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A Method for Synthesizing and Averaging Capillary Pressure Curves

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Capillary pressure is important in petroleum exploration and development. A partial list of applications includes evaluating reservoir rock, sealing capacity, transition zone thickness, pay versus nonpay, recovery efficiency, absolute and relative permeability. However, laboratory measurements are usually either unavailable or in limited numbers because of cost or lack of cores. Moreover, it is questionable to apply limited measurements to delineate an entire reservoir because of the heterogeneity of the reservoir rocks. In this study, we propose a method to synthesize capillary pressure curves from porosity and permeability, which are easily obtained from routine core analysis, thin sections and well logs. With the method proposed by this study, synthetic capillary pressure curves can be obtained and applied to petroleum exploration and production.

Our model is based on Thomeer's (1960, 1983) model:

$$\frac{S_b}{S_{b\infty}} = e^{-Fg/(\log Pc/Pd)} \qquad (1)$$

$$k = 3.8068 Fg^{-1.3334} (100 S_{b\infty}/P_d)^{2.0} \qquad (2)$$

Where k is air permeability in millidarcy, S_b is the fractional bulk volume occupied by mercury at pressure P_c, $S_{b\infty}$ is the fractional bulk volume occupied at infinite pressure, P_d is displacement pressure in psi, Fg is the pore geometrical factor.

If $S_{b\infty}$ is assumed equal to porosity, ϕ (fraction), then $S_b/S_{b\infty}$ is equal to non-wetting phase saturation, S_{nw} (fraction) and Eq.1 can be rewritten as:

$$\log P_c = -F_g/\ln (1 - S_w) + \log P_d \qquad (3)$$

where S_w is wetting phase saturation. Fg can be calculated by rearranging Eq.2:

$$Fg = e^{[1.3368 + 2 \ln (100 S_{b\infty}/P_d) - \ln k]/1.3334} \qquad (4)$$

P_d can be calculated by the following empirical equation:

$$\ln p_d = 5.458 - 1.255 \ln \sqrt{k/\phi} + 0.081 (\ln \sqrt{k/\phi})^2 \qquad (5)$$

This equation is based on 7 published data sets including 96 sandstone and carbonate samples, with a correlation of coefficient of 0.92 (R^2).

Synthetic capillary pressure curves can be obtained by combining Eq.3-5. As shown in Fig.1, the synthetic capillary pressures agree well with the measured curves.

For clean sandstones, the irreducible water saturation, S_{wir}, is usually negligible. However, for shaly sandstones, S_{wir} values are too high to be ignored. Taking S_{wir} into account, $S_{b\infty} = \phi\ (1\text{-}S_{wir})$, thus, $S_b/S_{b\infty} = (1\text{-}S_w)/(1\text{-}S_{wir})$, and the Eq.3 can be written as:

$$\log P_c = -F_g/\ln\ (\frac{1 - S_w}{1 - S_{wir}}) + \log\ P_d \qquad (6)$$

S_{wir} can be estimated by rearranging Coates and Denoo's (1981) permeability model

$$k = [\frac{100\phi^2(1 - S_{wir})}{S_{wir}}]^2 \qquad (7)$$

as:

$$S_{wir} = \frac{100\phi^2}{100\phi^2 + \sqrt{k}} \qquad (8)$$

Fig.2 shows the capillary pressures calculated by the clean sandstone model (Eq.3-5) and shaly sandstone model (Eq.4-6, 8). A better fit is obtained by taking S_{wir} into account. A higher accuracy is expected if S_{wir} can be accurately estimated.

The ''averaging'' procedure involves the following two steps: (1) divide a particular reservoir into several flow units according to porosity, permeability, and pore-throat radius. Each flow unit is assumed to be homogenous; (2) calculate the average porosity, permeability and capillary pressures for each flow unit. The average capillary pressure curve for the whole reservoir can be obtained by combining capillary pressure data from each unit. Therefore, water saturation profile, oil column, as well as oil-in-place can be calculated.

