for added information.

Additional Objective In the course of the trials, evidence was obtained which indicated that the bypass loop sampler gave the most accurate results. It was then seen to be important to investigate the need for operating the bypass loop at isokinetic flow rates, as advocated in previously published literature. The advantage of not running at isokinetic flow rate are that the loop flow control system can be dispensed with and that, if a lower than maximum isokinetic flow rate can be tolerated, a smaller bypass loop pump can be used.

4. NEW DEVELOPMENTS

The equipment actually used in the Rotterdam trials was in all cases except one, the first production model. The exception was the Endress & Hauser continuous water monitor, and even for this, the trial was its first BP use in 'real' circumstances. Some background to the new developments may be of interest.

4.1 Samplers

Because of the importance of automatic sampling for accurate crude oil measurement BP have felt it necessary to have alternative manufacturing sources for the sampling equipment in order to protect our supply position.

To this end in early 1984 a specification was drawn up and detailed discussions conducted with Maurer Instruments Limited (the successful developer and manufacturer under BP licence of the PIM (Piston Internal Mixing) Sample Cylinder). This company agreed to produce an alternative grab sampler design, and to manufacture samplers to meet our immediate requirements. A particular advantage resulting from commissioning the design of a new grab sampler at this time, was that data obtained by the National Engineering Laboratory, in the course of their automatic sampler study project, could be incorporated into the new design.

4.2 Flowmeter

We felt an American design for a trash resistant flowmeter had good potential, but we later had serious reservations about the possibility of the single large rotor blade jamming across the entry tapping. In addition, the device on offer was not designed to conform to European electrical safety certification requirements.

Because of these potential problems it was decided to commission the design and supply of a special trash resistant insertion flowmeter for crude oil sampler pacing:-

The design criteria for this included:

a) As large a diameter rotor as possible
b) No shrouding
c) The rotor supported in such a way that trash could not collect on a support and impinge into the rotor
d) As wide a flow turn down as possible but to be capable of metering at 0.3 m/sec.

Maurer Instruments Limited agreed to develop and produce an instrument to meet this outline specification.

The meter resulting from the Maurer development is shown in Figure 1. The main points are that it will insert through a 6" hot tapping (live line insertion), has no shrouding, has large diameter bearings and the rotor is only supported from the rear.

4.3 Continuous Water in Oil Monitor

The potential advantages of accurate continuous water in oil measurement are obvious. Since 1979 BP has been studying the capacitance technique in the belief that it can be developed to measure water in crude oils on-line in the fiscal context. In collaboration with Endress & Hauser this work has progressed to the point where an instrument, the Aquasyst, is now commercially available. The Rotterdam trials provided the first opportunity to fit the new instrument into a real on-line monitoring system.

The full development of this instrument was described in last year's North Sea Flow Metering Workshop in Glasgow in a paper presented by Messrs. M.B. Wilson and B.O. Richards, our colleagues in BP Central Engineering Department.

5. SITE TRIALS

5.1 Site Equipment

The field equipment was installed as shown in Figure 2. The 48" No. 1 header can be used for imports from either No. 1 or No. 2 jetty to the Entrepôt. The selected position covered some 70% of the crude imports to our refinery at Rotterdam. The entry nozzle to the in-line sampler, and to the bypass loop scoop were within 2" to 3" of each other, on the same plane in the pipeline. This was so that, should the line contents not be completely homogeneous, the sample presented to each sampler was likely to be almost identical and the comparison between in-line sampler and the bypass sampler results would still be valid.

The multi-entry probe for testing the cross pipe water profile could not be fitted in the same plane as the samplers because of limited space. However its position was only 12" upstream of the sampler entries. All of the equipment, except the profile test probe, was designed so that it could be fitted into the pressurised line.

The sampler controller used for the trials was an available Jiskoot type HSC3 controller modified for grab sampler duty. Despite limitations in its range of parcel size settings it served its purpose well.

5.2 Test Modes

The testing was carried out in two basic modes.

a) Tanker Discharge - with both samplers and the flowmeter working normally.
N.B. Under these conditions we were unable to perform successful profile testing because the low line pressures were not adequate to overcome the pressure drop in the profiling test system.

b) Tank to Tank Transfers. In this mode the base water content of the crude could be measured and additional water injected. Sea water from the fire main was injected into the No. 3 header approximately 57 metres from the sampling location, equivalent to a volume of approx. 21 m^3 (Figure 2). Mixing was caused by the jetting action of the water entering the line, and subsequently enhanced by downstream turbulance created by four blind tees, two valves and four bends. The actual percentage water added to the oil was calculated from measurements derived from a 2½" Fisher turbine meter in the water injection system, and the change in tank dips over periods of steady flow. We estimated the overall uncertainty of this procedure to be ±0.5% of water content. Because there were no outside influences (i.e. from the ship) the flow rates could be held constant throughout each trial period.

The main drawback with measuring water in the tank to tank transfer mode was that the crude oil/water mixture downstream of the injection point did not pass through a pump before reaching the sampling point. Hence it could be postulated that the water droplet size might be larger than would normally be expected in tanker discharges when the oil and water will usually experience considerable mixing and break up due to the action of the ships pumps. Nevertheless, the majority of the test results reported here were obtained in tank to tank transfers because this allowed repeated small (300 ml) samples to be drawn by the samplers, all under steady state conditions.

In all, 6 tanker discharges were monitored and 4 tank to tank transfers. The 4 transfers covered 24 separate runs with main line flows varying from 0.3 m/s to 0.9 m/s and with water contents from 1.44% to 3.82%. However not all runs were under homogeneous conditions.

6. RESULTS AND FINDINGS

6.1 Water Concentration Profile Tests

Water profile tests were carried out at the sampling location for two purposes.

1) To confirm the uniformity of water distribution under the test conditions used during the sampler trials.

2) To test the practicability of the procedures recommended in ISO/DIS 3171. This work was the subject of another project and is not discussed in this paper.

In brief it was concluded that, with Iranian Heavy crude with a water content up to 3%, the contents of the 48" pipeline at the sampler location were homogeneous at line velocities above 0.6 m/s, and non-homogeneous at velocities below 0.3 m/s. Therefore, in later transfers when profiling was not performed, Iranian heavy crude was always moved at velocities above 0.6 m/s.

