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Application of Deconvolution Methods to Eliminate Wellbore Storage Effect in Well Test Analysis, A Case Study

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Abstract

Well test is a reservoir engineering technique by which some of important specifications of reservoirs, including permeability, initial pressure and skin effect can be calculated. The analysis of well test data is based on the variations of bottom-hole pressure versus time. At the initial stages of well testing, bottom-hole flow rate is very high due to wellbore storage effect. This makes the analysis of well test data very difficult because the tests have a short duration. The interpretation of such data demands the accurate measurement of flow rate from the very beginning of such tests. In addition, down-hole measurement devices are very costly with low accuracy at lower flow rates. This is another serious challenge. Different deconvolution techniques are used to interpret initial pressure data affected by wellbore storage effect. This study used only the pressure response of the wellbore storage area to interpret well test data of two wells of a fractured reservoir in Iran and compared the obtained results with Horner's well test results. In addition, it used three MATLAB coding-based techniques namely material balance method, beta method and Russel's method for deconvolution purposes. The obtained results indicated the relative efficiency and appropriate accuracy of the techniques.

Keywords: Deconvolution, Wellbore Storage, Well Test Analysis.

Introduction

Well test is a reservoir engineering technique used to determine and describe a well and its circumferences. During a well testing, the response of a reservoir to production or injection changes is monitored. Since this response serves as an indicator of the reservoir specifications, it may be used in many cases to measure reservoir specifications. The majority of well test analyses measure the pressure response of a reservoir. This is why in many cases it is used as an equivalent method of transient pressure analysis. Decisions on the best production plan for a reservoir or the economic assessments of a reservoir need the size, specifications and deliverability of the reservoir. Therefore, attempts are done to determine reservoir conductivity (Kh), initial pressure and its limits. In late 1960s and early 1970s, most advances occurred in universities and by Ramey. In late 1970s, the analysis of graph types was widely developed by introducing independent variables by Gringarten et al. During this period, manual analyses were put aside and computer-based analyses were developed (Gringarten et al, 1975; Ramey, 1970). In 1983, Bourdet et al introduced the concept of derivative and converted well test to an accurate tool for the identification of reservoir specifications (Bourdet et al, 1998). Deconvolution techniques for the variable flow rates associated with the initial stages were first introduced by Russel in 1996 (Russel, 1996). However, normalized flow technique was first introduced by Gladfelter in 1955 that requires down-hole flow rates (Gladfelter, 1955). In 1982, Joseph and Koederitz, and in 1987 Kuchuk introduced beta deconvolution method (Joseph and Koederitz, 1982; Kuchuk, 1987). In 1993, Johnston introduced material balance method (Johnston, 1992). The advancement of analytical techniques completely depends on improved data. Up to early 1970s, bourdon mechanical pressure gauges, with limited accuracy and clarity, were used to measure pressure.

Dispersionability equation can be easily solved by applying Darcy's low and considering porosity, permeability, viscosity and compressibility independent from pressure. As far as incompliances and deviations from the considered assumptions are not considerable, approximate methods provide logical solutions. However, if the differences increase, numerical simulations should be used to model such incompliances (Earlougher, 1977). Therefore, this study evaluates wellbore storage effect in order to estimate reservoir specifications including permeability and skin factor.

Study literature

Deconvolution in well test

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The aim of wall testing is to obtain reservoir parameters including permeability and skin effect. Conventional techniques are conducted as pressure test for fixed flow rates. However, the variation of bottom-hole flow rates is remarkable at the initial stages of well testing due to wellbore storage effect. Therefore, the analysis of wall testing data with short test duration faces serious challenges and the interpretation of this data demands the accurate measurement of flow rate from the very beginning of well testing. Down-hole devices are not accurate, regardless of the fact that they are costly, and fail to measure lower flow rates (Y. Cheng, 2005; Y. Liu and Horne, 2013).

