

Webb, April 30, 1992 (1992b)

Date: 4/30/92
To: D. R. Anderson, 6342
From: S. W. Webb, 6344
Subject: Uncertainty Estimates for Two-Phase Characteristic Curves for 1992 40 CFR 191 Calculations

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to:D. R. Anderson, 6342

Steve
from:S. W. Webb, 6119

subject:Uncertainty Estimates for Two-Phase Characteristic Curves for 1992 40 CFR
191 Calculations

Two-phase characteristic curves (capillary pressure and relative permeability) have a large degree of uncertainty since no data on the WIPP materials have been obtained. The uncertainty in the threshold pressure has been discussed previously by Davies (Ref. 1). Uncertainties in the two-phase characteristic curves for RCRA calculations were discussed by Webb (Ref. 2). Due to time constraints, the two-phase characteristic curves were limited to the modified Brooks and Corey format. The characteristic curves will be expanded in this memo to include correlation uncertainty.

Uncertainties in the two-phase characteristic curves fall into the following categories:

1. Conceptual Model
2. Correlation Model
3. Parameter

The conceptual model for the two-phase interface is based on standard two-phase characteristic curves. Since a lower viscosity fluid (gas) is displacing a higher viscosity fluid (brine), the displacement interface will be unstable, and viscous and capillary fingering may occur. Fingering is a very complex phenomena which has not been quantified yet for the WIPP, but the processes are not captured in standard two-phase characteristic curves. Investigation into fingering has recently been initiated in 6119. It is not known what the impact will be on the displacement interface, but indications are that it could be significant. In addition, these standard curves are based on a uniform porous media; fractures are expected in the Salado, especially in the anhydrite interbeds. The conceptual model uncertainty of using standard two-phase characteristic curves derived for uniform porous media is large.

Uncertainty also exists in the choice of the correlation model. At present, the modified Brooks and Corey correlation is suggested based on comparison to a single set of data for an analogue material (tight gas sands) as discussed by Davies and LaVenue (Ref. 3). As has been repeatedly emphasized, there are no measurements for any Salado lithologies, so the correlation uncertainty is large. This aspect has been addressed to a

limited extent by Webb (Ref. 4) which shows a significant influence of the two-phase characteristic curves on the gas migration distance for the undisturbed scenario.

As an alternative, the van Genuchten/Parker correlation (Ref. 5,6) is included. The van Genuchten relationship for capillary pressure has been used by Yucca Mountain (Ref. 7,8) to fit their data, and the curve fits the Morrow et al. data about as well as the Brooks and Corey correlation (Ref. 9). While the Brooks and Corey model also fits the limited nonwetting phase relative permeability data of Morrow et al. reasonably well, the Parker extension to the van Genuchten model is not as successful (Ref. 9). Even so, the Van Genuchten/Parker model is included as correlation uncertainty since no data are available for WIPP specific materials.

While the van Genuchten form has been successfully compared to capillary pressure data, the variation of the fitting parameter m is only given for a limited subset. However, for large values of capillary pressure, which is expected for WIPP materials, the fitting parameter m is related to the Brooks and Corey parameter λ as $m = \lambda/(1+\lambda)$. As a first approximation, the variation of λ from Brooks and Corey can be used to determine the m distribution.

No definitive threshold pressure exists for the van Genuchten curve, so the Davies' correlation described above cannot be directly used to characterize the magnitude of the capillary pressure curve. In order to include this effect, it is proposed to equate the magnitude of the Brooks and Corey and the van Genuchten curves at an effective saturation of 0.5. This procedure will at least capture the trend of the change in the magnitude of capillary pressure for different materials.

Finally, parameter uncertainty is also large. As discussed in the preceding paragraph, there are no measurements and we rely on only one set of measurements on an analogue material. Since only one data set was used for parameter evaluation, no parameter range can be given.

With these large uncertainties in all areas, large ranges of parameters are necessary. The parameter ranges summarized below apply to the all lithologies in the Salado. The Brooks and Corey model is considered more reliable than the van Genuchten/Parker model based on limited data-model comparisons (Ref. 9); therefore, a weighting factor of 0.67 for Brooks and Corey and 0.33 for van Genuchten/Parker is tentatively recommended.

