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Water Injection Performance Calculations in Intisar 103A Oil Field, Libya

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Abstract

Using pressure and production records, formation properties and bottom-hole sample data, the performance of a Libyan oil reservoir (103A Intisar) was studied analytically to define and evaluate the natural forces acting on and within the reservoir. Use is made of material-balance method, the equations for natural water influx and MBAL, PVTP software to estimate the reserves. The reservoir pressure is an available data included in the production history data obtained from the operator company to indicate the reservoir performance. According to the reservoir behaviour studies, some assumptions were made and the calculations started depending on those assumptions. Then the results had been obtained such as the oil initial in place and the values of the water influx, and the recovery factor of the produced oil, and the indexes of the drive forces acting on and within the reservoir. These results helped to indicate the performance of the reservoir.

Keywords: Water; injection; performance; calculations; oil; reservoir.

1. Introduction

Petroleum is a complex mixture of hydrocarbons occurs underground in a geological structure (trap), which consists of an impermeable cap rock that prevents the fluid from going any farther, and a porous and permeable rock below that contains the fluid.
Petroleum is useful in supplying many of energy and chemical needs, 90% of chemicals used in the industry are made from petroleum, and more than the world half energy needs are supplied by it. Because of the international increase in petroleum demand, more wells are needed to be drilled. Petroleum is usually forced into the wellbore by the pressure of underground water (aquifer) that occurs below the hydrocarbon zone, after a period of production the underground water will lose some of its energy causing a decline phase in production, which is a problem needed to be handled.
The case study was about how to indicate the reservoir performance of the 103A, Intisar oil field which is included in the concession 103 located on Agedabia Trough, in the Eastern Sirte Basin.
It contains an estimated 4.1 billion barrels of original oil in place (OOIP), and has produced 2.2 billion barrels of oil to date. There are five reefal fields in Concession 103, approximately 80% of the oil discovered in 103A and 103D fields. For the whole 103A Field, fifty-eight wells have been drilled. Most of the wells were drilled in the late 1960's to early 1970's.
The 103A oil reservoir is considered as a weak water drive oil reservoir, after a brief period of production, the reservoir pressure is exposed to a sharp decline, this sharp decline made the reservoir management group of the field decided to put the reservoir on a pressure maintenance process (water injection) to increase reservoir pressure.
This pressure maintenance process made a big change on the bubble point pressure, after the process been started than the one before the pro-

cess. Samples had been taken for the PVT analysis to determine bubble point pressures and the other reservoir properties in each period in the late 1960's and the others ware in the middle 1970's.
Due to the big change in the bubble point pressure, the behavior of the 103A oil reservoir is split in two different behaviors; each one is acting with a different bubble point pressure. The first behavior is represented by the date before the pressure maintenance process starts effecting the reservoir pressure; this is where the first samples had been taken. The second behavior is represented by the date where the pressure maintenance process starts effecting the reservoir pressure and it starts increasing, this is where the second samples had been taken.

2. Material and Methods

PVT and production data was obtained as raw data from the operator and proceed using two different ways of calculations, which will be discussed in details with results in this paper as following.

