Estimation of Original Oil in Place for Belhedan Oil Field by Using Volumetric Method, Material Balance Equation Method, and Reservoir Simulation Method

Ali Omran Nasar [1*], Jibriel Abusaleem[2], Essa M. Tabar [3]

Department of Petroleum, College of Engineering, Sirte University, Libya
DOI: https://doi.org/10.21467/proceedings.2.35
* Corresponding author email: ali_omran95@yahoo.com

ABSTRACT

Knowing the amount of the hydrocarbon pore volume correctly is basically required to have properly design of oil and gas reservoirs. The accuracy in calculating of the hydrocarbon pore volume depends on the used method. Usually two conventional methods use to estimate the Original Oil In Place (OOIP) very quickly. These two methods are volumetric method and Material-Balance-Equation (MBE) method. However, there is another quick method that can be used to calculate (OOIP) which is reservoir simulation method. In this paper, three difference methods were used to calculate OOIP to provide Waha Oil Company with the calculated value.

Moreover, each method required sort of data; the volumetric method depends on static data. However MBE and reservoir simulation method require dynamic data of the reservoir and the area around. Usually the driving mechanism is the key point when MBE and reservoir simulation are used. The drive mechanism in studied area (Belhedan oil field) is described from the field information as a strong water drive with small gas-cap. The given field data don't have any information about the gas cap and the water dive. As a result, applying the MBE method to calculate OOIP for this case require some information about the gas cap and the aquifer. So the MBE gave a value of OOIP didn't agree with the value of OOIP that obtained from the volumetric and reservoir simulation. Lack in the information makes MBE unusable method in this case. It has been trying to solve this problem by use some correlation in calculate some parameters and ignore others. However, doing all that, the result couldn't reach any closed value that is calculated by volumetric and reservoir simulation which will explain. In the end of the paper, a prediction of well performance (well v-4) will be done from 1970 until 2020.

Keywords: Original Oil In Place, Volumetric Estimation, Material-Balance-Equation (MBE), and Reservoir Simulation Model.

1 Introduction

Knowing the amount of original oil in place is the most important parameter for reservoir engineers to make a quick decision whether the discovered area is profitable or not. There are two conventional methods and two unconventional methods use to calculate the OOIP. The two conventional methods are volumetric method and Material-Balance-Equation (MBE) method, and the two unconventional methods are reservoir simulation method and decline curve analysis method(1). In reservoir engineer's perspective, the most used methods in petroleum industry are volumetric method and reservoir simulation method. This is because, they are more sophisticated than the other methods to calculate OOIP. The volumetric is quick method and reservoir simulation is more accurate, for these reasons one of them usually is chosen. Among the mentioned methods this paper will focus on volumetric, MBE, and reservoir simulation.

The volumetric depends on basic data of reservoir rock and reservoir fluid properties. However, the reservoir simulation needs a lot of information starts with geological history and ends with production history additional to reservoir rock and fluid properties (1). On the other hand, MBE depends on combinations of fluid properties, rock properties, and production data. Since each method required different sort of data the result will be different, but which one is better this will be discussed. Moreover, each method has some advantages and disadvantages. First, volumetric is a simple method and doesn't require a lot of information; however it is limitations the reservoir heterogeneity where the reservoir assumed is a homogenous and not accurate enough. Second, MBE depends on production data which usually are available and other reservoir properties can be obtained from laboratory experiments. However, it isn't proper to be use when the reservoir is connected to aquifer or gas cap with no enough information about them. The reservoir simulation is quick and accurate method in calculating OOIP. The only problem can face reservoir engineers is building reservoir model that capable to produce hydrocarbon as the real reservoir. In the end, whether the calculation of initial hydrocarbon in place is made manually (volumetric – MBE) or by computer applications (reservoir simulation), the procedures are the same in principle. The three mentioned methods will be explained briefly and individually.

1.1 Volumetric Method

In a new area, usually volumetric estimation made before drilling first well, where the reservoir is assumed to be exists and there is no chance of failure. The volumetric method depends on calculation of reservoir volume which obtained of geophysical maps. There are different methods use to estimate it, like dividing the reservoir into small grid bulk or dividing the area of contour maps into pisses as show in Figure below.