6.2 Samplers

Both samplers operated faultlessly throughout the trials. They needed no attention from the moment they left the factory in the UK until the trial work finished - not even requiring setting up on installation. In our opinion this was a very encouraging introduction for newly developed equipment.

The tests to compare the accuracy of the in-line sampler against the bypass sampler produced 24 sets of results from tank to tank transfers and 6 sets of results from tanker discharges. Of the transfer results 8 were taken under non-homogeneous conditions. The results are presented in Table 1. The graphs plotted from these results (Fig. 3 and Fig. 4) show quite clearly that the water content of the samples taken by the in-line sampler are lower than those taken by the bypass sampler by around 5% relative i.e. 0.15% water at the 3% level. The graphs also show how closely the bypass sampler results agreed with the actual water content calculated from the tank level change and the water flowmeter reading. The uncertainty limits of this procedure are also shown on the graph. In addition, from the table of results it can be seen that the bypass sampler water content also agrees very closely with the water content measured at the centre point of the profile probe. Statistical analysis shows no significant difference between the actual and bypass water contents. One standard deviation is equivalent to 0.025% water. This compares with the laboratory test (IP 356) repeatability and reproducibility, quoted as 0.03% and 0.09% water respectively at the mid range water content used in the tests.

The reason for the differences in water content between the two samplers may, in part, be due to the probability that, in the tank to tank transfers, the droplet size may be larger than normal because no pump is used. The entrance to the bypass sampler fast loop system is a 1½" diameter pipe placed within the 48" main line, whereas the in-line sampler probe presents an entry port of ¼" x 3/8" to the sample. The probe entry area ratio is thus 10:1. This large difference can be expected to be significant in terms of the probes' ability to receive large water droplets. Also, although the in-line sampler has an extended entry port in front of it, bluff body effects may still have some effect. Bluff body effects on the bypass sampler are likely to be significantly less because of the longer extended entry port; 6" compared with 1½" on the in-line sampler. Another important aspect of the bypass system is that the pump will significantly increase the dispersion of the water before the flow reaches the samplers' entry port.

However, in three of the six tanker discharges monitored, the in-line sampler gave the higher water content (Table 2). There is no obvious explanation for this, but the answer may be in the condition of the sample containers used. Some of these are known to have internal rust spots which may have prevented complete laboratory mixing of the water into the oil. During the tank to tank tests new 500 cc plastic containers were used.

It is appreciated that during tank to tank transfers the water breakup would have been limited so that the dispersion may represent worst case conditions. However it must be accepted that these conditions can occur in some real life tanker discharges. Therefore if there is any doubt about water dispersion, an automatic sampling system should be designed to suit this worst case.

Consequently our recommendation to BP companies is to use bypass samplers. This view is reinforced by the possibility that, because of the general trash known to be carried in crude oil imports, the entry port to an in-line sampler could block, without any obvious evidence of this occurrence outside the line. This is because the sampler would still operate, but with the sample drawn back through the exit port. In these circumstances the water content of the resultant sample would almost certainly be low. The danger of entry port blockage does not occur with bypass samplers because a coarse strainer can be fitted into the fast loop to prevent fouling, with an optional differential pressure measurement to give warning should the strainer start to clog.

6.3 Fast Loop Flow Rate

Having concluded that the bypass sampler gave the most representative water contents results, it was then considered important to determine the real need to run the bypass loop at isokinetic flow rates. Previous published work has emphasised the importance of isokineticism but the practical difficulties and cost of achieving this in real sampling applications made it important to examine whether it has any significant effect on sampling accuracy.

A major difficulty is in defining exactly what the isokinetic velocities are at the point of sample extraction. It is generally assumed for the purpose of isokinetic sampling that the average line velocity will be applicable at the sampling point, but at a typical sampling location a stable velocity profile may not have been established. Therefore the magnitude and direction of the flow at a particular point are uncertain, especially at the lower flow rates.

During our own work in commissioning the system at Rotterdam at flows equivalent to isokinentic and above, we had observed that changing the flow rate had no obvious effect on the on-line water monitor reading. This cast doubts on the need for flow control. Confirmation of this would yield obvious advantages i.e. there would be no need for the complication of flow control equipment, and, if sub-isokineticism were acceptable, a smaller bypass loop pump could be used. Tests were therefore performed to determine the effects of varying the bypass loop flow rate. (Table 3). Although the tests showed possible pointers to the best method of bypass loop operation, the results were not completely satisfying. Further work is necessary to be absolutely sure.

Figure 5 shows the results of three runs with Iranian Heavy Crude in which the main line flow conditions were held constant and the bypass loop flow rate varied from 25% isokinetic flow to 4 times isokinetic flow. Manual samples were taken from the bypass loop, and the bypass sampler operated for only two of the three runs. The graphs suggest that above a certain minimum flow rate, the resultant sample water content does not vary. In a preliminary test, the fast loop flow rate was raised to 9 times the isokinetic rate, and a similar result was obtained. The unsatisfying aspect of these tests is the way in which the capacitance cell readings differed from the manual samples. Even so, a constant signal output is still seen at above the same flow rate of approximately 1 m/s. How much these thresholds are affected by the crude oil type, the water content and the physical design of the fast loop has still to be determined.

However, we feel that eventually it will be possible to design fast loops to run at 50% of the isokinetic flow rate of the maximum flow expected in the main oil line. Assuming a 20:1 flow turn down, loop flow rates will then be about 10 times isokinetic at the minimum main line flow rate. In the short term however, because there is still contention about the case for isokinetic sampling, our recommended sampling package shown in Figure 7 does include flow control. We have recommended that the whole question of isokinetic sampling should be investigated further because of the obvious advantages of not having to flow control the bypass loop. This work is now in hand at Rotterdam.