2.1. Material Balance Equation and Water Influx Model Calculations Using Microsoft Excel Software

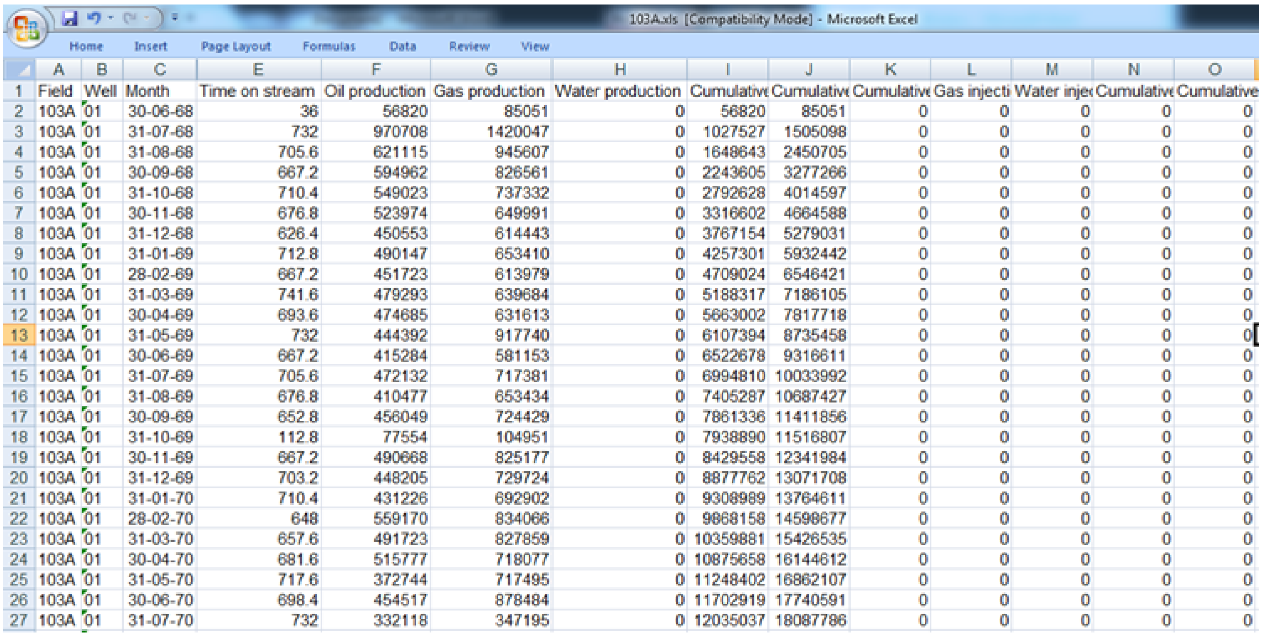
Microsoft Excel which is very functional software in long and repeated calculations is used for MBE model, and gave accurate results. See Figure 2.1.
The calculations of the 103A oil reservoir performance using this method went through a number of steps:

1. 1. Indicating the classification of the reservoir.
2. Estimating the Oil Initial in Place (OIIP) of the reservoir in (STB).
3. Calculating the water influx (We) from the aquifer to the oil reservoir .
4. Calculating the recovery factor (RF) of the produced oil in percentage of the oil initial in place in each specific date of oil production.
5. Calculating the drive indexes of each drive mechanism acting with the reservoir energy.
6. Calculating the water influx (We) Using water influx models.

3. Results and Discussion

3.1. 3.1 Indicating the Classification of the Reservoir

The first step of calculations to indicate the performance of the 103A oil reservoir was to identify the classification of the reservoir. Is it a volumetric reservoir or a reservoir with an open boundary? If it is an open boundary reservoir, does it interconnect with any type of water supporting? If yes, then which type of water supporting is it? Does the reservoir has a primary gas cap in place is there any secondary gas cap generated while production duration or it is mainly oil and dissolved gas in the reservoir?
The calculations to indicate the classification of the reservoir are went through out some assumptions.
Because there was not enough data except the reservoir production history, in the beginning, it was not possible to use the MBE method to classify the reservoir. But after studying the reservoir pressure (Pr) with time; Figure 2.1, and according to the pressure sharp decline in the early stage of production and to the cumulative water production (Wp) in the production history of the reservoir. It has been decided that if there is any water support in contact with the reservoir it would be an weak water support, where the aquifer has not mentioned affection on the reservoir pressure; it can be assumed that the reservoir is behaving as a volumetric oil reservoir. This assumption will act mainly on the period before the pressure maintenance process starts affecting the reservoir pressure and the pressure starts increasing.
The second question was if the reservoir has any primary gas cap? This question was answered after the initial bubble point pressure (Pbi) of the reservoir was inspected and compared with the initial reservoir pressure (Pri).It has been found that the Pbi equals 3,240 psi and the Pri equals 4,547 psi, which means that the Pri is greater than Pbi; which allows no dissolved gas to come out of solution to generate a primary gas cap.
And about the secondary gas cap, it can be detected by plotting the cumulative produced gas oil ratio (Rp) of the reservoir with time, Figure 3.2, it has been found that the solution gas has no chance to reaches the critical gas saturation and turns in to free gas.



