WATER IN OIL: ON-LINE MEASUREMENT. THE MFI WATER CUT METER IN OFFSHORE APPLICATION.

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1. SUMMARY

BP is currently investigating the performance of the MFI water cut meter for fiscal water content measurement of pressurised crude oil. A series of tests have been carried out to determine meter performance with reference to the ISO3171 (1) fiscal accuracy criteria. Manual sampling techniques have been developed in order to validate meter accuracy in measurement of instantaneous produced water content. Simultaneous flow rate, temperature, pressure, density and water content data were logged and flow weighted water content values calculated on a daily basis. The MFI daily average water cut was then compared with results obtained using the fiscal automatic sampling system. This paper presents the results and findings of a series of tests carried out on a 2 inch MFI water cut meter, installed in the fiscal sampling flow loop on the BP Forties Charlie platform. Data relate to the periods October 1993 and May to July 1994.

2. INTRODUCTION

2.1 Background

BP and Multi-Fluid International (MFI) have been in co-operation throughout the period of development of the on-line water cut meter. Early work on validating instrument accuracy was encouraging and BP Research, Sunbury, became involved with meter testing under actual service conditions. Following successful tests in measuring the produced water content of a variety of stabilised crude oils at Grangemouth and Rotterdam Refinery, together with results obtained by Statoil at Mongstad (2), BP Forties agreed on a long term trial to assess the meter's performance in an offshore environment.

A 2 inch MFI water cut meter was first installed in the fiscal sampling flow loop on the BP Forties Charlie platform in October 1993. After fiscal metering, Forties Blend crude oil is exported from Forties Charlie to Kinneil, Grangemouth. Typical, flow-loop oil temperature and pressure conditions are 35°C and 100 barg respectively. The original, prototype, meter was upgraded to allow compensation for changes in line pressure and oil density, and was installed in May 1994. The upgraded device incorporated an auto-zero function which enabled the instrument to calculate the flowing oil dry oil dielectric constant (ε) with reference to the measured density and simultaneous water content. Thus, the instrument zero is automatically 'calibrated' and updated according to changes in the flowing oil composition (dry oil density).

2.2 MFI Water Cut Meter: Operating Principle

Full details of the MFI water cut meter operating principle are given in the Manufacturer's Literature (3). Briefly, the meter uses a cavity resonator for measuring dielectric constant (ε). The meter utilises the large difference in the values of ε, for oil and water, to determine water content. The value of ε for dry oil sets the instrument zero, and the value of ε for the produced water sets the instrument span.

2.2 Compatibility of Data

Pressurised oil manual sampling techniques were developed to facilitate representative 'spot' sampling for accurate measurement of the instantaneous water content of the flowing oil.

The MFI water cut meter measures the saline water content of the flowing oil. The accuracy of the MFI meter was investigated by comparison with Karl Fischer coulometric titration (KF) which determines pure water content. Sample handling methodology was carried out in accordance with Forties Field Analysis (FFA) procedures. The actual KF analysis followed the procedures of IP386 (4) and therefore provided a traceable standard. Direct comparison of the KF, FFA, pure water content, %weight (%w/w), was made after conversion of the KF value to the equivalent saline produced water content, %volume (%v/v), see Appendix 1. The meter was deemed to indicate the 'correct' water content if the agreement between the KF and the MFI was within the ISO3171 fiscal acceptance criteria as follows:-

- produced water content 0 - 1 %v/v : ± 0.05 %v/v absolute.
- produced water content > 1 %v/v : ± 5 % relative.

Since comparisons of data are between results obtained from two separate sampling/measurement systems, each required to operate within an accuracy specification of ±5%, a more appropriate relative acceptance limit of ±7% (ie. $\sqrt{2} \times \pm 5\%$) could be applied.

3. MFI WATER CUT METER

3.1 Instrument Calibration

The main set-up calibration was carried out by input of the dry oil density (for instrument calculation of the corresponding dielectric constant, (ε)) and the produced water conductivity. These data set the instrument zero and span respectively. The meter measures water content in the range 0-20 %vol.

3.1.1 4-20mA Signals

Prior to datalogging, all the 4-20mA signals were calibrated. In order to maximise accuracy of each measurement, each signal span was set to the minimum acceptable range. Flow rate, density and line pressure signals were taken from the local control room computer. Temperature and water content signals were measured directly from the MFI unit. Particular attention was paid to the calibration of the 4-20mA output for the water cut signal. An accurate current loop meter was used for the calibration, which was carried out in accordance with the manufacturer's published procedures (3). The MFI water content 4-20mA output signal calibration was re-checked at the end of the trial period and no change was detected in the signal accuracy.

3.1.2 On-Line Water Content Calibration

The parameters required for on-line calibration were the flowing oil density and temperature, and the corresponding pipeline pure water content. Oil density and temperature data were obtained from the in-line fiscal densitometers and the MFI calibrated thermal sensor respectively. Comparative, instantaneous, oil water content determination was carried out by KF analysis of a pressurised oil manual 'spot' sample. On completion of input of the calibration data the MFI meter calculated a 'new' value for ε, and the corresponding water content correction to be applied to the 'old' measurements. The instrument then displayed an option to save the 'new' value for ε. When saved, all subsequent measurements were carried out using the updated calibration data.

3.2 Auto-Zero Function

The MFI meter utilises a relationship between dry oil dielectric constant (ε) and density. The instrument manufacturer has developed an automatic calibration method where the instrument is linked to the output of an in-line fiscal standard densitometer and compensates for changes in ε by relating to measured changes in the dry oil density of the flowing fluid. The dry oil density is itself calculated within the meter's software and is related to the metered water cut. The instrument automatically re-zeros according to changes in the composition of the flowing oil stream. Thus, the MFI water cut signal should be maintained at optimum accuracy.

