PUBLIC POWER CORPORATION
ATHENS, GREECE

NISYROS GEOTHERMAL DEVELOPMENT

NISYROS NIS-1

Injection Tests - July 1985

Consultants' Report

OS-85084

ORKUSTOFNUN
NATIONAL ENERGY AUTHORITY

VIRKIR CONSULTING GROUP LTD.

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Report No.: OS-85084 / JHD-41 B

October 1985

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1 Introduction

In accordance with a contract between the Public Power Corporation (PPC) on one hand and Virkir Consulting Group Ltd. and the National Energy Authority (Virkir/NEA) on the other, regarding the Nisyros geothermal development, well NIS-1 was injection tested between July 25 and 27, 1985. The purpose of the test was to estimate the reservoir transmissivity and the well skin factor. This information is necessary to determine whether the well is a possible producer after the damage that occurred during earlier output tests and workovers. The well might also be used as a reinjection well and information about its injectivity is therefore needed.

Mr. O. Sigurdsson went to Nisyros to supervise PPC personnel in carrying out the injection test of well NIS-1. An interim field report was submitted to PPC at the end of the test and a letter summarizing the test results was submitted in August. Both are included here in appendices.

The following report describes the injection tests more fully and discusses the conclusions drawn from their results.

2 Earlier tests

The following information on the completion and earlier tests of well NIS-1 in Nisyros was obtained from various reports made available to Virkir/NEA by PPC.

The well was completed on September 14, 1982 to a total depth of 1816 m. A 9 5/8" J-55, 40 lbm/ft BTC casing had been cemented to 1342 m depth and a 7" J-55, 23 lbm/ft slotted liner hanged from 1265 m to 1811 m in the 8 1/2" hole. It is assumed that the productive reservoir starts at 1420 m and extends to the bottom of the well.

Four successive flow tests were reported, each resulting in various mechanical problems and causing substantial damage to the well. The first flow test was performed between September 15 and 23, 1982. The well was brought into production for few hours after a tedious stimulation process. The test led to severe problems at the wellhead and surface facilities with valve plugging, line rupture, and about 100 tons of solids deposited at the separator outlet. Substantial damage was done to the well as six obstacles, attributed to casing collapses, were encountered during workover. The total depth of the well was reduced to 1754 m.

After reconditioning the well by placing a 7" C-75, 29 lbm/ft BTC casing to a depth of 1258,6 m and tying it to the 7" liner by a cement plug, further indication of well damage was found, commencing at 1560 m, as a Kuster temperature bomb would not pass below this depth.

A second flow test was carried out between October 22 and 25, 1982. After producing for less than 7 hours, the well died suddenly. Upon inspection a plug consisting of cuttings was found at 540 m depth and another constriction, a more than 100 m thick salt stack, at 1100 m. After workover the total depth of the well had been reduced to 1642.5 m.

The third flow test was conducted on November 22 and 23, 1982. The well flowed for 36 hours before dying as a consequence of cutting and salt plugs forming below 1146 m depth. A deformation of the 7" casing, encountered at 1235 m depth, was milled and the depth had again reduced, now to 1571 m.

The fourth flow test took place from November 28 to December 3, 1982. Production was initiated after about 22 hours of air lift. The well produced 12-14 tons/hr (3.3 - 3.9 kg/s) total for 96 hours before it was killed. There were indications that the depth of the well had been reduced further after this test.

A report of an injection test is also available, but its date is uncertain. The tested interval was from 1350 m to 1760 m so it must have been done before the second flow test on October 25, 1982, but most likely before the completion of the well, since to our knowledge, the well has not been cleaned or repaired after the fourth flow test in December 1982. The test consisted of two 20 minute injection steps, 1500 l/min (25 l/s) and 2000 l/min (33.3 l/s), respectively, followed by a falloff. Only wellhead pressure was recorded during this test and the falloff period recorded was only 7 minutes long.

3 Recommended testing procedure for well NIS-1

A tubing used for air lift during previous flow tests had been left in the well, but other surface equipment such as silencers or separators had been removed from the well site. To flow the well would therefore require shipping and installation of a silencer, pipes, air compressor and other necessary equipment. The well might also require some workover. All these things are expensive. Earlier experience of flow tests was not encouraging, resulting in severe problems and substantial well damage.

In view of this Virkir/NEA recommended that PPC limit the testing of well NIS-1 to a simple injection test (Telex to PPC 1985.05.07). The cost of an injection test would be considerably less than the cost of a flow test, since it would only require a pump and a small diameter supply line to the well. An injection test would reveal the physical conditions of the well and permit an estimate of the reservoir transmissivity and well injectivity. A decision on the feasibility of costly workover and flow test could be made based on the outcome of this test. Further, the injectivity of NIS-1 at the end of drilling was estimated to be about 1.1 l/s/bar. However, due to the 60% reduction of the production zone thickness during the flow tests, it was expected that an injection rate of 5 to 6 l/s (18-22 tons/hr) would fill the well given its present condition. Therefore only a small pump, with a capacity of only 5-10 l/s and a discharge head of 2 bars, would be needed for the injection test.

4 Testing of well NIS-1

Two injection tests were conducted in well NIS-1 in Nisyros. Prior to the tests PPC personnel had connected an electrical pump to a water supply line from a nearby pond to the well (Fig. 1). The first injection test started just after 12 o`clock on July 25, 1985. An electronic pressure probe located at 200 m depth in the well was used to record the pressure change continuously during the test. The zero reference depth was the upper flange of the 2" valve at the top of the wellhead. Flow rate was measured with a 35 mm orifice plate in the 99 mm ID supply line and a Barton differential pressure gauge. Before injection started, the stable water level was at 156.37 m depth. The progress of the test is summarized in table 1 and in figures 2 and 3. The average injection rate during the test was 2.62 kg/s (9.43 tons/hr) and the well filled up in 39 minutes. The injection was then discontinued and the pressure falloff monitored. During this test 6130 kg of ponded water were injected into the well.

This first test was more or less a trial to test the equipment that had been brought in to see whether it functioned correctly. Moreover, it also revealed thermal effects during the test and made it clear that the well had to be cooled all the way down to the producing zone to obtain reliable pressure transient data. The volume of the well could be expected to be 31 to 36 cubic meters. For injection water with an average temperature of 34 C, this required an injection of 30800 kg to 35800 kg to change out the water in the well before reliable pressure data could be anticipated.

The second injection test was carried out on July 26 and 27, 1985. The pressure probe was first placed at 175 m depth, but later during the injection lowered to 225 m, which was the depth capacity of the logging cable on the hand drum used for the tests. All readings during the test have been corrected to the 225 m depth reference. The test is summarized in table 2 and in figure 4. At the beginning of this test problems were encountered with the injection pump. There were difficulties in starting the pump and maintaining injection. These problems were found to be caused by a broken directional valve in the suction head for the pump. During this period two water slugs were injected, the first amounting to 617 kg and the second to 2371 kg, corresponding to an average injection rate of 2.57 kg/s (9.25 tons/hr) and 2.63 kg/s (9.47 tons/hr) respectively.

After the valve had been repaired, the injection test was conducted in three steps with an average injection rate of 2.68, 4.07, and 4.97 kg/s (9.65, 14.65, 17.89 tons/hr), respectively. This was followed by a short falloff as the water level fell in 64 minutes below the pressure gauge (225 m). The mass injection during the three injection steps was 29917 kg, 57591 kg, and 45663 kg with the total amounting to 136159 kg. The well never filled up during this test.

5 Theory for analysis

Injection of cold water is frequently used as a testing procedure for geothermal wells. Therefore such injection tests involve non-isothermal conditions, which must be recognized when analyzing these tests. In recent years several investigators have reported on the analysis of such tests. It has been shown that conventional methods of analysis, which assume isothermal conditions, can be used if appropriate fluid properties are used for each time interval analyzed. The choice of the fluid properties depends on the movement of the thermal front. Further, for fracture dominated reservoirs it seems that the existence of a cold zone around the feeds in the well has very little effect on the relationship between transmissivity and injectivity, but that factors such as the skin effect probably dominate the effect of the cold invasion.

Solutions of the following pressure diffusion equation, with various initial and boundary conditions, are used for analyzing transient pressure well testing data.

$$\frac{1}{r}\frac{\delta}{\delta r}\left(r \frac{k}{\mu} \frac{\delta P}{\delta r} \right) = \phi c_t \frac{\delta P}{\delta t}$$

Analytical solutions exist for isothermal fluid flow, but numerical solutions are used to include nonisothermal effects. The solutions describe how the pressure behavior with time depends on the formation transmissivity and storage. Modifications to the solutions are made to include wellbore storage and near-well permeability changes, referred to as a skin effect and quantified in terms of a skin factor.

