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Reserve and Oil Production Forecasting Evaluation: Case Study

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Abstract: The accurate information of oil and gas reserves is required for development of oil and gas field. Therefore, reserves need to be evaluated with increasing of data availability, especially, production and pressure. This research is intended to calculate the Original Oil in Place (OOIP) based on the latest data by using straight-line equation of material balance method. The result of reserve estimation is compared to the volumetric calculation. As part of the research, the type of drive mechanism is also analyzed, so that, the right material balance method can be selected to evaluate oil and gas reserve. The type of drive mechanism is evaluated by several methods such as by using the history production performance, drive index and Ganesh Thakur method. The result of Original Oil in Place (OOIP) calculation by using the material balance method is not too different with result of volumetric estimation. Furthermore, decline curve analysis method is used to estimate the base line of oil production. By assuming there is no change in a number of production wells and well completion, it can be estimated the maximum oil recoverable reserve and remaining reserve until the economic limit.

Key words: Reservoir, material balance method, drive mechanism, decline curve analysis, recoverable, reserve

INTRODUCTION

The S oil field is located in South Sumatra. The S field has divided into 2 clusters, S-C cluster and S-D cluster. S field was found in November 2000 and started in production in August 2003. The main oil reservoir in S field is Limestone of Baturaja formation. Because of the reservoir pressure is still high, so that, oil production can be done by natural flow method. There are 10 production wells in S-C cluster and 5 production wells in S-D cluster. 1 dry hole well in S-D field was plugged and abandoned.

As increasing the number of data, Original Oil in Place (OOIP) is needed to evaluate. At the first time of the field was found, the available data is very limited to geological information, so that, at this stage OOIP estimation is done by the volumetric method. At the development stage, generally the availabilities of reservoir, production and pressure data are quite a lot. In this stage OOIP estimation can be done with several methods. In this study, OOIP was estimated using straight-line equation of material balance method by Havlena and Odeh (1963, 1964). Furthermore, the decline curve analysis is used to estimate the production performance of oil in the future by using the rate of economic limit of 15 BOPD for each well.

MATERIALS AND METHODS

Drive mechanism: There are several methods can be used to determine the drive mechanism as follows:

History of production performance: Drive mechanism can be evaluated using the history of production performance data. Production performance is described in terms of relationship of oil production, pressure, solubility of gas (GOR) and water cut as a function of time. Based on the history production performance, the drive mechanism can be classified as follows.

Solution gas drive mechanism: The following is the characteristics of the solution gas drive:

- Rapid decline of oil production rate
- Reservoir pressure decline rapidly
- GOR increase rapidly and then decline
- No water production
- Recovery factor is about 8-20% of STOIP

The production performance of the solution gas drive is shown in Fig. 1.

Gas cap drive mechanism: The gas cap drive reservoir is characterized by the following production performance:

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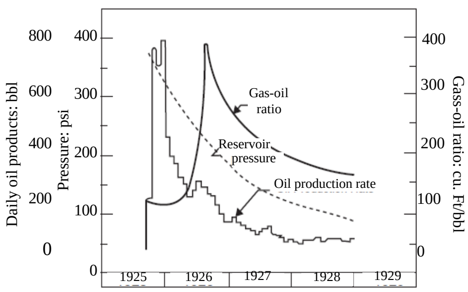

Fig. 1: Production performance of solution gas drive reservoir (Clark, 1969)

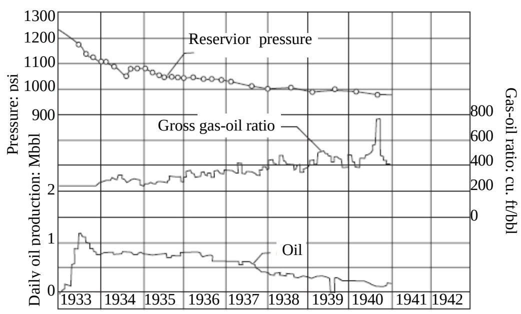

Fig. 2: Production performance of gas cap drive reservoir (Clark, 1969)

- Oil production rate decline with the pressure
- Reservoir pressure decline slowly
- As pressure decline, gas solutions evolved from crude oil and gas saturation continues to increase then the GOR increase rapidly
- Recovery factor is about 25-35% of STOIP

Reservoir performance of gas cap drive reservoir is shown on Fig. 2.

Water drive mechanism: The characteristics of the water drive reservoir are as follows:

- Usually the decline of pressure is very slowly because of the high influx rate of water from aquifer
- GOR is relatively constant or increase slowly
- Water production increase rapidly
- Recovery factor about 40-60% of STOIP

Figure 3 shown the production performance of water drive reservoir.

