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Determination of the Oil Initial in Place, Reserves, and Production Performance of the Safsaf C Oil Reservoir

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ABSTRACT
This study estimated the initial oil in place (OIIP) of SafsafCoil reservoir by using both volumetric methods and material balance equation. Also, oil reserves of this reservoir was estimated using production Decline Curve Analysis (DCA) method. First, three different volumetric techniques (Iso-pach method, Pore-volume method and Hydrocarbon pore volume method) were implemented in this study to estimate the initial oil in place. As these volumetric techniques depends on mapping for their calculation, so a powerful package software (Surfer) was used to generate maps. Second, Havelena and Odeh model was built as a Material Balance Equation (MBE) to estimate the initial oil in place. Field production history, PVT data and reservoir pressure history were prepared to apply the material balance equation. finally, Exponential decline method was used as a Decline Curve Analysis (DCA) to estimate oil reserves, remaining reserves, and remaining productive life of the reservoir.The results of this study revealed that SafsafC reservoir has an initial oil in place in the range of 11.59 to 12.11 MMSTB by implementing the three volumetric methods (Iso-pach, Pore-volume and Hydrocarbon pore volume). The results also revealed that initial oil in place obtained from material balance equation is 12.71MMSTB, which is in a good agreement with volumetric methods. Additionally, oil reserve of Safsaf C reservoir is 3.05 MMSTB for the total reservoir.The results of this study demonstrate that Infill drilling can be implemented to increase oil recovery, and continued water injection should be used to maintain the reservoir pressure.

KEYWORDS: -Safsaf C reservoir; volumetric method; material balance equation; decline curve analysis; oil initial in place; reserves

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I. INTRODUCTION

Three main types of techniques are used to estimate Hydrocarbon Initially in Place (HIIP). Volumetric Methods are “static” methods that estimate HIIP from static properties of the reservoir, including its porosity, thickness, and initial water saturation. The Material Balance Method, in contrast, is a “dynamic” method that estimates HIIP by analyzing historical data on production and pressure. A Long Duration Draw-Down Test (e.g. Reservoir Limit Test) can also be used to estimate HIIP, but because this method is normally limited to small hydrocarbon accumulations (i.e. single- or two-well reservoirs), it will not be considered in this study.

1.1 Volumetric Methods

Volumetric methods of estimating HIIP can be employed immediately after first discovery, before production begins. For this reason, they are the primary tool used for the techno/economic evaluation of oil properties and for the design of field-development projects (Dake, 1978), (Ahmed, 2010), (Craft & Hawkins, 1991).

The accuracy of HIIP estimates calculated using volumetric methods depends significantly on one’s understanding of regional geology and on the quality of the seismic analysis, both of which will improve as more wells are drilled and more accurate descriptions and geologic and petrophysical maps of reservoirs become available (Urayet, 2004).

Three different volumetric methods—Iso-Pach, Pore-Volume, and Hydrocarbon Pore Volume are used to estimate OIIP, and they all use the same basic data: petrophysical properties described by well logs, geological maps, and the physical properties of the oil at the initial reservoir conditions.

To estimate OIIP,each of these methods requires mapping. To assist in this mapping, *Surfer* software was used in this study. *Surfer* isa powerful contouring, gridding, and surface-mapping package that interpolates irregularly spaced XYZ data into a regularly spaced grid (Golden Software, 2009).

1.2 Material Balance Equation

Material Balance employ the Single Tank Model, treating reservoir systems as homogeneous units or "blocks." One of the earliest, simplest, and yet most reliable tank models is the Schilthius Tank Model, which is expressed as a Volumetric Material Balance Equation (Dake, 1978), (Craft & Hawkins, 1991), (Fair, 1994), (Ahmed, 2010).

The main assumptions of the Schilthius Tank Model can be summarized as follows:

- Constant Tank Volume: The formation section containing the initial hydrocarbons is assumed to be of a constant volume, one that does not change with production and injection.
- Constant Pressure Distribution: The pressure at every point in the reservoir and at every point in time is assumed to be equal to the average reservoir pressure. however, the system average pressure is allowed to change with time,
- Homogeneous Reservoir: Each property (including k_g, k_w, k_o, Ø, S_g, S_w, S_o, μ_g, μ_w, and μ_o) is assumed to have the same value across the reservoir at any given time.
- Constant Composition: The fluid-chemical composition is assumed to remain constant throughout production, except as reflected in the changes with pressure of the fluid properties (e.g. B_o, R_s, z-factor, and viscosity).
- Uniform Withdrawals: The volumes of fluids produced from and injected into the reservoir are assumed to be distributed uniformly throughout the system.

Material Balance Calculations are normally run to accomplish the following:

- To validate HIIP estimates obtained using the Static Volumetric Method.
- To identify the driving mechanism affecting the reservoir performance and, for water-drive systems, to identify the aquifer model and the water influx constants.
- To estimate the reserves ultimately recoverable.
- To forecast the ultimate performance of the reservoir.

