



# **Empirical Equations for Water/Oil Relative Permeability in Niger Delta Sandstone Reservoirs**

<sup>1</sup>Akpoturi Peters; <sup>2</sup>Usuolori O.B.A.; <sup>3</sup>Akpoturi Oby Katherine & <sup>4</sup>Eli Goodluck

<sup>1,2</sup>Department of Petroleum Engineering  
Delta State University of Science and Technology, Ozoro, Nigeria

<sup>3</sup> Department of Economics  
Delta State University of Science and Technology, Ozoro, Nigeria

<sup>3</sup> Department of Petroleum Engineering, Delta State University, Abraka, Nigeria

<sup>4</sup> Department of Petroleum Engineering, Federal University Otuoke, Bayelsa State, Nigeria

## **ABSTRACT**

Relative permeability data are essential for almost all calculations of fluid flow in petroleum engineering. Water/oil relative permeability curves play important roles in characterizing the simultaneous two-phase flow in porous rocks and predicting the performance of immiscible displacement processes in oil reservoirs. This paper presents new empirical equations for calculating water/oil imbibition's relative permeability curves. The models of relative permeability were developed using experimental data from 46 displacement core tests from sandstone reservoirs of Saudi fields. Three empirical equations are presented to calculate oil relative permeability, water relative permeability, and the endpoint of the water relative permeability curve. The relative permeability models were derived as a function of rock and fluid properties using step-wise linear and nonlinear regression analyses. The new empirical equations were both evaluated using the data utilized in the development and validated using published data, which were not used in the development stage, against previously published equations. Statistical results show that the new empirical equations developed in this study are in better agreement with experimental data than previous empirical equations, for both the data used in the development and validation stages. The new empirical equations can be used to determine water/oil relative permeability curves for other fields provided the reservoir data fall within the range of this study.

**Keywords:** Permeability , Multiphase system , Water/oil , Sandstone , Reservoir , Empirical Equations , and ultimate recovery

## **INTRODUCTION**

Relative permeability<sup>1-4</sup> is an important concept in describing the flow of multiphase systems. It is defined as the ratio of the effective permeability of a fluid at a given saturation to the absolute permeability of the rock. Data of relative permeabilities are essential for almost all calculations of fluid flow in petroleum reservoirs. The data are used in making engineering estimates of productivity, injectivity, and ultimate recovery. Some applications of relative permeability data include determination of free water surface, aid in evaluating drill-stem and production tests, determination of residual fluid saturations, fractional flow and frontal advance calculations to determine the fluid distributions, and making future predictions for all types of oil reservoir under different operational schemes. Undoubtedly, these data are considered

probably the most valuable information required in reservoir simulation studies. The producing gas-oil ratio and the producing water/oil ratio are two criteria used in history matching, which can be modified by relative permeability changes. More accurate prediction of relative permeability will reduce the trial and errors needed to improve the history matching.

Estimates of relative permeabilities are generally obtained from laboratory experiments with reservoir core samples using one of the measurement methods: steady state or unsteady state techniques. The relative permeability data may also be determined from field data using the production history of a reservoir and its fluid properties. However, this approach is not often recommended because it requires complete production history data and provides average values influenced by pressure and saturation gradients, differences in the depletion stage, and saturation variations in stratified reservoirs. In addition, the agreement between laboratory determined relative permeability's and those calculated from production history is generally poor. Because the laboratory measurement of relative permeabilities is rather delicate and time consuming, empirical correlations are usually employed to reproduce experimentally determined relative permeability curves, or to estimate them when experimental data from core samples are not available.

The purpose of this study is to develop new empirical equations to predict imbibitions water/oil relative permeability characteristics using experimentally obtained data for sandstone reservoir rocks. Multiple linear and nonlinear least-square regression techniques are applied on the new proposed models utilizing the experimental rock and fluid saturation data. The new empirical equations are evaluated against several empirical equations published in the literature<sup>4-11</sup> using the data utilized in the development, and validated using published relative permeability data.

## **MATERIALS AND METHODS**

### **Experimental Data**

Experimental water/oil imbibitions relative permeability data from different oil fields were gathered for the development of empirical equations. The experimental data are exclusively for sandstone reservoirs ranging from semi-consolidated to unconsolidated, fine to very fine-grained, well-sorted rock types. Steady state and unsteady state techniques of measuring water/oil relative permeability were employed on 46 water- flood core tests in obtaining a total of 827 experimental data points. Most of the water flood tests were conducted using the unsteady state method. A summary of core samples properties and test conditions used in the measurement of relative permeability values is given in **Table 1**. The obtained experimental data showed a wide range of core length, injection rate of displacing fluid, viscosity and viscosity ratios of fluids, and temperature.