Combination drive mechanism: The characteristics of combination drives are as follows:

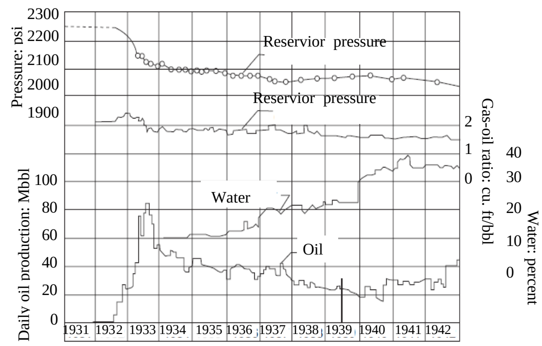

Fig. 3: Production performance of water drive reservoir (Clark, 1969)

- Decline of reservoir pressure is relatively small
- Water influx increases slowly in the bottom of the reservoir
- GOR of wells located in the up dip structure will increase rapidly due to the expansion of gas cap

Unfortunately, there is no example of graph of combination drive mechanism. The S field is characterized by this type of drive mechanism.

Drive index method: Drive index can be determined by modifying the material balance equation. The drive index is denoted by GDI, DDI and WDI as follows:

$$= \frac{\left(\;\; - \;\; \right)}{N\left[B\left(R - R\right)B\right]}$$

$$DDI = \frac{N\left(B_t - B_{ti}\right)}{N_p\left[B_o\left(R_p - R_s\right)B_g\right]}$$

$$WDI = \frac{N\left(W_e - B_w - W_p\right)}{N_p\left[B_o\left(R_p - R_s\right)B_g\right]}$$

$$GDI + DDI + WDI = 1$$

Where:

GDI = Gas cap Drive Index
DDI = Depletion Drive Index
WDI = Water Drive Index

The type of drive mechanism is identified from the dominant value of DDI, WDI and GDI. The sum of DDI, WDI and GDI is maximum equal to 1.

Material balance method: The general form of the material balance equation was first introduced by Schilthuis (1936). The material balance equation is arranged based on the simple logic and simple principles follow the law of material equilibrium in nature. The material equilibrium law stated that the amount of material after process will be equal to the initial amount material reduced by the amount of material produced by the process. In the oil and gas industry, the concept of material balance is widely used for:

- Estimation of Original Oil in Place (OOIP) and Original Gas in Place (OGIP)
- Water influx calculation
- Forecasting reservoir performance
- Determine the type of primary driving mechanisms and ultimate hydrocarbon recovery

OOIP estimation is done by the graphical method by using straight-line equation of material balance. The use of straight-line equation of material balance is depending on the type of primary driving mechanism of the reservoir. By assuming that there is no-pressure maintenance by gas or water injection, material balance equation can be simplified in the form of straight-line equation as presented by Havlena and Odeh (1963, 1964) as follows:

$$F = N\left[E_o + mE_g + E_{f,w}\right] + W_eB_w$$

The terms F, E_o, E_g and E_{fw} are defined by the following relationships:

- F = The underground withdrawal $F = N_p(B_o + (R_p - R_s)B_g) + B_wW_p$
- E_o = Oil and solution gas expansion $E_o = (B_o - B_{oi}) + (R_{si} - R_s)B_g$
- E_g = The gas cap expansion $E_g = B_{oi}(B_g/B_{gi} - 1)$
- E_{fw} = Connate water expansion and changing of hydrocarbon pore volume

$$E_{f,w} = (1+m)B_{oi}\left(\frac{C_wS_w + C_f}{1-S_w}\right)\Delta P$$

Havlena and Odeh rearranged the material balance equation into straight-line equation for several reservoir types as follows:

Solution gas drive mechanism: Assuming no water or gas injection, the material balance equation can be written as:

$$F = NE_t$$

A plot of underground withdrawal (F) versus Expansion total (E_t) should result a straight line through the origin with a slope equal to N.

Gas cap drive mechanism without water drive: By assuming natural water influx is negligible ($W_e = 0$), the material balance equation can be written as:

$$F = N\left(E_o + mE_g\right)$$

If, N and m are unknown, the equation above can be written as straight-line equation as follows:

$$\frac{F}{E_o} = N + mN\frac{E_g}{E_o}$$

If, F/E_o is plotted on the Y-axis and E_g/E_o on the X-axis there will be a straight line and the line will intersect the Y-axis. The intercept of the straight line on the Y-axis is proportional to N. While the slope of the straight line is proportional to mN.

Water drive mechanism without gas cap drive: For water drive reservoir without the initial gas cap and if the terms of $E_{f,w}$ is neglected. The straight-line equation of material balance can be expressed as:

$$\frac{F}{E_o} = N + \frac{W_e}{E_o}$$

If water influx is estimated using Van Everdingen and Hurst unsteady-state model, the above equation can be used for estimation of N and W_e simultaneously. The material balance equation then can be arranged as follows:

$$\frac{F}{E_o} = N + B\left(\frac{\sum \Delta pW_{eD}}{E_o}\right)$$

where, B is a water influx constant.

Decline curve analysis: Decline curves are one of the common methods usually used to predict future production performance. The use of the decline curve method is usually to estimate the maximum oil production (N_{pmax}), so that, the Recovery Factor (RF) and remaining reserve can be estimated. The assumptions and limitations in using the decline curve method are:

- There is no change in operating conditions during production such as changed of lifting method, flow line system and etc.,
- There is no change of well perforation and no work over on productive zone such as stimulation
- There is no change in a number of production well

In general, decline curve is a graphical plot of a production rate against time and rate against cumulative production. The method assumed that wells or reservoirs are produced on its capacity and the history of production is reflected of the reservoir productivity.

