WELL INTERFERENCE TEST IN THE CHINGSHUI GEOTHERMAL FIELD

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INTRODUCTION

The initial assessment of geothermal reservoirs usually has two main objectives. One is determination of the deliverability rate from the reservoir, and the other is estimation of the reserves, or the economically producible amount of steam in the system. Many geothermal reservoirs are complicated by the fact that neither the porosity-thickness product nor producible area are known, either early in the life or after extended production. The most reliable means of determining the deliverability is usually a pressure transient test. Pressure transient tests can be conducted in a reasonably short period of time, and early in the life of a geothermal development. However, estimation of steam reserves usually requires an extended period of production with observation of mean reservoir pressure at various stages of production. Material and energy balance performance matching with a detectable decline in pressure following production is the minimum information for performance matching. Thus it is necessary to produce a reservoir for an extended period of time before performance matching can be accomplished with reasonable precision.

The dilemma is that short-time pressure testing frequently provides inaccurate information on deliverability (permeability thickness or transmissivity), while long-term production testing is required to establish reserves. Fortunately, an interference test is a type of pressure transient test than can be accomplished in a reasonable period of time, and yet provide important information concerning apparent reserves early in the life of a geothermal development. The main purpose of this study is to illustrate the interpretation of interference tests.

INTERFERENCE TESTING

The main problem with pressure transient tests of individual wells is that distances in the reservoir are measured in units of the wellbore radius. A test of an individual well can yield important information concerning the condition of the well, the formation conductivity, and drainage boundaries of the well. However, long periods of production are required prior to the pressure transient testing for boundaries to be evident when distances are measured in units of wellbore radii. An alternative procedure is to observe pressure effects transmitted between two or more wells. This kind of test is usually called an interference test. The theory of interference testing was originally explained by C.V. Theis (1935). A modern discussion of interference testing procedures has been presented by Earlougher (1977). Because there are so many recent publications on this important subject in both the groundwater and the petroleum engineering literatures, we will repeat only the minimum necessary for the purposes of this paper.

One simple basis for interference test analysis is the continuous line source solution. This model assumes that a single well is produced starting at time zero at a constant rate in an infinitely large reservoir of constant properties. The pressure effects caused by the producing well may be observed at one or more distant wells which are not produced but used simply as pressure observation stations. The solution to this problem can be displayed on a piece of log-log coordinate paper. Figure 1 is a type-curve for this problem used commonly in the petroleum literature. Figure 1 presents a dimensionless pressure which is directly proportional to an observed pressure drawdown versus the ratio of a dimensionless time to the dimensionless distance between the produced and observation well squared. The dimensionless time is directly proportional to real time, and the dimensionless distance is directly proportional to real distance. An important characteristic of the logarithmic scale is that quantities proportional to the plotted scale are simply displaced linearly along the scale. Thus it is possible to graph the field data observed in an interference test as a pressure drop on the ordinate versus time on the abscissa, and make a direct comparison with the analytic solution represented by Fig. 1. This procedure is called log-log type-curve matching. This procedure has been outlined in detail in many references, such as Earlougher (1977).

Once a set of field data has been matched with the line source type-curve, it is possible to equate the pressure difference point with the dimensionless pressure from the type-curve to make quantitative calculations. In the usual case, the net formation thickness (h), the flowrate (q), the formation volume factor (B), and the viscosity (μ) of the produced fluid would be known. The objective of the pressure matchpoint would be calculation of the effective permeability to the flowing phase (k). From the time matchpoint, it would be possible then to calculate the porosity-compressibility product. In the ordinary case, the porosity would be known, and thus it would be possible to obtain a check on the average compressibility of the formation and fluid. An alternative would be to determine the in-place porosity under the assumption that the average compressibility of the rock-fluid system were known. This step is frequently done in petroleum engineering work as a check upon porosity derived either from core analyses or from well logging methods. In petroleum engineering application, one frequently obtains both effective permeabilities and porosities which agree with information known from other sources. For example, the effective permeability will frequently agree with that obtained from a pressure buildup test on a single well, while the porosity obtained from an interference test will frequently agree with porosities obtained from core analyses.

In the case of interference testing of geothermal systems, analysis is often more complex. In the use of the pressure matchpoint, it is frequently observed that the net formation thickness for the geothermal system is not known. This may be a result of the fact that the geothermal formations have not been fully penetrated by drilling, or that the geothermal system is a fractured system whose characteristics are not readily apparent. In the case of the time matchpoint, quite frequently the porosity is not known, and, since the thickness is not known, there is a dilemma as to the kind of useful calculation available from the time matchpoint. Fortunately, important and useful information can be obtained from the time matchpoint. The following example, taken from an interference test in the Chingshui field, will serve as an illustration.

