Sensitivity Analysis of Cumulative Oil Production and Production Rate on Block Heights and Capillary Continuity for an Iranian Carbonated Fractured Reservoir

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ABSTRACT:*Block heights and capillary continuity between matrix blocks play paramount role in the sensitivity analysis and therefore the history matching of cumulative oil production and production rate of carbonated fractured reservoirs. In this study, the influence of these parameters upon cumulative production and recovery factor of an Iranian fractured reservoir were studied by the usage of a simulator. Results show that, changing the block heights greatly affect on the cumulative production as well as the recovery factor. Also sensitivity analysis reveals that, the variations in cumulative production and recovery factor happen in a limited range of block heights. The aforementioned ranges of block heights for the studied reservoir were twice the height and one tenth of the height of the block height used in the history matching during the reservoir simulation. For block heights shorter than the original one, the influence of capillary continuity is paramount by increasing the cumulative production as well as the recovery factor. However, as the block height increased and reached twice the height of the original height, the influence of capillary continuity decreased and the system behaved similar to the situation where the block height was doubled without taking capillary continuity into consideration.*

KEY WORDS: *Sensitivity analysis, Block height, Capillary continuity, Carbonated fractured reservoir.*

INTRODUCTION

The south-west of Iran is one of the areas that has the highest concentration of fractured reservoir. In Iranian fractured carbonate reservoirs gravity drainage mechanism is as a dominant and active mechanism through gas injection, water alternative gas injection and in the gas invaded zone [1].

For modeling natural fractured reservoir, *Barenblatt* proposed a dual-media approach [2]. *Saidi* presented simulator for modeling fluid flow in fractured reservoir [3]. Block-block interaction is caused due to capillary continuity. Capillary continuity between isolated matrix block is recognized as favorable in fractured reservoirs

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dominated by gravity drainage [4]. The oil recovery by the gravity drainage process in a fractured reservoir strongly depends on the height of reservoir rock in vertical capillary continuity [5]. *Saidi et al.* suggested that interaction of matrix blocks occurred due to wetting phase liquid bridges across the horizontal fractures [6]. *Horie et al.* performed capillary continuity experiment on a vertical stack of three core samples with a total height of 90 cm. They found, good capillary contact was observed when the stack of cores was forced together with no spacing other than the voids resulting from the roughness of the adjacent core plug surfaces. It was stated that the total effective area of the liquid bridges across the fracture controlled the production rate [7]. *Stones et al.* reduced surface tension by adding surfactants to the wetting phase and thereby increased the bridging flow area [8]. A recent publication presented by sajadian et al. considers the capillary contact as function of fracture aperture. They were able to find a threshold aperture t_{fc}, above which no liquid bridges were formed [10].

Sensitivity analysis is the study of how the variation of the output of a model can be apportioned, qualitatively or quantitatively to different sources of variation. The procedure is based on determination of the sensitivity of the value of reservoir parameters used in the simulator. Sensitivity analysis changes each precedent variable at a time and then notes the changes of the resulting variable. In this paper, block height and capillary continuity were selected and effects of these parameters on cumulative oil production and production rate for this carbonated fractured reservoir were evaluated.

BASIC DEFINTION

A naturally fracture reservoir consists of two distinct regions, a matrix region containing finer pores and having a high storage capacity, but a low permeability, is interconnected with the fracture network region, which has a low storage capacity, but higher permeability.

In this type of reservoir interaction between fracture and matrix and the simultaneous flow of matrix-fracture system takes place mainly under the control of gravity and capillary forces and have a basic role in gas gravity drainage process.

