Well Test Interpretation

SKM4323

CONVENTIONAL INTERPRETATION METHODS

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WEEK 05

After Varying Flow Rates

- A test after varying flow rates is interpreted using the flow rate superposition principle discussed before:

$$p_i - p_{wf}(t) = \frac{B\mu}{2\pi kh} \sum_{i=1}^{n} (q_i - q_{i-1})\, p_D (t - t_{i-1}) \qquad \textbf{(4.30)}$$

- Once the wellbore storage affect has ended, the pressure variations are given by equation (4.3). Equation (4.30) becomes

$$p_i - p_{wf}(t) = \frac{B\mu}{4\pi kh} \sum_{i=1}^{n} (q_i - q_{i-1}) \left(\ln \frac{K(t - t_{i-1})}{r_w^2} + 0.81 + 2S \right) \qquad \textbf{(4.31)}$$

After Varying Flow Rates…/2

- The interpreter is interested in the pressure variations since the last change in flow rate, t_{n-1}. The pressure variation at the time when the change took place is:

$$p_i - p_{wf}(t_{n-1}) = \frac{B\mu}{4\pi kh}\sum_{i=1}^{n-1}(q_i - q_{i-1})\left(\ln\frac{K(t_{n-1} - t_i)}{r_w^2} + 0.81 + 2S\right)$$

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- The pressure buildup since the time when the well was shut in is expressed by

$$p_{ws}(\Delta t)-p_{wf}(t_{n\text{-}1})=$$
$$\frac{B\mu}{4\pi kh}\left\{\sum_{i=1}^{n\text{-}1}(q_i-q_{i-1})\ln\frac{t_{n\text{-}1}-t_{i\text{-}1}}{t_{n\text{-}1}-t_{i-1}+\Delta t}-(q_n-q_{n-1})(\ln\frac{K\,\Delta t}{r_w^2}+0.81+2S\right\}$$

(4.32)

Δt is the time elapsed since the last change in flow rate.

After Varying Flow Rates…/4

- It can be written as follows:

$$p_{ws}(\Delta t)-p_{wf}(t_{n\text{-}1})=\frac{162.6\,B\mu}{kh}$$

$$\left\{\sum_{i=1}^{n\text{-}1}(q_i-q_{i-1})\log\frac{t_{n\text{-}1}-t_{i\text{-}1}}{t_{n\text{-}1}-t_{i-1}+\Delta t}-(q_n-q_{n-1})(\log\Delta t+\log\frac{k}{\phi\mu c_t r_w^2}-3.23+0.87\,S)\right\}$$

(in practical US units) **(4.33)**

$$p_{ws}(\Delta t)-p_{wf}(t_{n\text{-}1})=\frac{21.5\,B\mu}{kh}$$

$$\left\{\sum_{i=1}^{n\text{-}1}(q_i-q_{i-1})\log\frac{t_{n\text{-}1}-t_{i\text{-}1}}{t_{n\text{-}1}-t_{i-1}+\Delta t}-(q_n-q_{n-1})(\log\Delta t+\log\frac{k}{\phi\mu c_t r_w^2}-3.10+0.87\,S)\right\}$$

(in practical metric units) **(4.34)**

After Varying Flow Rates…/5

Interpretation

- The pressure varies linearly versus the right-hand member (between parentheses) of equations (4.33) and (4.34). The member is a function of flow rates and time and is called the superposition function.
- If the value of pressure measured in the bottom of the hole is plotted versus the superposition function, a straight line a slope of m can be seen once the effect of wellbore storage has ended.

