PRJ, Vol. 4. (January 1992); P. 3–9, 5 FIGS, 3 TABLES.

ESTIMATION OF RECOVERY FACTOR OF LIBYAN CARBONATE OIL RESERVOIRS

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تقدير الإحتياطي النفطي لمكامن الصخور الكربونية الليبية

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يعتبر تقدير الإحتياطي النفطي الممكن إنتاجه بواسطة الطرق المتبعة حالياً وخاصة الحقول المكتشفة حديثاً والتي لم يتم وضعها على الإنتاج من أهم المعلومات التي يتم بناء عليها إستكمال الدراسات المختلفة لتحديد إقتصاديات ذلك المكمن.

وبالقاء نظرة فاحصة على المراجع العلمية الخاصة بتقدير الإحتياطي النفظي للمكامن الحديثة المكتشفة بناء على المعلومات الأولية البسيطة، نجد عدد محدود جداً على المستوى العالمي. فقد تم إستنتاج علاقة متبادلة للإحتياطي وعدد من خواص الصخور والموائع للمكامن ذات الصخور الرملية باستخدام معلومات تم تجميعها من الحقول النفطية بالولايات المتحدة الأمريكية.

تم من خلال هذه الدراسة إستنتاج وإستخلاص علاقة متبادلة بين عدداً من خواص صخور وموائع المكامن النفطية الليبية ومعامل الإستخراج أو الإحتياطي. فباستخدام المعلومات الخاصة بالمسامية، اللزوجة، التشبع، النفادية والسمك لعدد أربعون حقل نفطي ليبي ذات الصخور الكربونية وباستعمال طرق التحاليل بالمضاهاة (MULTIPLE CORRELATION ANALYSIS) تم تحديد علاقة بين الإحتياطي وتلك الخواص، مما يمكن من تقدير الإحتياطي لمكامن الصخور الكربونية المكتشفة حديثاً والمتواجدة عادة في المناطق العربية.

إن إستخدام العلاقة المستخلصة في هذه الدراسة ستمكن من تقدير الإحتياطي لمكامن الصخور الكربونية بدقة أكبر عنها من إستخدام العلاقات المستنتجة سابقاً والخاصة بالحقول الرملية.

ABSTRACT

Estimation of recovery factor of any newly discovered reservoir is an important piece of information needed to assess the economical viability of that reservoir. Therefore, it is essential to be able to predict as accurately as possible the reservoir reserves based on limited data available on hand for newly discovered reservoirs.

In this study, data collected from forty Libyan oil reservoirs were utilized to generate a correlation between reservoir future recovery factor and basic reservoir data of porosity, permeability, saturation, oil viscosity and net formation thickness. This correlation will provide a useful tool for any engineer dealing with carbonate oil reservoirs to predict with more confidence its recovery factor after drilling a wildcat well and collect limited data.

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INTRODUCTION

Our current life has been influenced by oil and gas more than any other natural resource, and indications are that oil and gas reserves will increase in importance in the remainder of this century. Oil and gas provide an inexpensive source of energy.

Reserve estimates have dictated actions of different Governments, entire industries, individual companies and lending institutions. Many people working in the petroleum industry, especially petroleum engineers spend a major part of their professional lives developing estimates of reserves together with new methods and techniques for improving these estimates. The confidence levels and the technique utilized by the petroleum engineer depend on the quantity, reliability and the maturity of the data available. The data quality, therefore, indicate the confidence one should have in the reserve estimates.

There are various methods used by the oil industry to estimate recovery factor such as analogy, volumetric calculations and performance techniques (numerical simulation models, material balance and decline curve analysis).

Before a reservoir is drilled, prospective reserves are usually estimated on the basis of analogy. On the other hand, if little or no production from the target formation exists, then statistical data from wells completed in the formation is used to predict the recovery factor of that reservoir. When performing a statistical analysis for prediction purposes, a simple average of various rock and fluid data needed to be employed in the technique is normally required.