	A	B	C	E	F	G	H	I	J	K	L	M	N	O
1	Field	Well	Month	Time on stream	Oil production	Gas production	Water production	Cumulative	Cumulative	Cumulative	Gas injecti	Water injec	Cumulative	Cumulative
2	103A	01	30-06-68	36	56820	85051	0	56820	85051	0	0	0	0	0
3	103A	01	31-07-68	732	970708	1420047	0	1027527	1505098	0	0	0	0	0
4	103A	01	31-08-68	705.6	621115	945607	0	1648643	2450705	0	0	0	0	0
5	103A	01	30-09-68	667.2	594962	826561	0	2243605	3277266	0	0	0	0	0
6	103A	01	31-10-68	710.4	549023	737332	0	2792628	4014597	0	0	0	0	0
7	103A	01	30-11-68	676.8	523974	649991	0	3316602	4664588	0	0	0	0	0
8	103A	01	31-12-68	626.4	450553	614443	0	3767154	5279031	0	0	0	0	0
9	103A	01	31-01-69	712.8	490147	653410	0	4257301	5932442	0	0	0	0	0
10	103A	01	28-02-69	667.2	451723	613979	0	4709024	6546421	0	0	0	0	0
11	103A	01	31-03-69	741.6	479293	639684	0	5188317	7186105	0	0	0	0	0
12	103A	01	30-04-69	693.6	474685	631613	0	5663002	7817718	0	0	0	0	0
13	103A	01	31-05-69	732	444392	917740	0	6107394	8735458	0	0	0	0	0
14	103A	01	30-06-69	667.2	415284	581153	0	6522678	9316611	0	0	0	0	0
15	103A	01	31-07-69	705.6	472132	717381	0	6994810	10033992	0	0	0	0	0
16	103A	01	31-08-69	676.8	410477	653434	0	7405287	10687427	0	0	0	0	0
17	103A	01	30-09-69	652.8	456049	724429	0	7861336	11411856	0	0	0	0	0
18	103A	01	31-10-69	112.8	77554	104951	0	7938890	11516807	0	0	0	0	0
19	103A	01	30-11-69	667.2	490668	825177	0	8429558	12341984	0	0	0	0	0
20	103A	01	31-12-69	703.2	448205	729724	0	8877762	13071708	0	0	0	0	0
21	103A	01	31-01-70	710.4	431226	692902	0	9308989	13764611	0	0	0	0	0
22	103A	01	28-02-70	648	559170	834066	0	9868158	14598677	0	0	0	0	0
23	103A	01	31-03-70	657.6	491723	827859	0	10359881	15426535	0	0	0	0	0
24	103A	01	30-04-70	681.6	515777	718077	0	10875658	16144612	0	0	0	0	0
25	103A	01	31-05-70	717.6	372744	717495	0	11248402	16862107	0	0	0	0	0
26	103A	01	30-06-70	698.4	454517	878484	0	11702919	17740591	0	0	0	0	0
27	103A	01	31-07-70	732	332118	347195	0	12035037	18087786	0	0	0	0	0

Figure 2.1: Screenshot for excel software

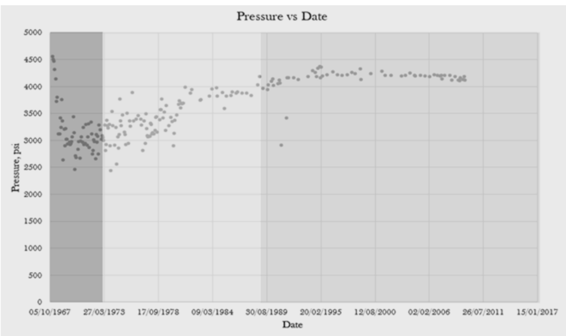


Figure 3.1: Reservoir pressure history and pressure identification of changing periods

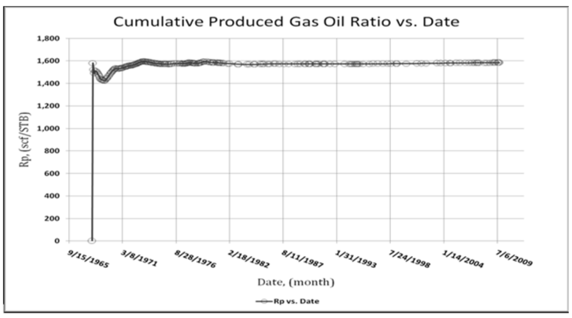


Figure 3.2: Cumulative produced gas oil ratio

According to that assumption and these studies, it could be assumed that103A reservoir is a volumetric under-saturated oil reservoir with no primary or secondary gas cap for the period before the pressure maintenance process is start affecting the reservoir pressure and the pressure is start increasing, and continue calculations according to these assumptions.

