PUBLIC POWER CORPORATION
ATHENS, GREECE

MILOS GEOTHERMAL DEVELOPMENT
MILOS M-1

Reinjection Trial - November 1986
Consultant's Report

ORKUSTOFNUN
NATIONAL ENERGY AUTHORITY

VIRKIR CONSULTING GROUP LTD.

REYKJAVÍK, ICELAND

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Omar Sigurdsson

Report No.: OS-87001

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Mailing address
SÍDUMÚLI 1, 108 REYKJAVÍK, ICELAND

Telephone
354-1-687311

Cable address
VIRKIR

Telex
2012 VIRKIR IS

Introduction

In accordance with a contract between the Public Power Corporation of Greece (PPC) on one hand, and the joint venture of the Virkir Consulting Group Ltd. and the National Energy Authority of Iceland (Virkir/NEA) on the other, the consultant Mr. Omar Sigurdsson travelled to Milos in November 1986. The purpose of the visit was to witness on behalf of PPC the initiation of the reinjection into well M-1 and to assist PPC in evaluating its effect on the physical conditions of the reinjection well. The concultant stayed in Milos for the first week of the reinjection trial from November 21 to December 1, 1986.

The following report summarizes the response of well M-1 during the first week of injection. The first falloff test and its results are described, as witnessed.

Field memos, which describe the situation and contain recommendations made during the stay in Milos, were handed to PPC representatives in the field. The memos are included in an appendix.

Injection into well M-1

The output of well M-2 is separated at 25 bara. The steam will be used for power generation but the brine was piped to the ponds M-1 and M-2. One possibility for disposal of the waste brine is direct hot reinjection. In order to evaluate this possibility further, it was decided to do a reinjection test on well M-1. The transmission of the brine to the well had been tested earlier this year.

The preparation of well M-1 for the injection started on November 21, 1986 with the measuring of static pressure and temperature profiles. These measurements were repeated the following day to confirm the first measurements and to check the consistency of the instruments. These profiles are shown in figures 1 and 2 and the measurements listed in tables 1 to 4. The pressure readings have in all instances been corrected for temperature effects in accordance with the calibration chart provided for the pressure gauge used. This chart is shown below.

Gauge : KUSTER KPG - 29271

Calibrated : 23 October 1984

Pressure (psi)	Deflection (in) at 350°F	500°F
500	0.244	0.249
1000	0.485	0.494
1500	0.727	0.740
2000	0.969	0.986
2500	1.211	1.232
3000	1.453	1.478
3500	1.695	1.724
4000	1.938	1.971
4125	1.998	2.033
4128	2.000	
4057.985		2.000

The warming up of the M-1 wellhead started shortly before midnight on November 22. Reinjection into well M-1 was initiated on November 23, 1986, at about 16:21, when a portion of the brine flow from the high pressure transmission pipe to the M-1 pond was diverted to the well. The brine flow into well M-1 was gradually increased until all the brine was injected at 17:55 by closing the high pressure pipe downstream from the well. It took the reinjection system some time to reach operational stability, which was achieved by throttling a valve on the high pressure pipe between coupon sampling pipe 3 and the M-1 wellhead. With these measures the pressure in the transmission system, including the coupon sampling pipe, was kept high, generally between 27 and 31 barg.

The wellhead pressure of M-1, on the other hand, declined from about 24 barg to less than 17 barg. There are many reasons for this, the main ones being that a cooler, denser fluid was now occupying the M-1 wellbore and that the actual reservoir pressure is as much as 7 bar lower than had been anticipated in documents from MHI/GEOSPAC, as VIRKIR/NEA had pointed out earlier. During the next few days several downhole pressure and temperature measurements were made to monitor the effect of the injection on well M-1 and the reservoir. These measurements are presented in tables 5 to 16 and shown in figures 2 to 6. The general response of well M-1 as measured at 790 m depth, during the time up to the falloff test, is given in table 17 and shown in figure 7.

The large pressure difference that developed between the high pressure transmission pipe and the M-1 wellhead raised a concern that the coupons in sample pipe 3 were no longer representative of scaling rate at the M-1 wellhead conditions. The coupons may have been indicative of the scaling rate in the high pressure pipe line, which had been tested earlier this year. In order to bring the coupons to conditions similar to those prevailing at the M-1 wellhead, it was advised that the throttling of the high pressure pipe would be done upstream of the coupon sampling pipe 3.

Falloff test

The first falloff test during this reinjection trial for well M-1 was carried out on November 30, 1986. At 9:45 the brine flow was diverted to the M-1 pond by opening a bypass valve on the high pressure transmission pipe and at 9:46 well M-1 was shutin. Reinjection into well M-1 had then been continious from the start of this trial on November 23, with a rate varying between 6.3 and 7.2 kg/s, and with a duration of 9685 minutes. Before the falloff test was started a pressure profile was measured, and during the test a pressure and a temperature run were made. The falloff was monitored at 1150 m depth. The main feeding zone for well M-1 is assumed to be near that depth and the temperature log taken towards the end of the falloff test confirms this. Reinjection into well M-1 was started again at 21:35 that same day.

During the falloff test a very small pressure decline was observed during the first 5 minutes but thereafter the pressure was approximately constant to the end of the test. The pressure change is within the uncertainty of the instrument used to measure the downhole pressure. Transient pressure analysis on the falloff data cannot be done, but a rough indicative estimate can be obtained, however.

Following the procedure described in Field Memo 5, the following values were obtained for the permeability thickness product and the skin factor:

$$kh = 3.84 \times 10^{-12}\ m^3 = 3.84\ Dm$$
$$s = -3.8$$

These values indicate slightly better conditions of the well than those found during the falloff test in April 1985, after the short cold water injection test. These results show that, during the first

week of reinjection opening of fractures overrides the possible effect of particle plugging and scaling.

Operational problems

The operational problems of the reinjection system that occurred during the first days of reinjection have mostly been corrected. The problem that could have had the most damaging effect on the reinjection well occurred on the second day of reinjection. The cause of the problem was that both the RIP flushing water flow and the fluid level in the high pressure collecting tank were too high so a portion of the brine had to be diverted to the M-2 pond. This combination caused the temperature of the reinjection brine to drop about 35°C below its temperature under normal operating conditions. The problem lasted for 7 hours during which the scaling tendency may have increased considerably. The first falloff test, however, did not indicate that this had caused any serious damage to well M-1.

Other problems concern the operational stability of the reinjection system and the representativeness of the scaling coupons in sample pipe 3. To maintain operational stability of the system the high pressure transmission pipe is throttled between the M-1 wellhead and coupon sampling pipe 3. Therefore the conditions prevailing at the M-1 wellhead are different from those prevailing at the coupons in sampling pipe 3. The coupons therefore do not reflect the scaling rate at the M-1 wellhead but are indicative of the scaling rate in the high pressure pipe near well M-1. As I left Milos, PPC and MHI had agreed to correct this by throttling the high pressure transmission pipe at sampling pipe 2. Further, PPC planned to put a coupon into well M-1 on a wireline to monitor the scaling rate inside the well. This coupon could be checked at any time without causing any contractual dispute.

Recommendations

For future long-term operation the throttling of the high pressure transmission pipe should be done near well M-1, but a few meters upstream of sampling pipe 3. This is to minimize scaling in the surface transmission pipe. Also, coupons in sampling pipe 3 could be used to monitor the scaling rate at the M-1 wellhead.

Results from the first falloff test are favorable, so a continuation of the reinjection trial is recommended.

Acknowledgements

I wish to thank the staff of PPC especially Mr. Koutroupis and Mr. Koutinas for their good cooperation during my stay in Milos. I would further like to acknowledge the dedicated work of the PPC well logging team.

