PROCEEDINGS, Twenty-Sixt Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 29-31, 2001-01-27
SGP-TR-162

"ADVANCES IN THE ANALYSIS OF PRESSURE INTERFERENCE TESTS"

Néstor Martínez R[1]. and Fernando Samaniego V[2].

[1,2] Pemex and UNAM, México, D.F.
ance@servidor.unam.mx

ABSTRACT

This paper presents an extension for linear and spherical flow conditions of the El-Khatib's method for the analysis of pressure interference tests through the use of the pressure derivative. For linear flow a graph of $\mathrm{Ln}\left|\sqrt{t}\ \partial\Delta p_{wf} / \partial t\right|$ vs 1/t should show a straight line with slope m_l and intercept b_L, which can be used to estimate the formation permeability and porosity; similarly, for spherical flow a graph of $\mathrm{Ln}\left|\sqrt{t^3}\partial\Delta p_{wf} / \partial t\right|$ vs 1/t should show a straight line with slope m_{sph} and intercept b_{sph}, which can be used to estimate the same above discussed parameters. A friendly computer code for the automated analysis of pressure interference tests is also discussed. Two field cases are presented to show the use of this program. The first deals with the interference tests conducted in the naturally fractured Klamath Falls geothermal field and the second is a test carried out in a river formed bed, dominated by linear flow conditions.

INTRODUCTION

Pressure interference tests were first described by Jacob (1940) for water producing wells, presenting a graphical method of analysis. Later in the petroleum engineering literature this method was known as type curve analysis (Ramey, 1970; Earlougher, 1977, Kamal 1983).

Conventionally the analysis of interference tests has considered radial flow; however, there are physical field flow conditions in some reservoirs where other flow conditions prevail, such as linear and spherical flow. The type curve matching method has the inherent disadvantage of the analysis dependency on the interpreter subjectivity, and the non-linear regression methods match the data to the selected reservoir flow model, with the disadvantage of being strongly affected by the data noise.

Usually the interpretation of these tests is carried out through the type curve technique or non-linear regression; in some special cases when the test time has been large and radial flow conditions prevail, it is possible to apply the semilogarithmic analysis based on a straight line fit of the pressure data.

El-Khatib (1987) developed an interference interpretation method based on the use of the pressure derivative that uses pressure data ranging from short to large times.

The main aim of this paper is to present an extensions for radial linear and spherical flow conditions of the El-Khatib's method for the analysis of pressure interference tests through the use of the pressure derivative. A friendly computer system for the automated analysis of pressure interference tests is also discussed.

EL-KHATIB'S METHOD

The transient radial flow solution has been the most used to interpret interference tests. This equation is usually known as the line source solution (Matthews and Russell, 1967):

$$\Delta p_r = \frac{\alpha q B \mu}{kh}\left[-\frac{1}{2}E_i\left(-\frac{\phi\mu c_t r^2}{4\beta kt}\right)\right]. \qquad (1)$$

The author derived this equation with respect to time:

$$\frac{\partial \Delta p_r}{\partial t} = \Delta p'_r = -\frac{\alpha/2qB\mu}{kh}\frac{e^{-948\phi\mu c_t r^2/kt}}{t}, \qquad (2)$$

where field units have been used.

Multiplying Eq. 2 by -t and taking logarithms of both sides:

$$\mathrm{Ln}\left(-t\,\Delta p'_r\right) = \mathrm{Ln}\left(\frac{\alpha q B\mu}{2kh}\right) - \frac{948\phi\mu c_t r^2}{kt} = \mathrm{Ln}(A) - \frac{b}{t}. \qquad (3)$$

It can be concluded from Eq. 3 that a semilogarithmic graph of $\mathrm{Ln}\left(-t\,\Delta p'_r\right)$ vs 1/t will show a straight line of slope (b) and ordinate to the origin (A), which can be used to estimate the transmissivity T and the formation storativity S:

$$T=\frac{kh}{\mu}=\frac{\alpha qB}{2A};\quad S=h\phi c_t=\frac{Tb}{948r^2}. \qquad (4)$$

The author also developed a technique for the analysis of an interference test under the influence of a two-rate flow variation at the active well.