4. DATA ACQUISITION AND SAMPLING METHODOLOGY

4.1 MFI / Datalogging

A Magus 2000 datalogger was used to log daily data (18:00-18:00) commensurate with the automatic sampler 'daily' sample accumulation period. Flow rate, pressure, oil density, temperature and MFI water content data were logged at 5 second intervals. A real time display graph was used to monitor the data collection and observe production and water content stability. Data were recorded on a daily basis and calculations of the flow weighted average MFI water content were carried out.

4.2 Manual 'Spot' Sampling

In order to acquire independent data on the instantaneous water content of the flowing oil, pressurised manual 'spot' samples were taken for KF analysis. Figure 1 shows the MFI water cut meter installation in the fast-loop pipework. The fiscal densitometers and the MFI installation are shown in Figure 1A. Figure 1B shows a close-up of the MFI meter and a 50 ml Piston Internal Mixing Receiver (PIMR) installed for manual sampling for calibration or instantaneous water content comparison purposes. Figure 2 shows the MFI electronics enclosure and the location of the two automatic samplers.

A 50ml PIMR was connected to the pressurised oil manual sampling point, adjacent to the MFI meter, using a 30cm length of ¼" OD flexible pressure hose. Oil was allowed to flow straight through the PIMR, via the internal mixing baffle plate, such that the sample chamber was not filled. When the instantaneous water content was observed to be constant (within about 0.05.-0.10 %v/v) the PIMR outlet valve was closed and pressurised oil was collected in the sample chamber. The PIMR sample was then allowed to cool and water content analysis was carried out in accordance with the FFA methodology.

On-line calibration and investigation of MFI water content data accuracy was carried out by comparison of instantaneous water content measurements. Manual 'spot' samples were obtained and corresponding MFI data recorded during the sampling period (5 - 10 seconds). Prior to sampling, the MFI water content reading was monitored via a portable computer terminal. The stability of the flowing oil water content was determined by observation and a 'spot' sample was taken at an appropriate time. Immediately the 'spot' sample was obtained, the actual time (synchronised with the datalogger clock) was recorded. The concurrent MFI water content measurement, together with the related line conditions (ie. pressure, temperature and density) were obtained from the datalogger by averaging the results over the sampling period. Water content stability was confirmed by observation of the datalogger results around the sampling time. If acceptable stability was not achieved, then a replacement manual sample was taken.

4.3 Automatic Sampling

The fiscal automatic sampling system on Forties Charlie comprises two flow proportional cell samplers installed in the sampling fast-loop, and spaced about 30 cm apart. Under normal operating conditions, 1 litre 'daily' and 3 litre 'weekly' samples are obtained. The samples are of pressurised oil and are collected in PIMRs. For the duration of the trials, arrangements were made to operate both automatic samplers at the same 'daily' sampling rate.

MFI flow weighted 'daily' water content results, calculated from the logged data, were compared with corresponding fiscal measurements obtained from the automatic sampling system. Test comparisons were made using the two concurrent 'daily' 1 litre PIMR samples to 'confirm' daily automatic sample representativity, thus providing 'valid' results.

MFI/Automatic sampler 'daily' water content data comparisons were deemed valid if none of the following faults were identified with the either the sampling, measuring or datalogging equipment:

(i)	Sampler operation suspect:	Monitored by grab size and visual inspection.
(ii)	Sample representativity suspect:	Deemed representative if both samples agreed within ±5% relative.
(iii)	MFI over-ranged:	Produced water content >20 %v/v.
(iv)	MFI down-time:	Data off line.
(v)	Datalogger fault:	Data loss due to logger down time (eg. power loss).

5. RESULTS

5.1 MFI / Manual 'Spot' Samples

5.1.1 Auto-Zero Off / Not Installed

A summary of the comparative data, obtained prior to fitting and enabling the MFI auto-zero function, is presented in Table 1. Figure 3 shows the absolute difference between the MFI water content values and the comparable reference 'spot' samples. These data are presented with reference to the ISO3171 limits of ±5%. Calibration data are identified separately, as indicated in Figure 3.

Overall the data indicate very good agreement with the reference manual 'spot' sampling results and are within the ±5% acceptance criteria, for produced water contents in the range 0-10.6 %v/v. The data reflect the findings of previous BP trials and the Statoil tests (2), carried out on stabilised crude oils.

5.1.2 Auto-Zero On

Comparative data, obtained after initialising the auto-zero function, are presented in Table 2 and shown in Figure 4.

It is observed that these data show a obvious improvement on the results obtained without the benefit of the auto-zero option. The average absolute difference between the MFI and reference water content was just 0.005 %v/v for the 14 data points. The results covered the range 0-7 %v/v produced water content, and indicate remarkable agreement between the MFI and reference manual 'spot' sample results. The data clearly demonstrate that the MFI water cut meter (auto-zero function enabled) provides instantaneous water content measurement well within the fiscal acceptance limits of ISO3171.

5.2 MFI / Automatic 'Daily' Samples

Data obtained from the comparison of MFI and automatic sampler 'daily' water content determinations are presented in Table 3.

Figure 5 shows the absolute differences between the MFI and the comparable autosampler average 'daily' samples. With the auto-zero on, 4 of the 19 data points are outside the acceptance criteria of ±5%. Since comparisons of data are between results obtained from two separate sampling/measurement systems, each required to operate within an accuracy specification of ±5%, a more appropriate relative acceptance limit of ±7% (ie. $\sqrt{2} \times \pm 5\%$) could be applied. Referring to the less stringent accuracy limits, just 1 of the 19 data points lies outside the acceptance band. These results are most encouraging, and consideration of the observed accuracy in the measurement of instantaneous water content reinforce the view that the MFI meter provides an accurate measure of the flowing oil produced water content.

