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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 – 01November 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

المــلخص

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

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

المعلومات الانتاجية التي أستعملت في تحليل موازنة المادة للفترة من 1- مايس- 1979 لغاية 1- تشرين الثاني- 2007. وأن الحقل أغلق بسبب الحرب العراقية الايرانية للفترة من أيلول - 1980 ال أب 1998 وكذلك بسبب حرب الخليج للفترة من أذار الى كانون الاول 2003.

أستعملت أثنا عشرة طريقة رئيسة بمختلف الامتدادت التحليلية لاثبات الاحتياطي الاولي لحقل الفكة من خلال تحليل التاريخ الانتاجي لبئر فكة 8. دقة النتائج تم تحليلها وأضهرت درجة مقبولة من الاعتماد.

أنجاز أثنا عشرة عملية حسابية بطرق تحليلة وعددية لتاريخ الانتاج ساعد على تقليل عدم توافقات حساب المحتوى النفطي الاولي للحقل وخاصة لمكمن الاسمري من خلال استعمال تشبعات النفط لكل طبقة ومقارنتها مع أستعمال 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 Characteristis

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 fromfrom 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**
		Mbbl	acres	psi(a)
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**		

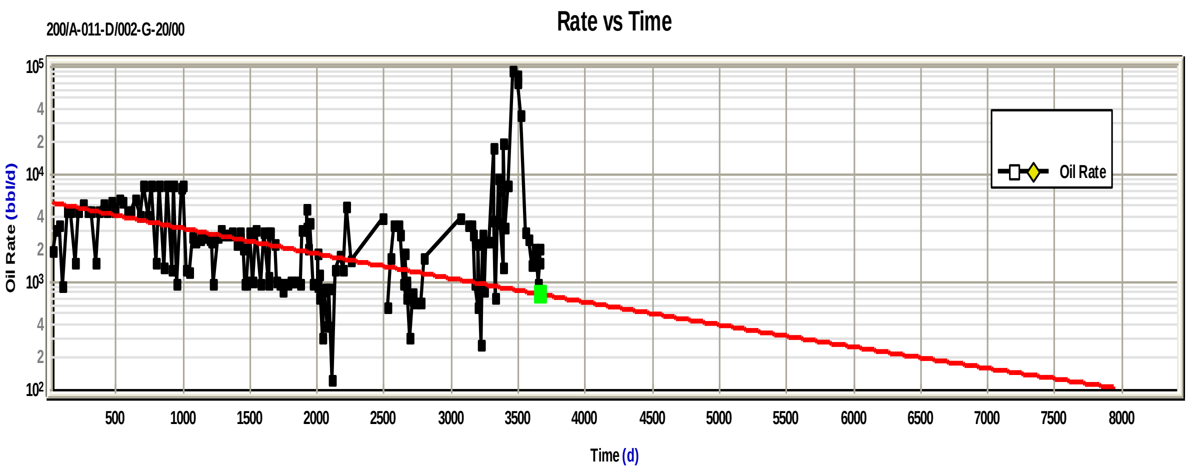

Fig. (1) Traditional analysis

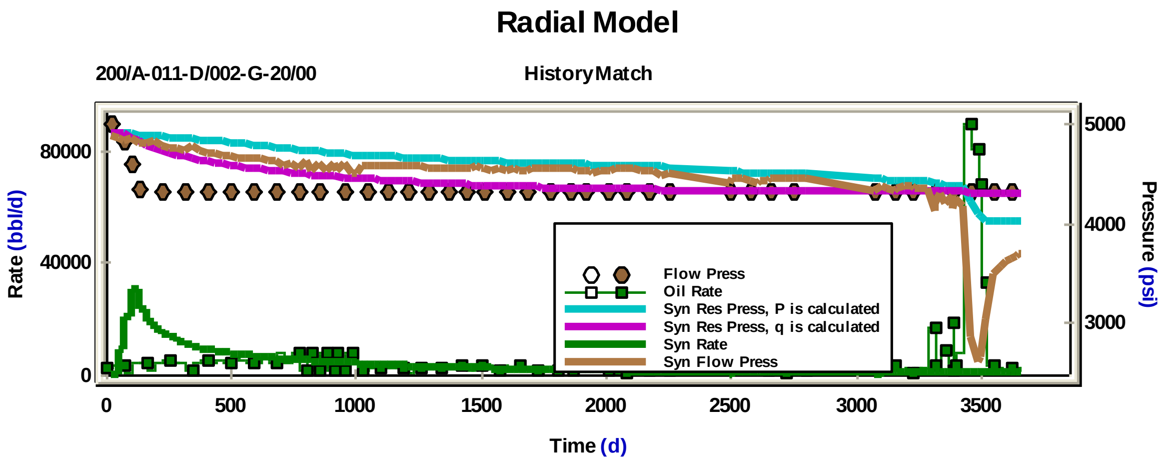