$$m = \frac{162.6\ B\mu}{kh}$$ (in practical US units) **(4.35)**

$$m = \frac{21.5\ B\mu}{kh}$$ (in practical metric units) **(4.36)**

After Varying Flow Rates…/6

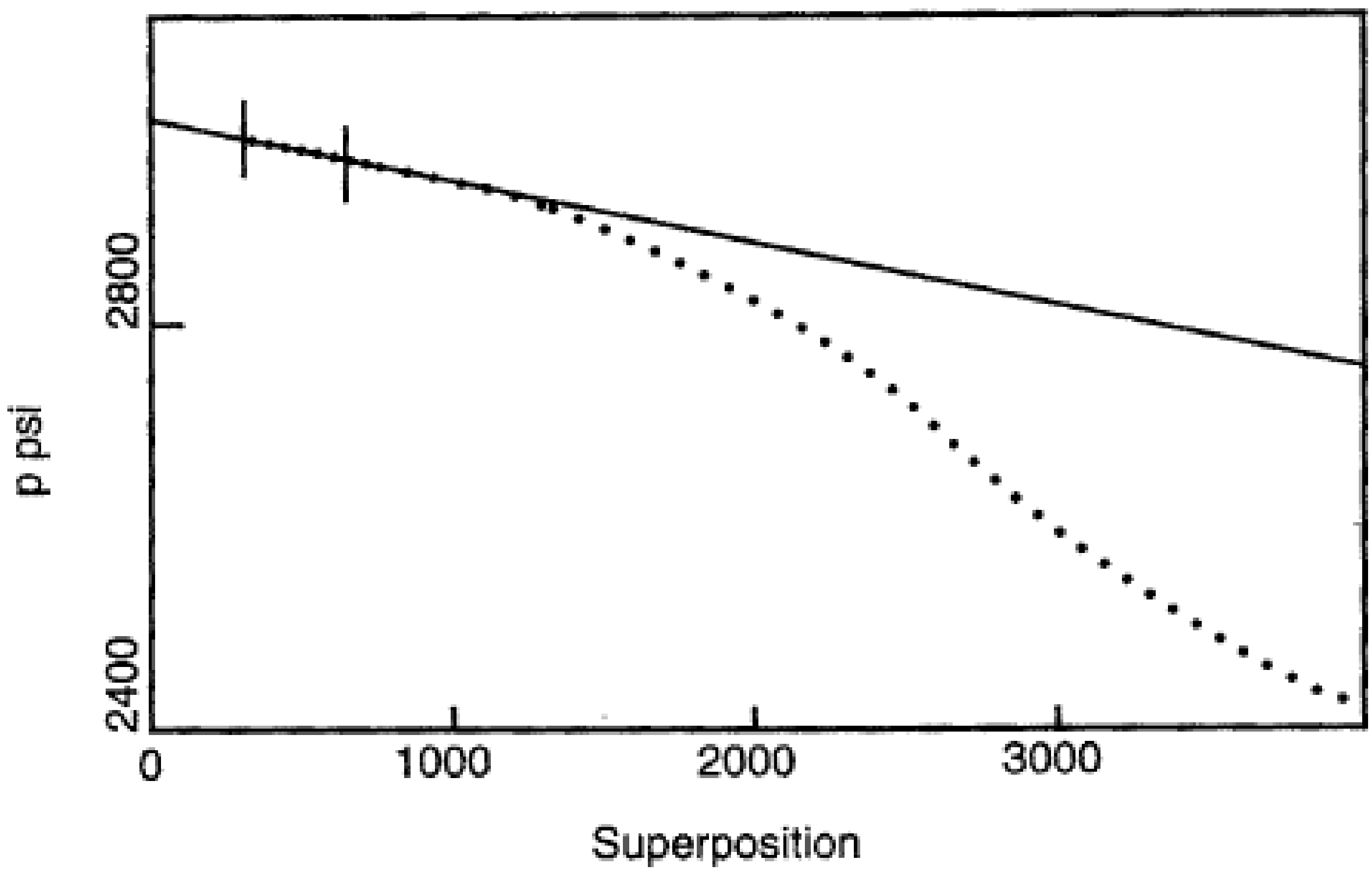

Fig. 4.7

After Varying Flow Rates…/7

Interpretation

- The slope is independent of flow rate. This is the advantage of the representation: the results obtained with different flow rates can be compared on the same graph.
- To find an expression of m which is dependent on flow rate comparable to what is obtained with Horner's method, the superposition function needs only to be divided by the last flow rate.

After Varying Flow Rates…/8

Interpretation

- The slope, m, of the straight line is used to determine the reservoir's **kh**:

$$kh = \frac{162.6\ B\mu}{m}$$ (in practical US units) **(4.37)**

$$kh = \frac{21.5\ B\mu}{m}$$ (in practical metric units) **(4.38)**

After Varying Flow Rates…/9

Interpretation

- The skin is determined based on the pressure value read on the straight line 1 hour after a last flow rate variation:

$$S = 1.151\left(\frac{p_{1h} - p_{wf}(t_{n-1})}{(q_{n-1} - q_n)\,m} - \log\frac{k}{\phi\mu c_t r_w^2} + 3.23\right) \quad \text{(US)} \qquad \textbf{(4.39)}$$

$$S = 1.151\left(\frac{p_{1h} - p_{wf}(t_{n-1})}{(q_{n-1} - q_n)\,m} - \log\frac{k}{\phi\mu c_t r_w^2} + 3.10\right) \quad \text{(metric)} \qquad \textbf{(4.40)}$$

After Varying Flow Rates…/10

Interpretation

- If the last flow rate variation is a shut-in, the pressure reading for infinite time, i.e. for value of the superposition function equal to zero, is used to determine the extrapolated reservoir pressure.

Example 4

(In-class workshop)

Simplification of the Flow Rate History

- To analyze the final buildup, the simplest method consists in reducing the flow rate history to one single rate and using Horner's method for the actual interpreting.
- The single-rate production data that replace the n-1 multirate reality must be governed by the following principle:
  - flow rate = the last rate;
  - equivalent production time:

$$t_{pe} = \frac{\sum_{i=1}^{n-1} q_i (t_i - t_{i-1})}{q_n} \qquad \textbf{(4.41)}$$

Simplification of the Flow Rate History…/2

- The production time is designed to provide a total production value identical to the production that was actually recorded.
- The real production time should not be used to compute and equivalent flow rate.

Buildup Radius of Investigation

- The theoretical radius of investigation depends only on the **duration of the pressure buildup**.
- The radius of investigation can be estimated by using the formula proposed before:

$$r_i = 0.032\sqrt{\frac{kt}{\phi \mu c_t}}$$ (in practical US units) **(4.42)**

$$r_i = 0.038\sqrt{\frac{kt}{\phi \mu c_t}}$$ (in practical metric units) **(4.43)**

Example 5

(In-class workshop)

References

1. Bourdarot, Gilles : Well Testing: Interpretation Methods, Éditions Technip, 1998.
2. Internet.