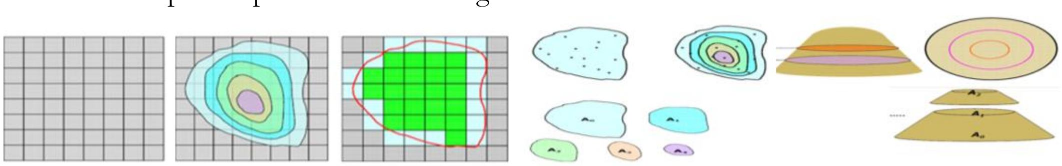

Figure 1: *Methods of reservoir volume calculations (2).*

After the volume is estimated by one of the shows methods in Figure 1, it should multiple by rock porosity and fluid saturation which will result the estimation of recoverable barrels of oil or mcf of gas. In order to covert recoverable hydrocarbon (oil or gas) to standard condition, it should be divided by its formation volume factor. The equation that uses to calculate OOIP by volumetric method can be written as:

$$OOIP = \frac{7758\,Ah\phi(1-S_{wi})}{B_{oi}} \quad (1)$$

1.2 Material Balance Equation, MBE

Material balance equation is the second method that used in this paper to estimate OOIP. Essentially, MBE depends on analyzing of production volumes, pressure condition, and fluid properties to calculate OOIP. In order to have proper understating of MBE solution assume a tank model that located at datum depth and behave like real reservoir condition that having different condition (reservoir pressure and fluid properties) as shown in Figure 2 [3]. After start producing from that model, the reservoir pressure will start decrease and the oil and gas condition will change and produce new materials in the reservoir beside that some other elements will inter to the reservoir as shown in tank below.

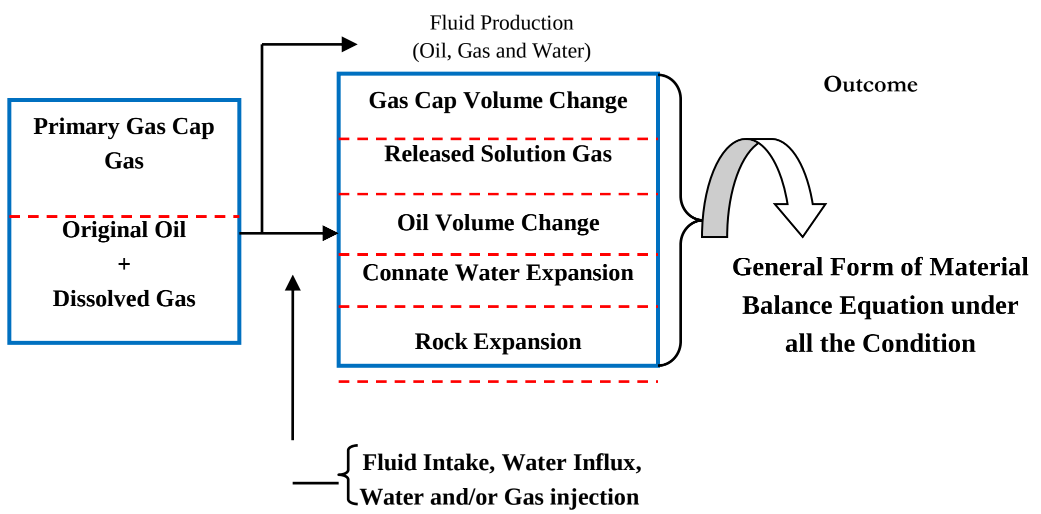

Figure 2: *Tank model of reservoir under original condition and after start producing* [3].

By replacing all mentioned terminologies and combine them, the general form of the material balance equation for the tank mode of above reservoir can be written as[3]:

$$N = \frac{Np\left[Bo + (Rp - Rs)Bg\right] - (We - WpBw) - GinjBginj - WinjBw}{(Bo - Boi) + (Rsi - Rs)Bg + mBoi\left[\frac{Bg}{Bgi} - 1\right] + Boi(1+m)\left[\frac{CwSwi + Cf}{1 - Swi}\right]\Delta p} \quad (2)$$

The above equation is the general form MBE which uses to estimate initial hydrocarbon pore volumes, predict reservoir pressure, calculate water influx, predict future reservoir performance, and predict ultimate hydrocarbon recovery under various types of primary drive mechanisms. Furthermore, the general form of the MBE has been developed to be an equation of straight line equation for simplicity, where some elements that are not exist in the reservoir [3]. The straight-line solution method requires plotting variable group versus another variable group. Each group depends on the driving mechanism of production in which the reservoir is producing, and it is the most important tasks. Depending on the driving mechanism the solution of MBE can be taken one of the several cases: undersaturated oil reservoir case, saturated oil reservoir case, gas cap reservoir case, water drive reservoirs case, and combination drive reservoirs case[3]. Since the driving mechanism of Belhedan oil fields is described as strong water drive with small cap gas, the solution of MBE as straight line equation should use either water drive case, or combination drive case. From field information the gas cap is very small and was neglected in any calculation, because there isn't enough information about it. In a water-drive reservoir mechanism, identifying the type of the aquifer and characterizing its properties are perhaps the most challenging tasks can face any reservoir engineers to calculate the amount of OOIP correctly. Havlena and Odeh solve the general form of MBE by rearrange the general form of MBE and ignores other for the purpose of simplicity by assuming no pressure maintenance comes from gas or water injection. The rearrangement of MBE equation can be written as [3]:

$$N_p\left[B_o+(R_p-R_s)B_g\right]-\left(W_e-W_pB_w\right)= N\left[\left(B_o-B_{oi}\right)+(R_{si}-R_s)B_g+\left[\frac{B_g}{B_{gi}}-1\right]+B_{oi}(1+m)\left[\frac{C_wS_{wi}+C_f}{1-S_{wi}}\right]\Delta p\right] \tag{3}$$

Moreover, Havlena and Odeh had simplified the above equation to be an equation of straight line equation and shortages the number of terms to have them in equation of couple groups with different names as shown below:

$$F-W_e=N(E_o+mE_g+E_{f,w}) \tag{4}$$

In equation 4, each new symbol have different name and represent different section of the reservoir which are: F represents the reservoir volume of cumulative oil and gas produced which named as the underground withdrawal. W_e refers to the net water influx that is retained in the reservoir. E_o, E_g , $E_{f,w}$ these group presents the expansion of oil and its originally dissolved gas production, net expansion of the gas cap that occurs with the production, and the expansion of the initial water and the reduction in the pore volume respectively.

Havlena and Odeh in 1963 expressed an equation for undersaturted oil reservoir where m=0, and rearranging the equation 4. So the equation can be written as [4]:

$$F=N\left(E_o+E_{f,w}\right)+W_e \tag{5}$$

Havlena and Odeh had further expressed equation 5 in a more condensed form as [4]:

$$\frac{F}{E_o+E_{f,w}}=N+\frac{W_e}{E_o+E_{f,w}} \tag{6}$$

Dake in 1978 points out that the term $E_{f,w}$ can frequently be neglected in water-drive reservoirs. This is because water influx helps to maintain the reservoir pressure. The equation 6 cannot be solved directly to calculate the OOIP, since it is require calculating water influx first. Several water influx models can be used to calculate the water influx. One of these models is Schilthuis steady-state method, which will be use in this study. The steady-state aquifer model as proposed by Schilthuis in 1936 is given by [4]:

$$W_e = C\int_0^t (P_i - P)dt = C\sum (P_i - P)\Delta t \qquad (7)$$

Combining equation 6 with 7 gives a straight line equation as shown below [4]:

$$\frac{F}{E_o + E_{f,w}} = N + C\frac{\sum (P_i - P)\Delta t}{E_o + E_{f,w}} \qquad (8)$$

1.3 Reservoir Simulation Modelling

Usually reservoir simulation uses to find the accurate value of hydrocarbon initially in place under different conditions, and also to help reservoir engineers having a proper understanding of reservoir behaviour and making prediction which help engineers in making investment decisions. In this study, a compositional reservoir simulator has been utilized with the intention of modelling and simulating the reservoir [5]. CMG (Computer Modelling Group) is the reservoir simulation that has been used. This commercial software is used in this study to determine reservoir capacities in order to maximize potential recovery and making oil prediction.

2 Data of Studied Reservoir

The data that are used in this study were obtained from Waha Oil Company. Table 1 and 2 presents basic information of reservoir fluid, rock properties, and average reservoir properties for each layer, respectively. Table 3 presents PVT data. The production data versus reservoir pressure had been clean up before it use because some data doesn't have pressure records, and it start from 1965.

Table 1: *Reservoir Data Summary as of July 2013 Belhedan - Gargaf Formation* [6]*:*

Basic Reservoir Data		Average Rock & Fluid Properties	
1-Top of Pay Formation, ft	6300	8- Porosity , %	8.0
2- Datum Depth, ft	6500	9- Permeability, md	10-100
3- Total producible Wells	29	10- Water Saturation, %	33.0
4-Productive Acreage, acres	18600	11- Rock Compressibility, Psia-1	$4.6*10^{-6}$
5- Average Net Pay, ft	190	12- Water Compressibility, Psia-1	$3.3*10^{-6}$
6- Original BHP at Datum, Psia	3100	13-F.V.Fat Original Pressure, RB/STB	1.135
7- Reservoir Temperature, deg F	210	14- Current Reservoir Pressure, Psia	2322