3.1.1. Estimating the Oil Initial in Place (OIIP)

In this objective the reservoir production history were the point of start to the calculations for estimating the oil initial in place of the case study. To be qualified to use the MBE method, first some properties and parameters obtain must be obtained, which must be used in the calculations such as: Pb, Bo, R.V, Rs . . . etc.
These data of properties is been measured and recorded in the company PVT analysis reports by CCE Separator and Diff. testes, the testes have been made on 5 different wells in the reservoir during different dates:
All the PVT data of each well have been studied separately as a function of the test pressure. Then the PVT data of all the wells have been studied together as a function of the test pressure. After studying the tests properties of all wells together.

Table 3.1: Represent the different wells during different dates

Well name	Sample date
A03	Dec.1967
A16	May.1968
A19	Aug.1968
A28	Mar.1976
A38	Nov.1977
A03	Mar.1978

Table 3.2: Represent the best properties two wells

Well name	Sample date
A03	Dec.1967
A28	Mar.1976

It has been perceived that each three wells are having a similar behavior according to the PVT testing time (the 1960‘s and the 1970‘s) [Figure 3.3]; so each three wells from the same time has been studied together as a function of the test pressure. It has been observed that there is a well which characterized by the best properties behavior such as the viscosity (μo) according to the highest Pb. These wells are:
The properties of these two wells will represent the properties of the whole reservoir. Well A03 represents the period from the start of production to 1975 where the pressure maintenance process is not effecting the Pr. And well A28 represents the period from 1976 to 2009. The time when the well A28 starts representing the reservoir properties is the time where the pressure maintenance process starts effecting the reservoir pressure and the pressure starts increasing.

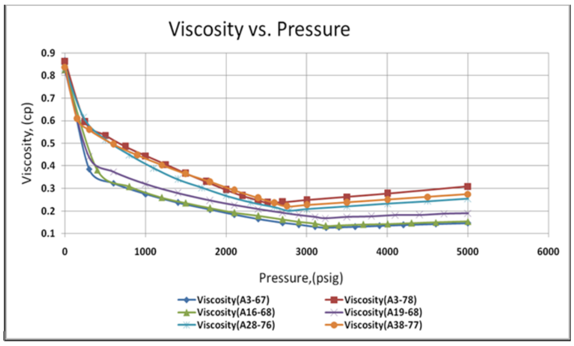


Figure 3.3: Oil viscosities for all wells

After obtaining the wells that may represent the reservoir properties in the two different periods, the properties must be converted as a function of the Pr.
This can be done by extracting function of pressure equations for each property needed from the data obtained by the testes measured on the selected wells depending on the time of each well, these extracted equations now will represent the properties needed in the calculations for each pressure in the reservoir.
After these properties has been obtained they must be adjusted to the separator condition to clear off the volume of the gas that going to liberated up in the stock tank from the material balance calculations, the adjustment is done by following the same extracting equations procedure which in previous.
Before continuing the OIIP calculations, first it must be mentioned that some of the cumulative water injection (Winj) data in production history are missing at the early stage of injection process. And to obtain these data then previous data have to be a simulated to the data available with injection date. Extracting a function of injection date equation will represent the missing Winj data, this will also provide a simulated initial date of starting injecting water in to the aquifer.
Now after the missing data and the properties have been obtained and adjusted, the calculations of the OIIP estimation can be continued.
For estimating the value of the OIIP in (STB) using the MBE methods, it has been decided to use the MBE as an Equation of a Straight Line. These calculations are only applicable in the period before the pressure maintenance process starts effecting the Pr, the period were the reservoir is acting as an under-saturated volumetric oil reservoir was assumed.
The calculations has been continued by calculating the expansion of oil and its originally dissolved gas (Eo), followed by calculating the expansion of the initial water and the reduction in the pore volume (Ef.w), and the calculations of the underground withdrawal (F).
And after the all parts of parameters have been calculated, now it can made sure if the assumptions about the reservoir were right.
To check this, Havlena and Odeh method were used for identifying the classification of the reservoir.