(Havlena & Odeh, 1963) rearranged the Material Balance Equation into one for a straight line. Their straight-line method requires two variable groups to be plotted against each other, both of which are chosen based on the production mechanism. This study used the straight-line method to estimate the OIIP of the Safsaf C reservoir.

1.3 Decline Curve Analysis

Decline Curve Analysis is a basic tool for predicting production rates and estimating remaining oil reserves and remaining productive life (Cutler, 1924). (Urayet, 2002) reported that calculating reserves—especially in the early life of a reservoir—is the most difficult aspect of reservoir engineering because the only tools available for doing so are macro-analysis techniques that rely on reservoir models in which the characteristics of most points in the reservoir are linear interpolations from known points (i.e. holes that have been drilled). Especially in water-drive systems, reserve values are significantly influenced by variations in permeability (in both the horizontal and vertical directions), layering, pore size, and pore throat size, but such variation is rarely taken into consideration.

The most popular decline curves are those that represent declines in the rate of oil or gas production using Rate-Time Plots. Rate-Cumulative Plots are also popular, however, and plot production rates against cumulative oil or gas production. Both techniques can be applied to single wills, total reservoir, and cumulative production.Three mathematical formulas are used to estimate future production: Hyperbolic Decline, Exponential Decline, and Harmonic Decline (Arps, 1945).

Because it is frequently used for strong water drive reservoirs,Exponential Decline was used in this study to represent or extrapolate the production data of the Safsaf C reservoir.

II. SAFSAF C: BACKGROUND AND RESERVOIR DESCRIPTION

The Safsaf field is located inNorth Africa and was discovered in 1985 through drilling wells C1 and D1, which are located in two different structures (Safsaf C and D). Oil was found in the Facha member of the Gir formation, and production from the Facha member began in 1990 (Fig. 1).

The C block is north of the D block and separated from it by a structural low (or "saddle"). The saddle between C and D is believed to be a low-permeability zone, and the pressure distribution of both blocks C and D is shown in fig. 2. To date, a total of six wells—3 producers and 3 injectors—have been drilled into the structure of C (Fig. 3).