6.4 Maurer Flowmeter

This flowmeter has been installed in the 48" line since October 1984, without fouling. The flowmeter has been removed from the line for inspection at regular intervals and the rotor has always been found to be completely clean and free spinning. On one occasion a strand of thread was seen on the support stem but, because of the special design of the flowmeter, this had no influence on its operation. There is positive evidence that trash has been present in the main line because it has been picked up by the bypass loop scoop and caused blockage problems in the bypass loop turbine flow meter. In several instances the debris has been reminiscent of the contents of a hay stack.

Because of electrical noise on the flowmeter signal this was averaged by the computer before being fed to the flow recorder. However the signal fed to the sampler controller was in the raw state.

The original flow rangeability specification for the flowmeter was 0.3 m/s to 5 m/s. This range was easily met. (Test certificate, Fig. 6). However, because the meter was installed on the 48" line, which is capable of accepting flow from two of the 30" jetty lines, there were periods when the main line flow was less than 0.3 m/s. Under these circumstances the output from the flowmeter decreased to zero. Tests with an oscilloscope showed that the rotor was still turning, but that its output was lost in signal noise. This evidence was presented to the flowmeter manufacturer who is now investigating the possibility of metering at a lower velocity while still retaining the trash resistant design.

6.5 Capacitance Water Monitor

The Endress and Hauser Aquasyst capacitance water monitor operated successfully in the fast loop for the duration of the trial. It was found to be very useful in setting up the test conditions and for observing the water peaks as they occurred. However, to ensure that all calibration data has the same basis, all trial results have been referred back to laboratory testing using the Karl Fischer technique.

7. RECOMMENDATIONS

7.1 Further Work

Although the results of the work to date indicated that flow rate control may be unnecessary, this conclusion has been based on limited tests. It was therefore considered to be advantageous to pursue the investigation further while the facilities are still available at our Rotterdam Refinery. Consequently additional tests have now been arranged with the assistance of the National Engineering Laboratory. The involvement of an independent body was thought to be necessary because the evidence we have at present is at variance with the literature and with the conclusions of the other major oil companies. It is important that BP's final sampling package has the broad acceptance of other oil companies so that eventually we can all have similar systems. This will hopefully help towards resolving disputes.

7.2 Sampling Package

The objective of all of BP's work on automatic sampling over the last few years has been to put us in a position to recommend a definitive total sampling package. We consider now that we are in a position to do this. Figure 7 shows diagrammatically our recommended scheme. It comprises the following components -

7.2.1 Pipeline Mixing

In any sampling system the first consideration must be to ensure that the water and oil are mixed homogeneously. While, at many sites this may occur naturally due to pipework configurations and/or pumps, there may be applications when the line contents are not always homogeneous, possibly due to low flow rates.

In applications where homogeneity is in doubt some form of artificial mixing is required. Previous work has shown that mixing by jet injection is highly efficient. Therefore a proprietary jet mixing system has been recommended.

The jet mix system now supplied by Jiskoot Autocontrol Limited uses the internal jet design recommended as a result of BP's work at Finnart. Several such systems have been purchased by companies outside of BP and are said to be in successful operation. For applications where mixing is only necessary at low flow rates the main line flowmeter can be used to control the jetting pump.

7.2.2 Bypass Loop System

The bypass loop system is shown with its entry through a Maurer scoop tube. This would be sized either with 1¼" or 1" entry diameter, depending upon line and pump size. It can be supplied for live line entry. A coarse strainer should be fitted in the loop upstream of the pump to prevent trash being carried forward to the sampler and the fast loop flowmeter. The strainer may be a dual arrangement, or fitted with a differential pressure measurement to give early warning of fouling due to debris.

Because the theory that isokinetic flow control is unnecessary has not yet been fully proven, we are recommending a simple flow control system. The set point value will be cascaded from the main line flowmeter. To meet the requirement of isokinetic flow at all main line flow rates, the pump will be sized to ensure that the velocity at the inlet scoop tube is equal to the maximum expected main line velocity. If it can be shown eventually that fast loop flow control is not necessary, the size of the pump can be halved (para 6.3.).

7.2.3 Sampler

Grab samplers of the BP design are manufactured by Jiskoot Autocontrol Ltd. and Maurer Instruments Ltd. The instruments used in the trials reported here were made by Maurer and incorporate design changes arising from the latest results of the NEL Sampling Project.

The sample collection system is very much 'user's choice', and will depend on the application. However it is important that a relief valve is fitted after the sampler to protect it from the very high pressures which can be generated by it if it is operated against a shut off sample collection system.

7.2.4 Controller

At the moment there are at least four models of sampler controller available for safe area locations, all of which are in service with various users. It is expected SIRA will carry out an evaluation of these four models.