The gravity drainage takes place mainly when gas from gas-saturated fractures displaces the oil of the matrix. In fractured reservoir the presence of vertical or

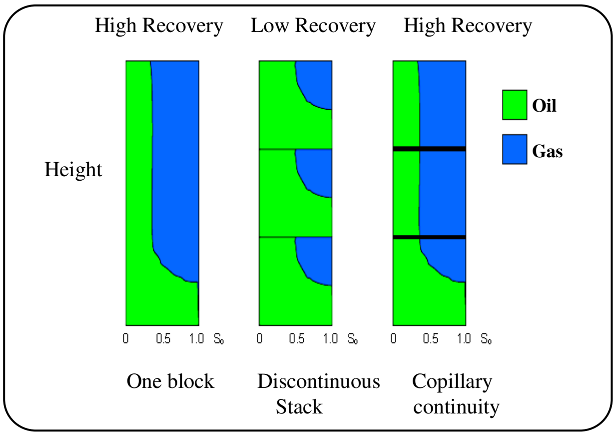

Fig. 1: Effect of capillary contact between vertically stacked matrix blocks during gravity drainage.

inclined fractures could cause the GOC or WOC to advance ahead of corresponding contact in the matrix block. In the gravity drainage mechanism, the difference between the density of the fluids and the elevation of the two contacts are major parameters, which cause the fluid movement in the block and result in oil production from the matrix blocks. When surrounded by gas, the matrix blocks will release their oil as soon as the gravitational forces exceed the capillary force.

Oil/gas gravity drainage mechanism is more efficient than water oil gravity drainage, as the density contrast between gas and oil is much bigger than that, between water and oil. Gas/oil gravity drainage is an important recovery mechanism in oil producing from fracture reservoir.

In an actual fractured reservoir the blocks are neither completely isolated from other blocks and nor are they in full capillary contact. When the blocks are isolated from each other they would act independently. The flow rate and ultimate recovery of N equal blocks in one column would be N times the flow rate and ultimate recovery from one block. While if there is full capillary continuity between the N blocks in on column, the stack-block would act as one block with the height equal to the sum of N blocks (Fig. 1).

Capillary continuity between the matrix blocks and block height are important phenomenon's that affect on oil recovery in gas gravity drainage mechanism. Effect of these phenomenon's under gas injection have been carried out on Eclipse 100 to illustrate the dependence of the capillary continuity and the position of areal contact between the matrix blocks on total production and production rate of an Iranian carbonated fractured reservoir.

The interaction effect of blocks has been intensively studied by many authors. This effect was experimentally developed by saidi [6-10]. Between the two adjacent blocks that both located in the gas-invaded zone, a wet region may create oil bridge and thus continuous oil phase among the blocks. This continuous oil phase due to irregularities in fractures is represented by a film of oil remaining between the blocks in the case of narrow fractures. The extension of this wet region is estimated to be of the same order of magnitude as the cross-flow section of the block if the extension of the block is not too big compared with the capillary height. Festoy and Van Golf-Racht [11] showed that the matrix to matrix contact between the blocks in a vertical stack improves the oil recovery significantly. According to them, high oil recovery and sustained production rates from some fractured reservoirs flowing below bubble point pressure may be attributed to some degree of matrix to matrix contact between the blocks in a vertical stack [12].

The flow of oil in the gas-invaded zone will be to a large extent vertical flow through the matrix where, oil is expelled into the fracture by gravity forces. The rate is controlled by the density difference between oil and gas and the height of matrix blocks

For gas oil system, the capillary pressure opposes the fluid exchange between the matrix block and the fracture. Oil displacement in the matrix block can only be possible if the capillary pressure corresponds to the threshold pressure. In other words, to assure displacement of matrix oil by the gas in fractures, height difference between the gas-oil contacts in the matrix and the fracture must be higher than the capillary threshold height. The relationship between block height and capillary threshold height controls the oil production rate from the block.

When the block height is large compared with capillary threshold height, the influence of capillary pressure on rate is negligible. If the height of the matrix block is less than the capillary threshold height, oil will not be recovered from the matrix blocks unless there is a capillary continuity between them.