FIELD TEST RESULTS

The Chingshui geothermal field is located in the northeast portion of Taiwan (see Fig. 2). A review of the geology of the Chingshui field was presented by Chiang et al., and results of pressure buildup testing on one of the wells in the field was presented by Shen and Chang, at the Fifth Geothermal Reservoir Engineering Workshop, Stanford University, December 1979. Both pressure buildup testing and interference testing of wells in the Chingshui field were performed during 1979. Two preliminary interference tests were conducted to determine whether detectable pressure responses would be available. The third interference test presents a comprehensive set of information for the Chingshui field. The third interference test was conducted during November of 1979. During this test, Well 16T was produced, and pressure responses were observed in Wells 4, 5, 9, 12, 13, and 14T. Figure 2 is a scale map of the locations of these wells, and shows both surface and downhole locations. Because all wells were drifted, it was necessary to estimate distances between the bottomhole locations for interpretation of interference tests. The results of the third interference test are presented in Table 1. As can be seen, the production rate of weir hot water ranged from 80 to 84 tons/hour during the eleven-day interference test. The test was conducted by observing wellhead pressures at the observation wells. A complete set of interference data is presented in Table 1 because field data appears to be rare in the literature. The interference effects for Well 13 do not appear to be reliable. There was some malfunction of equipment in the inert gas release pipeline at the wellhead on this well, and this perhaps had an effect on the pressure record. The interpretation of the interference test results by log-log type-curve matching will be presented for only Well 4T. Table 2 presents an outline of the calculations. As can be seen from Table 2, the pressure matchpoint yielded a permeability-thickness of 28,800 md-ft. Because the thickness of the Chingshui field is not known, it is not possible to separate this product into effective permeability and net thickness with accuracy. However, ranges of thickness may be considered to indicate the approximate level of the effective permeability. For example, if the net thickness is 1000 ft, then the effective permeability is approximately 30 md for this liquid-dominated system. The time matchpoint calculation shown on Table 2 indicates that the porosity thickness is 528 ft. Because the thickness was not known in the pressure matchpoint, it is necessary to insert the permeability thickness in the numerator of the time matchpoint. Consequently, an unknown thickness must be added to the denominator. Because this was apparently a liquid-filled and fractured system, it was estimated that the total effective compressibility was approximately 10^{-5} psi^{-1}. Consequently the unknown porosity thickness was calculated in this case. Again the actual net formation thickness is not known. If it is assumed that the net thickness is 1000 ft, the porosity would have to be on the order of 50% of bulk volume in this case. A porosity of this order of magnitude appears totally unreasonable, so the indiction is that the net formation thickness is probably many times the 1000 ft assumed.

Table 3 summarizes the results of type-curve matching for all of the well pairs during this test. As can be seen in Table 3, the results from Wells 4, 9, and 12 were reasonably similar. All indicated permeability thicknesses on the order of 25,000 md ft, and porosity thicknesses in the range of 200 to 500 ft.

As mentioned earlier, pressure buildup tests were also performed on all of the wells in the Chingshui field during 1979. The report by Shen and Chang presents results of pressure buildup tests for Well 4T. The permeability thickness for this well is 17,600 md ft. Normally, we would expect closer agreement between the results of interference testing and pressure buildup testing. Additional interference testing will be performed in the Chingshui field in the future.

The main importance of the porosity thickness result from interference testing is that it can provide an estimate of the fluid content per unit area in the system. Calculation of the pounds of steam per unit area can be made on the basis of a material balance. If this is done, the main parameter that appears in the calculation is porosity times thickness. Thus results of interference testing can provide the first estimates of the producible fluid content of a geothermal system.

Inspection of the calculation in Table 2 and reflection on this method indicates several possible sources of error, and thus a need for qualification of the results. One great source of uncertainty is the total effective compressibility of the system. Therefore, it would be better to consider porosity thickness and compressibility as a product ($\phi h c_t$). Another serious problem may be estimation of the distance between the bottomhole locations of the producing well and the pressure observation wells. As can be seen in Fig. 2, the bottomhole location for the Chingshui wells were in question because of the drifting of the wells. Thus it is often important to have bottomhole surveys on geothermal wells. Nevertheless, the results of interference testing in the Chingshui field appear to have provided the first estimate of the quantity of reservoir fluid in place. Interference testing appears to provide a useful method for initial estimation of useful fluid content of geothermal systems.

REFERENCES

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Shen, K.Y., and Chang, C.R.Y.: "Pressure Buildup Test of Well CPC-CS-4T, Chingshui Geothermal Field," Proc., Fifth Workshop on Geothermal Engineering, Stanford University, December 12-14, 1979.

