A Correlation of Oil Recovery Factors for Water-Drive Reservoirs in the Niger Delta

Paper 20

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Only two major parameters are required for the recovery factor calculations in this work, unlike other multi-parameter correlations. This makes this correlation very easy to apply. An expression has also been developed, and included for predicting residual oil saturation, where core or log analysis data are not available.

The results obtained using these models have ben compared with other published models, and applied to many cases studied, with better predictions. Graphical and statistical error analyses also confirm good correlations.

Notes

A TWO-PARAMETER CORRELATION FOR PREDICTING OIL RECOVERY FACTOR IN WATER-DRIVE RESERVOIRS

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ABSTRACT
A simple correlation has been developed for estimating primary recovery factors for Niger Delta oil reservoirs. The correlation which was developed from data collected across the Niger Delta, is valid for reservoirs with strong water drives.

Only two major parameters are required for the recovery factor calculations in this work, unlike other multi-parameter correlations. This makes this correlation very easy to apply. An expression has also been included for predicting residual oil saturation, where core or log analysis data are not available.

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These correlations should also yield good predictions for reservoirs from other regions that have similar reservoir and fluid characteristics.

INTRODUCTION
Primary oil recovery factor represents the fraction of the ultimate oil recovery to the oil initially in place. It is a factor which essentially depends on an interplay of such parameters as reservoir geology, reservoir fluid type, predominant drive mechanism, as well as the production and reservoir management practices.

A knowledge of recovery factor is useful in evaluating reserves, in reservoir/field development planning, and in attaching value to a lease for the purpose of purchase or sale.

The importance of recovery factor in reservoir management has led to the development of several prediction techniques. Predictive models for recovery factor vary from the simplistic "rule of Thumb" approaches, to complex mathematical formulations. The commonly used models however, are based on principles such as reservoir volumetric and material balance considerations, analyses of oil production and oil cut trends, or use of statistical correlations. While methods that use pressure-production history provide good estimates of the developed reserves, statistical correlations are useful for estimating reserves of new prospects as well as the undeveloped reserves in partially developed reservoirs.

Some of the earliest works on statistical correlation of recovery factors include those of Craze and Buckley (4), Muskat and Taylor (5), Guthrie and Greenberger (7), Arps (8), and Arps et al. (9).

DEVELOPMENT OF THE CORRELATIONS

This work is based on a similar approach to the work of Arps et al. on recovery efficiency (9).

For reservoirs with very strong water drives, oil recovery can be expressed as:

$$\text{Recovery} = \frac{7758*\phi*(Soi-Sor)}{Boi} \quad \text{stb/acre-ft.} \qquad (1)$$

Equation (1) can simply be expressed as:

$$r = f(Swi, Sor) \qquad (2)$$

Thus, a correlation can be developed to relate recovery factor to the initial water saturation, and residual oil saturation.

Equation (1) when used to obtain an expression for recovery factor can be expressed in the form:

$$r = C * \frac{(1 - Swi - Sor)}{(1 - Swi)} \qquad (3)$$

Where,

C = A modification parameter.

Equation (3) is a modification of the well-known expression for estimating recovery factors in water-drive reservoirs. The modification parameter C, which accounts for such factors as sweep efficiency, can easily be obtained by using the method of least squares, as shown in the appendix.

The main handicap in the use of equation (3) is the determination of a realistic value for Sor, the residual oil saturation. This has been addressed by deriving an expression for its estimation when data from core analysis and well logs are not available. In order to do this, it was assumed that:

$$Sor = f(Swi, Uo) \qquad (4)$$

This is considered fairly valid if it is assumed that Swi captures the effects of the reservoir rock while oil viscosity incorporates the effects of reservoir oil characteristics.

By using core analysis data from 205 reservoirs in the Niger delta, simple linear equations were established. Implicit in these derivations is that residual gas saturation is negligible.

RESULTS AND DISCUSSION

Some of the basic input data and results are shown in Table 1. The recovery factor correlation obtained can be expressed as:

$$r=0.8447862\frac{1-Sw_i-So_r}{1-Sw_i}\,.........(5)$$

Where, Sor, the residual oil saturation can be estimated from:

$$So_r=0.430211+0.042846\ln\mu_o-0.60733Sw_i.........(6)$$

Equations (5) and (6) are simple linear expressions which can be used to estimate oil recovery factor in the Niger Delta.