5.3 'Daily' Logged Data

The datalogger was programed to log 'daily' data files of flow rate, pressure, oil density, temperature and MFI water content. All data channels were logged at 5 second intervals. 'Daily' data files comprised a log of 1 minute average values from the logged data channels. The 'daily' data files were imported into spreadsheet format and plots of 'instantaneous' pipeline water content and oil density made. A change in flowing oil density will occur as a result of a change in the produced water content. Thus water content and oil density should show the same instantaneous trend. The equivalent oil dry oil density at 0 barg and 15°C was also computed. Major change in dry oil composition should only occur as a result of a major alteration in production. Thus the dry oil density (at standard conditions) should remain essentially constant. A demonstration plot is shown in Figure 6. MFI water content and oil density data are plotted against time for the 24 hour period of automatic sampling for Test A8. The water content and density data have been scaled to show peaks of comparable amplitude. Clearly the MFI water content and fiscal densitometer plots show almost identical trends. Furthermore the computed dry oil data show an essentially constant value despite observed differences in pipeline oil density of up to 0.015 kg/l.

Although the data do not prove instrument accuracy, the graphs presented in Figure 6 demonstrate consistency of MFI data. Combined with the accuracy in measurement of instantaneous water content, verified from the results of the comparisons with the reference manual 'spot' samples, it appears that the MFI meter should readily satisfy fiscal accuracy requirements for determination of daily average water content.

5.4 Operational Considerations

During the BP trials, there were several instances of instrument down-time as a result of software limitations. These problems are currently being addressed by the manufacturer and should be overcome in due course. Continuous trouble free service, with the minimum of maintenance, is as important as accuracy of determination in an on-line monitoring/measurement system. Long term trials are needed to prove instrument acceptability for both accuracy and operational requirements.

6. CONCLUSIONS

The results of the BP Forties offshore application trials have demonstrated that the MFI water cut meter is capable of accurate water content measurement of a pressurised oil stream. The test instrument had a range of operation from 0-20 %vol and worked well, within the operational range. Unstable water content is common on Forties Charlie and water contents above 20 % are not unusual. In order to provide a fair test of the MFI meter, stability of production was required providing continuous water content below the maximum 20 % throughout daily sample accumulation periods.

Problems associated with instrument down-time have been attributed to limitations in software and corrective action is currently being taken by the manufacturer. Long term stability and trouble free operation are important factors for on-line measurement systems. Ongoing trials should provide the data needed to confirm acceptance for fiscal measurement within the oil industry.

7. REFERENCES

1. INTERNATIONAL STANDARD ISO 3171: 1988(E)
   Petroleum Liquids - Automatic Pipeline Sampling.

2. OKLAND,O. BERENTSEN, H. and OLSEN, O. - Testing Water in Oil Monitors at the Mongstad Terminal.
   North Sea Flow Measurement Workshop 1993, 26-28 October, Bergen.

3. MFI WATER CUT METER. INSTALLATION AND USER'S MANUAL
   Multi-Fluid International AS, PO Box 112, N-4033 Forus, Norway.

4. STANDARD METHODS FOR ANALYSIS AND TESTING OF PETROLEUM AND RELATED PRODUCTS
   Designation IP386/90 (ASTM D4928-89)
   Determination of Water Content of Crude Oil-Coulometric Karl Fischer Method.

APPENDIX I

CONVERSION OF WATER CONTENT:

(%WEIGHT PURE WATER TO % VOLUME SALINE WATER)

(i) $\%v/v^* = (\%w/w^*/Db_{(T,P)})/((\%w/w^*/Db_{(T,P)})+((100-\%w/w^*)/Dd_{(T,P)}))$

ie. $$\% v/v^*_{(T,P)} = \frac{\text{Volume Produced Water}_{(T,P)}}{\text{Volume Produced Water}_{(T,P)} + \text{Volume Dry Oil}_{(T,P)}}$$

(ii) $\%v/v^* = \%w/w \times SCF \times Dl_{(T,P)}/Db_{(T,P)}$

ie. $$\% v/v^*_{(T,P)} = \%\text{Weight Pure Water} \times \text{Salt Correction Factor} \times \frac{\text{Line Density}_{(T,P)}}{\text{Brine Density}_{(T,P)}}$$

Where:

$\%v/v^*$	is the %volume of produced/saline water at line conditions.
$\%w/w^*$	is the %weight of produced/saline water at line conditions.
$Db_{(T,P)}$	is the produced/saline water density at line conditions.
$Dd_{(T,P)}$	is the dry oil density at line conditions.

Equations (i) and (ii) are equivalent, and represent the calculations used by MFI and the Forties System Allocation Schedule of Analysis (FSASA) respectively.

MFI / MANUAL 'SPOT' SAMPLE WATER CONTENT COMPARISON **TABLE 1**

(Auto-Zero Off / Not Installed)

Test Ref No	Sample Water Content (pure) (%w/w)	Sample Water Content (produced) (%v/v)	MFI Reading (%v/v)	MFI Water Content (%v/v)	Diff (MFI-Sample) (%v/v)	Relative Diff (%)
M1	4.70	4.04	5.62	4.10	0.06	1.4
M2	3.58	3.07	4.59	3.07	0.00	0.0
M3	4.59	3.94	4.12	4.12	0.18	4.6
M4	0.90	0.77	0.64	0.76	-0.01	-0.7
M5	9.29	8.05	8.38	8.38	0.33	4.1
M6	10.67	9.28	9.40	9.40	0.12	1.3
M7	4.86	4.15	4.26	4.26	0.11	2.7
M8	4.79	4.08	4.23	4.23	0.15	3.6
M9	5.69	4.88	5.07	4.90	0.02	0.5
M10	5.52	4.72	5.03	4.86	0.14	2.9
M11	10.61	9.19	9.32	9.32	0.13	1.5
M12	8.67	7.48	8.05	8.05	0.57	7.7
M13	3.55	3.02	3.01	3.01	-0.01	-0.5
M14	11.72	10.18	10.50	10.50	0.32	3.2
M15	8.95	7.70	8.06	8.06	0.36	4.7
M16	11.67	10.16	10.56	10.56	0.40	4.0
M17	10.34	8.93	9.30	9.30	0.37	4.1
M18	9.40	8.11	8.22	8.22	0.11	1.3
M19	12.21	10.61	10.64	10.64	0.03	0.3
M20	9.33	8.05	8.17	8.17	0.12	1.5
M21	6.78	5.81	5.88	5.88	0.07	1.2
M22	5.30	4.54	4.78	4.57	0.03	0.6
M23	4.31	3.68	3.62	3.62	-0.06	-1.6
M24	3.14	2.67	2.60	2.60	-0.07	-2.7
M25	2.85	2.43	2.47	2.47	0.04	1.8
M26	3.10	2.64	2.59	2.59	-0.05	-2.0
M27	3.20	2.73	2.63	2.63	-0.10	-3.6
M28	2.92	2.49	2.51	2.51	0.02	0.9
M29	0.60	0.51	0.31	0.51	0.01	1.2
M30	11.45	10.00	10.31	10.31	0.31	3.1
M31	7.36	6.35	6.65	6.65	0.30	4.8
M32	7.86	6.77	6.62	6.62	-0.15	-2.3
M33	3.17	2.71	2.80	2.80	0.09	3.2
M34	4.36	3.74	4.00	4.00	0.26	6.9
M35	3.17	2.71	2.82	2.71	0.00	0.1