**TABLE 1- STATISTICAL DATA DESCRIPTION OF CORE SAMPLES AND FLUID PROPERTIES**

Property	Mm.	Max.	Mean	Std Dev
Core length, cm	4.39	31.55	14.40	10.99
Areaofcore,cm <sup>2</sup>	10.01	11.58	10.96	0.340
Porosity, %	23.07	33.80	28.55	2.680
Pore volume, cm <sup>3</sup>	13.80	105.19	43.32	32.05
Displacement rate, cm <sup>3</sup> /min	1.56	9.02	6.38	2.233
Scaling factor, Lp.v, cm <sup>2</sup> cp/min	1.00	4.98	2.37 0.	986
Water viscosity, cp	0.387	1.073	0.62	0.186
Oil viscosity, cp	1.10	16.00	6.35	4.070
Temperature during flood, °F	74.0	165.0	133.3	28.65

The experimental data were checked for the capillary end effects using the criteria of Rapoport and Leas<sup>2</sup>. The scaling factor was calculated for each displacement test and the obtained results (Table 1) were within the range of published experimental values. Relative permeability curves were generated utilizing the experimental displacement data and core properties, and using a computer program that implements the JBN method<sup>13</sup> to calculate relative permeabilities from unsteady-state two-phase flow in displacement experiment.

#### **Development of Empirical Equations**

Non-linear and linear multiple least-square regression analysis procedures were applied on the experimental data using SAS software package<sup>1-4</sup>. Nonlinear and linear least-square regression Fortran programs<sup>15</sup> were developed and used in this study. Several model selection techniques including stepwise regression and R-square were used in selecting the best regression equations from the specified set of parameters. All these selection methods showed excellent agreements of regression results and the stepwise regression technique was selected for the final results.

**Table 2 shows the range of rock and fluid saturation properties of the 46 sets of imbibition water/oil relative permeability curves for sandstone reservoir rocks utilized in the regression analysis**

TABLE 2— RANGES OF ROCK AND FLUID SATURATION PROPERTIES		
Property	Min.	Max.
Water saturation, %	11.728	93.8 12
Connate water saturation, %	11.728	38.556
Residual oil saturation, %	6.188	39.850
Effective oil permeability at Swi, md	25.30	4790.0
Effective water permeability at Sor, md	4.329	1084.1

Oil Relative Permeability Model. The oil relative permeability model was derived as a function of rock and fluid saturation properties.

$$k_{ro} = f(S_w, S_{wi}, S_{or}, k_{ro}(s_{wi}))$$

The best empirical equation for estimating oil relative permeability curve was found as:

$$k_{ro} = k_{ro}(s_{wi}) \left( \frac{1 - s_w}{1 - s_{wi}} \right)^{3.661763} \left( \frac{1 - s_w - s_{or}}{1 - s_{wi} - s_{or}} \right)^{0.7}$$

The above equation was developed using multiple linear least-square regression applying the appropriate transformation, to generate the coefficients of the linearized model. The physical parameter,  $k_{ro}(S_{wi})$ , usually has the value of 1. The above equation satisfies exactly the requirements that:

- (i) At  $S_w = S_{wi}$ ,  $k_{ro} = k_{ro}(s_{wi})$ , and
- (ii) At  $S_w = 1 - S_{or}$ ,  $k_{ro} = 0$

Equation (2) was developed with a correlation coefficient of 0.979 indicating that 98% of the data variation about the mean is explained by the model. Analysis of the significance of the independent parameters of the model is presented in Table 3. All the considered independent variables have very small probability values indicating very low probability of not being significant in the model.

TABLE 3-T TEST FOR REGRESSION COEFFICIENTS OF OIL RELATIVE PERMEABILITY MODEL		
Independent variable	T for H0: $\rho > \sqrt{T}$	
$Ln \left( \frac{1 - S_w}{1 - S_{wi}} \right)$	24.665	0.0001
$Ln \left( \frac{1 - S_w - S_{or}}{1 - S_{wi} - S_{or}} \right)$	10.896	0.0001

Figure 1 shows the error distribution histogram constructed as the deviations frequency versus the residual for this study’s oil relative permeability empirical equation. Most of the errors distributed closely around the mean of zero while less than 1% of data deviations occur at the residual extremes.

