Simulation of Oil Reservoirs Driving Indices and Recovery Mechanisms

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Abstract

Different recovery mechanisms are activated during the production from reservoirs. Wells sometimes are kept with the injection. Therefore the evaluation of injection indices depended on material injection, seems to be necessary. This study is going to determine the drive indices for a reservoir by making a model using Eclipse. The model consists a gas cap and aquifer, in which there is an injection well used to show water drive index. The summation of reservoir drive indices is equal to one and changing in one drive index can cause changes in the other drive indices. The relation between the all exciting drives and their effects on each other were shown by changing the production conditions in the model. A second model was simulated to know the effects of gas injection process, which is used to keep pressure and production from the reservoir. The role of effective parameters, including gas oil ratio and water cut in 3000 days, were evaluated in the second model. The optimum gas injection rate and influence of drive indices in the simulated field were obtained from the results of this work.

Keywords: Aquifer, Gas cap, Indices, Injection, Recovery mechanisms

Introduction

Material balance evaluation (MBE) has long been identified as a useful means of establishing the connected volume of hydrocarbon initially in place (at reservoir condition) and reservoir drive mechanism. Analysis of MBE results can also prove its invaluable role in addressing questions about reservoir compartmentalization and fluid contacts [1].

One of the basic laws for the calculation of process parameters is the law of conservation of mass, which is used in the form of the material balance equation in hydrodynamic simulations. The material balance equation describes the relationship between pressure, production rate and initial reserves of fluids [2].

The aims of the MBE were to guide the construction of most realistic 3D simulation models by establishing connected hydrocarbon volumes and addressing uncertainties in reservoir compartmentalization and hydrocarbon contacts. Furthermore, the MBE was aimed to facilitate more efficient history matched by establishing the reservoir drive mechanisms [1]. Material balance has not been replaced by reservoir simulation; rather it is complementary to simulation and can provide valuable insights to reservoir performance which cannot be obtained by simulation [3].

When the material balance equation is used, the additional assumption about the pressure and uniformity equilibrium between the different reservoirs layers with different permeability drained at the same time of the system of production wells is made. For determining pressure via material balance equation at any time, depending on the production rate, it is assumed that production is uniformly made throughout the entire area according to the distribution of reserves. This assumption would only be possible if the formation is completely homogeneous, and wells are placed uniformly in the field area and production is performed simultaneously in accordance with the drained reserves.

The use of the material balance equation is effective in solving several problems of projecting, analysis and determining the prospects of the field development under water drive [4].

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It has been observed that each drive mechanism has certain typical performance characteristics in terms of ultimate recovery factor, pressure decline rate, gas-oil ratio (GOR), and water production [5].

Recovery mechanisms can be different in heavy oil reservoirs in comparison with the light oil reservoirs. Recovery from some of the heavy oil reservoirs by cold production is estimated to be as high as 20%. The high recovery is often associated with a low pressure decline rate in the reservoir and a slow increase of GOR in the two phase region below the bubble point, as well as geomechanical effects [6].

Injection with the different materials can be done for increasing production. High pressure air injection (HPAI) can be considered as one of these materials. It has been speculated that oil recovery by high pressure air injection is mainly attributable to in situ generated flue gas displacement [7].

The following presences are characterized for industrial injection phase: sufficiently large initial volume of injection, the combination of the displacement of water from the trap with a parallel operation being constructed storage and consequently, a substantial change of gas pressure in time. Accordingly, calculations of this stage are different from reconnaissance injection. The estimations are based on the method of successive approximations, use of the material balance equation and the formula of water inflow to the enlarged well [8]. It should be emphasized that the recovery mechanism is not an inherent property of the formation. If the reservoir is completely isolated by dumping or thinning permeable zones from communication with aquifers, a natural process of recovery can only occur at the expense of the energy of the dissolved gas or expanding gas cap. If producing formation is presented by limestone, the natural characteristics of cavernous or fracture which is saturated in contact with the oil of active water zone, are similar to any fields with hydraulic energy [9].