TABLE 1 MILOS WELL M-1. PRESSURE MEASUREMENT

Date 86.11.21 Gauge KP-29271 Measured by PPC
Wellhead pressure 24.00 bar Flow 0.00 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	23.98	
100.00	33.65	
200.00	42.09	
300.00	50.25	
400.00	59.03	
500.00	67.04	
600.00	75.07	
700.00	82.62	
800.00	89.78	
850.00	93.24	
900.00	97.32	
950.00	101.17	
1000.00	104.75	
1050.00	108.36	
1100.00	112.45	
1150.00	116.31	

TABLE 2 MILOS WELL M-1. TEMPERATURE MEASUREMENT

Date 86.11.21 Gauge KT-27124 Measured by PPC
Wellhead pressure 24.00 bar Flow 0.00 kg/s

DEPTH m	TEMPERATURE °C	REMARKS
0.00	22.98	
100.00	125.04	
200.00	178.75	
300.00	220.72	
400.00	244.40	
500.00	265.48	
600.00	289.18	
700.00	298.26	
800.00	307.83	
850.00	309.09	
900.00	309.57	
950.00	312.88	
1000.00	315.73	
1050.00	316.99	
1100.00	316.68	CLOCK RAN OUT

TABLE 3 MILOS WELL M-1. PRESSURE MEASUREMENT

Date 86.11.22 Gauge KP-29271 Measured by PPC
Wellhead pressure 24.00 bar Flow 0.00 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	24.09	
100.00	33.61	
200.00	41.66	
300.00	49.82	
400.00	58.36	
500.00	66.71	
600.00	74.55	
700.00	82.35	
800.00	89.85	
850.00	93.69	
900.00	97.21	
950.00	101.33	
1000.00	105.14	
1050.00	108.59	
1100.00	112.22	
1150.00	116.27	

TABLE 4 MILOS WELL M-1. TEMPERATURE MEASUREMENT

Date 86.11.22 Gauge KT-27124 Measured by PPC
Wellhead pressure 24.00 bar Flow 0.00 kg/s

DEPTH m	TEMPERATURE °C	REMARKS
0.00	18.65	
100.00	127.23	
200.00	181.20	
300.00	223.28	
400.00	247.76	
500.00	268.01	
600.00	292.82	
700.00	300.56	
800.00	310.04	
850.00	311.46	
900.00	312.09	
950.00	316.04	
1000.00	318.26	
1050.00	319.05	
1100.00	321.42	
1150.00	322.68	

TABLE 5 MILOS WELL M-1. PRESSURE MEASUREMENT

Date 86.11.22 Gauge KP-29271 Measured by PPC
Wellhead pressure 24.50 bar Flow 0.00 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	24.48	12H CLOCK STOPPED
204.00	42.88	AFTER 20 min AT
790.00	89.48	790m DEPTH
790.00	89.65	

TABLE 6 MILOS WELL M-1. PRESSURE MESUREMENT

Date 86.11.23 Gauge KP-29271 Measured by PPC
Wellhead pressure 25.70 bar Injection 7.00 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	25.70	INJECTION STARTED
200.00	41.40	AT 16:21, FULL
400.00	59.35	INJECTION AT
600.00	76.91	17:55
790.00	92.96	

TABLE 7 MILOS WELL M-1. PRESSURE MEASUREMENT

Date 86.11.23 Gauge KP-29271 Measured by PPC
Wellhead pressure 22.00 bar Injection 7.00 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	21.81	
200.00	38.97	
400.00	57.53	
600.00	75.50	
790.00	92.08	

TABLE 8 MILOS WELL M-1. PRESSURE MEASUREMENT

Date 86.11.24 Gauge KP-29271 Measured by PPC
Wellhead pressure 19.00 bar Injection 6.89 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	18.97	
100.00	27.50	
200.00	36.04	
300.00	45.27	
400.00	54.58	
500.00	63.36	
600.00	72.64	
700.00	81.67	
790.00	90.22	
900.00	100.13	
950.00	104.63	
1000.00	108.80	
1050.00	113.17	
1100.00	117.77	
1150.00	122.35	

TABLE 9 MILOS WELL M-1. TEMPERATURE MEASUREMENT

Date 86.11.24 Gauge KT-27124 Measured by PPC
Wellhead pressure 19.00 bar Injection 6.89 kg/s

DEPTH m	TEMPERATURE °C	REMARKS
0.00	165.76	CLOCK STOPPED AT
100.00	166.23	0 AND 100 m DEPTH
200.00	169.35	RIP FLUSHING WATER
300.00	171.84	FLOW TOO HIGH
400.00	174.15	
500.00	177.98	
600.00	181.51	
700.00	185.34	
800.00	188.71	
850.00	192.55	
900.00	193.77	
950.00	195.46	
1000.00	196.38	
1050.00	198.07	
1100.00	199.45	
1150.00	201.59	

TABLE 10 MILOS WELL M-1. PRESSURE MEASUREMENT

Date 86.11.25 Gauge KP-29271 Measured by PPC
Wellhead pressure 18.70 bar Injection 6.89 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	18.69	
200.00	35.34	
400.00	53.69	
600.00	71.82	
790.00	88.63	

TABLE 11 MILOS WELL M-1 TEMPERATURE MEASUREMENT

Date 86.11.27 Gauge KT-27124 Measured by PPC
Wellhead pressure 17.00 bar Injection 7.17 kg/s

DEPTH m	TEMPERATURE °C	REMARKS
0.00	138.15	
100.00	209.26	
200.00	209.72	
300.00	210.03	
400.00	210.79	
500.00	212.33	
600.00	214.01	
700.00	216.01	
790.00	218.00	
850.00	221.52	
900.00	222.80	
950.00	225.84	CLOCK STOPPED

TABLE 12 MILOS WELL M-1 PRESSURE MEASUREMENT

Date 86.11.27 Gauge KP-29271 Measured by PPC
Wellhead pressure 17.00 bar Injection 7.17 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	16.86	
200.00	33.50	
400.00	52.29	
600.00	70.19	
790.00	87.16	

TABLE 13 MILOS WELL M-1 PRESSURE MEASUREMENT

Date 86.11.29 Gauge KP-29271 Measured by PPC
Wellhead pressure 16.00 bar Injection 6.33 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	16.14	PEN GOES 0.10 mm
200.00	32.38	BELOW BASELINE
400.00	50.87	ON RETURN
600.00	68.79	
790.00	85.98	

TABLE 14 MILOS WELL M-1 PRESSURE MESUREMENT

Date 86.11.30 Gauge KP-29271 Measured by PPC
Wellhead pressure 16.00 bar Injection 6.28 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	16.08	BEFORE FIRST
200.00	32.27	FALLOFF TEST
400.00	50.60	FALLOFF STARTED
600.00	68.62	AT 9:46
790.00	85.75	
1000.00	104.90	
1150.00	117.59	

TABLE 15 MILOS WELL M-1 PRESSURE MEASUREMENT

Date 86.11.30 Gauge KP-29271 Measured by PPC
Wellhead pressure 17.30 bar Injection 0.00 kg/s

DEPTH m	PRESSURE bar	REMARKS
0.00	17.30	MEASURED DURING
200.00	35.94	THE FALLOFF TEST
400.00	52.34	
600.00	70.65	
790.00	86.89	
1000.00	104.19	
1150.00	116.84	

TABLE 16 MILOS WELL M-1 TEMPERATURE MEASUREMENT

Date 86.11.30 Gauge KT-27124 Measured by PPC
Wellhead pressure 17.30 bar Injection 0.00 kg/s