Transmissivity (kh/μ) is the product of the fluid mobility and the reservoir thickness (h), where the fluid mobility is the reservoir permeability (k) divided by the fluid dynamic viscosity (μ). The transmissivity is a measure of how easily a fluid flows through a porous medium. The transmissivity is commonly reported for geothermal well tests rather than the permeability, since by the nature of geothermal systems it is often not possible to define the reservoir thickness accurately.

Alteration in near well permeability may be caused by drilling and completion techniques or by solid deposition from well fluids at or near the well face. These near-well permeability changes are referred to as a skin effect and measured in terms of a skin factor (s). Positive values of the skin factor indicate a region of reduced permeability near the well, whereas negative values indicate a region of enhanced permeability. It is therefore obvious that the skin effect affects the well performance, since the injected or discharged fluid must pass through the formation immediately surrounding the well.

Injectivity (II) is used to define the injection capacity of a well. It is the relationship between the injection rate and the corresponding pressure rise due to the injection. Injectivity is a function of the transmissivity and other factors and is usually determined from injection tests that are conducted with a series of constant step rate injections. To determine the injectivity satisfactorily the injection steps have to reach steady state conditions, which is seldom the case in practical geothermal well testing. Therefore, the short term injectivity is slightly time-dependent, and for geothermal wells thermal effects will also affect it by causing changes in the formation permeability. The thermal effects during injection are in many cases advantageous, since they will to some extent cause widening of fissures, due to thermal contraction of the reservoir rock and thus increase the near-well permeability of the formation.

6 Analyses of injection tests in well NIS-1

The first injection test, which was performed on July 25, 1985, was not analyzed. The injection step was short because the well filled up and is mostly dominated by wellbore storage effects. The falloff step is dominated by wellbore storage during the first 50 minutes and at later times by thermal recovery in the well. It was not attempted to analyze the small transition period available in this step because injection steps are generally considered more reliable for interpretation than falloff steps. The reason is that the thermal effects within the well are much less pronounced during injection than during falloff.

The second injection test was conducted on July 26 and 27, 1985. As mentioned before problems were encountered with the injection pump at the beginning of the test. Therefore, the first two spikes seen in figure 4 are not included in the analysis. The actual injection test was conducted in three steps followed by a falloff. The average injection rates were 2.68, 4.07, and 4.97 kg/s, respectively. The first injection step, which lasted for 186 minutes, was heavily influenced by thermal effects, and at the end of it the pressure dropped rapidly as the hot water column in the well was replaced by injected pond water. At the end of the first step 32905 kg had been injected if the two earlier spikes are included. For 34 C water this corresponds to a volume of about 33.1 cubic meters. This step is not considered in the analysis of the test.

The second and the third injection steps, which lasted 236 and 153 minutes, respectively, are shown as points in figures 5 and 6. The first 20 to 30 minutes in each step are dominated by the wellbore storage effect, but the steps were not long enough to develop fully a semilog straight line behavior to allow for a graphical solution. Therefore the analysis of these steps was aided by a computer. The measured data is fitted by the computer to an analytical solution which assumes an infinite acting horizontal reservoir and includes skin and wellbore storage. The best fit with the measured data is shown as solid lines in figures 5 and 6 and summarized in table 3. The parameters of the best fitting solution are as follows:

Transmissivity	kh/μ = 1.859 E-09	m**3/Pa s
Formation storage	$\phi c_t h$ = 4.763 E-08	m/Pa
Skin factor	s =+1.714	
Wellbore storage	C_D = 2.823 E+03	

Sensitivity analyses indicate that only the formation storage can be varied some without affecting the goodness of the fit too much.

When the structure and geometry of a reservoir are not known or indicated by the behavior of a well test, the test is generally interpreted with a solution for the fluid flow that assumes an infinite acting system. A simplified version of this solution is sometimes called Theis solution. However, to check further the results obtained an analytical double porosity model was tried. It gave almost as good of a fit as was obtained earlier and resulted in nearly identical values for the reservoir parameters as obtained before.

The short term injectivity index can be determined from the last two injection steps as:

$$II = 0.13 \ (kg/s)/bar$$

This value for the injectivity is in a good agreement with the transmissivity obtained earlier.

The falloff step was not analyzed since it is dominated by the wellbore storage effect and possibly other disturbances.

7 Summary of results

The analysis of the injection tests in well NIS-1 gave the following results:

Transmissivity	kh/μ =	1.9 E-09	m**3/Pa s
Formation storage	$\phi c_t h$ =	4.8 E-08	m/Pa
Skin factor	s =	+1.7	
Wellbore storage	C_D =	2.8 E+03	

and

Injectivity index	II =	0.13	(kg/s)/bar

The low values for transmissivity and injectivity indicate a low formation permeability in the vicinity of well NIS-1. Further, the positive value for the skin factor indicates a zone of reduced permeability near the well.

The skin factor is lower than one would expect, considering the damage that has occurred in this well during earlier flow tests. One must, however, bear in mind that only the small open interval of the well is tested during these injection tests. Furthermore, a skin factor of about +2 is high for a geothermal well. Productive geothermal wells usually display a negative skin factor in the range -1 to -3. This is due to the geological nature of many geothermal systems where the fluid flow is mainly along small fissures in the rock matrix.

8 Conclusions

The conclusions that can be drawn from the results of the injection tests are that the transmissivity in the vicinity of well NIS-1 is low, five to ten times lower than is common for commercially productive wells. Furthermore, the well exhibits a positive skin factor indicating a reduced performance of the well.

The short term injection capacity of the well is about 5 kg/s without the use of a high pressure injection pump. An injection of 7 kg/s could require a wellhead pressure of 15 bar. How the injection capacity will develop under a long term injection is not known. It is possible that the injection capacity will increase due to cooling of the reservoir formation as discussed before. On the other hand, in view of the low transmissivity, precipitation of chemicals from the injected fluid at the well face or in the formation will rapidly reduce the injection capacity.

9 Recommendation

Due to the low transmissivity in the vicinity of well NIS-1, the positive skin value, and in view of earlier output tests, it is not considered feasible to undertake costly workover to put the well into production. It is therefore recommended that the well will be left as it is.

During future development on the Nisyros geothermal reservoir, well NIS-1 can be used as an early reinjector as it will accept about 5 kg/s of reinjection water. Because of the very low transmissivity all injected water must be of good quality, containing very little suspended matter, and be of low silica supersaturation.

TABLES

TABLE 1

NISYROS WELL-1

INJECTION TEST

Date	Time	Time change min	Pressure bar	Rate kg/s	Depth to gauge m	Remarks
850725	1050	0.0	0.00	0.00	200.00	INSTRUMENT IN WELL
850725	1100	10.0	4.22	0.00	200.00	
850725	1147	57.0	4.25	0.00	200.00	INSTRUMENT STABLE
850725	1150	60.0	4.25	0.00	200.00	
850725	1200	70.0	4.25	0.00	200.00	
850725	1205	75.0	4.25	0.00	200.00	INJECTION STARTS
850725	1206	1.0	4.74	2.57	200.00	
850725	1207	2.0	5.85	2.57	200.00	
850725	1208	3.0	6.80	2.57	200.00	
850725	1209	4.0	7.06	2.57	200.00	
850725	1210	5.0	7.17	2.57	200.00	
850725	1211	6.0	7.66	2.57	200.00	
850725	1212	7.0	8.24	2.63	200.00	
850725	1213	8.0	8.86	2.63	200.00	
850725	1214	9.0	9.47	2.63	200.00	
850725	1215	10.0	10.07	2.63	200.00	
850725	1217	12.0	11.19	2.63	200.00	
850725	1219	14.0	12.27	2.63	200.00	
850725	1221	16.0	13.30	2.63	200.00	
850725	1223	18.0	14.28	2.60	200.00	
850725	1225	20.0	15.23	2.60	200.00	
850725	1227	22.0	16.10	2.60	200.00	
850725	1229	24.0	16.95	2.60	200.00	
850725	1231	26.0	17.74	2.60	200.00	
850725	1233	28.0	18.50	2.65	200.00	
850725	1235	30.0	19.22	2.65	200.00	
850725	1237	32.0	19.93	2.65	200.00	
850725	1239	34.0	20.62	2.65	200.00	
850725	1241	36.0	20.98	2.65	200.00	
850725	1243	38.0	21.16	2.65	200.00	
850725	1244	39.0	21.34	2.65	200.00	WELL FLOWS
850725	1245	1.0	21.10	0.00	200.00	FALLOFF
850725	1246	2.0	21.04	0.00	200.00	
850725	1247	3.0	20.92	0.00	200.00	
850725	1248	4.0	20.64	0.00	200.00	
850725	1249	5.0	20.12	0.00	200.00	
850725	1250	6.0	19.86	0.00	200.00	
850725	1251	7.0	19.51	0.00	200.00	
850725	1252	8.0	19.15	0.00	200.00	
850725	1253	9.0	18.80	0.00	200.00	
850725	1254	10.0	18.45	0.00	200.00	
850725	1256	12.0	17.79	0.00	200.00	
850725	1258	14.0	17.13	0.00	200.00	
850725	1300	16.0	16.47	0.00	200.00	
850725	1302	18.0	15.87	0.00	200.00	
850725	1304	20.0	15.26	0.00	200.00	
850725	1309	25.0	13.83	0.00	200.00	
850725	1314	30.0	12.48	0.00	200.00	
850725	1319	35.0	11.25	0.00	200.00	
850725	1324	40.0	10.11	0.00	200.00	