VERIFICATION OF THE CORRELATIONS

Equations (5), and (6) were verified by undertaking error analyses using graphical and statistical techniques, as well as by applying the correlations to some reservoirs of extensive production history.

Figures 1, and 2 show the crossplots of the estimated and experimental values.

The average absolute deviation was obtained from:

$$AAD=\frac{\sum^{N} Y_{EXP}-Y_{EST}}{N}...............(7)$$

While the coefficient of correlation was also calculated. The average absolute deviation for the recovery factor was estimated at 2%, while the coefficient of correlation was 0.83 . The coefficient of correlation for the Sor, was also established at 0.83. The results obtained using the recovery factor model of this study were compared with those from Guthrie and Greenberger, as well as other in-house correlations of some oil companies.

Table 2 is a summary of the results obtained from twelve case studies. This has also been graphically represented in figure 3. The reservoirs presented in Table 2 have production history of between 15 -20 years, and are still producing in 1993.

The results from this work seem to be more realistic in most of the reservoirs assessed, while the correlation also demonstrated a wider range of applicability than others.

CONCLUSION

Two simple correlations that could be used to predict oil recovery from strong water-drive reservoirs in the Niger Delta have been presented. One of the correlations predict the oil recovery factor, while the other estimates the residual oil saturation, where experimental and log data are not available. They have been applied to a number of producing reservoirs with results that seem more realistic than existing correlations.

Statistical and error analyses also confirm very small deviation of about 2%, and coefficient of correlation of 83%.

ACKNOWLEDGEMENTS

TABLE 2: PERFORMANCE OF THE CORRELATION IN SOME CASE STUDIES AND COMPARISON WITH OTHERS

RESERVOIR	Swi	oil vis. (cp)	Sor	Np/N (To Date)	RECOVERY FACTOR MODELS RF	G&G	X
1	0.12	0.20	0.29	0.48	0.57	0.58	0.45
2	0.22	0.50	0.27	0.36	0.56	0.44	0.56
3	0.19	0.25	0.26	0.38	0.58	0.48	0.53
4	0.15	1.00	0.34	0.36	0.51	0.52	0.38
5	0.17	0.91	0.32	0.43	0.52	0.56	0.49
6	0.25	2.40	0.32	0.13	0.49	0.40	0.51
7	0.30	2.20	0.28	0.34	0.50	0.35	0.48
8	0.42	0.70	0.16	0.01	0.61	0.37	0.04
9	0.47	4.20	0.21	0.10	0.52	0.24	0.10
10	0.23	4.10	0.35	NA	0.46	0.38	0.55
11	0.30	0.61	0.23	0.35	0.57	0.42	0.45
12	0.15	0.24	0.28	0.74	0.57	0.59	0.75

APPENDIX -EVALUATION OF PARAMETER C OF EQN.4 BY METHOD OF LEAST SQUARES

The expression for recovery factor (eqn. 2), can be written as:

$$r=C\frac{So_i-So_r}{So_r}......(8)$$

Using the method of least squares, the objective is to find the

value of C which minimises the sum of the squares of the residuals. That is,

$$\sum r_i-\sum C[(So_i-So_r)(So_i)^{-1}]_i^2=minimum......(9)$$

For equation 10 to be true, it's derivative with respect to C must equal zero. That is:

