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THE IMPLEMENTATION OF A FRACTAL MODEL TO ANALYZE INTERFERENCE TEST DATA IN THE DARAJAT GEOTHERMAL FIELD

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ABSTRACT

This paper describes the implementation of an advance model based on a fractal interpretation of the fractured medium. Using the fractal concept, type curves for analyzing pressure transient test data have been devoloped. Using the resulting formulation several type curves have been generated for analyzing the interference test data in the geothermal reservoirs especially in naturally fracture reservoirs.

The objectives of this study were to implement the new type curve for analyzing interference test data in the Darajat Geothermal Field, Amoseas Indonesia, Inc., to obtain reservoir characteristics such as permeability, transmissibility, storativity and fractal dimension.

The results of interference tests match perfectly on the type curve generated using the fractal model and the proposed type curves perform better than the conventional one, especially in evaluating early time data of the interference test and the dimension of fractal medium.

1. INTRODUCTION

The use of a fractal model in Pressure Transient Test Analysis was introduced by Chang and Yortsos in 1990. Their concept was derived from assumtion of Warren and Root model where the reservoir contains two systems with contrast in porosity and pemeability properties, which are known as matrix and fracture network.

The fracture network is assumsed to be connected and distributed as an fractal object in a homogeneous medium (matrix) of Euclidean Geometry. Fluid flow from reservoir to well occurs only through the perfectly connected fracture network. Based on these assumtions, Chang and Yortsos developed the unsteady-state flow of slightly compressible fluid and proposed an extension of the diffusivity equation to model transient flow in fractal reservoirs, especially in single well testing (Pressure Drawdown and Pressure Buildup Testing).

This paper presents the application of a fractal model in multiple well testing (particularly in Interference Testing). The physical and mathematical model descriptions are developed from the Chang and Yortsos model. By Type Curve Matching technique, we can analyze the interference test data in reservoirs considered as a complex naturally reservoir like the Darajat geothermal field. Besides transmisibility and storativity we can also obtain the fractal dimension of the reservoir which can be used to predict the complexity of the reservoir.

2. DEVELOPMENT OF THE PROPOSED MODEL

The fractal model is able to describe the complex naturally fractured reservoir which has a large number of different scales, poor fracture connectivity and disordered spatial distribution[6]. In the pressure transient case, the implementation of the fractal model has been examined by Acuna et al[2], for analyzing single well test data in the naturally fractured reservoir of a geothermal field.

Using their model, the method that could be used in the Interference Test Analysis was developed. By considering at least two interference wells in a fractal reservoir, one of them is an active well and the others are observation wells, a pressure transient equation was formulated by Abdassah and Aprilian[7]. Using that equation a procedure of type curve matching is then proposed for analyzing some reservoir parameters such as permeability, transmissibility, storativity and fractal dimension.

2.1. Mathematical Model

From the Chang and Yortsos concept[6], the general form of the pressure transient equation in a fractal reservoir for a single well can be written as :

$$P_D(r_D, t_D) = \frac{r_D^{\theta+2-D}}{\Gamma(\delta)(\theta+2)} \int_y^{\infty} z^{\delta-2} \exp(-z)\,dz \quad (1)$$

where :

$$y = \frac{r_D^{\theta+2}}{(\theta+2)^2 t_D} \quad (2)$$

$$\delta = \frac{D}{\theta+2} \quad (3)$$

Equation (1) can be rewritten as :

$$PDF(r_D, t_D) = \frac{(\theta+2)^{1-2\delta}}{\Gamma(\delta)(1-\delta)} t_D^{1-\delta} \exp\left(-\frac{1}{(\theta+2)^2 TDF}\right) + \frac{\Gamma(\delta-1)}{\Gamma(\delta)(\theta+2)} \quad (4)$$

Equation (4) shows that the dimensionless pressure is a function of dimensionless time and distance. Based on this equation, the formulation for the Interference Test case is then developed by involving several assumptions as follows :

- The tested reservoir is a fractal reservoir, infinite acting, horizontal and uniform thickness.
- At least two interference wells, one of them is active well (either produced or injected well with constant rate) and others are observation wells.
- Both skin and wellbore storage effects at each well are negligible.

