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Impact of Hydraulic Fracturing on Productivity of Gas Condensate Wells

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Abstract

Having an increase in the discovery of gas reservoirs all over the world, the most common problem related to gas condensate wells while producing below dew point condition is condensate banking. As the bottom hole pressure drops below the dew point, the liquid starts to exist and condensate begins to accumulate. Relative permeability of gas will be reduced as well as the well productivity will start to decline.

The effect of applying a hydraulic fracture to gas condensate wells is the main objective of this paper. A simulator is utilized to investigate the physical modifications that could happen to gas and condensate during the production life of an arbitrary well.

Performing a good designed hydraulic fracture to a gas condensate well typically enhances the production of such well. This increase depends basically on certain factors such as non-Darcy flow, capillary number and capillary pressure. Non-Darcy flow has a dominant impact on gas and condensate productivity index after performing a hydraulic fracture as the simulator indicates..

***Keywords**: Reservoir simulation, Compositional simulator, Hydraulic fracturing, Gas production, Condensate banking, Non-Darcy flow.*

1. Introduction

Gas condensate reservoir modelling indicates that a condensate ring is formed at the area surrounding the wellbore when the bottom hole pressure decreased to be below dew point pressure. This phenomena highly reduces gas effective permeability and hence the well productivity.

Hydraulic fracturing is done by pumping fluid in the well with high pumping pressure that can break the formation. The normal fracture is a single, vertical fracture created and propagated in two wings opposite to each other [1,11]. It worth to mention that there are not many published cases that have not taken into account the effect of the non-Darcy flow which is clearly noticed in gas wells with high production rate when the flow arriving at the smaller area around wellbore.

Increasing the well production is the main aim of applying hydraulic fracturing to the gas condensate reservoir. It worth to mention that there are not many published cases that study hydraulic fracturing of gas condensate reservoirs. And most of the studies done have not taken into account the effect of some of the very important factors, such as the non-Darcy flow [2,9,13].

Non-Darcy flow is clearly noticed gas wells with high production rate when the flow arriving at the smaller area around wellbore and hence the gas velocity exceeds the Reynolds number for laminar flow and results in a turbulent flow. Regarding the non-Darcy flow is a rate-dependent skin effect is that the turbulent flow most likely happens around the wellbore [12].

The main purpose of this paper is to study and analyse the effect of applying hydraulic fracture on the gas and condensate production of this special type of reservoirs which is the gas condensate reservoir. And also the effects of some factors which have an impact on the well productivity. This can be done by modelling an arbitrary well compositionally and studying the results with and without definite factors such as non-Darcy flow, capillary number and capillary pressure [3,10].

2. Methodology

The study aims to illustrate the impact of performing hydraulic fracture in a well on the production of the gas and condensate by modelling an arbitrary well and inserting all reservoir and fluids physical and chemical properties to the simulator. The use of compositional simulator is very necessary to perform a suitable model that can predict physical changes like condensate banking. An arbitrary well was created in the created grid with (50/50/1) blocks for the reservoir.

2.1. Equation of state model and BIC

Peng Robinson equation of state was considered in this model to understand the phase behaviour because it is better for gas and condensate combination than Soave Redlich Kwong equation of state. The binary interaction values between hydrocarbon components themselves are ignored. However, the values for CO_2 and N_2 with hydrocarbons are summarised in Table 1.

Table 1. BICs used for gas condensate fluid

Component	N_2	CO_2
C1	-0.05	0.05
C (2-3)	-0.05	0.05
C (4-6)	-0.05	0.05
C7	-0.05	0.05

2.2. Gridding

The reservoir model is considered a square area and the well is at the centre. The real length, width and thickness of the reservoir 6000 x 6000 x 70 ft. The gridding has its smallest grid block in size at right angle to the fracture is 0.1 ft. Using refinement option in the simulator, there is a possibility to more refine middle grid blocks. The well main block size (0.8 by 4) ft.