Exponential decline curve: Exponential decline curve is characterized by plot of oil rate and time in semilog will form a straight line. The following equations are used in the exponential decline curve analysis:

$$q = q_o e^{Dt}$$

$$D = \frac{\ln q_o - \ln q}{t}$$

$$t = \frac{Np}{q_o - q} \ln\left(\frac{q_o}{q}\right)$$

$$N_p = \frac{q_o - q_t}{D}$$

Where:

D = Cont. Decline rate
q_o = Initial production rate (BOPD)
q = Future production rate (BOPD)
t = Time
N_p = Cumulative oil production (STB)

Harmonic decline curve: The type of harmonic decline is rarely found in the oil field. The predicted results of oil production using this type of decline are usually too optimistic, so, rarely used for forecasting oil production. The harmonic decline is shown by the following equation:

$$D = \frac{dq/dt}{q}$$

$$q = q_i \left(1 + D_i t\right)^{-1/b}$$

$$Np = \frac{q_i}{D_i} \ln\left(\frac{q_i}{q}\right)$$

Where:

N_p = Cumulative oil production (STB)
q_i = Initial production rate (BOPD)
q = Future production rate (BOPD)
t = Time
b = Decline exponent represents curvature of curve

Hyperbolic decline curve: Hyperbolic decline curve is shown by the following equations:

$$q = q_i \left(1 + D_i bt\right)^{-1/b}$$

$$Np = \frac{q_i^{\,b}}{(1-b)D_i}\left(q_i^{1-b} - q^{1-b}\right)$$

Where:

D = Cont. Decline rate
q_i = Initial production rate at decline (BOPD)
q = Future production rate (BOPD)
b = The decline exponent represents the curvature of the curve. The value of b is between 0 until 1

RESULTS AND DISCUSSION

Drive mechanism analysis: The production performance analysis of S field is intended to determine the type of drive mechanism. The analysis is carried out by using plots of history production data of oil, pressure, gas solubility and water cut over the time. Figure 4 shows the production performance of the S-C cluster. Figure 4 shows that the decline in oil production followed by a rapidly rising of water cut. It is indicated that the water is rising quickly to the wellbore. The characteristic of history production performance indicates a water drive reservoir. It is supported by stable pressure history data during the well being produced. The stable GOR and the initial reservoir pressure lower than the bubble point pressure were indicated the presence of an initial gas cap. Thus, it can be concluded that the drive mechanism of the S-C cluster is dominated by a combination of drive mechanism.

The history production performance of the S-D cluster is shown in Fig. 5. Profile of history production performance of S-D cluster is similar to the S-C cluster. The rapid rises of water cut and stable decline of pressure are characteristics of the reservoir supported by water drive.

The identification of drive mechanism is also done by the drive index method. The drive index identification results are shown in Fig. 6 for S-C cluster and Fig. 7 for S-D clusters. Figure 6 shows that the S-C cluster at the beginning of production is dominated by the gas cap drive but furthermore, water drive becomes more dominant. While Fig. 7 indicates that the S-D cluster is dominated by water drive over the time period of production.

Original Oil in Place (OOIP) Estimation: In this study, the straight-line equation of material balance method of Havlena and Odeh is used for OOIP estimation. The

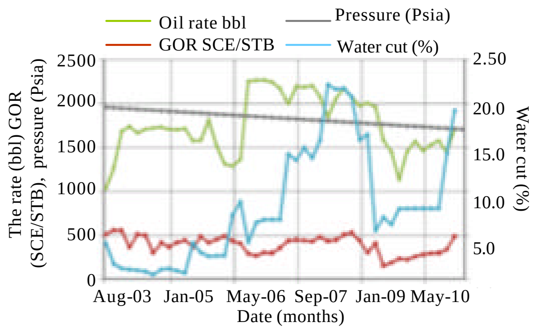

Fig. 4: History production performance of S-C cluster

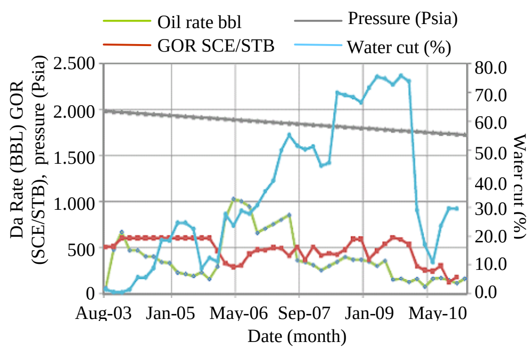

Fig. 5: History production performance of S-D cluster

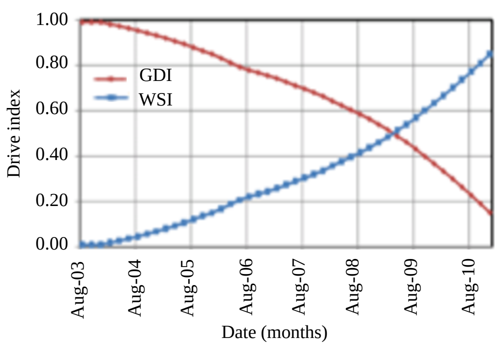

Fig. 6: Identification of drive mechanism using drive index method of S-C cluster