DEVELOPMENT OF THE NEW THEORY

Based on the previous work of El-Khatib, in this paper extensions are presented for radial, linear and spherical flow conditions.

Radial Flow

In the present paper, Eq. 2 was generalized for a sequence of N pressure pulses; the resulting equation is given by

$$\mathrm{Ln}\left|\Delta t(\Delta p'_r + C_i)\frac{q_1}{(q_{i-1}-q_i)}\right| = \ln A - \frac{b}{\Delta t}, \qquad (5)$$

where

$$C_i = A\left\{\begin{array}{l}\dfrac{e^{-b/(t_i+\Delta t)}}{(t_i+\Delta t)}\\ +\displaystyle\sum_{k=1}^{i-1}\frac{e^{-b/(t_i+\Delta t-t_k)}}{(t_i+\Delta t-t_k)}\left(\frac{q_{k+1}-q_k}{q_1}\right)\end{array}\right\}. \qquad (6)$$

Equations 5 and 6 are the basis upon which a general N pressure pulses, interference radial flow test can be analyzed; Eq. 5 can be applied to analyze any of the pulses or to the N pulses for a global analysis. Fig. 1 describes the rate versus time sequence in a N pulse test. It is important to notice that the data gathered for the N pulses where graphed in accordance to Eq. 5 follow a semilogarithmic straight line. This result is also valid for the forthcoming discussions related to linear and spherical flows.

Spherical Flow

Chatas (1966) described the geometrical characteristics of spherical reservoir systems, the unsteady state flow of such systems and examples of engineering applications. Engineering concepts were investigated to indicate particular solutions of interest. For the case of constant rate, the pressure drop Δp_{sph} has been expressed by

$$\Delta p_{sph}=\frac{\alpha qB\mu}{2kr}\mathrm{erfc}\left(\sqrt{\frac{\phi\mu c_t r^2}{4\beta kt}}\right). \qquad (7)$$

Following a similar approach to that previously described for radial flow, based on Eq. 7 a pressure derivative with respect to time was obtained:

$$\frac{\partial\Delta p_{sph}}{\partial t}=-\frac{\alpha qB\mu}{2\sqrt{\pi}kr}\sqrt{\frac{\phi\mu c_t r^2}{4\beta kt^3}}\,e^{-\left(\frac{\phi\mu c_t r^2}{4\beta kt}\right)}. \qquad (8)$$

Multiplying Eq. 8 by $\sqrt{t^3}$

$$\sqrt{t^3}\frac{\partial\Delta p_{sph}}{\partial t}=-\frac{\alpha qB\mu}{2\sqrt{\pi}kr}\sqrt{\frac{\phi\mu c_t r^2}{4\beta k}}\,e^{-\left(\frac{\phi\mu c_t r^2}{4\beta kt}\right)}. \qquad (9)$$

Multiplying by (-1) and taking logarithms of both sides, Eq. 9 becomes

$$\mathrm{Ln}\left|-\sqrt{t^3}\frac{\partial\Delta p_{sph}}{\partial t}\right|= \mathrm{Ln}\left(\frac{\alpha qB\mu}{2\sqrt{\pi}k}\sqrt{\frac{\phi\mu c_t}{4\beta k}}\right)-\frac{\phi\mu c_t r^2}{4\beta kt}=\mathrm{Ln}(A)-\frac{b}{t}. \qquad (10)$$

This equation tells us that if we plot $\mathrm{Ln}\left|-\sqrt{t^3}\Delta p'_{sph}\right|$ vs 1/t, we should obtain a straight line. If we express Eq. 10 in base 10 logarithms we can find

$$\frac{k}{\mu}=\frac{\phi c_t r^2}{4\beta\mathrm{Ln}(10)b};\ f c_t=\frac{2a\,bqB}{10^A}\sqrt{\frac{(\mathrm{Ln}(10)b)^3}{p\,r^6}}. \qquad (11)$$

