Analytical and Numerical Analysis for Estimation

Hydrocarbon in Place for Fauqi Oil Field

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Abstract:

The Fauqi oil field is located about 50Km north-east Amara town in Iraq. This field has two producing reservoir units, the Asmari and the deeper Mishrif. Fauqi field is an anticline crossing the Iraqi-Iranian border and approximately 15 km long and 6 km wide.

The Fauqi anticline is most probably segmented by several faults due to its location on Zagrous mountains area. Since, it is not possible to get full knowledge on the extent, orientation and segmentation of the field.

Production data used for the Material Balance analyses is comprised of a record, by well, of monthly cumulative oil production for the period 01 May 1979 – 01 November 2007. The field was shut in due to the Iran-Iraq war between September 1980 and August 1998 and due to Gulf war between March to December 2003.

Twelve major modules, with different degrees of analytical sophistication have been used to prove oil initially in place (STOIIP) for Fauqi oil field throughout analyzing single well production history of FQ-8A. The accuracy for the obtained results has been investigated which show an acceptable degree of reliability.
Performing the twelve of different analytical and numerical calculation for the production history of Fauqi oil well Fq-8A, may assist to reduce the uncertainties in the reservoir calculation of the STOIIP especially in Asmari reservoir which show a considerable degree of uncertainty between the analytical (multiple column model) and the (full tank model) and also with the numerical calculation.

الملخص

يقع حقل الفكّة بمسافة 50 كم شمال شرق مدينة العمارة في العراق. هذا الحقل يمتلك وحدتين مكمنتين. الاسمري والاعمق هي المشرف. حقل الفكّة يتكون من قبة تمتد داخل الحدود الإيرانية وله أبعاد حوالي 15 كم طول و 6 كم عرض.

حقل الفكّة على اغلب الاحتمال يتكون من فوالق وشقوق بسبب وجوده على شريط جبال زاكروس ، مع ذلك فإنه غير الممكن معرفة أطوال وأتجاهات الشقوق في الحقل من دون أجراء المسوحات الزلزالية.

المعلومات الانتاجية التي استعملت في تحليل موازنة المادة للفترة من 1- مارس- 1979 لغاية 1- تشرين الثاني- 2007. وأن الحقل أغلق بسبب الحرب العراقية الإيرانية للفترة من يليول- 1980 إلى 1998 وكذلك بسبب حرب الخليج للفترة من ذار الى كانون الأول 2003.

أستخدمت آثنا عشرة طريقة رئيسة بمختلف الامتداد التحليلية لإثبات الاحتياطي الاولي لحقل الفكّة من خلال تحليل التاريخ الانتاجي لبئر فكّة 8. دقة النتائج تم تحليلها وأظهرت درجة مقبولة من الاعتماد.

أنجاز آثنا عشرة عملية حسابية بطرق تحليلة وعددية لتاريخ الانتاج ساعد على تقليل عدم توافقات حساب المحتوى النفطي الاولي للحقل وخاصة لمكمن الاسمري من خلال استعمال تشعيع النفط لكل طبقة ومقارنتها مع استعمال معدل التشبع لكل الحقل.
Introduction

Accurate determination of oil in place in a reservoir is important when decisions are being made regarding development of a field; it is even more important later when decisions are made regarding installation of fluid injection projects when less of the oil remains; and it is extremely important in considering the recovery of additional oil by tertiary methods [1].

Frequently, interpreting pressure-production performance of the reservoir through material balance techniques helps to establish the reliability of volumetric estimates. In some very heterogeneous reservoir rocks or in some reservoirs of limited areal extent, a material balance estimate is superior to the volumetric estimate. Uncertainties exist in all factors involved in both types of estimates [2].

Because of alteration of cores during coring, handling, and analysis, volumetric estimates of oil in place in unconsolidated reservoirs are subject to added uncertainties [2].

Errors in the oil, gas and water production data are unavoidable. It has always been a matter of concern that these errors may have a serious effect on the results of model studies to determine the original oil-in-place [3].
Reservoir Characteristics

Stratigraphy of Asmari reservoir [4]

From top to bottom the Asmari consists of a dominated subunit (Jeribe/Euphrates), a limestone subunit (Upper Kirkuk), a siliclastic subunit (Buzurgan), and the carbonates of the Middle/Lower Kirkuk. Fractures may play an important role for fluid flow in the Asmari reservoir.