RESERVOIR DESCRIPTION

To illustrate our simulation approach we run simulations on a model of an Iranian carbonate fractured reservoir. This field is located in southwest of Iran. Production from the Asmari reservoir in this field was commenced in 1966. Initial volume oil in place is estimated from volumetric calculation to be approximately 12MMMSTB. The reservoir pressure behavior shows that dominate drive mechanism is gas cap drive. There is no substantial connected aquifer providing pressure support. The primary production mechanism active in this field is gravity drainage occasioned by gas cap expansion drive. Gas injection into the Asmari reservoir gas cap was commenced in early 1999 through five well. It can be seen that the gas arrests and even reverses the continued pressure decline [15].

Table 1: Basice rock and fluid parameters [13, 15].

P_i, Psia	3645
P_b, Psia	2880
μ_0, cp	$0.468 \le \mu_0 \le 1.724$
μ_w, cp	0.64
ρ_w, lb/ ft^3	71.021
B_0, rb/stb	1.47
B_w, rb/stb	1.01
R_s, Msc$f$/stb	0.775
ϕ_f, %	0.3
. .ϕ_m %	$2.5\le \phi_m \le 20.$
K_f, mD	$150 \le K_f \le 400$
K_m, mD	$0.05 \le k_m \le 0.5$

BASIC ROCK AND FLUID PARAMETERS

The basic rock and fluid parameters considered during this study are shown in table 1. The reservoir was divided into 8 rock types. Figs. 2 and 3 represent the gas-oil primary drainage capillary pressure and the relative permeabilities as a function of water saturation for the reservoir. Zero Oil-Gas capillary pressure and straight line Oil-Gas relative permeabilities with end points as 0 and 1 have been considered for the fracture. The primary production mechanism in this field is gravity drainage accessioned by gas cap expansion drive. Rockcompression oil expansion and water influx are all lower in the gas cap. Gas injection into the reservoir gas cap commenced through five wells [13].

Table 2: The results of sensitivity analysis in various block height.

Dimension Variation	0.02	0.1	0.5	BASE	2	3	4	5
FOPT(stb)	1725465300	1727901700	1761047900	1825654\00	1886795000	1889526900	1889722900	1889116000
FOPR(stb/day)	OCT/07	OCT/07	APR/08	APR/09	APR/15	Oct/17	Oct/17	Oct/17

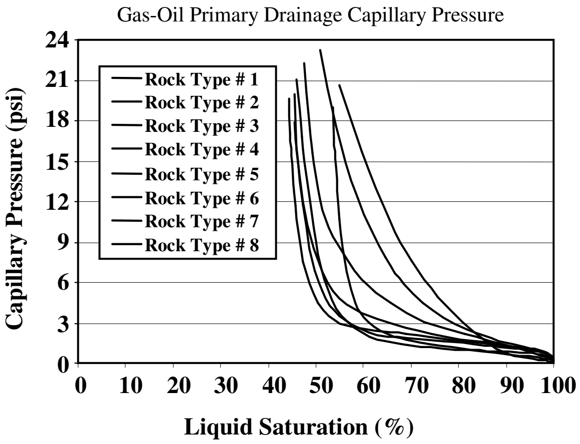

Fig. 2: Gas-Oil primary drainage capillary pressure.

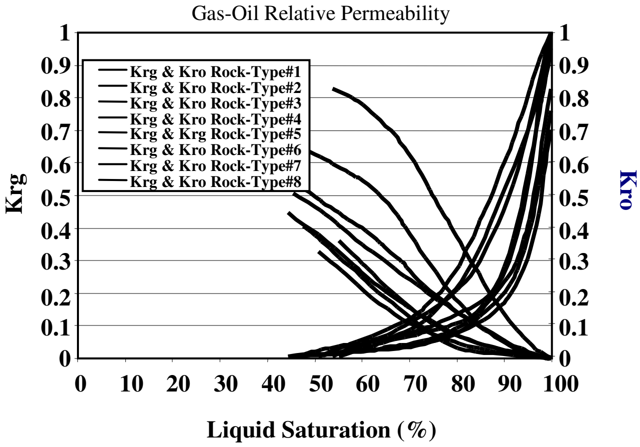

Fig. 3: Oil and gas Relative permeability VS. liq.saturation.