DEPTH m	TEMPERATURE °C	REMARKS
0.00	76.85	MEASURED IN THE
200.00	198.37	END OF THE
400.00	226.64	FALLOFF TEST
600.00	238.80	
790.00	258.69	
1000.00	285.71	
1150.00	257.11	

TABLE 17 MILOS WELL M-1. PRESSURE AND TEMPERATURE AT 790 m DEPTH

Date	Time	Pressure bar	Tempera-ture °C	Injection kg/s	REMARKS
861121	1155	89.06	307.80	0.00	
861122	1455	89.10	310.00	0.00	
861122	2300	89.48	310.00	0.00	BLEEDING STARTS
861122	2320	89.65	310.00	0.00	CLOCK STOP
861123	1900	94.83	218.00	7.00	INJECTION STARTED
861123	1910	94.77	218.00	7.00	AT 16:21
861123	1920	94.49	218.00	7.00	FULL INJECTION
861123	1930	94.32	218.00	7.00	OBTAINED AT 17:55
861123	1940	93.70	218.00	7.00	
861123	1950	93.48	218.00	7.00	
861123	2000	93.09	218.00	7.00	
861123	2010	92.81	218.00	7.00	
861123	2020	92.63	218.00	7.00	
861123	2030	92.30	218.00	7.00	
861123	2035	92.25	218.00	7.00	
861123	2222	92.08	218.00	7.00	SECOND RUN
861123	2232	92.36	218.00	7.00	
861123	2242	92.30	218.00	7.00	
861123	2252	92.25	218.00	7.00	
861123	2302	92.25	218.00	7.00	
861123	2312	92.08	218.00	7.00	
861123	2322	92.02	218.00	7.00	
861123	2332	91.96	218.00	7.00	
861123	2342	91.96	218.00	7.00	
861123	2352	91.91	218.00	7.00	
861123	2357	91.91	218.00	7.00	
861124	1150	90.22	188.70	6.89	RIP FLUSH TOO HIGH
861125	0949	88.63	218.00	6.89	PROBLEM CORRECTED
861127	1910	87.16	218.00	7.17	
861129	1050	85.98	218.00	6.33	
861130	0924	85.75	218.00	6.28	FALLOFF AT 9:46

Figure I

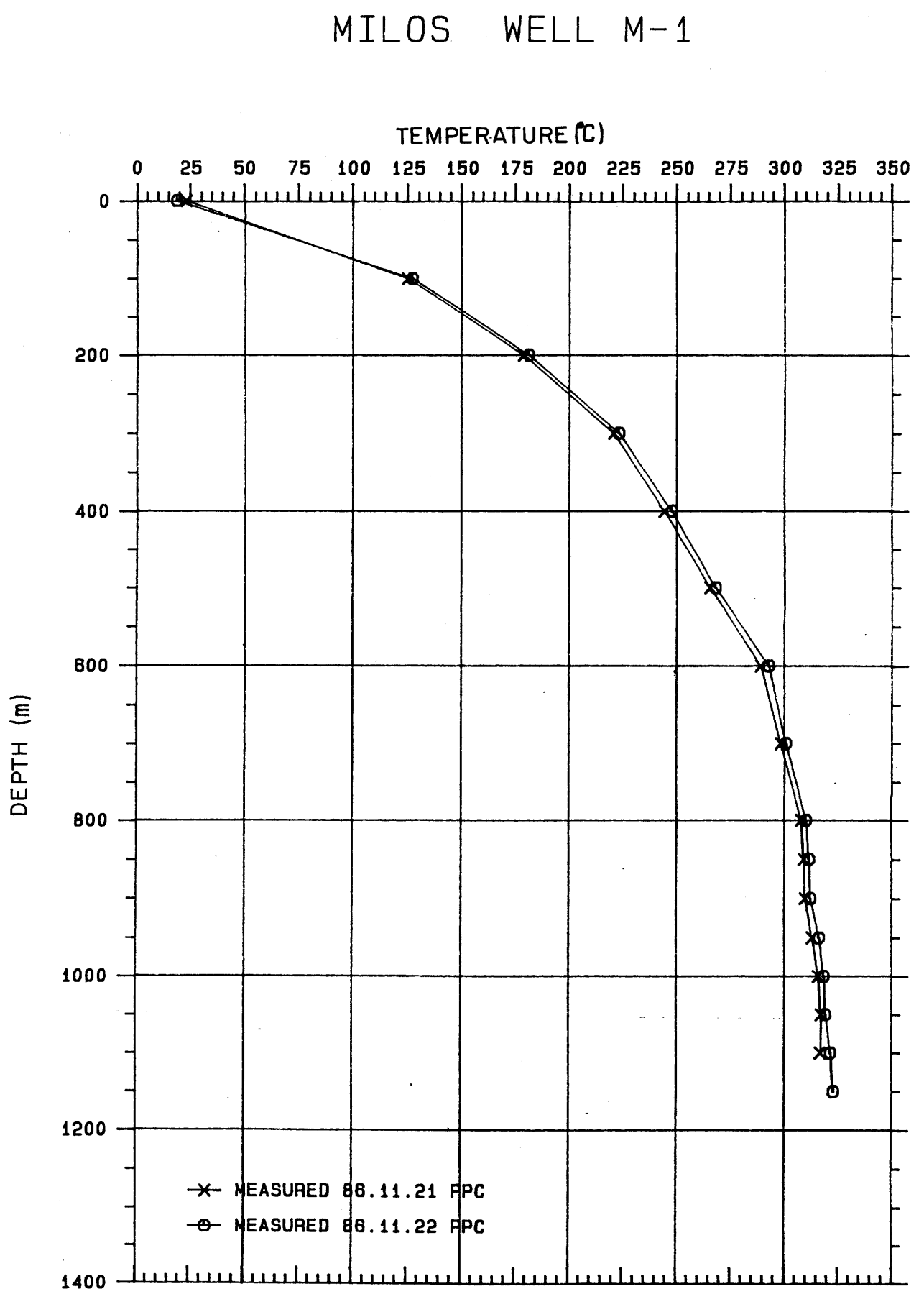

MILOS WELL M-1
TEMPERATURE (C)
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350
DEPTH (m)
0 200 400 600 800 1000 1200 1400
MEASURED 86.11.21 PPC
MEASURED 86.11.22 PPC