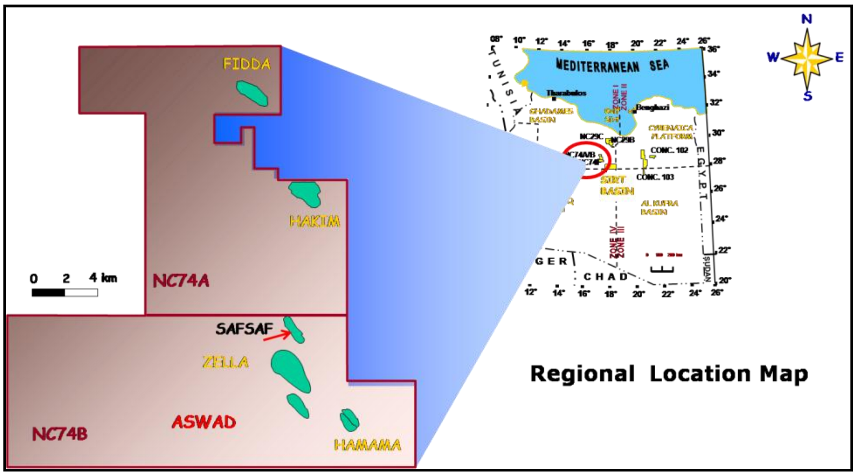

Fig.1 The location of the Safsaf field

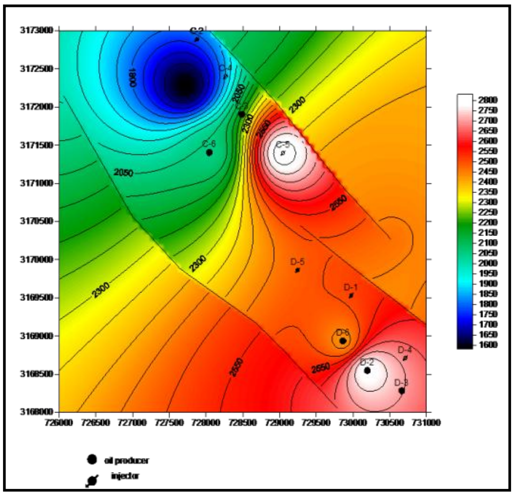

Fig. 2 Isobaric mapof theSafsaf field

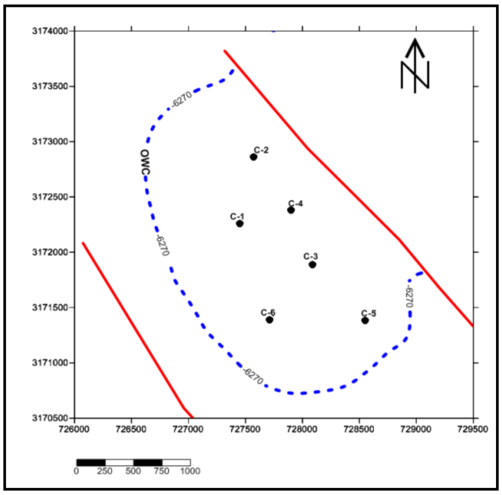

Fig. 3 Map of well locations in Safsaf C

All of the wells produce from the carbonate Facha formation. The Safsaf formation is bounded by several faults, all of which are assumed to have small throws such that they may not seal completely. The overlaying Hon Evaporites provide a seal for the reservoir. The porous interval below the oil interval consists of very-low-permeability rock. Diagenesis took place in the water interval and is believed to have decreased the permeability of the water-filled pores.

The Facha reservoir is composed of a series of dolomite and limestone layers separated by tight anhydritic stringers. These anhydrite layers prevent vertical communication between the flow units, particularly in the upper parts of the reservoir. Table 1 presents data from the Safsaf C reservoir.

Table 1 : Safsaf C reservoir : data summary

Formation Depth, (D)	7,200	ft
Avg. Net Pay, (h)	44	ft
Initial Pressure, (P_i)	3,080	Psia
Current Pressure of C-Block, (P)	1,816	Psia
Reservoir Temperature, (T_{res})	186	°F
Avg. Porosity, ($\phi_{avg.}$)	18	%
Initial Water Saturation, (S_{wi})	28	%
Avg. Permeability, ($k_{avg.}$)	20	md
Saturation Pressure, ($P_{sat.}$)	2,100	Psia
Gas Oil Ratio, (GOR)	1,500	scf/STB
FVF @ Initial Pressure, (B_{oi})	2.28	RB/STB
Oil Viscosity @ Initial Pressure, (μ_o)	0.28	cp
Oil Gravity, (API)	50	°API

III. CASE STUDY APPLICATIONS

3.1 Volumetric Methods Calculations

All three volumetric techniques were used in this study—the Iso-pach method, the Pore-Volume method, and the HPV method. The Simpson Rule was used to calculate the reservoir volume according to the following equation:

$$V_f = \frac{h}{3}[a_0 + 2a_1 + 4a_2 + 2a_3 + 4a_4 + \cdots + 4a_{n-2} + 2a_{n-1} + a_n] + \frac{t_n * a_n}{2} \quad (1)$$

where V_f is the net pay volume, h is the contour interval, a_i is the area of contour i, and t_n is the greatest thickness level above the *n*th contour.

Because all volumetric methods rely on mapping, *Surfer* was used to generate the contour maps used with each method.

3.1.1 Procedure for the Iso-pach Method

1. The average porosity, average water saturation, and net pay thickness were calculated for each well and for the reservoir (Table 2).
2. The net-pay-thickness map of the Safsaf C reservoir was generated for use with the Iso-pach method (Fig. 4)
3. The areas of the sections enclosed by the contours shown in the pay-thickness maps were calculated.
4. Net pay volume $V_f$was calculated using the Simpson rule.
5. The OIIP was calculated using the following equation (2)

$$OIIP\ (STB) = \frac{(1-\overline{S_{wi}})V_f\overline{\emptyset}}{5.615\ B_{oi}} \quad (2)$$

3.1.2 Procedure for the Hydrocarbon Pore Volume Method

1. The average porosity, average water saturation, and net pay thickness were calculated for each well and for the reservoir.
2. The net-pay-thickness map of the Safsaf C reservoir was generated for use with the HPV method.
3. The HPV per 1 ft^2 of reservoir area was calculated for each well individually:

$$HPV = \left(1 * h_n * \overline{\emptyset} * (1 - S_{wi})\right) \quad (3)$$

4. The volume of the hydrocarbon in place (V_{hydr}) was calculated using equation (1).
5. The OIIP was calculated using the following equation (4)

$$OIIP\ (STB) = \frac{V_{hydr}}{5.615\ B_{oi}} \quad (4)$$

3.1.3 Procedure for the Pore Volume Method

1. The average porosity, average water saturation, and net pay thickness were calculated for each well and for the reservoir.
2. The iso-porosity, iso-water-saturation, and net-pay-thickness maps of the Safsaf C reservoir were generated.
3. A suitable grid was placed over the three iso maps, which covered the entire net-pay area.
4. The values for h_n, $\emptyset$ and S_{wi} were estimated for each grid square.
5. The initial volume (V_i) of each grid square was calculated using the following equation (5)

$$V_i = \left(h_n * \overline{\emptyset} * (1 - S_{wi})\right) * grid\ area \tag{5}$$

6. OIIP was calculated using the following equation (6)

$$OIIP\ (STB) = \frac{\sum V_i}{5.615\ B_{oi}} \tag{6}$$

3.2 Material Balance Calculations

The following data were prepared before the material balance calculations were completed using the Havelena and Odeh model.