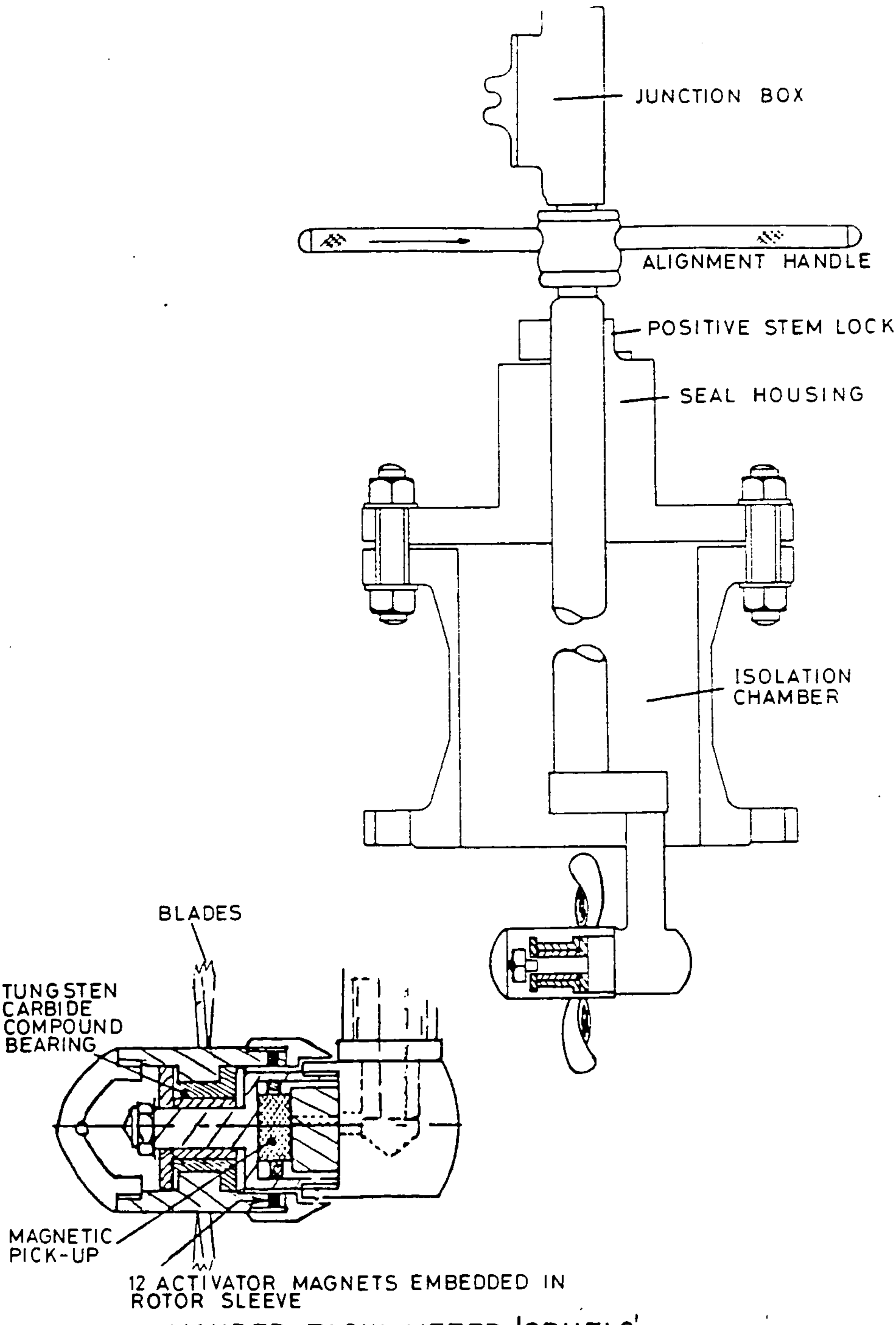
For applications requiring an explosion proof controller the choice is somewhat more limited.

7.2.5 Flowmeter

The main oil line flowmeter described in this paper and recommended for BP systems is the Maurer Cruflo. It can be live line fitted through a 6" hot tap. N.B. the trepanned hole must be at least 148 mm diameter.

8. ACKNOWLEDGEMENT

Permission to publish this paper has been given by The British Petroleum Company PLC.



MAURER FLOW METER 'CRUFLO'