cont. TABLE 1

NISYROS WELL-1

INJECTION TEST

Date	Time	Time change min	Pressure bar	Rate kg/s	Depth to gauge m	Remarks
850725	1329	45.0	9.08	0.00	200.00	
850725	1334	50.0	8.12	0.00	200.00	
850725	1338	54.0	7.43	0.00	200.00	
850725	1339	55.0	7.27	0.00	200.00	
850725	1344	60.0	6.47	0.00	200.00	
850725	1349	65.0	5.77	0.00	200.00	
850725	1354	70.0	5.12	0.00	200.00	
850725	1359	75.0	4.54	0.00	200.00	
850725	1404	80.0	4.03	0.00	200.00	
850725	1409	85.0	3.62	0.00	200.00	
850725	1414	90.0	3.23	0.00	200.00	
850725	1419	95.0	2.88	0.00	200.00	
850725	1424	100.0	2.59	0.00	200.00	
850725	1434	110.0	2.15	0.00	200.00	
850725	1444	120.0	1.92	0.00	200.00	
850725	1454	130.0	1.81	0.00	200.00	
850725	1459	135.0	1.80	0.00	200.00	THERMAL RECOVERY
850725	1504	140.0	1.82	0.00	200.00	DOMINATES DATA
850725	1514	150.0	1.89	0.00	200.00	
850725	1524	160.0	1.97	0.00	200.00	
850725	1530	166.0	2.01	0.00	200.00	RECORDING STOPPED

TABLE 2

NISYROS WELL-1

INJECTION TEST

Date	Time	Time change min	Pressure bar	Rate kg/s	Depth to gauge m	Remarks
850726	0832	0.0	4.66	0.00	225.00	PROBE ACTUALLY AT 175M
850726	0842	10.0	4.66	0.00	225.00	INSTRUMENTS STABLE
850726	0850	18.0	4.66	0.00	225.00	PROBLEMS WITH
850726	0900	28.0	4.66	0.00	225.00	STARTING PUMP
850726	0903	31.0	4.66	0.00	225.00	
850726	0904	1.0	4.72	2.57	225.00	INJECTION STARTS
850726	0905	2.0	5.01	2.57	225.00	
850726	0906	3.0	5.09	2.57	225.00	
850726	0907	4.0	5.09	2.57	225.00	PUMP STOPS
850726	0908	1.0	5.07	0.00	225.00	FALLOFF
850726	0909	2.0	5.05	0.00	225.00	
850726	0910	3.0	5.02	0.00	225.00	
850726	0911	4.0	5.00	0.00	225.00	
850726	0912	5.0	4.97	0.00	225.00	
850726	0913	6.0	4.94	0.00	225.00	
850726	0914	7.0	4.92	0.00	225.00	
850726	0915	8.0	4.90	0.00	225.00	
850726	0916	9.0	4.92	0.00	225.00	THERMAL EFFECTS
850726	0917	10.0	4.91	0.00	225.00	
850726	0919	12.0	4.91	0.00	225.00	RECORDING STOPPED
850726	1105	0.0	4.64	0.00	225.00	RECORDING STARTED
850726	1106	1.0	4.74	2.63	225.00	INJECTION STARTED
850726	1107	2.0	5.58	2.63	225.00	
850726	1108	3.0	6.18	2.63	225.00	
850726	1109	4.0	6.89	2.63	225.00	
850726	1110	5.0	7.72	2.63	225.00	
850726	1111	6.0	8.37	2.63	225.00	
850726	1112	7.0	9.06	2.63	225.00	
850726	1113	8.0	9.68	2.63	225.00	
850726	1114	9.0	10.29	2.64	225.00	
850726	1115	10.0	10.88	2.64	225.00	
850726	1117	12.0	12.03	2.64	225.00	
850726	1119	14.0	13.13	2.64	225.00	
850726	1120	15.0	13.52	2.64	225.00	VALVE BREAKS
850726	1121	1.0	13.40	0.00	225.00	FALLOFF
850726	1122	2.0	13.19	0.00	225.00	
850726	1123	3.0	12.98	0.00	225.00	
850726	1124	4.0	12.77	0.00	225.00	
850726	1125	5.0	12.56	0.00	225.00	
850726	1126	6.0	12.36	0.00	225.00	
850726	1127	7.0	12.15	0.00	225.00	
850726	1128	8.0	11.95	0.00	225.00	
850726	1129	9.0	11.75	0.00	225.00	
850726	1130	10.0	11.54	0.00	225.00	
850726	1132	12.0	11.15	0.00	225.00	
850726	1134	14.0	10.76	0.00	225.00	
850726	1136	16.0	10.40	0.00	225.00	
850726	1138	18.0	10.04	0.00	225.00	
850726	1140	20.0	9.69	0.00	225.00	
850726	1145	25.0	8.86	0.00	225.00	

cont. TABLE 2

NISYROS WELL-1

INJECTION TEST

Date	Time	Time change min	Pressure bar	Rate kg/s	Depth to gauge m	Remarks
850726	1150	30.0	8.11	0.00	225.00	RECORDING STOPPED
850726	1406	0.0	3.87	0.00	225.00	W.L. BELOW 175 M
850726	1407	1.0	4.38	2.63	225.00	INJECTION STARTED
850726	1408	2.0	4.89	2.63	225.00	
850726	1409	3.0	5.40	2.63	225.00	
850726	1410	4.0	5.92	2.63	225.00	
850726	1411	5.0	6.41	2.63	225.00	
850726	1412	6.0	6.88	2.63	225.00	
850726	1413	7.0	7.36	2.63	225.00	
850726	1414	8.0	7.83	2.69	225.00	
850726	1415	9.0	8.27	2.69	225.00	
850726	1416	10.0	8.71	2.69	225.00	
850726	1418	12.0	9.59	2.69	225.00	
850726	1420	14.0	10.42	2.69	225.00	
850726	1422	16.0	11.53	2.69	225.00	FLOW DISTURBANCE
850726	1424	18.0	12.46	2.69	225.00	
850726	1426	20.0	13.19	2.69	225.00	
850726	1431	25.0	14.92	2.57	225.00	
850726	1436	30.0	16.51	2.57	225.00	
850726	1441	35.0	17.99	2.57	225.00	
850726	1445	39.0	19.07	2.57	225.00	
850726	1446	40.0	19.14	2.57	225.00	P BEGINS TO DROP
850726	1451	45.0	19.06	2.57	225.00	
850726	1456	50.0	19.02	2.57	225.00	P RISES
850726	1501	55.0	19.11	2.54	225.00	
850726	1505	59.0	19.28	2.54	225.00	
850726	1506	60.0	19.25	2.54	225.00	P DROPS
850726	1511	65.0	19.09	2.54	225.00	
850726	1516	70.0	19.01	2.54	225.00	
850726	1521	75.0	18.98	2.54	225.00	
850726	1526	80.0	19.27	2.72	225.00	P RISES
850726	1531	85.0	19.71	2.72	225.00	
850726	1536	90.0	20.13	2.72	225.00	
850726	1541	95.0	20.56	2.69	225.00	
850726	1542	96.0	20.64	2.69	225.00	
850726	1546	100.0	20.25	2.69	225.00	P DROPS
850726	1556	110.0	19.11	2.69	225.00	
850726	1601	115.0	18.65	2.76	225.00	
850726	1606	120.0	17.94	2.76	225.00	P DROP INCREASES
850726	1616	130.0	16.47	2.76	225.00	
850726	1621	135.0	15.83	2.76	225.00	
850726	1623	137.0	15.66	2.76	225.00	P RISES
850726	1626	140.0	16.70	2.75	225.00	
850726	1629	143.0	18.13	2.75	225.00	
850726	1631	145.0	15.33	2.75	225.00	P DROPS
850726	1636	150.0	12.50	2.75	225.00	
850726	1646	160.0	9.03	2.75	225.00	
850726	1656	170.0	6.87	2.73	225.00	
850726	1706	180.0	5.21	2.81	225.00	
850726	1712	186.0	4.55	2.81	225.00	