The general interpretation equation of the ith pulse can be written:

$$\mathrm{Ln}\left|\sqrt{\Delta t^3}(\Delta p'_{sf}+C_i)\frac{q_1}{(q_{i-1}-q_i)}\right|=\mathrm{Ln}A-\frac{b}{\Delta t}, \qquad (12)$$

where

$$C_i = A\left\{\begin{array}{l}\dfrac{e^{-b/(t_i+\Delta t)}}{\sqrt{(t_i+\Delta t)^3}}+\\ \displaystyle\sum_{k=1}^{i-1}\frac{e^{-b/(t_i+\Delta t-t_k)}}{\sqrt{(t_i+\Delta t-t_k)^3}}\left(\frac{q_{k+1}-q_k}{q_1}\right)\end{array}\right\}. \quad (13)$$

Linear Flow

Linear Flow is exhibited in interference tests in formations with linear geometry. Fig. 2 shows a schematic view of a test under linear flow conditions. Miller (1960) presented solutions for the pressure distribution in linear systems. For the purpose of this paper, only his solution for the case of a well producing at a constant rate in an infinite system will be considered. For pressure interference tests Miller's solution can be used considering that only half of the flow rate of the active well comes from the observation well side (Fig. 2). The pressure drop for this flow conditions is given by

$$\Delta p_L = 2\pi\alpha\frac{qB\mu}{kbh}\left[\begin{array}{l}\sqrt{\dfrac{4\beta\eta t}{\pi}}\,e^{-\left(\frac{x^2}{4\beta\eta t}\right)}\\ -x\,erfc\left(\sqrt{\dfrac{x^2}{4\beta\eta t}}\right)\end{array}\right]. \quad (14)$$

Similarly to the previous discussions on radial and spherical flows, based on Eq. 14, a pressure derivative with respect to time was obtained

$$\frac{\partial\Delta p_L}{\partial t} = A\left[\begin{array}{l}2\dfrac{\partial}{\partial t}\left(\sqrt{t}\,e^{-\left(\frac{b}{t}\right)}\right)-\\ \sqrt{\dfrac{\pi\phi\mu c_t x^2}{\beta k}}\dfrac{\partial}{\partial t}erfc\left(\sqrt{\dfrac{b}{t}}\right)\end{array}\right], \quad (15)$$

where

$$A = 2\pi\alpha\frac{qB\mu}{kb_L h}\sqrt{\frac{\beta k}{\pi\phi\mu c_t}}\ ;\quad b = \left(\frac{x^2}{4\beta\eta}\right). \quad (16)$$

Eq. 15 can be simplifier, obtaining

$$\frac{\partial\Delta p_L}{\partial t} = 2\pi\alpha\frac{qB\mu}{kbh}\sqrt{\frac{\beta\eta}{\pi t}}\,e^{-\left(\frac{x^2}{4\beta\eta t}\right)}. \quad (17)$$

Multiplying by $\sqrt{t}$ and taking logarithms of sides of this equation, we obtain

$$Ln\left|\sqrt{t}\frac{\partial\Delta p_L}{\partial t}\right| = Ln\left(2\pi\alpha\frac{qB\mu}{kbh}\sqrt{\frac{\beta\eta}{\pi}}\right)-\frac{x^2}{4\beta\eta t} = Ln(A)-\frac{b}{t} \quad (18)$$

This equation indicates that if we plot $Ln\left|\sqrt{t}\frac{\partial\Delta p_L}{\partial t}\right|$ vs 1/t we should obtain a straight line of slope b and ordinate to the origin A (Eq. 16), which can be used to estimate the transmissivity T and the storativity of the formation S:

$$T = \frac{kh}{\mu} = \frac{\phi c_t h x^2}{4\beta Ln(10)b};$$
$$S = \phi h c_t = \frac{4\alpha\beta qB}{xb_L 10^A}\sqrt{\pi Ln(10)b}\,. \quad (19)$$

