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 النفطي 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.*

## 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

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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 $\pm 6.2$ 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 Empirical H ft. | Reported Empirical RF frac. | 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

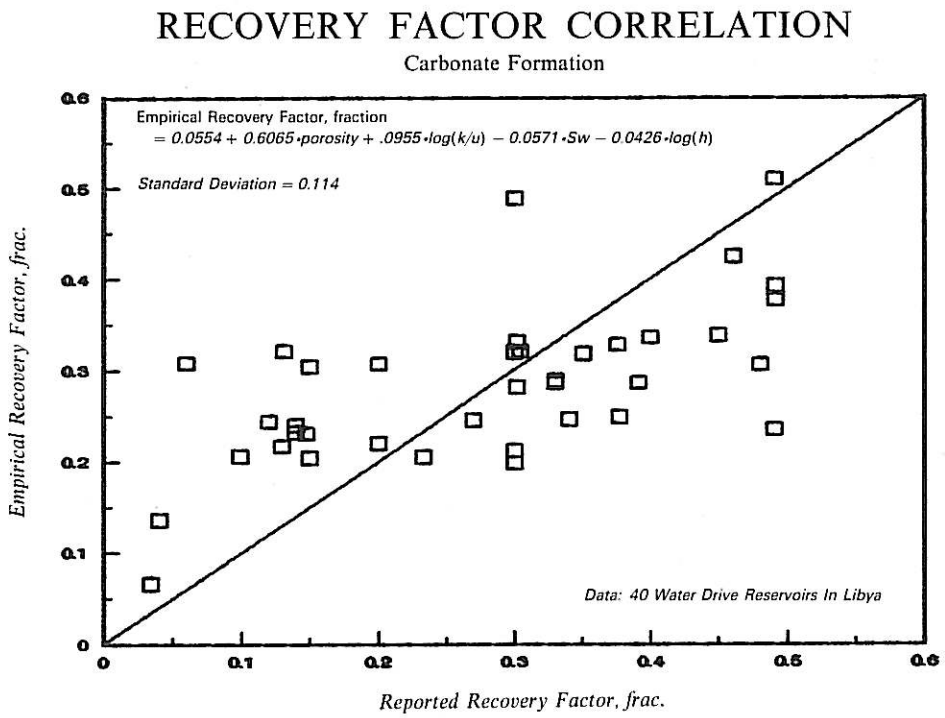



FIG. 1. Relationship between empirical and reported recovery factors for carbonate formation – water drive reservoirs.

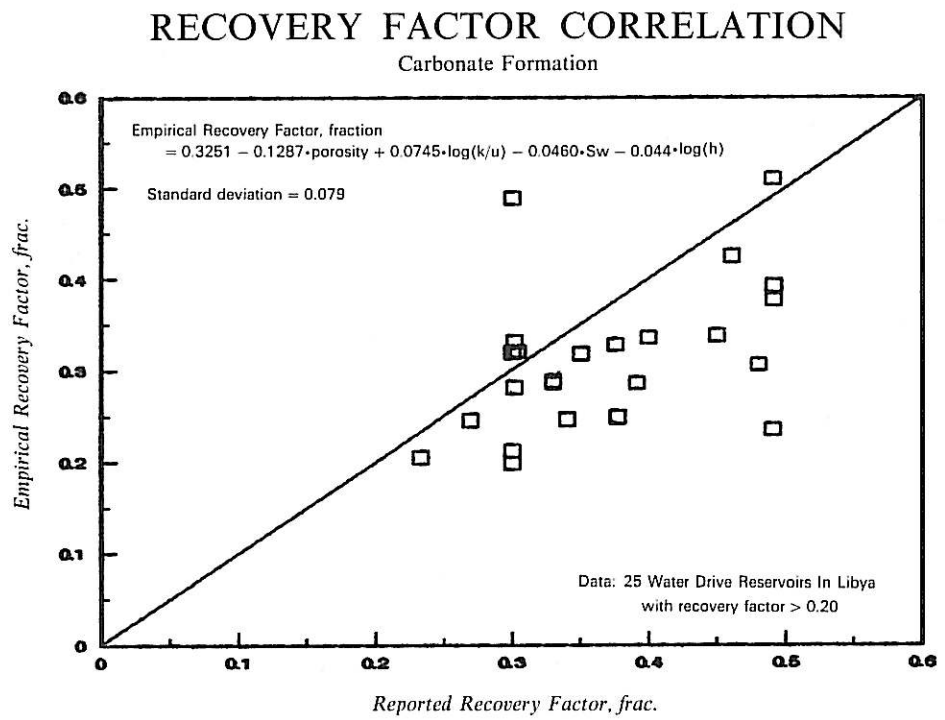



FIG. 2. Relationship between empirical and reported recovery factors for carbonate formation – water drive reservoirs.

