Simulation study of hydraulic fracturing in carbonate oil reservoir by using KGD model

Assoc. Prof. Dr. Khaled Benyounes[1]

Mohamed Kerrouche[2]

Prof. Dr. Abderrahmane Mellak[1]

[1] Laboratoire Génie Physique des Hydrocabures, Faculté des Hydrocarbures et de la Chmie, University M'Hamed Bougara of Boumerdes, **Algeria**
[2] Faculté des Hydrocarbures et de la Chmie, University M'Hamed Bougara of Boumerdes, **Algeria**

ABSTRACT

Many oil and gas low permeable reservoirs have been stimulated to enhance productivity. Acid fracturing is one of the commonly used well stimulation treatment in carbonate formations, such as limestone, dolomite, and chalk. Carbonate reservoirs are good candidates for acid fracturing since strong acids such as hydrochloric acid react easily with carbonate. The acid reacts within the fracture to create a differentially etched surface that will maintain a conductive pathway. Habitually, a pad fluid is injected ahead of the acid to initiate the fracture, and then an ordinary acid or fluid containing acid is injected. During the injection of pad, several models of fracture geometry have been used, which define the development of fracture geometry with time and treatment pressure. The dimension of a fracture affects the hydrocarbon production from the reservoir. Among the models used in the classic hydraulic fracturing are 2D models, where the KGD and the PKN models are most popular. In this wok, we have used the KGD model to simulate the geometry of fracture. We have showed that the half-length and width of fracture are affected by the injected time of PAD and flow index of fluid frac. An important half-length has been found for a low flow index with a maximal injection time. The increase in flow index leads to the growth of width. The half-length of the fracture increases gradually as the increase of the pumping rate of the fluid. The initial rate of fractured wells increases with the injection time by fixing the injection rate and for the same injection time, the production presents an optimum point. It is noted that the penetration of the acid increases with increase in flow index. The effect acid contact time on the initial oil flow rate and productivity index ratio were also investigated successfully

Keywords: carbonate, oil, acid fracturing; stimulation, productivity index

INTRODUCTION

Hydraulic fracturing is a old technology in the oil and gas industry, it was originated from petroleum industry since 1947. Hydraulic fracturing is a old technology in the oil and gas industry. It was originated from petroleum industry since 1947. Nowadays, hydraulic fracturing has become very common technique implemented each year in different geological formations such as low permeability reservoirs, weakly consolidated formations, coal beds for methane extraction, naturally fractured reservoirs. The stimulation technique with regard to petroleum production refers to a gamut of activities used to improve the petroleum production of different hydrocarbon reservoirs (conventional and unconventional) by increasing reservoir permeability Economides et al., 2013). It exists two different situations that allow to the application of simulation technologies. The first is caused by the formation damage induced by the drilling phase and the second is due to production operations (Economides et al., 2013). Hydraulic fracturing (acid or proppant) is usually necessary to increase productivity index of the well especially in low permeability reservoir and increase the flow of oil and gas from wells drilled that have been damaged. Then, the permeability is diminished because the pores have been plugged and the fluid flow in this portion may be substantially reduced. To stimulate a damaged reservoir, a short, conductive hydraulic fracture is often the desired solution[1]. Acid fracturing is a stimulation technique for hydrocarbon fields widely used by the oil industry in order to increase the production from a well[2]. The use acid to stimulate a carbonate formation is not a recent practice, it dates back 1895.Acid fracturing is frequently used in carbonate reservoirs, i.e. those having a high CaCO3 content. Acid fracturing in carbonate reservoirs knows a success because of high degree of natural fractures generally present and the problems of placing proppant due to fluid leak-off into the natural fracture formations. Operationally, acid fracturing is easy because the propping agents are not used, where the risk of a screen-out and subsequent problems of proppant flowback and cleanout from the wellbore are excluded[3]. Usually, a viscous pad fluid is injected before the acid to initiate the fracture and create the desired fracture geometry(i.e., length, height, and width) , then followed by the injection of lower viscosity into the fracture[4].Generally, conductivity of acid-etched fractures have high ,but the penetration is quite limited. By cons, the propped fractures have limited conductivity with fracture more developed. However, The improvement of acids performance, such as organic acid, gelled acid, emulsion acid, foam acid, self-diverting acid, and Nitric Acid Powder(NAP),can also help achieve a long, effective penetration[3]. Thus, it is very substantial to study hydraulic fracturing design before proceeds any hydraulic fracturing stimulation treatment for the well. The design of hydraulic fracturing treatment is used as a prediction tool for the optimization of fracture geometry. Before a fracturing treatment, a engineering computation must be done regoursely, these consist of calculation of viscosity and volume, injection rate, volumes of different phases of the job, surface and bottomhole injection pressure, hydraulic horsepower required at the surface, and the mechanical equipment needed for this[5]. The designs for acid fracturing operation are nearly similar from those applied to hydraulic fracturing with propant agent. The main objectives in acid fracturing design are the penetration distance of live acid down the fracture (acid penetration length) and the conductivity created by the fracture. These parameters are needed for predicting productivity after treatment[6-8].Because of its importance in predicting the success of stimulation , acid penetration into a fracture has been investigated by several authors[9-12].