MODEL DESCRIPTION

In this project, we applied a dual continuum approach in black oil simulator (ECLIPS 100) [15]. A fine grid simulation studies on Eclipse 100 has been carried in Cartesian co-ordinate system. The matrix blocks in the vertical stack have been separated by horizontal fractures. The system is similar to that of *Kazemi model* [14]. The matrix blocks have been gridded from 30 120 1 to 30 120 18 grid pattern and horizontal fractures have each been gridded from 30 120 19 to 30 120 36 grid pattern. The heights of matrix blocks are variable throughout this reservoir [15].

The aforementioned range of block height for the studied reservoir began from one tenth of the values for history matching and expanded to fourfold of the history matching value and this was simulated from Jan. 2007 to Oct. 2017.

INVESTIGATION OF SENSITIVITY ANALYSIS OF BLOCK HELGHT ON CUMULATIVE OIL PRODUCTION AND RECOVERY FACTOR

The results of simulation can be observed from Figs. 4 and 5 also table 2. This table shows the results of FOPT until Oct. 2017 and the time that reservoir can maintain the proposed production rate (6000 Stb/day, maximum stabilized rate of production for this reservoir in master development plane) relevant to changes that happened in the block height. Fig. 4 represents FOPT vs. Time and Fig. 5 FOPR vs. Time for variation of block height on total production and rate of production for twice, threefold, fourfold, 5 %, 10 % and 50 % of the initial value of block height used in the history matching during the reservoir simulation, respectively. From Figs. 4 and 5 and table 2 of results it is observed that for block heights bigger than the original one (until up to fourfold), the influence of block height is paramount by increasing the cumulative oil production as well as the production rate. However, as the block height is increased, and reaches fourfold of the original one, the influence of it is decreased and for the values bigger than fourfold the cumulative oil production is decreased. As block height is increased, the oil production and simultaneous reservoir pressure drop increased and liberated gas has not adequate time to adjoin to the gas cap. So, the total released gas reaches to its critical point and gas is produced from production wells. Again, librated gas invades the matrix and blockade oil in the matrix. Gas is produced from production wells while decreasing total oil production.

Table 3: The results of sensitivity analysis in various block height.

Dimension Variation	0.5	BASE	1.5	2
FOPT (withoutcapillary continuity) (stb)	1761047900	1825654400	1867449100	1886795000
FOPR (withoutcapillary continuity) (stb/day)	01-Apr-08	01-Apr-09	01-Jul-11	01-Apr-15
FOPT (with capillary continuity) (stb)	1840556000	1872508800	1888389000	1888776200
FOPR (with capillary continuity) (stb/day)	01-Jul-09	01-Jan-12	01-Jan-17	01-Oct-17

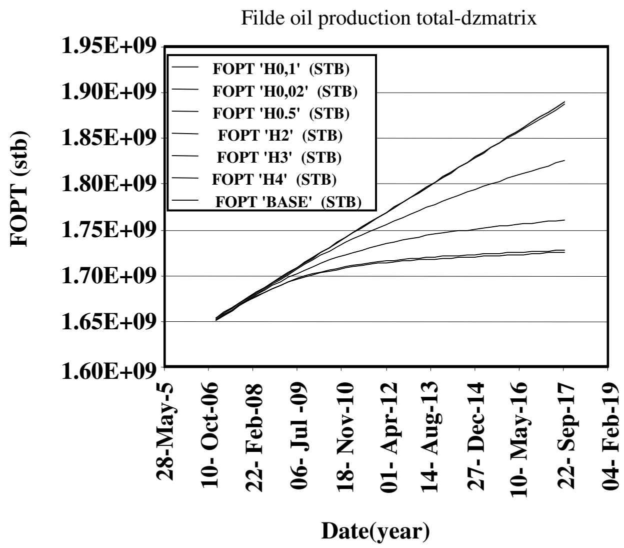

Fig. 4: FOPT vs Time for simulating block height effect.