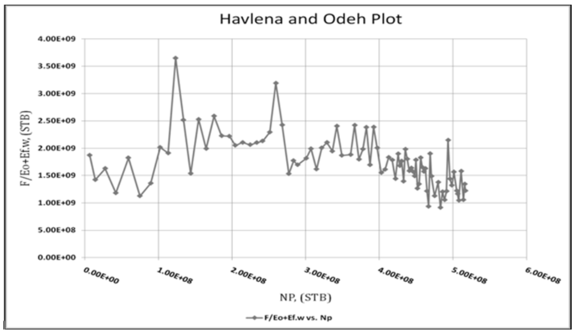


Figure 3.4: Reservoir classification method

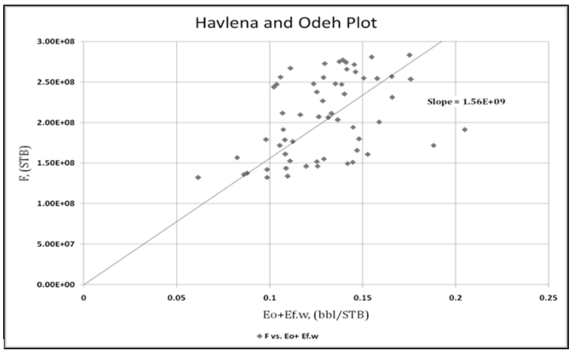


Figure 3.5: OIIP estimation

After plotting the results Figure 3.4, it is decided that is assumptions about the case study reservoir were correct with a high percentage of positive probability.
The estimation of the OIIP now can be done by using the Havlena and Odeh straight line material balance solution method by plotting the $F vs. Eo + Ef.w$ and the best fitting of the plotted data with the slope of it will represent the value of the OIIP (STB).
After calculating the slope, the OIIP value of the case study resulted to be 1.56 MMMSTB, this result came after canceling the dates with the missing Winj out of calculations Figure 3.5, and by using the simulated data of the Winj the previous plot shows that the OIIP value is resulted to be 1.68 MMMSTB.
Finally, it has been decided the OIIP for this case study is 1.56 MMMSTB.

3.1.2. Calculating The Water Influxes (We) in to The Oil Reservoir in (bbl)

The calculations of the We using the material balance method in the two parts behavior of the case study is acting with the same of We formulations in each part, because according to the Pb for each part the two parts behavior are making the reservoir acting as an under-saturated oil reservoir.
But it must be noted that the properties parameters of each part behavior have been taken from different sources (A03),(A28), according to the behavior, time and the big change in Pb as have been mentioned previously.
The calculations of We using material balance method have been made by using of, where the m = zero, since the reservoir is under-saturated.
According to these calculation it is perceived that most of the water influx's from the aquifer in to the reservoir is came from the water injected into the aquifer and it has the most of the affection on the Pr , And the natural water influx's from the aquifer is not mentioned.

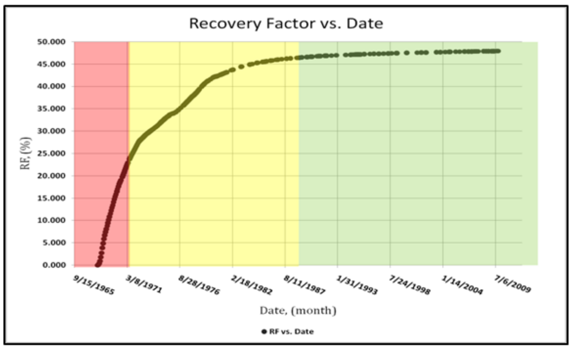


Figure 3.6: Recovery factor

3.1.3. Calculating The Recovery Factor (RF) of The Produced Oil in Percentage of The Oil Initial in Place in Each Specific Date of Oil Production

The calculations of the RF is been done by dividing the cumulative produced oil NP, by the oil initial in place in each date of the production history, Figure 3.6.
After these calculations, it has been perceived that 34% of the oil had been produced in the first part of the reservoir behavior before the pressure is start increasing, and there was a 14% of oil had been produced from a 48% of total RF had been produced to the last of the available production history.