2.2. The Proposed Type Curves

In generating the proposed type curves, the equation was derived based on the dimensionless variables of pressure, time and spatial coordinate which had been defined by Chang and Yortsos. These dimensionless variables are :

$$P_D = \frac{2\pi k_f(r) h r_D^{\theta+2-D}}{q\mu}(Pi - P) \quad (5)$$

$$t_D = \frac{k_f(r) t \; r_D^{\theta+2}}{\phi_f(r)\mu C_t r_b^2} \quad (6)$$

$$r_D = \frac{r}{r_w} \quad (7)$$

where r_b is the distance between two interference wells. By introducing the parameter δ, as defined in Equation (3) into Equation (5), the equation becomes :

$$\frac{P_D}{r_D^{(\theta+2)(1-\delta)}} = \frac{k_f(r)h}{141.2qB\mu}(Pi - P) \quad (8)$$

If the left hand side of Equation (8) or $\frac{P_D}{r_D^{(\theta+2)(1-\delta)}}$ is defined as a Dimensionless Pressure Function (PDF). The equation then can be written in field units as :

$$PDF = \frac{2\pi k_f(r)h}{q\mu}(Pi - P) \quad (9)$$

Similar to the above steps, equation (6) becomes :

$$TDF = 0.0002637 \frac{k_f(r)t}{\phi_f(r)\mu C_t r_b^2} \quad (10)$$

By substituting Equation (9) and (10) into Equation (2), we obtain :

$$PDF(r_D, t_D) = \frac{(\theta+2)^{1-2\delta}}{\Gamma(\delta)(1-\delta)} t_D^{1-\delta}\exp\left(-\frac{1}{(\theta+2)^2 TDF}\right) + \frac{\Gamma(\delta-1) r_D^{(\theta+2)(1-\delta)}}{\Gamma(\delta)(\theta+2)} \quad (11)$$

For relatively large TDF the exponential value of this equation is approximately equal to one, or TDF ≈ t_D. Consequently the PDF is linearly proportional to $t_{D1-\delta}$. On the other hand, the plot of PDF versus TDF in a log scale will produce a straight line for relatively large TDF (at late time period) with slope of (1-δ). A early time or at small TDF, the plot PDF versus TDF is a function of :

$$t_D^{1-\delta}\exp\left(-\frac{1}{(\theta+2)^2 TDF}\right) \quad (12)$$

Using Equation (11), the type curves then can be generated by plotting PDF versus TDF for different values of θ between 0 and 0,5 (Acuna et al[1,2]). The resulting plots show that the curves from various values of θ are parallel to each other (see Figure 1) and each of them is not a function of the tested well distance. In the study, therefore the average value of θ or 0, 25 was chosen and used further in generating the type curves. The resulting type curve can be seen in Figure 2.

The type curve of dimensionless pressure derivative was also generated, by plotting the derivative of PDF versus TDF on logarithmic paper (see Figure 3), based on the following equation :

$$\frac{dPDF}{d\ln TDF} = \frac{t_D^{1-\delta}\exp\left(-\frac{1}{(\theta+2)^2 TDF}\right)}{\Gamma(\delta)(\theta+2)^{2\delta-1} r_D^{(\theta+2)(1-\delta)}} \quad (13)$$

The plot of dlog PDF/dlog TDF versus TDF was also generated in this study and the result is presented in Figure 4. This plot could be used to identify the existence of fractal structure since the same tends to the constant value of (1-δ).

2.3. The Type Curve Matching Procedures

The matching procedure used in this study (Figure 3) is similar to that developed by Earlougher[2]. The procedure is performed by plotting of ΔP versus Δt on log-log paper with the same scale as the one in the type curve. After the matching process is completed and then a match point is selected arbitrarily. Calculation of the reservoir properties then can be performed by using the following equation :

$$\frac{k_f(r)h}{\mu} = 1.1513 \cdot W \cdot \frac{RZT}{M_s}\frac{(PDF)_{MP}}{(\Delta P)_{MP}} \quad (14)$$

$$\phi_f(r)\, C_t\, h = 6.8180.10^{-9} B \frac{1}{r_b^2}\frac{k_f(r)h}{\mu}\frac{t_{MP}}{(TDF)_{MP}} \quad (15)$$

Equations (14) and (15) in this case, are used for determining transmissibility and storativity of the reservoir, respectively. In addition to that, Fractal Dimension (D) of the reservoir can also be determined simultaneously from the matching. It should be remembered that the type curves used in this calculation were generated using the value of θ (conductivity ratio) equal to 0.25.