The objective of this study is the investigation of material balance and drive indices during production in reservoir depending on the water injection rate by simulation of the reservoir. In this work, all possible indices are examined for knowing their changes at any time and situation of reservoir.

2. Methodology

The material balance equation (MBE) is a basic way for describing and evaluation of reservoir performance during the production.

The next essential parameters can be defined by correct applying of MBE:

- Estimation of hydrocarbon-in-place volume;
- Prediction of the reservoir performance for future;
- Prediction of ultimate hydrocarbon recovery under various types of primary driving mechanisms.

The concept of the material balance equation was presented by Schilthuis [10]. In its simplest form, the equation can be written on volumetric basis as:

$$V_i = V_{rem} + V_{pro} \quad (1)$$

Classification of recovery mechanisms is essentially arbitrary, excluding energy depletion of the dissolved gas and the complete replacement of oil by water. If the quantity of the ultimate oil had been a major criterion for recovery, many formation layers with partial replacement of oil by water would fall into one category with the pure water pressure system, while, others would be combined with layers, working due to gas energy. The general MBE equation is presented as below:

$$DDI + SDI + WDI + EDI + WII + GII = 1 \quad (2)$$

The different terms in the above equation are described as below:

Depletion Drive: This drive mechanism takes place in the condition which oil volume expands in the reservoir with dissolved gas. This driving mechanism is represented by the first term of the equation (2):

$$DDI = N (B_t - B_{ti}) /A \qquad (3)$$

The parameter A is defined by:

$$A=N_p [B_t+ (R_p-R_{si}) B_g] \qquad (4)$$

Segregation Drive: Segregation drive exists in the reservoirs with a gas cap and oil displacement which occurs by the expansion of free gas in the gas cap. This mechanism of production is defined by the second term of equation (2):

$$SDI = [NmB_{ti}(B_g-B_{gi}) /B_{gi}] /A \qquad (5)$$

Water Drive: Water drive is the strong factor for oil movement in the reservoirs, in which oil is surrounded in lower layers by water. This drive is shown as the third term of equation (2):

$$WDI = (W_e -W_pB_w) /A \qquad (6)$$

Expansion Drive: The rock and fluid expansions in under saturated oil reservoirs with no water influx are operating factor of recovery.

$$EDI= \{NB_{oi}m[(c_wS_{wi}+c_f) / (1-S_{wi})](P_i-P)\} /A \qquad (7)$$

Water and Gas injection Drive: These are usually used to pressure maintenance.

$$WII+GII= [W_{inj}B_{winj}+G_{inj}B_{ginj}] /A \qquad (8)$$

Cole [11] pointed out that since the summation of all existing indexes in every time is equal to one, it is a fact that by changing one of the indexes, the other indices are changed. Strong water drives of reservoir usually get into maximum recovery from the field. Where the water drive is too weak to provide an effective displacing force, it may be possible to utilize the displacing energy of the gas cap. At any point, the depletion drive index should be held as low as possible at all times, as this is normally the most inefficient driving force available [12, 13].

Equation (2) must be solved periodically to detect whether there has been any change in the effective driving indexes of the reservoir. Since the forces for displacement of oil and gas in the reservoir, are subject to change from time to time. Changes in fluid withdrawal rates are primarily responsible for changes in the driving indexes. By this fact, it is not unlikely; reducing the oil production rate could result in an increased water drive index and a correspondingly reduced depletion drive index in a reservoir containing a weak water drive. Finally, the net water influx (gross water influx minus water production) will be an important factor.

In the reservoir, which has a very weak water drive, but enough large gas cap, the most effective mechanism in production of reservoir may be the gas cap. In this situation, a large gas-cap-drive index is desirable. The gas cap expansion rate could be limited by the low vertical permeability of formation. In this case, the drive index of gas cap would be sensitive to rate. The effectiveness of the gas cap expansion due to the production of free gas in the reservoir will be reduced by coning of gas into producing wells. Clearly, gas coning can be stronger by high production rate.