Fig. (2) Analytical radial model analysis

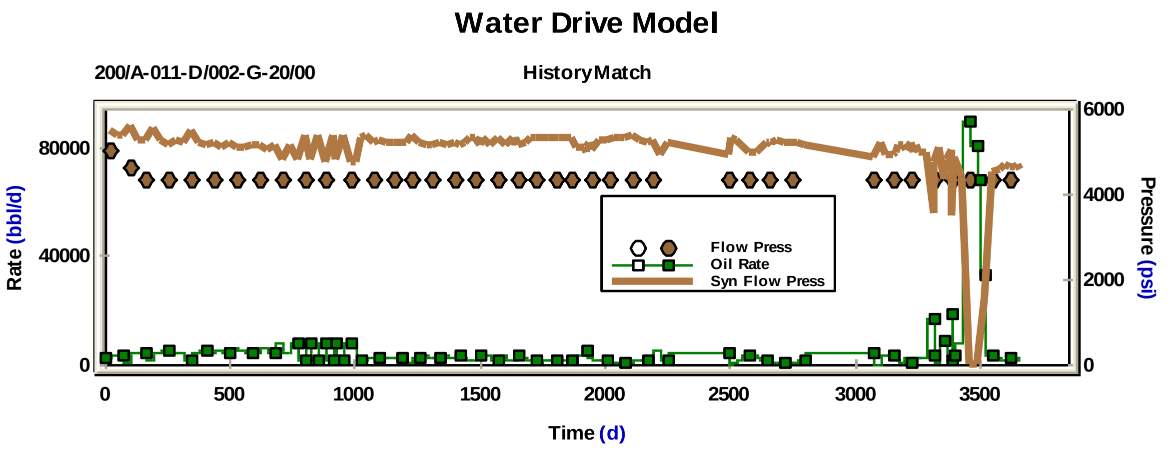

Fig. (3) Analytical water drive model analysis

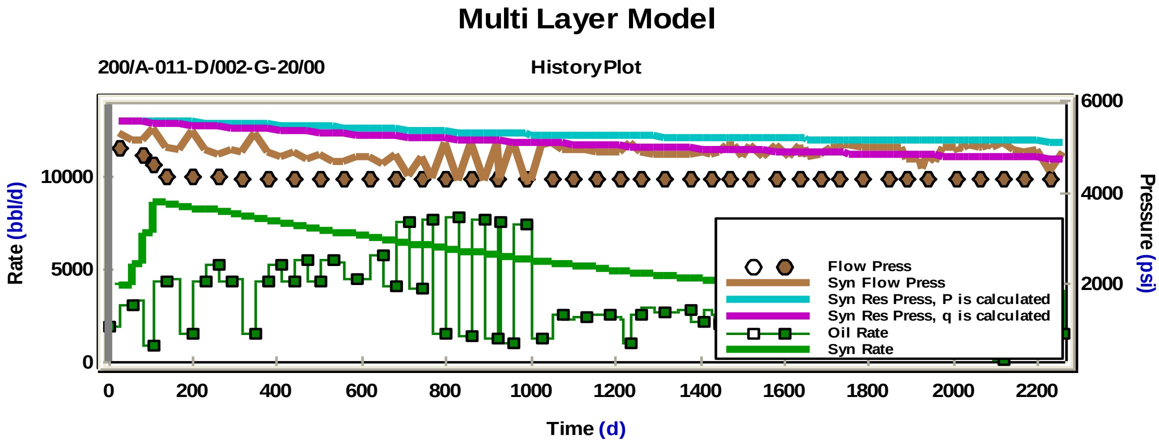

Fig. (4) Analytical multilayer model

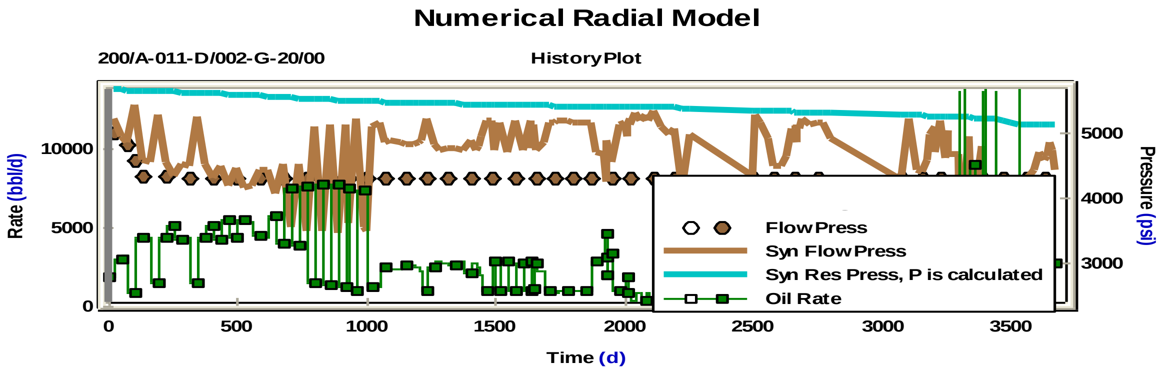

Fig.(5) Numerical radial model analysis for oil production history

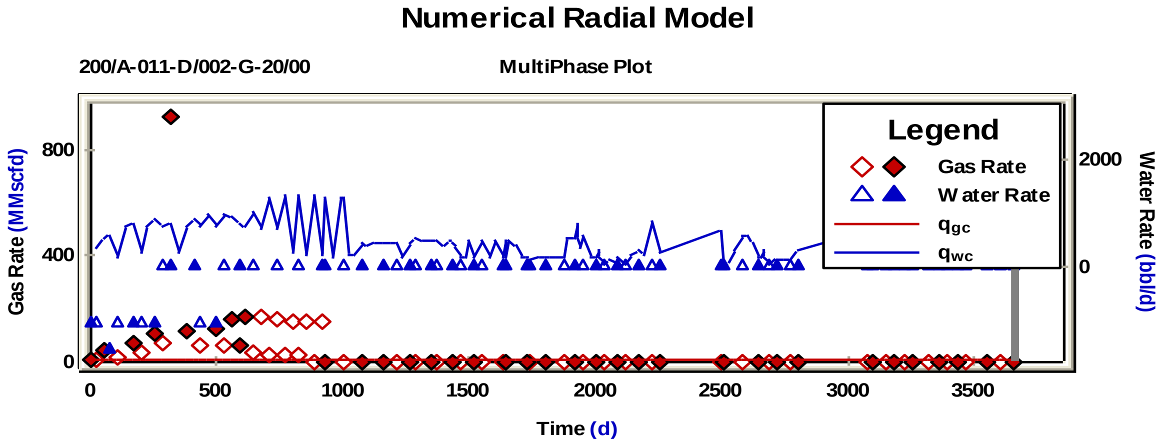

Fig. (6) Numerical radial model analysis for multiphase production history

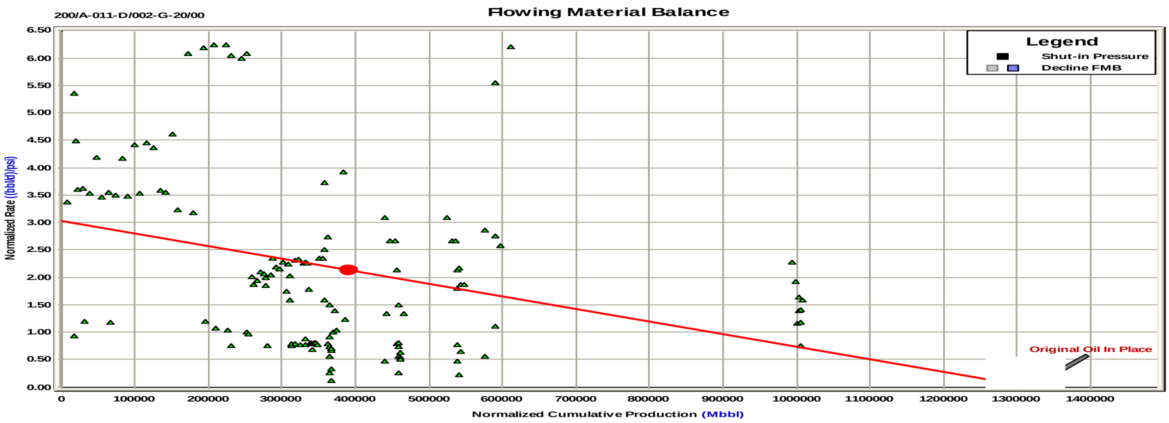

Fig. (7) Flowing material balance analysis for oil production historv

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
		Mbbl	acres	psi(a)
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	