cont. TABLE 2

NISYROS WELL-1

INJECTION TEST

Date	Time	Time change min	Pressure bar	Rate kg/s	Depth to gauge m	Remarks
850726	1713	1.0	4.73	4.02	225.00	INJECTION INCREASED
850726	1714	2.0	4.90	4.02	225.00	
850726	1715	3.0	5.06	4.02	225.00	
850726	1716	4.0	5.24	4.02	225.00	
850726	1717	5.0	5.40	4.02	225.00	
850726	1718	6.0	5.55	4.02	225.00	
850726	1719	7.0	5.67	4.02	225.00	
850726	1720	8.0	5.79	4.02	225.00	
850726	1721	9.0	5.90	4.02	225.00	
850726	1722	10.0	6.01	4.02	225.00	
850726	1724	12.0	6.19	4.02	225.00	
850726	1726	14.0	6.36	4.02	225.00	
850726	1728	16.0	6.51	4.02	225.00	
850726	1730	18.0	6.64	4.02	225.00	
850726	1732	20.0	6.77	4.02	225.00	
850726	1737	25.0	7.06	4.02	225.00	
850726	1742	30.0	7.32	3.99	225.00	
850726	1747	35.0	7.55	3.99	225.00	
850726	1752	40.0	7.82	4.08	225.00	RATE ADJUSTED
850726	1757	45.0	8.13	4.08	225.00	
850726	1802	50.0	8.41	4.08	225.00	
850726	1807	55.0	8.73	4.08	225.00	
850726	1812	60.0	9.07	4.10	225.00	
850726	1817	65.0	9.38	4.10	225.00	
850726	1822	70.0	9.61	4.10	225.00	
850726	1827	75.0	9.84	4.10	225.00	
850726	1832	80.0	10.05	4.04	225.00	
850726	1837	85.0	10.24	4.04	225.00	
850726	1842	90.0	10.36	4.02	225.00	
850726	1847	95.0	10.44	4.14	225.00	RATE READJUSTED
850726	1852	100.0	10.60	4.07	225.00	
850726	1902	110.0	10.76	4.07	225.00	
850726	1912	120.0	10.99	4.07	225.00	
850726	1922	130.0	11.22	4.07	225.00	
850726	1932	140.0	11.41	4.07	225.00	
850726	1942	150.0	11.60	4.07	225.00	
850726	1952	160.0	11.71	4.02	225.00	
850726	2002	170.0	11.93	4.08	225.00	
850726	2012	180.0	12.10	4.08	225.00	
850726	2022	190.0	12.24	4.08	225.00	
850726	2032	200.0	12.32	4.08	225.00	
850726	2042	210.0	12.44	4.08	225.00	
850726	2052	220.0	12.62	4.10	225.00	
850726	2102	230.0	12.74	4.10	225.00	
850726	2108	236.0	12.87	4.10	225.00	
850726	2109	1.0	13.03	4.98	225.00	INJECTION INCREASED
850726	2110	2.0	13.17	4.93	225.00	
850726	2111	3.0	13.29	4.93	225.00	
850726	2112	4.0	13.39	4.93	225.00	
850726	2113	5.0	13.50	4.93	225.00	

cont. TABLE 2

NISYROS WELL-1

INJECTION TEST

Date	Time	Time change min	Pressure bar	Rate kg/s	Depth to gauge m	Remarks
850726	2114	6.0	13.62	4.93	225.00	
850726	2115	7.0	13.69	4.93	225.00	
850726	2116	8.0	13.80	4.93	225.00	
850726	2117	9.0	13.90	4.93	225.00	
850726	2118	10.0	14.01	4.93	225.00	
850726	2120	12.0	14.18	4.98	225.00	
850726	2122	14.0	14.28	4.98	225.00	
850726	2124	16.0	14.38	4.98	225.00	
850726	2126	18.0	14.46	4.98	225.00	
850726	2128	20.0	14.53	4.86	225.00	
850726	2133	25.0	14.64	4.86	225.00	
850726	2138	30.0	14.83	4.86	225.00	
850726	2143	35.0	15.05	4.86	225.00	
850726	2148	40.0	15.23	4.97	225.00	
850726	2153	45.0	15.40	4.97	225.00	
850726	2158	50.0	15.56	4.97	225.00	
850726	2203	55.0	15.75	5.01	225.00	
850726	2208	60.0	15.92	5.01	225.00	
850726	2213	65.0	16.04	5.01	225.00	
850726	2218	70.0	16.22	5.01	225.00	
850726	2223	75.0	16.34	5.00	225.00	
850726	2228	80.0	16.54	5.00	225.00	
850726	2233	85.0	16.72	5.00	225.00	
850726	2238	90.0	16.86	5.00	225.00	
850726	2243	95.0	16.99	5.00	225.00	
850726	2248	100.0	17.06	4.98	225.00	
850726	2258	110.0	17.33	4.98	225.00	
850726	2307	119.0	17.48	5.00	225.00	PROBE LOWERED TO
850726	2311	123.0	17.58	5.01	225.00	225 M DEPTH
850726	2313	125.0	17.61	5.01	225.00	
850726	2318	130.0	17.74	5.01	225.00	
850726	2328	140.0	18.00	5.01	225.00	
850726	2338	150.0	18.13	4.97	225.00	
850726	2341	153.0	18.16	4.96	225.00	INJECTION STOPPED
850726	2342	1.0	17.30	0.00	225.00	FALLOFF
850726	2343	2.0	16.46	0.00	225.00	
850726	2344	3.0	15.69	0.00	225.00	
850726	2345	4.0	14.97	0.00	225.00	
850726	2346	5.0	14.30	0.00	225.00	
850726	2347	6.0	13.68	0.00	225.00	
850726	2348	7.0	13.09	0.00	225.00	
850726	2349	8.0	12.55	0.00	225.00	
850726	2350	9.0	12.04	0.00	225.00	
850726	2351	10.0	11.62	0.00	225.00	
850726	2353	12.0	10.76	0.00	225.00	
850726	2355	14.0	10.03	0.00	225.00	
850726	2357	16.0	9.44	0.00	225.00	
850726	2359	18.0	8.87	0.00	225.00	
850727	0001	20.0	8.34	0.00	225.00	
850727	0006	25.0	7.48	0.00	225.00	

cont. TABLE 2

NISYROS WELL-1

INJECTION TEST

Date	Time	Time change min	Pressure bar	Rate kg/s	Depth to gauge m	Remarks
850727	0011	30.0	6.87	0.00	225.00	
850727	0016	35.0	6.40	0.00	225.00	
850727	0021	40.0	5.95	0.00	225.00	
850727	0026	45.0	5.35	0.00	225.00	
850727	0031	50.0	4.44	0.00	225.00	
850727	0036	55.0	3.53	0.00	225.00	
850727	0038	57.0	3.06	0.00	225.00	
850727	0041	60.0	1.70	0.00	225.00	
850727	0044	63.0	0.41	0.00	225.00	W.L. GOES BELOW 225 M
850727	0045	64.0	0.00	0.00	225.00	RECORDING STOPPED

TABLE 3

INJECTION TEST

Country : GREECE
Location : NISYROS
Well number : NIS-1
Date measured : 26 July 1985

RESULTS OF COMPUTER ANALYSIS

Initial Pressure,	Pi (bar)	: 4.974E+00
Transmissivity,	T (m**3/Pa s)	: 1.859E-09
Formation Storage,	S (m/Pa)	: 4.763E-08
Skin Factor,	s	: 1.714E+00
Wellbore Storage,	CD	: 2.823E+03