MFI / MANUAL 'SPOT' SAMPLE WATER CONTENT COMPARISON

TABLE 2

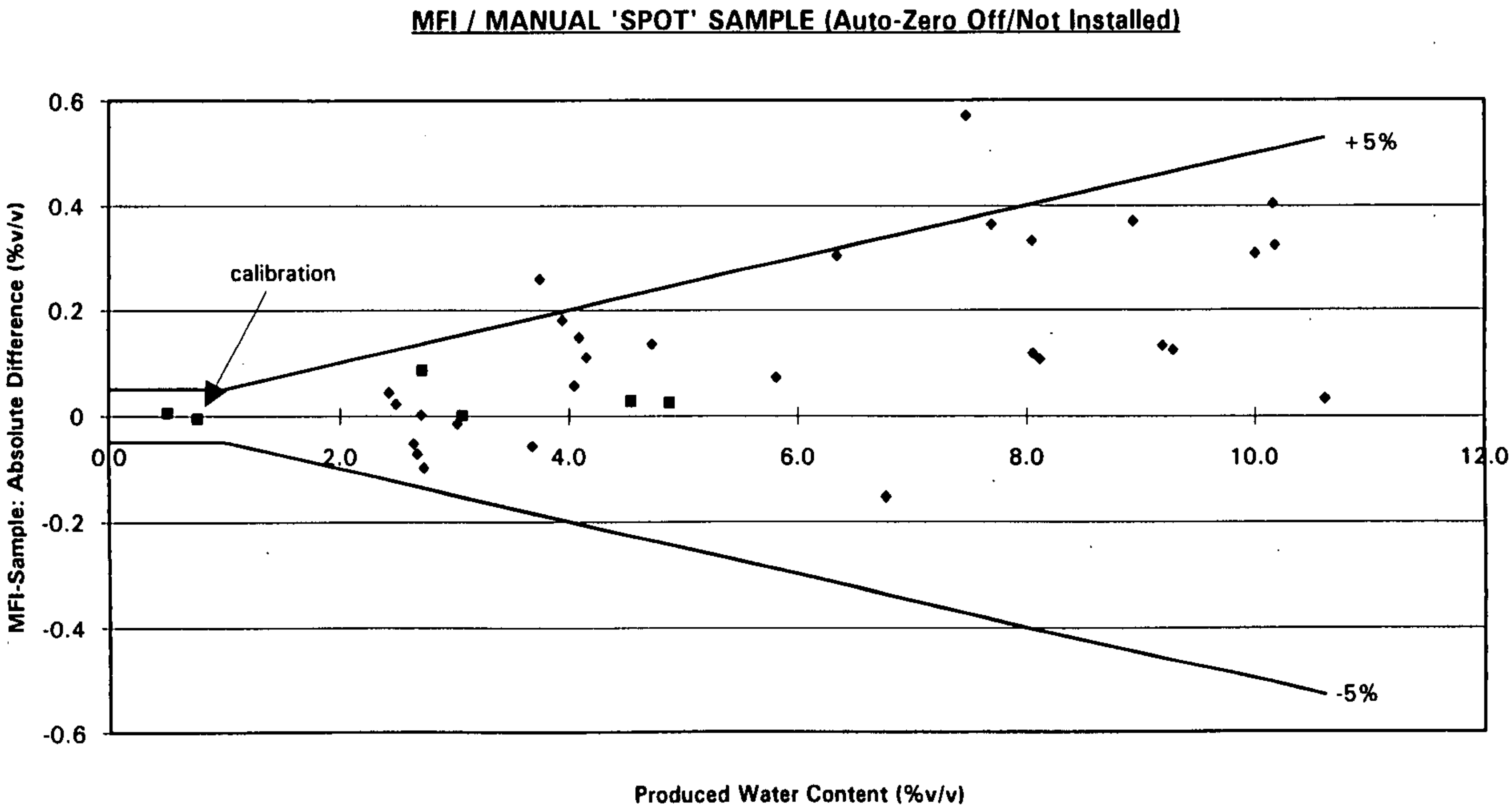
(Auto-Zero On)

Test Ref No	Sample Water Content		MFI Reading	MFI Water Content	Diff (MFI-Sample)	Relative Diff
	(pure) (%w/w)	(produced) (%v/v)	(%v/v)	(%v/v)	(%v/v)	(%)
M36	1.83	1.56	1.83	1.57	0.01	0.5
M37	2.15	1.83	2.10	1.84	0.01	0.5
M38	4.17	3.57	3.87	3.61	0.04	1.1
M39	6.60	5.69	5.95	5.69	0.00	0.0
M40	5.66	4.86	4.95	4.93	0.07	1.4
M41	5.05	4.34	4.29	4.29	-0.05	-1.2
M42	6.16	5.31	5.30	5.30	-0.01	-0.1
M43	6.65	5.71	5.55	5.55	-0.16	-2.8
M44	6.42	5.48	5.61	5.61	0.13	2.4
M45	8.12	6.97	6.97	6.97	0.00	0.0
M46	1.40	1.19	1.24	1.24	0.05	4.0
M47	3.54	3.03	2.97	2.97	-0.06	-2.1
M48	2.71	2.31	2.35	2.35	0.04	1.6
M49	1.77	1.51	1.52	1.52	0.01	0.7