**Water Relative Permeability Model.** The water relative permeability model was developed as a function of fluid saturations and porosity following the work of Chierici’6 for water relative permeability.

$$k_{rw} = f(S_w, S_{wi}, S_{or}, k_{rw(sor)})$$

The following empirical equation was found to reproduce accurately the experimental water relative permeability data:

$$k_{rw} = k_{rw(sor)}$$

$$\text{Exp} \left[ -1.05086 \left( \frac{S_w - S_{wi}}{1 - S_w - S_{or}} \right) - 0.46163 \right]$$

Nonlinear least-square regression was applied on the experimental data to generate the correlating coefficients of the model. The first exponential term of equation (4), water relative permeability at residual oil saturation, represents very accurately the end point of water relative permeability curve. A new empirical equation is developed, Eq. (5), to calculate the relative permeability of water at residual oil saturation. It was derived as a function of residual oil saturation and porosity and it individually contributes for more than 54% of the improvement of accuracy of the entire model. Dividing the water relative permeability data by this term can normalize the water relative permeability curve. Equation (5) was developed with a correlation coefficient of 0.919 using regression analysis.

$$k_{rw(sor)} = \text{Exp}[-5.41463\emptyset(1 - S_{or})]$$

The water relative permeability model implicitly satisfies the initial and end points of water relative permeability curves:

- (i) At  $S_w = S_{wi}$ ,  $\frac{S_w - S_{wi}}{1 - S_w - S_{or}} = 0$ , and  $e = 0$   
 Implying that  $k_{rw} = 0$
- (ii) At  $S_w = 1 - S_{or}$ ,  $\frac{S_w - S_{wi}}{1 - S_w - S_{or}} = \infty$ , and  $e = 0$   
 Implying that  $k_{rw} = \text{Exp}[-5.41463\emptyset(1 - S_{or})]$

The empirical equation obtained using this model agrees very closely with experimental data. Equation (4) was developed with a correlation coefficient of 0.9304 implying that 93% of the data variation around the zero mean is accounted for by the model. The significance F-test statistic for this model is 2433.0 with “Prob > F” value of 0.0001 indicates that all the independent variables included in the considered model contribute significantly to the improvement of the model. **Figure 2** shows the error distribution histogram constructed as the deviations frequency vs. the residual for water relative permeability empirical equation. Most of the errors distributed closely around the mean of zero while less than 1% of data deviations occur at the residual extremes.

**Behaviour of Models**

It is important that the dependent variables of regression models comply with the behavior of their independent correlating variables. The behaviors of regression models of this study were examined against their correlating parameters of physical properties. The average experimental values of irreducible

water saturation, residual oil saturation, and porosity were used to calculate water and oil relative permeability from regression models for the range of water saturation. **Figure 3** depicts a typical behavior of water/Oil relative permeability curves as generated by the models of this study. For the same case, a semilog plot of water/oil relative permeability curves is generated in **Fig. 4**. **Figure 5** compares core sample measured data of relative permeability with empirical equations developed in this study.

Parametric analysis was performed to investigate the effect of other physical parameters, which are not included in the models, on the characteristics of oil and water relative permeability curves. The physical parameters considered are temperature, porosity, and type of measurement method. Unlike for oil relative permeability model, the porosity was found a strong independent variable to be included in the water relative permeability model particularly in estimating the endpoint. This indicates that the porosity has an influence on the characteristic of water relative permeability curve. Temperature and classifying data by type of measurement method were found to have almost no effect. Reference 21 gives the details.

**Evaluation of Published Empirical Equations**

The new developed empirical equations were evaluated against six published empirical equations for checking their performance and degree of accuracy in estimating the water/oil relative permeability curves. These published empirical equations<sup>4</sup> include those developed by Wyllie, Pirson, Naar et al., Jones, Land, and Honarpour et al. Two error analysis techniques were used: statistical and graphical error analysis.