3. RESULTS

The interference test data used in this study were taken from the Darajat Geothermal Field operated by Amoseas Indonesia Inc. About 100 days of interference test programs were carried out by Amoseas[4]. The active well was DRJ#21 and monitor wells were DRJ#16 and DRJ#S_1 both of which had interference responses. The pressure response data can be seen in Table 1 and Table 2.

By the type curve matching procedure, a perfect match can be obtained on the curve which corresponds to δ = 0.8 for DRJ#16 and δ = 0.5 for DRJ#S_1 (Figure 5 and 6), using the corresponding values of both test data and dimensionless parameters at the selected match point.

Using these relations we can determine transmissibility, storativity and fractal dimension of the Darajat Geothermal Field, and the results shown in Table 3. The plots of the field data were also performed for both pressure derivative and pressure slope curves as shown in Figure 7 and Figure 8 respectively.

4. DISCUSSION

The equation used for the interference pressure test case in this study, is simply an extension of the pressure transient equation of a fractal reservoirs has been developed for single well case by the Chang and Yortsos. The extension of the equation in this case is done by substituting the radius distance of the single well equation by the distance between the two wells of the interference test problem. In the case of pressure interference test, the reservoir properties evaluated could represent an average reservoir properties of the area between the two interference wells. For the single well tests case, on the other hand, the reservoir properties evaluated would represent an average reservoir properties of the surrounding well only. Besides transmissibility and storativity, an important reservoir parameter that could be determined using this particular type curve is the fractal dimension. This parameter can be used for identifying the complexity of a reservoir. From previous works, however, this parameter can not be determined.

In order to obtain a correct match in the type curve matching, all data points must be able to match perfectly on the type curves, including at early time, intermediate and late time data. Using the conventional type curve, however data points obtained from the interference test in Darajat Geothermal field can not be match with the type curve at early time as shown in Figure 9 and 10. The matching process was also performed on the pressure derivative and the slope curves, but they show a poor match. This phenomenon could be improved by introducing a smoothing technique on the measured data.

The results from interference test analysis with the fractal type curves and conventional curves shown in Table 3. Compared with the conventional type curve, the implementation of a fractal model using the new type curve is able to better match the observed pressure data and gives more information than conventional model, especially in a fractal concept the dimension of fractal could estimate.

5. CONCLUSIONS

1. The results of interference test from Darajat Geothermal field, Amoseas Indonesia Inc., match perfectly on the type curve generated using the fractal model.
2. The proposed type curves perform better than the conventional one, especially in evaluating for early time data of the interference test and dimension of a fractal medium.
3. From the matching technique using the proposed type curves, the important reservoir parameters such as transmissibility, storativity, and the fractal dimension can be evaluated.
4. Based on the value of transmissibility results, the DRJ#16 and DRJ#S_1 wells were the potential productive zones.

NOMENCLATURE

B	= formation volume factor, RB/STB
C_t	= total compressibility, psi^{-1}
D	= fractal dimension
h	= formation thickness, ft
k	= permeability, mD
P	= pressure, psi
PDF	= Dimensionless Pressure Function
q	= production rate, STB/day
r_b	= the distance of tested wells, ft
r_w	= the radius of wellbore, ft
t	= time, hour
TDF	= Dimensionless Time Function
y	= transform variable defined by Equation (2)
z	= dummy variable
Γ	= gamma function
δ	= variable defined by Equation (3)
θ	= conductivity index
μ	= viscosity, cp
ϕ	= porosity, fraction
β	= $D - \theta - 1$

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Table 1. The Pressure Response in Well - DRJ#16

t (hours)	P (psia)	ΔP (psia)
7	514.0044	0.9956
22	513.9545	1.0455
34	513.8625	1.1375
48	513.7955	1.2045
62	513.6759	1.3241
72	513.6310	1.3690
85	513.5410	1.4590
102	513.4973	1.5027
115	513.4229	1.5771
131	513.4229	1.6367
143	513.3633	1.6963
157	513.3037	1.7409
167	513.2591	1.7856
181	513.2144	1.8302
192	513.1698	1.8451
202	513.1549	1.9195
225	513.0805	1.9493