Theis, C.V.: "The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Groundwater Storage," Trans., AGU (1935), 16, 519.

TABLE 1: INTERFERENCE TEST, CHINGSHUI GEOTHERMAL FIELD, 1979

Observation Wells: 4, 5, 9, 12, 13, 14
Flowing Well: 16

WELLHEAD PRESSURES, PSI

Δt Hours	No. 4	Δp	No. 5	Δp	No. 9	Δp	No. 12	Δp	No. 13	Δp	No. 14	Δp	No. 16	Tons/Hr
0	172		194		138		187		159		133		258	
18.5	171	1	189	5	137	1	185	2	158	1	133	0	69	24
42.5	168	4	180	14	135	3	162	5	158	1	130	3	58	83.5
66.5	166	6	180	14	133	5	182	5	158	1	125	8	56	83.1
90.5	166	6	180	14	130	8	180	7	209		125	8	56	83.1
114.5	165	7	180	14	130	8	179	8	207		123	10	56	82
138.5	164	8	180	14	130	8	178	9	207		121	12	56	82.4
162.5	164	8	180	14	129	9	177	10	263		120	13	54	82.4
186.5	163	9	180	14	128	10	176	11	263		119	14	54	81
210.5	162	10	180	14	127	11	175	12	263		119	15	53	80
234.5	162	10	180	14	127	11	175	12	263		117	16	52	80
258.5	161	11	180	14	126	12	175	12	263*		115	18	52	80**

* Some problems occurred in 2" inert gas release pipeline and pressure recorder.

** Equivalent of well stream production rate of 17,160 BBL/D

TABLE 2: INTERFERENCE CALCULATIONS FOR WELL 4T

Log-Log Type-Curve Matching
Matchpoint: $\Delta p = 10$ psi

$t = 100$ hours

$p_D = 0.9$

$t_D/r_D^2 = 1.2$

$$p_D = \frac{kh\Delta p}{141.2\ q\mu B}$$

$$0.9 = \frac{kh(10)}{(141.2)\ (17160)\ (0.12)\ (1.1)}$$

Therefore: $kh = 28.785$ md-ft

$$t_D/r_D^2 = \frac{0.000264\ kht}{\phi h \mu c_t r_w^2}$$

$$1.2 = \frac{(0.000264)\ (28785)\ (100)}{\phi h\ (0.12)\ (10^{-5})\ (1000)^2}$$

Therefore: $\phi h = 528$ ft

TABLE 3: RESULTS OF TYPE-CURVE MATCHING

	4	5	9	12	13	14
Matchpoint						
Δp = 10 psi, p_D =	0.90	0.26	0.80	0.90	*	0.44
t = 100 hrs, t_D/r_D^2 =	1.20	1.55	1.07	1.67		0.70
Distance, ft	1000	213	1000	1000		820
kh, md-ft	28,800	8,300	25,600	28,800		14,100
ϕh, ft	528	2,600	196	379		658

*Test failed.