Brooks and Corey (Weighting Factor = 0.67)

Threshold Pressure (P_t)
 Expected Value and Range given by Davies (Ref. 1)
 Residual Saturations (S_{lr} and S_{gr})
 Expected Value = 0.2
 Range between 0.0 and 0.4 with uniform distribution
 Pore-Size Distribution Parameter (λ)
 Expected Value = 0.7
 Range between 0.2 and 10.

van Genuchten/Parker (Weighting Factor = 0.33)

Pressure Constant (P_o)

Equate with Brooks and Corey capillary pressure at $S_e=0.5$

Residual Saturation (S_{1r})

Expected Value = 0.2

Range between 0.0 and 0.4 with uniform distribution

Maximum Liquid Saturation (S_{1s})

Expected Value = 1.0

No range

Pore-Size Distribution Parameter (m)

Calculate λ using Brooks and Corey distribution

Approximate m from $m = \lambda/(1+\lambda)$

The residual saturation value of 0. for the critical gas saturation (S_{gr}) is an important parameter and is specified to try to estimate possible effects of fingering. This analogy is weak at best but it is the best that can be done at present. The large range for the pore-size distribution parameter is based on values given by Mualem (Ref. 10) for real porous media. Since we do not know anything about the structure of the Salado materials, a wide range is appropriate.

The capillary and relative permeability curves are shown in Figure 1 for the λ and m ranges specified above. The equations for the correlations are summarized in the appendix.

Work is currently in progress evaluating fracture two-phase characteristic curves as well as equivalent continuum approaches which combine matrix and fracture behavior. These additional two-phase characteristic curves are expected for the 1993 PA calculations.

References

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3. Memo to R. P. Rechard from P. Davies and A. M. LaVenue, "Additional Data for Characterizing 2-Phase Flow Behavior in Waste-Generated Gas Simulations and Pilot Point Information for Final Culebra 2-D Model (SAND89-7068/1)," November 19, 1990.

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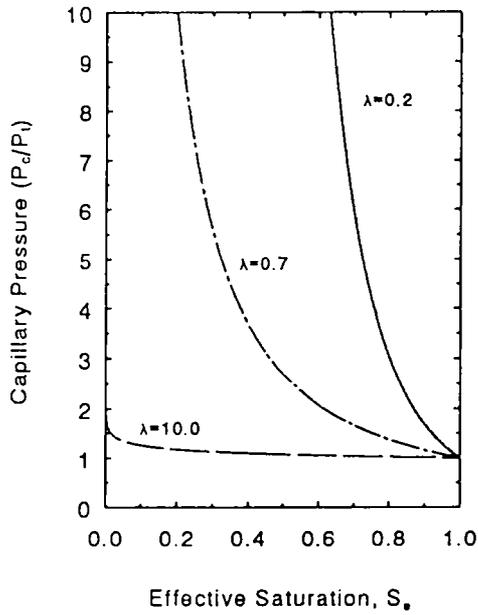
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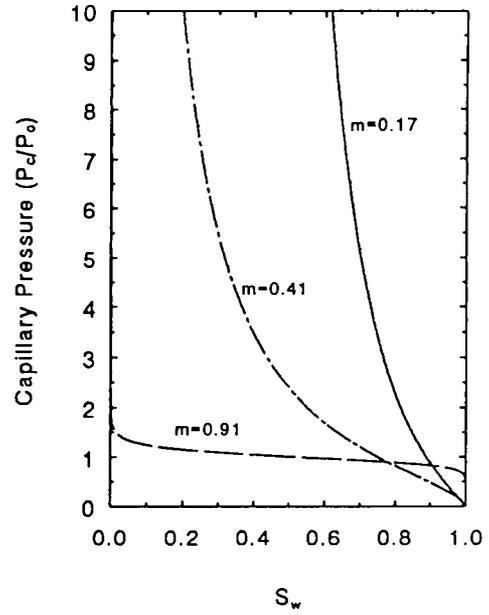
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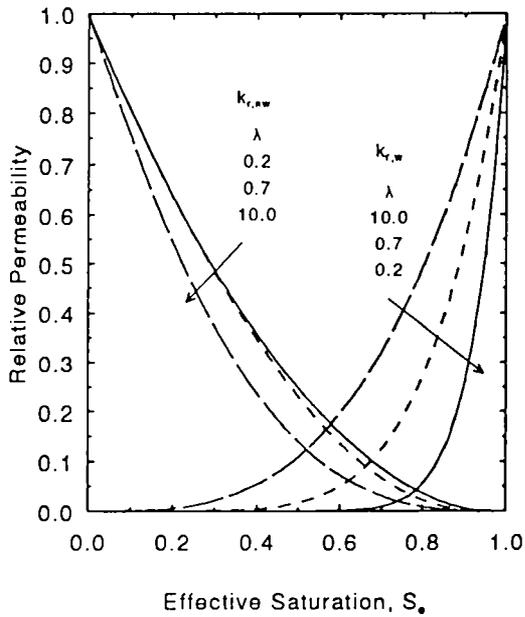
Modified Brooks and Corey
Effect of λ