- The cumulative production history of the reservoir; i.e. N_p, G_p, and W_p, as well as the cumulative injection data in case of injection projects; i.e. W_i and/or G_{inj}(Table 2).
- The history for average reservoir pressure (Table 2).
- Oil, gas, and water PVT data (Table 3).

The Havelena and Odeh model was built to estimate the OIIP of Safsaf C. The general form of the material balance equation is:

$$N = \frac{N_p\{B_t + (R_p - R_{si})B_g\} + W_p B_w - W_i B_w - G_i B_g - W_e}{(B_t - B_{ti}) + mB_{ti}\left(\frac{B_g}{B_{gi}} - 1\right) + (1+m)B_{ti}\left(\frac{c_f + c_w S_{wi}}{1 - S_{wi}}\right)\Delta_p} \tag{7}$$

Since the Safsaf C reservoir is above the bubble-point pressure, no water influx, and gas injection, the above equation can be written as follows:

$$N = \frac{N_p B_o + W_p B_w - W_i}{(B_o - B_{oi}) + B_{oi}\left[\frac{c_f + c_w S_{wi}}{1 - S_{wi}}\right]\Delta_p} \tag{8}$$

Table 2: Reservoir pressure and production history for Safsaf C

Date	Pressure psi	Cum. Oil MMSTB	Cum. Gas MMscf	Cum. WTR MMSTB	Cum.Gas MMscf	Cum WTR Inj. MMSTB
6/30/1990	3,080	0.0000	0.0000	0.0000	0	0.0000
8/31/1990	2,858	0.1952	353.97	0.0007	0	0.0000
1/31/1991	2,360	0.3007	547.31	0.0080	0	0.0000
5/31/1991	2,540	0.3201	579.49	0.0084	0	0.0000
8/31/1991	2,305	0.3451	619.80	0.0089	0	0.0000
11/30/1991	2,420	0.3717	683.64	0.0089	0	0.0000
2/29/1992	2,438	0.3998	736.53	0.0089	0	0.0000
9/30/1992	2,273	0.4961	918.87	0.0123	0	0.0256
11/30/1992	2,394	0.5330	966.80	0.0124	0	0.0553
4/30/1993	2,099	0.6242	1077.96	0.0137	0	0.1281
10/31/1993	2,135	0.6705	1224.84	0.0146	0	0.1877
8/31/1994	2,072	0.7941	1479.88	0.0192	0	0.4650
9/30/1995	2,030	1.0058	1892.91	0.0219	0	1.0479
11/30/1996	2,025	1.2665	2463.13	0.0368	0	1.6960
2/28/1997	2,044	1.3449	2602.38	0.0427	0	1.8583

Table 3: PVT data for Safsaf C

Pressure psi	Relative Volume of Oil and Gas, (v/v_{sat})	Viscosity of Oil, (cp) @ 202 °F	GOR (Liberated per Barrel of Residual Oil)	GOR (In Solution per Barrel of Residual Oil)	Oil FVF (Bbl/STB)
5,000	0.9063	0.32			3.080
4,490	0.9169	0.31			3.116
3,995	0.9291	0.31			3.157
3,519	0.9426	0.30			3.203
2,994	0.9595	0.29			3.260
2,200	0.9948	0.28			3.380
BP=2,108	**1.0000**	**0.27**	**0**	**3,231**	**3.398**
1,873	1.0963	0.28	506	2,725	3.064
1,503	1.3511	0.29	1,150	2,081	2.692
1,051	2.0108	0.31	1,694	1,537	2.354
627		0.34	2,138	1,093	2.079
203		0.37	2,738	493	1.659
15		0.82	3,231	0	1.075

From equation (8), the following equations can be written as:

$$F = N_p B_o + W_p B_w - W_i \tag{9}$$

$$E_o = B_o - B_{oi} \tag{10}$$

$$E_{f,w} = B_{oi}\left(\frac{c_f + c_w S_{wi}}{1 - S_{wi}}\right)\Delta_p \tag{11}$$

where F represent total production volume minus the total injected volume (bbls), E_o represents the expansion of oil and its originally dissolved gas (bbl/stb), and $E_{f,w}$ represents the expansion of the initial water and the reduction in the pore volume (bbl/stb).

To estimate the OIIP using the straight-line method of MBE, equations 9, 10, and 11 were then used to plot F versus E_o + $E_{f,w}$.

3.3 Production Forecasting via Decline Curve Analysis

Decline Curve Analysis was used to identify the decline type, the decline factor, and the initial decline rate, which were then used to determine the other evaluation parameters, including the total reserves, remaining reserves, and abandonment time.