The general interpretation equation for the ith pulse can be written:

$$Ln\left|\sqrt{\Delta t}\,(\Delta p'_L + C_i)\frac{q_1}{(q_{i-1}-q_i)}\right| = LnA-\frac{b}{\Delta t}, \quad (20)$$

where

$$C_i = A\left\{\begin{array}{l}\dfrac{e^{-b/(t_i+\Delta t)}}{\sqrt{(t_i+\Delta t)}}+\\ \displaystyle\sum_{k=1}^{i-1}\frac{e^{-b/(t_i+\Delta t-t_k)}}{\sqrt{(t_i+\Delta t-t_k)}}\left(\frac{q_{k+1}-q_k}{q_1}\right)\end{array}\right\}. \quad (21)$$

DISCUSSION OF THE NEW THEORY

The general interpretation equations developed for radial, spherical and linear flow were satisfactorily tested using many synthetic and real tests published in the literature. Based on this analysis, it was observed that as the duration of the pulse increases, the pressure derivative increases its accuracy, which results in better parameter estimations. In addition, increasing the number of pressure data points improves the analysis.

To interpret a field test we have several options:
(1) Single analysis of each of the pulses: N values of the transmissivity and of the storativity are obtained. This approach requires the carrying out of (N-1) iterative processes to estimate the values of the C_i parameter (for example given by Eq. 6 for radial flow).
(2) Analysis of the first pulse and matching of the remaining pulses. With the estimations of the straight line interception A and the slope b (See Eq. 3 for radial flow) obtained with the first pulse, the values of the $C_i(i\neq1)$ parameter are calculated for the other pulses. If the data of these pulses when graphed in accordance to the interpretation equation (Eq. 5 for radial flow) follow a straight line, the analysis of the multiple pulse inteference test is considered reliable.
(3) Analysis of the ith pulse and matching of the remaining pulses. The analysis procedure is similar to that previously described in option (2), but based on starting results for the ith pulse.
(4) Integrated analysis of all the pressure pulses. This analysis technique requires (N-1) iterative processes to estimate values for the parameters C_i, which would allow that the pressure data for all the pulses could be graphed through the interpretation equation, showing a single straight-line behavior.

THE INTERTEST SYSTEM

The INTERTEST system is a friendly computer code developed in this study for the automated analysis of pressure interference tests. This program was written in VISUAL BASIC ® version 6, with WINDOWS ® interfaces Fig. 3 presents the flow diagram of the INTERTEST system.
INTERTEST uses the principle of superposition in time and space to handle the interpretation of a test with several active wells, with variable production and/or injection histories; it includes several flow models, such as radial, spherical and linear. Most of the conventional interference analysis techniques are considered, in addition to new techniques described in this paper and others discussed elsewhere (Martínez R., 2000).
INTERTEST has been designed to be run in IBM compatible PC's, requiring for its optimum use a Pentium type mathematical coprocessor, a minimum hard disk capacity of 5 Mb and of 8 Mb RAM and a VGA monitor.

An important feature of INTERTEST is the possibility of checking simultaneously on the PC screen, results obtained through several techniques of analysis, which it is considered as a consistency check. It other words, the type curve analysis and the semilogarithmic analysis can be shown at the same time, observing for instance directly changes on the straight line fit as a result of changes in the type curve analysis, until complete consistency is achieved.
For the cases of spherical and linear flow, to the best knowledge of the authors, no consistency analysis was previously present in the literature. Based on the theory developed in this work this analysis is now possible.

FIELD EXAMPLES

Pressure Interference Under Linear Flow Conditions.

This example is taken from the work of Economides and Ogbe (1987). Two wells were drilled in a river-formed bed, estimated to be about 400 ft wide (Fig. 2); well A was produced for 30 hr, while well B located 1800 ft from well A was shut-in. The pressure versus time data recorded at well B and related flow data appear in Table 1. Fig. 4 presents the type curve match obtained with the INTERTEST program. An excellent match can be observed for the pulse data, drawdown and buildup, at the active well.
To improve the analysis INTERTEST computes the dimensionless ratio between the production time and the square of the distance from the active to the observation well t_{pD}/x_D^2 . It can be observed that the estimated values for the permeability and porosity through the type curve and the new semilogarithmic analysis are very consistent. The values estimated by Economides and Ogbe (1987) by means of a conventional manual math are k=171 mD and ϕ=0.092, which closely agree with the values k=168.44 and ϕ = 0.091, obtained through INTERTEST. It is important to keep in mind as already discussed, that for linear flow, INTERTEST uses half of the rate, 250 STB/D for this example.
With the values of the estimated parameters (Fig. 4), a non-linear regression of the pressure data was performed. Fig. 5 presents a graphical comparison of the measured data and the estimated values through the linear flow model. The calculated values after three iterations were k=166.407 mD and ϕ =0.089, with an error of 0.921 psi. The error reported by INTERTEST is equal to the absolute summation of the pressure

differences between measured and calculated (model) pressures, divided by the number of pressure data used in the analysis.