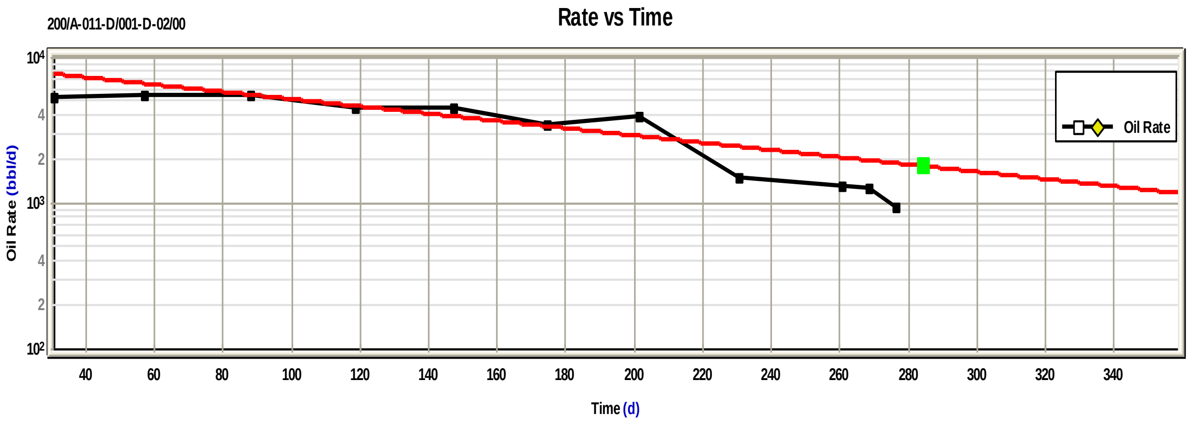

Fig. (8) Traditional analysis

Radial Model

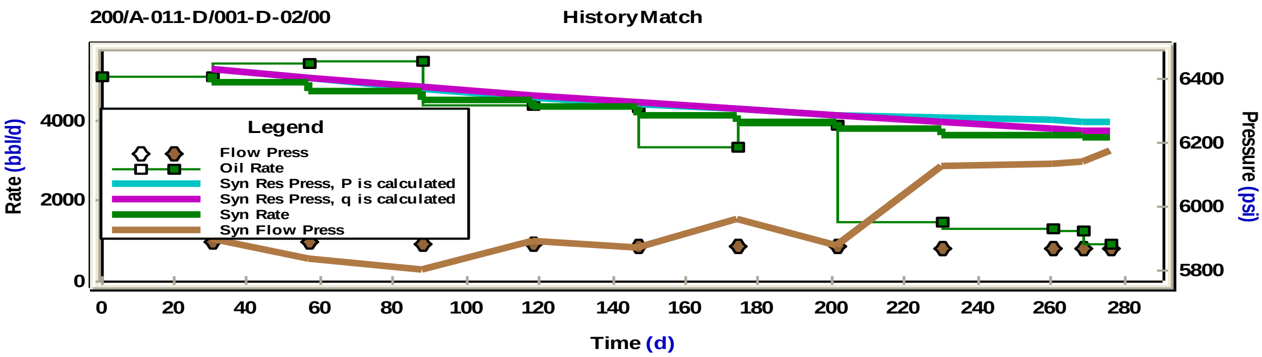

Fig. (9) Analytical radial model analysis

Water Drive Model

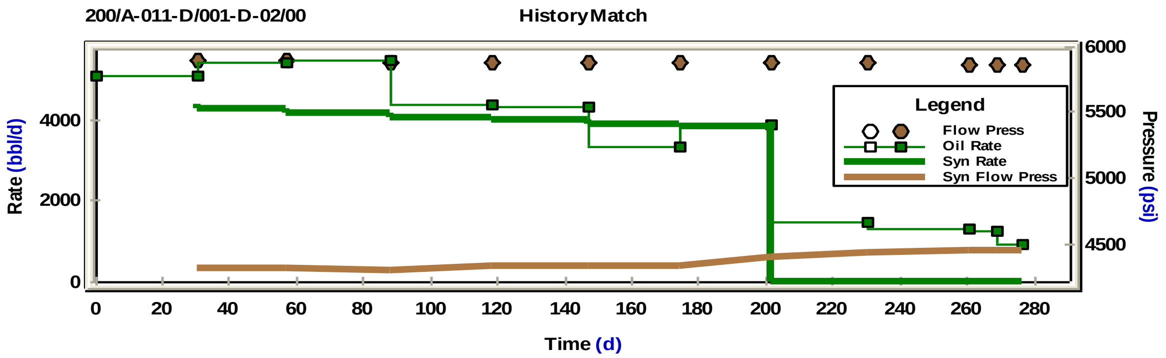

Fig. (10) Analytical water drive model analysis

Multi Layer Model

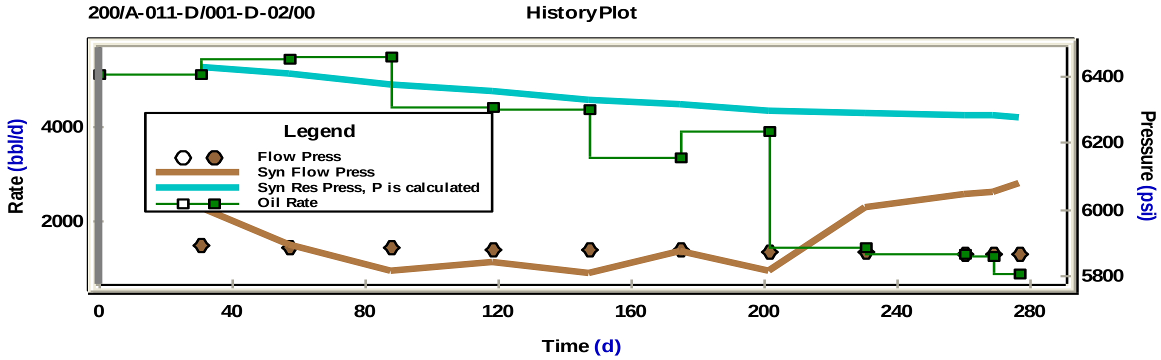

Fig. (11) Analytical multilayer model analysis