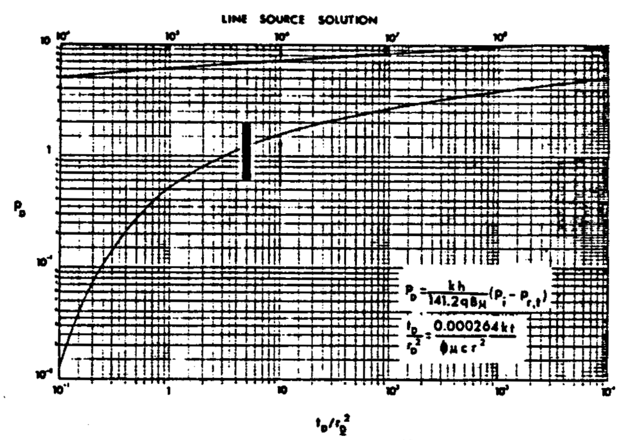
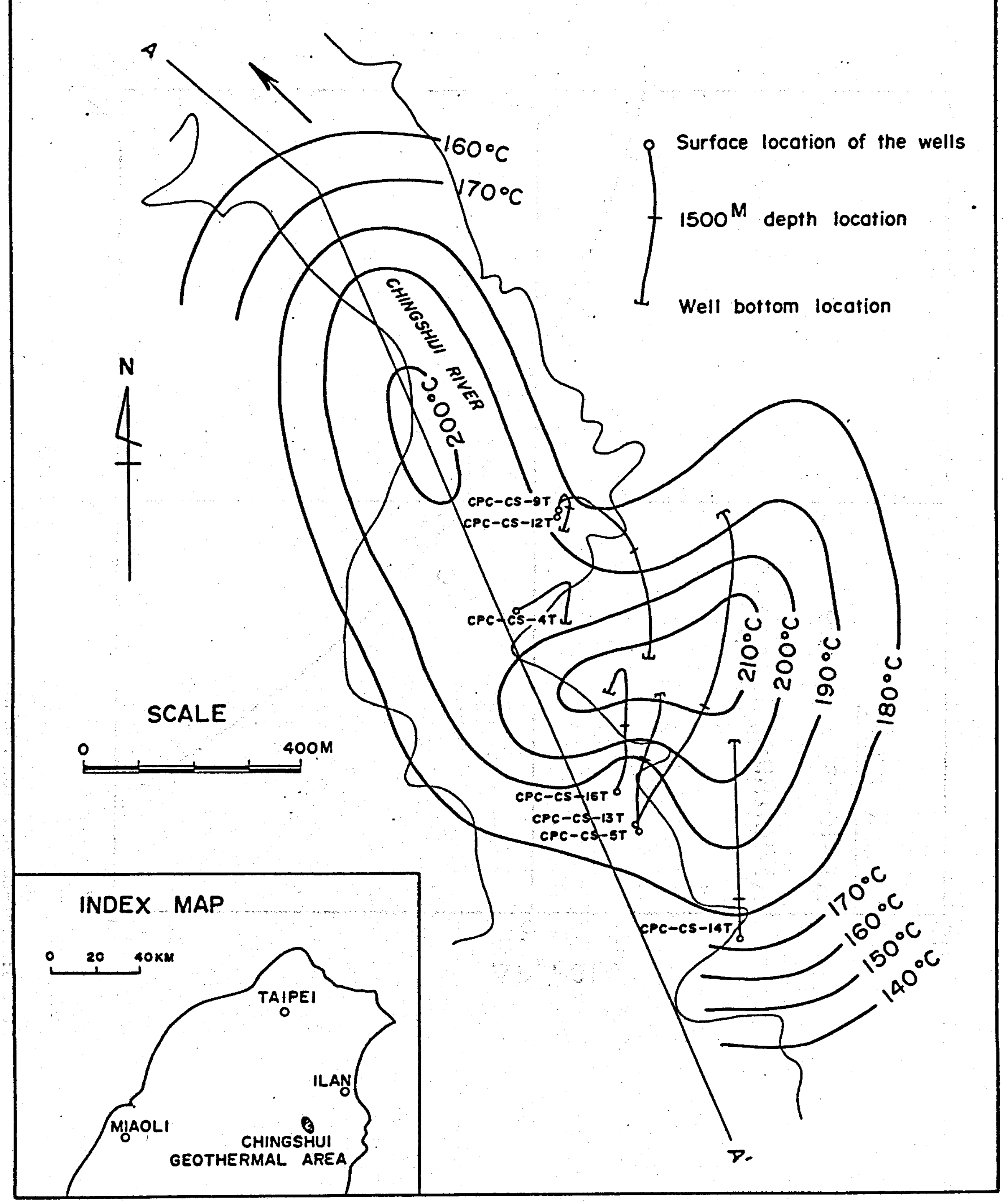


FIG. 1: CONTINUOUS LINE-SOURCE SOLUTION TYPE-CURVE

FIG. 2: Location of the wells and the Isotherms of Presumed Formation Temperature for 1500M depth in the Chingshui Geothermal Area