One of the most important parameters for effective evaluation of gas cap driver is the extent of conservation of the gas cap. As a practical experience, it will sometimes be impossible because of lease agreements to completely distinguish gas cap gas production. If free gas is being produced, the gas-cap-drive index can often be markedly increased by shut-in wells with high gas-oil ratio and, if possible, transfer their allowances to other wells with low gas-oil ratio.

3. Simulation and Results

Simulation model of the reservoir has 4000×400×200 dimensions. An injection well, which is drilled in the water zone, is used to change water drive index during production. Four producing wells, which have the constant total production rate, which is equal to 400 STBD in 3000 days, are operated on the model. As shown in Figure 1, water injection rate is changed in three periods with different amounts. Clearly, expansion drive index is high when reservoir pressure is located above the bubble point and on the other side when the pressure declines below bubble point; the expansion drive index gets low. This drive index has two parts: the rock compaction drive (fraction of total oil produced by rock compaction - FORFR) and oil expansion drive (fraction of total oil produced by oil expansion - FORFE). Water influx drive, water injection drive and water expansion drive are shown by one term, which is called FORFW [13].

Change in GOR of the reservoir during the production life is shown in Figure 2. It is seen that at first GOR is constant (when pressure is above the oil bubble point pressure) and after that pressure declines below bubble point, GOR increases.

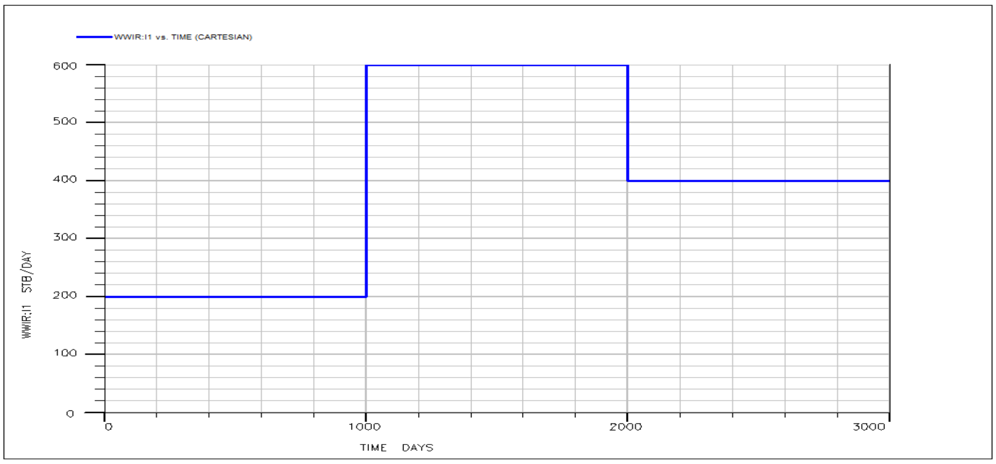

Figure 1: Water injection into the reservoir

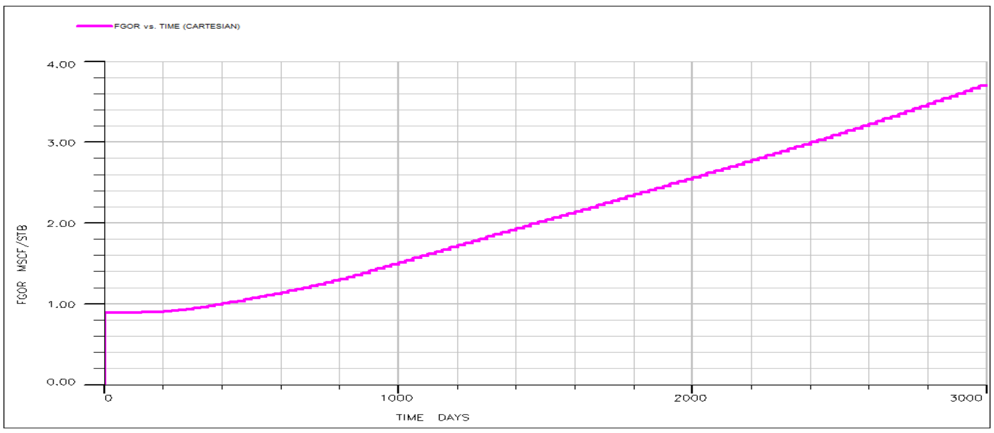

Figure 2: GOR profile during reservoir life

Figure 3 shows oil expansion drive index. This index is high at the beginning of production since pressure is above the bubble point; when pressure drops below the bubble point, this index significantly declines.