The elimination of the effect of flow rate variations on the registered pressure of wall testing is called deconvolution. Deconvolution is a mathematical concept where a new ***f * g*** function is derived out of ***f*** and ***g*** functions. This new-generated function shows the overlap of ***f*** and ***g*** as well as the transmission of function ***f*** through function ***g***.

Deconvolution operator is defined as follows:

$$f * g = \int_0^t f(\tau) g(t-\tau) d\tau \qquad (1)$$

Dozens of techniques have been suggested to eliminate wellbore storage effect in wall testing. Russel's straight approximation technique (1966) is one of them where the measured pressures, influenced by storage effect are modified to virtual pressures equivalent to a fixed flow rate (Russel, 1966). Despite its simplicity, Russel's technique suffers some drawbacks such as low accuracy and wrong estimation of skin factor.

Rote normalization technique was successfully used in some cases by Goldfleter (195), Fetkovich and Vienot (Fetkovich. M.J, and Vienot, 1984). This is a suitable technique for locations where it is possible to continuously read flow rates. These techniques are generally used to interpret well test data affected by continuous variations of flow rate.

The use of flow rate normalization technique demands the accurate measurement of bottom-hole flow rates during well test. Generally, this method accurately estimates permeability but provides non-reliable estimations of skin factor.

Beta-deconvolution method was used by Joseph and Koederitz (1982) and Kuchuk (1981). Material balance deconvolution method was introduced by Johnston in 1992. He showed that this method provides an accurate approximation for pressure data influenced by wellbore storage effect.

Deconvolution methods in wall testing

Van Everdingen (1953) and Hirst (1953) separately introduced an exponential model for flow rate at wellbore storage time during transient pressure tests. It was called beta-deconvolution method. Material balance deconvolution method demands the measurement of bottom-hole flow rate. Johnston showed that reservoir flow rate can approximately be derived from pressure data. In this technique, time and pressure drop are corrected simultaneously.

Russle's method modifies pressure as follows. Ref. (Russel, 1996) explains this method in detail.

$$P_{WR} = \frac{P_{WS}(\Delta t) - P_{wf}(\Delta t = 0)}{1 - \frac{1}{C_2.\Delta t}} = f(\Delta t = 1hr) + m_{SL}.\log(\Delta t) \qquad (2)$$

Why deconvolution methods are adopted in carbonated reservoirs

In carbonated reservoirs with low quality rocks, the required time for pressure stability is very long and sometimes it takes more than 100 hours. Therefore, to assess wall status and to receive pressure information it is necessary to test the wall for a long period of time which is impossible in many cases due to the following reasons:

- Governance of particular production policy, such as commitment to production, makes it impossible to shut wells, especially those with high production rates.
- Longer shut-in times are impossible due to the formation of asphalt that blocks wall bore in some reservoirs which their fluid is susceptible to the formation of asphaltene.
- In drilling rig-aided wall testing the pressure growth tests are not completed due to the necessity of the minimization of the waiting time of rigs, especially in case of carbonated reservoirs with low quality specifications.
- A dead weight tester is generally used in pressure tests due to the visibility of pressure growth. In this case, the stabilization time of bottom-hole and well head pressures are considered to be occurred at the same time and the test is stopped. This is a conceptual error because the stabilization of well head pressure does not depend on the stabilization of bottom-hole pressure at all, which has been approved by experience too.

Currently, the majority of well test data are affected by the abovementioned reasons and there is no technique to interpret the data, except deconvolution techniques.

Study Method

This study evaluates the specifications of Shadgan reservoir where the data of two well tests are analyzed. Horner's scheme method is used to analyze well test data in order to observe the effect of the elimination of wellbore storage on well test data.

This study estimates reservoir specifications including permeability and skin factor at wellbore storage time using MATLAB and beta deconvolution method. Following the deconvolution of data associated with initial stages (wellbore storage), Horner's scheme method is used for analysis purposes.