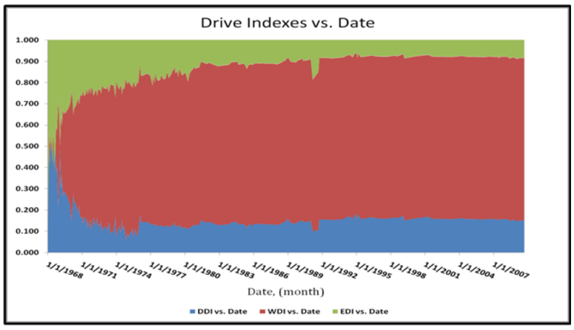


Figure 3.7: Drive indexes

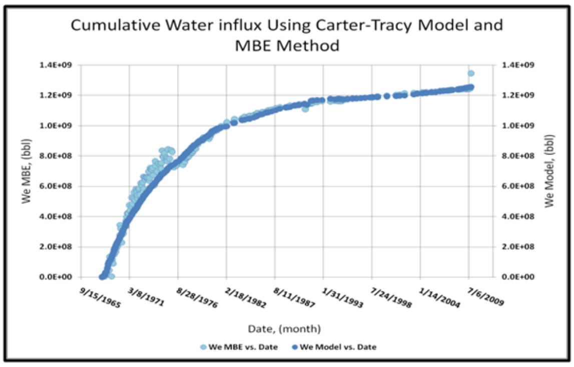


Figure 3.8: We from Carter-Tracy unsteady state model with We from material balance calculations

3.1.4. Calculating The Drive Indexes of Each Drive Mechanism Acting on The Reservoir Energy

There are three types of drive indexes is acting on reservoir energy, Figure 3.7:

1. Depletion Drive Index (DDI): this drive index has been calculated, and it shows that the depletion drive mechanism action on the reservoir productivity was so small and all of it is affecting before the Water drive starts affecting on the reservoir productivity.

2. Water Drive Index (WDI): this drive index has been calculated, it shows that the affection on the reservoir productivity was almost from the water drive mechanism.

3. Expansion Drive Index (EDI): this drive index has been calculated as EDI= 1-WDI-DDI, it shows that the expansion drive index has a not mentioned affection on the reservoir productivity.

3.1.5. Calculating the Water Influx We Using Water Influx Model

The purpose of this step is to identify if the water influx, which have been calculated by the material balance method is a steady sate or semi-steady stat or an unsteady state water influx.
It has been done by calculating different types of water influx models using data about the case study aquifer, then compare the calculated models results with the results of the water influx, which have been calculated by the martial balance method.
In the end of the calculated results comparatives, a water influx model with results which matching the results of water influx has been obtained, which have been calculated by the material balance method.
This mentioned water influx model was Carter-Tracy unsteady-state model.
This model results, are matching the results of water influx, which have been calculated by the material balance method with a high degree of accuracy, Figure 3.8.
In the end of this step, it has been decided that the water influx of the case study is an unsteady-state water influx model.

3.2. PVTP Computer Software

This computer software has been used as a method to extract an Equation of Sate that the program will use as a reference to calculate the reservoir PVT properties as a function of pressure.
To start using the extracted EOS for calculating the PVT properties, firstly the EOS must be calibrated to the real PVT analysis data of the selected two wells in the reports, which have been mentioned previously.
This EOS extracting is occurs by inputting the PVT reports data for the wells that representing the oil reservoir behavior in the PVTP software, each well data will be represented by a different EOS, the data is inputted in the software in two different PVT tests CCE and DIFF test.
After extracting the EOS, the calibration can be done by matching the EOS results data with the inputted reports data, and after a good match between the data has been found, the EOS now can be used for any point of the reservoir pressure.
In the case study, two EOSs must be extracted, each EOS is working with a different part of the reservoir behavior:

"Peng Robinson" EOS: working with the first part of the reservoir behavior when before the Pr is start increasing.
"Soave-Redlich-Kwong" EOS: working with the second part of the reservoir behavior when after the Pr is start increasing.
The usage of these two EOS is to export a black oil table, which is going to be used in the MBAL computer software to indicate the reservoir performance.