Table 2. The Presssure Response in Well - DRJ#S_1

t (hours)	P (psia)	ΔP (psia)
3	368.8245	1.1755
6	368.7930	1.2070
12	368.6500	1.3500
24	368.2740	1.7260
48	367.5955	2.4045
72	367.2040	2.7960
96	366.6210	3.3790
120	366.3440	3.6560
144	365.9220	4.0780
168	365.4435	4.5565
192	365.1245	4.8755
216	364.9900	5.0100
240	364.6645	5.0355
264	364.2745	5.7255
288	363.8395	6.1605
312	363.4055	6.5945
336	363.1390	6.8610

Table 3. The Results of Interference Test Analysis

WELLS	PARAMETERS	CONVENTIONAL	FRACTAL
DRJ#16	Transmissibility, kh/μ (md.m/cp)	763×10^5	827×10^5
	Pcrmcability Thicknccs, kh (mD.m)	1297	1406
	Storativity, $\phi C_t h$ ($psia^{-1}$.m)	1.9729×10^{-7}	4.1433×10^{-6}
	Dimension of Fractal, D	-	1.8
DRJ#S_1	Transmissibility, kh/μ (md.m/cp)	143×10^5	167×10^5
	Permeability Thickness, kh (mD.m)	243	285
	Storativity, $\phi C_t h$ ($psia^{-1}$.m)	2.2388×10^{-7}	2.6247×10^{-6}
	Dimension of Fractal, D	-	1.125