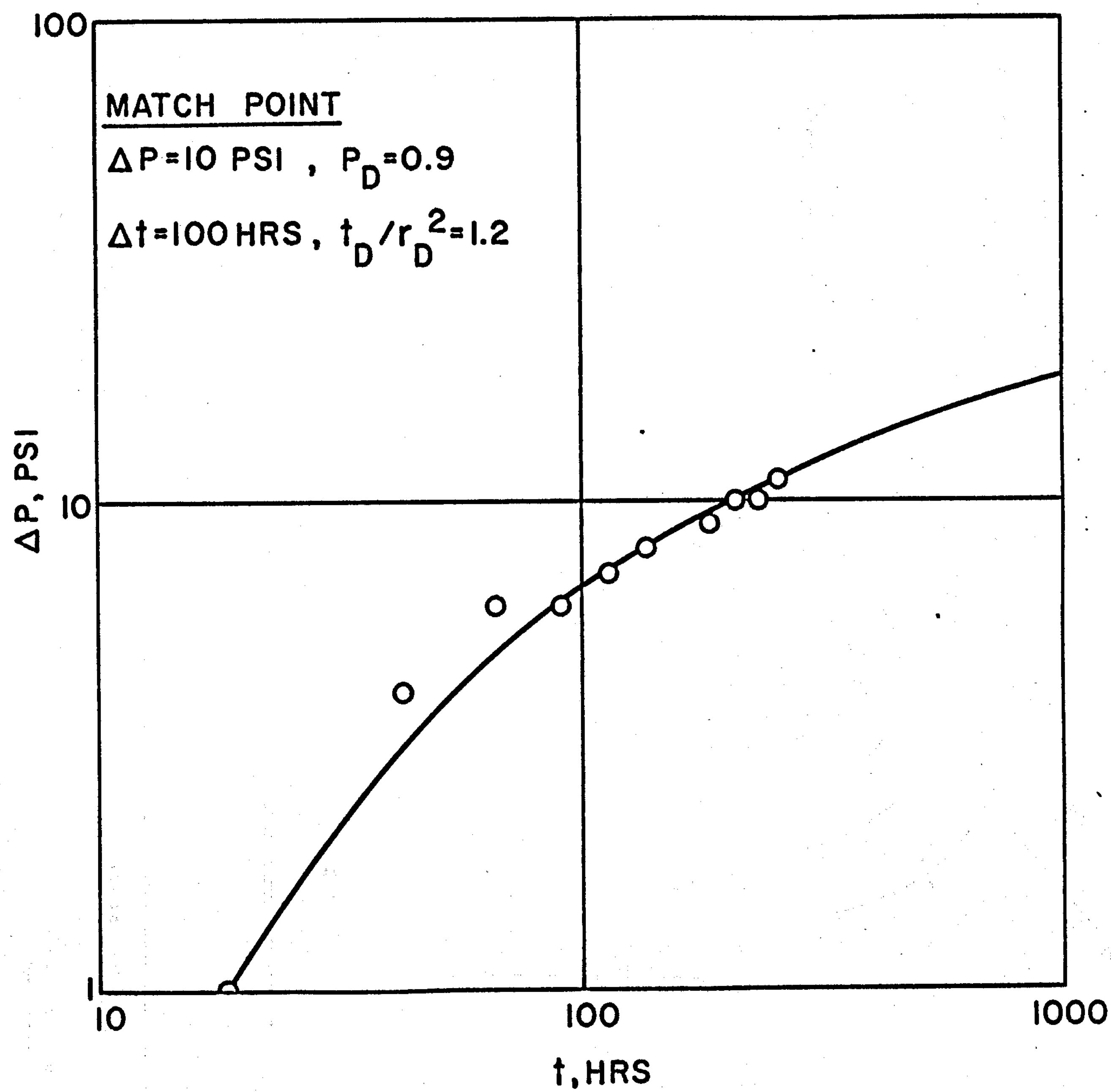


FIG. 3: TYPE-CURVE MATCH FOR WELL 4T