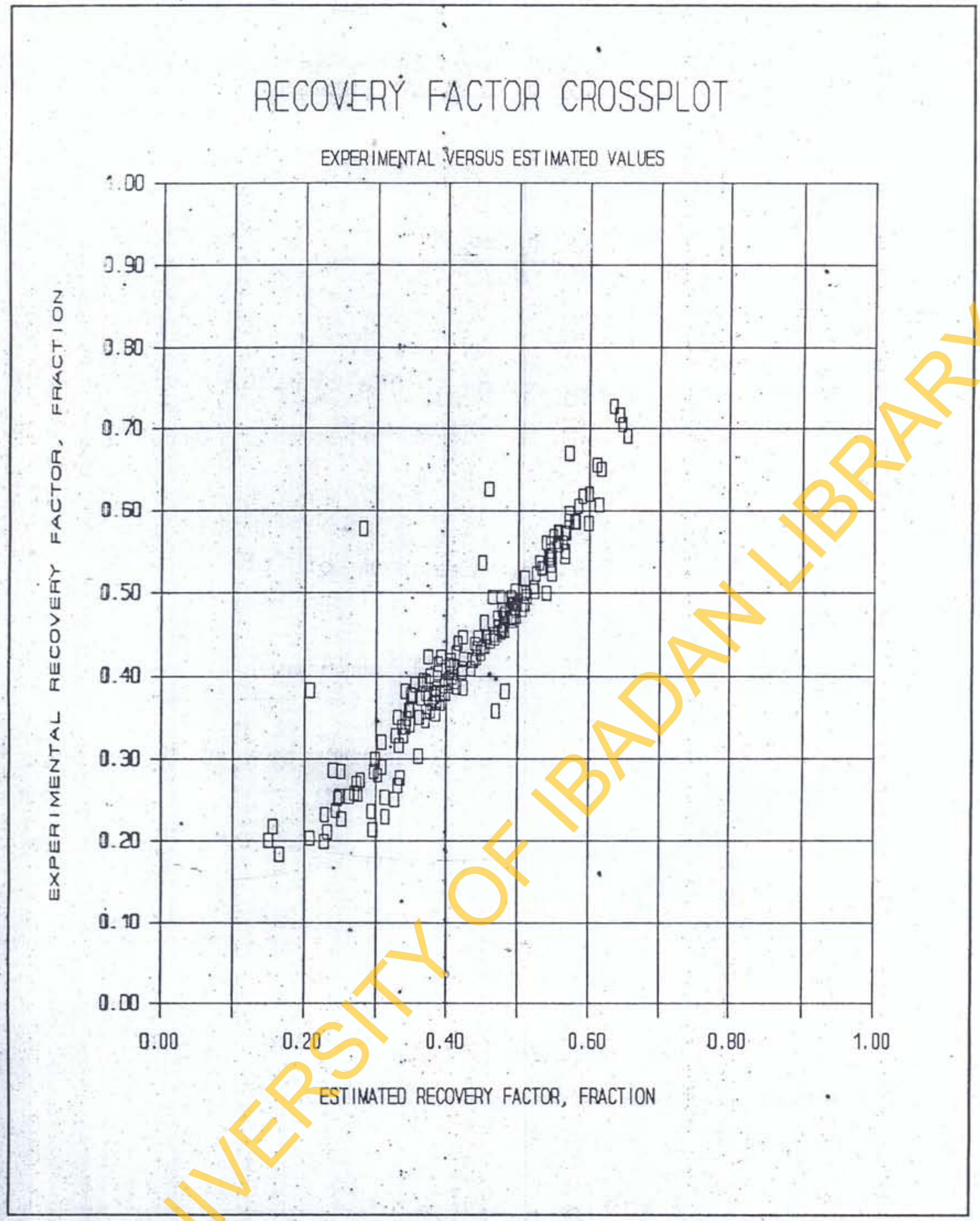
$$\frac{\delta}{\delta C}\sum[r-C(So_i-So_r)(So_i)^{-1}]_i^2=0......(10)$$