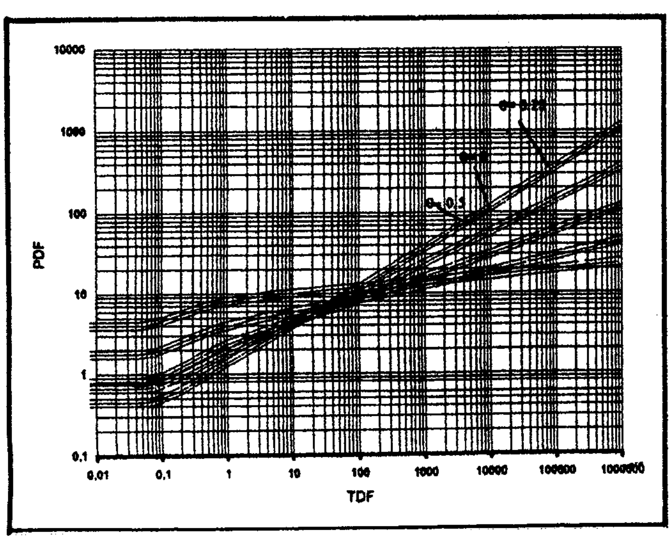

Figure 1. Plot of PDF vs TDF for Different Values of θ

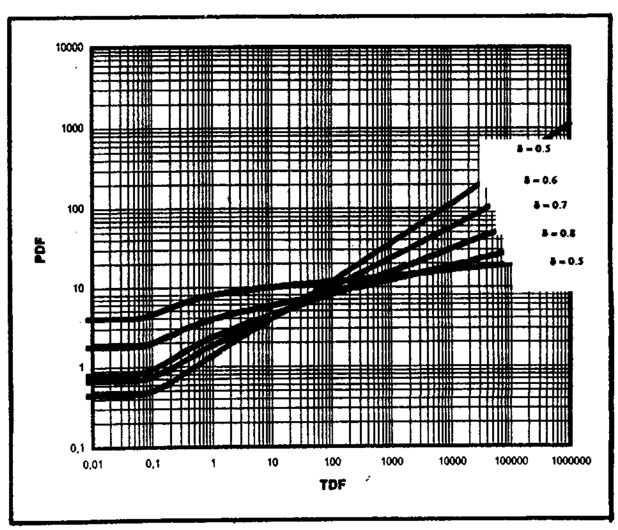

Figure 2. Plot of PDF vs TDF for Different Values of δ

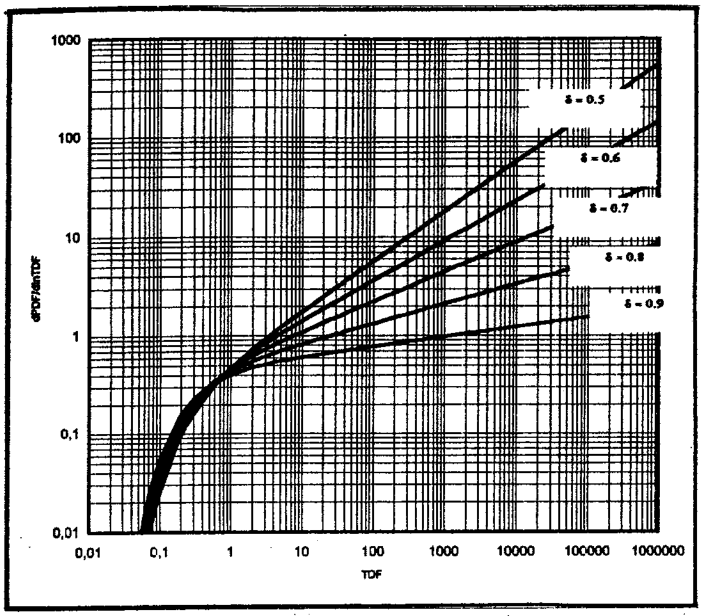

Figure 3. Derivative Plot of PDF vs TDF

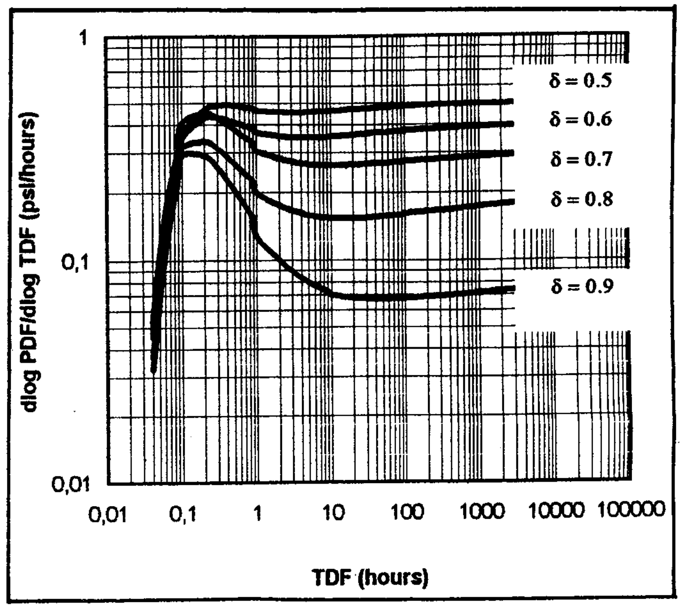