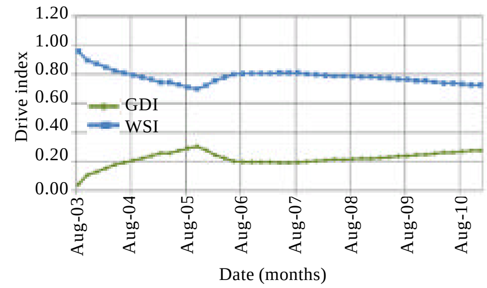

Fig. 7: Identification of drive mechanism using drive index method of S-D cluster

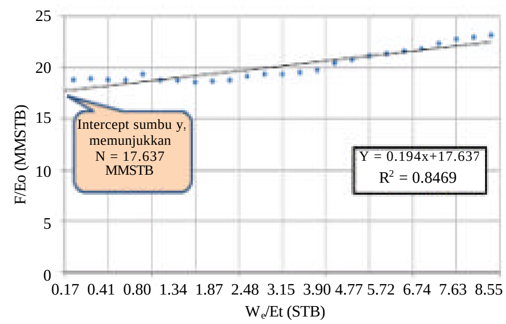

Fig. 8: Plot F/E_t and W_e/E_t of S-C cluster

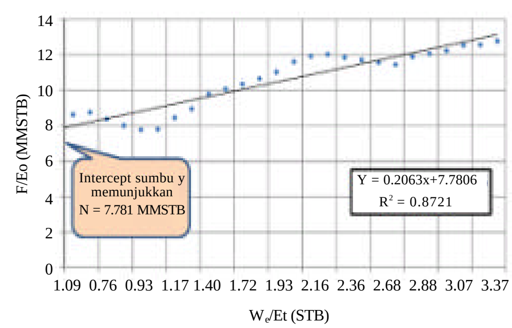

Fig. 9: Plot F/E_o and We/E_o of S-D Cluster

Table 1: The comparasion of OOIP of volumetric and material balance method of S-C cluster

Methods	S-C
(MMSTB)	
Volumetric	16.947
Material balance	17.637

Table 2: The comparasion of OOIP of volumetric and material balance method of S-D Cluster

Methods	S-D
(MMSTB)	
Volumetrik	4.271
Material balance	7.781

straight-line equation for water drive reservoir with initial gas cap is used for estimation of OOIP of cluster S-C while OOIP of S-D cluster is estimated using straight-line equation for water drive reservoir. The calculation result of underground fluid withdrawal (F), fluid expansion (E_o, E_g, $E_{f,w}$, E_t) is shown in Table 4 and 5 (attached). Water influx rate (W_e) is determined using the Van Everdingen and Hurst (1949). The results of the water influx calculation are shown in Table 5 and 6 (attached).

The plot of F/E_t vs. W_e/E_t will form a straight line where the intersection of the line with the Y axis represents the OOIP (Fig. 8 and 9). Using this method is obtained OOIP 17.637 MMSTB for S-C cluster and 7.781 MMSTB for S-D cluster. The comparison of an OOIP calculation results with the volumetric method is shown in Table 1 and 2.

Table 1 shows the difference of a calculation results by using both material balance and volumetric methods is not too large about 3%. But for the S-D cluster (Table 2) shows a large difference of calculation results of OOIP about 45%. The large difference of an estimation results of OOIP is supposed likely due to the limited of PVT data.

Forecasting oil production analysis: In this research, production forecasting in S field is done by using decline curve analysis method. Production forecasting is intended to estimate the amount of oil productions and the life time of production period until the economic limit rate. The decline rate (D) is determined based on the trend of production spanned from 2007-2008 (Fig. 10 and 11). The reason is that during the production period there is no change in the number of production wells and no work over. Based on the trend of history production data, the exponential decline curve method is used for prediction of oil production in S-C and S-D clusters.

The life time of production period of S-C cluster is about 24 years until August 2035 and ultimate oil recovery (Np_{max}) is 9.225 MMSTB (Fig. 12). Meanwhile, the life time of production period of S-D cluster is 20 years until February 2031 and ultimate oil recovery (Np_{max}) is 1.661 MSTB (Fig. 13).