van Genuchten
Effect of m



Brooks and Corey
Effect of λ



Parker et al.
Effect of m

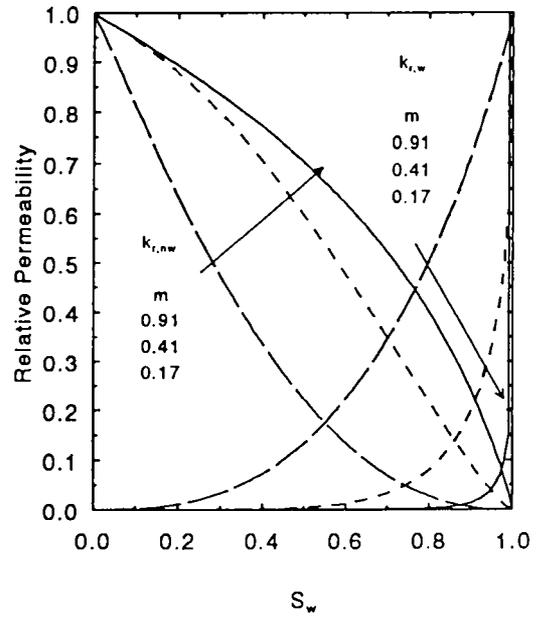


Figure 1
Capillary Pressure and
Relative Permeability Functions

Appendix
Two-Phase Characteristic Curves

The relationships defining the various sets of two-phase characteristic curves are summarized below.

Brooks and Corey

The modified Brooks and Corey relationships used by Davies and LaVenue (1991) are

Capillary Pressure

$$P_c = \frac{P_t}{S_e^{1/\lambda}} \quad (\text{A-1})$$

Relative Permeability

$$k_{r,l} = S_e^{(2+3\lambda)/\lambda} \quad (\text{A-2})$$

$$k_{r,g} = \left(1 - S_e\right)^2 \left(1 - S_e^{(2+\lambda)/\lambda}\right) \quad (\text{A-3})$$

$$S_e = \frac{S_1 - S_{1r}}{1 - S_{gr} - S_{1r}} \quad (\text{A-4})$$

The capillary pressure relationship, equation A-1, is used throughout the entire saturation region ($0 \leq S_1 \leq 1$) even though, as discussed by Corey (1986), this relationship may not be appropriate at the higher liquid saturations when $S_e > 1.0$.

van Genuchten/Parker et al.

The relationships for the van genuchten/Parker et al. (1987) characteristic curves are

Capillary Pressure

$$P_c = P_o \left[S_e^{-1/m} - 1 \right]^{1-m} \quad (\text{A-5})$$

Relative Permeability

$$k_{r,l} = S_e^{1/2} \left[1 - \left(1 - S_e^{1/m} \right)^m \right]^2 \quad (\text{A-6})$$

$$k_{r,g} = \left(1 - S_e \right)^{1/2} \left(1 - S_e^{1/m} \right)^{2m} \quad (\text{A-7})$$

where

$$S_e = \frac{S_l - S_{lr}}{S_{ls} - S_{lr}} \quad (\text{A-8})$$

where S_{ls} is the maximum wetting phase saturation.