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025289 Stone's kro Methods and Modifications

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Stone's Methods 1 and 2 (1,2) for three-phase kro have been modified for the non-unit krocw case by various authors. It is the purpose of this note to suggest that Stone's methods require no such modification. This statement is basically a semantical step beyond the same observation noted by Baker (3).

Stone's Method 1 gives kro as

$$kro(Sw,Sg) = R \times krow(Sw) \times krog(Sg) \qquad (1)$$

Stone states his kro expressions reduce to krow when Sg=0 and to krog when Sw=Swc. It is clear, then, that he used a reference permeability k = kocw for defining relative permeabilities.

Writing Stone's Eq. (1) in terms of effective permeabilities gives

$$ko(Sw,Sg) = R \times kow \times kog/kocw \qquad (2)$$

This ko can be expressed in terms of relative permeabilities using an arbitrary reference permeability k by simply dividing Eq. (2) by k,

$$kro(Sw,Sg) = R \times krocw \times Krow \times Krog \qquad (3)$$

Stone's Method 2 is

$$kro(Sw,Sg) = (krow + krw) \times (krog + krg) - krw - krg \qquad (4)$$

and effective ko is

$$ko(Sw,Sg) = (kow + kw) \times (kog + kg)/kocw - kw - kg \qquad (5)$$

Division by k gives his three-phase kro for an arbitrary reference permeability,

$$kro(Sw,Sg) = (krow + krw) \times (krog + krg)/krocw - krw - krg \qquad (6)$$

The above are not modifications of Stone's methods. Eqs. (1)-(3) are his Method 1 and Eqs. (4)-(6) are his Method 2, requiring only that we note his definition of k from his statement that his methods reduce correctly to 2-phase krow and krog. Eq. (3) is given by Aziz and Settari (4) as a modification of Stone's Method 1. Eq. (6) is reported as a variation or adjustment (5), or modification (6) of Stone's Method 2.

Dietrich and Bondor (5) give Hirasaki's method, which is a modification of Stone's Method 1, in a general form for any reference permeability. Baker gives that method for unit krocw as

$$kro(Sw,Sg) = krow \times krog - Sg \times (1-krow) \times (1-krog) \qquad (7)$$

Applying the same steps taken above from Eq. (1) to Eq. (3) and Eq. (4) to Eq. (6) gives Hirasaki's method for any reference permeability as

$$kro(Sw,Sg) = krocw \times [Krow \times Krog - Sg \times (1-Krow) \times (1-Krog)] \quad (8)$$

The equation

$$kro(Sw,Sg) = krocw \times [(Krow + krw) \times (Krog + krg) - krw - krg] \quad (9)$$

credited to various authors, as noted by Baker, is a modification of Stone's Method 2 For Stone's and Hirasaki's methods, ko is independent of reference permeability k. This is not true for Eq (9); in other words, ko from Eq (9) is a function of reference permeability k. Baker gives an extensive review and evaluation of these and other three-phase kro methods.

Nomenclature

km	=	effective permeability of phase m
k	=	reference permeability used to define relative permeabilities
krm	=	relative permeability of phase m, km/k
krw(Sw)	=	relative permeability of water, a function of Sw
krg(Sg)	=	" " of gas, a function of Sg
krow(Sw)	=	" " of oil with Sg=0, a function of Sw
krog(Sg)	=	" " of oil with Sw=Swc, a function of Sg
krocw	=	" " of oil at Sw=Swc, Sg=0
kocw	=	effective permeability to oil at Sw=Swc, Sg=0
Krow	=	krow/krocw
Krog	=	krog/krocw
kro(Sw,Sg)	=	three-phase oil relative permeability, a function of Sw and Sg.
Som	=	minimum or residual oil saturation, below which kro = 0, a parameter in the Stone 1 Method.
Sw*	=	(Sw - Swc)/(1 - Swc - Som)
Sg*	=	Sg/(1 - Swc - Som)
R	=	(1 - Sw* - Sg*)/(1 - Sw*) x (1 - Sg*))

References

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