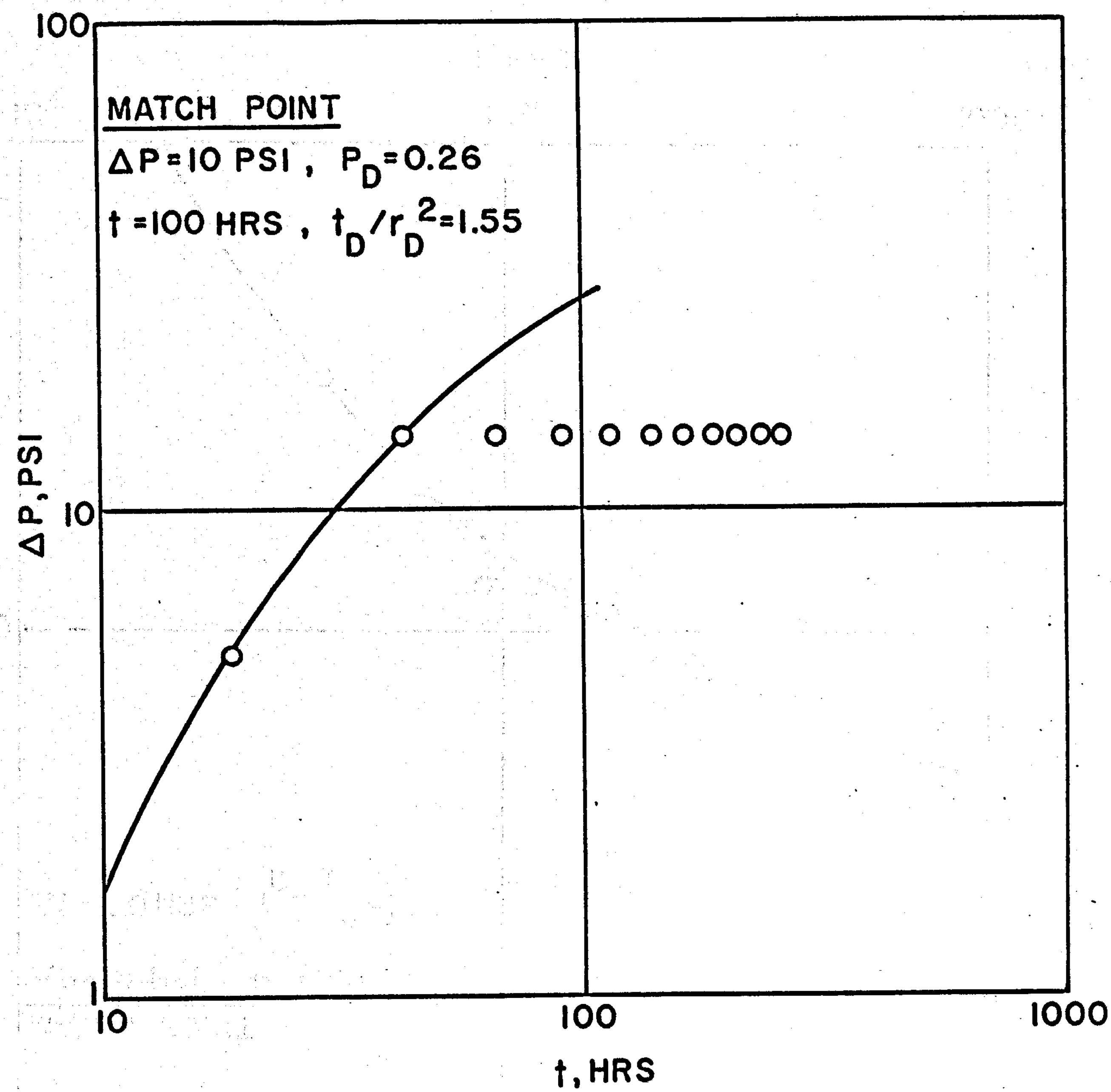


FIG. 4: TYPE-CURVE MATCH FOR WELL 5T

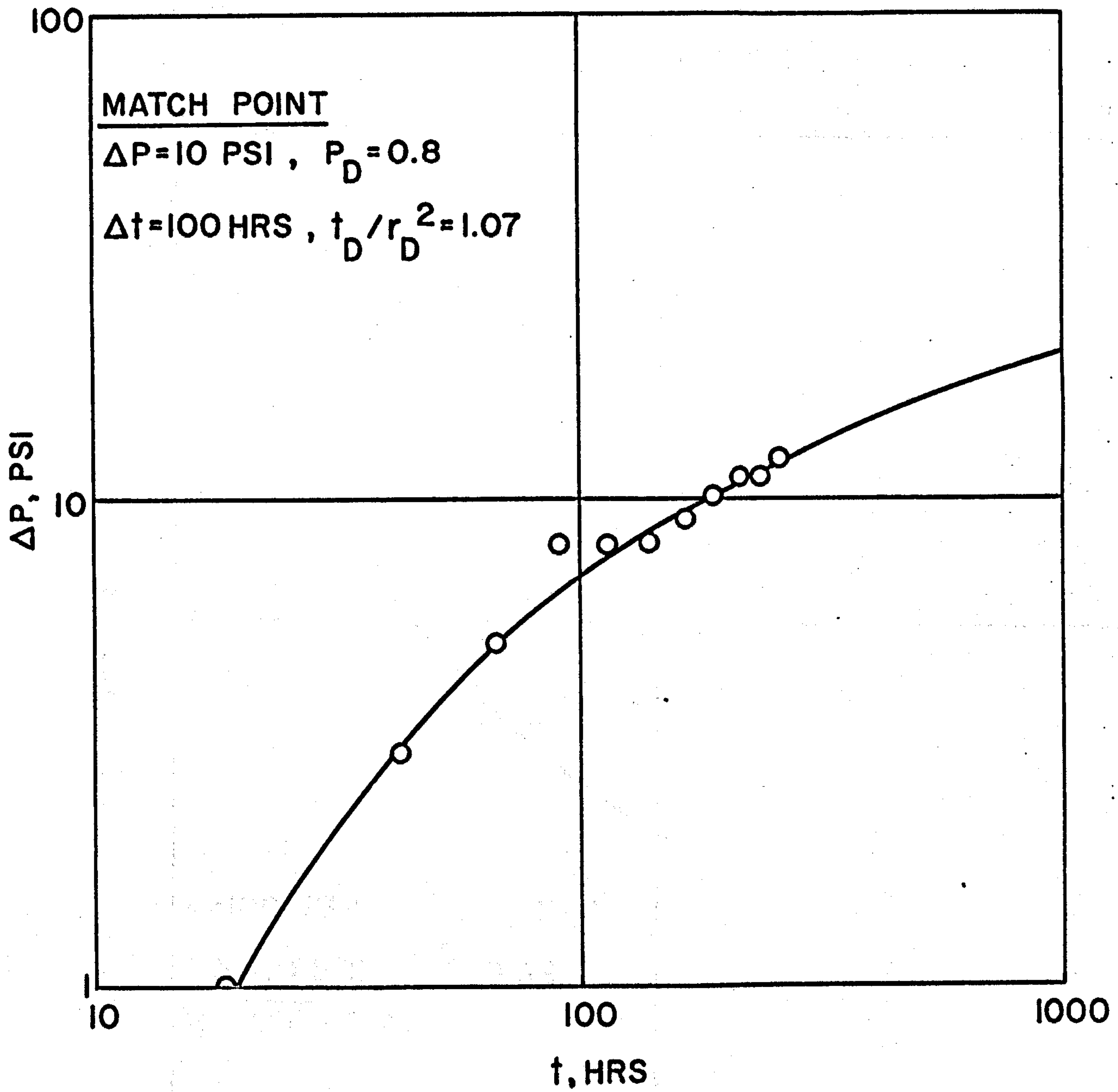