**Statistical Error Analysis.** The statistical parameters used to compare the degree of accuracy of the water/oil relative permeability empirical equations are: average error, absolute average error, standard deviation, root-mean-square, minimum and maximum absolute average error, and the F-test statistic.<sup>7</sup> These parameters were computed for the published empirical equations using the 827 experimentally obtained data points. **Table 4** shows the statistical accuracy of empirical equations for oil relative permeability. The empirical equation of this study achieved the lowest errors, standard deviation and root-mean-square error, with the highest F-test statistic. Empirical equation of Honarpour et al. stood second in the accuracy of errors but with lower F-test statistic than Wyllie’s empirical equation. Naar et al.’s empirical equation showed poor accuracy, with the highest errors and the lowest F-test statistic.

TABLE 4 — STATISTICAL ACCURACY OF OIL RELATIVE PERMEABILITY EMPIRICAL EQUATIONS							
Author	Year	Eav	Eab	S <sup>2</sup>	rms	E <sub>max</sub>	F-test
Wyllie	1951	-0.10	0.10	0.02	0.13	0.56	3160
Pirson	1958	-0.13	0.14	0.02	0.15	0.35	676
Naar	1961	-0.22	0.22	0.07	0.26	0.70	450
Jones	1966	-0.15	0.15	0.03	0.18	0.59	644
Land	1968	-0.09	0.09	0.02	0.13	0.59	548
Honarpour	1982	-0.06	0.06	0.01	0.09	0.54	1622
Eq. (2)	1994	0.00	0.04	0.00	0.07	0.48	9029

The statistical accuracy of empirical equations for water relative permeability is given in Table 5. The empirical equation of this study again achieved the highest accuracy of estimating water relative permeability curves with the lowest errors and highest F-test statistic. Honarpour et al.’s empirical equation for oil-wet and intermediate wettability stood second in the accuracy of errors but with unsatisfactory F-test statistic. Naar et al., Jones and Land have all the same empirical equation and hence have the same unsatisfactory performance of accuracy. Wyllie’s empirical equation showed similar performance of errors to Honarpour et al.’s empirical equation for oil-wet and intermediate wettability, but with better F-test statistic. Pirson’s empirical equation showed poor performance of accuracy with the highest errors, and Honarpour et al.’s empirical equation (for water-wet and intermediate) yielded the lowest F-test statistic.

TABLE 5 — STATISTICAL ACCURACY OF WATER  
RELATIVE PERMEABILITY EMPIRICAL EQUATIONS

Author	Year	Eav	Eab	S <sup>2</sup>	rms	E <sub>max</sub>	F-test
Wyllie	1951	0.38	0.39	0.19	0.44	0.89	693
Pirson	1958	0.51	0.51	0.33	0.58	1.00	317
Naar *	1961	0.44	0.44	0.24	0.49	0.95	672
Hanarpour, water-wet	1982	0.45	0.45	0.27	0.52	0.93	128
Honarpour, oi'-wet	1982	0,37	0.37	0.18	0.42	0.83	170
Eq. (4)	1994	0.02	0.07	0.01	0.10	0.46	2433

**Graphical Error Analysis.** The crossplot graphical error analysis technique is used in the evaluation of performance of this study and other published empirical equations.

**Figures 6 through 12** show the crossplots of estimated vs. measured values for oil relative permeability empirical equations. Most of the plotted points of this study's empirical equation fall very close to the perfect 45° straight line. All other published empirical equations overestimate the experimental data of oil relative permeability with high deviations from the perfect 45° line.

Crossplots for water relative permeability empirical equations are shown in Figs. 13 through 18. The closeness of the data points to the perfect 45° line for this study's empirical equation is obvious. All other published empirical equations reveal their underestimation of the experimental data of water relative permeability.

#### **Validation of New Empirical Equations**

The new developed empirical equations for water/oil imbibition relative permeability calculations were validated using published relative permeability data in the literature that were not utilized in the models developed in this study. This procedure was undertaken to examine the applicability of the new empirical equations and evaluate their performance of accuracy against previously published empirical equations. A total of 45 data points from four published sets<sup>18-21</sup> of water/oil relative permeability were used for validation of empirical equations. These data are summarized in **Table 6**.