2.3. Reservoir and fluid characteristics

Data given to the simulator include many of reservoir characteristics such as the reservoir is mainly sandstone structurally folded. Simulation is considering one production layer and the reservoir is nearly homogeneous with an average 20% porosity and an estimated permeability of about 1 md. The net to gross ratio value is 0.6 and permeability is 7500 md inside the fracture.

The minimum P_{wf} for the simulator to run is 1500 psi, which means that the fluid will pass the retrograde area in the phase envelope. The internal diameter of the wellbore is 3 inch. The equivalent wellbore radius can be estimated by Peaceman equation [4]. Initial parameters for the reservoir pressure and temperature are 3400 psi and 325°F. The saturation of water at the beginning of modelling is 0.25 and gas saturation is 0.68. Table 2. shows the Peng Robinson equation of state parameters for the model [5].

Table 2. Equation of state parameters

Component	Mole Frac.	P c, psi	T c, R	Acentric factor
N_2	0.0284	493.45	226.16	0.04
CO_2	0.0612	1071.16	548.56	0.224
C1	0.463498	666.38	344.08	0.008
C2-3	0.161399	662.794	607.238	0.1263
C4-6	0.144899	507.473	830.096	0.2338
C7P1	0.101689	293.457	914.884	0.3309
C7P2	0.038438	210.981	1466.902	0.5921
C7P3	0.002471	123.656	1973.41	1.0444

Fig. 1.a indicates the phase envelope which shows the dew point pressure value at 320°F is 3100 psi. And Fig. 1.b indicates liquid dropout curve got from the simulator and from this curve the highest liquid dropout can be known which has a value of 39% at 325°F.

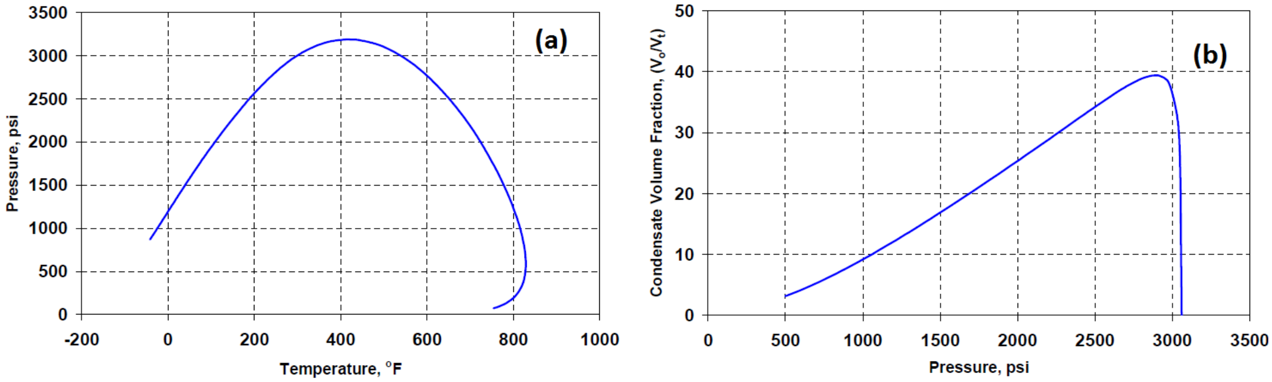

Fig. 1. Fluid data a) Phase envelope & b) Liquid dropout curve

Relative permeability changes can be modelled by using Pope relative permeability model [6]. It shows that relative permeability depends on interfacial tension as well as depends on viscous, capillary and gravity forces. Forces affecting condensate movement are gravity forces, Capillary forces prevent condensate from movement and viscous forces coming because of the pressure differential at gas produced.