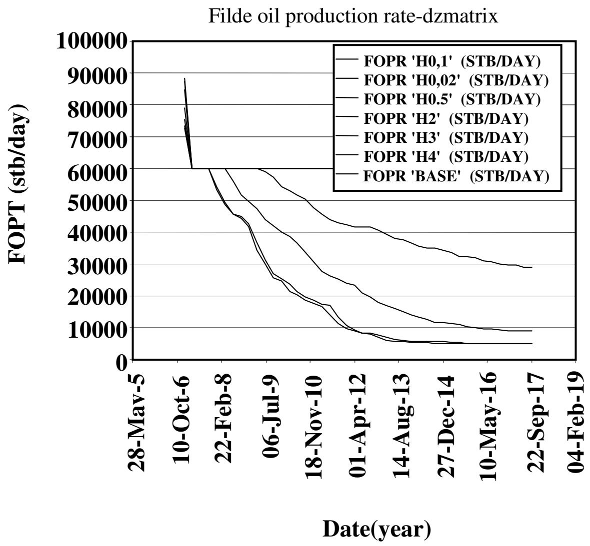

Fig. 5: FOPR vs Time for simulating block height effect.

With increasing of block height, the reservoir can sustain the proposed rate for a longer time. However, as the block heights is increased and reach fourfold of the original one, the influence of block heights decreased and constant production rate is yielded. Then, the reservoir can maintain the proposed production rate (6000 Stb/day) during the all of production time.

The results of variations of the average block height on cumulative production can be displayed as the following equation:

$$\text{FOPT} = X^4 + 338X^3 + (3.4E+4)X^2 - (3.17E+4)X + (1.1E+9) \quad (1)$$

Where X is the average block height.

Equation (1) can be used only for this reservoir and adjacent reservoir that these are separated by a huge bake thrust fault. These equations have been acquired by Lagrangian Polynminals method via average reservoir characteristic (block height) and FOPT (until Oct. 2017) for this reservoir.

INVESTIGATION OF SENSITVITY ANALYSIS OF CAPILLARY CONTINUTTY ON CUMULATIVE OIL PRODUCTION AND PRODUCTION RATE

Firstly we explain about method that has been applied for creating capillary continuity. As mention before this part we applied a dual continuum approach in black oil simulator, there fore some grids have matrix properties and others have fracture properties. In this approach for creating capillary continuity, the grids have fracture properties filled whit materials same as matrix materials.

The results of simulation can be observed from Figs. 6 and 7. These figures show the results of FOPT until Oct/2017 and the time that reservoir can maintain the proposed production rate (6000 Stb/day) relevant to changes that happened in the height of block in the case with full capillary continuity and without capillary continuity. Fig. 6 represents FOPT vs. Time and Fig. 7 FOPR vs. Time for variation of height of block in the case with capillary continuity (CCH0.5, CCBASE, CCH1.5 and CCH2) and without capillary continuity

Table 4: Results of changing in position of matrix contact.