Data Analysis

1. Analysis of well test data analysis- Shadgan well number A

Shadgan well number A underwent pressure build-up test following 2000 hours production with a flow rate of 5000 gallons per day. Table 1 shows well test results. Table 2 shows some specifications of the well rock and fluid.

Table 1: well test data of Shadgan well number A

item	△t(hr)	P(psi)	item	△t(hr)	P(psi)	item	△t(hr)	P(psi)
1	0	4738	13	0.15	4758.731	25	3.0097	4763.048
2	0.0014	4739.8	14	0.2	4759.358	26	4.0097	4763.557
3	0.0028	4744.355	15	0.25	4759.696	27	6.0264	4764.157
4	0.0056	4747.456	16	0.3	4759.966	28	10.1097	4765.004
5	0.0083	4749	17	0.4	4760.391	29	18.6097	4766.1
6	0.0115	4751.8	18	0.5	4760.709	30	24.4431	4766.431
7	0.0167	4753	19	0.6	4760.968	31	30.4431	4766.737
8	0.0208	4754.22	20	0.7	4761.189	32	36.9431	4767.003
9	0.0306	4756	21	0.8	4761.381			
10	0.05	4757.141	22	0.9	4761.544			
11	0.075	4757.907	23	1.0014	4761.688			
12	0.1	4758.372	24	2.0014	4762.553			

Table 2: rock and fluid specifications of Shadgan well number A

property	unit	Value
Formation thickness	ft	90
Porosity	%	13
Well radius	ft	0.075
Fluid viscosity	Cp	0.45
Volume factor. B	bbl/STB	1. 2
Total compressibility factor	1/psi	5×10^{-5}

2. Analysis of well test data of Shadgan well number A using Horner's method

This study uses Horner's method to analyze well test data. To this end, pressure-time curve was first developed and then, the logarithmic curve of data was plotted using Horner's method shown in Fig. 1. The wellbore storage completion time was then calculated which is about 6 minutes and it was extended to the semi-logarithmic curve shown in Fig. 2.