MFI / AUTO SAMPLER 'DAILY' WATER CONTENT COMPARISON **TABLE 3**

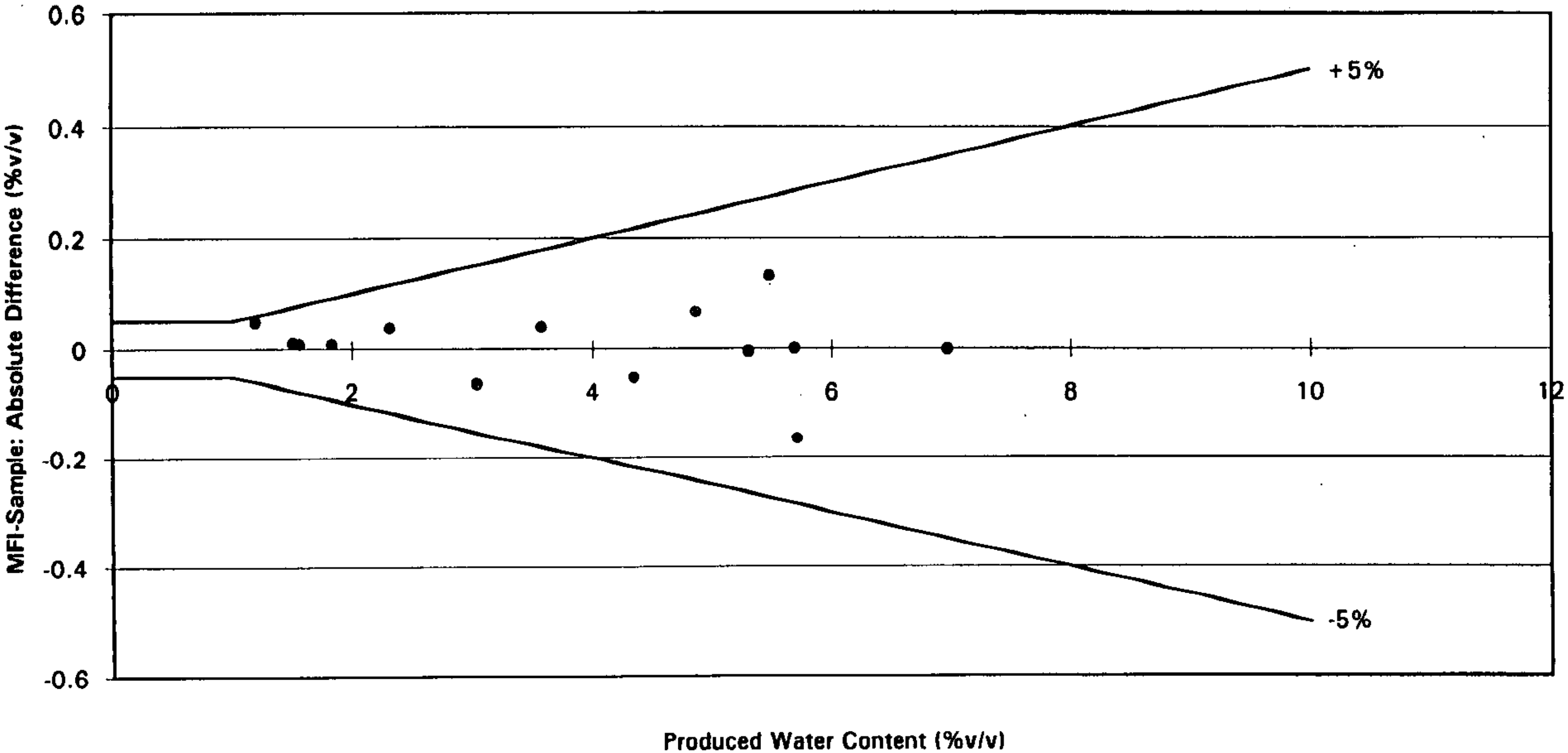
Test Ref No	Auto Sample Water Content					MFI Water Cut (2) (%v/v)	Absolute Difference (2)-(1) (%v/v)	Relative Difference (2)-(1) (%)
	Sampler No 1 (%w/w)	Sampler No 2 (%w/w)	Relative Difference (%)	Average (pure) (%w/w)	Average (1) (produced) (%v/v)			
A1	11.140	11.652	-4.6	11.396	9.970	10.500	0.530	5.3
A2	7.604	7.585	0.2	7.595	6.652	6.980	0.328	4.9
A3	6.751	6.937	-2.8	6.844	5.900	6.290	0.390	6.6
A4	5.655	5.748	-1.6	5.702	4.899	5.170	0.271	5.5
A5	5.183	5.287	-2.0	5.235	4.492	4.719	0.227	5.1
A6*	4.938	4.908	0.6	4.923	4.224	4.227	0.003	0.1
A7	3.267	3.232	1.1	3.250	2.783	2.789	0.006	0.2
A8	3.565	3.638	-2.0	3.602	3.085	3.217	0.132	4.3
A9	5.899	6.096	-3.3	5.998	5.166	5.317	0.151	2.9
A10	6.087	6.347	-4.3	6.217	5.337	5.255	-0.082	-1.5
A11	3.603	3.607	-0.1	3.605	3.081	2.956	-0.125	-4.1
A12	7.137	7.204	-0.9	7.171	6.200	6.322	0.122	2.0
A13	5.407	5.158	4.6	5.283	4.527	4.420	-0.107	-2.4
A14	6.352	6.392	-0.6	6.372	5.485	5.507	0.022	0.4
A15	5.293	5.301	-0.2	5.297	4.509	4.271	-0.238	-5.3
A16	3.214	3.250	-1.1	3.232	2.762	2.503	-0.259	-9.4
A17	3.476	3.514	-1.1	3.495	2.982	3.038	0.056	1.9
A18	6.405	6.528	-1.9	6.467	5.549	5.869	0.320	5.8
A19	5.101	5.109	-0.2	5.105	4.379	4.431	0.052	1.2
A20	5.530	5.345	3.3	5.438	4.676	4.840	0.164	3.5
A21	6.077	5.986	1.5	6.032	5.182	5.140	-0.042	-0.8
A22	5.558	5.650	-1.7	5.604	4.819	4.755	-0.064	-1.3
A23	4.779	4.655	2.6	4.717	4.042	3.970	-0.072	-1.8
A24	2.832	2.854	-0.8	2.843	2.423	2.262	-0.161	-6.6