ISBN: 978-81-936820-5-0
Series: AIJR Proceedings
Proceedings DOI: 10.21467/proceedings.2

Table 2: *Gargaf Layers, Average Reservoir Properties above the Oil-Water Contact* [(6)]:

Gargaf Layer	Gross, ft	Net ft	Net/Gross	Porosity,%	Sw, %	HCPTh, ft
GL-1	39.7	27.0	0.68	8.5	37.6	1.43
GL-2	80.1	47.7	0.60	7.6	37.8	2.55
GL-3	75.6	37.6	0.50	6.7	36.3	1.97
GL-4	74.5	38.8	0.52	7.0	35.7	2.11
GL-5	52.9	27.0	0.51	6.8	38.9	1.37
GL-6	29.4	21.0	0.71	7.5	31.5	1.07

Table 3: *PVT Data for well v42* [(6)]:

P, Psia	V/Vsat	B_{od}, rb/stb	R_{sd} ,scf/stb	μ_{od},cp	C_{od} 1/psi	B_o rb/STB	R_s scf/STB
478	1.0386	1.154	122			1.123	84.3
536	1.0000	1.158	133	1.29		1.127	95.0
600	0.9994	1.157			9.38E-06	1.126	
700	0.9984	1.156		1.31	1.00E-05	1.125	
800	0.9975	1.155			9.02E-06	1.124	
900	0.9966	1.154			9.03E-06	1.123	
1000	0.9956	1.153		1.35	1.00E-05	1.122	
1200	0.9938	1.151			9.06E-06	1.120	
1400	0.9921	1.149		1.39	8.57E-06	1.118	
1700	0.9896	1.146			8.42E-06	1.115	
2000	0.9871	1.143			8.44E-06	1.112	
2300	0.9846	1.140			8.46E-06	1.109	
2600	0.9823	1.138			7.80E-06	1.107	
3000	0.9794	1.134			7.40E-06	1.103	
3500	0.9757	1.130			7.58E-06	1.099	
4000	0.9722	1.126			7.20E-06	1.096	

3 Results and Discussion

The calculation of OOIP has been done by using different methods. The result of each method was compared and sent it to Waha Oil Company as it's required.

3.1 First, Volumetric Method

Estimation of OOIP has traditionally been done using volumetric method. All the data need to calculate OOIP are listed in Tables 1 and 2, which include an average value of porosity, saturation, and total net pay thickness for the six layers. Applying equation 1 the initial oil in place is calculated to be 1.29 MMMSTB as shown below.

$$OOIP = \frac{7758\,Ah\phi(1-S_{wi})}{B_{oi}} = \frac{7758*18600*190*0.08*(1-0.33)}{1.135} = 1.294MMMSTB$$

It is well know that the volumetric method is a quick and an easy method of calculating OOIP. However, its result isn't that accurate when it compare with other methods, but it is satisfied method which can be use to make a quick decision when its need it.

3.2 Second, Material Balance Equation Method, MBE

The MBE method supposes to be more accurate in the results than the volumetric method, but due to the lack of information about the aquifer around the reservoir, and changing in the reservoir pressure, the MBE mightn't be the correct choice. The reservoir pressure has been changed rapidly in increasing and decreasing. The changing in the pressure is a result of opening and closing the well as it is mentioned from the company in additional to water influx. Using MBE as straight line equation in such this case which is depending basically on the reservoir pressure and production data will led for incorrect value of OOIP. Since it's a straight line equation, which is require smooth changing of reservoir pressure. In order to calculate the OOIP by MBE as straight line equation there are two important elements must be known, these elements are; reservoir type and reservoir driving mechanism. First, since the reservoir pressure in given data is higher than the bubble point pressure, the reservoir is labeled as an undersaturated oil reservoir. Second, The driving mechanism can be obtained by plotting $F/E_o+E_{f,w}$ versus Np to see if the reservoir has water influx or not. To start calculating OOIP all the data are available except one is missing which is the oil formation volume factor, for that a correlation of plotting oil formation volume factor from the PVT experiment versus reservoir pressure as shown Figure 3.

