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Forchheimer equation

By consideration of data such as shown in Figure 1, Forchheimer (1901) suggested the quadratic alternative to Darcy’s Law:

\[ \frac{dP}{dx} = -k \left( \rho \mu \frac{u}{\rho g} \right) - \rho \mu \frac{u^2}{2 \rho g} \]

where
- \( k \): permeability [L²]
- \( \mu \): dynamic viscosity [ML⁻¹T⁻¹]
- \( P \): fluid pressure [L¹]
- \( x \): distance [L]
- \( \rho \): fluid density [M/L³]
- \( b \): Forchheimer parameter

From a dimensional analysis Ward (1964) established that

\[ b = f(k^{0.5}) \]

From an empirical analysis Geertsma (1974) proposed that

\[ b = 0.005 \phi^{-0.5} \]

where \( \phi \) is porosity.

Step-drawdown tests

A common way to test a well is to pump at sequentially increasing rates; a step drawdown test. After a certain amount of time, drawdown in the well, \( s_w \), reaches a quasi-steady value. These drawdowns are plotted against pumping rate, \( Q_w \), and a quadratic is fitted (the Jacob Method):

\[ s_w = A Q_w + B Q_w^2 \]

where \( A \) and \( B \) are known as the formation loss and well loss factors, respectively. Comparison with the large - time solution for Forchheimer flow to a well (Mathias et al., 2008)

\[ s_w = \frac{Q_w}{4 \pi T} \left( \frac{47}{Sc_r^2} \right)^{0.5772} + \frac{b Q_w^2}{(2.57)^4 r_w g} \]

where
- \( H \): formation thickness [L]
- \( T \): time [T]
- \( T = H \phi \rho \mu [L^2 T^-1] \): transmissivity
- \( S = H \phi (c_r + c_s) / g \): storativity
- \( r_w \): well radius [L]
- \( g \): gravity [L/T²]
- \( c_r, c_s \): rock and fluid compressibility

suggests that \( B = \frac{b}{(2.57)^4 r_w g} \)

so field-scale estimates of \( b \) can be obtained from values of \( B \).

Further reading