3. Discussion of simulation results

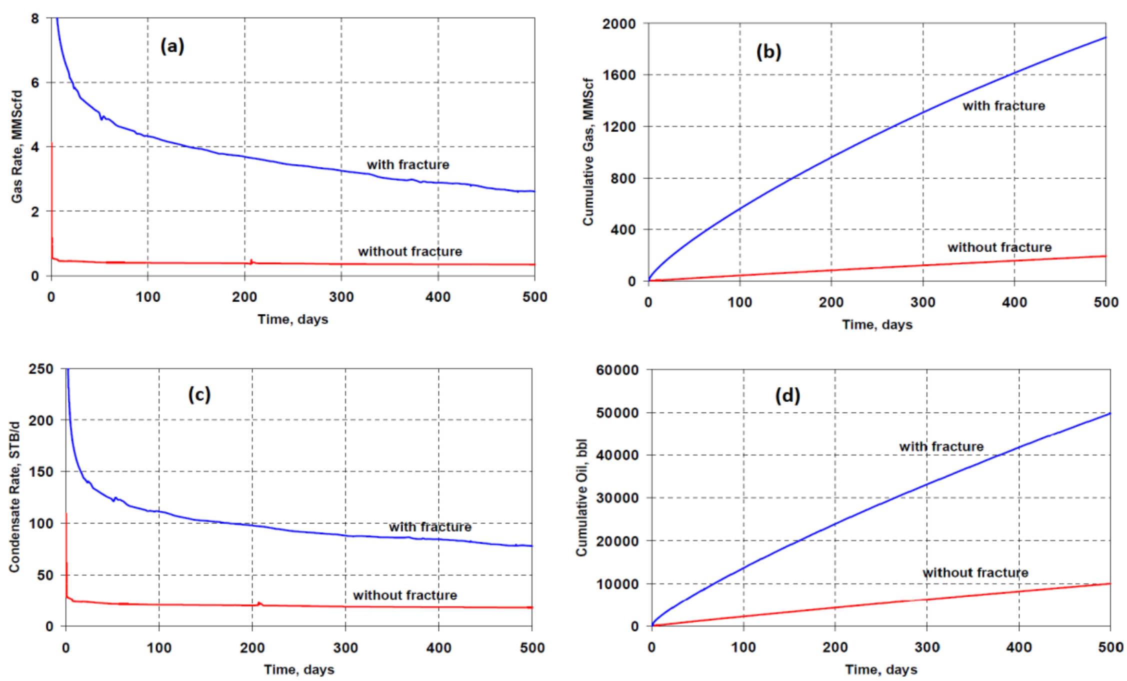

Fig. 2. Hydraulic fracture impact on a) Gas rate, b) Cumulative gas production, c) Condensate rate & d) Cumulative condensate production

Fig. 2.a explains the gas flow rates before and after performing a hydraulic fracture. After 500 days, there is an increase in the gas production rate by a factor of 8 due to the hydraulic fracture. Fig. 2.b indicates the same attitude, after 500 days, there is a noticeable increase in the cumulative gas produced by a factor of 9 due to the hydraulic fracture.

Fig. 2.c &d represent the behaviour of the condensate rate and cumulative condensate production which have similarity to gas. Condensate rate is higher than "without fracture" scenario by a factor of 4. On the same hand, cumulative condensate produced for the "with fracture" scenario is 5 times more than that for "without fracture" scenario.