3.3. MBAL Computer Software

The results of this computer software will allow us to indicate the reservoir performance. The first step in this software is to adjust the software to use material balance calculations, then prepare the reservoir model in the software by choosing the type of the reservoir fluid and input the PVT data and the other properties of the reservoir such as the production history of the reservoir.
In this case study, oil is chosen as the type of the reservoir fluid. The black oil tables that are exported from the PVTP computer software are imported, to represent the PVT data for the case study calculations in the MBAL software.
Then Carter-Tracy unsteady-state model are selected to represent the water influxes in to the reservoir, and production data of the reservoir in to the software has been inputted, by this step, the reservoir model is ready for data matching.
After the inputted data has been matched, the software will estimate the OIIP and drive mechanisms for the reservoir model that is represent the case study. The software is estimated 1.52 MMMSTB of oil initially in place for the case study, and gave a schematic indication for the drive mechanisms effecting the reservoir, which shows that the water drive has the biggest part of it , Figure 3.9.
For the final step to indicate the reservoir performance, the software was ordered to run a simulation of the matched data.
This order will allow the software to simulate different types of results that allowed us to indicate the reservoir performance of the case study.

4. Conclusion

The objective was to indicate the reservoir performance according to these behaviors using two different methods of indications:

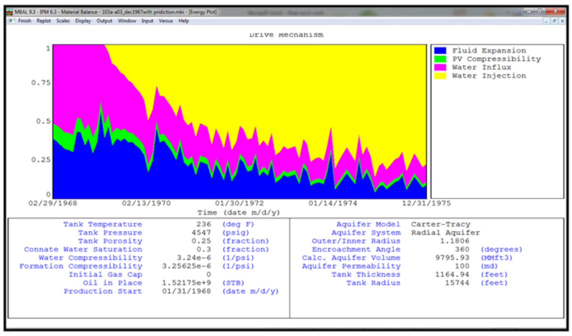


Figure 3.9: Drive indexes calculations by MBAL

1. Material Balance Equation and Water Influx Models Calculations using excel software.
2. Computer Software and Programs.

The most difficult issue in this project was how to estimate the OIIP according this behavior of the reservoir to complete calculations to the reservoir performance indication.
After some assumptions on the reservoir statues, it is possible to estimate the OIIP for the reservoir, successfully complete the calculations and came out with results that leads to indicate the performance of the 103A oil reservoir, which has been discussed in the chapter three in details.
According to the results of the reservoir performance study and after monitoring the reservoir pressure and the recovery factor with the cumulative produced oil, it has been perceived that reservoir pressure started increasing after a while of the water injection. And the recovery factor did not exceed 48% after 41 years of oil production. Where the recovery factor of produced oil was only 14% from the date of pressure felt the water injected to the resent date of the available production history.
According to the previous studies it has been perceived that the bad production planning of the reservoir caused the sharp pressure decline to the reservoir pressure and the management decision about the water injection process succeed to increase the reservoir pressure but failed in increasing the oil recovery factor.
According to this result, it is recommended to perform well testing to indicate the recent reservoir characterizations, and to see if it is possible to plan a reservoir management to put the reservoir on suitable EOR process trying to increase the

recover factor and produce the most of the remaining oil.

List of Symbols

Pri = Initial reservoir pressure,psi
Pr = Volumetric average reservoir pressure
ΔP= Change in reservoir pressure = Pri
Pb = Bubble point pressure, psi
N = Initial (original) oil in place, STB
Np = Cumulative oil produced, STB
Gp = Cumulative gas produced, scf
Wp = Cumulative water produced, bbl
Rp = Cumulative gas-oil ratio, scf/STB
GOR= Instantaneous gas-oil ratio, scf/STB
Rsi = Initial gas solubility, scf/STB
Rs = Gas solubility, scf/STB
Boi = Initial oil formation volume factor
Bo = Oil formation volume factor, bbl/STB
Bgi = Initial gas formation volume factor
Bg = Gas formation volume factor, bbl/scf
$Winj$ = Cumulative water injected
$Ginj$ = Cumulative gas injected,scf.
We = Cumulative water influx

Acknowledgment

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