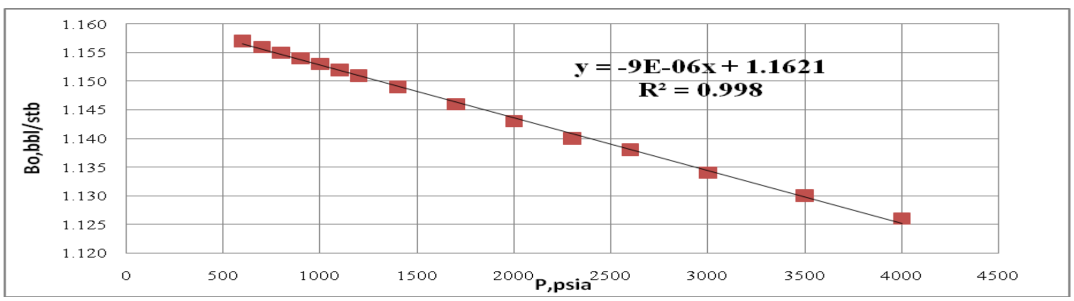

Figure 3: *Curve fitting for B_o vs pressure.*

From Figure 3 a straight line equation can be used to estimate Bo for any given reservoir pressure by: Bo = -9E-06x + 1.1621. Now calculating OOIP by using MBE can be achieve quickly since all the required data are available. After calculation by using Havlena and Odeh approach, the result of MBE as straight line equation couldn't give a correct value of OOIP since no exact straight line could be obtained as shown in Figure 4. This is return to the change in the reservoir pressure and lacking in the information about the aquifer. Such this case has been introduced by other publishers and their values were far away from the one that is calculated by other methods. The calculations are shown in Table 4a & 4b.

As a rule of thumb, the best straight line passes through the large number of points and middles the other. The OOIP from the MBE as straight line is 1E09 which less than the value obtained from the volumetric method. Right now a decision couldn't be making whether this value is the correct or the volumetric estimation. In the end of MBE method, MBAL software for MBE method is used to see if better result can be obtained. MBAL is commonly used for modelling the dynamic reservoir effects prior to building a numerical simulator model [7]. As a result, the result shows difference from MS excel sheet which gave higher value of OOIP which is 2.2 E09, it is indicate whether MBAL or excel sheet the result can never reach a closed value of the volumetric estimation.

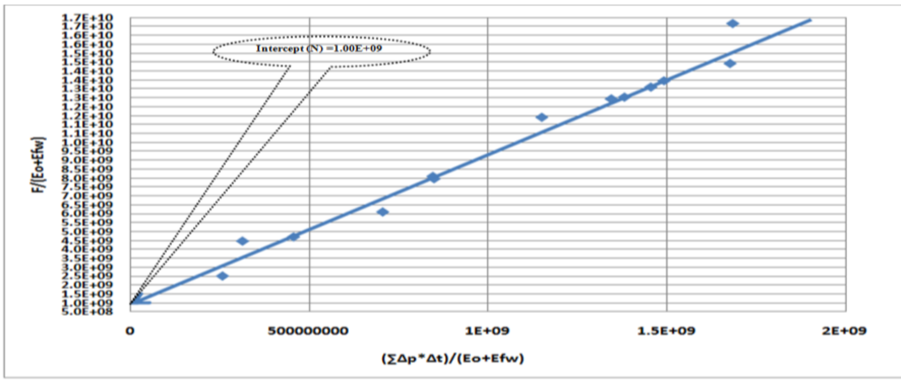

Figure 4: *Plot $F/(E_o+E_{f,w})$ vs $(\sum\Delta p*\Delta t)/(E_o+E_{fw})$ for well v42.*

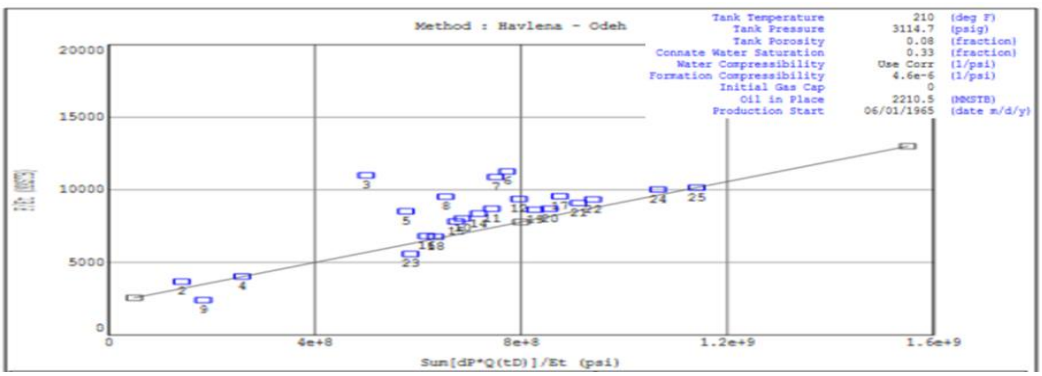

Figure 5: *MBAL software result for estimation OOIP by using MBE method, analysis window* [7].