Interference Test in the Naturally Fractured Klamath Falls Geothermal Reservoir.

Data presented by Benson et al. (1980) are those of several interference tests conducted in the Klamath Falls geothermal field, Oregon. The purpose of this test was to determine the impact of producing large quantities of brine on the many geothermal wells already in use for space heating and to evaluate inter-well communication.

Three observation wells, Parks, Glen Head and Adamcheck were monitored, while City well was pumped. Next, the pressure data registered at Parks well will be analyzed. A quartz crystal gauge was used to monitor pressure response, with a resolution of 0.01 psi. The maximum drawdown was 0.25 psi. The small time lag for the pressure response (down to 10 s), indicates a high degree of reservoir communication.

Deruyck et al. (1982) analyzed this test through conventional type curve methods. They matched unambiguously the results against the type curve developed on the pseudo-steady state interporosity flow assumption. The values for the storativity ratio ω and the interporosity coefficient λ determined were, $\omega = 0.09$ and $\lambda = 1.3\text{x}10^{-6}$.

Fig. 6 presents the type curve match obtained through INTERTEST, for the same interporosity flow assumption. It can be observed that due to the short distance between the active and the observation well (180 ft), and to the good resolution of the gauge, the naturally fractured characteristics of the reservoir were well defined. It can also be noticed that for large test times the pressure data follow the semilogarithmic solution. The estimated values from this analysis, kh = $4.38\text{x}10^{6}$ mD-ft, $(\phi Vc_t)_f$ h = $1.39\text{x}10^{-3}$ft/psi, $(\phi Vc_t)_{f+m}$h=15.21 ft/psi, ω=0.09 and λ =$1.23\text{x}10^{-6}$, closely agree with the results of Deruyck et al.

Fig. 6 also shows a small graph of the data interpreted through the new semilogarithmic analysis with the same previously type curve estimated values.

Fig. 7 shows the semilogarithmic graph of the pressure interference test in well Parks; these results show an excellent straight line fit of the late time data and the two parallel straight lines characteristics of double porosity systems are observed.

With the previously estimated values for the reservoir parameters taken as a starting solution, a non-linear regression of the pressure data was carried out by means of INTERTEST, obtaining after three iterations the following results: kh=$4.3 \text{ x } 10^{6}$ mD-ft, $(\phi Vc_t)_f$ h=$1.32\text{x}10^{-3}$ ft/psi, ω = 0.088 and λ=$1.281\text{x}10^{-6}$, with an error of $3.27\text{x}10^{-4}$ psi.

Based on the previous discussion, it can be concluded that the results obtained through the three techniques, type curve, semilogarithmic and non-linear regression, indicate a reliable analysis.

CONCLUSIONS

The main aim of this work has been to present an extension for radial, linear and spherical flow conditions, of the El–Khatib’s method for the analysis of pressure interference tests through the use of the pressure derivative. In addition, a friendly computer code for the automated analysis of pressure interference test is also discussed.

From the results of this work, the following conclusions can be made:

(1) A generalized radial flow interpretation equation for a sequence of N pressure pulses was presented.
(2) General flow interpretation equations based on the pressure derivative were developed for linear and spherical conditions.
(3) An iterative integrated analysis of all the pressure pulses was derived.
(4) A friendly computer code for the analysis of pressure interference tests was developed.
(5) The new theory for the interpretation of pressure interference tests and the computer system were successfully tested through field tests.