Dimension Variation	BASE	CCBASE	CCH2	CCH3	CCH4	CCH5
FOPT(stb)	1825654400	1872508800	1851392600	1845854700	1831204100	1839593600
FOPR(stb/day)	APR/09	JAN/12	JAN/10	JAN/10	APR/9	OCT/09

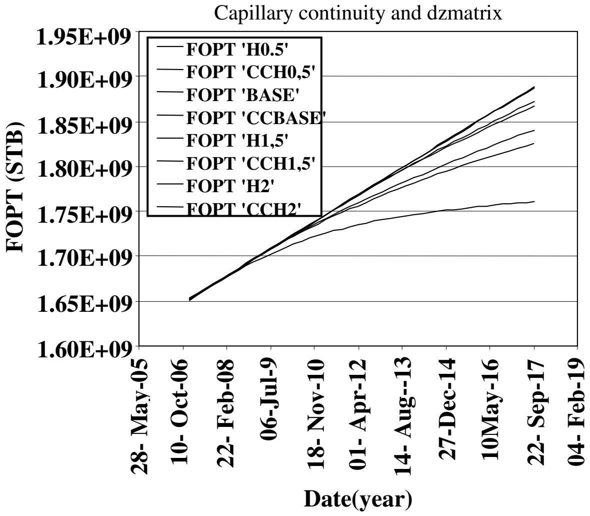

Fig. 6: FOPT vs. Time for variation of height of block in the case with capillary continuity and without capillary continuity.

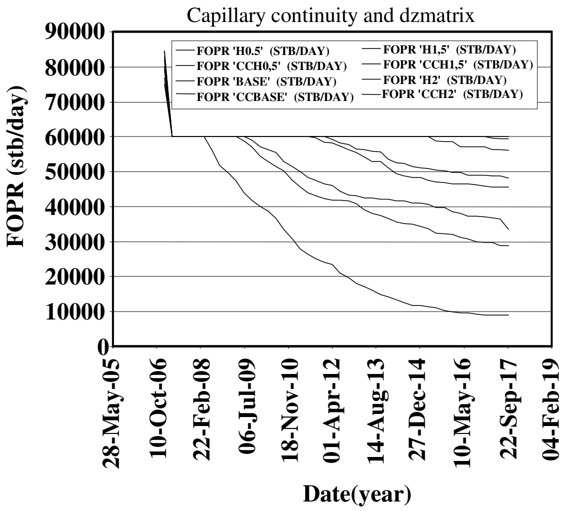

Fig. 7: FOPR vs. Time for variation of height of block in the case with capillary continuity and without capillary continuity.

(H0.5, BASE, H1.5 and H2) on total production and rate of production for twice (H2), and 50 % (H0.5) of the initial value of block height used in the history matching during the reservoir simulation, respectively. From Figs. 6 and 7 and table 3 of results it is observed that for block heights bigger than the original one (until to twofold), the influence of capillary continuity is paramount by increasing the cumulative production as well as the production rate. However, as the block height is increased, and reaches twice of the original one, capillary continuity is not influenced on cumulative oil production and production rate. With decreasing of block height, the influence of this is increased and for the values bigger than twice the influence of this is decreased and is became equal to case that capillary continuity does not exist in the reservoir.

EFFECT OF POSITION OF MATRIX TO MATRIX CONTACT

This part contains some models. All these models with their name were made to examine the effect of capillary continuity in form of position of matrix to matrix contact on total production and rate of production. As a sensitivity analysis the position of grid blocks that the blocks are connected to each other through them, have changed.

For comparing effect of position of capillary continuity, we divided reservoir to three sections (section one:1×120×36 to10×120×36, section two: 11×120×36 to 20×120×36 and section three: 21×120×36 to 30×120×36) and was simulated 6 different models for this reservoir from Jan. 2007 to Oct. 2017.

1- No capillary continuity (BASE).

2- Full capillary continuity (CCBASE).

3- The blocks are connected to each other through section one and three (CCH2).

4- The blocks are connected to each other through section 3 three (CCH3).

5- The blocks are connected to each other through section one (CCH4).

6- The blocks are connected to each other through section two (CCH5).

The results of simulation can be observed from Figs. 8 and 9 also table 4. Fig. 8 show amount of FOPT vs.