Remaining reserve: Remaining reserve is calculated by subtracting the ultimate oil recovery (Np_{max}) with

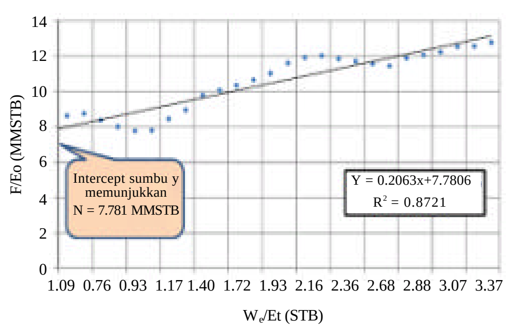

Fig. 10: Decline rate (D) estimation of S-C cluster

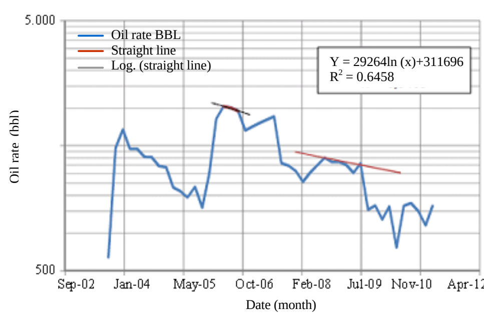

Fig. 11: Decline rate (D) estimation of S-D cluster

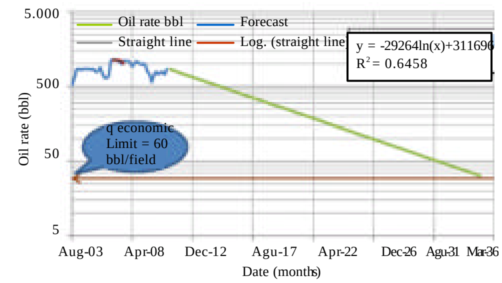

Fig. 12: Oil production forecasting of S-C cluster

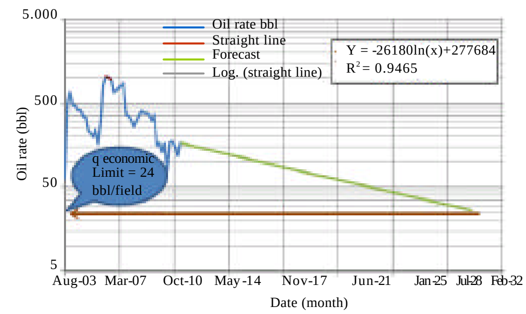

Fig. 13: Oil production forecasting of S-D cluster equation for water drive reservoir

Table 3: Calculation of havlena and odeh parameter S-C cluster

	Material balance havlena dan odeh parameters				
Date	F MMBBL	E_o BBL/STB	E_g BBL/STB	$E_{f,w}$ BBL/STB	E_t BBL/STB
Aug-03	0.0000	0.0000	0.0000	0.0000	0.0000
Oct-03	0.0762	0.0023	0.0039	0.0001	0.0062
Dec-03	0.1749	0.0060	0.0078	0.0001	0.0139
Feb-04	0.3057	0.0084	0.0118	0.0002	0.0204
Apr-04	0.4243	0.0107	0.0157	0.0002	0.0267
Jun-04	0.5447	0.0116	0.0197	0.0003	0.0316
Aug-04	0.6679	0.0123	0.0237	0.0004	0.0364
Oct-04	0.7796	0.0133	0.0278	0.0004	0.0415
Dec-04	0.8987	0.0141	0.0318	0.0005	0.0464
Feb-05	1.0218	0.0180	0.0360	0.0005	0.0546
Apr-05	1.1480	0.0205	0.0400	0.0006	0.0610
Jun-05	1.2805	0.0229	0.0441	0.0006	0.0677
Aug-05	1.3995	0.0254	0.0483	0.0007	0.0744
Oct-05	1.5245	0.0279	0.0525	0.0008	0.0811
Dec-05	1.6698	0.0287	0.0567	0.0008	0.0863
Feb-06	1.7757	0.0327	0.0610	0.0009	0.0946
Apr-06	1.8734	0.0338	0.0651	0.0009	0.0999
Jun-06	1.9839	0.0364	0.0694	0.0010	0.1068
Aug-06	2.0952	0.0374	0.0738	0.0011	0.1122
Oct-06	2.2355	0.0399	0.0781	0.0011	0.1191
Dec-06	2.3853	0.0408	0.0825	0.0012	0.1245
Feb-07	2.5487	0.0433	0.0870	0.0012	0.1315
Apr-07	2.7199	0.0480	0.0913	0.0013	0.1405
Jun-07	2.8838	0.0505	0.0957	0.0014	0.1476
Aug-07	3.0630	0.0533	0.1002	0.0014	0.1550
Oct-07	3.2483	0.0527	0.1047	0.0015	0.1589
Dec-07	3.4537	0.0554	0.1093	0.0015	0.1662
Feb-08	3.6526	0.0571	0.1139	0.0016	0.1726
Apr-08	3.8678	0.0609	0.1185	0.0016	0.1810
Jun-08	4.0707	0.0635	0.1231	0.0017	0.1883