FRACTURE PROPAGATION MODEL

For non-Newtonian fluid, the KGD-C represents the association of the Carter model and the KGD model, the maximum width equation is as follows:

$$w_f = 11.1^{\left(\frac{1}{(2n+2)}\right)}\ 3.24^{\left(\frac{n}{(2n+2)}\right)} \left[\frac{1+2n}{n}\right]^{\left(\frac{n}{(2n+2)}\right)} k^{\left(\frac{1}{(2n+2)}\right)} \left[\frac{q_i^n\ {x_f}^2}{E'\ h_f^n}\right]^{\left(\frac{1}{(2n+2)}\right)} \quad (1)$$

Where E' is the plane strain modulus and is related to Young's modulus, E, by

$$E' = \frac{E}{(1-\nu^2)} \quad (2)$$

The parameters n' and k' are the power law rheological properties of the fracturing fluid. qi is the injection rate, hf is the fracture height, x f is the fracture half length and ν is the Poisson ratio. The average width can then be calculated by multiplying the maximum width by a constant shape factor.

$$\bar{w} = w_f\ \frac{\pi}{5} \quad (3)$$

Using the Carter II solution and considering fluid leak-off and spurt loss, the following relation between fracture geometry and fluid injection is as following:

$$x_f = \frac{(\bar{w} + 2Sp)qi}{4\, C_l^2 \pi h_f}\left[\exp(\beta).erfc(\beta) + \frac{2\beta}{\sqrt{\pi}} - 1\right] \quad (4)$$

With :

$$\beta = \frac{2C_l\sqrt{\pi\, ti}}{(\bar{w} + 2sp)} \quad (5)$$

Fracture Conductivity Calculation

The average ideal width represents the total volume of rock dissolved divided by the fracture area, which can be calculated as follows:

$$W_a = \frac{X\,V}{2\rho\,(1-\varphi)h_f\,x_f} \quad (6)$$

where X is the acid dissolving power, V is the total volume of acid injected, h_f is the fracture height, and x_f is the fracture half-length.

The ideal fracture conductivity is:

$$\left(W_{kf}\right)_i = \frac{(W_a)^3}{12} \quad (7)$$

Neriode and Kruk have developed a formula to calculate the fracture conductivity which take into account the closure pressure, the equation is:

$$C_{fw} = C_1 e^{-C_2\, p_c} \quad (8)$$

$$C_1 = 2.94\,10^{-4}\left(W_{kf}\right)_i^{0.822}$$

$$C_2 = (36.82 - 1.885\ln(S_{roche})).10^{-7} \quad \text{if } 0 < S_{rock} < 1.38\,.10^8 \text{ Pa}$$

$$C_2 = (9.1 - 0.404\ln(S_{roche})).10^{-7} \quad \text{if } 1.38\ 10^8 < S_{rock} < 3.45\ 10^9 \text{ Pa}$$

Where C_{fw} is fracture conductivity (md-ft), $(W_{kf})_i$ is average actual etched width (in.), p_c is closure pressure (psi), C_1 and C_2 are constants as defined above, and S_{rock} is rock embedment strength (psi).