By searching the literature regarding recovery factor estimate based on limited rock and fluid data obtained from a newly discovered oil field, one notices that limited work has been done. In a reservoir study made by Craze & Buckley [1], 70 of 103 fields analysed produced wholly or partially by water-drive conditions.

Arps [2] indicated that data obviously is related to the reservoir oil viscosity and permeability. He obtained average correlation between oil viscosity and oil residual saturation, and took into consideration another variable, reservoir permeability.

Guthrie & Greenberger [3] conducted a statistical study using multiple correlation analysis methods. They found a correlation between water-drive recovery and five variables, permeability, saturation, viscosity, porosity and net formation thickness for water-drive sandstone reservoirs. They indicated that 50 percent of the fields had recoveries within ± 6.2 percent of the predicted recovery by the correlation. This correlation is used extensively for sandstone or carbonate reservoirs to obtain a rough estimate of recovery efficiency despite its limitations.

Since most of the Libyan oil reservoirs and Middle East oil reservoirs are of carbonate type (limestone and dolomite type of lithology), it is essential to utilize data from fields representing Libyan reservoirs. In this study, data from 89 carbonate and sandstone Libyan reservoirs were employed to try to develop different correlations between recovery factor and various fluid and rock data. Most useful correlation developed using multiple regression analysis for water-drive carbonate reservoir was 40 Libyan reservoirs data representing different carbonate horizons with water influx mechanism.

Results indicate that 0.113 standard deviation exists in this type of reservoir. Meanwhile, if only reservoirs with recovery factors of 20 percent or higher are used, we observe improvement in correlation results. A substantial reduction in standard deviation from 0.113 to 0.079 percent is observed, i.e. a more reliable correlation.

DISCUSSION

Reserve estimates are just those estimates which can be no better than the data on which they are based and are subjected to the experience of the estimator. Unfortunately, reliable reserve figures are most needed during the early stages of a project, when only a minimum amount of information is available. As the field is put on production, more data and information become available. As the project matures, this increase in data with which to work, changes the method or methods used to predict the recovery factor and improves the confidence in the reserves estimates. Recovery factor is estimated during various stages of oil reservoir life. These stages are before drilling, or any subsurface development, after drilling few wells, before producing the reservoir, after some performance information is available and after performance trends are well established. In this study, the main period of the life of the reservoir in recovery efficiency could be estimated after drilling few wells and before producing the reservoir.

Various types of reservoirs were analysed to develop a correlation between recovery factor and various fluid and rock properties, porosity, permeability, saturation and viscosity. The main correlation developed for water-drive carbonate oil reservoirs were data from 40 Libyan oil reservoirs, see Table 1, which were utilized to develop the correlation. The empirical correlation obtained was:

$$RF = 0.0554 + 0.6065\ \text{porosity} + 0.0955 \log\left(\frac{K}{\mu}\right) - 0.0571 S_w - 0.0426 \log H$$

As shown in Fig. 1 data is scattered mostly below the chosen line for recovery factor of 20% or higher and above the line for points with recovery factor below 20% with a standard deviation of 0.114. Therefore, elimination of data points of RF below 20% were tested and results were plotted in Fig. 2. As shown in Fig. 2, more fair distribution of data was obtained with a standard deviation of 0.079.

The correlation between oil recovery and various data for water-drive carbonate reservoirs with RF greater than 20% is:

$$RF = 0.3251 - 0.1287\ \text{porosity} + 0.0745 \log\left(\frac{K}{\mu}\right) - 0.046\ S_w - 0.0433 \log H$$