FIG. 5: TYPE-CURVE MATCH FOR WELL 9T

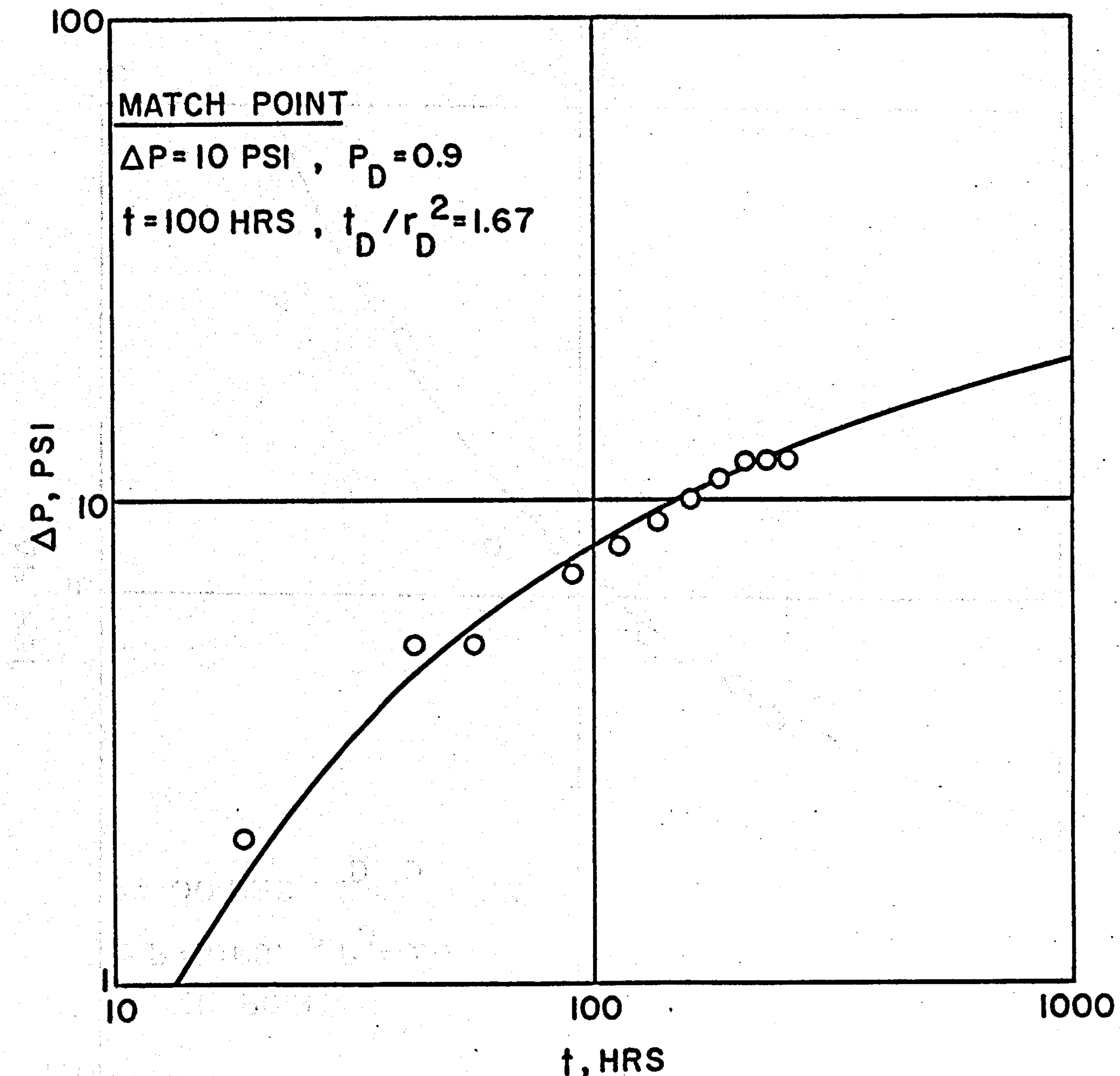


FIG. 6: TYPE-CURVE