The exponential decline formula was selected to represent or extrapolate the production data for the Safsaf C reservoir. The general form of the DCA is given in equation (12)

$$\frac{q}{dq/_{dt}} = -bt - \frac{1}{a_i} \tag{12}$$

where q is the production rate at any time, t represents the time from the start of production decline, a_i is a decline factor representing the initial rate of decline, and b is a reservoir constant that ranges between 0 and 1.0. For strong-water drive reservoirs, the value of b is generally very near to 0. In such situations, Equation (12) can be written in the following form, which is known as Exponential Decline.

$$\left(\frac{q}{dq/_{dt}}\right) = -\frac{1}{a_i} \tag{13}$$

Decline Curve Analysis was applied to production data from the Safsaf C reservoir. The production history was divided into two main periods:

- Period (1): from the 28th of February 2002, to the 31st of July 2007.
- Period (2): from the 30th of January 2008, to the 31st of May 2012.

IV. RESULTS AND DISCUSSION

4.1 Volumetric Methods Calculations

Table 4 shows the results for average porosity, average water saturation, and net pay thickness for each well. It also shows the contour intervals obtained using the volumetric methods.

Table 4: Average properties of the Safsaf C reservoir

Well #	Net Pay	Avg. Porosity	Avg. WTR Sat.	Isopach Map	Pore Vol. Map	H.C. Map	$\phi \times h$	$S_{wi} \times h$
	ft	%	%	ft-Interval	ft-Interval	ft-Interval		
C1	30.5	16.91	23.87	30.5	5.16	3.93	515.76	728.04
C2	27.0	19.15	48.65	27.0	5.17	2.66	517.05	1,313.55
C3	57.5	19.25	24.48	57.5	11.07	8.36	1,106.88	1,407.60
C4	2.5	15.41	50.70	2.5	0.39	0.19	38.53	126.75
C5	39.5	18.54	25.26	39.5	7.32	5.47	732.33	997.77
C6	35.0	16.32	20.87	35.0	5.71	4.52	571.20	730.45
Sum:	192.0	105.58	193.83				3,481.74	5,304.16

As Table 4 shows, the average porosity (18.3%) and average water saturation (27.63%) of the reservoir were calculated using the thickness-weight method.

4.1.1 Results for the Iso-Pach Method

Fig. 4 shows the iso-pach map of the Safsaf C reservoir built using *Surfer*. The productive area was estimated from the map using planimeter. Then, the net pay volume and OIIP were calculated (see Table 5).

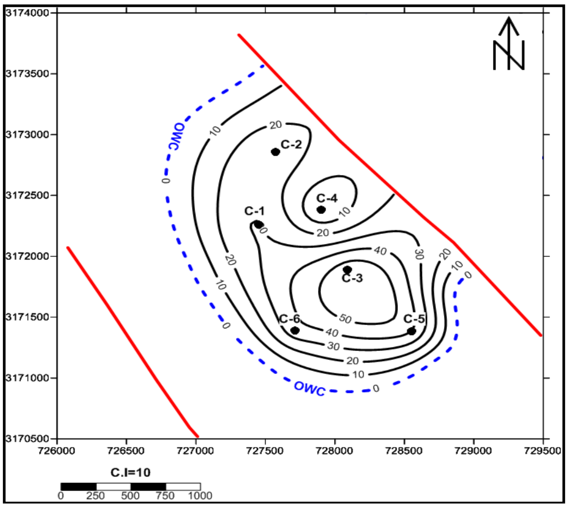

Fig. 4 Iso-pach map of the Safsaf C reservoir

Table 5: Calculations and results for the Iso-pach method

Productive Area	Planimeter Area, cm^2	Area, acre	Ratio of Areas, unitless	Interval (h), ft	Interval * Ratio	ΔV Acre-ft
A_0	93.50	1217.97	#	#	#	#
A_1	69.50	905.34	0.74	10.00	7.43	10,617
A_2	46.25	602.47	0.67	10.00	6.65	7,539
A_3	22.50	293.10	0.49	10.00	4.86	4,386
A_4	11.25	146.55	0.50	10.00	5.00	2,198
A_5	5.25	68.39	0.47	10.00	4.67	1,050
A_6	0.00	0.00	0.00	7.50	0.00	171
Sum				57.5		**V_f = 25,961**
OIIP = 11.59 MMSTB						

4.1.2 Results for the Hydrocarbon Pore Volume Method

Surfer was used to build a map for Hydrocarbon pore volume (Fig. 5). Then, the hydrocarbon pore volume was calculated for each separate well. Finally, total HPV and OIIP were calculated (Table 6).