Prediction of oil flow rate and productivity index ratio

The fracture pseudo-skin effect, S_f, can be assessed by using the Cinco-Ley and Samaniego equation[13]:

$$S_f = F - \ln\left(\frac{x_f}{r_w}\right) \quad (9)$$

$$F_{CD} = \frac{k_{fw}}{k\,x_f} \quad (10)$$

$$U = \ln(F_{CD}) \quad (11)$$

$$F = \frac{(1.65 - 0.32U + 0.116U^2)}{(1 + 0.18U + 0.064U^2 + 0.005U^3)} \quad (12)$$

Where F_{CD} is the dimensionless fracture conductivity, k_f is the fracture permeability, k is the reservoir permeability, and r_w is the wellbore radius.

The oil flow rate and productivity index ratio are estimated from the following equation:

$$q_o = k\, h_f\left(P_e - P_{wf}\right)\left[141.2\ \mu\ B\ \ln\left(\frac{r_e}{r_w}\right) + S_f\right]^{-1} \quad (13)$$

$$\frac{J}{J_0} = \frac{\ln\left[\frac{r_e}{r_w}\right]}{\ln\left[\frac{r_e}{r_w}\right] + S_f} \quad (14)$$

RESULTS AND DISCUSSION

Sensitivity analysis for treatment parameters

The sensitivity study is applied to a tight carbonate oil formation. The reservoir data and treatment parameters in the table 1 have been taken from literature[14, 15]. In this study, an integrated program was elaborated using Matlab 2010.

Table 1 Reservoir and fracture treatment data

Parameter	Value	Parameter	Value
Pe	3500 Psi	Deff	$4*10^{-8}$ m^2/sec
K	12.5 md	X pour HCL 15%	0.082
Re	900 ft	ρ acide	$1.07*10^3$ Kg/m^3
Φ	0.15	t acide	30 -75 min
σ_c	4000 Psi	ti	60 -200 min
S_{roche}	60 000 Psi	n	0.2-:0.9
E’	6.13 10^{10} Pa	qi	10 -50 BPM
γ	0.25	C_L	$9.84*10^{-6}$ m/ ($s^{1/2}$)
hf	51.8 m	Sp	0
μ	10 cpo	K’	2.87 Pa.s^n
Bo	1.15 RB/STB		