NOMENCLATURE

A	Intersection of the semilogarithmic graph for radial flow, Eq. 3
B	Formation volume factor, RB/STB.
b	Slope of the semilogarithmic radial flow graph.
b_L	Width of the Linear System (Fig. 2), ft.
s.c.	Standard conditions, 14.7 psia and T = 60°F.
c_t	Total compressibility, psi^{-1}.
e	2.7182
E_i	Exponential integral, $E_i(x) = \int_x^{\infty} \frac{e^{-u}}{u} du$
erf	Error function, $erf(x) = \frac{2}{\sqrt{p}} \int_0^x e^{-u^2} du$

erfc Complementary error function, $\mathrm{erfc}(x) = 1 - \mathrm{erf}(x)$
h Formation thickness, ft
k Permeability, mD
log Common logarithm base 10
Ln Natural logarithm, base e
L Distance between the active and the observation well (Fig. 2), ft
N Number of pulses (Fig. 1)
p Pressure, psi
q Flow rate, STB/D
r Radial distance, ft
r_w Wellbore radius, ft
S Storativity (Eq. 4), ft/psi
T Transmisivity, mD-ft/cp
t time, hr
t_{pD} Dimensionless producing time for linear flow $(t_{pD} = \beta k t_p / \phi\mu c_t x^2)$
V Ratio of volume of one porous system (matrix or fractures) to bulk volume
x Linear distance, ft
x_D Dimensionless linear distance ($x_D = x/L$)
α, β Unit conversion constants $\alpha = 141.2$, $\beta = 0.0002637$
Δp Pressure drop, psi
$\Delta p'$ Pressure derivative, psi/hr
ϕ Porosity, fraction
μ Viscosity, cp
η Diffusivity constant ($\eta = k/(\phi\mu c_t)$), (mD)-(psi) / (cp)

subscripts:

L Linear flow
r Radial flow
sp Spherical flow
t Total
w Well

Acknowledgments
The authors wish to thank Eng. María del Carmen Maldonado for her help in the preparation of this paper.

REFERENCES

1. Benson, S. M., Goranson, C. B. (1980), “Evaluation of City Well 1, Klamath Falls, Oregón, LBL (April 1980), Report 10848.
2. Brigham, W. E. (1970):, “Planning and Analysis of Pulse-Tests”, JPT (May 1970) 618-624; Trans., AIME, 249.
3. Chatas A.T. (1966), “Unsteady Spherical Flow in Petroleum Reservoirs”, paper SPE 1365 (1966).
4. Deruyck G.B. and Bourdet D. P. (1982), “Interpretation of interference Test in Reservoirs with double porosity behavior-Theory and Field Examples”, (Sept. 1982), SPE 11025.
5. Earlougher, R.C., Jr. (1977), “Advances in Well Test Analysis”, Monograph Volume 5, Society of Petroleum Engineers, Richardson, Tex.(1977).
6. Economides, M. J. and Ogbe, O.D. (1987), “How to Analyze Interference Well Tests”, World Oil (July-Sept.-Oct. 1987) 38-42, 54-57, 71-76.
7. El-Khatib, N.A.F., (1987) “A New Approach to Interference Test Analysis”, SPE Formation Evaluation (Dec.) 609-610.
8. Kamal, M. M. (1983), “Interference and Pulse Testing - A Review”, JPT (Dec. 1983) 2257-2270.
9. Martínez, R. N. (1987), “Nuevos Procedimientos para la Caracterización Dinámica de Yacimientos a Partir de Pruebas de Pozos Múltiples”, M. Sc. Report, School of Engineering, National University of México (2000).
10. Matthews C.S. and D.G. Rusell D.G. (1967), Pressure Buildup and Flow Tests in Wells, Monograph Volume 1, SPE Henry L. Doherty Series, 1967, Richardson, Tex.
11. Miller F.G. (1960), “Theory of Unsteady-state Influx of Water in Linear Reservoirs”, paper 1498-G, Stanford California (March 1960) 1-45.
12. Ramey, H. J., Jr. (1970), “Short Time Well Test Data Interpretation in the Presence of Skin Effect and Wellbore Storage”, JPT (Jan. 1970) 97-104; Trans., AIME, 249.