Table 1. Water Drive-Carbonate Reservoirs Data

Field	POR frac.	K md	U cp	Sw frac.	Reported H ft.	Reported RF frac.	Empirical RF frac.	Without H RF frac.
Ali NC29B	0.230	90.0	0.650	0.460	37.0	0.480	0.306	0.307
Almas NC29C	0.236	16.0	0.580	0.455	58.0	0.490	0.235	0.244
Intisar 103E	0.190	190.0	1.100	0.440	17.0	0.200	0.307	0.290
103D Elgiza	0.266	43.0	3.200	0.287	30.0	0.270	0.245	0.239
Intisar 103B	0.200	490.0	0.024	0.230	33.0	0.49	0.510	0.502
Sabah Beda C(I)	0.241	353.0	0.800	0.185	36.2	0.491	0.377	0.371
Sabah Beda C(II)	0.272	353.0	0.800	0.354	26.3	0.491	0.392	0.386
W. Sabah Beda C(I)	0.206	200.0	0.800	0.236	33.0	0.302	0.331	0.322
W. Sabah Beda C(II)	0.203	100.0	0.800	0.494	44.0	0.302	0.281	0.284
E. Sabah Bedac	0.182	200.0	0.800	0.197	29.5	0.131	0.321	0.308
Elgiza E &W	0.260	150.0	1.400	0.430	32.0	0.350	0.318	0.317
Gialo	0.222	153.0	3.080	0.310	98.0	0.377	0.249	0.264
Choboc (Kalash)	0.388	520.0	0.540	0.450	27.3	0.300	0.489	0.492
Tagrifet (Farrud)	0.250	35.0	2.030	0.270	35.0	0.120	0.244	0.239
Farrud (Mabruk)	0.246	145.0	0.790	0.450	38.0	0.375	0.328	0.330
Bouri	0.150	300.0	3.490	0.200	500.0	0.150	0.204	0.242
Ed Dib (Gir/Fach)	0.240	100.0	0.700	0.350	85.0	0.150	0.304	0.318
Um-Farroud	0.240	40.0	0.700	0.270	38.0	0.330	0.286	0.283
Field 4Z DOL	0.240	40.0	2.600	0.270	38.0	0.148	0.231	0.228
BuMras(Mabruk) LS	0.260	340.0	13.000	0.450	7.4	0.391	0.286	0.258
Daba (Farr UD)	0.220	45.0	1.650	0.570	53.0	0.200	0.220	0.230
Facha (Mabruk)	0.250	23.0	0.940	0.770	24.0	0.140	0.240	0.242
103E Elgiza B	0.050	250.0	6.500	0.500	49.0	0.040	0.136	0.134
103E Elgiza A	0.268	370.0	6.500	0.410	18.6	0.060	0.308	0.297
103E Gir B	0.246	200.0	1.700	0.311	30.8	0.304	0.321	0.315
103E Gir A	0.245	16.0	1.700	0.300	56.0	0.233	0.205	0.210
Bahi PL7 LS	0.280	150.0	0.700	0.445	103.2	0.400	0.336	0.359
Bahra PL7 LS	0.301	34.5	1.230	0.448	28.8	0.330	0.288	0.288
Nasser	0.186	5000.0	0.880	0.220	122.0	0.461	0.425	0.440
Gialo	0.200	45.0	3.000	0.520	18.0	0.099	0.206	0.193
"Paleocene LS	0.252	14.5	0.670	0.301	49.6	0.340	0.246	0.249
"4B Paleocene	0.195	400.0	0.840	0.555	85.0	0.300	0.320	0.332
Barash P'cene LS	0.200	388.0	1.190	0.471	16.6	0.450	0.338	0.322
Kasrab P Basel D	0.237	27.1	2.400	0.440	29.0	0.300	0.212	0.208
Warid Field	0.220	2.0	3.700	0.500	40.0	0.034	0.066	0.069
Beda Field	0.200	60.0	2.800	0.500	60.0	0.300	0.199	0.208
Kotla Field	0.220	60.0	2.000	0.350	150.0	0.130	0.217	0.240
Umm-Faroud	0.240	40.0	0.700	0.270	38.0	0.330	0.286	0.283
Facha (Gir) Dol	0.240	25.0	1.400	0.330	42.0	0.140	0.232	0.232

Empirical Recovery Factor, including H, fraction = 0.0554 + 0.6065 (porosity) + .0954 (log(k/μ) − 0.0571 (Sw) − 0.0426(log(H)) Standard Deviation = 0.114 Empirical Recovery Factor, without H, fraction = −0.0358 + 0.6603 (porosity) + 0.0957(log(k/μ)) − 0.0304 (Sw) Standard Deviation = 0.113

Another correlation was obtained for solution gas drive carbonate-oil reservoirs. Data from only 7 Libyan reservoirs were utilized, with the following result:

$$RF = 0.3514 - 1.1967 \text{ porosity} + 0.00955 \log\left(\frac{K}{\mu}\right) + 0.0205\, S_w - 0.0434 \log H$$

With standard deviation of 0.035, due to limited data used in the correlation, not much confidence is given to this result, (see Fig. 3, and Table 2).

