Study of pressure behaviour of a well near two intersecting faults

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Abstract. A pressure build up test was performed in a dry gas exploration well. According to geological data indicated that there are two intersecting faults near the well. The analysis result provided not only information of the reservoir characteristics such as average reservoir pressure, permeability, and formation damage, but also confirmation of the presence of those two intersecting faults. In this study, a reservoir simulator was used to model pressure build up test of a well located near two intersecting faults. The effect of several parameters namely the distance between well to the faults, flow rate, and reservoir pressure, on bottom hole pressure behaviour was observed. The simulation results showed that the effect of variation of the distance between well and faults as well as that of reservoir pressure on estimation of permeability and skin factor is not significant. While, the variation of flow rate may result in a significant deviation. If a constant flow rate cannot be maintained during flowing period of the pressure build up test.

1. Introduction

An exploration well was completed with a perforation interval at depth of 1487.5-1490.5 m in a gas reservoir located in West Java Province, Indonesia. According to the drilling, logging, and other geological data shows that the lithology of the reservoir is a sandstone formation. In addition, there are two intersecting faults near the well. A pressure build up test was conducted to determine the ability of a reservoir to produce through the production well and to determine the characteristics of the reservoir. Characteristics and parameters of a well-known reservoir can be used as a consideration for the development process that will be carried out on the reservoir. The analysis of the well test result provided not only information of the reservoir characteristics and productivity of the well, but also confirmation of the presence of those two intersecting faults and the distance from the well to the faults as well.

Reservoir compartments are generally segmented by faults that prevent the migration of hydrocarbons [1,2]. Pressure behavior of a constant-rate well located within multiple-sealing-fault systems and closed rectangular drainage areas has been studied and modeled by several researchers [3-8]. Earlougher and Kazemi the last straight line slope of pressure behavior plot in a well near a fault was twice the first slope [9]. Tiab and Chriclow found that for a well located near two perpendicular fault system, the last straight line slope of pressure behavior plot was four times the first one [10].

The objective of this research is to study the variation of the distance of the well from the faults, flow rate, reservoir pressure, and porosity to the behavior of the bottom hole pressure well. The pressure...
behavior was shown in Horner’s plot. The analysis of the Horner’s curves indicated the alteration of permeability and skin factor resulted from the variation of the parameters. Furthermore, the limitation of the parameters for the well was also observed.

2. Literature review
Pressure build up test is basically executed with producing well at a constant rate \( q \) for a period of time \( t_p \) to establish a stabilized pressure distribution and then the well is closed [11]. For low gas reservoir pressure, the pressure behavior during transient period of pressure build test can be expressed in terms of pressure squared equation [12]:

\[
p_{ws}^2 = \frac{1.637 \times 10^6 q T \mu_g z}{k h} \log \left( \frac{t_p + \Delta t}{\Delta t} \right)
\]

where \( p_{ws}, q, T, k, h, \mu_g, z, t_p, \) and \( \Delta t \) are shut-in bottom hole pressure, flow rate, temperature, permeability, formation thickness, average gas viscosity, gas deviation factor, production time, and shut-in time respectively. The semi-log plot of the shut-in bottom-hole pressure \( (p_{ws}^2) \) versus \( \log(t_p+\Delta t)/\Delta t \) will give a straight line of slope \( m \). This relationship represents Horner plot. From the curve, information such as formation permeability and skin factor is obtained [13-17]. Permeability \( (k) \) can be estimated from the following equation [12].

\[
k = \frac{1.637 \times 10^6 q T \mu_g z}{m h}
\]

After determining the permeability, the total skin factor \( (s') \) can be obtained as follows [13].

\[
s' = 1.151 \left[ \frac{p_{ws}^2 - p_{wf}^2}{m} - \log \left( \frac{k \Delta t}{\phi \mu_g c r_w^2} \right) + 3.23 \right]
\]

where \( \phi, c, \) and \( r_w \) are porosity, average gas compressibility, and well radius, respectively.

3. Method
The procedure of the research is shown in Figure 2. The data of the X well and reservoir rock and fluid properties are listed in Table 1.

| Parameters | Values |
|------------|--------|
| \( r_w \) | 3.5 in |
| \( h \) | 9.454 ft |
| \( \phi \) | 0.2 |
| \( T \) | 220.89 \(^\circ\) F |
| \( \mu \) | 0.01454 cp |

| Parameters | Values |
|------------|--------|
| \( c_t \) | 9.152E-4 psi\(^{-1}\) |
| \( p_r \) | 552.88 psi |
| \( q \) | 411.15 Mscfd |
| \( t_p \) | 3.537 hrs |
| \( \Delta t \) | 44.58 hrs |

Reservoir simulator was used to predict the effect of several parameters on the determination of permeability and skin factor. The parameters were the distance between well and the faults, flow rate, reservoir pressure, and porosity.