Table 1. Pressure Interference and Flow Data for a linear Flow Pressure Interference Test (Economides and Ogbe, 1987)

Time, (hrs)	Pressure, (psi)	Additional Data
0	2442.0	
10	2435.8	
15	2422.6	
20	2414.7	Q = 500 STB/D
25	2400.7	Bo = 1.1
30	2387.6	μ = 0.95 cp
35	2378.9	$c_t = 8*10^{-6}$ psi^{-1}
40	2373.7	b = 400 ft
75	2378.9	h = 25 ft
100	2385.8	
250	2405.0	

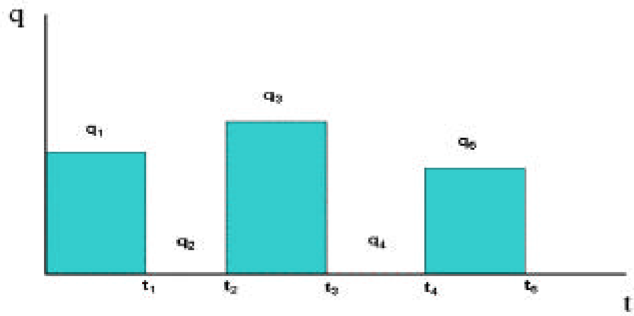

Fig. 1. Rate versus time sequence in an interferenc N pulses test.

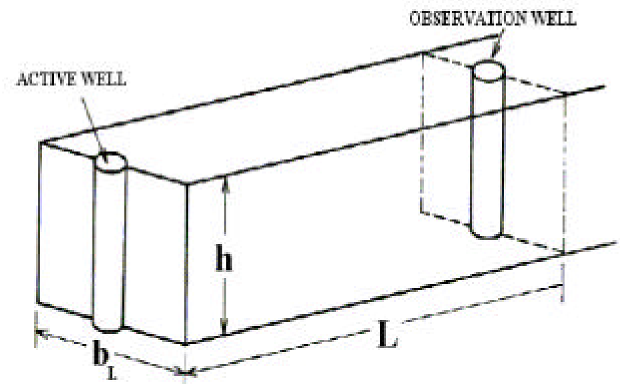

Fig. 2. Schematic view of a pressure interference test under linear flow conditions

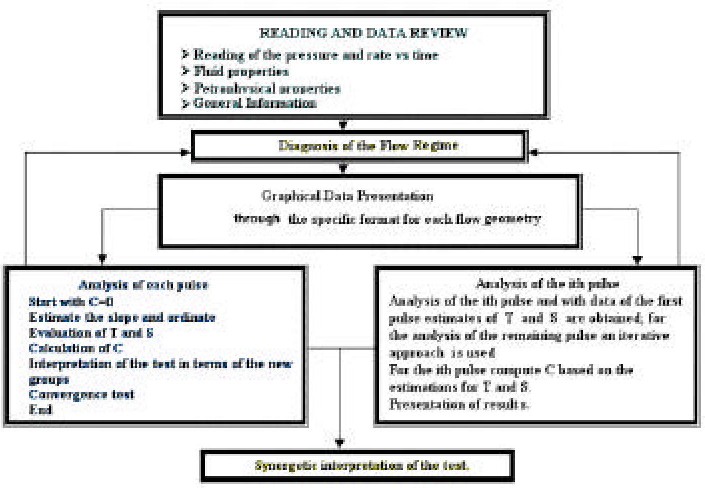

Fig. 3. Flow diagram of the INTERTEST System.

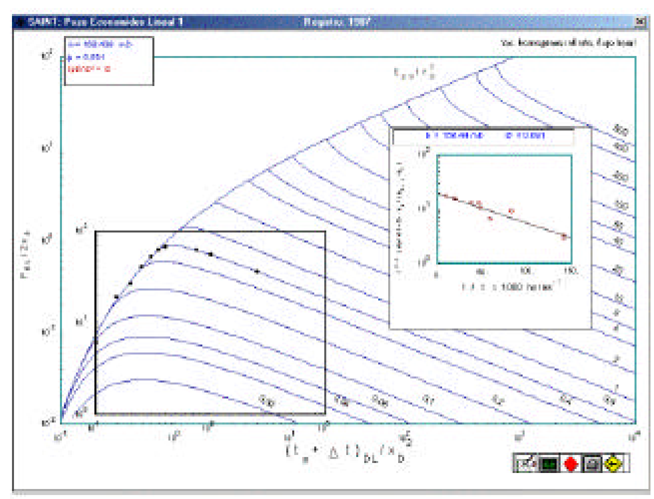

Fig. 4. Analysis of an interference linear flow test through a type curve approach and in terms of the new groups.