From the analysis of data from 9 Libyan carbonate oil reservoirs with water injection, see Table 3, the following correlation was obtained, where standard deviation is 0.073:

$$RF = -0.2224 + 0.1262 \log\left(\frac{K}{\mu}\right) - 0.0163\, S_w + 0.1722 \log H$$

Again, not much confidence is given to this correlation due to the limited data used (Fig. 4).

The effect of using limited data, i.e. no pay thickness was utilized in the analysis, was also examined

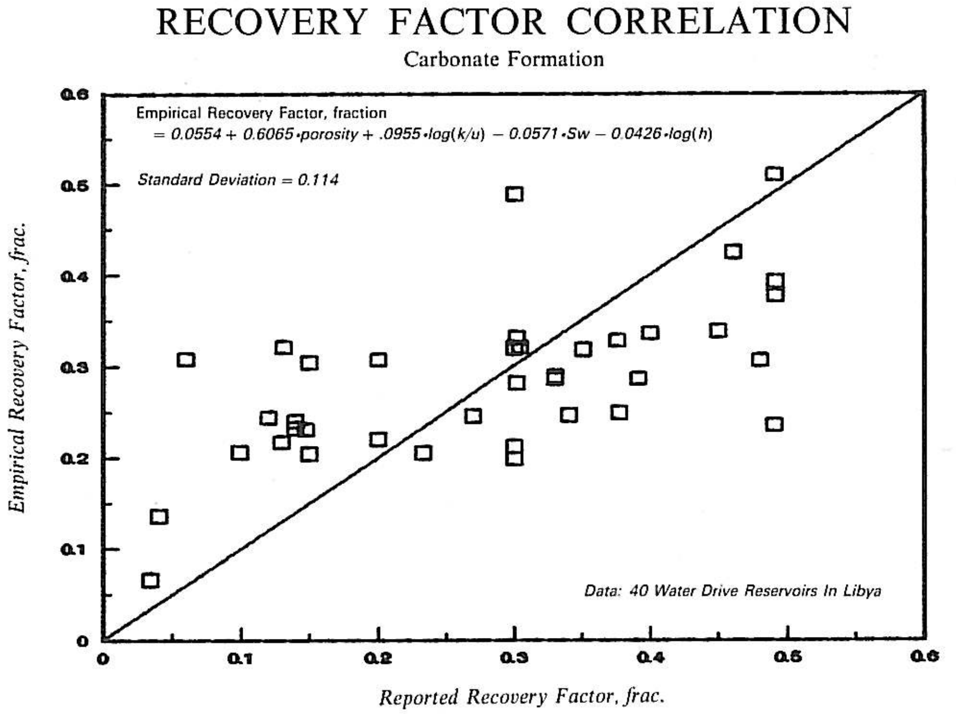

FIG. 1. Relationship between empirical and reported recovery factors for carbonate formation – water drive reservoirs.