Figure 2

MILOS WELL M-1

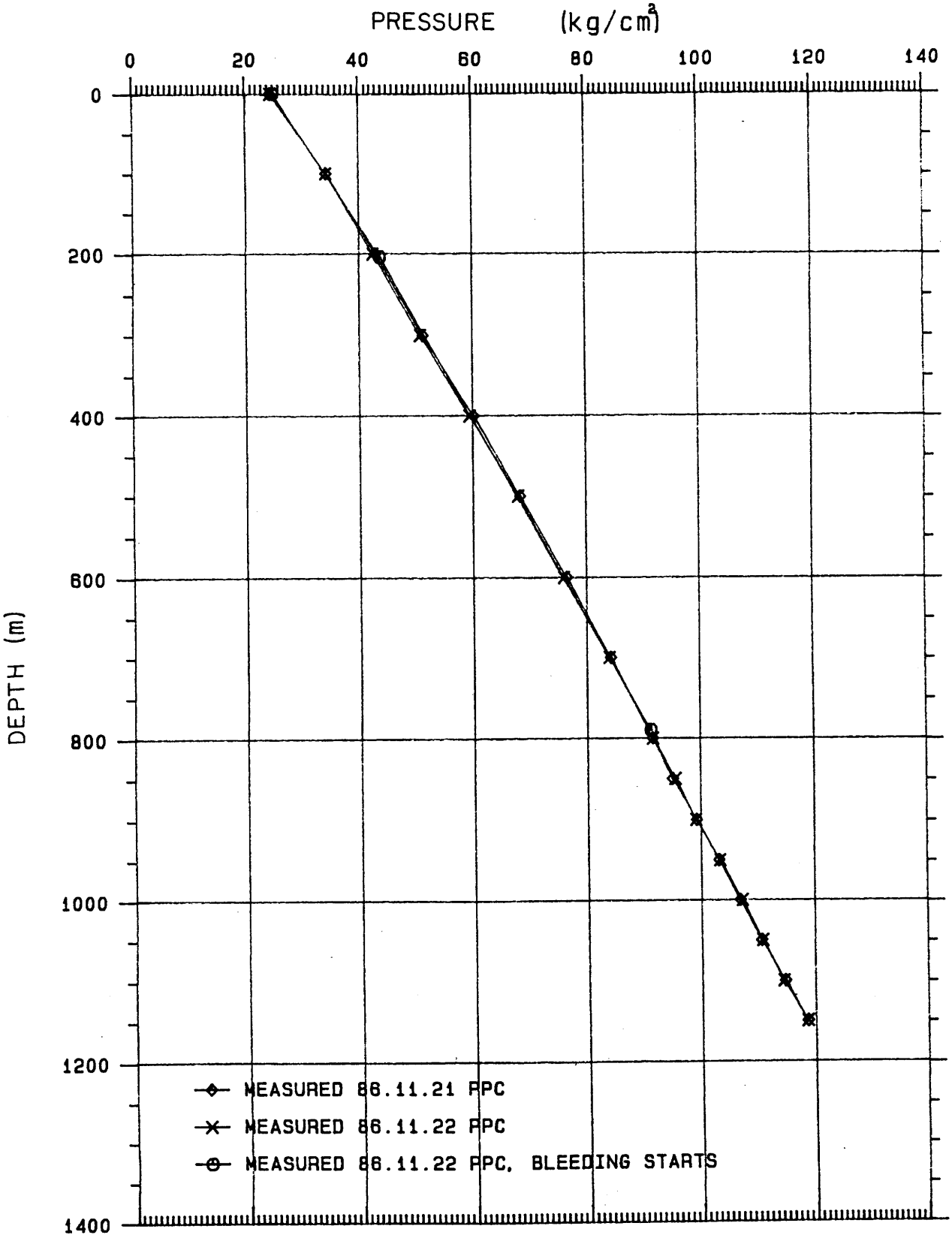


Figure 3

MILOS WELL M-1

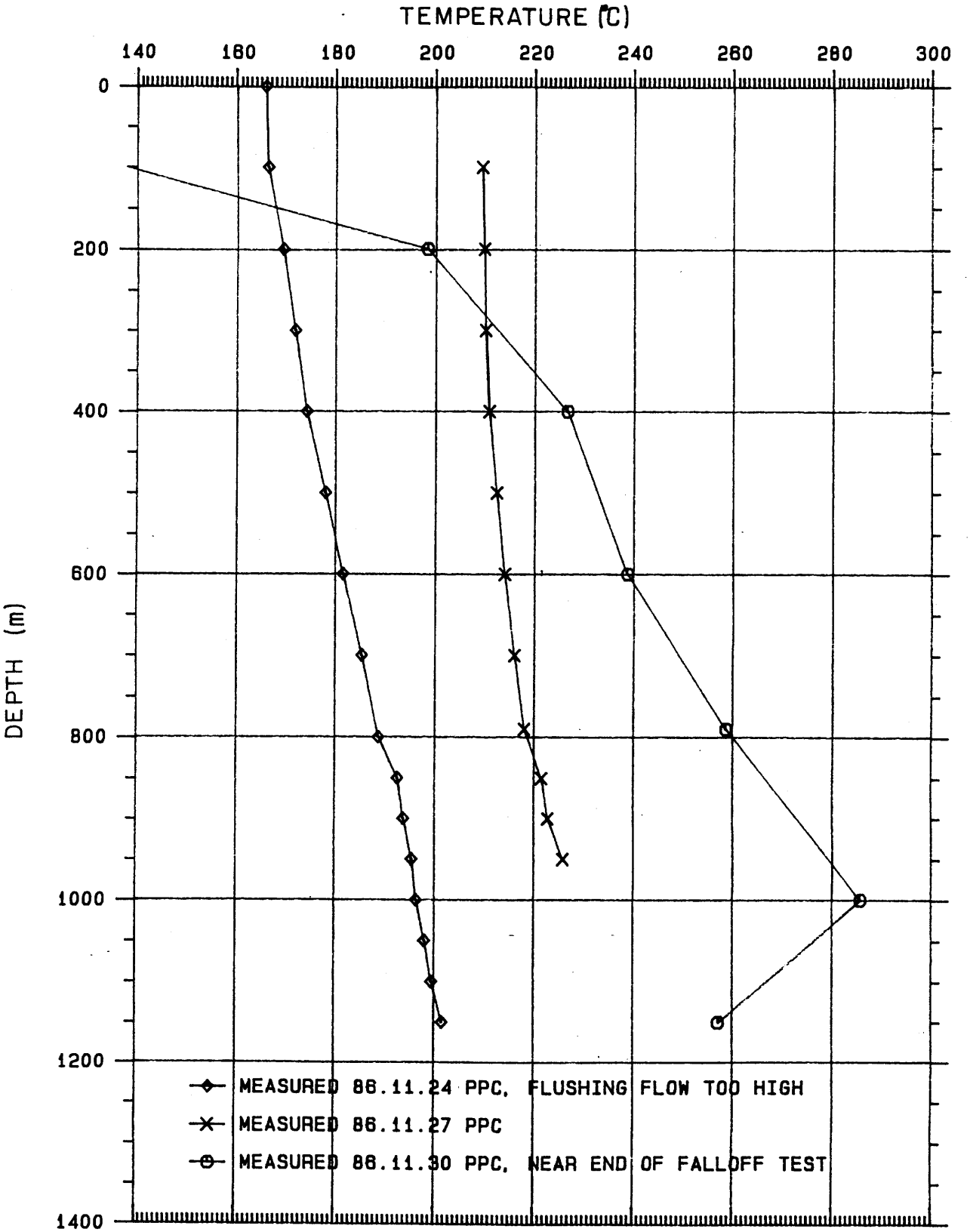


Figure 4

MILOS WELL M-1

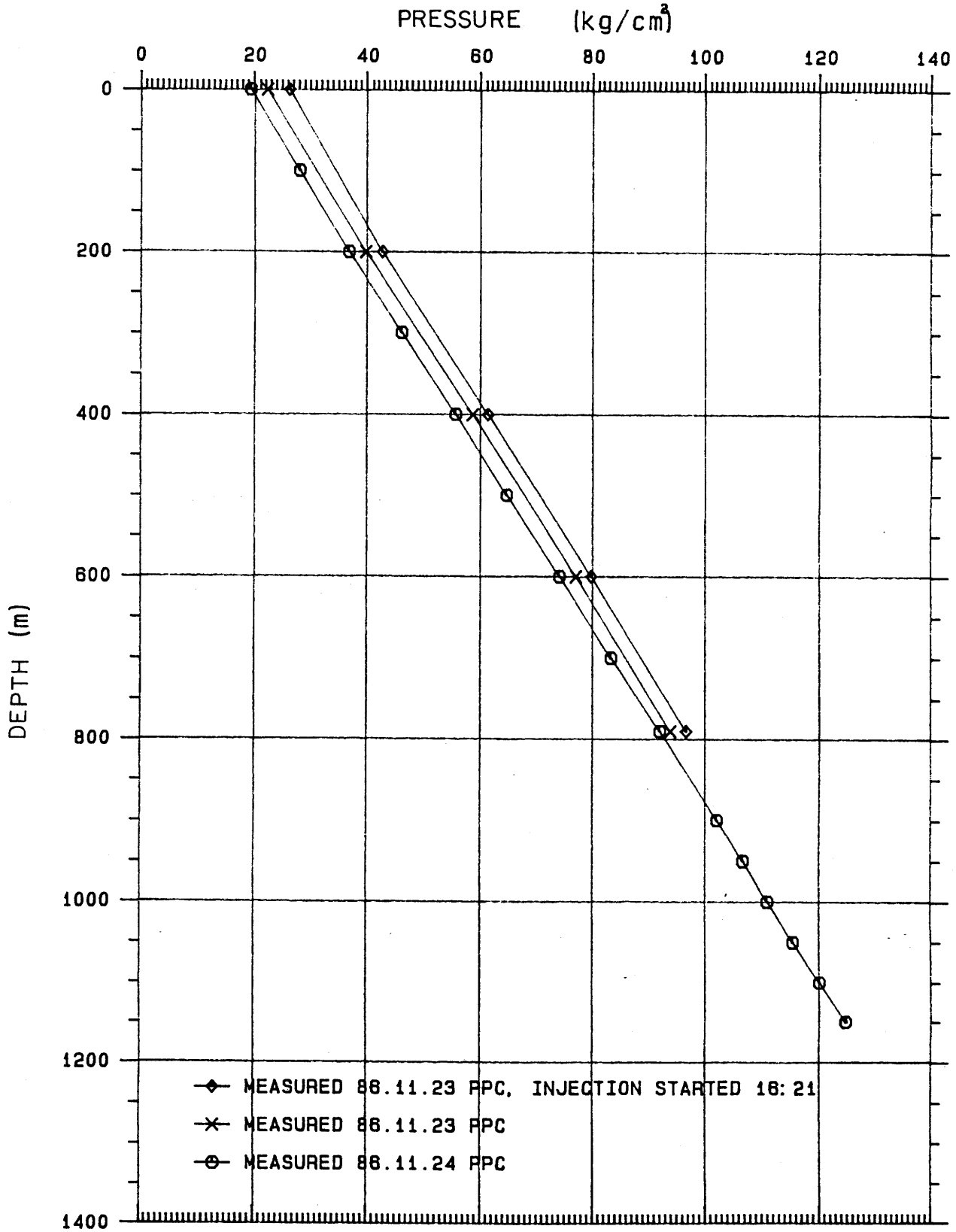


Figure 5