Table 4-a: *Calculation of OOIP using MS excel of well V42* [6]:

Date	Np	Wp	P	Bo	Δt	Δp	Eo
m/d/year	MSTB	MSTB	psia	bbl /STB	days	psia	bbl /STB
6/1/1965	4349.1	1.1	3079	1.1340	0	21	0
6/1/1974	12454.5	23.3	2796	1.1370	3285	304	0.001936
6/1/1976	13396.1	29.8	3032	1.1350	730	68	-0.000188
6/1/1982	16799	56.7	2727	1.1380	2190	373	0.002557
6/1/1983	17138.7	67.8	2962	1.1350	365	138	0.000442
6/1/1986	18646.1	77.6	3007	1.1350	1095	93	0.000037
6/1/1988	19583.7	108.3	2986	1.1350	365	114	0.000226
6/1/1989	20020.8	108.9	2338	1.1410	365	762	0.006058
6/1/1991	21202.9	128.9	2951	1.1360	730	149	0.000541
6/1/1992	21747.9	137.5	2982	1.1350	365	118	0.000262

6/1/1994	22570.9	147.8	3031	1.1350	365	69	-0.000179
6/1/1996	23421	191.3	2916	1.1360	730	184	0.000856
6/1/1997	24150.8	279.8	2853	1.1360	365	247	0.001423
6/1/1999	25037.8	579.6	2764	1.1370	730	336	0.002224
6/1/2000	25404.2	741.2	2935	1.1360	365	165	0.000685
6/1/2001	25770	906.9	2748	1.1370	365	352	0.002368
6/1/2002	26068.7	1023.8	2850	1.1360	365	250	0.00145
6/1/2003	26245	1060.4	2850	1.1360	365	250	0.00145
6/1/2005	26999.4	1553.9	2850	1.1360	730	250	0.00145
6/1/2006	27402.7	1922.5	2850	1.1360	365	250	0.00145
6/1/2008	28144.9	2703.3	2600	1.1390	730	500	0.0037
6/1/2009	28367	3119.8	2850	1.1360	365	250	0.00145

Table 4-b: *Calculation of OOIP using MS excel of well V42* (6):

Efw	Eo+Efw	F	F/(Eo+Efw)	Δp*Δt	∑Δp*Δt	(∑Δp*Δt)/(Eo+Efw)
bbl /STB	**bbl /STB**	**bbl**	**STB**	**Psiadays**	**Psiadays**	**Psiadays/ bbl /STB**
8.61E-05	-5.25E-04	4.93E+06	-9.40E+09	0.00E+00	0.00E+00	0.00E+00
1.25E-03	3.18E-03	1.42E+07	4.46E+09	9.99E+05	9.99E+05	3.14E+08
2.79E-04	9.09E-05	1.52E+07	1.68E+11	4.96E+04	1.05E+06	1.15E+10
1.53E-03	4.09E-03	1.92E+07	4.69E+09	8.17E+05	1.87E+06	4.56E+08
5.66E-04	1.01E-03	1.95E+07	1.94E+10	5.04E+04	1.92E+06	1.90E+09
3.82E-04	4.19E-04	2.12E+07	5.08E+10	1.02E+05	2.02E+06	4.82E+09
4.68E-04	6.94E-04	2.24E+07	3.22E+10	4.16E+04	2.09E+06	3.01E+09
3.13E-03	9.18E-03	2.30E+07	2.50E+09	2.78E+05	2.37E+06	2.58E+08
6.11E-04	1.15E-03	2.42E+07	2.10E+10	1.09E+05	2.48E+06	2.15E+09
4.84E-04	7.46E-04	2.48E+07	3.33E+10	4.31E+04	2.52E+06	3.38E+09
2.83E-04	1.04E-04	2.58E+07	2.48E+11	2.52E+04	2.58E+06	2.48E+10
7.55E-04	1.61E-03	2.68E+07	1.67E+10	1.34E+05	2.71E+06	1.68E+09
1.01E-03	2.44E-03	2.78E+07	1.14E+10	9.02E+04	2.80E+06	1.15E+09
1.38E-03	3.60E-03	2.91E+07	8.08E+09	2.45E+05	3.05E+06	8.46E+08
6.77E-04	1.36E-03	2.97E+07	2.18E+10	6.02E+04	3.11E+06	2.28E+09
1.44E-03	3.81E-03	3.03E+07	7.95E+09	1.28E+05	3.23E+06	8.49E+08
1.03E-03	2.48E-03	3.08E+07	1.24E+10	9.13E+04	3.33E+06	1.34E+09
1.03E-03	2.48E-03	3.10E+07	1.25E+10	9.13E+04	3.42E+06	1.38E+09
1.03E-03	2.48E-03	3.24E+07	1.31E+10	1.83E+05	3.60E+06	1.45E+09
1.03E-03	2.48E-03	3.33E+07	1.34E+10	9.13E+04	3.69E+06	1.49E+09
2.05E-03	5.75E-03	3.50E+07	6.09E+09	3.65E+05	4.06E+06	7.05E+08
1.03E-03	2.48E-03	3.57E+07	1.44E+10	9.13E+04	4.15E+06	1.68E+09