The rock compaction drive index is shown in Figure 4. This index is high when pressure is above the bubble point. As shown in the Figure 4, fraction of total oil produced by rock expansion (EDI-expansion drive index) rapidly decreases in the first 1000 days because of water injection. Water drive (water injection drive) increases when water rate increases, and as far as the total drive indices are constant and equal to one at any time, increase in water index substantiates changes in the rock compaction drive index. Similarly, in 2000 days.

Figure 5 simultaneously depicts water drive, water injection rate and water expansion index. These three indices are presented in FORFW, which shows the fraction of total produced oil by water influx. FORFW decreases in first 1000 days, and gas cap and gas solution drive increase in this period. Then, FORFW increases up to 2000 days because of growth in water injection rate. During the third period, FORFW increases slower in comparison with index in the second 1000 days because the water injection rate reduces.

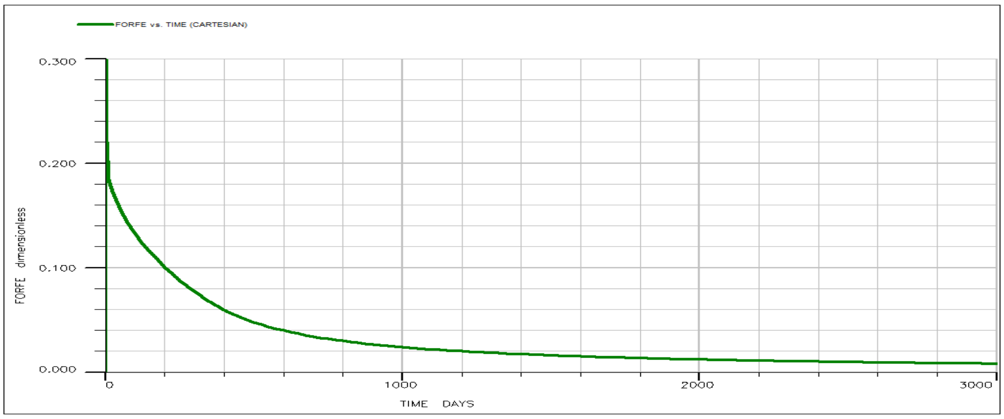

Figure 3: Oil expansion drive index changes

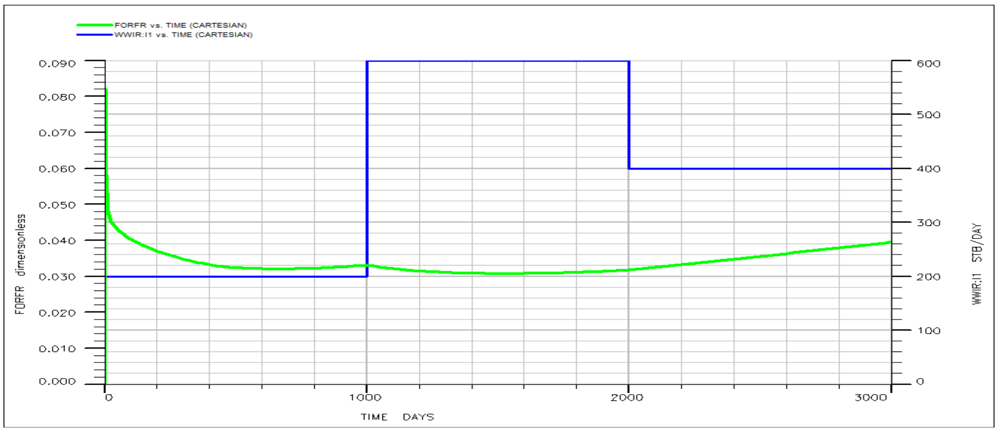

Figure 4: Rock compaction index changes

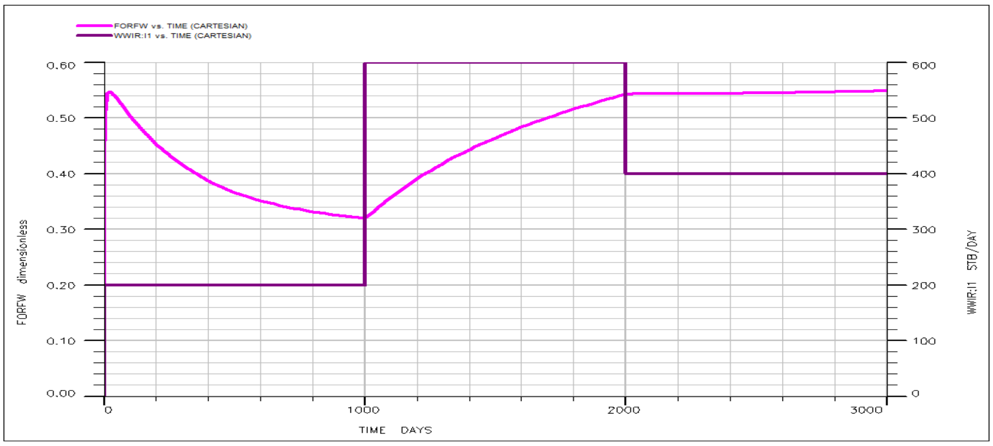

Figure 5: Water drive, water injection rate and water expansion index changes

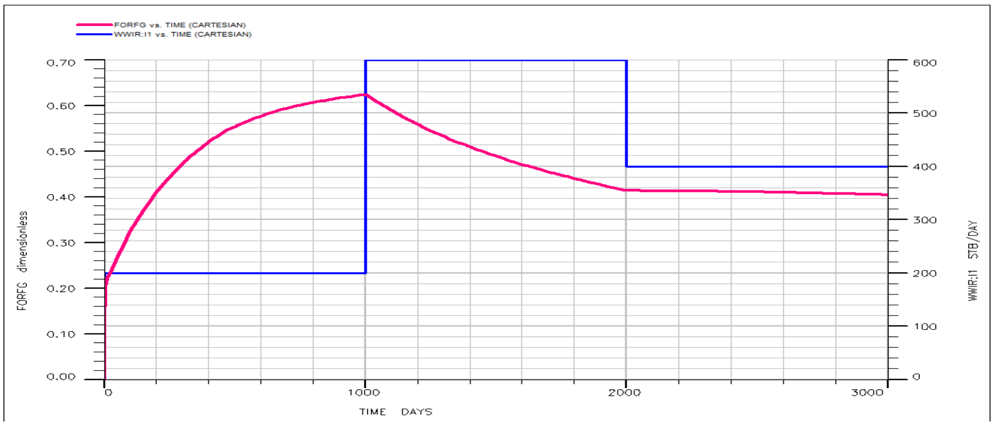

Figure 6: Gas cap and solution gas drive indices changes

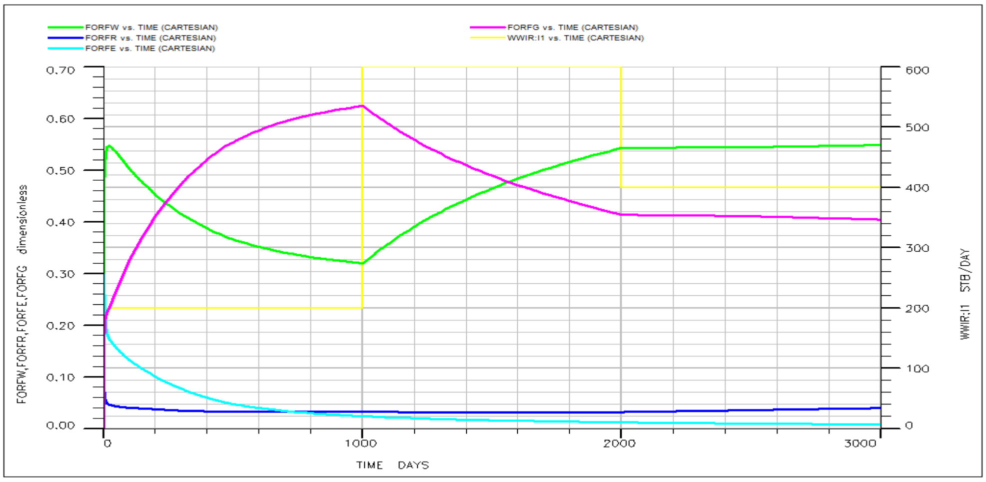

Figure 7: All drive indices changes for producing field with water injection well