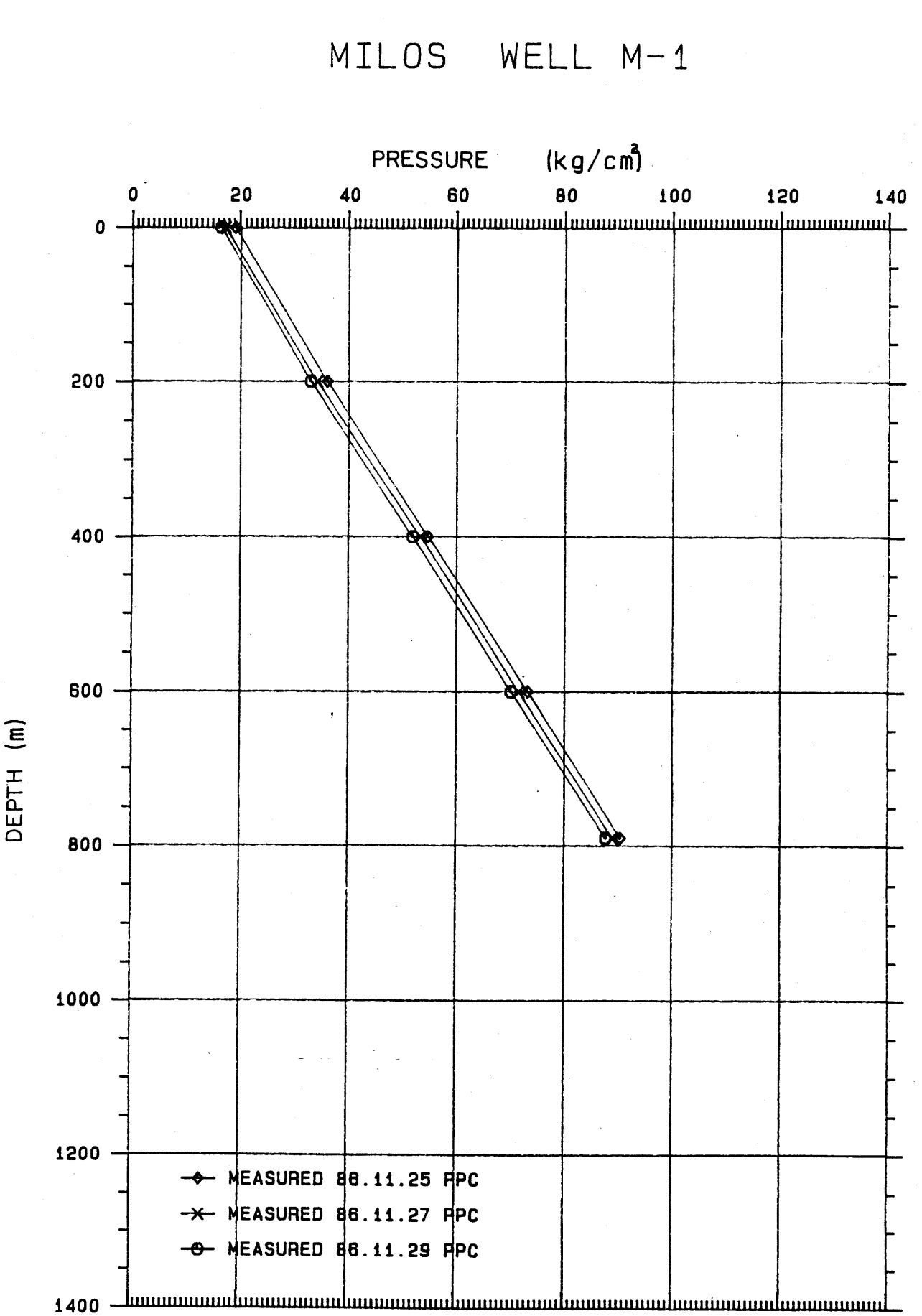

MILOS WELL M-1
PRESSURE (kg/cm²)
0
20
40
60
80
100
120
140
DEPTH (m)
0
200
400
600
800
1000
1200
1400
MEASURED 86.11.25 PPC
MEASURED 86.11.27 PPC
MEASURED 86.11.29 PPC