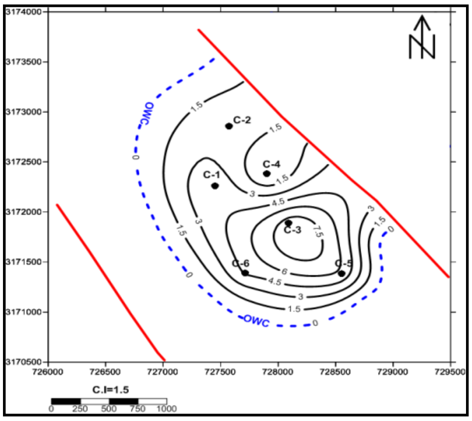

Fig. 5 Map of hydrocarbon pore volume for the Safsaf C reservoir

Table 6: Calculations and results for the map of Hydrocarbon pore volume

Productive Area	Planimeter Area, cm^2	Area, acre	Ratio of Areas, unitless	Interval (h), ft	Interval * Ratio	ΔV Acre-ft
A_0	93.50	1217.97	#	#	#	#
A_1	63.00	820.67	0.67	1.50	1.01	1,529
A_2	36.00	468.95	0.57	1.50	0.86	967
A_3	22.00	286.58	0.61	1.50	0.92	567
A_4	12.00	156.32	0.55	1.50	0.82	332
A_5	3.50	45.59	0.29	1.50	0.44	143
A_6	0.00	0.00	0.00	0.86	0.00	13
Sum				8.36		**V_{hydr} = 3,551**
OIIP = 12.08 MMSTB						

4.1.3 Results for the Pore Volume Method

As with the previous methods, *Surfer* was used to build maps for pore volume, iso-porosity, and iso-water saturation (Fig. 6, 7, and 8). The initial hydrocarbon volume for each grid square of the map for pole volume was calculated from that square's porosity, oil saturation, and thickness. Then, the total hydrocarbon volume and the OIIP were estimated (Table 7).

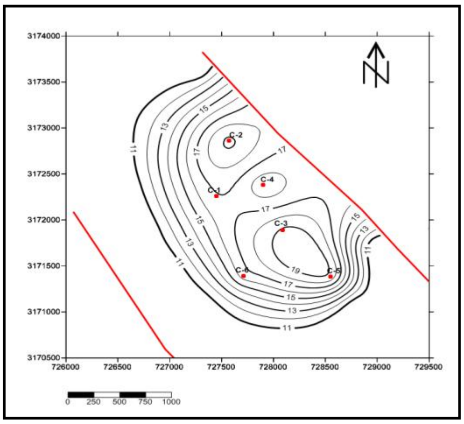

Fig. 6 Iso-porosity map of the Safsaf C reservoir

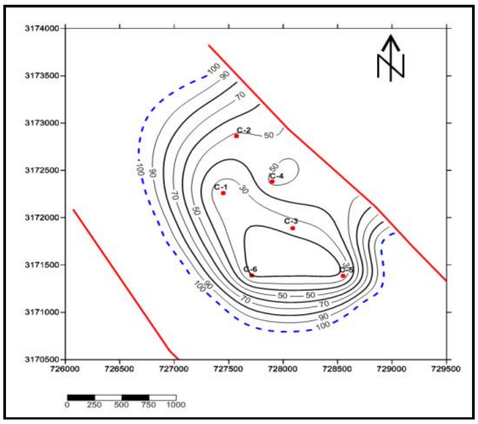

Fig. 7 Iso-water saturation map of the Safsaf C reservoir

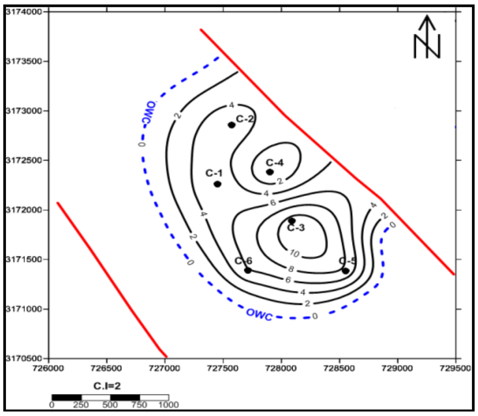

Fig. 8 Pore volume map of the Safsaf C reservoir

Table 7: Calculations and results for the Pore volume method

Productive Area	Planimeter Area, cm^2	Area, acre	Ratio of Areas, unitless	Interval (h), ft	Interval * Ratio	ΔV Acre-ft
A_0	93.50	1217.97	#	#	#	#
A_1	68.50	892.31	0.73	2.00	1.47	2,110
A_2	42.00	547.11	0.61	2.00	1.23	1,439
A_3	19.50	254.02	0.46	2.00	0.93	783
A_4	10.50	136.78	0.54	2.00	1.08	391
A_5	3.75	48.85	0.36	2.00	0.71	178
A_6	0.00	0.00	0.00	1.07	0.00	17
Sum				11.07		**V_i = 4,919**
OIIP = 12.11 MMSTB						

Although the three volumetric methods employed different calculations, the results revealed that the values they yielded for OIIP were almost identical, ranging between 11.59 and 12.11 MMSTB.

4.2 Results for Material Balance

The following results (shown in Table 8) were obtained by applying the straight-line formulation of the material balance equation and using the production history, pressure history, and PVT of Safsaf C.