Table 3: Continue

Date	F MMBBL	E_o BBL/STB	E_g BBL/STB	$E_{f,w}$ BBL/STB	E_t BBL/STB
	Material balance havlena dan odeh parameters				
Aug-08	4.2803	0.0664	0.1278	0.0018	0.1960
Oct-08	4.5099	0.0674	0.1325	0.0018	0.2017
Dec-08	4.7367	0.0687	0.1372	0.0019	0.2078
Feb-09	4.9481	0.0713	0.1421	0.0019	0.2153
Apr-09	5.1313	0.0726	0.1467	0.0020	0.2213
Jun-09	5.3334	0.0769	0.1515	0.0021	0.2305
Aug-09	5.4381	0.0799	0.1564	0.0021	0.2384
Oct-09	5.5247	0.0794	0.1613	0.0022	0.2429
Dec-09	5.6144	0.0807	0.1662	0.0022	0.2491
Feb-10	5.7251	0.0828	0.1712	0.0023	0.2564
Apr-10	5.8490	0.0851	0.1761	0.0024	0.2635
Jun-10	5.9703	0.0871	0.1811	0.0024	0.2706
Aug-10	6.0965	0.0892	0.1861	0.0025	0.2778
Oct-10	6.2495	0.0937	0.1912	0.0025	0.2875
Dec-10	6.3876	0.0965	0.1964	0.0026	0.2955
Feb-11	6.5946	0.1014	0.2016	0.0027	0.3056

Table 4: Calculation of havlena and odeh parameter S-D cluster

Date	F MMBBL	E_o BBL/STB	E_g BBL/STB	$E_{f,w}$ BBL/STB	E_t BBL/STB
	Material balance havlena dan odeh parameters				
Aug-03	0.0009	0.0000	0.0000	0.0000	0.0000
Oct-03	0.0527	0.0014	0.0041	0.0001	0.0056
Dec-03	0.1028	0.0063	0.0082	0.0001	0.0146
Feb-04	0.1467	0.0107	0.0123	0.0002	0.0232
Apr-04	0.1890	0.0155	0.0164	0.0002	0.0321
Jun-04	0.2273	0.0207	0.0206	0.0003	0.0415
Aug-04	0.2640	0.0253	0.0248	0.0003	0.0504
Oct-04	0.2987	0.0300	0.0290	0.0004	0.0594
Dec-04	0.3343	0.0349	0.0333	0.0004	0.0686
Feb-05	0.3605	0.0397	0.0376	0.0005	0.0778
Apr-05	0.3855	0.0447	0.0418	0.0005	0.0870
Jun-05	0.4078	0.0466	0.0461	0.0006	0.0933
Aug-05	0.4327	0.0517	0.0505	0.0007	0.1028
Oct-05	0.4542	0.0568	0.0548	0.0007	0.1123
Dec-05	0.4796	0.0617	0.0593	0.0008	0.1218
Feb-06	0.5202	0.0667	0.0638	0.0008	0.1313
Apr-06	0.6062	0.0718	0.0681	0.0009	0.1407
Jun-06	0.6905	0.0772	0.0726	0.0009	0.1508
Aug-06	0.7746	0.0791	0.0771	0.0010	0.1573
Oct-06	0.8485	0.0843	0.0817	0.0010	0.1670
Dec-06	0.9251	0.0895	0.0863	0.0011	0.1769
Feb-07	1.0111	0.0949	0.0910	0.0012	0.1871
Apr-07	1.1108	0.1008	0.0955	0.0012	0.1975
Jun-07	1.2313	0.1061	0.1002	0.0013	0.2075
Aug-07	1.3143	0.1103	0.1049	0.0013	0.2165
Oct-07	1.3685	0.1138	0.1096	0.0014	0.2248
Dec-07	1.4167	0.1195	0.1144	0.0014	0.2353
Feb-08	1.4606	0.1248	0.1193	0.0015	0.2455
Apr-08	1.5048	0.1301	0.1240	0.0015	0.2557
Jun-08	1.5543	0.1359	0.1289	0.0016	0.2664
Aug-08	1.6457	0.1384	0.1338	0.0016	0.2738
Oct-08	1.7369	0.1440	0.1388	0.0017	0.2845
Dec-08	1.8305	0.1498	0.1437	0.0018	0.2953
Feb-09	1.9050	0.1520	0.1488	0.0018	0.3026
Apr-09	1.9833	0.1580	0.1537	0.0019	0.3135
Jun-09	2.0886	0.1636	0.1588	0.0019	0.3243
Aug-09	2.1523	0.1693	0.1639	0.0020	0.3352
Oct-09	2.2033	0.1720	0.1691	0.0020	0.3431
Dec-09	2.2534	0.1778	0.1742	0.0021	0.3542

Table 4: Continue

Date	F MMBBL	E_o BBL/STB	E_g BBL/STB	$E_{f,w}$ BBL/STB	E_t BBL/STB
	Material balance havlena dan odeh parameters				
Feb-10	2.3018	0.1803	0.1796	0.0021	0.3620
Apr-10	2.3186	0.1863	0.1846	0.0022	0.3732
Jun-10	2.3354	0.1927	0.1899	0.0022	0.3848
Aug-10	2.3503	0.1952	0.1953	0.0023	0.3928
Oct-10	2.3697	0.2012	0.2006	0.0024	0.4042
Dec-10	2.3869	0.2077	0.2061	0.0024	0.4162
Feb-11	2.4012	0.2101	0.2116	0.0025	0.4242