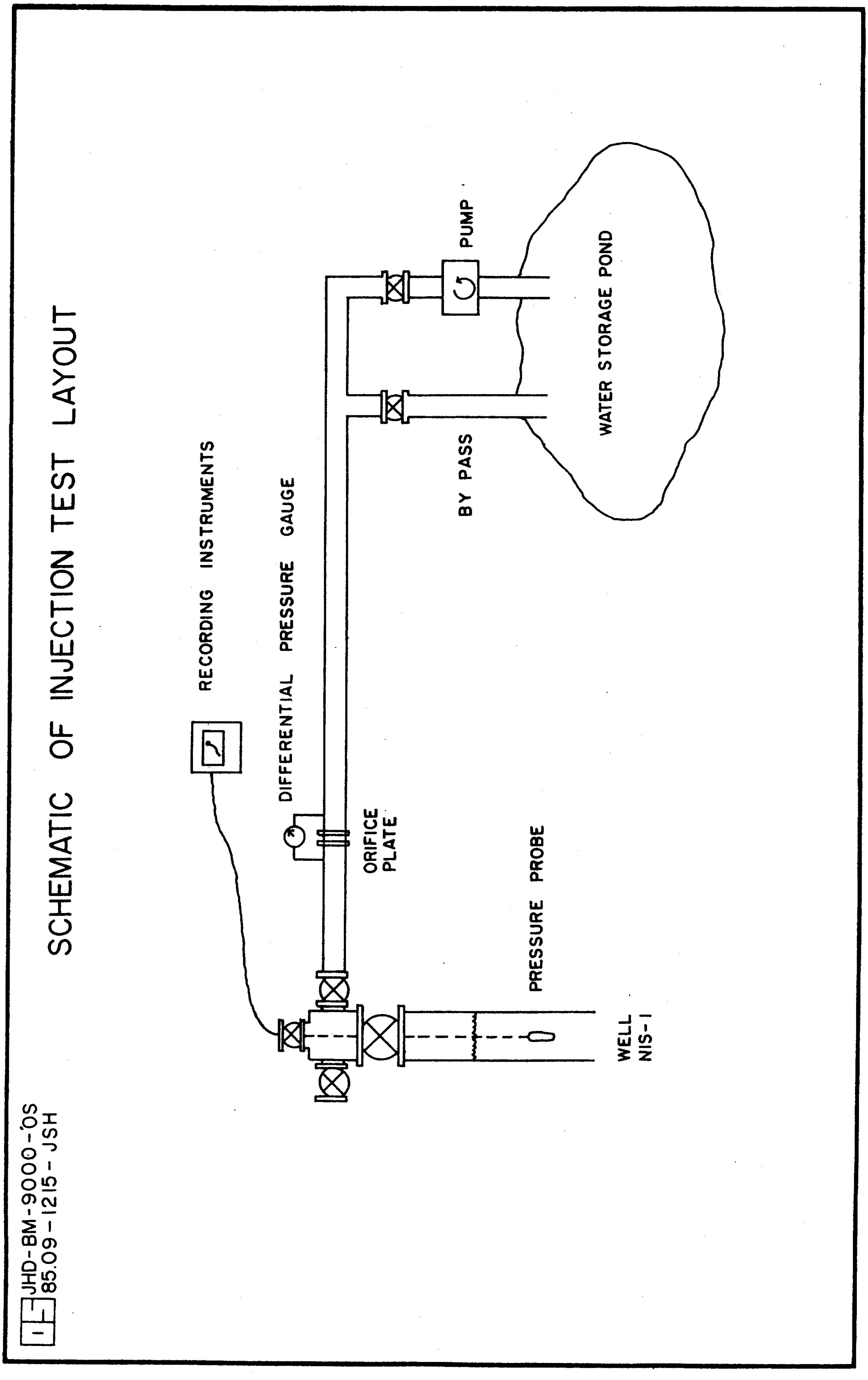
Point No.	Measured Pressure bar	Calculated Pressure bar	Absolute Difference bar	Relative Difference %
1	0.4730E+01	0.5072E+01	-0.3417E+00	7.2
2	0.4900E+01	0.5168E+01	-0.2678E+00	5.5
3	0.5060E+01	0.5262E+01	-0.2024E+00	4.0
4	0.5240E+01	0.5356E+01	-0.1156E+00	2.2
5	0.5400E+01	0.5447E+01	-0.4745E-01	0.9
6	0.5550E+01	0.5538E+01	0.1203E-01	0.2
7	0.5670E+01	0.5627E+01	0.4278E-01	0.8
8	0.5790E+01	0.5715E+01	0.7476E-01	1.3
9	0.5900E+01	0.5802E+01	0.9794E-01	1.7
10	0.6010E+01	0.5888E+01	0.1223E+00	2.0
11	0.6190E+01	0.6056E+01	0.1344E+00	2.2
12	0.6360E+01	0.6219E+01	0.1409E+00	2.2
13	0.6510E+01	0.6378E+01	0.1317E+00	2.0
14	0.6640E+01	0.6534E+01	0.1064E+00	1.6
15	0.6770E+01	0.6685E+01	0.8510E-01	1.3
16	0.7060E+01	0.7047E+01	0.1298E-01	0.2
17	0.7320E+01	0.7388E+01	-0.6750E-01	0.9
18	0.7550E+01	0.7708E+01	-0.1580E+00	2.1
19	0.7820E+01	0.8010E+01	-0.1901E+00	2.4
20	0.8130E+01	0.8295E+01	-0.1650E+00	2.0
21	0.8410E+01	0.8564E+01	-0.1539E+00	1.8
22	0.8730E+01	0.8818E+01	-0.8798E-01	1.0
23	0.9070E+01	0.9058E+01	0.1181E-01	0.1
24	0.9380E+01	0.9285E+01	0.9457E-01	1.0
25	0.9610E+01	0.9501E+01	0.1094E+00	1.1
26	0.9840E+01	0.9704E+01	0.1357E+00	1.4
27	0.1005E+02	0.9897E+01	0.1525E+00	1.5
28	0.1024E+02	0.1008E+02	0.1594E+00	1.6
29	0.1036E+02	0.1025E+02	0.1056E+00	1.0
30	0.1044E+02	0.1042E+02	0.2055E-01	0.2
31	0.1060E+02	0.1058E+02	0.2380E-01	0.2
32	0.1076E+02	0.1087E+02	-0.1068E+00	1.0
33	0.1099E+02	0.1113E+02	-0.1399E+00	1.3
34	0.1122E+02	0.1137E+02	-0.1485E+00	1.3
35	0.1141E+02	0.1159E+02	-0.1753E+00	1.5
36	0.1160E+02	0.1178E+02	-0.1827E+00	1.6
37	0.1171E+02	0.1196E+02	-0.2527E+00	2.2