FIG. 1

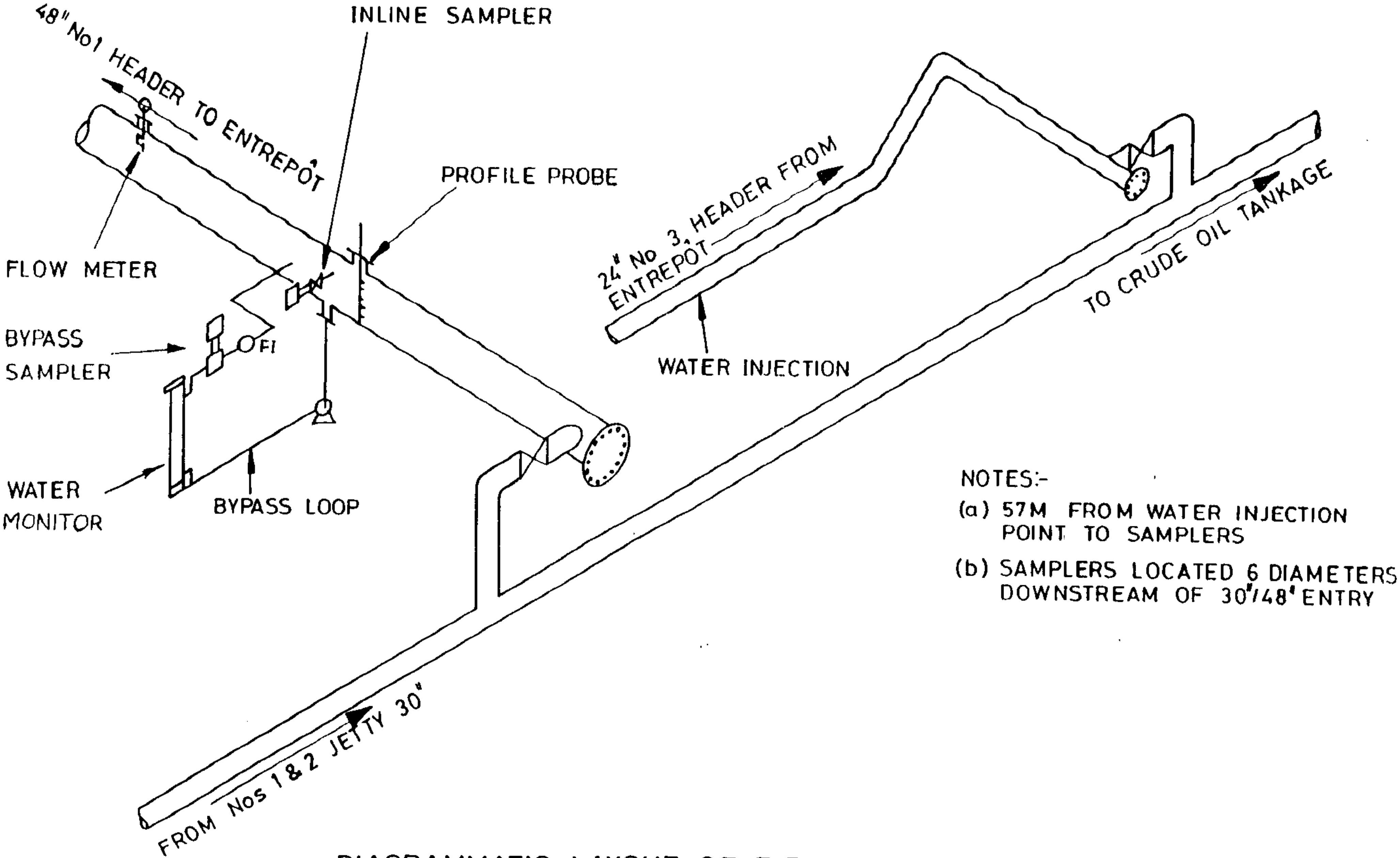
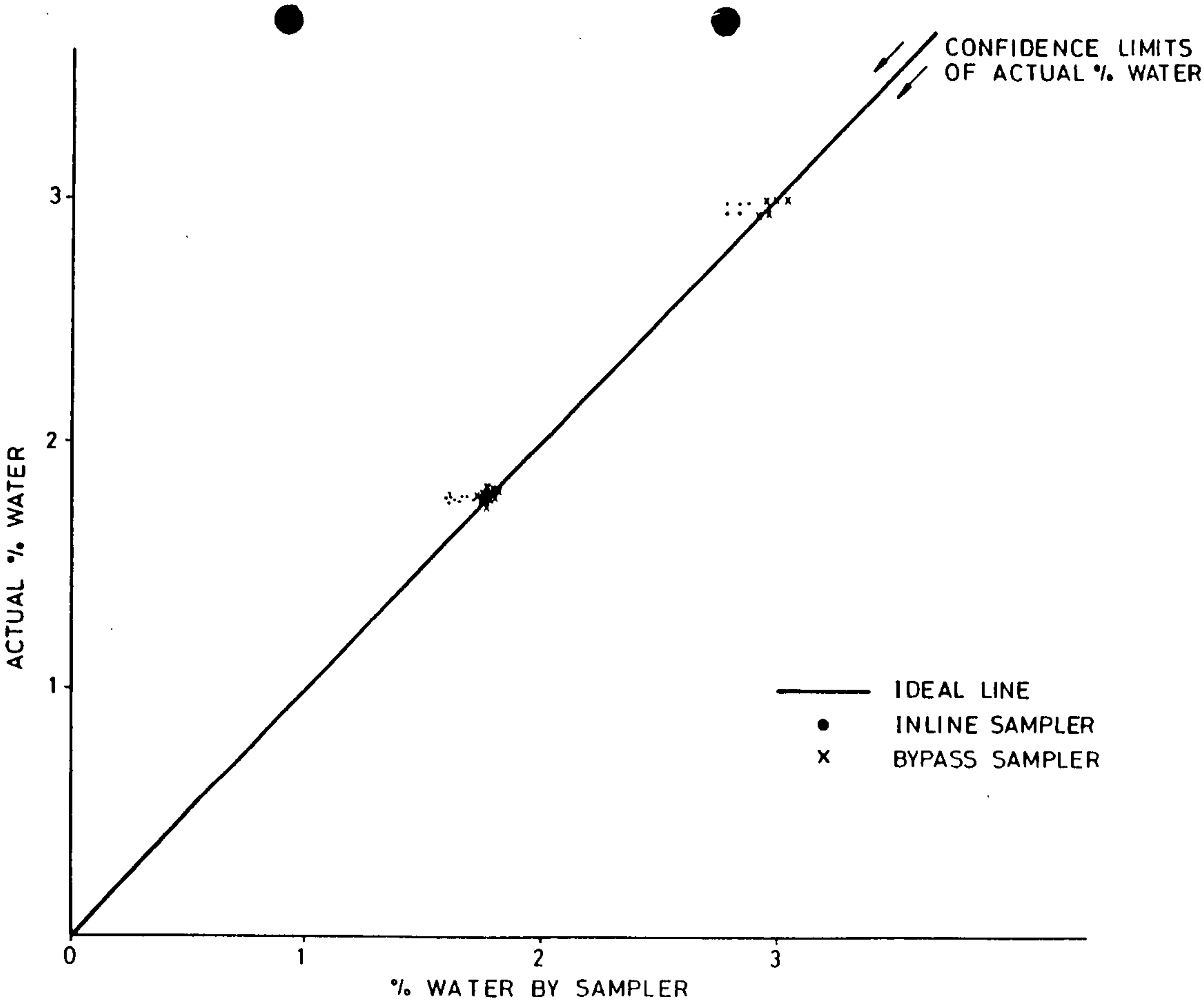


FIG. 2

DIAGRAMMATIC LAYOUT OF FIELD EQUIPMENT



ACTUAL % WATER –v– % WATER BY INLINE & BYPASS SAMPLERS
(HOMOGENEOUS CONDITIONS ONLY)