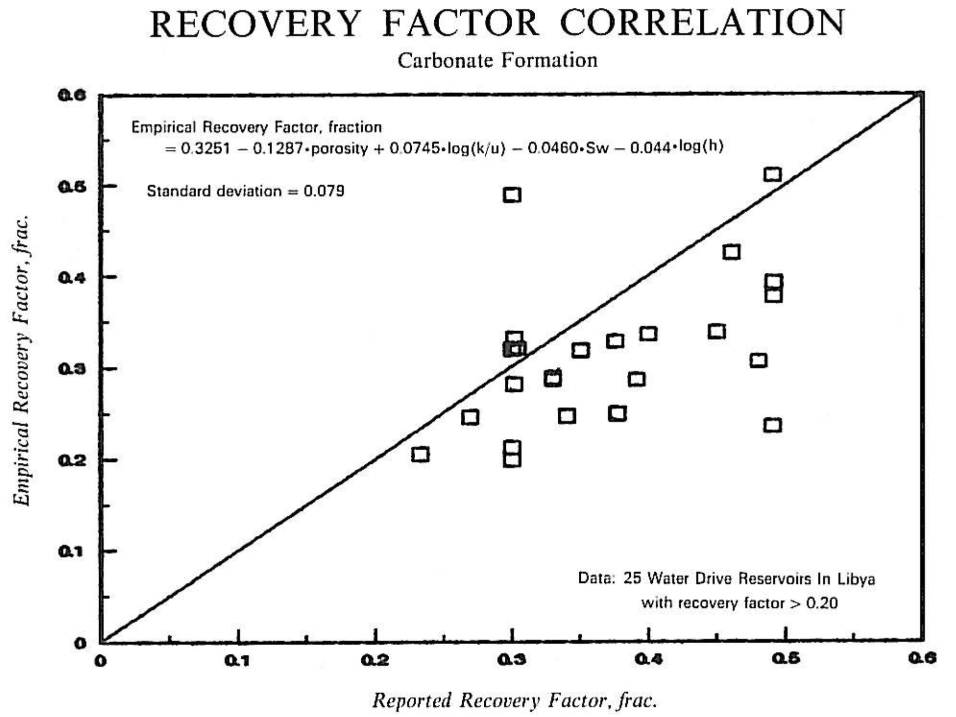

FIG. 2. Relationship between empirical and reported recovery factors for carbonate formation – water drive reservoirs.

for the case of water-drive carbonate reservoirs and the following empirical correlation was obtained:

$$RF = -0.0358 + 0.6603 \text{ porosity} + 0.0957 \log\left(\frac{K}{\mu}\right) - 0.0304\, S_w$$

With standard deviation of 0.113, the data and the distribution of the results are presented in Table 1 and Fig. 5 respectively.

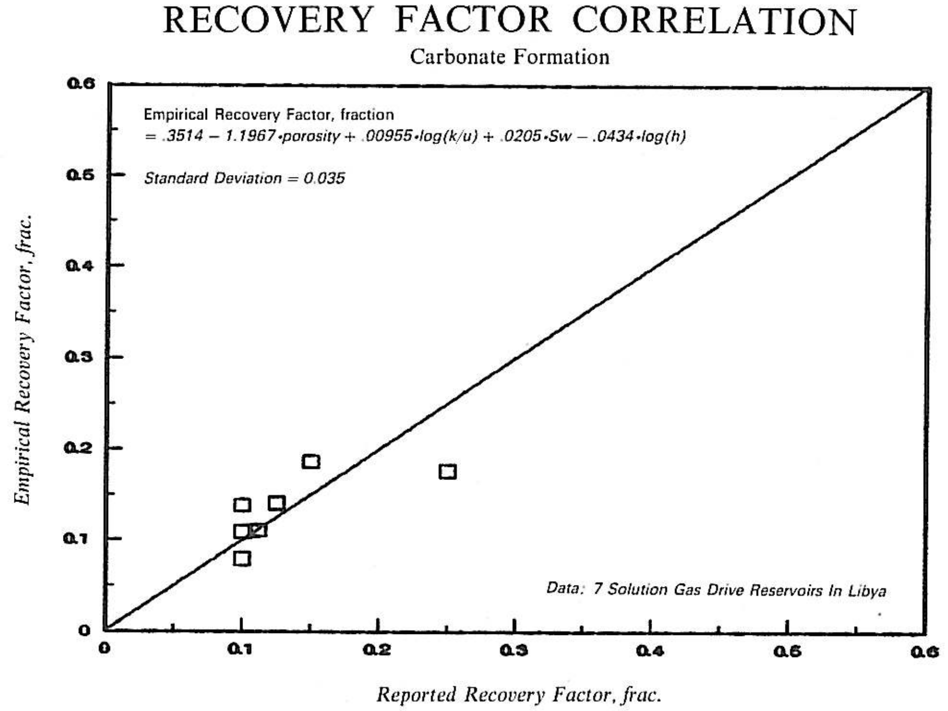

FIG. 3. Relationship between empirical and reported recovery factors for carbonate formation – solution gas drive reservoirs.