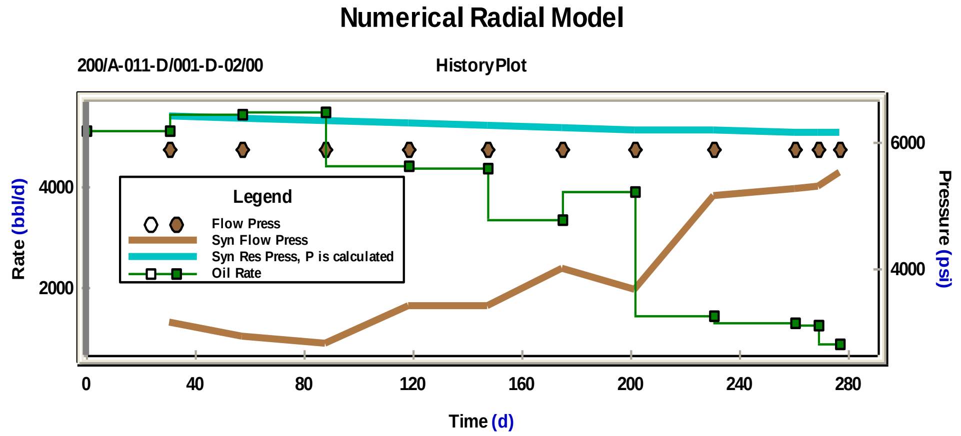

Fig. (12) Analytical multilayer model analysis

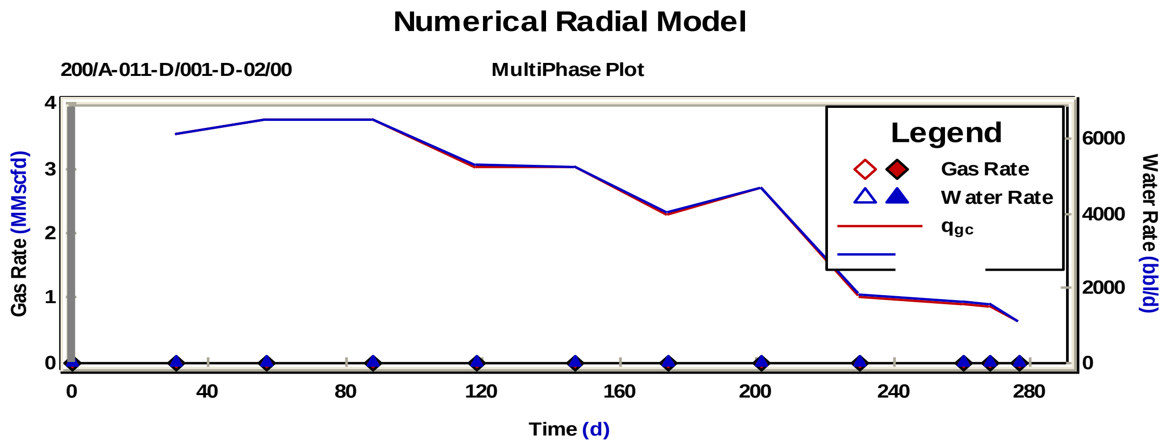

Fig. (13) Numerical radial History Plot model analysis

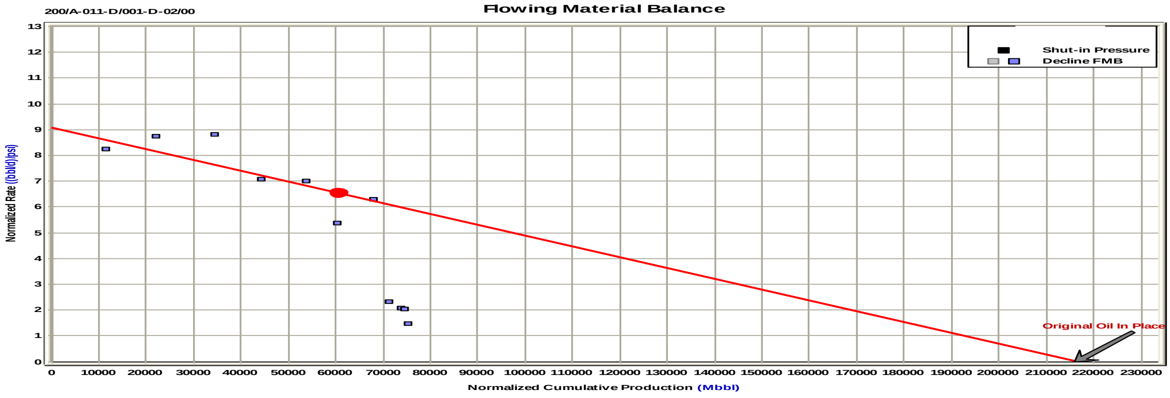

Fig. (14) Numerical Multiphase radial model analysis

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. **Fig. (14) Flowing material balance analysis for oil production history** ted in zagrous mountains area, and it is probably segmented by several faults and/or fractures; since the STOIIP estimation may subject to some uncertainties However, a 3-D seismic data is important to provide high confidence in STOIIP estimation.
3. 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