Figure 4. Plot of dlog PDF/ dlog TDF vs TDF

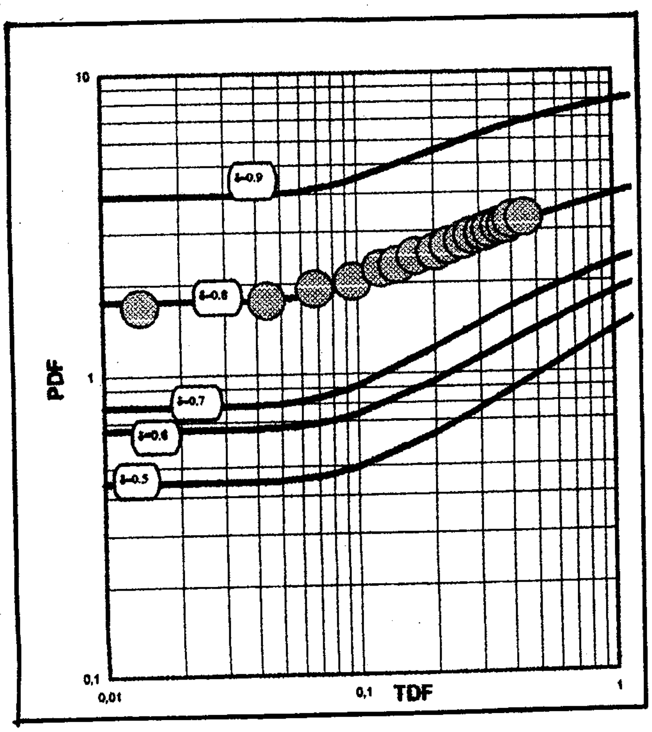

Figure 5. The Type Curve Matching of DR#16

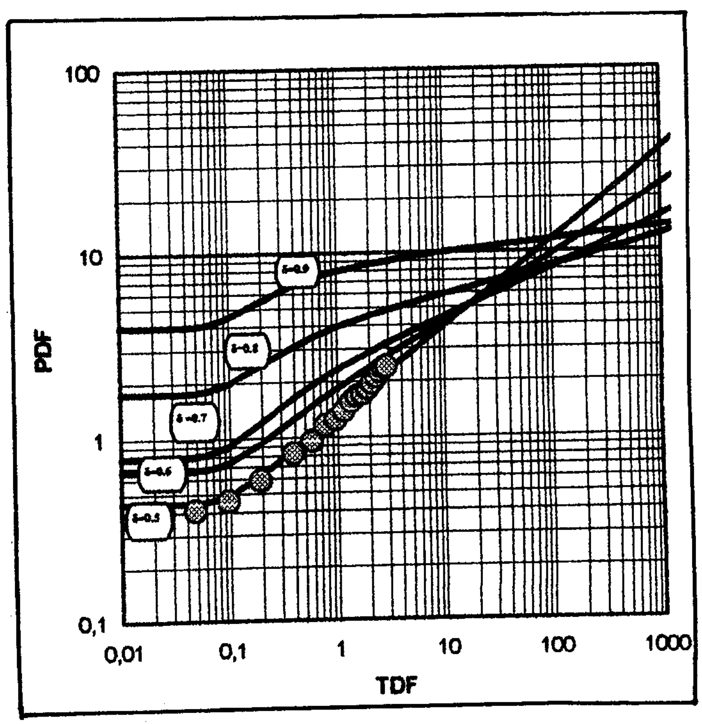

Figure 6. The Type Curve Matching of DR#S_1

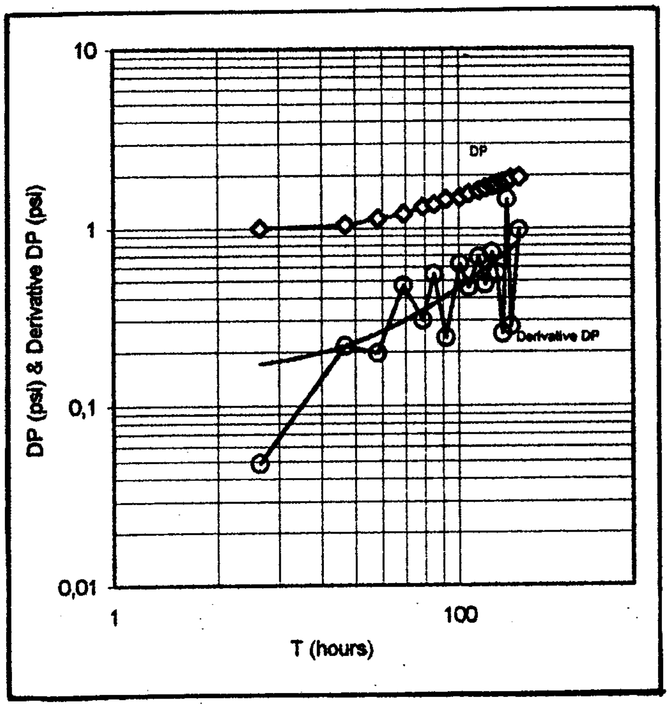

Figure 7. Plot of Pressure and Derivative Pressure DRJ#16