FIG. 3

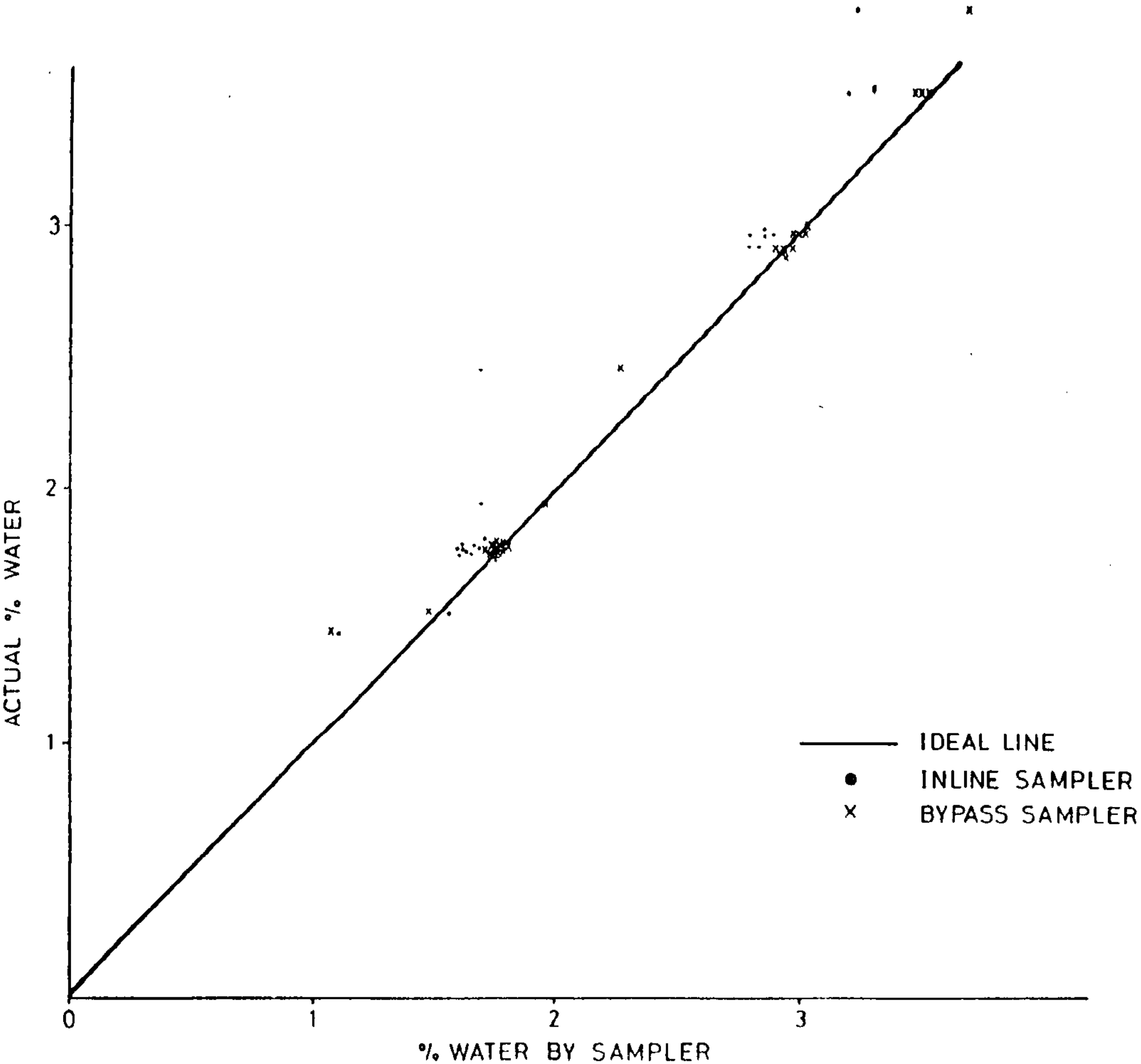
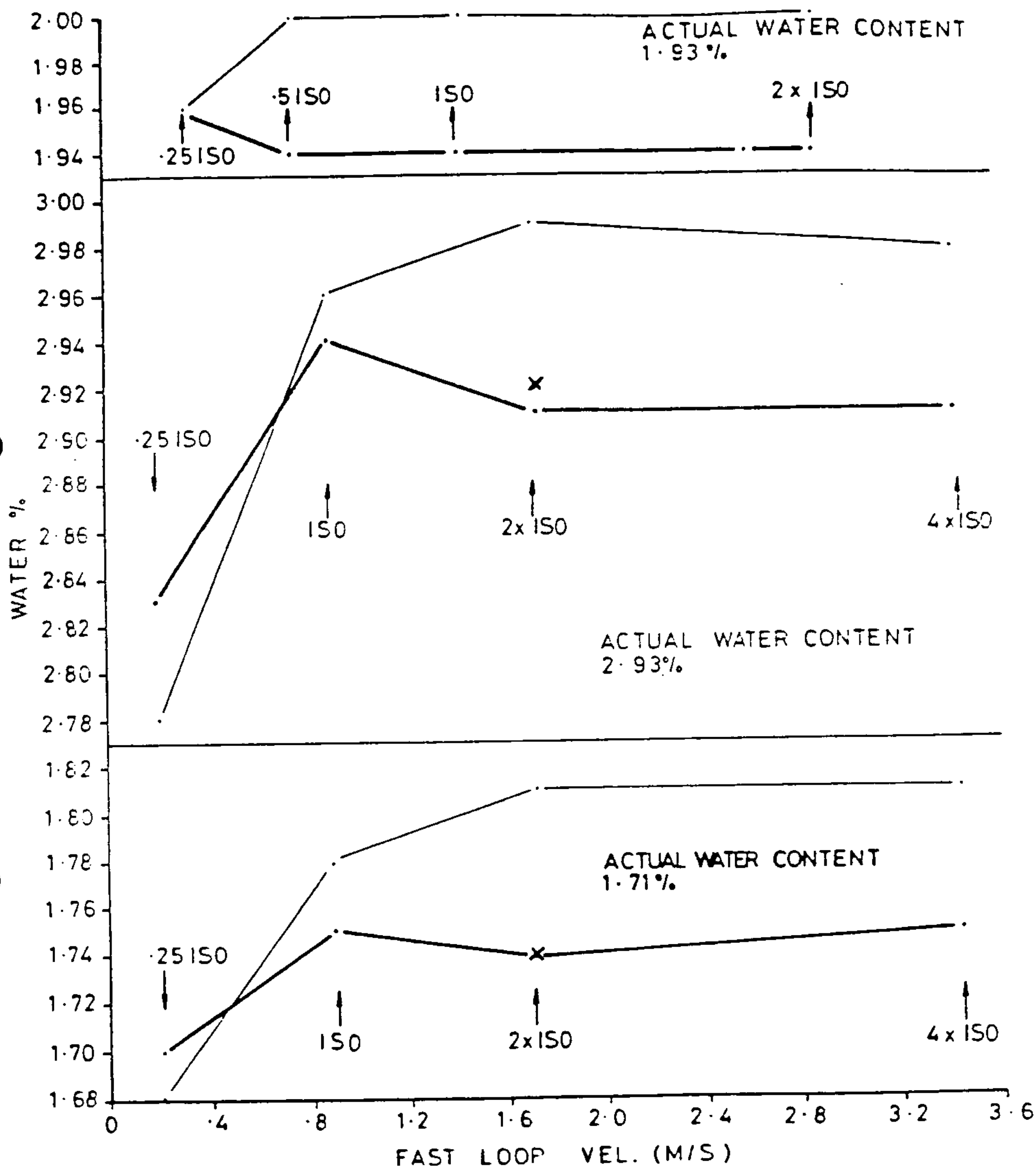