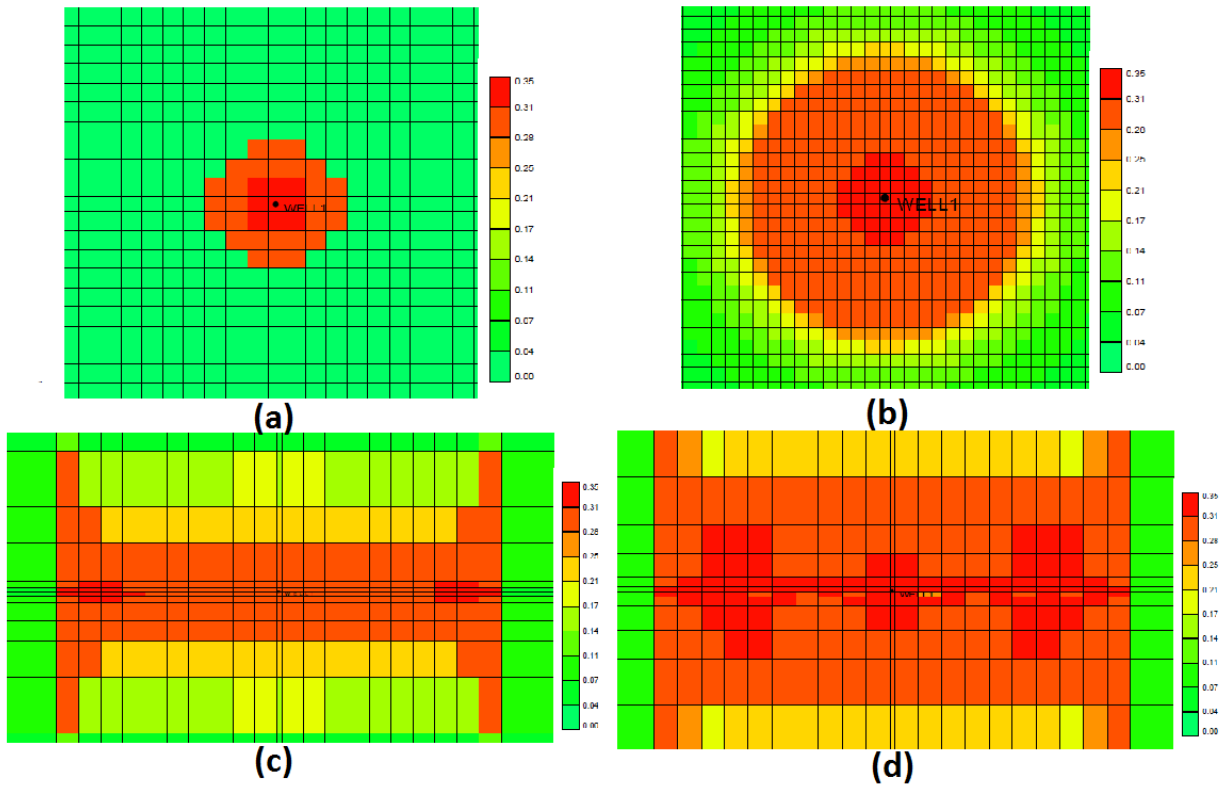

Fig. 3. Plan view of condensate saturation for a) "without fracture" after 800 days, b) "without fracture" after 3500 days, c) "with fracture" after 500 days & d) "with fracture" after 800 days

Fig. 3.a &b draw a plan view of original case condensate saturation profile before fracture after 800 and 3500 days. Fig. 3.c &d show the condensate saturation profiles after performing hydraulic fracture by 500 and 800 days. Both profiles are completely different. For the first one "without fracture" case, the flow is ideally radial. Therefore, a uniform circular condensate saturation profile around the wellbore can be noticed. But oppositely the condensate saturation profile for "with fracture" scenario is elliptical.

3.1. Data validation

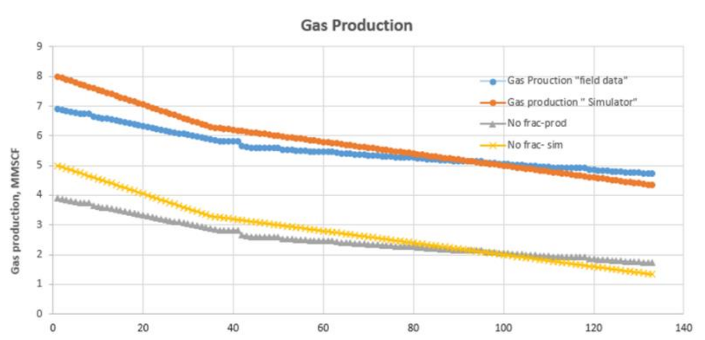

Fig. 4. Gas production log during 135 days for a) field data "with fracture", b) simulator data "with fracture", c) field data "without fracture" & d) simulator data "without fracture"

Fig. 4. showed the gas production data log obtained from the field and compared to data generated by the simulator. Hence the results achieved by the modelling is validated by the field data and there is a great enhancement in the gas production after performing the hydraulic fracture to the reservoir. An absolute error of 7% between field and simulator data which is accepted.