4. Results and discussion
The result of pressure build up test of X well was analyzed using pressure derivative curve and Horner plot. Figure 1 presents a pressure derivative curve of bottom-hole pressure during well testing. The figure shows that the pressure derivative data are scattered. It may be due to phase separation in the well during shut-in period [17,18]. In last segment of the curve, it tends to bend upward. The uptrend curve at last segment of the curve indicates that the propagation of pressure transient has reached closed boundaries of the reservoir [17]. Figure 2 show a Horner plot of the pressure build up test data. The plot
also confirms that there are faults in the vicinity of the well, since the slope is doubling up in the last segment of the curve [19,20].

Figure 1. Pressure derivative plot.

The study was continued by analyzing the effect of the distance between well and faults, flow rate, and reservoir pressure on the calculation of permeability and skin factor. Figure 3 shows the Horner plots of various distance between well and the corner of two intersecting faults from 176.8 ft to 742.5 ft. The permeability and skin factor were estimated from the figure and Eqs 2 and 3. The values of permeability and skin factor are given in Table 2. The table shows that there is a small fluctuation of permeability and skin factor due to the distance variation. The average value of $k$ and $s$ is $12.10 \pm 0.398$ and $-1.70 \pm 0.124$, respectively.

Figure 4 shows the Horner plots of various reservoir pressures from 553 psi to 1000 psi. The permeability and skin factor due to the variation of reservoir pressure are given in Table 3. The table also shows that there is a small fluctuation of permeability and skin factor due to the variation of reservoir pressure. The average value of $k$ and $s$ is $12.52 \pm 0.218$ and $-1.30 \pm 0.217$, respectively.

Figure 5 shows the Horner plots of flow rate of PBU test from 102.79 Mscfd to 1644.58 Mscfd. The permeability and skin factor due to the variation of flow rate are given in Table 4. The table shows that there is a significant deviation of permeability and skin factor due to the flow rate variation, especially for flow rates of 822.29 Mscfd and 1644.58 Mscfd. Figure 6 shows the profile of flow rate for all scenarios. It is obvious that the flow rates of 822.29 Mscfd and 1644.58 Mscfd are beyond the capacity of the well. Accordingly, the well is not able to maintain the flow rates during flowing period. It makes a stabilized pressure distribution cannot be established.
Figure 2. Pressure build up plot.

Table 2. The effect of distance on the estimation of k and s.

| Distance, ft | k, mD | s  |
|-------------|-------|----|
| 176.80      | 11.95 | -1.77 |
| 318.20      | 12.69 | -1.52 |
| 411.15      | 12.27 | -1.63 |
| 601.00      | 11.95 | -1.75 |
| 742.50      | 11.64 | -1.83 |

Table 3. The effect of reservoir pressure on the determination of k and s.

| Pr, psi | k, mD | s  |
|---------|-------|----|
| 553     | 12.27 | -1.63 |
| 700     | 12.38 | -1.37 |
| 800     | 12.48 | -1.25 |
| 900     | 12.69 | -1.16 |
| 1000    | 12.80 | -1.07 |

Figure 3. The effect of the distance between well and faults on bottom-hole pressure behavior.
Figure 4. The effect of reservoir pressure on bottom-hole pressure behavior.

Table 4. The effect of flow rate on the determination of k and s.

| q, Mscfd | k, mD   | s     |
|----------|---------|-------|
| 102.79   | 12.48149| -1.18 |
| 205.57   | 13.85657| -0.889|
| 411.15   | 12.26994| -1.63 |
| 822.29   | 16.07785| -2.45 |
| 1644.58  | 29.29977| -3.04 |

Figure 5. The effect of flow rate on bottom-hole pressure behavior.
5. Conclusion

Based on the discussion presented above, several conclusions are made as follows. The effect of variation of the distance between well and faults as well as that of reservoir pressure on estimation of permeability and skin factor is not significant. The variation of flow rate may result in a significant deviation. In order to avoid the deviation, the flow rate should be set so that it can be maintained during flowing period of the pressure build up test.

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