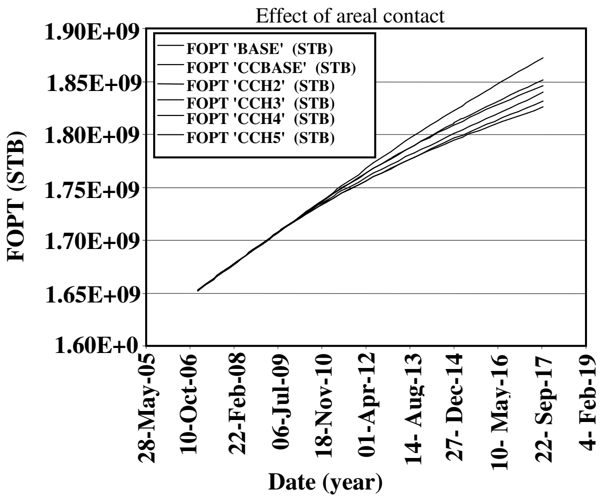

Fig. 8: FOPT vs. Time for comparing the effect of position of matrix contact.

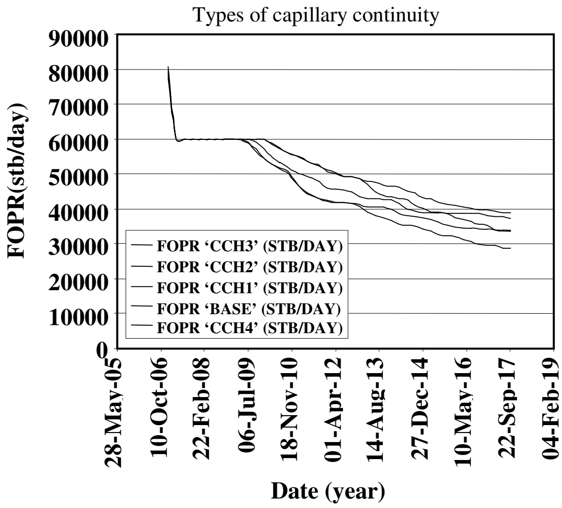

Fig. 9: FOPR vs. Time for comparing the effect of position of matrix contact.

time and Fig. 9 FOPR vs. time for variation of position of capillary continuity, respectively. Table 4 compares the result of six models for this reservoir. This Table show the results of FOPT until Oct. 2017 and the time that reservoir can maintain the proposed production rate (6000 Stb/day) relevant to changes that happened in position of matrix to matrix contact in reservoir. From Figs. 8 and 9 and table 4 of results it is observed that the largest FOPT belong to full capillary continuity (CCBASE) after this CCH2 and later CCH3, agree with Figs. 8 and 9 CCH2 and CCH3 have same trend and confirm to each other in 01/APR/2013. The following position is CCH5 that rate of production equals with CCH2 on APR/2017. Next to is CCH4 that it is the same as CCBASE in 2013. CCH3, CCH4 and CCH5 are related to position that block is connected to the next block through one third of reservoir. Table 4 compares the result of three models and shows that the greatest FOPT is related to CCH3. Reference to the reservoir, the tertiary section has the best permeability and porosity. For CCH3 model that is located in the tertiary section influence of capillary continuity is paramount by increasing the permeability and porosity in the reservoir.

SENSITIVITY ANALYSIS OF CUMULATIVE OIL PRODUCTION AND PRODUCTION RATE ON MATRIX/FRACTURE PERMEABILITY AND σ FOR THIS RESERVOIR

Similar to block height sensitivity analysis was done on matrix/fracture permeability andσ. Sensitivity analysis reveals that the variations in cumulative oil production and oil production rate occur in a limited range of matrix/fracture permeability and σ (Figs. 10 and 11). This range for matrix/fracture permeability extends from threefold the permeability to one tenth used in the history matching during the reservoir simulation and for the σ is limited to fivefold the σ and one tenth one, that used in the history matching during the reservoir simulation.