Thickness
Jeribe/Euphrates: There is a variable thickness ranging from 25 to 57 m.
Upper Kirkuk: This unit has a variable thickness ranging from 76 to 131 m. The three sand sub layers (Sand 1, 2 and 3) within the Upper Kirkuk record rather consistent thickness.
Buzurgan: This thickness for this subunit range from 65 to 120 m.

Middle/Lower Kirkuk: Apparently of variable thickness from 110 to 220 m.

Total Asmari: only small thickness variations are observed for the entire Asmari ranging from 360 to 400 m.

Porosity
Jeribe/Euphrates: the porosity ranges from 2 to 25 % and porosity (average 9 %).
Upper Kirkuk: The sandstone sub layers maximum porosity within the Upper Kirkuk unit is to 32 %. The surrounding limestones of the Upper Kirkuk have lower porosity values, below 10 %.
Buzurgan: The subunit has porosity range of 5 to 32
Formation permeability
Jeribe/Euphrates: the permeability of this subunit varies from 0.1 to 1000 md. The common values below 100 md are more frequent.
Upper Kirkuk: The Upper Kirkuk carbonates permeability range of 0.1 to 50 md.
Buzurgan: The subunit has average permeability of 100’s md.
Middle/Lower Kirkuk: The permeability taken similar to that of Upper Kirkuk subunit.

Stratigraphy of Mishrif Reservoir
Thickness
Each of subunits (mA, mB11, mB12, mB21, mC1, mC2) has small thickness changes range from 345 to 375 m for the entire Mishrif formation.

Porosity
The average porosity for the entire mB21 is 10 %. The average porosity for the mC1 is 7 %. In general the northern wells record a slightly higher average porosity than wells in the South.

Formation permeability
The core permeability have high difference range varies from 0.1 to 300 md. However, the average permeability is 1.55 md.
Results and Discussion

Twelve major modules, with different degrees of analytical sophistication have been analyzed to provide reasonable confidence for estimation STOIIP for Fauqi oil field, throughout analyzing single well production history of FQ-8A; the pressure measurements already corrected to datum of 3030 mSL for the Asmari and 3950 mSL for Mishrif reservoirs. These major models have been illustrated in Appendix.

1- Asmari Reservoir:

The analytical and numerical simulation for the production history matching of well FQ-8A shown in figs. (1-6) and the analysis of flowing material balance shown in fig. (7), in addition to that models depends for type curve matching, provide the STOIIP for the entire Asmari formation of Fauqi oil field as listed in Table (1); while, the detailed analysis of multilayer reservoir has been listed in Table (2) to provide more detailed analysis of the STOIIP for the individual layers of Asmari reservoir.

The results show large uncertainties (58%) in the Asmari STOIIP between the analytical and numerical methods. The STOIIP [1.01 MMMbbl] for analytical (multiple columns model) to [1.6 MMMbbl] (full tank) numerical modeling. Moreover, the analytical multiple oil columns provide about (30%) difference than other analytical of radial, water drive and material balance modeling.
Since, it could be concluded that the analytical models may provide the most exact estimation for STOIP than numerical solution considering only single phase flowing in the reservoir. Moreover, the analytical multiple columns thickness of (1.01 MMMbbl) may consider the most accurate estimation for the STOIP in Asmari reservoir for Fauqi oil field. Hence, the reservoir is divided into three oil pay units are: Jeribe (includes 1 & 2,), Upper Kirkuk (includes 1 & 2) and Upper Kirkuk 3; this estimation represents the STOIP for the entire reservoir including that exists with the Iranian border.

Hence, it could be stated some useful information prevailed from analyzing the production history of radial model as shown in fig. (2); it could be seen the early observed pressure decline is less than predicted suggesting the need for pressure support from an aquifer. Since, because the reservoir has a circular geometry, suggestion for limited pressure support of edge-water drive aquifer model was selected; this was done in order to represent the vertical communication that exists between the individual reservoirs; this modeling of water drive has been shown in fig. (3).