* MFI Auto-Zero Function Enabled

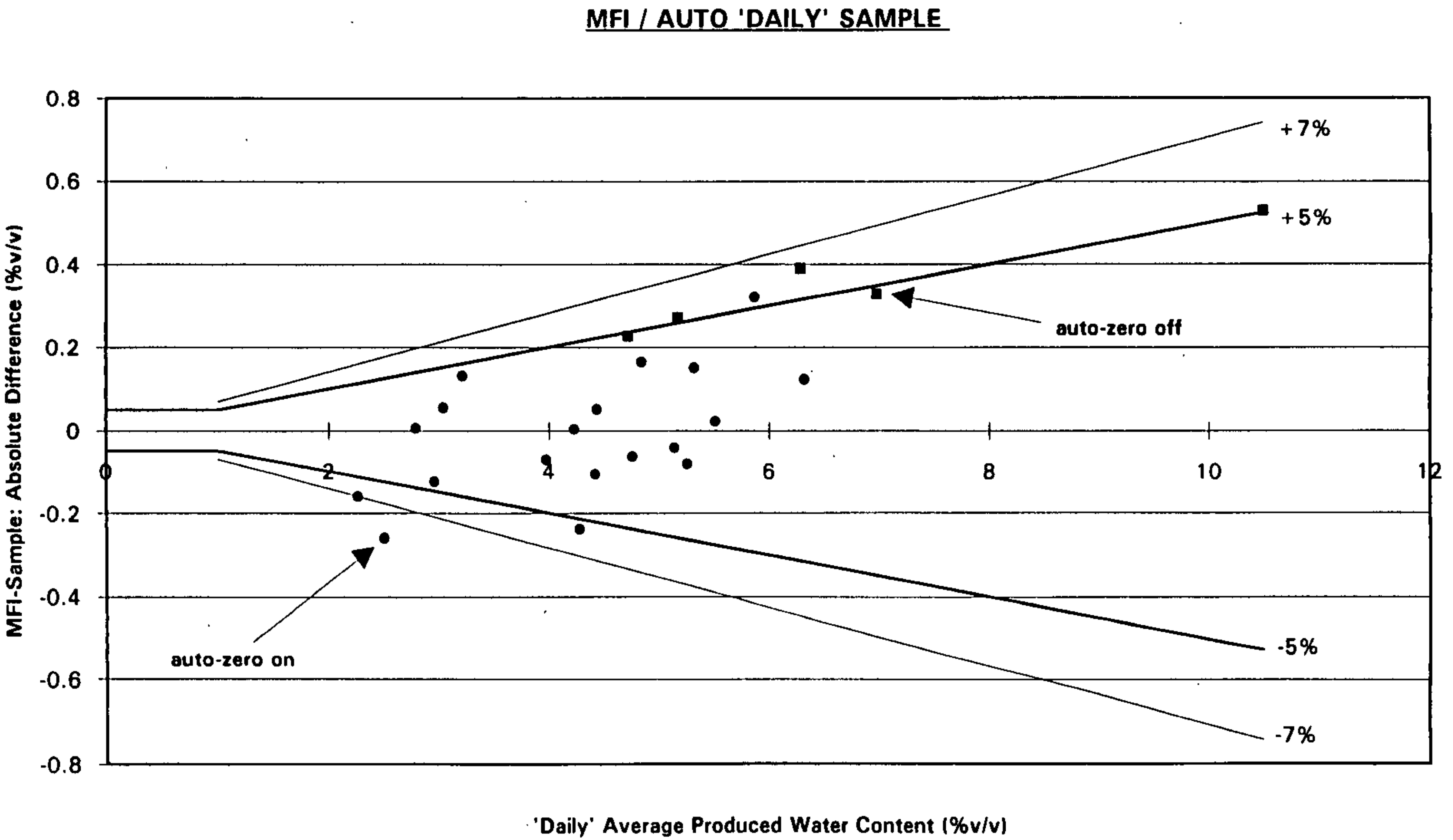

MFI / MANUAL 'SPOT' SAMPLE (Auto-Zero Off/Not Installed)
MFI-Sample: Absolute Difference (%v/v)
Produced Water Content (%v/v)
calibration
+5%
-5%
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0.0
2.0
4.0
6.0
8.0
10.0
12.0

[FIGURE 3]

MFI / MANUAL 'SPOT' SAMPLE (Auto-Zero On)