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.

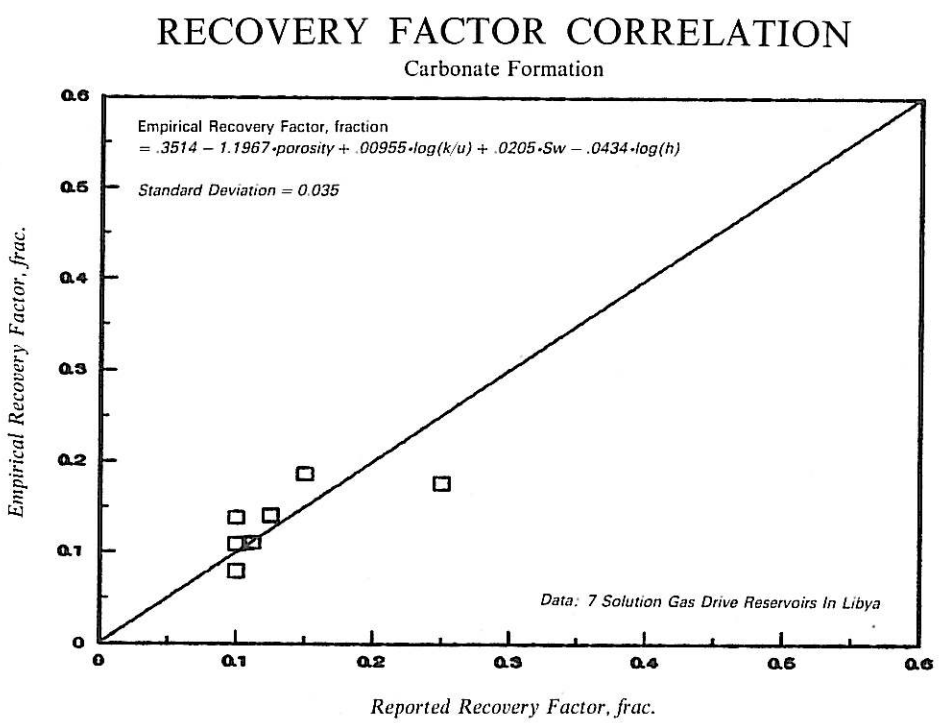



FIG. 3. Relationship between empirical and reported recovery factors for carbonate formation – solution gas drive reservoirs.

**Table 2. Solution Gas Drive- Carbonate Reservoir Data**

| | | | | | Reported Emperical | | |
|---|---|---|---|---|---|---|---|
| FIELD | POR frac. | K md | U cp | Sw frac. | h ft | RF frac. | 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 (porosity) + .00955(log(k/μ)) + .0205 (Sw) – .0434(log(h)
Standard Deviation = 0.035

**Table 3. Water Injection-Carbonate Reservoir Data**

| | | | | | Reported Emperical | | |
|---|---|---|---|---|---|---|---|
| FIELD | POR frac. | K md | U cp | Sw frac. | h ft | RF frac. | 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/μ) – 0.0163(Sw) + 0.1722(log(h)) Standard Deviation = 0.073