TABLE 6-SUMMARY OF PUBLISHED DATA USED FOR VALIDATION OF EMPIRICAL  
EQUATIONS

Source	Field	Data Points	Data Sets
Willhite	Chesney MP-4	28	2
Braun & Blackwell	Berea	8	1
Jones & Roszelle	-	9	1

The new empirical equations were compared with published empirical equations of Wyllie, Pirson, Naar et al., Jones, Land, and Honarpour et al. Each set of published data was used for comparison of published empirical equations with those developed in this study. The results showed that the new empirical equations reproduced very accurately experimental relative permeability data than other published equations. Table 7 shows results of statistical accuracy for oil relative permeability models using the compiled published data sets. Empirical equations of oil relative permeability were compared in terms of average error, average absolute error, standard deviation, maximum absolute error, and coefficient of determination. The oil relative permeability model of this study yields better results of accuracy than other published models for oil relative permeability by showing lower values of errors and higher coefficient of determination. Empirical equations of Pirson and Honarpour et al. show similar performance of accuracy; however, Pirson's equation has a higher coefficient of determination than

Honarpour's et al. does. Empirical equation of Naar et al. performs poorly compared to other empirical equations.

TABLE 7 — STATISTICAL ACCURACY OF OIL RELATIVE PERMEABILITY EMPIRICAL EQUATIONS							
Author	Year	Eav	Eab	S <sup>2</sup>	rms	E <sub>max</sub>	F-test
Wyllie	1951	-0.14	0.14	0.03	0.16	0.30	0.70
Pirson	1958	-0.10	0.13	0.02	0.15	0.30	0.91
Naar	1961	-0.28	0.28	0.10	0.31	0.51	0.12
Jones	1966	-0.19	0.19	0.05	0.22	0.38	0.44
Land	1968	-0.09	0.09	0.02	0.13	0.33	0.79
Honar-	1982	0.01	0.05	0.01	0.09	0.39	0.91
Eq. (2)	1994	-0.01	0.04	0.01	0.07	0.23	0.94

**Table 8** gives statistical accuracy of results for water relative permeability models using compiled sets of published data. Empirical equations of water relative permeability were compared in terms of average error, average absolute error, standard deviation, maximum absolute error, and F-test statistic. Inclusion of r<sup>2</sup> parameter in this error analysis was impractical because small values of F-test given by empirical equations of Honarpour et al. and Pirson resulted in negative r<sup>2</sup> values. It should be noted that the F-test statistic has a strong direct relation with the coefficient of determination. The highest performance of accuracy is achieved by this study which gives lower errors and higher F-test statistic than the results obtained for other studies.

TABLE 8 — STATISTICAL ACCURACY OF WATER RELATIVE PERMEABILITY EMPIRICAL EQUATIONS							
Author	Year	Eav	Eab	S <sup>2</sup>	rms	E <sub>max</sub>	F-test
Wyllie	1951	0.05	0.05	0.01	0.08	0.21	72
Pirson	1958	0.12	0.12	0.03	0.16	0.45	11
Naar*	1961	0.08	0.08	0.01	0.11	0.30	34
Honarpour, water-wet	1982	0.08	0.09	0.02	0.12	0.36	4
Honarpour, oil-wet	1982	0.00	0.05	0.01	0.07	0.18	19
Eq. (4)	1994	0.00	0.02	0.00	0.03	0.07	368

## CONCLUSIONS

Multiple linear and nonlinear least-square regression analyses were applied on collected laboratory experimental data for development of empirical equations for water/oil relative permeability. The following conclusions were reached as a result of this study:

1. New empirical models are presented for calculating imbibitions water/oil relative permeability curves of sandstone reservoir rocks. These empirical equations can predict relative permeability in sandstones with properties falling within the range of data used in this development.
2. The newly developed empirical equations satisfy exactly the initial and end points requirements of water/oil relative permeability curves. The endpoint water relative permeability empirical equation developed in this study was found to reproduce accurately experimental values.
3. Comparative evaluation of existing empirical equations was made and the new empirical equations give better results of accuracy than previously published equations for the data used in this study.
4. The new empirical equations were validated using published relative permeability data. They showed better results of accuracy in estimating measured relative permeability data than other published equations.
5. Parametric analysis showed that porosity has an influence on the characteristic of water relative permeability curve, and therefore it should be included in the model for better prediction of the endpoint

in particular. Temperature and the type of measurement method of relative permeability data showed insignificant effects on water and oil relative permeability curves.