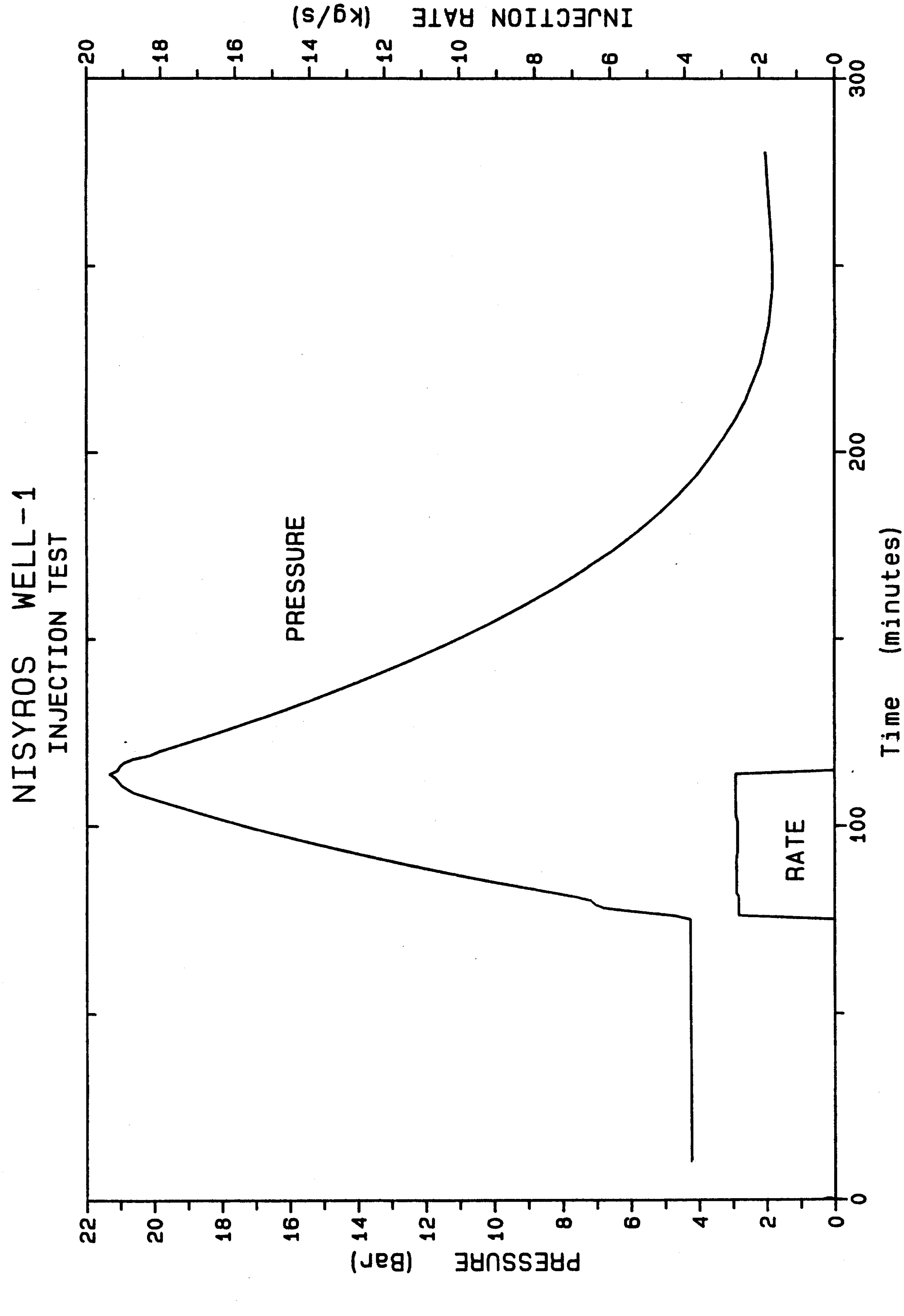
cont. TABLE 3

Point No.	Measured Pressure bar	Calculated Pressure bar	Absolute Difference bar	Relative Difference %
38	0.1193E+02	0.1213E+02	-0.1973E+00	1.7
39	0.1210E+02	0.1228E+02	-0.1779E+00	1.5
40	0.1224E+02	0.1242E+02	-0.1762E+00	1.4
41	0.1232E+02	0.1254E+02	-0.2232E+00	1.8
42	0.1244E+02	0.1266E+02	-0.2201E+00	1.8
43	0.1262E+02	0.1277E+02	-0.1480E+00	1.2
44	0.1274E+02	0.1287E+02	-0.1277E+00	1.0
45	0.1287E+02	0.1292E+02	-0.5393E-01	0.4
46	0.1303E+02	0.1300E+02	0.3367E-01	0.3
47	0.1317E+02	0.1307E+02	0.1024E+00	0.8
48	0.1329E+02	0.1314E+02	0.1522E+00	1.1
49	0.1339E+02	0.1321E+02	0.1829E+00	1.4
50	0.1350E+02	0.1328E+02	0.2246E+00	1.7
51	0.1362E+02	0.1334E+02	0.2772E+00	2.0
52	0.1369E+02	0.1341E+02	0.2807E+00	2.1
53	0.1380E+02	0.1347E+02	0.3251E+00	2.4
54	0.1390E+02	0.1354E+02	0.3603E+00	2.6
55	0.1401E+02	0.1360E+02	0.4063E+00	2.9
56	0.1418E+02	0.1373E+02	0.4507E+00	3.2
57	0.1428E+02	0.1385E+02	0.4282E+00	3.0
58	0.1438E+02	0.1397E+02	0.4087E+00	2.8
59	0.1446E+02	0.1409E+02	0.3721E+00	2.6
60	0.1453E+02	0.1420E+02	0.3282E+00	2.3
61	0.1464E+02	0.1448E+02	0.1650E+00	1.1
62	0.1483E+02	0.1473E+02	0.9712E-01	0.7
63	0.1505E+02	0.1498E+02	0.7348E-01	0.5
64	0.1523E+02	0.1521E+02	0.2305E-01	0.2
65	0.1540E+02	0.1543E+02	-0.2510E-01	0.2
66	0.1556E+02	0.1563E+02	-0.7180E-01	0.5
67	0.1575E+02	0.1583E+02	-0.7780E-01	0.5
68	0.1592E+02	0.1601E+02	-0.9379E-01	0.6
69	0.1604E+02	0.1619E+02	-0.1504E+00	0.9
70	0.1622E+02	0.1636E+02	-0.1382E+00	0.9
71	0.1634E+02	0.1652E+02	-0.1778E+00	1.1
72	0.1654E+02	0.1667E+02	-0.1297E+00	0.8
73	0.1672E+02	0.1681E+02	-0.9426E-01	0.6
74	0.1686E+02	0.1695E+02	-0.9199E-01	0.5
75	0.1699E+02	0.1708E+02	-0.9329E-01	0.5
76	0.1706E+02	0.1721E+02	-0.1485E+00	0.9
77	0.1733E+02	0.1744E+02	-0.1121E+00	0.6
78	0.1748E+02	0.1763E+02	-0.1549E+00	0.9
79	0.1758E+02	0.1772E+02	-0.1357E+00	0.8
80	0.1761E+02	0.1776E+02	-0.1451E+00	0.8
81	0.1774E+02	0.1785E+02	-0.1105E+00	0.6
82	0.1800E+02	0.1803E+02	-0.2931E-01	0.2
83	0.1813E+02	0.1819E+02	-0.6363E-01	0.4
84	0.1816E+02	0.1824E+02	-0.8032E-01	0.4

Average Variance : 3.3E-02
Average Relative Difference : 1.42 %

FIGURES


SCHEMATIC OF INJECTION TEST LAYOUT
RECORDING INSTRUMENTS
DIFFERENTIAL PRESSURE GAUGE
ORIFICE PLATE
PRESSURE PROBE
BY PASS
PUMP
WATER STORAGE POND
WELL NIS-1
JHD-BM-9000-OS
85.09-1215-JSH