Table 2. Solution Gas Drive- Carbonate Reservoir Data

FIELD	POR frac.	K md	U cp	Sw frac.	h ft	Reported RF frac.	Emperical RF frac.
Hofra (Thalita)	0.170	6.0	0.580	0.330	32.0	0.150	0.186
Dahra B	0.330	150.0	0.630	0.420	17.6	0.100	0.138
Mellugh (Facha)	0.250	25.0	0.354	0.390	25.0	0.250	0.176
Defa LS	0.160	3.2	1.600	0.320	94.0	0.112	0.110
AA Area LS	0.244	14.7	1.200	0.400	27.7	0.100	0.109
Hofra – Dahra B	0.320	25.0	0.620	0.360	14.2	0.100	0.079
Hofra Dahra B & Mabruk	0.330	150.0	0.600	0.420	17.6	0.125	0.140

Empirical Recovery Factor, frac. $= .3514 - 1.1967\,(\text{porosity}) + .00955(\log(k/\mu)) + .0205\,(Sw) - .0434(\log(h)$
Standard Deviation $= 0.035$

Table 3. Water Injection-Carbonate Reservoir Data

FIELD	POR frac.	K md	U cp	Sw frac.	h ft	Reported RF frac.	Emperical RF frac.
Intisar C103 Reef	0.220	85.0	0.560	0.494	141.0	0.550	0.414
Intisar A103 Reef	0.198	18.0	0.160	0.113	648.0	0.472	0.518
Zella NC74B Facha	0.195	7.7	0.176	0.199	117.0	0.350	0.338
Fidaa Facha	0.209	125.0	0.970	0.370	67.0	0.300	0.343
North Hakim Facha	0.204	14.0	0.150	0.222	29.0	0.300	0.276
South Hakim Facha	0.216	27.0	0.420	0.251	46.0	0.300	0.285
Gham Farrud	0.250	50.0	0.400	0.250	50.0	0.300	0.328
Gham Farrud	0.270	50.0	0.400	0.250	55.0	0.300	0.335
Zeuad	0.270	50.0	0.400	0.250	55.0	0.300	0.335

Empirical Recovery Factor, frac. $= 0.2224 - .1262(\log(k/\mu) - 0.0163(Sw) + 0.1722(\log(h))$ Standard Deviation $= 0.073$