**Nomenclature**

- E = error or residual
- Exp = exponential function (Exp x = e<sup>x</sup>)
- E<sub>ab</sub> = average absolute error
- E<sub>av</sub> = average error
- E<sub>max</sub> = maximum absolute error
- E<sub>min</sub> = minimum absolute error
- F = F-test statistic
- k<sub>ro</sub> = relative permeability to oil, fraction
- k<sub>rw</sub> = relative permeability to water, fraction
- k<sub>ro(Swi)</sub> = relative permeability to oil at irreducible water saturation, frac.
- k<sub>rw(Sor)</sub> = relative permeability to water at residual oil' saturation, frac.
- n = number of data points
- r = correlation coefficient
- R<sup>2</sup> = coefficient of determination
- Rms = root mean square
- S<sub>o</sub> = oil saturation, fraction
- S<sub>or</sub> = residual oil saturation, fraction
- S<sub>w</sub> = water saturation, fraction
- S<sub>wf</sub> = water saturation at breakthrough, fraction
- S<sub>wi</sub> = irreducible water saturation, fraction
- s = standard deviation
- t = T-test statistic
- ∅ = porosity, fraction

**Subscripts**

- est = estimated value
- exp = experimental value
- o = oil phase
- w = water phase

**REFERENCES**

1. Amyx, J.W., Bass, D.M. Jr., and Whiting, R.L.: Petroleum Reservoir Engineering, McGraw-Hill Book Co., New York (1999).
2. Frick, T.: Petroleum Production Handbook, SPE of AIME, Dallas, TX. (1997).
3. Heaviside, J., Black. C.J.J. and Berry, J.F.: "Fundamentals of Relative Permeability Experimental and Theoretical Considerations," paper SPE 12173 presented at the 1983 SPE Annual Technical Conference and Exhibition, San Francisco, CA, Oct. 5-8.
4. Honarpour, M., Koederitz, L., and Harvey, A.H.: Relative Permeability of Petroleum Reservoirs, CRC Press Inc., Boca Raton (1999).
5. Wyllie, M.R.J.: "Interrelationship between Wetting and Non-wetting Phase Relative Permeability," Trans., AIME (2001) 192,381-82.
6. Pirson, S.J.: Oil Reservoir Engineering, McGraw-Hill Book Co. Inc., New York City (2000).
7. Naar, J. and Henderson, J.H.: "An Imbibition Model - Its Application to Flow Behavior and the Prediction of Oil Recovery," SPEJ (June 1999) 6 1-70; Trans., AIME, 222.
8. Naar, J. and Wygal, R.J.: "Three-Phase Imbibition Relative Permeability," SPEJ (Dec. 2001) 254-58; Trans., AIME, 222.
9. Naar, J., Wygal, R.J. and Henderson, J.H.: "Imbibition Relative Permeability in Unconsolidated Porous Media," SPEJ (March 2002) 254-58; Trans., AIME, 223.

10. Land, C.S.: "Calculation of Imbibition Relative Permeability for Two- and Three-Phase Flow from Rock Properties" SPEJ (June 1998) 149-56. –
11. Honarpour, M., Koederitz, L., and Harvey, A.H.: "Empirical Equations for Estimating Two-Phase Relative Permeability in Consolidated Rock," JPT (Dec. 2002) 2905-08.
12. Rapoport, L.A. and Leas, W.J.: "Properties of Linear Water- floods," JPT (May 2001) 139-48; Trans., AIME, 198.
13. Johnson, E.F., Bossier, D.P., and Naumann, V.O.: "Calculation of Relative Permeability from Displacement Experiments," Trans., AIME (1999) 216, 370-72
14. Chierici, G.L.: "Novel Relations for Drainage and Imbibitions Relative Permeabilities," SPEJ (June 1994) 275-76.
15. Walpole, R.E. and Myers, R.H.: Probability and Statistics for Engineers and Scientists, 5th ed., Macmillan Pub. Co., New York (2003).
16. Willhite, G.P.: Water flooding, Textbook Series, SPE, Richardson, TX (1996) 3.
17. Braun, E.M., and Blackwell, R.J.: "A Steady-State Technique for Measuring Oil-Water Relative Permeability Curves at Reservoir Conditions," paper SPE 10155 presented at the 2001 SPE 56th Annual Technical Conference and Exhibition, San Antonio, TX, Oct. 5-7.
18. Jones, S.C., and Roszelle, W.O.: "Graphical Techniques for Determining Relative permeability from Displacement Experiments," JPT (May 1998) 807-817.
19. Al-Fattah, S.M.: "Development of Empirical Equations for Water/Oil Relative Permeability," MS Thesis, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia (Dec. 2004).