NISYROS WELL-1
INJECTION TEST
PRESSURE
RATE
Time (minutes)
PRESSURE (Bar)
INJECTION RATE (kg/s)
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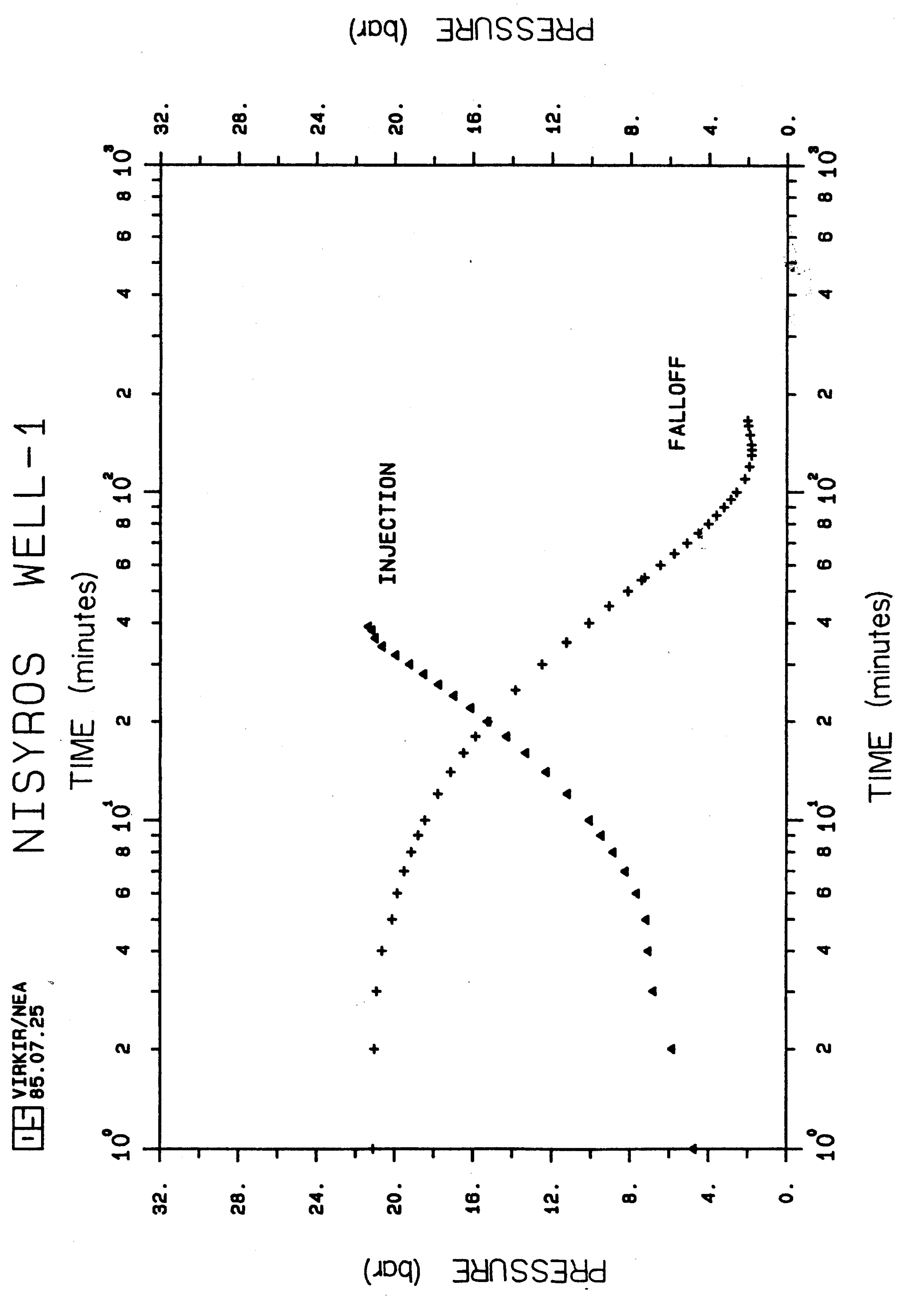
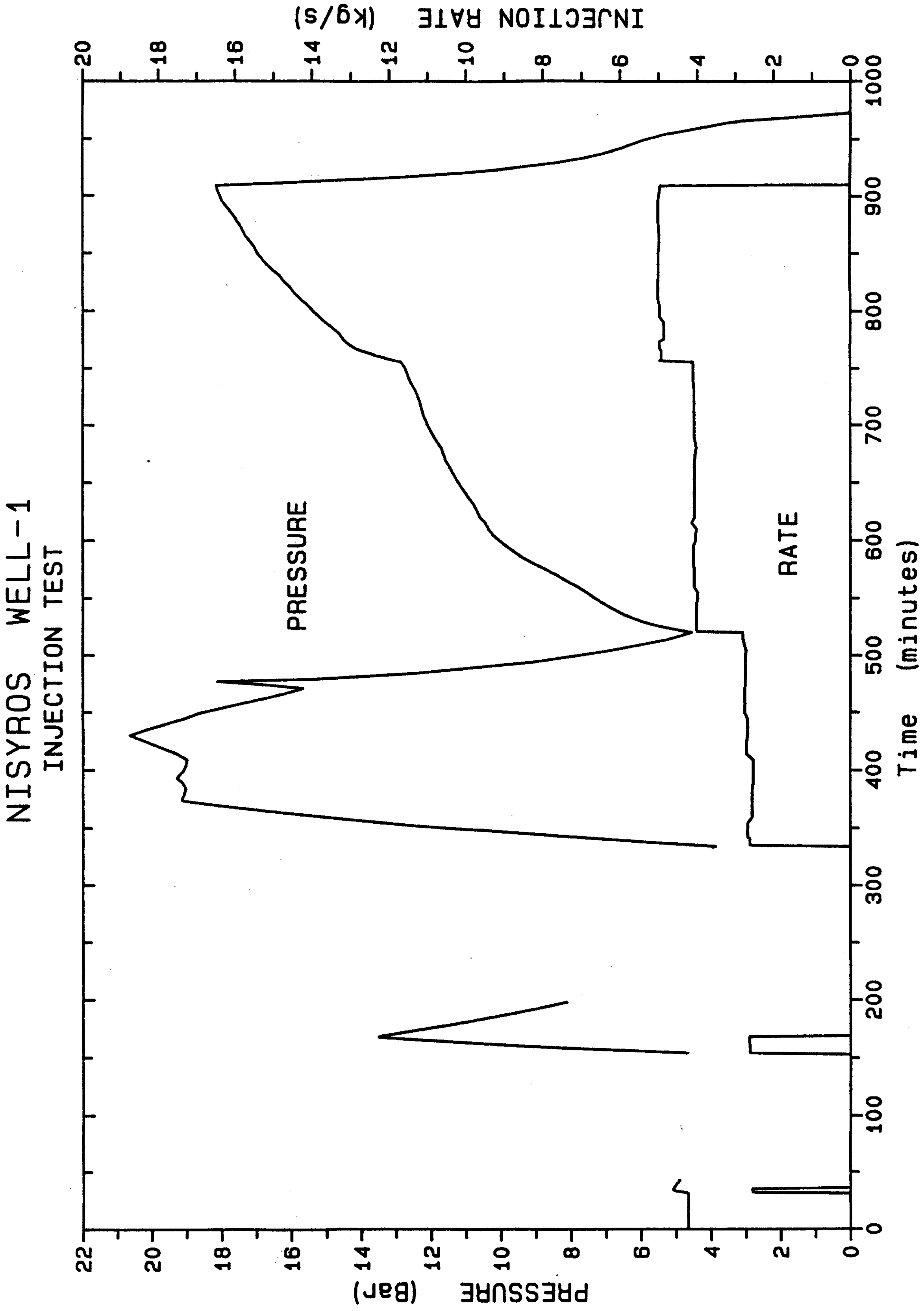
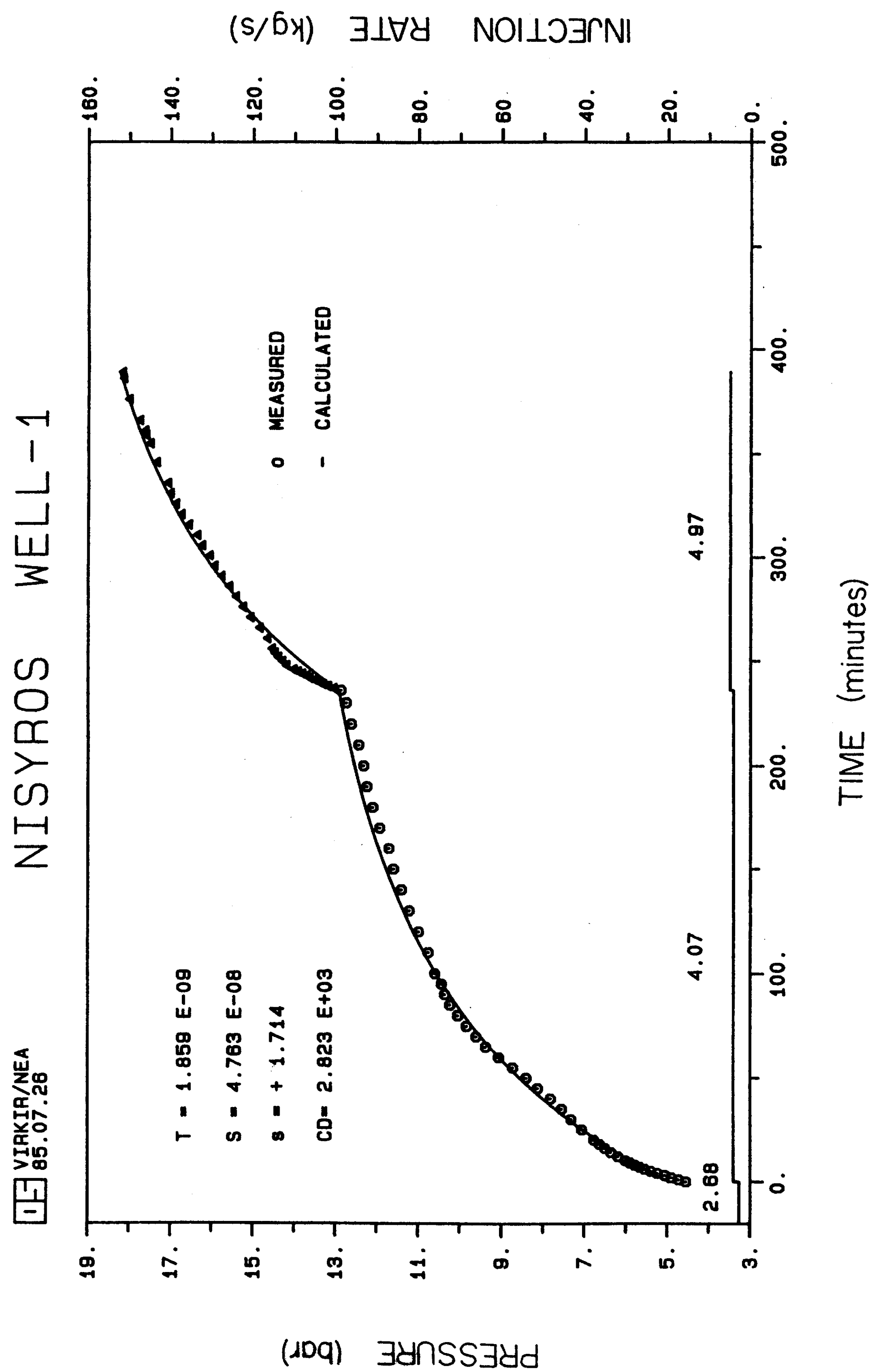
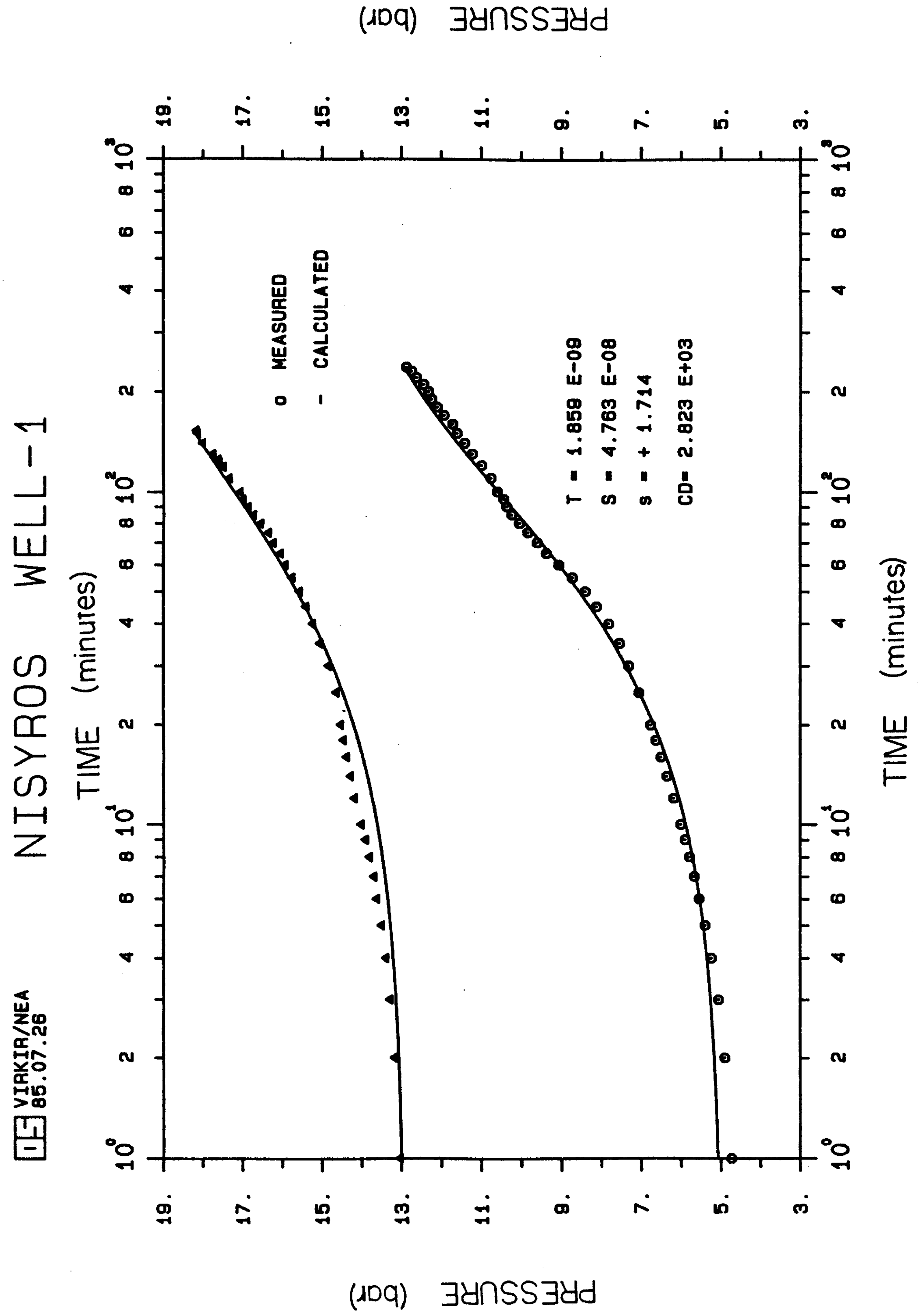
100
200
300
0
2
4
6
8
10
12
14
16
18
20
22