Figure 6

MILOS WELL M-1

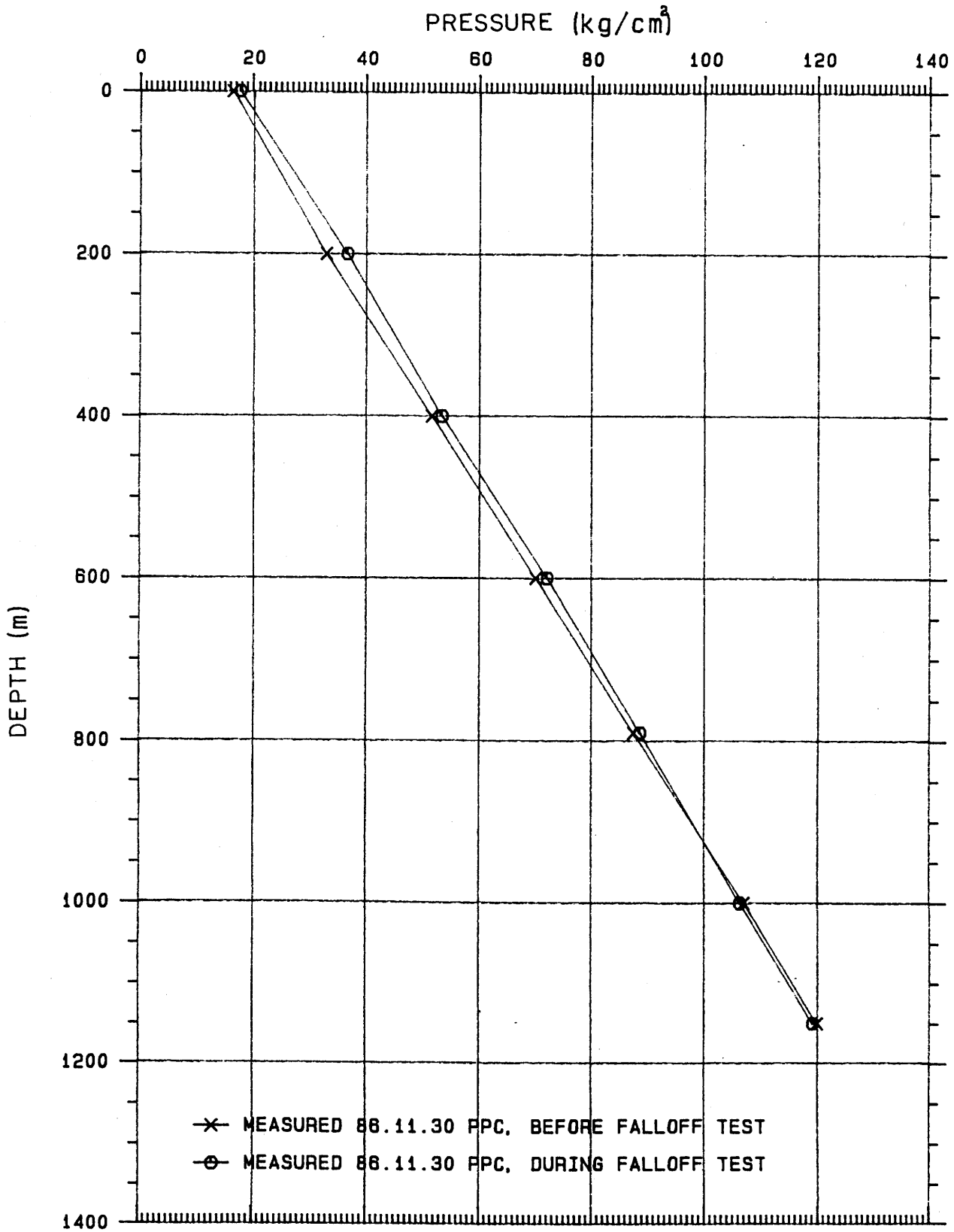
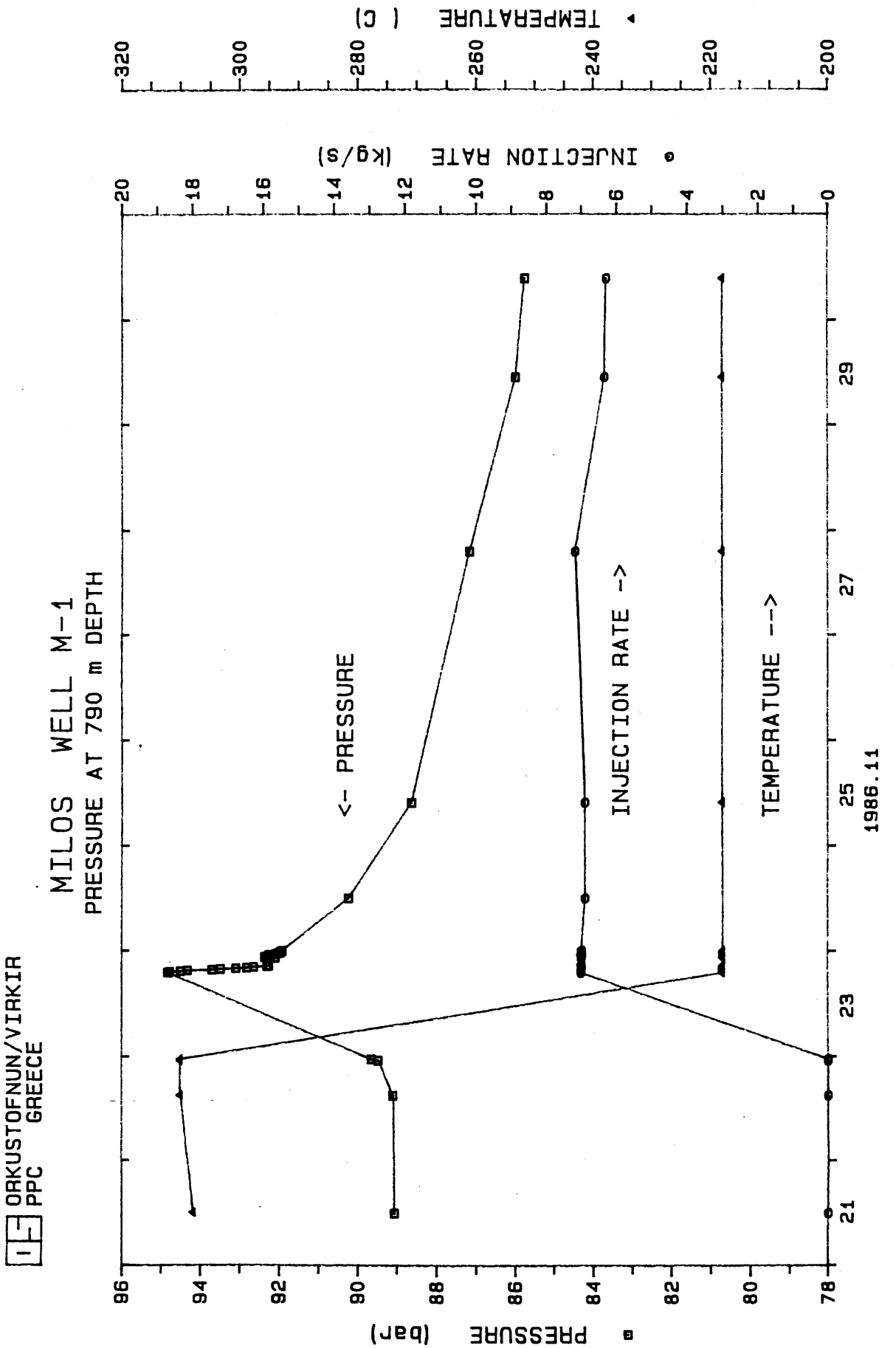


Figure 7


ORKUSTOFNUN/VIRKIR
PPC GREECE
MILOS WELL M-1
PRESSURE AT 790 m DEPTH
<- PRESSURE
INJECTION RATE ->
TEMPERATURE -->
PRESSURE (bar)
INJECTION RATE (kg/s)
TEMPERATURE (C)
1986.11

VIRKIR/NEA

Field memo 1 Milos 1986.11.22

To: Mrs. Rea Tassiou, PPC

From: Mr. O. Sigurdsson, VIRKIR/NEA

MONITORING PROCEDURS FOR WELL M-1 DURING REINJECTION

After an unformal meeting yesterday afternoon with Mr. P. Quinlivan (GENZL) and Mr. H. Sakanashi along with PPC personnel and further discussions with Mr. G. Koutinas this morning on the subject of monitoring well M-1 during reinjection the following procedures are recommended. These procedures assume that an unplanned interruption will not occur during the reinjection program.