Table 8: Results for material balance for the Safsaf C reservoir

Bo Bbl/STB	N MMSTB	F MMSTB	E_o Bbl/STB	$E_{f,w}$ Bbl/STB	$E_o + E_{f,w}$ Bbl/STB
2.72	0.00	0.00	0.00	0.0000	0.0000
2.75	19.19	0.54	0.0244	0.0037	0.0280
2.81	8.83	0.85	0.0849	0.0119	0.0967
2.79	12.70	0.90	0.0621	0.0089	0.0710
2.82	9.37	0.98	0.0920	0.0128	0.1048
2.80	11.94	1.05	0.0772	0.0109	0.0880
2.80	13.22	1.13	0.0749	0.0106	0.0854
2.82	12.67	1.39	0.0963	0.0133	0.1096
2.80	15.84	1.45	0.0805	0.0113	0.0918
2.84	12.23	1.66	0.1198	0.0162	0.1360
2.84	13.29	1.73	0.1148	0.0156	0.1304
2.85	12.98	1.82	0.1235	0.0166	0.1401
2.85	12.60	1.85	0.1294	0.0173	0.1467
2.85	13.30	1.96	0.1301	0.0174	0.1475
2.85	14.02	2.03	0.1274	0.0171	0.1445

The above data were plotted as shown in Fig. 9, and the OIIP of Safsaf C was found to be 12.71 MMSTB when the straight-line formulation of MBE was used.

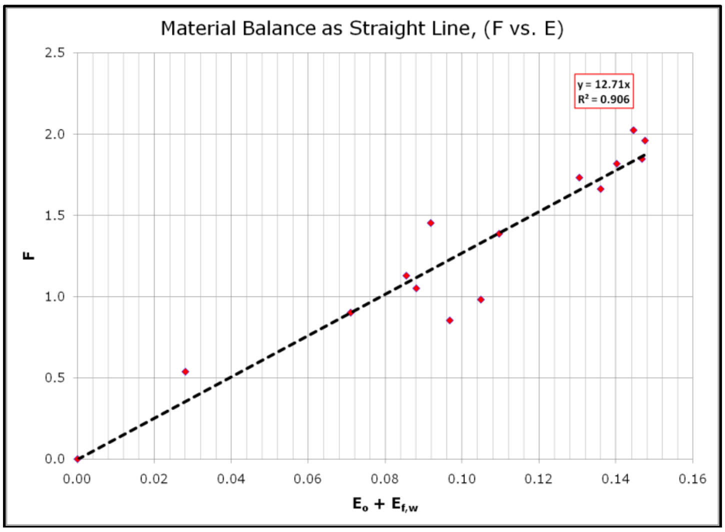

Fig. 9 OIIP of Safsaf C using the straight-line equation of MBE.

The following table 9 shows, the material balance equation and the three volumeric methods yielded OIIP values that were very nearly the same.

Table 9: A comparison of the OIIP results for the Safsaf C reservoir

No.	Method	OIIP (N), MMSTB
1.	Iso-pach	11.59
2.	Pore volume	12.11
3.	Hydrocarbon pore volume	12.08
4.	Material balance equation	12.71

4.3 Results for the Decline Curve Analysis

As explained above, Exponential Decline was applied to the production history of Safsaf C to estimate its total and remaining reserves. The analysis considered two distinct two periods.

The first period ranged from February 28th, 2002 to July 31st, 2007. Table 10 shows the results of the decline curve analysis for this period, and Fig. 10 shows the match between the production history and the data obtained by using exponential decline and the oil production forecast for the Safsaf C reservoir, which included a final rate of 40 BPD in January 2020.

Table 10: Results of the production decline analysis for the first period of the Safsaf C reservoir

Period	From	To
	2/28/2002	7/31/2007
# of Points	66	
b	0.00	
q_i, BPD	259	
a_i,1/year	0.1032144	
q cal. at end of Period, BPD	148	
Np at end of Period, BBL	2,574,314	
Assumed q_e, BPD	15	
Remaining Reserves, BBL	471,058	
Total Reserves, BBL	3,045,372	

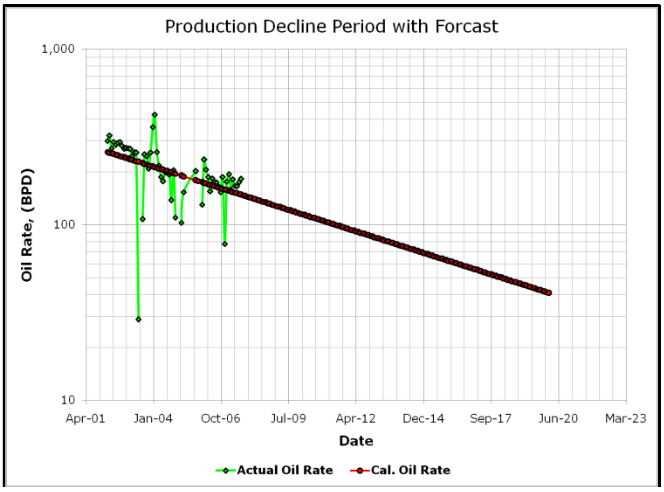

Fig. 10 The first-decline production period with forecast of the Safsaf C reservoir

The second period ranged from January 30th, 2008 to May 31st, 2012. Table 11 shows the results of the decline curve analysis, and Fig. 11 shows the production history matching the decline curve analysis calculations and the production forecast of the reservoir.