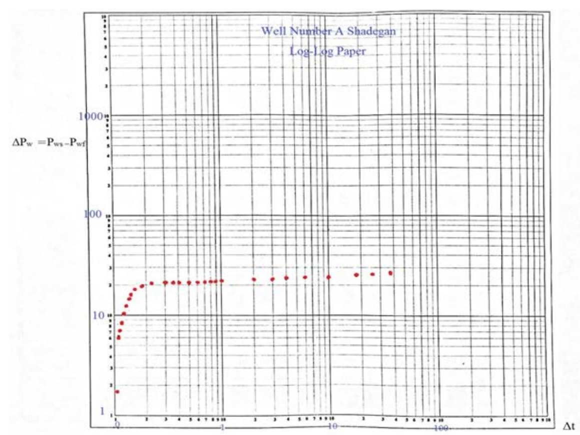

Figure 1: log. curve of build-up pressure test of Shadgan well number A

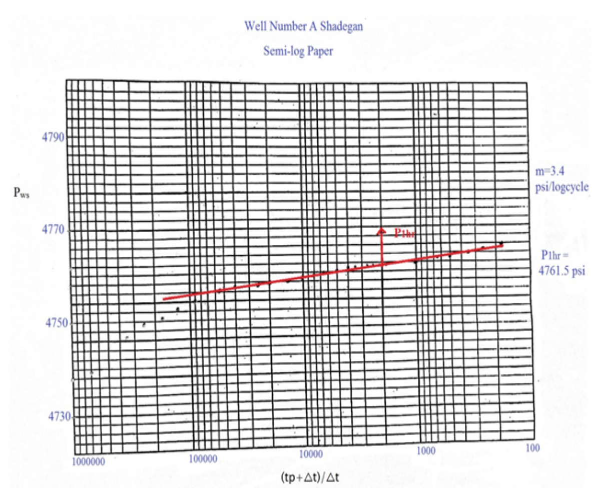

Figure 2: semi-log curve of build-up pressure test of Shadgan well number A

3. Analysis of deconvolution data of Shadgan well number A using Beta method

Table 3: elimination of wellbore storage effect from data

item	ΔP_w	ΔP_{wD}	ΔP_{wI}	ΔP_{wID}	ΔP_{ws}	P_{ws}	item	ΔP_w	ΔP_{wD}	ΔP_{wI}	ΔP_{wID}	ΔP_{ws}	P_{ws}
1	1.80	3.18	0.90	1.24	-1.87	4736.1	17	22.71	1.44	20.95	1.79	22.83	4760.9
2	6.35	5.10	2.49	2.86	18.04	4756.04	18	22.97	1.44	21.27	1.72	23.08	4761.1
3	9.46	4.73	5.20	4.42	13.88	4751.8	19	23.19	1.45	21.52	1.68	23.30	4761.3
4	11.00	6.11	6.83	4.48	16.60	4754.6	20	23.38	1.42	21.74	1.64	23.49	4761.5
5	13.80	5.48	8.38	4.69	16.88	4754.8	21	23.54	1.37	21.94	1.61	23.64	4761.6
6	15.00	4.35	10.26	5.26	17.15	4764.4	22	23.69	0.92	22.11	1.07	23.73	4761.7
7	16.22	4.49	11.31	4.36	17.89	4655.7	23	24.55	1.36	23.11	1.57	24.64	4762.6
8	18.00	3.06	13.17	4.14	18.85	4756.1	24	25.05	1.50	23.68	1.45	25.14	4763.18
9	19.14	2.15	15.26	3.96	19.64	4759.5	25	25.56	1.47	24.08	1.33	25.64	4763.8
10	19.91	1.85	16.68	3.43	20.26	4759.3	26	26.16	1.43	24.68	1.35	26.23	4764.2
11	20.17	1.10	17.55	2.49	20.51	4758.8	27	27.00	1.56	25.45	1.39	27.09	4765.0
12	20.23	1.379	18.43	2.55	20.92	4759.3	28	28.10	1.85	26.41	1.82	28.23	4766.2
13	21.36	1.93	19.17	2.19	21.58	4759.9	29	28.43	1.32	26.85	1.62	28.51	4766.5
14	21.70	1.52	19.64	2.09	21.85	4760.07	30	28.74	1.39	27.19	1.55	28.82	4766.8
15	21.97	1.39	20.01	1.81	22.09	4760.2	31	29.00	1.32	27.49	1.54	29.08	4767.06
16	22.39	1.49	20.55	1.88	22.52	4760.6	32	29.18	1.22	27.71	1.50	29.25	4767.98

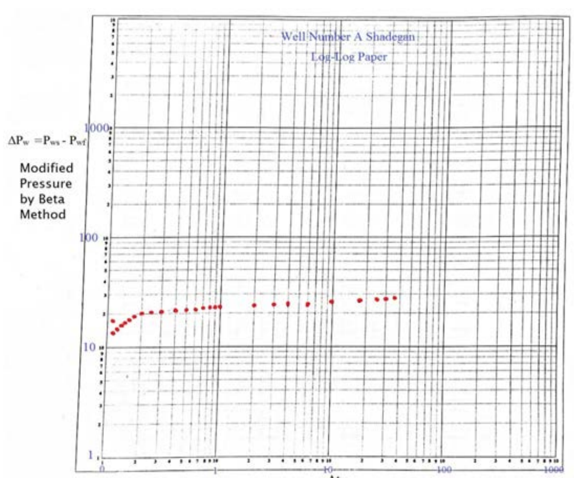

Figure 3: log. Curve of Shadgan well number A after the elimination of wellbore storage effect by beta method