However, figs. (4-6) show also the predicted pressure response versus the pressure history in three different analysis for STOIIP, as could be seen the quality of the history match is acceptable indicating that Asmari reservoir of Fauqi oil field is surrounded by active drive aquifer. The strength of the aquifer is also may be due to fractures that may exist in Asmari formation.
Table (1) STOIIP results for Fauqi oil field-Asmari reservoir generated by different analysis

| Well name: FQ8A | Analysis Types                      | Report | STOIIP   | Area     | Pbar     |
|-----------------|-------------------------------------|--------|----------|----------|----------|
|                 | Traditional::Analysis                | 1      | 1327231  | 14049.51 |          |
|                 | Fetkovich::Radial                    | 1      | 1482959  | 15698    |          |
|                 | Blasingame::Water Drive              | 1      | 1332378  | 14104.75 | 5251.2   |
|                 | AG Rate vs. Time::Water Drive        | 1      | 1319606  | 13968.8  | 5248.2   |
|                 | Transient::Radial                    | 1      | 1330262  | 14081.6  | 5250.7   |
|                 | NPI::Water Drive                     | 1      | 1325112  | 14027.08 | 5249.5   |
|                 | Flowing Material Balance: FMB       | 1      | 1316104  | 13932    |          |
|                 | Wattenbarger::Dimensionless Channel  | 1      | 1316017  | 13931.84 | 5247.4   |
|                 | Specialized Analysis::Radial         | 0      |          |          |          |
|                 | Model::Radial                        | 1      | 1309085  | 13957.76 |          |
|                 | Model::Fracture                      | 0      |          |          |          |
|                 | Model::Horizontal                    | 0      |          |          |          |
|                 | Model::Water drive                   | 1      | 1337156  | 14135.72 |          |
|                 | Model::Composite                     | 0      |          |          |          |
|                 | Model::Multilayer                    | 1      | 1011074  | 34001.24 |          |
|                 | Numerical::Radial                    | 1      | 1600978  | 14007    |          |
Table (2) STOIIP results for Fauqi oil field-Asmari reservoir - Multilayer analysis

|                                | Jeribe/Euphrates | Upper Kirkuk | Middle/Lower Kirkuk |
|--------------------------------|------------------|--------------|---------------------|
| Average Permeability- md        | 260              | 239          | 226                 |
| Average net pay thickness- ft   | 25               | 54           | 57                  |
| Reservoir radius- ft            | 14000            |              |                     |
| STOIP- MMbbl                    | 245473           | 392757       | 372843              |
| Total STOIIP                    | 1011074          |              |                     |

Fig. (1) Traditional analysis
Fig. (2) Analytical radial model analysis

Fig. (3) Analytical water drive model analysis
Fig. (4) Analytical multilayer model

Fig. (5) Numerical radial model analysis for oil production history
Mishrif formation

Production from the Mishrif formation comes primarily from the mB21 reservoir; since the analysis is confined to the mB21 reservoir.

The analytical and numerical simulation for the production history matching of Mishrif formation shown in Figs. (8-13) and the analysis of flowing material balance shown in Fig. (14), in addition to that models depends for type curve matching, provide the STOIIP for the entire Mishrif formation as listed in Table (3).
The analytical and numerical results for the production history of well FQ-8A that comes from Mishrif formation, show very close results indicating more confidential analysis than that obtained from Asmari reservoir in spite of the limited production history that is available to analyze the Mishrif reservoir. The STOIIP from 215 MMbbl for analytical (flowing material balance) to 294 MMbbl for analytical (multiple columns model) provides less difference variation than that of Asmari reservoir.

However, almost analytical modeling and material balance calculations provide approximately same results of (244 MMbbl) which could be considered the most reliable case than numerical result of (218 MMbbl).

Figs. (9 - 13) show the pressure response versus the pressure history. As could be noticed the early observed pressure decline suggests a weak pressure support, it also can be observed increase in reservoir pressure during the extended period of no production between 1980 and 1998 indicates that there is aquifer pressure support.
Table (3) STOIIP results for Fauqi oil field-Mishrif mb21 reservoir generated by different analysis

| Analysis Types                      | Report | OOIP   | Area  | Pbar  |
|-------------------------------------|--------|--------|-------|-------|
| Traditional::Analysis               | 1      | 258286.4 | 3957.74 |       |
| Fetkovich::Radial                  | 1      | 254923.8 | 3906.21 |       |
| Blasingame::Radial                 | 1      | 215164.7 | 3297.16 | 6296.6 |
| AG Rate vs. Time::Radial           | 1      | 246933  | 3783.77 | 6324.4 |
| Transient::Radial                  | 1      | 224256.7 | 3832.88 | 6221.5 |
| NPI::Radial                        | 1      | 243061.5 | 3724.44 | 6321.4 |
| Flowing Material Balance::FMB      | 1      | 215996  | 3309.72 |       |
| Wattenbarger::Dimensionless Channel| 1      | 301596.8 | 4621.73 | 6358.5 |
| Specialized Analysis::Radial       | 1      |         |       |       |
| Model::Radial                      | 1      | 244740.4 | 3750.17 |       |
| Model::Fracture                    | 0      |         |       |       |
| Model::Horizontal                  | 0      |         |       |       |
| Model::Water drive                 | 1      | 244740.4 | 5663.99 |       |
| Model::Composite                   | 0      |         |       |       |
| Model::Multilayer                  | 0      | 294190.7 |         |       |
| Numerical::Radial                  | 1      | 218746.6 | 3734.81 |       |