Table 11: Results of the production decline analysis for the second period of the Safsaf C reservoir

Period	From	To
	1/30/2008	5/31/2012
# of Points	47	
b	0	
q_i, BPD	247	
a_i,1/year	0.224533	
q cal. at end of Period, BPD	104	
Np at end of Period, BBL	2,910,758	
Assumed q_e, BPD	15	
Remaining Reserves, BBL	143,911	
Total Reserves, BBL	3,054,669	

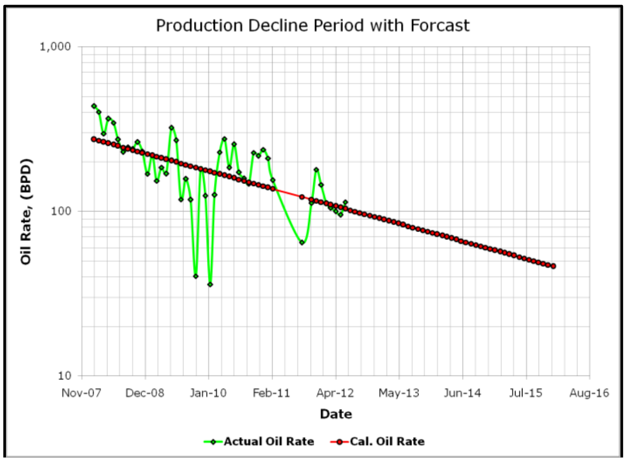

Fig. 11The second-decline production period and forecast of Safsaf C reservoir

To better interpret the production history of the Safsaf C reservoir, the first- and second-decline production periods were combined (Fig. 12) to show the calculations for the decline curve analysis. Doing so revealed that an increase in production occurred after the first-decline period due to workover operation of well C6 from September 2006 through December 2006. Although production increased at the beginning of the second period, the decline rate in the second period was higher than in the first period.

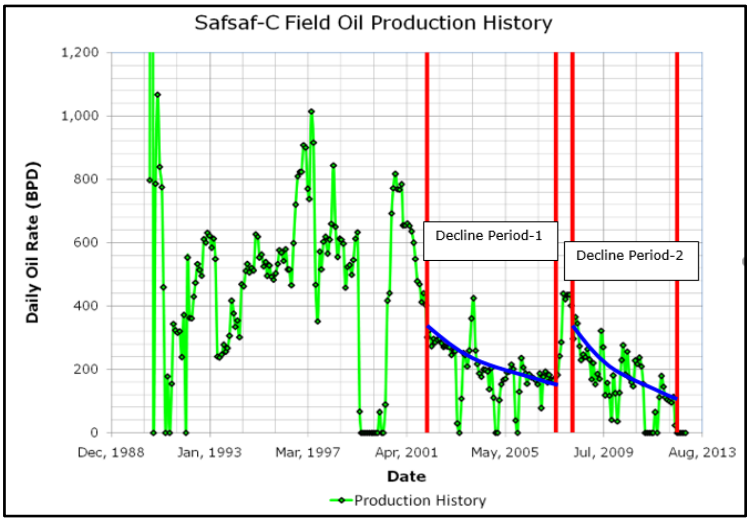

Fig. 12 Production history of Safsaf C and a decline curve analysis of both periods

V. CONCLUSIONS

The Safsaf C reservoir has been in production for more than twenty years and is volumetrically undersaturated. Significant drops in pressure have been detected, and water injection to maintain pressure was initiated as early as two years from the start of production. This study estimated the OIIP of Safsaf C using various volumetric methods and the straight-line formulation of the material balance equation. It also estimated the total and remaining reserves using the exponential method of decline curve analysis.

1. OIIP was estimated using volumetric methods that utilized Isopach, pore volume, and H.C. pore volume maps. The OIIP values ranged from 11.59 to 12.11 MMSTB.
2. OIIP was also estimated using the straight-line formulation of the material balance equation. The results were in good agreement with those of the volumetric methods: the value for OIIP was 12.71 MMSTB.
3. Total reserves were estimated using a normal Decline Curve Analysis, and the results showed a value 3.05 MMSTB.
4. The study revealed that the reservoir can be developed by using infill drilling and continuing water injection to maintain pressure.
5.

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