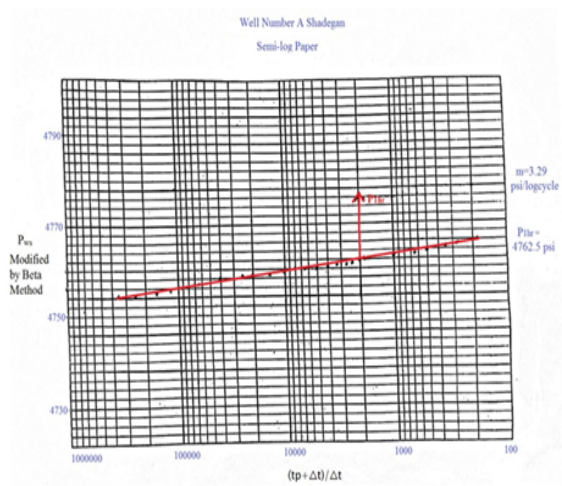

Figure 4: semi-log. Curve of Shadgan well number A after the elimination of wellbore storage effect by beta method

4. Permeability and skin factor derived from well testing of Shadgan well number A based on deconvolution techniques

Table 4 shows well test data of Shadgan well number A.

Table 4: well test data of Shadgan well number A

Calculation error percent S	calculation error percent K	S	K (md)	ΔP_{1hr}	-
-	-	1.382	1433	23.5	Horner’s

					method
0.6	0.049	1.982	1482.6	24.5	Bet method

Table 5: well test data of Shadgan well number B

item	△t(hr)	P(psi)	item	△t(hr)	P(psi)	item	△t(hr)	P(psi)
1	0.0000	4448	14	0.25	4588	27	4	4612
2	0.005556	4456.22	15	0.3	4592	28	5	4613
3	0.016667	4470.7	16	0.35	4594	29	6	4614
4	0.027778	4484.73	17	0.4	4596	30	7	4614.5
5	0.033333	4491.08	18	0.5	4599	31	8	4615
6	0.038889	4497.3	19	0.6	4600.75	32	9	4616
7	0.05	4509.3	20	0.7	4602	33	10	4617
8	0.061111	4519.65	21	0.8	4603.8	34	15	4619
9	0.083333	4537.98	22	0.9	4604.98	35	20	4620
10	0.1	4549.18	23	1	4606	36	25	4621
11	0.116667	4557	24	1.5	4609	37	30	4622
12	0.15	4570	25	2	4609.5	38	36	4623
13	0.2	4582.3	26	3	4611			

5. Analysis of well testing data of Shadgan well number B

Shadgan well number B underwent pressure build-up test following 1800 hours production with a flow rate of 2000 gallons per day. Table 5 shows registered well test data. Table 6 shows some specifications of the well rock and fluid

Table 6: rock and fluid specifications of Shadgan well number B

property	**unit**	**Value**
Formation thickness	ft	75
Porosity	%	14
Well radius	ft	0.75
Fluid viscosity	Cp	0.45
Volume factor. B	bbl/STB	1. 2
Total compressibility factor	1/psi	5×10^{-5}

6. Analysis of well test data of Shadgan well number B by Horner's method

This study uses Horner's method to analyze well test data. To this end, pressure-time curve was first developed and then, the logarithmic curve (Fig. 7-4) and semi-logarithmic curve (Fig. 8-4) of data were sketched using Horner's method. The wellbore storage completion time was then calculated which is about 1 hour.

$$m = -10.1\, Psi/\log cycl$$

$$k = \frac{162.6 Q\mu B}{mh} = \frac{162.6\times 2000\times 0.45\times 1.2}{10.1\times 75} = 231.8 md$$

$$P_{1hr} = 4606\, psi \Rightarrow \Delta P_{1hr} = 158\, psi$$

$$s = 1.151\left[\frac{P_{1hr} - P_{wf(\Delta t=0)}}{m} - \log\left(\frac{k}{\phi\mu C_t r_w^2}\right) + 3.23\right]$$

$$= 8.332$$

$$s = 1.151\left[\frac{4606-4448}{10.1} - \log\left(\frac{231.8}{0.14\times 0.45\times 5\times 10^{-5}\times\left(0.75^2\right)}\right) + 3.23\right]$$

$$= 12.38$$

$$\Delta P_{skin} = 0.87|m|s = 108.7\, psi$$

7. Analysis of the deconvolution of well test data of Shadgan well number B by Beta method

Fig. 5 shows the logarithmic curve and Fig. 6 shows the semi-logarithmic curve of modified data by Beta method