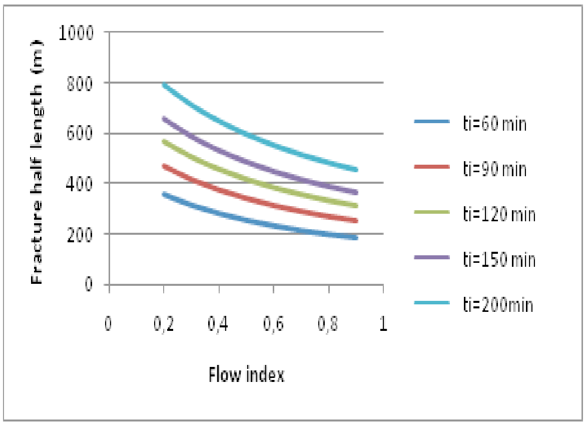

Fig.1 Fracture half length as a function of flow index for different ti

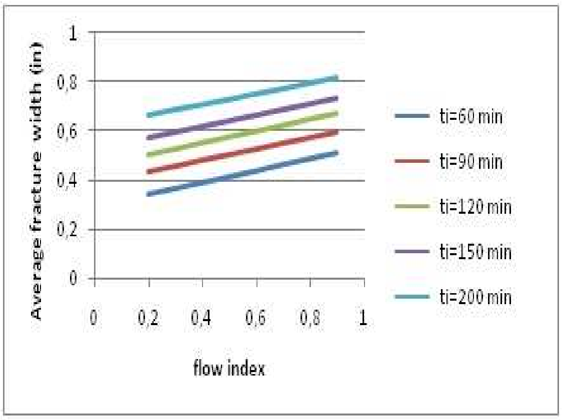

Fig. 2: Average fracture width versus power law exponent for different ti

The effect of flow index on fracture half-length for various values of injection time is given in figure 1. For a given injection time, It is to highlight that the fracture half-length diminishes with increasing power law exponent. This obtain result seems interesting, this allows to optimize the value of flow index (n) from a fracturing design program. To reach high fracture half-lengths, it is sufficient to choose a fracturing fluid with a flow index lowest possible. For this, the nature of the polymer and its concentration, and the type of crosslinking agent must be taken into consideration.

Figure 2 illustrates the influence of flow index on average fracture width for different values of injection time. It can be observed that the average fracture width increases with increasing flow index for different injection times. It is also to note that it exists an optimum value of flow index which to lead to optimize the fracture lengths and average fracture widths. For a given viscosity of fluid frac, It is clear that with an increase of injection rate and time, the fracture width will increase . The rheological model based on the power law equation is one of the most popular in use today , the apparent viscosity of the fracturation fluid can be determined from this eqation.Thus, optimum flow index can help design the apparent viscosity, satisfying the leakoff coefficient of formation. Acid fracturing could be performed to reduce the skin factor and improve the near wellbore area. As we can seen from figure 3, whatever the value range of flow index (0.2-0.9), all the skin factors is negative at different injection times. This factor is minimized for a non-Newtonian fluid. It is reasonable that the decrease in the flow index induces to the increase in the half-length of the fracture, and consequently, the pseudo-skin due to acid fracturing decreases. According to the results of this simulation, it was noticed that the fracture is not damaged; it is marked by a negative skin for different values of power law exponent.