Figure 6 indicates gas cap and solution gas drive indices (fraction of total produced oil by gas influx - FORFG). FORFG increases in the first 1000 days because the water injection rate is not high. FORFW increases by increasing water rate in the second 1000 days. Consequently, FORFG rapidly decreases. Finally, FORFG decreases very slowly with decreasing water injection rate in the third period.

As shown in Figure 7, the total drive indices summation is equal to one at any time. Changing one drive can cause changes in the other drives.

Conclusion

In the reservoirs, different production mechanisms help produce oil from the formations during the production. Water driving indice is increased with the water injection into the reservoir. Expansion drives (rock compaction and oil expansion) are so small and decrease to constant values during production by comparing the all driving indices. Water drive indice is increased with the water injection and the gas influx effect decreases because the summation of indices in the reservoir must be remained constant. In this model, the gas cap in the reservoir has the big effect on the production mechanism; it means that there is a big gas cap which moves the oil from the reservoir to well.

In this article, the described results of the operational parameters for oil field development were obtained by using the developed model, which is based on the modified material balance equation for reservoirs. The result of the simulation can be applied for effective consideration of different drive indices simultaneously in oil during water injection. Presence of gas injection in oil wells has effects on the values of drive indices; therefore, examination of its effects is suggested for further works.

Nomenclature