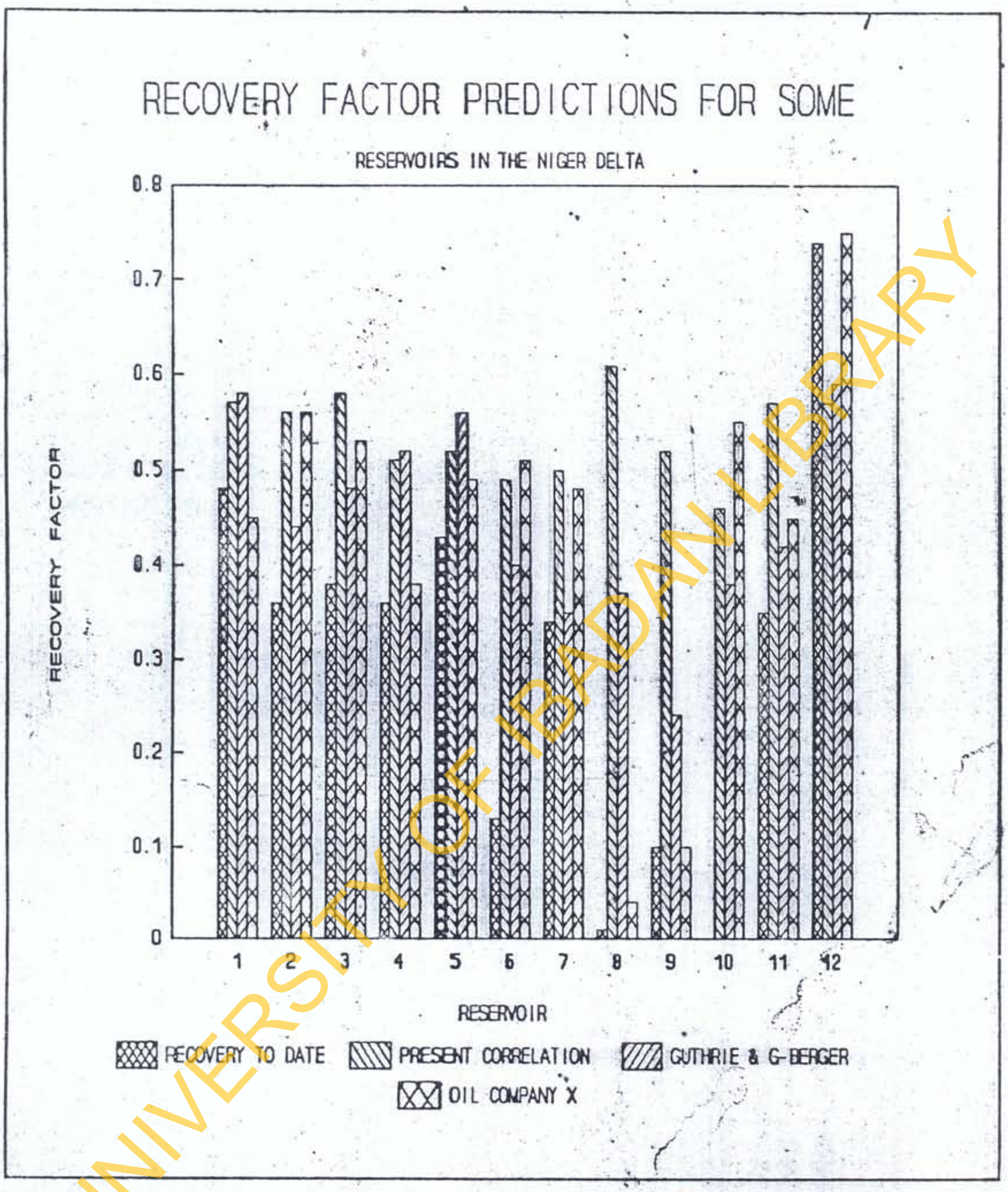
This simplifies to:

$$r(So_i-So_r)So_i^{-1}-C[(So_i-So_r)So_i^{-1}]^2=0.....(11)$$

Which gives:

$$C=\frac{\sum r(So_i-So_r)(So_i)^{-1}}{\sum[(So_i-So_r)(So_i)^{-1}]^2}......(12)$$


RECOVERY FACTOR CROSSPLOT
EXPERIMENTAL VERSUS ESTIMATED VALUES
EXPERIMENTAL RECOVERY FACTOR, FRACTION
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.00
0.20
0.40
0.60
0.80
1.00
ESTIMATED RECOVERY FACTOR, FRACTION


RECOVERY FACTOR PREDICTIONS FOR SOME
RESERVOIRS IN THE NIGER DELTA
RECOVERY FACTOR
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
11
12
RESERVOIR
RECOVERY TO DATE
PRESENT CORRELATION
GUTHRIE & G-BERGER
OIL COMPANY X