Table 5: Water Influx Hurst-Van Everdingen S-C cluster

Date	P,psia	We MMBBL	Date	P,psia	We MMBBL
Aug-03	1967	-	Jun-07	1832	1.1269
Oct-03	1961	0.0011	Aug-07	1826	1.2617
Dec-03	1955	0.0037	Oct-07	1820	1.4064
Feb-04	1949	0.0083	Dec-07	1814	1.5615
Apr-04	1943	0.0154	Feb-08	1808	1.7273
Jun-04	1937	0.0254	Apr-08	1803	1.9041
Aug-04	1931	0.0387	Jun-08	1797	2.0921
Oct-04	1926	0.0556	Aug-08	1791	2.2918
Dec-04	1920	0.0766	Oct-08	1785	2.5034
Feb-05	1914	0.1021	Dec-08	1779	2.7277
Apr-05	1908	0.1324	Feb-09	1773	2.9645
Jun-05	1902	0.1678	Apr-09	1768	3.2139
Aug-05	1896	0.2088	Jun-09	1762	3.4765
Oct-05	1890	0.2558	Aug-09	1756	3.7526
Dec-05	1885	0.3090	Oct-09	1750	4.0425
Feb-06	1879	0.3688	Dec-09	1744	4.3467
Apr-06	1873	0.4356	Feb-10	1738	4.6653
Jun-06	1867	0.5096	Apr-10	1732	4.9986
Aug-06	1861	0.5914	Jun-10	1727	5.3471
Oct-06	1855	0.6811	Aug-10	1721	5.7109
Dec-06	1849	0.7792	Oct-10	1715	6.0904
Feb-07	1844	0.8860	Dec-10	1709	6.4860
Apr-07	1838	1.0018	Feb-11	1703	6.8979

Table 6: Water influx calculation using Hurst-Van Everdingen for S-D cluster

Date	P,psia	We MMBBL	Date	P,psia	We MMBBL
Aug-03	1975	-	Jun-07	1835	0.7263
Oct-03	1969	0.0007	Aug-07	1828	0.8138
Dec-03	1963	0.0023	Oct-07	1822	0.9077
Feb-04	1956	0.0052	Dec-07	1816	1.0085
Apr-04	1950	0.0097	Feb-08	1810	1.1163
Jun-04	1944	0.0160	Apr-08	1804	1.2313
Aug-04	1938	0.0244	Jun-08	1798	1.3537
Oct-04	1932	0.0352	Aug-08	1792	1.4837
Dec-04	1926	0.0486	Oct-08	1786	1.6216
Feb-05	1920	0.0648	Dec-08	1780	1.7678
Apr-05	1914	0.0842	Feb-09	1773	1.9223
Jun-05	1908	0.1069	Apr-09	1767	2.0851
Aug-05	1902	0.1332	Jun-09	1761	2.2566
Oct-05	1895	0.1633	Aug-09	1755	2.4370
Dec-05	1889	0.1975	Oct-09	1749	2.6265
Feb-06	1883	0.2360	Dec-09	1743	2.8254
Apr-06	1877	0.2791	Feb-10	1737	3.0338
Jun-06	1871	0.3269	Apr-10	1731	3.2520
Aug-06	1865	0.3796	Jun-10	1725	3.4802
Oct-06	1859	0.4376	Aug-10	1719	3.7186
Dec-06	1853	0.5011	Oct-10	1713	3.9673
Feb-07	1847	0.5702	Dec-10	1706	4.2266
Apr-07	1841	0.6452	Feb-11	1700	4.4968

Table 7: Calculation of F/Et and W_e/E_t S-C cluster

Date	P,psia	F/E_t MMSTB	W_e/E_t STB	Date	P,psia	F/E_t MMSTB	W_e/E_t STB
Aug-03	1967	-	-	Jun-07	1832	19.5348	15.4205
Oct-03	1961	12.2144	4.5366	Aug-07	1826	19.7650	15.6102
Dec-03	1955	12.5702	3.6485	Oct-07	1820	20.4468	16.5480
Feb-04	1949	14.9770	6.4523	Dec-07	1814	20.7800	16.7993
Apr-04	1943	15.8864	8.4444	Feb-08	1808	21.1614	17.1801
Jun-04	1937	17.2313	10.7395	Apr-08	1803	21.3648	17.1012
Aug-04	1931	18.3272	12.5553	Jun-08	1797	21.6151	17.2527
Oct-04	1926	18.7838	13.7891	Aug-08	1791	21.8413	17.3488
Dec-04	1920	19.3659	14.9188	Oct-08	1785	22.3555	17.8349
Feb-05	1914	18.7267	13.9621	Dec-08	1779	22.7896	18.2303
Apr-05	1908	18.8097	14.0175	Feb-09	1773	22.9800	18.3082
Jun-05	1902	18.9189	14.0261	Apr-09	1768	23.1919	18.5944
Aug-05	1896	18.8165	13.9512	Jun-09	1762	23.1379	18.3424
Oct-05	1890	18.7934	13.8000	Aug-09	1756	22.8146	18.1867
Dec-05	1885	19.3592	14.4248	Oct-09	1750	22.7496	18.3882
Feb-06	1879	18.7698	13.8812	Dec-09	1744	22.5349	18.2772
Apr-06	1873	18.7574	13.9662	Feb-10	1738	22.3314	18.1338
Jun-06	1867	18.5765	13.6381	Apr-10	1732	22.1984	18.0347
Aug-06	1861	18.6753	13.8438	Jun-10	1727	22.0632	17.9387
Oct-06	1855	18.7702	14.0645	Aug-10	1721	21.9430	17.8222
Dec-06	1849	19.1627	14.8764	Oct-10	1715	21.7379	17.4965
Feb-07	1844	19.3745	15.2481	Dec-10	1709	21.6169	17.3351
Apr-07	1838	19.3553	15.1608	Feb-11	1703	21.5759	17.0696