MATCH FOR WELL 12T

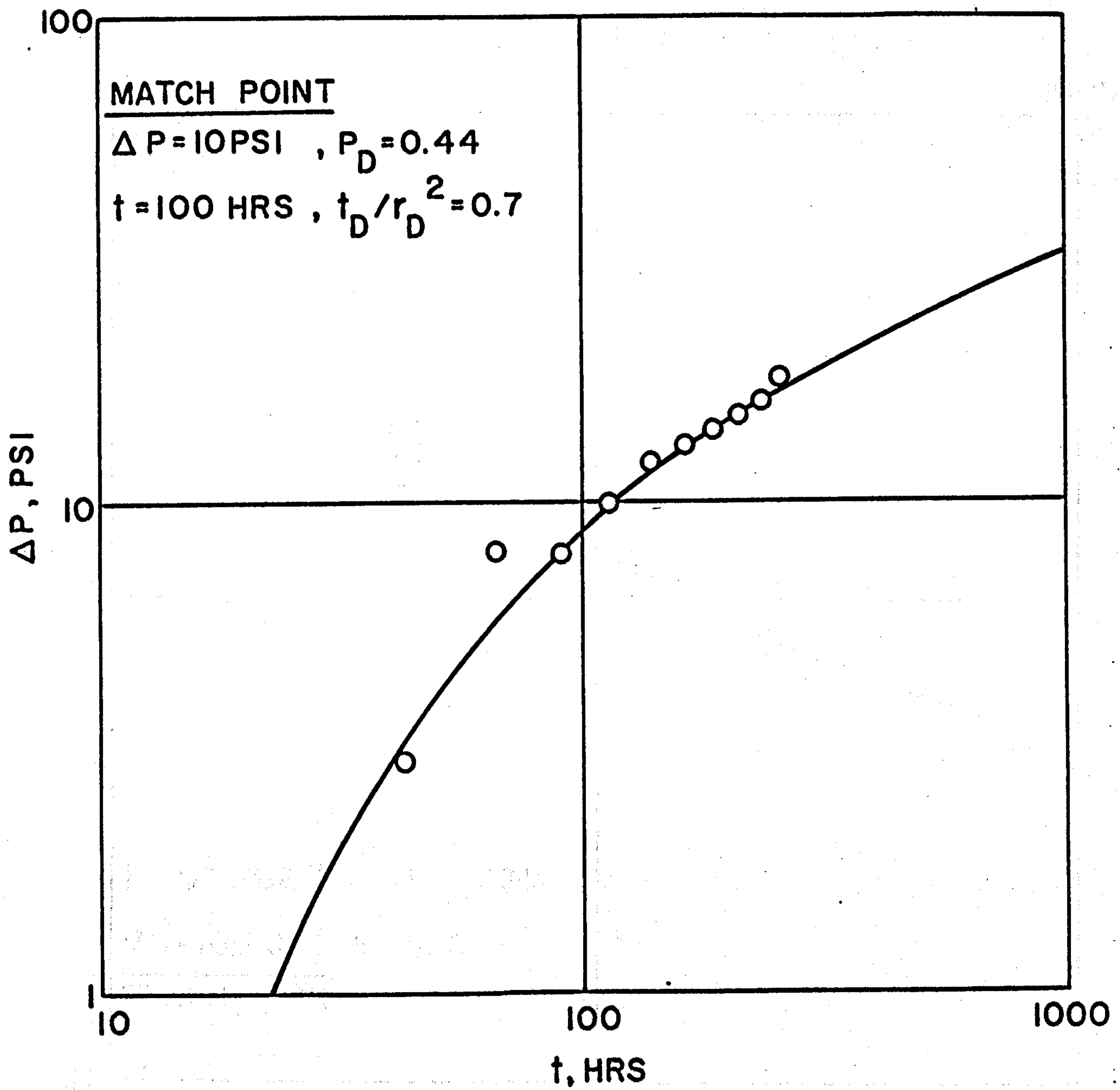


FIG. 7: TYPE-CURVE MATCH FOR WELL 14T