B_g	bbl/scf	Gas formation volume factor
B_{gi}	bbl/scf	Initial gas formation volume factor
B_{ginj}	bbl/scf	Injected gas formation volume factor
B_{oi}	bbl/STB	Initial oil formation volume factor,
B_t	bbl/STB	Total (two phase) formation volume factor
B_{ti}	bbl/STB	Initial two phase formation volume factor
B_w	bbl/STB	Water formation volume factor
B_{winj}	bbl/STB	Injected water formation volume factor
c_f	psi^{-1}	Formation (rock) compressibility
c_w	psi^{-1}	Water compressibility
DDI		Depletion drive index
EDI		Expansion (rock and liquid) drive index
FGOR	Mscf/STB	Field gas oil ratio
FORFE		Fraction of total oil produced by oil expansion
FORFG		Fraction of total oil produced by gas influx
FORFR		Fraction of total oil produced by rock compaction
FORFW		Fraction of total oil produced by water influx
GII		Gas injection index
G_{inj}	scf	Cumulative gas injected
GOR	scf/STB	Instantaneous gas-oil ratio
HPAI		High pressure air injection
m		ratio of initial gas cap to initial oil volume, bbl/bbl
MBE		Material balance equation
N	STB	Initial oil in place
N_p	STB	Cumulative oil produced
P	psi	Volumetric average reservoir pressure
P_i	psi	Initial reservoir pressure
R_p	scf/STB	Cumulative gas-oil ratio
R_{si}	scf/STB	Initial gas solubility
SDI		Segregation (gas cap) drive index
STBD		Stock tank barrel per day
S_{wi}		Initial water saturation
V_i		Initial volume
V_{pro}		Produced volume
V_{rem}		Remaining volume

WDI		Water drive index	W_p	bbl	Cumulative water produced
W_e	bbl	Cumulative water influx	*WWIR*	bbl/day	Well water injection rate
WII		Water injection index			
W_{inj}	STB	Cumulative water injected			

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