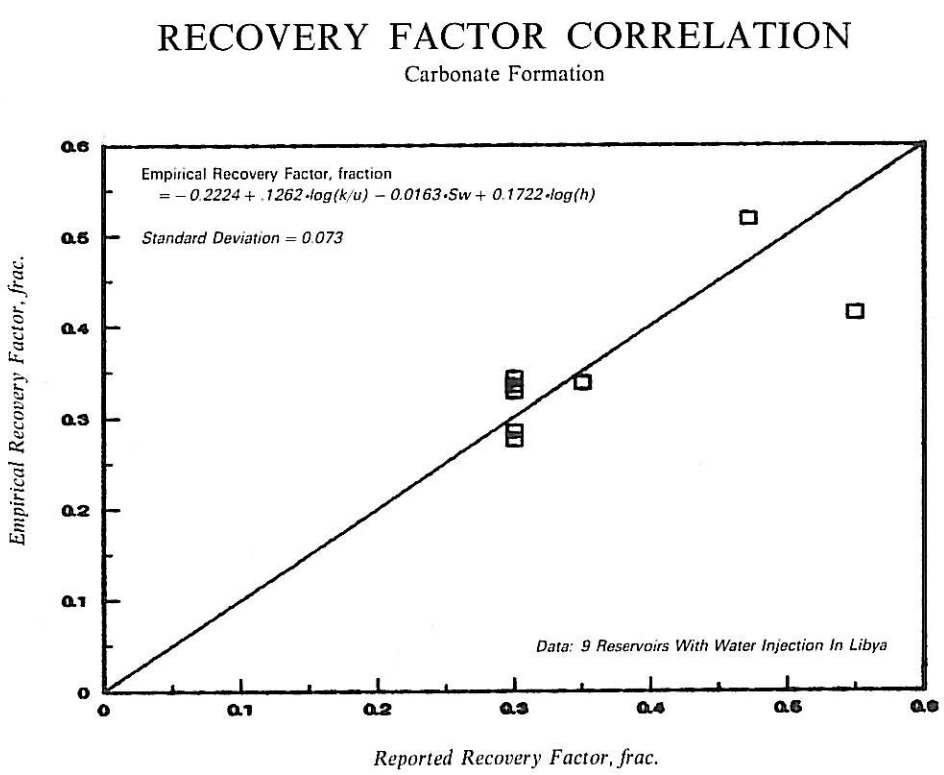



FIG. 4. Relationship between empirical and reported recovery factors for carbonate formation – water injection reservoirs.

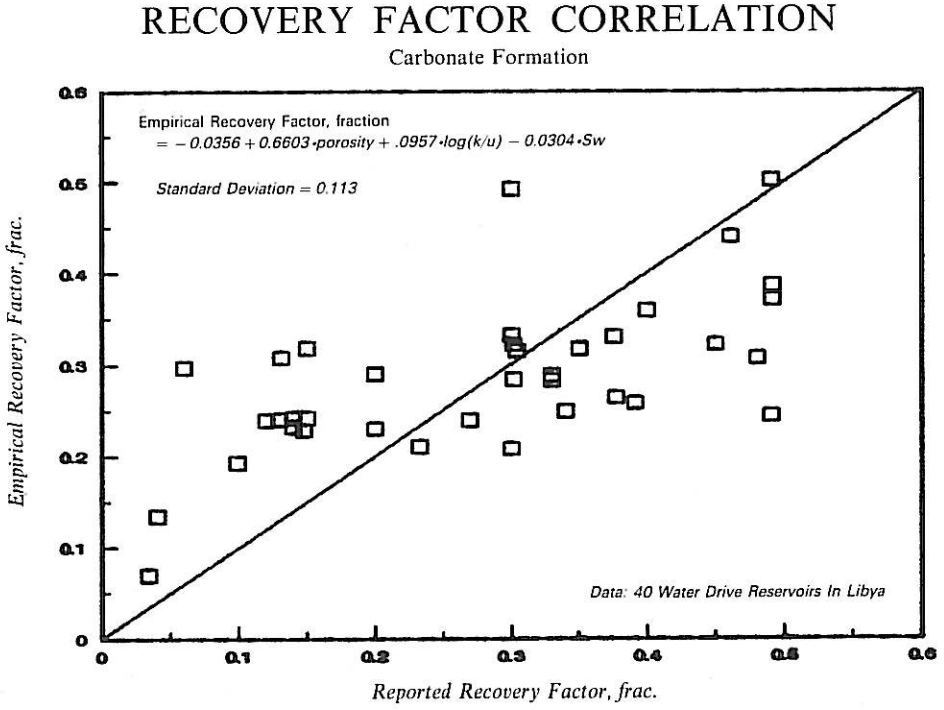



FIG. 5. Relationship between empirical and reported recovery factors for carbonate formation – water drive reservoirs excluding pay thickness.

## 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.

## ACKNOWLEDGEMENT

The authors would like to thank all Libyan Oil Companies and NOC Production Department for providing the data used in this study and for their permission to publish the work. Thanks are also extended to WAHA Oil Company for granting permission to use their computer facilities.

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