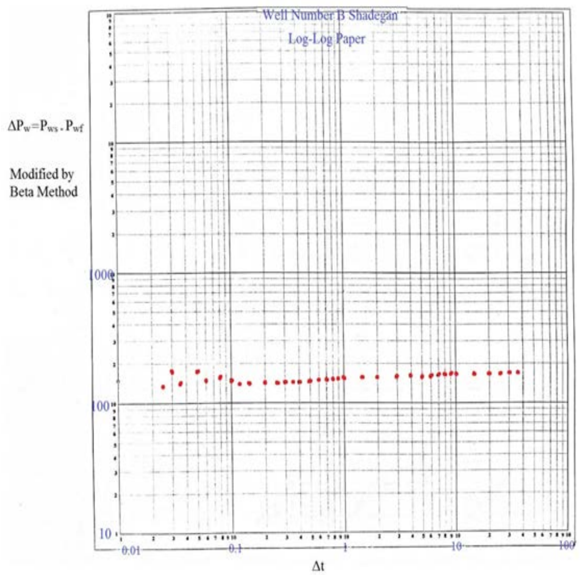

Figure 5: Log. Curve of data of Shadgan well number B after the elimination of wellbore storage effect by Beta method

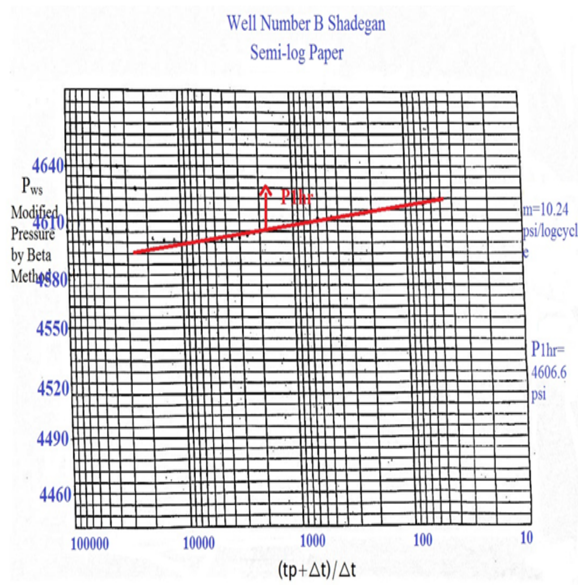

Figure 6: semi-log. Curve of data of Shadgan well number B after the elimination of wellbore storage effect by Beta method

Table 7: elimination of wellbore storage effect from Shadgan well number B by beta method