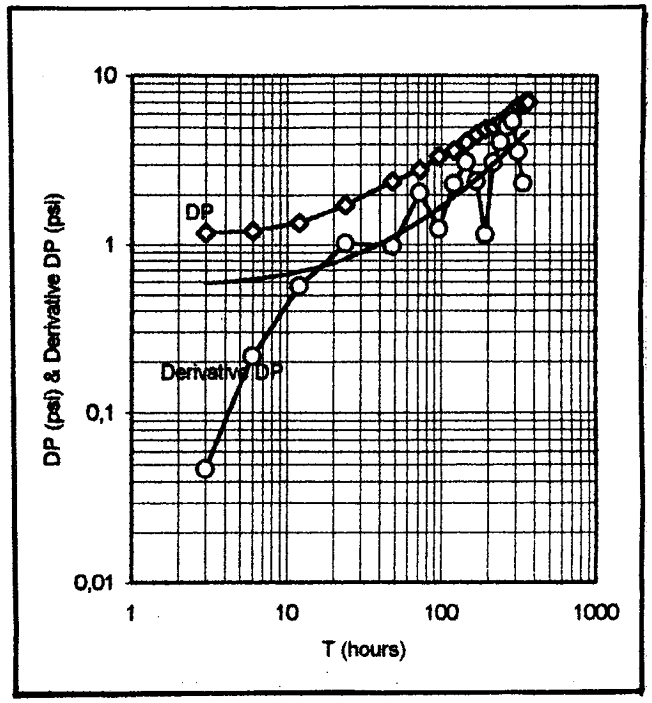

Figure 8. Plot of Pressure and Derivative Pressure DRJ#S_1

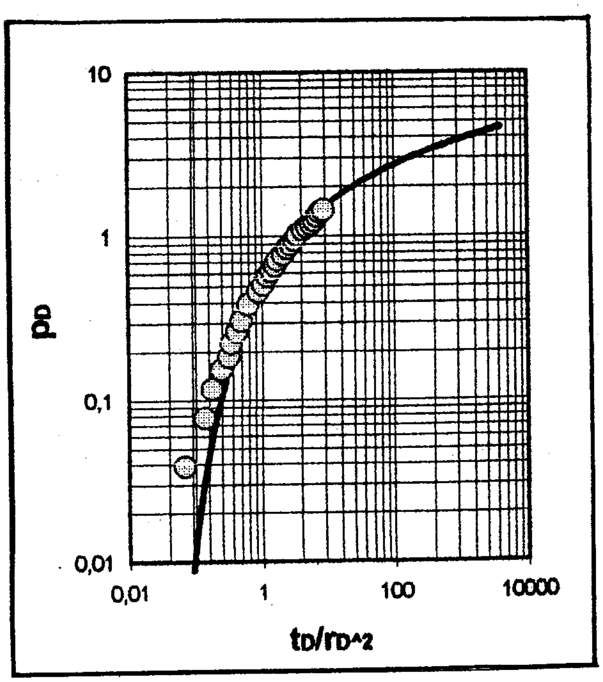

Figure 9. The Type Curve Matching of DR#16
Using Conventional Type Curve

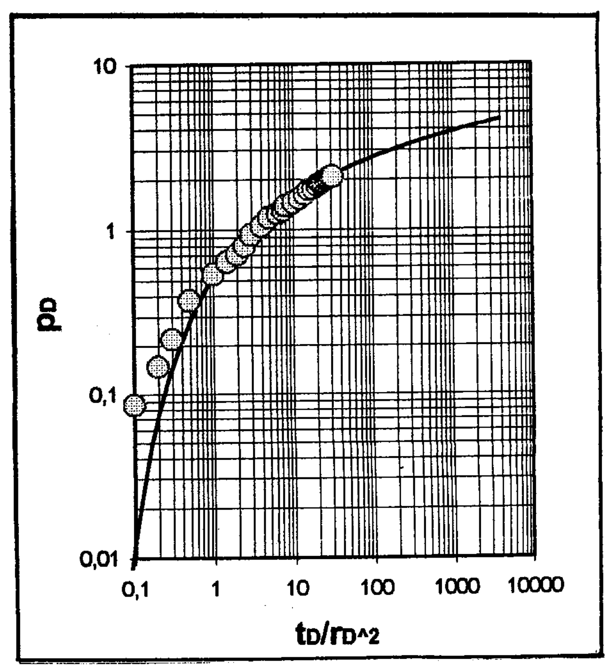

Figure 10. The Type Curve Matching of DR#S_1
Using Conventional Type Curve