FIG. 4

ACTUAL % WATER –v– % WATER BY INLINE & BYPASS SAMPLERS

(HOMOGENEOUS & NON HOMOGENEOUS CONDITIONS)

FAST LOOP ISOKINETIC FLOW TESTS



WATER CONTENT FROM MANUAL SAMPLES

WATER CONTENT FROM CAPACITANCE CELL

× BYPASS SAMPLER

FIG. 5

FLOW METER TEST CERTIFICATE

CUSTOMER: BP-Harlow

ORDER NO: XED-700-86-1/EL25

METER SERIAL NO: 4070

WORKS ORDER NO: 8746

METER DATA

Meter Type: IP-6

Materials: 316 st/st

Nominal Flow Range:

Pickup: high output magnetic

TEST DATA

Insertion Meter Type IP-6 Serial No: 4070 was mounted in a 10" NB pipe spool piece and calibrated on the AOT-Andover meter prover. The AOT calibration data is attached herewith.

Base Annulus Area = 0.545 ft^2

Blockage Factor = 0.933

Nett Annulus Area = 0.508 ft^2 = 0.0472m^2

Fluid-Water Temperature 20°C

RUN DATA

time(seconds)	flow rate (m^3/min)	Axial Velocity (m/sec)	Total Pulses	Frequency	'K' factor metres/puls
37.72	20.925	7.388	10852	287.69	0.0257
46.66	16.916	5.973	10844	232.40	0.0257
60.80	12.982	4.582	10824	178.02	0.0257
89.65	8.804	3.109	10798	120.44	0.0258
161.31	4.893	1.728	10753	66.66	0.0259
Extrapolated Values (	2.832	1.0	-	38.58	0.0259
(	1.416	0.5	-	19.29	0.0259
857.06	0.920	0.325	9614	11.20	0.0290

NOTE:

To obtain flowrate in pipe size greater than 24" ID use equation:

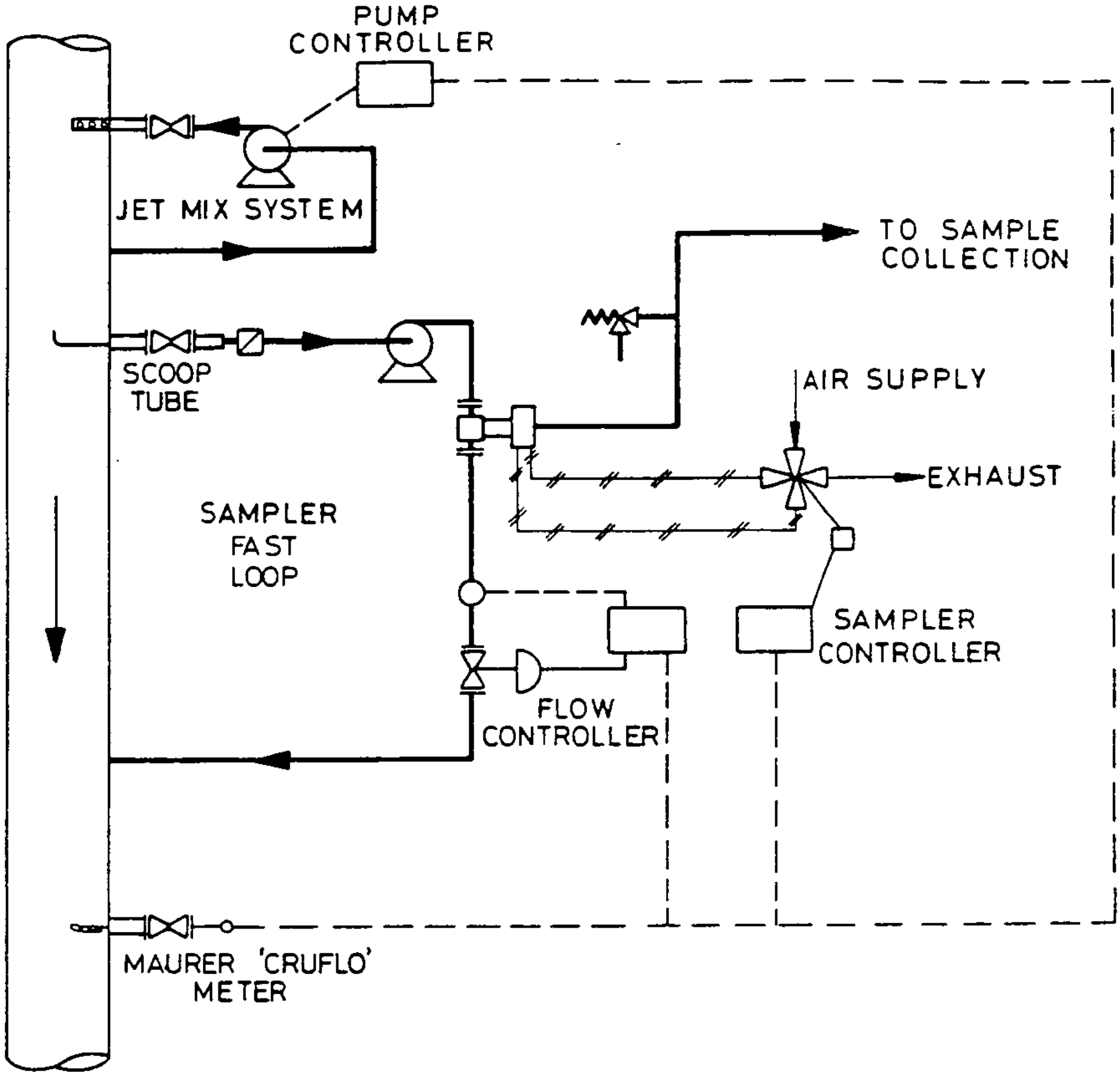
$Q\ (m^3/sec)$ = 'K' factor x frequency x annulus area (M^2)

INSPECTOR: [signature]

DATE: 8.10.84

FIG 6

RECOMMENDED SAMPLING SYSTEM SCHEMATIC



MAIN COMPONENTS:-

JET MIX SYSTEM (a) JISKOOT JET

(b) PUMP WITH STOP/START CONTROLLED FROM MAIN LINE FLOW.