During warmup of M-1 wellhead

It is recommended that before the bleeding from the high pressure reinjection line into well M-1 is started, that a pressure gauge with a 12 hour clock is lowered to 800 m and left there. Start the bleeding and warmup of M-1 wellhead. Recover the pressure gauge after 6 to 8 hours or sooner if the warming up takes a shorter time.

During the first 30 days of reinjection trial

Before the reinjection into well M-1 starts, lower a pressure gauge with 12 hour clock to 800 m. Start the reinjection. Recover the pressure gauge after 8 hours.

On the following days there after a pressure profile to total depth is measured with 3 hour clock (day 2, 10, 20 and 30).

Instead of measuring pressure profiles at all times the workload and the load on the equipment can be reduced by measuring pressure points at 800 m depth. Pressure point should be measured at 800 m depth with 3 hour clock on day 3, 5, 7, 15 and 25.

Temperature profiles to total depth are measured with 3 hour clock on day 2, 5, 10, 20 and 30.

Falloff test will be performed on the seventh day of reinjection. After the pressure gauge has been recovered after measuring the pressure point at 800 m it is refitted with a 6 hour clock and lowered to 1150 m depth.

The brine flow is diverted to the bypass pipe to the M-1 pond and well M-1 shut. The pressure gauge is recovered after 4 hours and rerun with the 6 hour clock to 1150 m. The pressure gauge is recovered again after about 5 hours and reinjection started again. The pressure cards should be read immediately and interpreted.

Falloff test at the end of the 30 day reinjection should be made in the same manner. After measuring the pressure and temperature profiles, a pressure gauge with 6 hour clock is set at 1150 m depth. The falloff test is started and the gauge recovered after 5 hours. The pressure gauge is rerun with 12 hour clock and recovered again after 10 hours. The cards should be read immediately and interpreted. Reinjection is started again.

During the next 3 months of reinjection.

During the next step in reinjection evaluation over the next 3 months it is recommended that similar measurements are made as for the first 30 days. The measurements include measuring pressure profiles in well M-1 to total depth with 3 hour clock on day 45, 90 and 120. Pressure points should be measured at 800 m depth with 3 hour clock on day 60, 75 and 105.

Temperature profiles are measured to total depth with 3 hour clock on days 45 and 120. At the end of the reinjection period a falloff test is performed. A pressure gauge with 12 hour clock is set at 1150 m depth. The brine flow is diverted from well M-1 to the M-1 pond. The pressure gauge is recovered after 10 hours.

During the recovery period after 4 months of reinjection

During the next days the following pressure and temperature measurements are recommended. Pressure profiles should be measured after the shutin of well M-1 on day 2, 3, 5, 8 and 14. Temperature profiles should similarly be measured on day 2, 5 and 14. The profiles are measured to total depth with 3 hour clocks.

On day 15 the well M-1 is backflushed and the brine analyzed.

Unplanned interruptions.

If a pressure measurement gives an indication that the respond of well M-1 to reinjection is deviating from the established trend

to the worse, another pressure profile should be measured the same day and not later than the day after. If it confirms the former findings the reinjection should be interrupted and a falloff test made.

Based on the outcome of the falloff test a decision will be taken on the continuation of the reinjection to well M-1. Reinjection into M-1 will not be initiated again unless PPC has granted it based on the results from the falloff test analyses. The results should demonstrate that conditions of well M-1 are not worsening.

VIRKIR/NEA

Field memo 2

Milos 1986.11.26

To: N. Koutroupis, PPC

From: O. Sigurdsson, VIRKIR/NEA

ON THE SUBJECT OF SCALING COUPONS

Brine produced by well M-2 and separated at 25 bara has been transmitted and injected into well M-1 since November 23, at 17:55 in the afternoon. In order to regulate the brine flow system (i.e. level in hot water collecting tank, level control valve etc.) the high pressure pipe line is throttled about 3 m downstream of coupon sampling pipe (sampling pipe 3) and about 4 m upstream of M-1 wellhead. These past days the pressure in the high pressure pipe line has been on the average 28 bara or higher while the wellhead pressure of well M-1 has decreased from 25 bara to 19 bara with corresponding reduction in wellhead temperature. Under these circumstances the coupons do not reflect the scaling rate tendency at the M-1 wellhead, but are rather indicative of the scaling rate in the high pressure pipe line. For the coupons to reflect the scaling rate conditions at the M-1 wellhead, the high pressure pipe line should be throttled a minimum of 5 m upstream of the coupon sampling pipe (sampling pipe 3). For the currently prevailing conditions at M-1 wellhead, the concentration of silica is supersaturated and questionable that other brine quality criteria decided by PPC are met. Scaling in the upper part of well M-1 and M-1 wellhead can therefore be expected to be significant.

Operational problems that occurred between 11 AM and 18 PM on November 24, 1986 and are described in a letter from MHI to PPC, caused the temperature of the reinjected brine to drop to dangerously low values (refer to temperature log taken in well M-1 at that time) which can have enhanced the scaling rate in the high pressure pipe line and especially in well M-1.

Approval of MHI request for cleaning and reinserting the scaling coupons can <u>not</u> be recommended, since this occurrence did not interrupt injection into well M-1. Furthermore, coupons are at present in considerably better environment preventing scaling than M-1 well. Consequently, the insertion period for the coupons will not be reduced from the planned 30 days.

VIRKIR/NEA

Field memo 3 Milos 1986.11.27

To: Mr. N. Koutroupis, PPC

From: Mr. O. Sigurdsson, VIRKIR/NEA

STATUS OF REINJECTION WELL M-1

Reinjection into well M-1 started on November 23, 1986 at about 16:21 when a portion of the brine flow from the high pressure transmission pipe was diverted to the well. The brine flow into well M-1 was gradually increased until all brine was injected at 17:55 by closing the HP-pipe downstream from the well. At the beginning of injection the wellhead pressure of M-1 was about 25 bara with small fluctuations. It took some time to obtain an operational stability of the system but was received by throttling a valve between coupon sampling pipe 3 and the wellhead of M-1. Since reinjection started the wellhead pressure of M-1 has declined from 25 bara to 18 bara. Down hole temperature and pressure are monitored regularly by measuring temperature and pressure profiles to total depth or alternating pressure to 790 m depth. Before the injection a static temperature profile indicated that temperature were higher than 200°C at 250 m depth and that the reservoir temperature near the bottom of the well (1150 m) were 323°C. A representative flowing temperature profile was obtained to day. It indicates temperature of about 209°C in the upper most part of the well and that temperature increases to 226°C at 950 m depth. The clock in the temperature tool stopped at this point but temperature of about 230°C can be postulated at bottom. Pressure readings have not yet been corrected for temperature effects. To do so efficiently it can be necessary to calibrate the pressure tool at temperatures above 300°C. Currently the calibration chart for the pressure tool is only up to 260°C. Uncorrected pressure readings indicate a static bottom hole pressure of about 121 bara and 92.6 bara at 790 m depth. During bleeding the pressure in the upper part of the well were increased due to heating and lightening of the fluid column in the well. When injection started it had to overcome this relatively high pressure in the upper part of the well. This caused the pressure to be increased from the static conditions. For continued injection the fluid column in the well is cooled and pressure at the main feeding zone approaches its equilibrium again. Since during this process the fluid column in the well is colder than before the

pressure drop at the wellhead is greater. Uncorrected readings from the pressure measurement made to day give the pressure 88.9 bara at 790 m, which can be extrapolated to the bottom to give 122 bara.