1. FAST Technical Library, " Rate Transient Analysis-V.4.5" Software Development company, Calgary, Alberta- 2011.
2. Lewelling, Henry , rubb, W.E., Variables Affecting Restored-State Determination of in-Place Oil ; SPE-194, October 1-3, 1952, Presented at the fall meeting of the Petroleum Branch, American Institute of Mining and Metallurgical Engineers.
3. Elkins, Lincoln F ; Uncertainty of Oil in Place in unconsolidated Sand Reservoirs - A Case History; SPE 3789,Nov. 1972.
4. Reservoir and Fields Development Directorate- Ministry of Oil, Iraq. 2010.

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;

$$D = -\frac{(\Delta q / q)}{\Delta t} = -\frac{(\Delta q)}{\Delta t} / q$$

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).

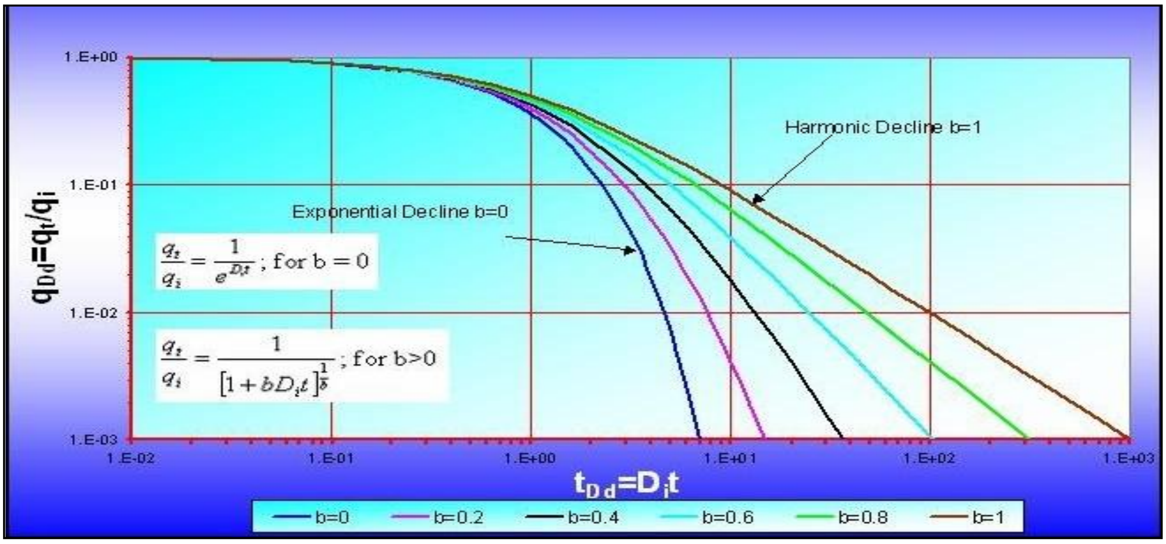

Fig. (15) Arps Dimensionless type curves for empirical rate – time decline equations

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.

$$\frac{1}{P_{DID}} = \frac{1}{\left(\frac{dP_{DI}}{d\,ln(t_D)}\right)}$$

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).