3.3 Third, Reservoir Simulation Method

In this study, reservoir simulation software was used to calculate the initial oil in place. CMG (Computer Modelling Group) is reservoir engineering software. CMG consist of different applications which are BUIDER, IMEX, and RESULTS. The BUILDER is to build reservoir simulation model, IMEX for black oil reservoir, and RESULTS to have results graph [8]. As a result, a reservoir simulation model was built with 29 vertical wells. The input data for that model were obtained from Waha Oil Company as listed in Tables1, 2, and 3. In this case of field study, there is a lot of missing information, which returns to the difficulty to obtain them either from the company or from the reservoir itself. For this reason, CMG software was chosen in this study to estimate the OOIP. This simulator can generate some information which aren't available from the source. To build model there are some steps need to be followed. First, start with basic information which includes: started date, field unit, and grid number. Second, a grid system type has been used to build the area for the Belhedan reservoir. The surface area of the reservoir is 18600 acre, and consists from six layers with different reservoir properties. Third, reservoir rock and fluid used as an average value for each layer. After inserting all the required data, the reservoir model becomes ready to run and get result. Only one step still left in this model is drilling wells. A twenty nine vertical well has been drilled in the reservoir. The run was achieved and the result will be discussed acceptable. In the end, Figure 6 shows the grid top, grid thickness, reservoir porosity, permeability, net pay, water saturation, and other information as showed below.

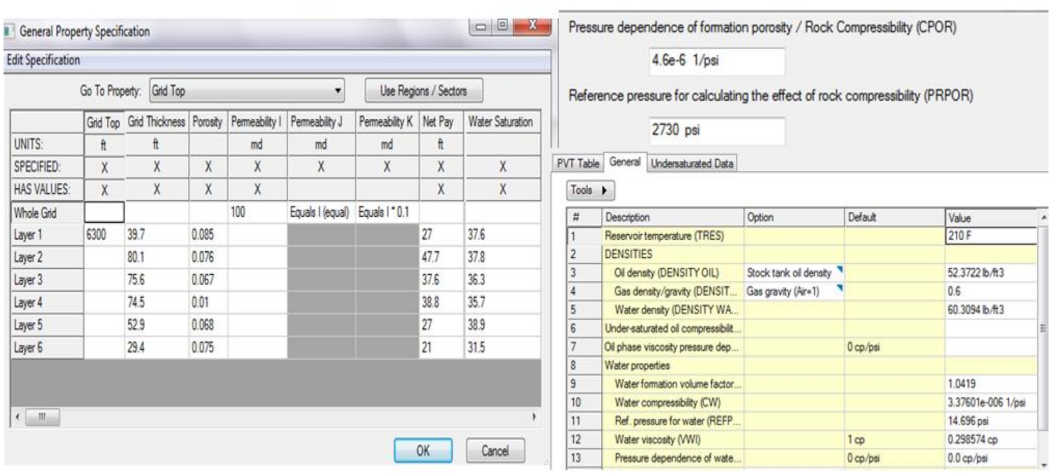

Figure 6: *General property specification* [8]

Finally, after the model has been run and the result of that model of original oil in place is highlty which is 1.4 MMMScf. The result of OOIP is acceptable and close to volumetric method then MBE, which make simulation has the correct value as sent it to the company for verification. Figure 7 shows the results of CMG model and oil prediction from 1965 to 2020 respectively. The prediction was done without having history matching where the well assumed producing oil from the day started until 2020.