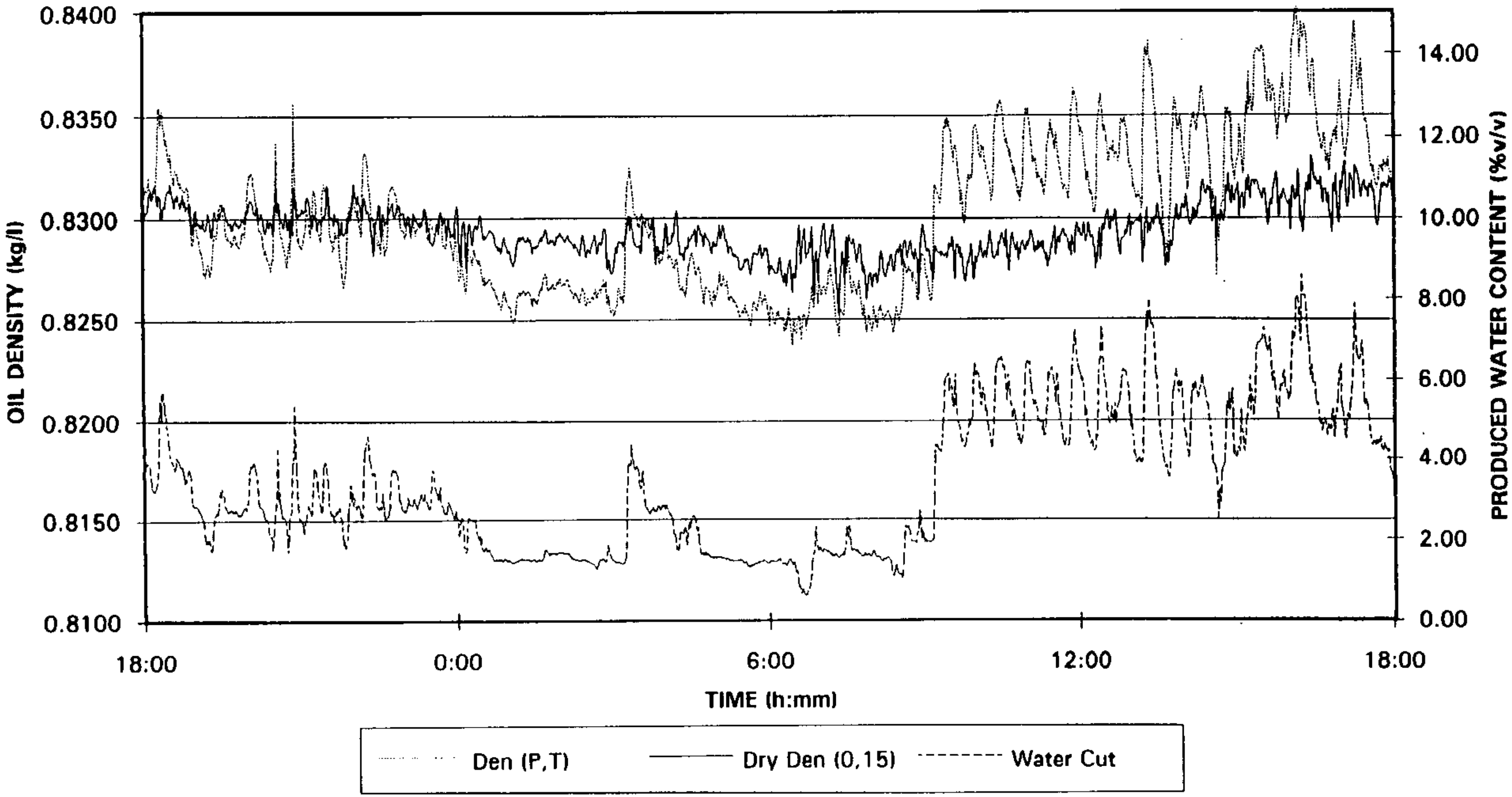


[FIGURE 4]


MFI / AUTO 'DAILY' SAMPLE
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
MFI-Sample: Absolute Difference (%v/v)
0
2
4
6
8
10
12
'Daily' Average Produced Water Content (%v/v)
+7%
+5%
-5%
-7%
auto-zero off
auto-zero on

[FIGURE 5]

MFI TEST A8: WATER CONTENT AND OIL DENSTIY DATA



[FIGURE 6]