3.2. Effect of Non-Darcy flow

This part of the study will focus on considering the non-Darcy flow coefficient on the production of a gas condensate reservoir including the scenario "with fracture". Forchheimer non-Darcy flow correlation [7] will be used by the simulator Eq. (1)

$$\frac{\mu}{K}u + \beta\rho u^2 = -\frac{dp}{dr} \tag{1}$$

Geertsma correlation [8] Eq. (2) considered that with water causes a much higher β value compared to the dry gas.

$$\beta = \frac{0.005}{(KK_{rg})^{0.5}[\varphi(1 - Sw)]^{5.5}} \tag{2}$$

The results are summarised by having figures for gas flow rates, and productivity index for "with non-Darcy" and "without non-Darcy" flow. Fig. 4.a indicates the gas flow rate for "with non-Darcy" and "without non-Darcy" flow with time. Non-Darcy flow caused a reduction in gas flow rate to the half. Fig. 4.b indicates the productivity index with time for "with non-Darcy" and "without non-Darcy" flow. After five hundred days, productivity index for "with non-Darcy" is less than half the productivity index for "without non-Darcy". This change is not small to be neglected and on the other hand, give an explanation to the highly unreasonable values of productivity improvement after applying hydraulic fracturing. The values of gas speed are considered very high. Hence, the non-Darcy coefficient is very high and should be considered.

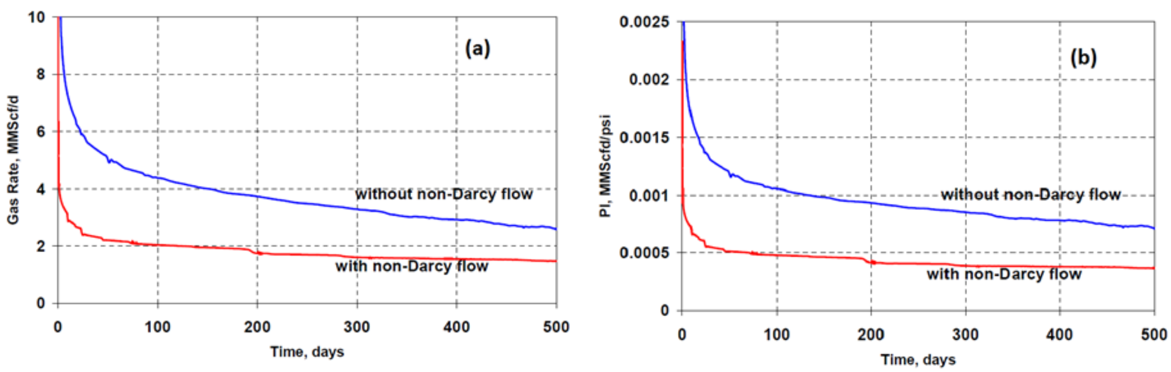

Fig. 4. Non-Darcy flow impact on a) Gas rate & b) Productivity index

3.3. Effect of trapping number

The trapping number is a vectorial summation of bond number and capillary number. The velocity and permeability in the fracture are very high compared to the reservoir. In this study, the bond number can be neglected and the only weighted factor is the capillary number due to high-pressure gradients near the well. Applying the same methodology by creating two scenarios, one with and other without trapping number. The three-phase Relative Permeability Model by Pope will be utilized to calculate relative permeability at different trapping numbers.

Table 3 shows the model parameters used in this study. In these simulations, water does not flow because it is assumed to be at residual water saturation. Simulations were performed with and without capillary number and the results plotted in Fig. 5.