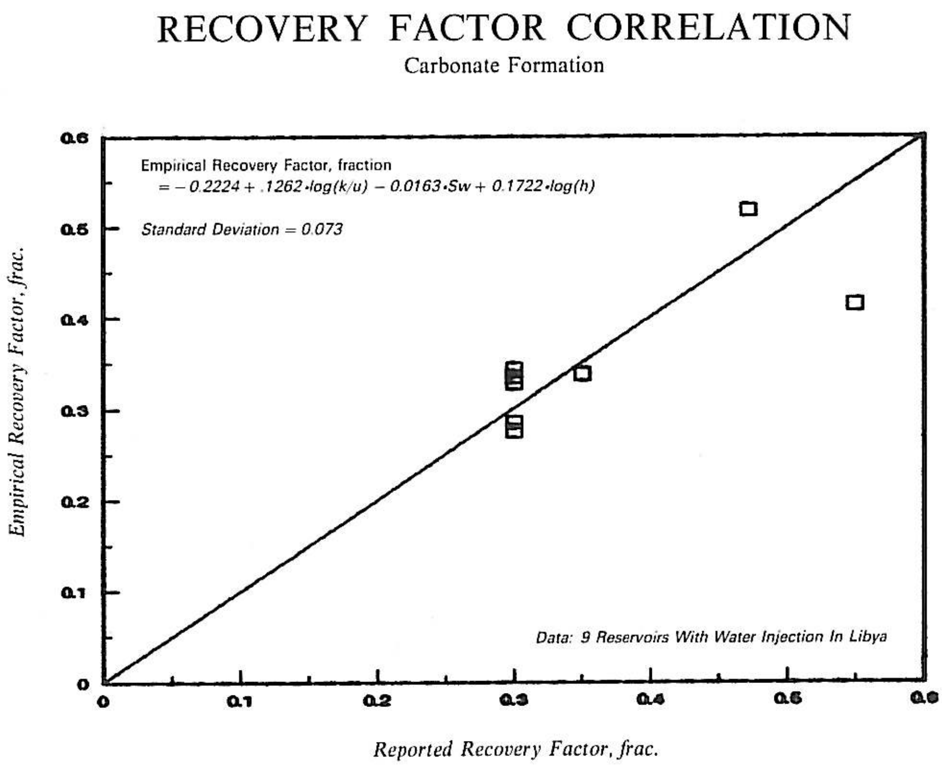

FIG. 4. Relationship between empirical and reported recovery factors for carbonate formation – water injection reservoirs.

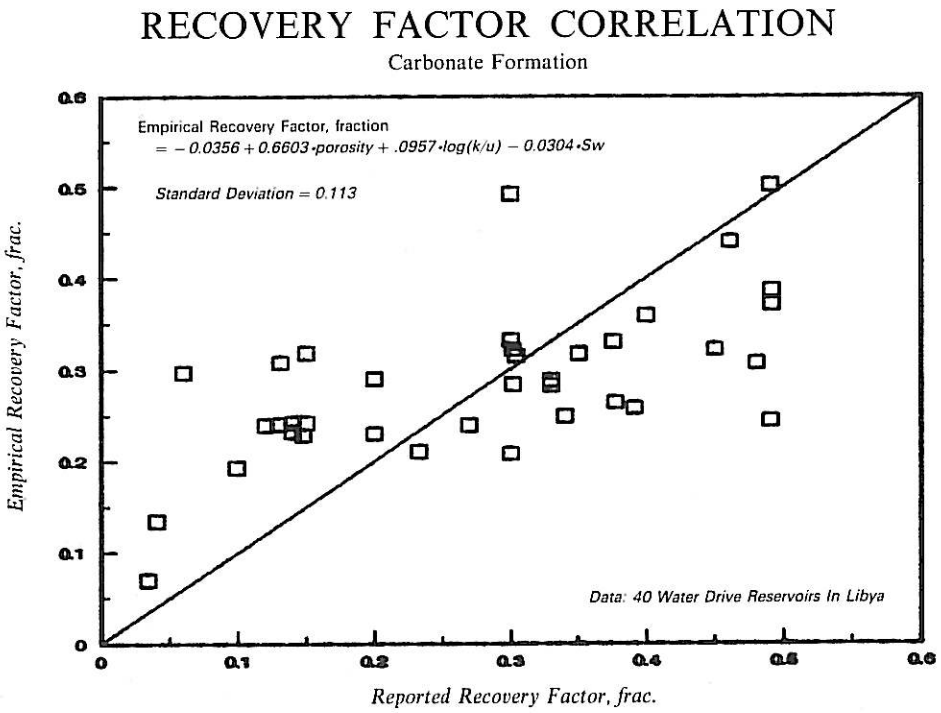

FIG. 5. Relationship between empirical and reported recovery factors for carbonate formation – water drive reservoirs excluding pay thickness.

CONCLUSIONS

1. A new correlation for Libyan carbonate oil reservoirs to estimate RF using limited data was developed.
   This correlation could be used in estimating the oil recovery factor for all newly discovered Middle East water-drive carbonate oil reservoirs.
2. A correlation for solution-gas drive carbonate oil reservoirs was obtained to be used as a rough estimate of RF.
3. Libyan sandstone water-drive reservoirs correlation was also developed.

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