Presently the bottom hole pressure (1150 m) is within 2 bar from its initial value. It can therefore be postulated that it will reach its equilibrium during the next 1 to 3 days. Similarly it can be expected that the wellhead pressure could drop to 16 bara. Most likely will the decrease in wellhead pressure be less and a steam cap formed in the top of the well. Temperature should remain similar in the well as was measured to day.

As could have been expected and cautioned earlier in letters from VIRKIR/NEA to PPC (refer to letter from 1986.04.18), the reservoir formation can not sustain a backpressure to enable a reinjection at 25 bara wellhead pressure in the early state of reinjection. This reduce in wellhead pressure, which has been realized, is advantageous for the reinjection process, since it gives a higher tolerance for the method in the sense it increases the reinjection life time for the well. On the other hand can this pressure decrease and the temperature decrease, increase the scaling tendency at the M-1 wellhead. Based on theoretical approximations alone it is impossible to speculate how much the danger of scaling has increased at M-1 from the formerly tested conditions at 25 bara in the HP pipe line.

Based on the above our recommendations are:

1. Continue the injection for the present conditions until November 29, 1986, when an interruption in the reinjection is scheduled for a falloff test.
2. During the falloff test a throttle valve for the HP-transmission pipe should be placed a minumum of 5 m upstream from the coupon sampling pipe number 3.
3. Scaling coupons should be removed from the sampling pipe (3), weighted and scaling thickness measured. The coupons should then be cleaned, reweighted and inserted again into sampling pipe 3. When reinjection is started again the coupons will be indicative of scaling rate at M-1 wellhead conditions. The coupons could then be checked regularly to monitor the scaling rate at M-1 wellhead or at times when there is a concern that scaling may have increased excessively.
4. To monitor the scaling rate in the HP-transmission pipe scaling coupons should be inserted in sampling pipes 1 and 2.
5. PPC should consider to reduce the insertion period for the scaling coupons in sample pipe 3 from 30 days to 23 days.

VIRKIR/NEA

Field memo 4 Milos 1986.11.29

To : Mr. N. Koutroupis, PPC
Mr. M. Chlamboutakis, PPC

From: Mr. O. Sigurdsson VIRKIR/NEA

SUGGESTED PROCEDURES FOR FALLOFF TEST IN WELL M-1

The following procedures are suggested for the successful execution of the falloff test.

1. Before the falloff test is started, lower a pressure tool fitted with a 6 hour clock into well M-1. On the way down measure pressure at 0, 200, 400, 600, 790 and 1000 m for 4 minutes at each point.
2. Lower the pressure tool to bottom and record the time when the pressure gauge is at 1150 m. Allow the tool to stabilize for 5 minutes.
3. Divert brine flow from M-1 well to M-1 pond. Record carefully the time when the injection into well M-1 is stopped. The flow diversion should take as litle time as practically possible.
4. Before the clock has run for 5 1/2 hours the pressure tool should be recovered from the well. Record carefully the time when the tool is lifted from bottom.
5. Refit the pressure gauge with a 6 hour clock and repeat the pressure measurements going down the hole at 0, 200, 400, 600, 790 and 1000 m. Each step should not exceed 4 minutes.
6. Carefully record the time when the tool is at bottom (1150 m).
7. Before the clock has run for 5 1/2 hours the pressure gauge should be recovered from the well. Carefully record the time when the pressure gauge is lifted from the bottom.

This concludes the test. The cards from the pressure gauge should be read immediately to enable interpretation.

VIRKIR/NEA

Field memo 5 Milos 1986.12.01

To: Mr. N. Koutroupis, PPC

From: Mr. O. Sigurdsson, VIRKIR/NEA

PRELIMINARY RESULTS OF FALLOFF TEST IN WELL M-1

The first falloff test for checking the effects of reinjection on well M-1 was carried out yesterday. At 9:45 the brine flow was diverted to the M-1 pond by opening the bypass valve and at 9:46 well M-1 was shutin. Reinjection into M-1 had then lasted for 9685 minutes. Two pressure runs were made during the falloff and at the end one temperature run. Reinjection into M-1 well was started again at 21:35 last night.

Before the falloff was started, the pressure at 1150 m depth was estimated as 117.6 barg, but an initial reservoir pressure at that depth is estimated to be 116.3 barg. The falloff was monitored at 1150 m depth, but the main feeding zone for well M-1 is assumed to be near the bottom and the temperature log taken at the end of the falloff test confirms that. Temperature at the bottom was believed to be 230°C during injection and during the falloff test it recovered to 257.1°C in 650 minutes.

During the falloff test very small pressure decline was observed which was within the accuracy of the instruments used for the test. This makes it difficult to do a regular transient analyzis on the data. However, a rough indicative estimate can be done. The final pressure reading recorded during the falloff test was after 498 minutes from the beginning of the test. It gives an estimated pressure of 116.8 barg or about 0.5 bar higher than the estimated initial reservoir pressure. Assuming that the pressure will fall to the initial reservoir pressure given enough time, one can make the following interpretation:

$$\text{Take} \quad \frac{tp + \Delta t}{\Delta t} = \frac{9685 + 498}{498} = 20.45$$

Plot 116.8 barg for this time ratio on a Horner graph (P vs. $(tp + \Delta t)/\Delta t$). Draw a straight line between that point and

the initial pressure (116.3 barg) plotted at $(tp + \Delta t)/\Delta t = 1$. The slope obtained for the line is m = -0.381 bar/cycle.

Now

$$m = \frac{2.303\ Q\nu}{4\pi\ kh}$$

$$s = 1.151 \left[\frac{Pi - P1Hr}{m} - \log \left(\frac{k}{\mu \phi\ c_t\ r_w^2} \right) - 3.91 \right]$$

Thermodynamic values of water at 322°C which is the reservoir temperature should be used in the above equations. This gives:

ν = kinematic viscosity = 0.125×10^{-6} m^2/s

μ = dynamic viscosity = 83.5×10^{-6} Pa s

For comparison with earlier falloff tests the same values for other parameters should be used i.e.

c_t = compressibility = 3×10^{-9} Pa^{-1}

ϕ = porosity = 0.1

r_w = well radius = 0.1 m

h = reservoir thickness = 350 m

Using these values the following is obtained for an injection rate Q = 6.39 kg/s (23 ton/hr) prior to shutin

kh = 3.84×10^{-12} m^3 = 3.84 Dm

s = -3.8

These results are slightly better than those obtained earlier for the well and indicate that the reinjection has not caused damage to the well regarding the connection or easy of flow between the well and its reservoir formation.

For continued reinjection down hole conditions of well M-1 should be monitored in similar manner as upto now. During prolonged injection the temperature profile in the well will be fairly stable. Down hole pressure measurements will therefore reflect the conditions of the well even if they are not corrected for temperature effects. In that sense it is anticipated that uncorrected pressure at 790 m depth will not fall lower than 85.2 barg which corresponds to the bottom hole pressure at its initial value of 116.3 barg.

To visually observe the changing pressure in the well, three graphs should be made where

1 pressure plotted versus actual time
2 pressure plotted versus log time
3 pressure divided by flow rate plotted versus log time

If graph 2 is plotting smoothly but graph 3 deviating from its trend then the brine flow meter should be checked. Graph 1 gives an indication what time should be selected to start plotting graphs 2 and 3.

In general the operational performance of the reinjection system this past week has been adequate and the respond of well M-1 to the reinjection favorable. Monitoring of the scaling rate at or near the wellhead of M-1, however, has been of considerable concern but not possible so far. For enabling regular check for the scaling rate it is suggested that coupon hung in a wireline will be placed in the well near the top. It is also cautioned that the wireline will become brittle during prolonged exposure to the geothermal brine. It is therefore necessary to change this wireline portion regularly.