Table 3. Parameters in three-phase relative permeability model

Parameter	Value	Parameter	Value	Parameter	Value
S_{wr}	0.3	K°_{rg}	0.3	τ	1
S_{or}	0.3	T_w	250	τ_o	1
S_{gr}	0.35	T_o	3000	τ_o	1
K°_{ro}	0.25	T_g	24556		

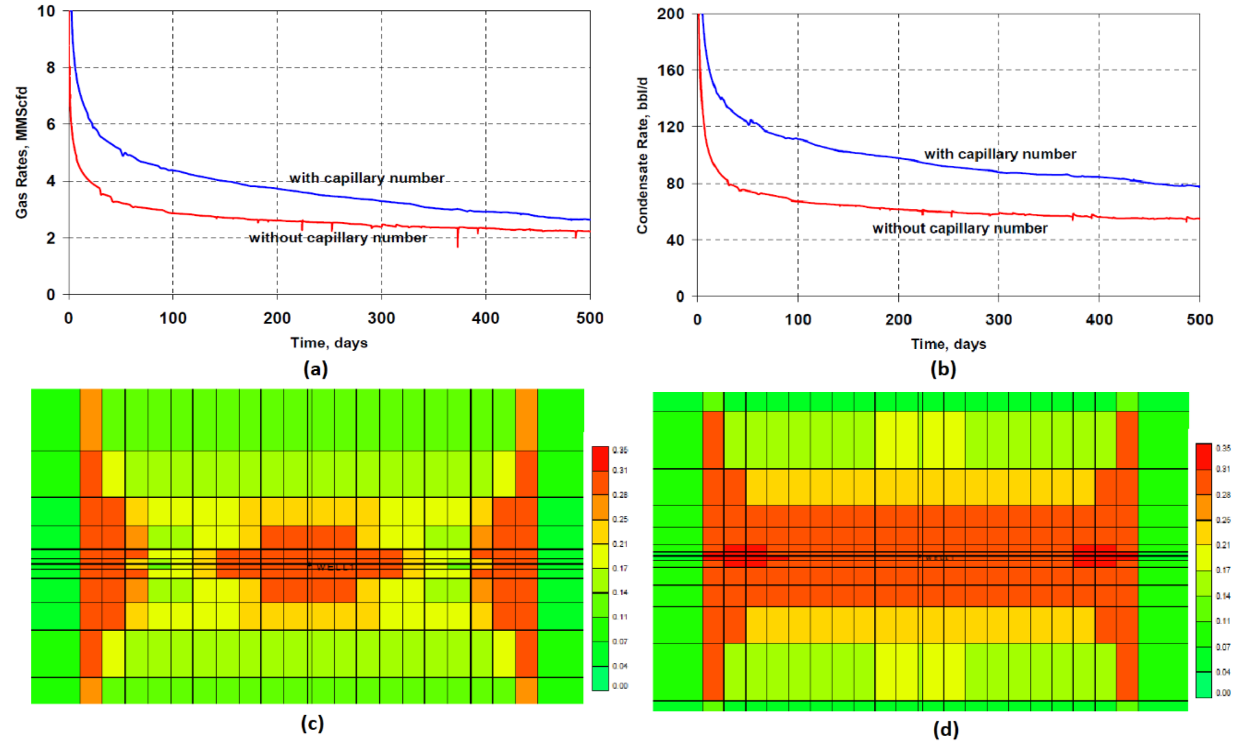

Fig. 5. Capillary number impact on a) Gas rate, b) Condensate rate. Plan view of condensate saturation around the fracture after 500 days c) without including capillary number & d) with including capillary number

Fig. 5.a shows the plot of gas flow rate with and without capillary number. Applying capillary number increase the expected gas flow rate by 1.6 at the end of 500 days of production and increase it much higher at the beginning of the production. This is because inside the fracture gas relative permeability will be much higher than in the reservoir itself.