Table 8: Calculation of F/E_o and W_e/E_o S-D Cluster

Date	P,psia	F/E_o MMSTB	W_e/E_o STB	Date	P,psia	F/E_o MMSTB	W_e/E_o STB
Aug-03	1975	-	-	Jun-07	1835	5.9333	5.4326
Oct-03	1969	9.4804	10.7530	Aug-07	1828	6.0718	5.5749
Dec-03	1963	7.0402	6.9478	Oct-07	1822	6.0877	5.5754
Feb-04	1956	6.3276	6.0361	Dec-07	1816	6.0213	5.4823
Apr-04	1950	5.8886	5.3186	Feb-08	1810	5.9491	5.3959
Jun-04	1944	5.4737	4.7345	Apr-08	1804	5.8857	5.3092
Aug-04	1938	5.2356	4.4077	Jun-08	1798	5.8350	5.2280
Oct-04	1932	5.0286	4.1325	Aug-08	1792	6.0096	5.4139
Dec-04	1926	4.8720	3.9191	Oct-08	1786	6.1048	5.4843
Feb-05	1920	4.6338	3.6434	Dec-08	1780	6.1996	5.5522
Apr-05	1914	4.4304	3.4050	Feb-09	1773	6.2949	5.6429
Jun-05	1908	4.3712	3.3598	Apr-09	1767	6.3257	5.6600
Aug-05	1902	4.2101	3.1710	Jun-09	1761	6.4402	5.7339
Oct-05	1895	4.0430	2.9803	Aug-09	1755	6.4211	5.6866
Dec-05	1889	3.9392	2.8560	Oct-09	1749	6.4209	5.6685
Feb-06	1883	3.9613	3.0434	Dec-09	1743	6.3624	5.5808
Apr-06	1877	4.3073	3.5806	Feb-10	1737	6.3591	5.5724
Jun-06	1871	4.5802	3.9885	Apr-10	1731	6.2134	5.4146
Aug-06	1865	4.9254	4.4662	Jun-10	1725	6.0685	5.2596
Oct-06	1859	5.0798	4.6522	Aug-10	1719	5.9841	5.1854
Dec-06	1853	5.2308	4.7837	Oct-10	1713	5.8626	5.0563
Feb-07	1847	5.4055	4.9395	Dec-10	1706	5.7357	4.9218
Apr-07	1841	5.6249	5.1208	Feb-11	1700	5.6604	4.8617

cumulative oil production (N_p). The Remaining Reserve (RR) for S-C cluster is 4.4 MMSTB while S-D cluster is 532 MSTB.

CONCLUSION

Evaluation of oil reserves and oil production forecasting has been made for S-C and S-D cluster of S field: The estimation of drive mechanism using history of production performance and drive index method shows the combination drive for S-C cluster and water drive for S-D cluster. The estimation result of Original Oil in Place (OOIP) by using straight-line equation of material balance method is 17.637 MMSTB for S-C cluster and 7.781 MMSTB for S-D cluster.

The large difference in OOIP from volumetric calculation and material balance method for S-D cluster is highly due to limited of PVT data. The value of RF for S-C cluster is 54% and S-D cluster is 39%. Using decline curve analysis is obtained the life time of the production period is 24 years for S-C cluster, and incremental oil production is 4.396 MMSTB.

Meanwhile, the life time of the production period of S-D cluster is 20 years and incremental oil production is 532 MSTB. The type of decline curve of S-C and S-D cluster is exponential as indicated from history production performance.

List of symbols:

B_o = Oil formation volume factor (bbl/STB)
B_{oi} = Oil formation volume factor at initial pressure (bbl/STB)
B_g = Gas formation volume factor (bbl/SCF)
B_{gi} = Gas formation volume factor at initial pressure (bbl/SCF)
B_w = Water formation volume factor (bbl/STB)
OOIP = Original Oil in Place (STB)
W_e = Cumulative of water influx (bbl)
N_p = Cumulative of oil production (STB)
W_p = Cumulative of water production (STB)
G_p = Cumulative of gas production (SCF)
F = Underground withdrawal (bbl)
E_o = Oil and solution gas expansion (bbl/STB)
E_g = Gas cap expansion (bbl/STB)
T = Time (days)
D = Decline rate constant
Q_i = Initial production rate (BOPD)
Q_o = Oil production rate (bbl)
Q_w = Water production rate (bbl)
Q_g = Gas production rate (SCF)
RF = Recovery factor (%)
Np_{max} = Maximum cumulative production (STB)

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