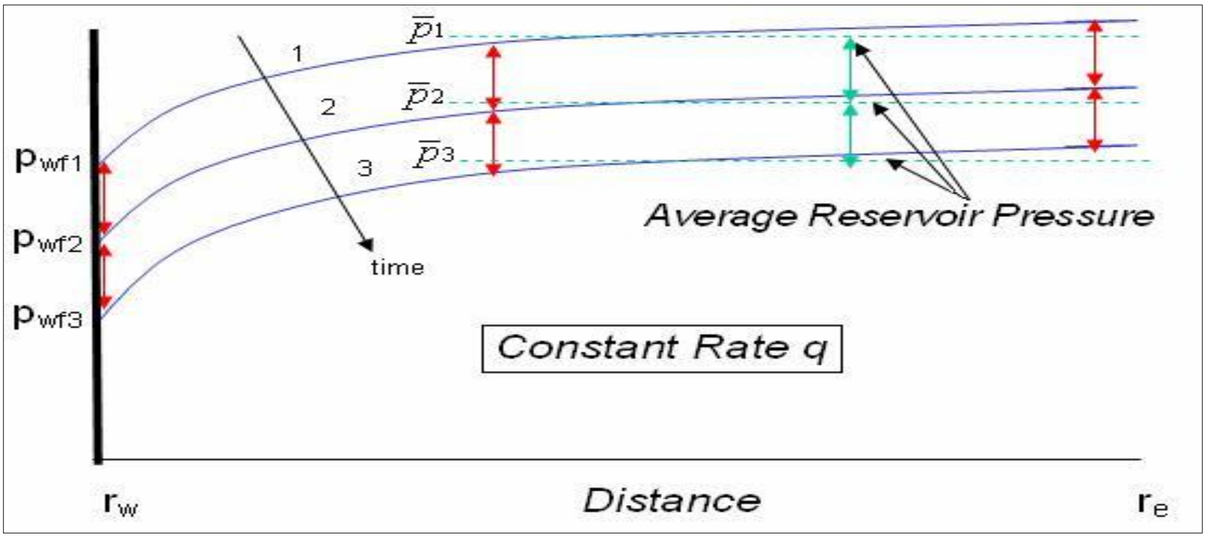

Fig. (16) Decline in Average Reservoir Pressure With Radial Distance for Constant Flow Rate

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.

$$P_{Di} = \frac{1}{t_{DA}} \int_0^{t_{DA}} P_D(t)dt$$

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 analysisx 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.

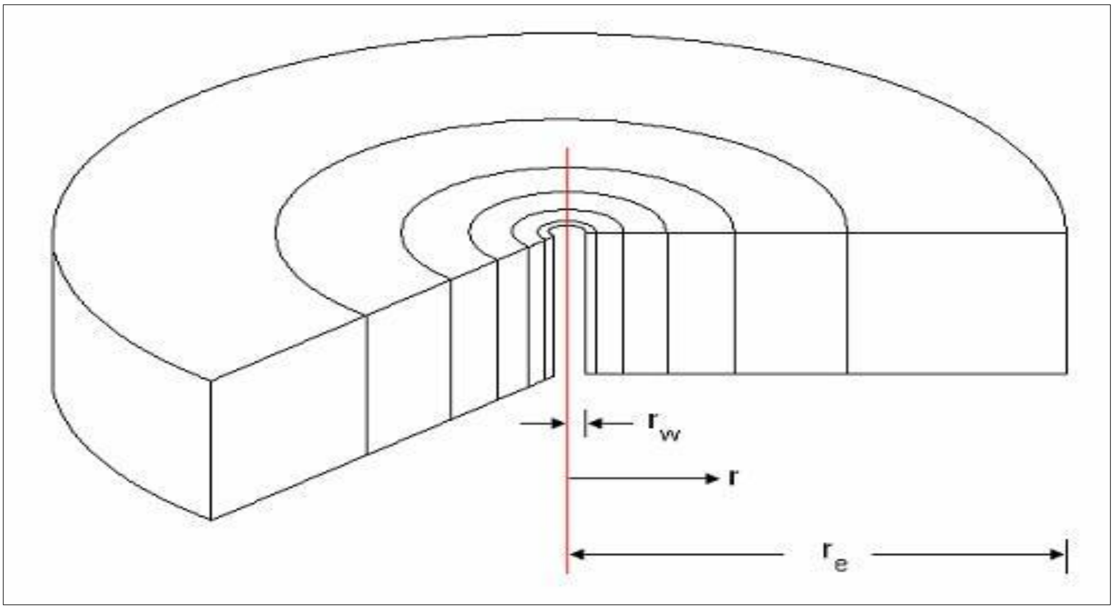

Fig. (17) Cylindrical Grids in Numerical Modeling For Single Well