Fig. 5.b shows the condensate rate with capillary number is higher than that without capillary number by a factor around 1.4. Fig. 5.c &d show the plan view of the condensate saturation distribution at the end of 500 days by applying or not a capillary number. It is noticed that when applying capillary number, there is more condensation around the fracture and this is because a larger volume of gas has been produced.

3.4. Effect of capillary pressure

The capillary pressure is defined as the ratio between the viscous force to the capillary force and it had been ignored for all the work done above is ignored. Section 2.4 studies the impact of capillary pressure on the production parameters of gas condensate reservoirs after performing a hydraulic fracture. The value of $k/_{\varphi}$ for this specific study is 5 in the reservoir and 37500 in the fracture. It worth to highlight that Gas water capillary pressure is identical to condensate water capillary pressure.

Due to low interfacial tension between gas and condensate, the gas-condensate capillary pressure will be considered zero. Fig. 6.a& b illustrate the little enhancement in gas flow rates and productivity index for a gas condensate well after applying hydraulic fracture with and without considering capillary pressure in the simulator. Gas production has an increase by an order of 1.15 meanwhile condensate production increase cannot be mentioned.

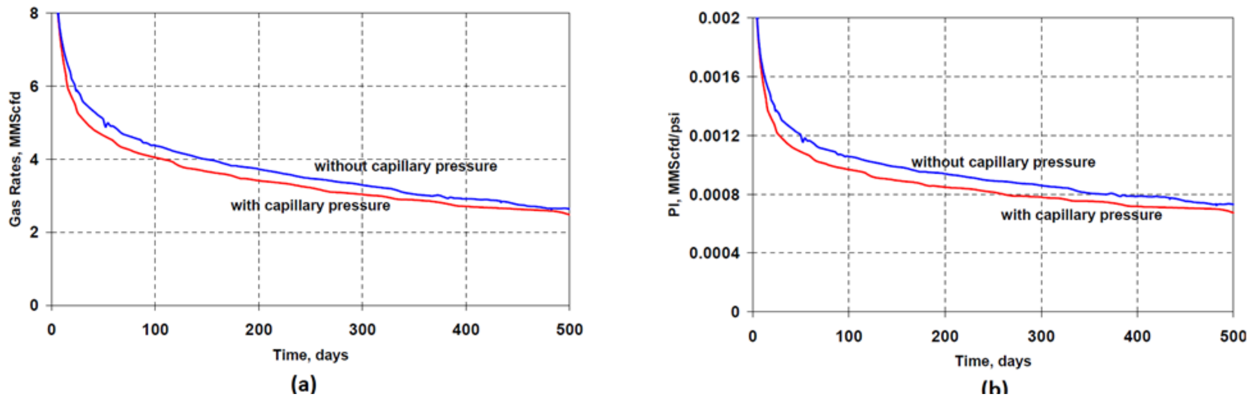

Fig. 6. Capillary pressure impact on a) Gas rate & b) Productivity index

4. Conclusion

The main objective of this study was to understand the impact of definite factors that affect the flow in a fractured gas condensate reservoir and hence affect the production. A good understanding of such factors was analysed by setting up a compositional model by the compositional simulator with all reservoir and fluid data, which was then utilized to be the base scenario for studying the impact of including non-Darcy condition, capillary number, and capillary pressure.

The basic results indicated that production of gas condensate reservoirs can be enhanced by a factor of 9 due to the impact of carrying out a hydraulic fracture. Many runs have been performed to deeply check the impact of such parameters (Non-Darcy coefficient, capillary number, and capillary pressure). The conclusion can be highlighted in the following points:

1. Non-Darcy flow has a dominant effect on the gas and condensate production after applying the hydraulic fracture. Considering the effect of Non-Darcy flow can give the right estimation of production rather than overestimation. Most of the work done previously have ignored the impact of non-Darcy flow.
2. The capillary number has an obvious impact on the production of a hydraulically fractured gas condensate well. It is an important application to catch the changes happened near-wellbore especially the gas relative permeability. Ignoring such option when performing compositional modelling can underestimate both gas and condensate production.
3. Capillary pressure has the least impact on the well productivity either for gas or the condensate. There are no changes, especially for condensate production, whether the capillary pressure is considered or not.