NISYROS WELL-1
VIRKIR/NEA
85.07.25
TIME (minutes)
PRESSURE (bar)
INJECTION
FALLOFF


NISYROS WELL-1
INJECTION TEST
PRESSURE
RATE
Time (minutes)
PRESSURE (Bar)
INJECTION RATE (kg/s)


NISYROS WELL-1
VIRKIR/NEA
85.07.26
T = 1.859 E-09
S = 4.763 E-08
s = + 1.714
CD= 2.823 E+03
o MEASURED
- CALCULATED
2.88
4.07
4.97
PRESSURE (bar)
INJECTION RATE (kg/s)
TIME (minutes)
19.
17.
15.
13.
11.
9.
7.
5.
3.
160.
140.
120.
100.
80.
60.
40.
20.
0.
100.
200.
300.
400.
500.


NISYROS WELL-1
VIRKIR/NEA
85.07.26
TIME (minutes)
PRESSURE (bar)
o MEASURED
- CALCULATED
T = 1.859 E-09
S = 4.763 E-08
s = + 1.714
CD= 2.823 E+03
19.
17.
15.
13.
11.
9.
7.
5.
3.

APPENDIX 1

Athens 29-7-1985

Public Power Corporation
Alternative Energy Source Department
10, Navarinou Street
106 80 Athens, GREECE

Re: **NISYROS WELL-1**

Arrived to Athens Greece in the afternoon on the 23rd of July 1985. The morning after I met with Mr. Adamis at the PPC office in Athens and discussed with him the continue of my journey to Nisyros. In the afternoon the same day travel plans were laid out and in the evening my journey to Nisyros continued. At the arrival to Nisyros shortly before midnight Iwas met and assisted by Mr. Vondicakis and Mr. Bambakaris.

In the morning July the 25th, we went out to the geothermal field in Nisyros to Well-1. There additional measuring equipments supplied by VIRKIR/NEA were put into position for the injection testing. The first injection test was started just after 12 o`clock with the electronic pressure probe at 200 m depth and zero reference to the upper flangs of the 2" valve at the top of the wellhead. Before injection started stable water level was at 156.37 m depth. Injection rate was adjusted to 2.6 kg/s (9.36 ton/hr). For that rate the well filled up in 39 minutes. The injection was discontinued and the falloff recorded. The next 136 minutes the water level dropped in the well to a low of about 182 m depth. Then thermal recovery of the well started to influence the data and the testing was stopped at 15:30. During this test about 6080 kg of ponded water were injected into the well.

This test was useful in the way that it familiarized me with the well. It also revealed the thermal influence of the well on the test. Thenit was a trial for the instruments to function correctly and indication that a correct orifice plate for the possible injection range was used.

On a brief meeting with Mr. Vondicakis that evening a second test was planned and decided to inject for long enough time to make sure that, the well would be cooled down to the pay zone during that test.

The following day the second test was carried out. It got a late start due to miscellaneous problems, which were found to originate from a broken valve in the suction head for the injection pump. After the valve had been repaired the test started at 14:06 with an injection of 2.6 kg/s (9.36 ton/hr). The water level rose up to 24 m depth in 40 minutes, but then started to fall again due to the cooling of the water column in the well. After about 3 hr of injection the water level had dropped to 174 m depth. The injection rate was then increased to 4.0 kg/s (14.4 ton/hr). This step was nearly 4 hr long and during that time the water level rose to 89 m depth. Finally the injection rate was increased to 5.0 kg/s (18 ton/hr). This step lasted for 2.5 hr during which the water level rose to 40 m depth. The injection was stopped at 23:41 and the falloff monitored until the water level fell below 225 m depth, the depth capacity of the logging cable on the hand drum. The test concluded 45 minutes after midnight.

Preliminary results from these tests give an estimate for the injectivity index in the order of

$$II = 0.2 \quad (kg/s)/bar$$

and transmissivity on the order of

$$T = kh/u = 4.0 \text{ E-}10 \quad m^{**}3/Pa\ s$$

The error trend in these estimates is that the injectivity index could be over estimated where as the transmissivity could be under estimated.

Complete analysis of the tests will be performed at the NEA office in Iceland and the results will be forewarded to you at the earliest possible time.

Sincerely,

Omar Sigurdsson

APPENDIX 2

VIRKIR/ORKUSTOFNUN
August 18th, 1985

Mr. P. N. Adamis
Head of Geothermal Sector
PUBLIC POWER CORPORATION
ATHENS, GREECE.

INJECTION TEST NISYROS WELL-1
SUMMARY OF RESULTS

Injection tests were carried out on well-1 in NISYROS between July 25 - 27, 1985. The data collected during the injection tests has now been processed and the results are available. A final report on the injection tests, which will include these results is, however, not ready due to delays during our summer vacation period. During my stay in Greece you expressed your desire to obtain the results from the tests not later than in the beginning of September 1985. Since I will be leaving soon for Hawaii to participate in the Geothermal Resources Council meeting, I see a further delay on the final report past the time of your wishes. In order to minimize the inconvenience that this delay may cause you and enable you to carry on your work that will require these results, they will be summarized here briefly.

Two injection tests were done in well NIS-1 in NISYROS. The first was done on July 25, 1985 and the second on July 26-27. During the first test 6130 kg of ponded water were injected at an average rate of 2.62 kg/s. The well filled up in 39 min.

During the second test 136159 kg were injected. At the beginning of this test, problems with the pump were encounted. After they had been corrected the average injection rates for the three steps were 2.68 - 4.07 - 4.97 kg/s respectively. The well never filled up during this test.

A computer analysis of the injection steps has resulted in a transmissivity

$$kh/u = 1.9 \text{ E-09}$$

and a skin factor

$$s = + 2$$

The short term injectivity index has been determined as

$$II = 0.13 \text{ (kg/s)/bar}$$

which is in agreement with the transmissivity value.

I hope that the knowledge of these results will minimize your inconveniences due to the delay of the final report. The values given here will not change in the final report.

Sincerely,

Omar Sigurdsson Res. Eng.