item	ΔP_w	ΔP_{wD}	ΔP_{wI}	ΔP_{wID}	ΔP_{ws}	P_{ws}	item	ΔP_w	ΔP_{wD}	ΔP_{wI}	ΔP_{wID}	ΔP_{ws}	P_{ws}
1	0	0	0	0			20	153.87	10.67	130.9	23.38	155.61	4603.7
2	8.09	7.52	4.04	3.76	58.07	4506.2	21	155.67	11.92	133.9	21.79	157.47	4605.6
3	22.5	21.3	11.56	11.04	221.6	4669.7	22	156.85	9.9	136.44	20.5	158.23	4606.3
4	36.6	33.96	18.77	17.84	157.0	4605.05	23	157.87	6.7	138.53	15.06	158.5	4606.6
5	42.9	37.71	22.27	20.6	191.8	4640	24	160.87	5.25	145.47	16.2	161.41	4609.5
6	49.1	42.51	25.67	23.2	157.6	4605.6	25	161.37	2.66	149.38	10.8	161.55	4609.6
7	61.1	50.2	32.22	28.7	193.8	4641.9	26	162.87	3.75	153.6	10.01	163.1	4611.2
8	71.5	52.58	38.43	32.03	160.4	4608.5	27	163.87	4	156.06	8.18	164.07	4612.2
9	89.8	63.27	49.69	40.48	186.2	4634.3	28	164.87	5	157.7	7.33	165.09	4613.2
10	101.05	57.05	57.32	43.2	157.2	4605.3	29	165.87	4.5	159	6.8	166.06	4614.1
11	108.8	48.58	64.12	42.4	143.0	4596.2	30	166.37	3.5	160.01	6.44	166.5	4614.6
12	121.8	45.54	75.51	44.1	148.1	4596.3	31	166.87	6	160.84	6.2	167.1	4615.2
13	134.1	36	88.64	45.6	150.8	4597.02	32	167.87	9	161.56	6.32	168.22	4616.3
14	139.8	24.25	98.31	42.33	148.7	4596.8	33	168.87	5	162.2	5.3	169.03	4617.1
15	143.8	18	105.5	38.61	149.3	4597.5	34	170.87	4.5	164.78	6.27	171.03	4619.1
16	145.8	14	111.1	35.2	149.6	4597.7	35	171.87	4	166.43	5.66	172	4620.1
17	147.8	13.33	115.6	29.87	150.8	4598.9	36	172.87	5	167.62	5.36	173.02	4621.1
18	150.8	11.8	122.3	29.08	153.3	4601.4	37	173.87	5.45	168.57	5.74	174.05	4622.1
19	152.6	9	127.2	25.8	154.2	4602.3	38	174.87	6	169.54	5.79	175.07	4623.2

8. Permeability and skin factor derived from well testing of Shadgan well number B based on deconvolution methods

Table 8 shows well test data of Shadgan well number B.

Table 8: well test data of Shadgan well number B

Calculation error percent S	calculation error percent K	S	K(md)	$\triangle P_{1hr}$	-
-	-	12.38	231.8	158	Horner's method
0.17	3.2	12.21	228.6	158.6	Bet method

Results

Deconvolution methods show a suitable efficiency in interpreting well test data associated with wellbore storage effect times. Therefore, some required results can be derived from incomplete well test data.

As a case study, two wells of Shadgan Asmari reservoir were studied and the obtained specifications, derived by Horner's method without considering wellbore storage effect time, were compared with the results of deconvolution methods that obtained the specifications during wellbore storage effect. In many cases the results were satisfactory.

Among the aforementioned three methods, material balance method is more stable, provides higher accuracy and eliminates wellbore storage effect within shorter times from the beginning of test. Beta method ranks the second. According to above observations, Russel's method goes with high errors, especially in calculating skin factor.

Bottom-hole pressure versus time is the main data source required for well testing. Pressure variation is very high at well shut-in time during pressure build-up test. Therefore, the capability of pressure gauge in measuring bottom-hole pressure in shorter intervals is of high importance because small errors in registering field data result in remarkable errors in the interpretation of deconvolution results because deconvolution methods are too instable.

Normally, pressure build-up test is limited to 2 to 3 days due to economic considerations in order to return the studied well to production circuit. However, in deconvolution methods this time is very short and the methods are more cost effective. Sometimes, longer shut-in times lead to the formation of asphaltene with consequent huge costs. Using deconvolution methods, this long period is eliminated too.

Suggestions

1- Considering the efficiency of deconvolution methods, adopting them in pressure build-up tests is very cost effective
2- Production commitment policies and the probability of asphaltene formation during long-term non production conditions are among factors made deconvolution methods more attractive.

High-accurate and precise pressure gauges should be used, especially in the initial stages where small errors will lead to drastic errors. Quartz gauges can register pressure in shorter times, with higher accuracy and more frequently. Therefore, it is suggested that they are replaced by mechanical pressure gauges.

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