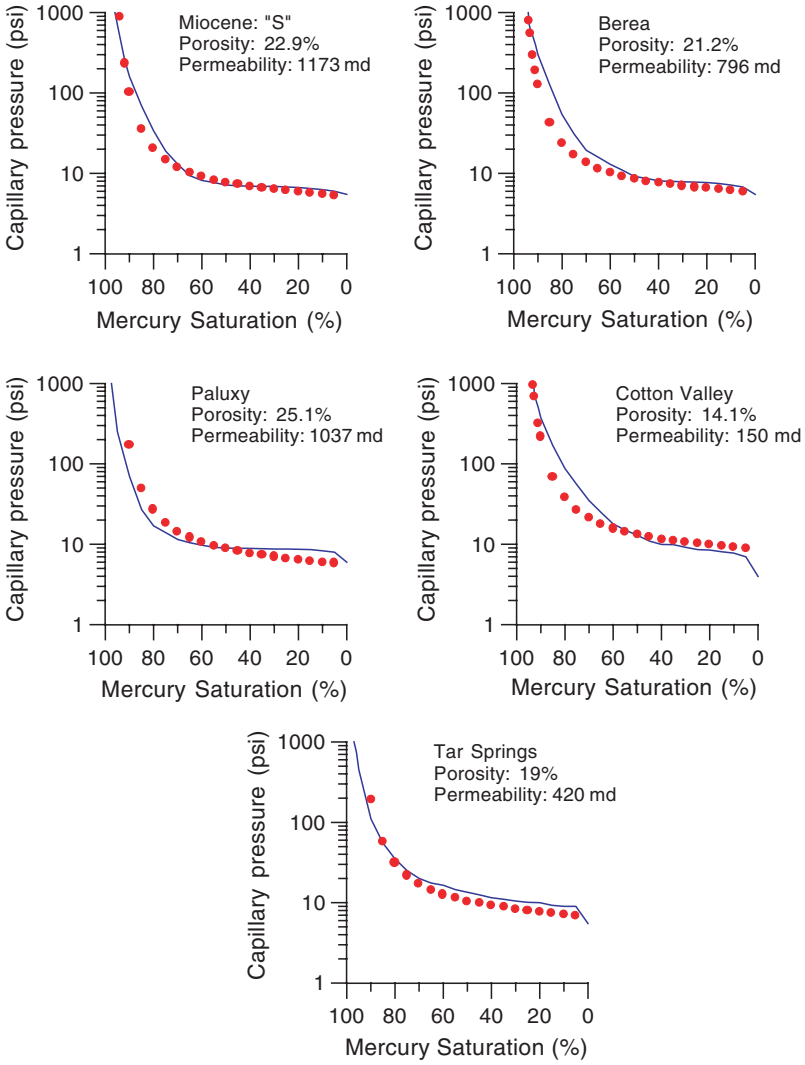

Fig.1 Comparison of synthetic (dots) and measured (solid curves) capillary pressures (data from Neasham, 1977). Capillary pressures are calculated with Eq.3-5.

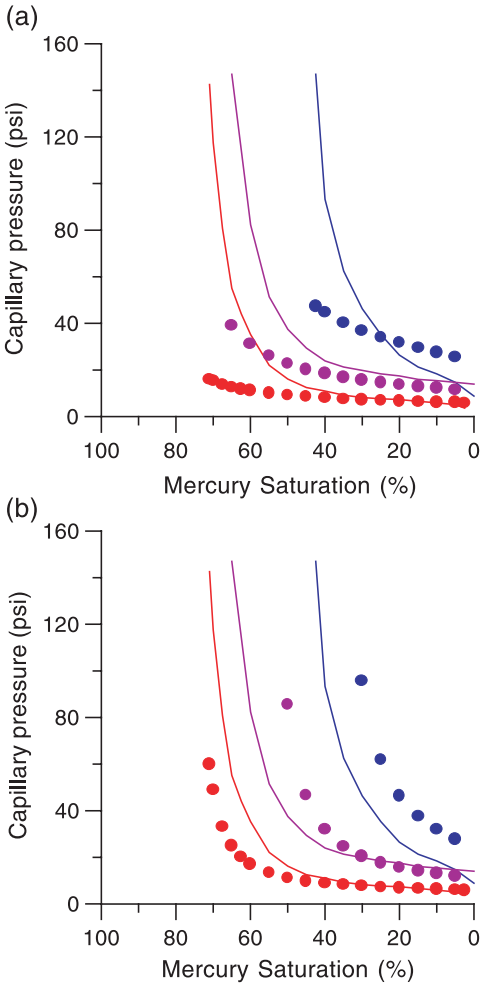

Fig.2 Comparison between synthetic (dots) and measured (solid curves) capillary pressures for three shaly sandstone samples (Frio sandstone, Purcell, 1949). (a) shows the results of clean sandstone model (Eq.3-5); (b) shows the results of shaly sandstone model (Eq.4-6,8)