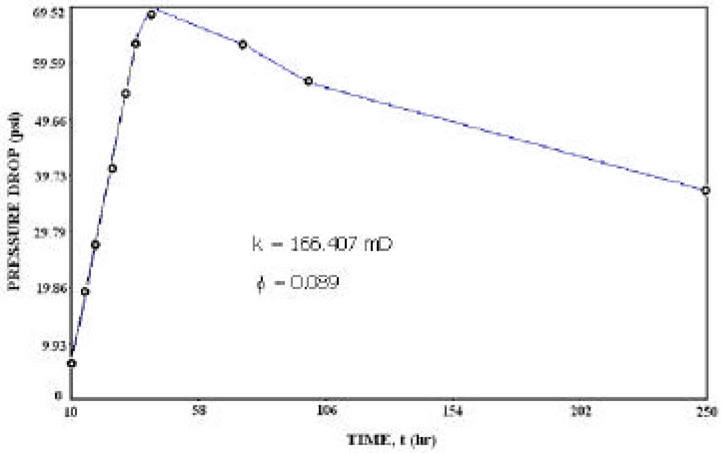

Fig. 5. Regression analysis of an interference linear flow test by means of the INTERTEST System.

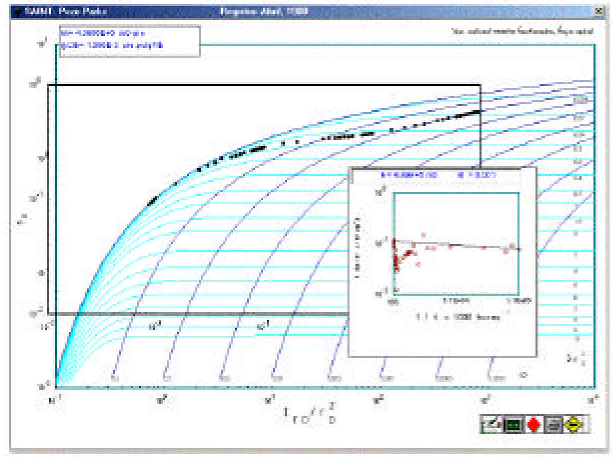

Fig. 6. Type curve analysis of the pressure interference test in well Parks, producing from the naturally fractured Klamath Falls geothermal reservoir.

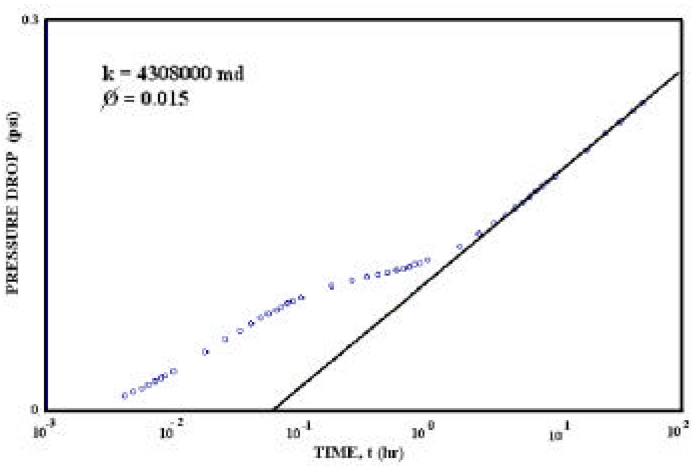

Fig. 7. Semilogarithmic analysis of the pressure interference test in well park, producing from the naturally fractured Klamath Falls geothermal reservoir.