Fig. (8) Traditional analysis
Fig. (9) Analytical radial model analysis

Fig. (10) Analytical water drive model analysis

Fig. (11) Analytical multilayer model analysis
Fig. (12) Analytical multilayer model analysis

Fig. (13) Numerical radial History Plot model analysis
Conclusions

1. The twelve analytical and numerical simulation models show that the most reliable estimation of OOIP is approximately (1,011,000 Mbbl) for Asmari reservoir using multi column model and about (244,000 Mbbl) for Mishrif reservoir.

2. Performing twelve of different analytical and numerical calculation for the production history of Fauqi oil well Fq-8A, may assist to reduce the uncertainties in the reservoir calculation of the STOIIP especially in Asmari reservoir which shows a considerable degree
of uncertainty between the analytical (multiple column model) and the (full tank model) and also with the numerical calculation.

4. The calculated STOIIP for Mishrif is 244 MMbbl. has more reliability than that of Asmari reservoir in spite of limited production history data got for this reservoir.

5. Assess the information from 3D seismic survey to obtain faults and fracture information. In addition to running detailed production logging test (PLT) to understand intervals contributing in fluids production, will be very important to provide full detailed study for this field.

References

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Symbols

D                          Exponential flow rate decline
FMB                        Flowing material balance
Pbar                       Average reservoir pressure
PLT                        Production log tools
q                          Flow rate (bbl/D)
q_D                        Dimensionless Flow Rate
STOIIP                     Stock tank oil initially in place.
t_D                        Dimensionless Time
t                          Time (days)

Appendix

Analytical Modeling (1)

Traditional Modeling

These analytical modeling Decline curve analysis is a graphical procedure used for analyzing declining production rates and forecasting future performance of oil and gas wells. A curve fit of past production performance is done using certain standard curves. This curve fit is then extrapolated to predict potential future performance. Decline curve analysis is a basic tool for estimating recoverable
reserves. Conventional or basic decline curve analysis can be used only when the production history is long enough that a trend can be identified.

It is implicitly assumed, when using decline curve analysis, the factors causing the historical decline continue unchanged during the forecast period. These factors include both reservoir conditions and operating conditions. Some of the reservoir factors that affect the decline rate include: pressure depletion, number of producing wells, drive mechanism, reservoir characteristics, saturation changes, and relative permeability. Operating conditions that influence the decline rate are: separator pressure, tubing size, choke setting, workovers, compression, operating hours, and artificial lift. As long as these conditions do not change, the trend in decline can be analyzed and extrapolated to forecast future well performance. If these conditions are altered, for example through a well workover, then the decline rate determined pre-workover will not be applicable to the post-workover period.

Decline curve analysis is derived from empirical observations of the production performance of oil and gas wells. Three types of decline have been observed historically: exponential, hyperbolic, and harmonic. All decline curve theory starts from the definition of the instantaneous or current decline rate (D) as follows;
Fetkovich Analysis

Fetkovich presented a new set of type curves that extended the Arps type curves into the transient flow region. He recognized that decline curve analysis was applicable only during the time period when production was in boundary dominated flow; i.e., during the depletion period. This meant that the early production life of a well was not analyzable by the conventional decline curve methods.

Fetkovich used analytical flow equations to generate type curves for transient flow, and he combined them with the Arps empirical decline curve equations, see fig. (15). Accordingly, the Fetkovich type curves are made up of two regions which have been blended to be continuous and thereby encompass the whole production life from early time (transient flow) to late time (boundary dominated flow).
Blasingame et. al. Decline Analysis

Blasingame and his students have developed a production decline method that accounts for variations in bottomhole flowing pressure in the transient regime in addition, changing PVT properties with reservoir pressure phenomena. The method uses a form of superposition time function that only requires one depletion stem for type curve matching; the harmonic stem. One important advantage of this method is the type curves used for matching are identical to those used for Fetkovich decline analysis, without the empirical depletion stems.
Blasingame et. al. have shown that boundary-dominated flow with both declining rates and pressures appear as pseudo-steady state depletion at a constant rate, provided the rate and pressure decline monotonically.