SAMPLER FAST LOOP (a) SCOOP TUBE - EITHER 1" OR 1 1/2" DEPENDING ON LINE SIZE. LIVE LINE INSERTION POSSIBLE.

(b) COURSE FILTER WITH OPTIONAL D.P. MEASUREMENT

(c) PUMP SIZED TO GIVE ISOKINETIC ENTRY AT SCOOP TUBE FOR MAX. EXPECTED MAIN LINE FLOW.

(d) CELL SAMPLER WITH CONTROLLER.

(e) FLOW CONTROL SYSTEM WITH CASCADE FROM MAIN LINE FLOW.

(f) SAMPLE COLLECTION SYSTEM WITH USER OPTIONS (eg CAN WEIGH & CAN CHANGEOVER)

MAIN LINE FLOW METER (a) MAURER 'CRUFLO' TRASH RESISTANT FLOW METER 6" ENTRY - LIVE LINE INSERTION

FIG. 7

TANK-TO-TANK TRANSFER WITH WATER INJECTION

DATE	CRUDE	HOMOGENOUS	MAIN LINE VELOCITY M/S	ACTUAL % WATER	SAMPLER RESULT IN LINE % WATER	SAMPLER RESULT BYPASS % WATER	DIFFERENCE	AVE. CENTRE PROFILE PROBE % WATER	AVE. FAST LOOP % WATER	ACTUAL % WATER − % WATER BYPASS	ACTUAL % WATER − % WATER INLINE
20.3.85	FULMAR	no	0.27	2.46	1.68	2.25	-0.57	1.73	2.57		
		no	0.27	3.82	3.20	3.67	- 0.47	3.68	3.47		
		no	0.27	1.44	1.10	1.08	+ 0.02	1.14	2.89		
		no	0.52	1.94	1.68	1.95	- 0.27	1.95	1.95		
9.4.85	IRANIAN HEAVY	yes	0.67	1.76	1.61	1.74	- 0.13	1.74	1.73	0.02	0.15
		yes	0.67	1.76	1.61	1.75	- 0.14	1.73	1.73	0.01	0.15
		yes	0.67	1.76	1.61	1.75	- 0.14	1.74	1.73	0.01	0.15
10.4.85		yes	0.67	2.98	2.78	2.99	- 0.21	3.02	3.00	- 0.01	0.20
		yes	0.67	2.98	2.87	2.96	- 0.09	2.92	2.98	0.02	0.11
		yes	0.67	2.98	2.85	3.02	- 0.17	3.00	2.98	- 0.04	0.13
		yes	0.67	2.98	2.93	3.02	- 0.09	3.01	2.99	- 0.04	0.05
		no	0.29	1.52	1.56	1.48	+ 0.08	1.31	1.61		
		no	0.29	3.51	3.18	3.45	- 0.27	3.42	3.54		
		no	0.29	3.51	3.28	3.47	- 0.19	2.96	3.64		
		no	0.29	3.51	3.29	3.49	- 0.21	3.44	3.64		
8.5.85		yes	0.90	1.77	1.6	1.73	- 0.06		1.74	0.04	0.17
		yes	0.90	1.77	1.67	1.73	- 0.06		1.74	0.04	0.1
		yes	0.90	1.77	1.68	1.76	- 0.08		1.78	- 0.01	0.09
		yes	0.89	1.77	1.64	1.76	- 0.12		1.76	0.01	0.13
		yes	0.89	1.76	1.66	1.77	- 0.11		1.76	- 0.01	0.1
		yes	0.89	1.76	1.72	1.77	- 0.05		1.78	- 0.01	0.04
		yes	0.87	2.93	2.78	2.94	- 0.016		2.92	- 0.01	0.15
		yes	0.87	2.93	2.93	2.91	+ 0.02		2.93	0.02	0
		yes	0.87	2.93	2.82	2.91	- 0.09		2.95	0.02	0.11

TABLE 2

TANKER DISCHARGES

AUTOMATIC SAMPLER RESULTS

% WATER

DATE	VESSEL	CRUDE	INLINE	BYPASS	
7.2.85	FANNY	EKOFISK	0.38	0.39	
28.2.85	DON HUMBERTO	MAYA	0.61	0.55	Very low fast loop flow due to crude viscosity. Pump overloading.
29.2.85	DON HUMBERTO	ISTHMUS	0.07	0.10	
17.2.85	KABKAS	KIRKUK	0.05	0.06	
20.5.85	METCO CLYDE	BERYL	0.19 0.19	0.13 0.16	Repeat Laboratory Test.
21.5.85	IRANZU	RAS BUDRAN ZEIT BAY	0.59	0.41	Only front (wet) end of Zeit Bay sampled

TABLE 3

BYPASS LOOP - ISOKINETIC TESTS

Sample Number	% Water (Lab Test)	% Water Average	Flow Rate % Isokinetic	Capacitance Probe % Water	Bypass Loop Entry Velocity M/S	Actual % Water
			100	1.78	0.89	
3 4 5	1.68 1.71 1.72	1.70	25	1.68	0.2	
6 7 8	1.76 1.76 1.74	1.75	100	1.78	0.89	
9 10 11	1.75 1.75 1.74	1.75	400	1.81	3.44	1.71
12 13 14	1.74 1.74 1.75	1.74	200	1.81	1.72	
21 22 23	2.87 2.79 2.84	2.83	25	2.78	0.2	
24 25 26	2.93 2.97 2.93	2.94	100	2.96	0.89	
27 28 29	2.92 2.90 2.92	2.91	400	2.98	3.44	2.93
30 31 32	2.90 2.93 2.91	2.91	200	2.99	1.79	
36 37 38	1.97 1.96 1.94	1.96	25	1.96	0.34	
39 40 41	1.93 1.94 1.94	1.94	50	2.00	0.76	
42 43 44	1.95 1.94 1.92	1.94	100	2.00	1.44	1.93
45 46 47	1.94 1.95 1.93	1.94	200	2.00	2.89	

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.