For the σ (Figs. 10 and 11), it is observed the effect of varying σ on rate of production, is similar to change of matrix permeability but sensitivity of σis lower than matrix permeability.

Influence of increasing the fractures permeability on production rate and total production is low compared to the matrix permeability.

CONCLUTIONS

From results of the sensitivity analysis, following conclusions are observed:

The variations in cumulative oil production and oil production rate occur in a limited range of block height. This range for block heights extends from fourfold the block heights to one tenth used in the history matching during the reservoir simulation.

Whenever we require simultaneous variation in cumulative oil production and production rate, variation of the block heights, matrix permeability and σ are adequate. But if we require variation in cumulative production with low variation in production rate, variation of the fracture permeability is adequate.

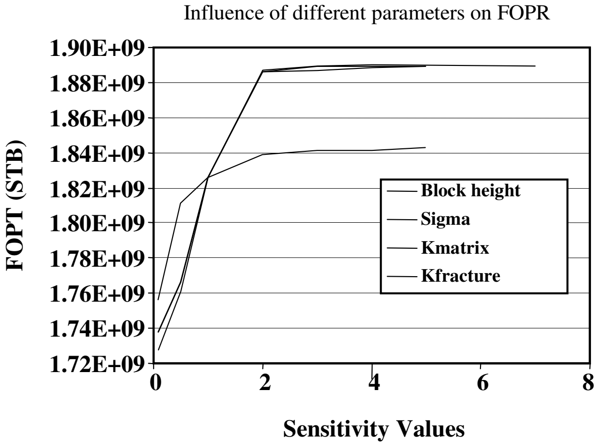

Fig. 10: FOPT vs sensitivity values of block height, matrix/fracture permeability and σ

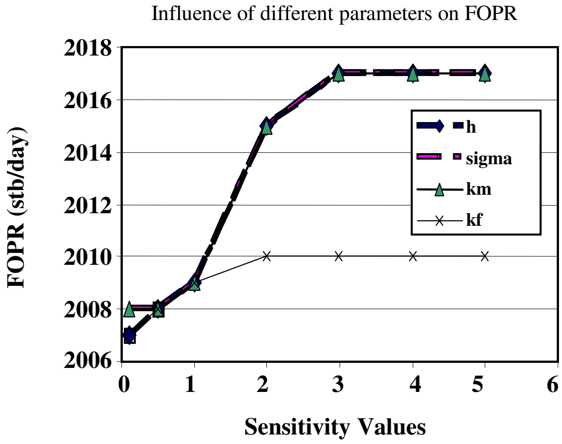

Fig. 11: FOPR vs sensitivity values of block height, matrix/fracture permeability and σ

Capillary continuity is the most important parameter that affecting the cumulative oil production and production rate of this fracture reservoir.

With increasing capillary continuity (until up to twofold of original block height), the cumulative oil production increase and the production rate can sustain proposed rate (6000 stb/day) for longer time.

For block height bigger than twofold of original one influence of capillary continuity reduced and is equal to case that block height is increased without capillary continuity.

The position of the contact has influence on cumulative oil production and production rate.

The third section of this reservoir have the best permeability and porosity for this reason, influence of capillary continuity in this section (CCH3) is the greatest than other sections.

Nomenclature

P_i, psia	Initial reservoir pressure
P_b, psia	Bubble point pressure
μ_o, cp	Reservoir oil viscosity
μ_w, cp	Reservoir water viscosity
ρ_w, lb/ft^3	Reservoir water density
ρ_o, lb/ft^3	Reservoir oil density
B_o, rb/stb	Oil formation volume factor
B_w, rb/stb	Water formation volume factor
R_s, Mscf/stb	Solution gas oil ratio
ϕ_f, %	Fracture porosity
ϕ_m, %	Matrix porosity
K_f, mD	Absolute fracture permeability
K_m, mD	Absolute matrix permeability
W_f	Fracture width
FOPT, (stb)	Field oil production total

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