<u>MFI WATER CUT METER INSTALLATION</u>

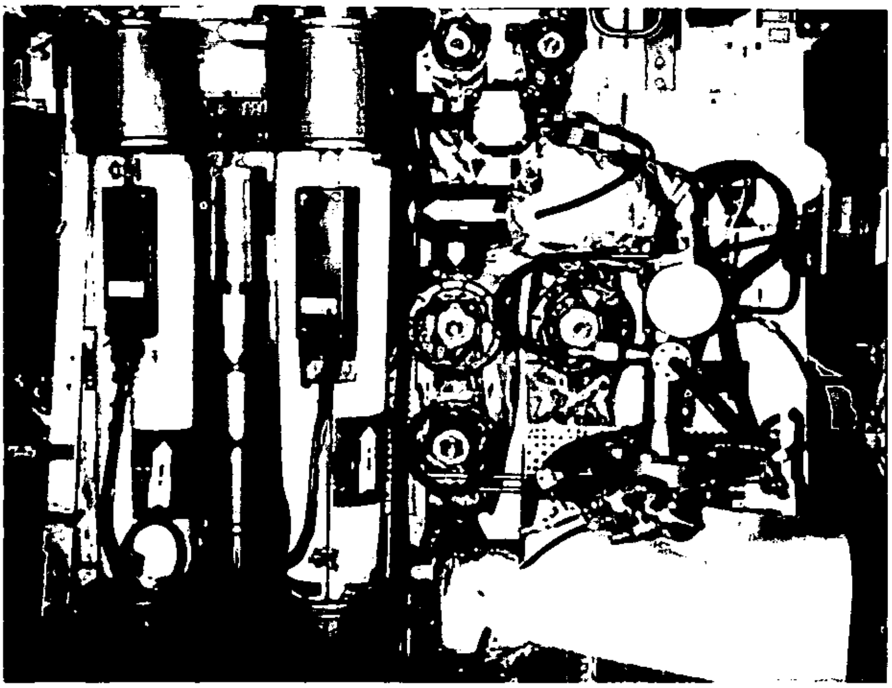


FIGURE 1A: FISCAL DENSITOMETERS AND MFI METER INSTALLATION

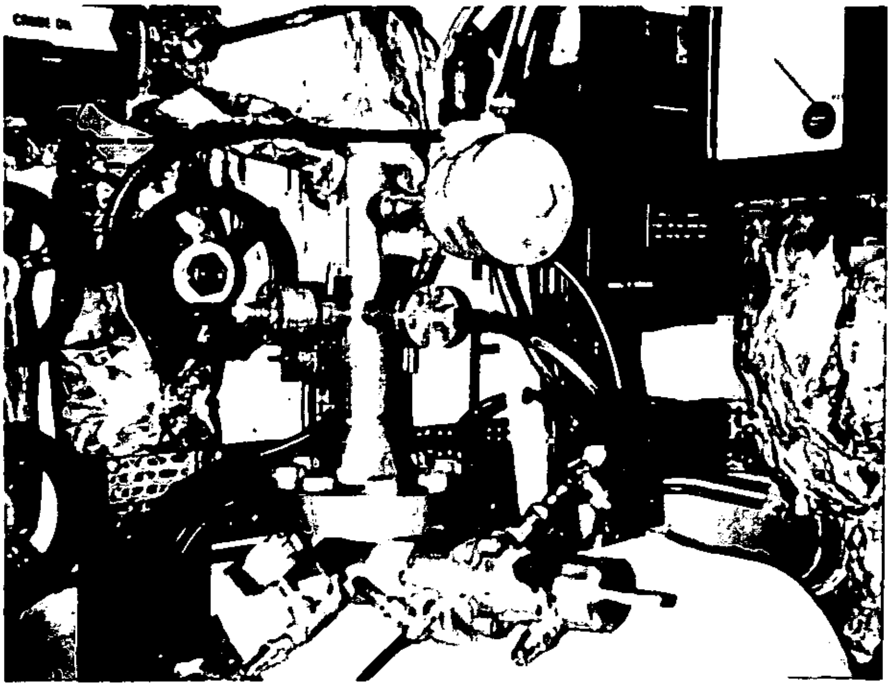
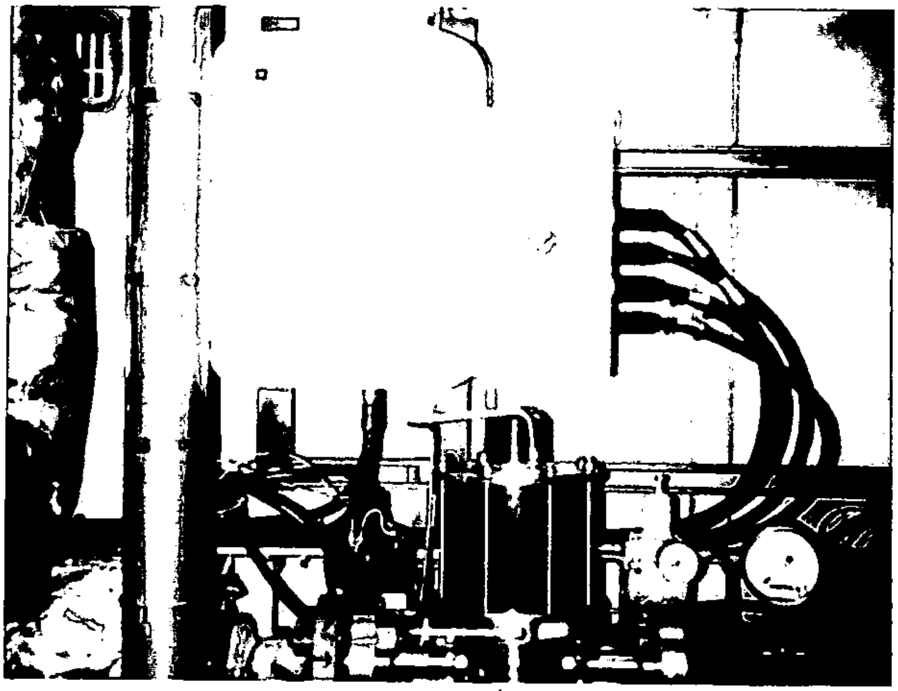
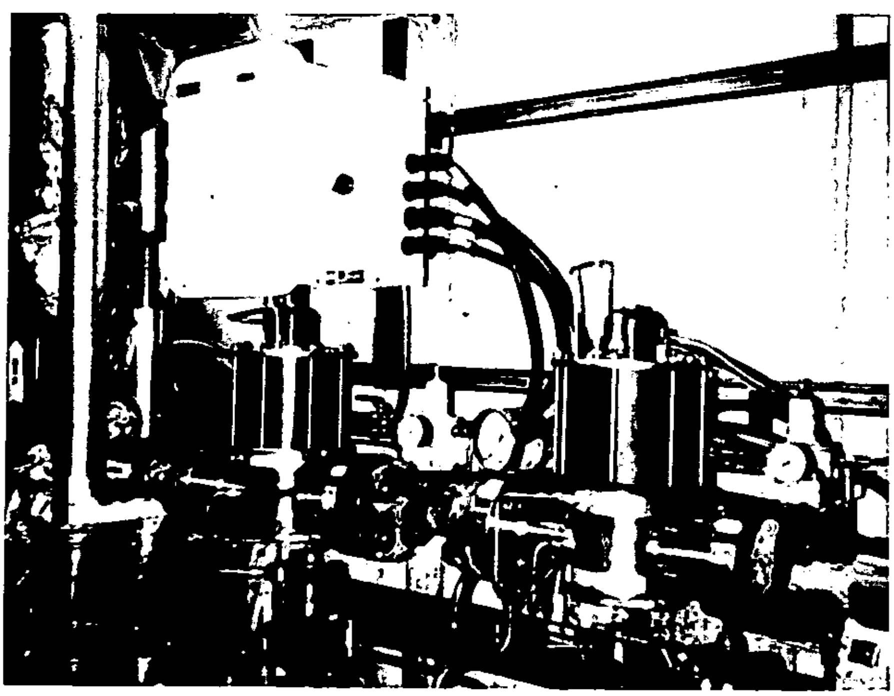


FIGURE 1B: MFI METER AND 50ml PIMR (FOR 'SPOT' SAMPLING)

[FIGURE 1]

<u>AUTOMATIC SAMPLERS AND MFI ELECTRONICS ENCLOSURE</u>





[FIGURE 2]