**Transient Type curve Matching Equations**

The evaluation of transient parameters is accomplished using the transient stems of the dimensionless type curve model. Unlike the boundary dominated flow case, the definition of the characteristic dimensionless variables changes according to the chosen transient model. The transient data works better with the Transient format ($q_D$ vs $t_D$), it should be noted that boundary dominated flow analysis is not advised, using this method. And this is used to define the inverse pressure integral derivative.

\[
\frac{1}{P_{DI_D}} = \frac{1}{\frac{dP_{DI}}{d\ln(t_D)}}
\]

**Agarwal-Gardner Type curve Analysis**

Agarwal and Gardner have compiled and presented new decline type curves for analyzing production data. Their methods build upon the work of both Fetkovich and Palacio-Blasingame, utilizing the concepts of the equivalence between constant rate and constant pressure solutions. Agarwal et. al. propose the use of rate-cumulative
type curves for estimating gas or oil in place. $q/P$ is plotted against dimensionless cumulative production.

$$Q_{DA} = \frac{t_{DA}}{p_D} = q_D * t_{DA}$$

**Flowing Material Balance**

The Flowing Material Balance uses the concept of stabilized or "pseudo-steady-state" flow to evaluate total in-place fluid volumes. In a conventional material-balance calculation, reservoir pressure is measured or extrapolated based on stabilized shut-in pressures at the well. In a flowing situation, the average reservoir pressure clearly cannot be measured. However, in a stabilized flow situation, there is very close connectivity between well flowing pressures (which can be measured) and the average reservoir pressure, see fig. (16).

![Diagram](image-url)

**Fig. (16) Decline in Average Reservoir Pressure With Radial Distance for Constant Flow Rate**
**Normalized Pressure Integral (NPI)**

The Normalized Pressure Integral was initially developed by Blasingame in 1989 (Type-Curve Analysis Using the Pressure Integral Method, Blasingame et. al.). The objective of the method was to present a robust diagnostic method for drawdown’s that did not suffer from noise and data scatter, as is typical of the standard well test derivative. The solution involves using a pressure integral curve as the base curve for noisy drawdown analysis.

\[
P_{Di} = \frac{1}{t_{DA}} \int_{0}^{t_{DM}} P_D(t)dt
\]

**Wattenbarger Type curve Analysis**

Long linear flow has been observed in many gas wells. These wells are usually in very tight gas reservoirs with hydraulically fractures designed to extend to or nearly to the drainage boundary of the well. Wattenbarger et al. (1998) presented new type curves to analyze the production data of these gas wells. They assumed a hydraulically fractured well in the center of a rectangular reservoir. The fracture is assumed to be extended to the boundaries of the reservoir.
Numerical (Multi-phase) Modeling:

The assumption of the analytical models for production data analysis is *single phase flow* in the reservoir. In order to accommodate multiple flowing phases, the model must be able to handle changing fluid saturations and relative permeabilities. Since these phenomena are highly non-linear, analytical solutions are very difficult to obtain and use. Thus, numerical models are generally used to provide solutions for the multi-phase flow problem.

The advantages of numerical method approach are that the reservoir heterogeneity, mass transfer between phases, and forces/mechanisms responsible for flow can be taken into consideration adequately, for instance, multiphase flow, capillary and gravity forces, spatial variations of rock properties, fluid properties, and relative permeability characteristics can be represented accurately in a numerical model. In general, analytical methods provide exact solutions to simplified problems, while numerical methods yield approximate solutions to the exact problems.

The Numerical modeling assumes a cylindrical reservoir model used for single-well studies. Cylindrical grids are used in the reservoir (see fig. 17). The grid block size increases logarithmically in size outward from the well. Small grids near the wellbore can effectively simulate the well behavior. In current version of Rate Transient Analysis software, numerical model is a one-dimension radial model,
and gas is modeled by single-phase model, oil can be modeled either by single-phase model (pressure above the bubble-point) or by multiphase model.

![Cylindrical Grids in Numerical Modeling For Single Well](image)

**Fig. (17) Cylindrical Grids in Numerical Modeling For Single Well**