Symbols

p_c	*Pressure at the critical point (psi)*	q	*Gas flow rate (MMSCF/D)*	β	*Non-Darcy flow coefficient*
T_c	*Temperature at critical point (F)*	P_s	*Average reservoir static pressure (psi)*	Sc	*Condensate saturation*
k	*Adjustable pure component parameter*	P_{wf}	*Bottom hole flowing pressure (psi)*	Sw	*Water saturation*
ω	*Acentric factor*	ρ	*Density of the fluid (lb/ ft^3)*	φ	*Porosity*
r_e	*Equivalent radius (ft)*	K	*Permeability of the rock (md)*	N_T	*Trapping number*
J	*Productivity index (MMSCF/D/Psi)*	μ	*Newtonian viscosity of the fluid*	N_c	*Capillary number*

References

[1] Bagherzadeh A, Shahbazi K, Fattahi M, Gerami S. Investigating the applicability and effects of hydraulic fracturing technology on well productivity in one of the Iranian gas condensate reservoirs. Carbonates and Evaporites, 2017; 33(4)

[2] Kabir A, Ahmed M, Elew D. Three Dimensional Compositional Variation in Gas Condensate Reservoirs. SPE Middle East Oil and Gas Show and Conference 2019.

[3] Mott R. Engineering Calculations of Gas Condensate Well Productivity. SPE Annual Technical Conference and Exhibition 2002.

[4] Peaceman D. Interpretation of Well-Block Pressures in Numerical Reservoir Simulation With Nonsquare Grid Blocks and Anisotropic Permeability. Society of Petroleum Engineers Journal, 1983; 23(03): 531–543.

[5] Stryjek R, Vera JH. PRSV: An improved peng-Robinson equation of state for pure compounds and mixtures. The Canadian Journal of Chemical Engineering, 1986; 64(2): 323–333.

[6] Pope G, Wu W, Narayanaswamy G, Delshad M, Sharma M, Wang P. Modelling Relative Permeability Effects in Gas-Condensate Reservoirs With a New Trapping Model. SPE Reservoir Evaluation & Engineering, 2000; 3(02): 171–178.

[7] Forchheimer P. Wasserbewegung durch Boden. Z. Ver. Deutsch. Ing., 1901; 45, 1782-1788.

[8] Geertsma J. Estimating the Coefficient of Inertial Resistance in Fluid Flow Through Porous Media. Society of Petroleum Engineers Journal, 1974; 14(05), 445–450.

[9] Mohan J, Pope GA, Sharma MM. Effect of Non-Darcy Flow on Well Productivity in a Hydraulically Fractured Gas/Condensate Well. SPE Annual Technical Conference and Exhibition, 2009; 12(4) SPE-103025-PA.

[10] Moneim SS, Rabee R, Shehata AM, Aly AM. Modelling hydraulic fractures in finite difference simulators using amalgam LGR (Local Grid Refinement). North Africa Technical Conference and Exhibition 2012.

[11] Constantinides GN, Payatakes AC. Determination of the Effects of Capillary Number, Viscosity Ratio and Wettability on the Capillary Pressure-Saturation Relation Using an Advanced Pore Network Simulator. Abu Dhabi International Petroleum Exhibition and Conference 2002.

[12] Sedarat E, Taheri A, Ataei AR. The Effect of Hydraulic Fracturing on the Performance of Gas Condensate Systems. Petroleum Science and Technology, 2014; 32(8): 912-921.

[13] Al-Otaibi A, Wu Y. An Alternative Approach to Modeling Non-Darcy Flow for Pressure Transient Analysis in Porous and Fractured Reservoirs. SPE/DGS Saudi Arabia Section Technical Symposium and Exhibition 2011.

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