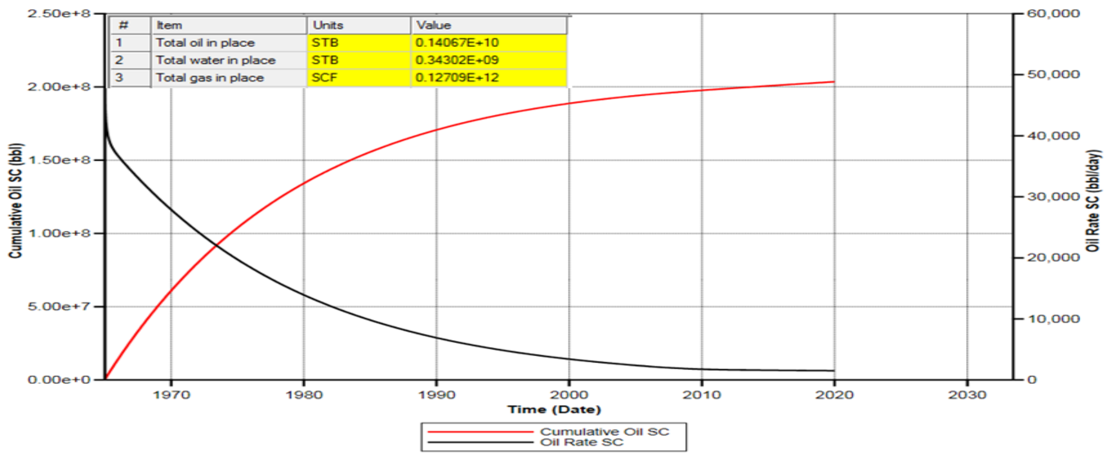

Figure 7: *Result of simulation run and cumulative oil prediction and oil flow rate*(8)

4 Conclusions

Three different methods were used to calculate the OOIP. The obtained results from these methods were different. The difference in the results between them returns to the availability of the reservoir data. The amount of OOIP that is getting from Waha Oil Company is around 1.36 MMMSTB which is close to software result and volumetric result. The diversity in the results is return for some reasons which can be summary as: First, Volumetric method is the easiest, quickest method and doesn't need much information to estimate OOIP. Second, results of MBE as straight line equation method by excel or MBAL software aren't acceptable at all, because there are some missing information about the driving mechanism that providing the energy to the reservoir. Third, Reservoir simulation method is a modern method in petroleum industry to calculate the OOIP and making prediction and history matching as well, the software is more acceptable since it generate any other information in case its missing.

5 Acknowledgment

The authors would like to express their gratitude to the Waha Oil Company for supplying the data, and to West Virginia University for providing the software used in this study.

References

[1] B.C Craft, M. Hawkins, "*Applied Petroleum Reservoir Engineering*", Englewood Cliffs, NJ 07632, 1991.

[2] Aminian, K, "*Class Note of Reservoir Engineering PNGE 330*", Spring 2006.

[3] Tariq Ahmed, "*Applied Reservoir Engineering*, second Edition Handbook, Butterworth-Heinemann 2001.

[4] Tariq Ahmed, Paul D. Mc Kinney, "*Advanced Reservoir Engineering*", Anadarko Canada Corporation, 2005.

[5] West Virginia University, "*Petroleum Engineering Department*", http:// www.wvu.edu,2014.

[6] Waha Oil Company, "*Reservoir Engineering Department*", January 1st 2014.

[7] MBAL software, "*West Virginia University, Petroleum Engineering Department*", http:// www.wvu.edu,2014.

[8] CMG software, "*West Virginia University, Petroleum Engineering Department*", http:// www.wvu.edu,2014.

Nomenclature

Ø= Porosity, dimensionless.
A= Cross section area, acre
Pi= Initial reservoir pressure, Psi
P =Average reservoir pressure, Psi
Pb= Bubble point pressure, Psi
Np= Cumulative oil produced, STB
Wp= Cumulative water produced, bbl
Rsi= Initial gas solubility, scf/STB
Boi= Initial oil formation volume factor, bbl/STB
Bgi= Initial gas formation volume factor, bbl/scf
Winj= Cumulative water injected, bbl
W_e = Cumulative water influx, bbl
m=Ratio of gas-cap to reservoir oil volume, bbl/bbl
S_w = Water saturation, percentage
h = Net pay thickness, ft
Δp= Change in reservoir pressure = P_i – P, Psi
N=Initial (original) oil in place, STB
Gp=Cumulative gas produced, scf
Rp= Cumulative gas-oil ratio, scf/STB
Rs= Gas solubility, scf/STB
Bo= Oil formation volume factor, bbl/STB
Bg= Gas formation volume factor, bbl/scf
Ginj =Cumulative gas injected, scf
G =Initial gas-cap gas, scf
C_f =Formation (rock) compressibility Psi^{-1}
C_w =Water compressibility, Psi^{-1}