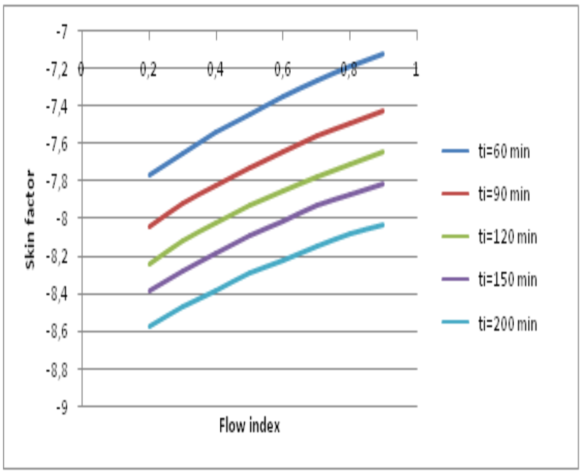

Fig.3 Variation of the pseudo-skin of the fracture as a function of the flow

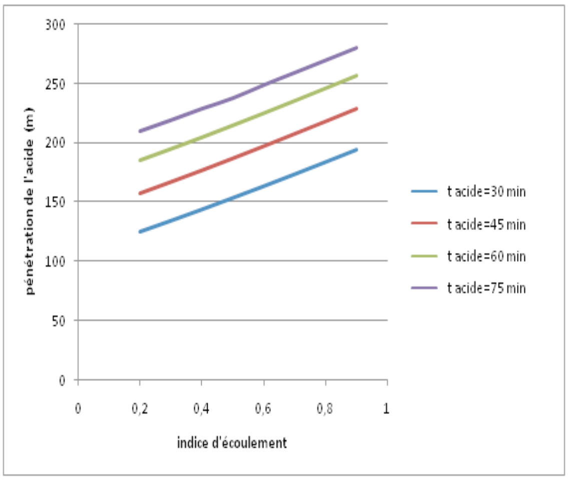

Fig.4 Acid penetration as a function of flow index

The impact of flow index on acid penetration for different values of acid contact time and fixed value of injection rate is given in Figure 4. This indicates that the acid penetration rises with increasing flow index for various acid contact times. It is interesting to note that flow index and acid contact time promote in creating fracture and in etching the carbonates and finally affecting the skin factor. Figure 5 provides the effect of power law exponent on initial oil flow rate for different values of acid contact time and for fixed value of injection rate. The prediction of initial oil flow rate was based on the power law exponent, injection rate and time, and acid contact time. The examination of the evolution of the initial oil flow rate shows clearly that its maximum value correspond for n=0, 2 for all values of tacid. This result is important since the higher oil production is directly linked at maximum acid contact time; this is the indication of the success of stimulation treatment. From this analysis, a designer must optimize all the parameters related to the operation of stimulation, this will enable it to obtain the limit values of each treatment parameter. Figure 6 shows that the productivity index ratio decreases progressively with increasing flow index for different values of acid contact time and for fixed values of injection rate. It is interesting to indicate that the power law exponent of acid fracturing fluid must have an optimum value that has to be evaluated, satisfying all constraints. It can be seen that the value of the production gain varies in the interval 2.9 to 3.4. These results are very important because it will be said that a stimulation operation is successful if the productivity is multiplied by two.

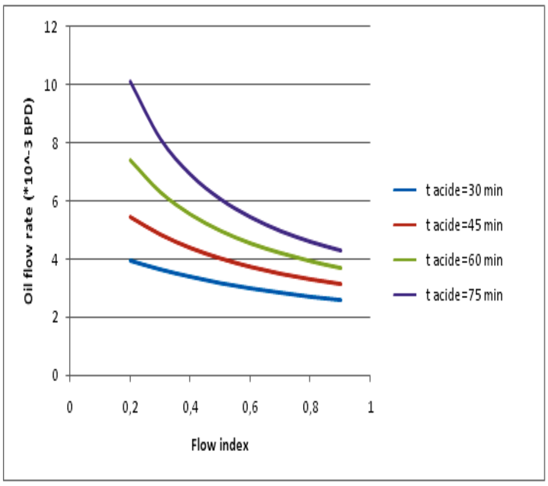

Fig.5 Oil flow rate as a function of flow index

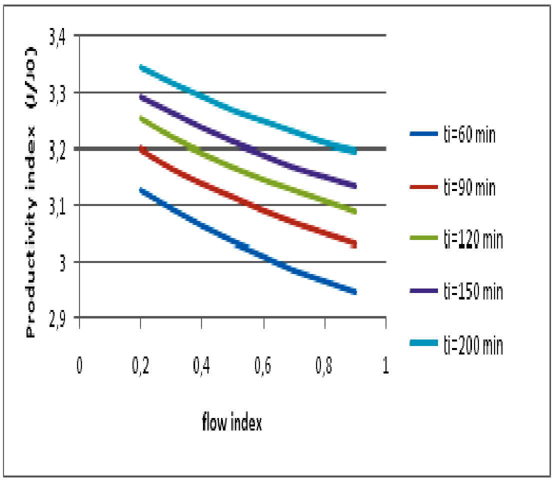

Fig.6 Productivity index as a function of flow index

For fixed value of injection rate, the effect of power law exponent on etched width for various values of acid contact time is shown in Figure 7. It is obvious that the etched width increases with increasing power law exponent for different acid contact times. It is interesting to note that flow index and acid contact time play an important role in creating fracture and in etching the carbonates and finally affecting the fracture conductivity. Figure 8 demonstrates the effects of acid contact time and flow index on fracture conductivity. Conductivity increases with increasing contact time. It is to be expected that a greater etched width would be created by additional acid.

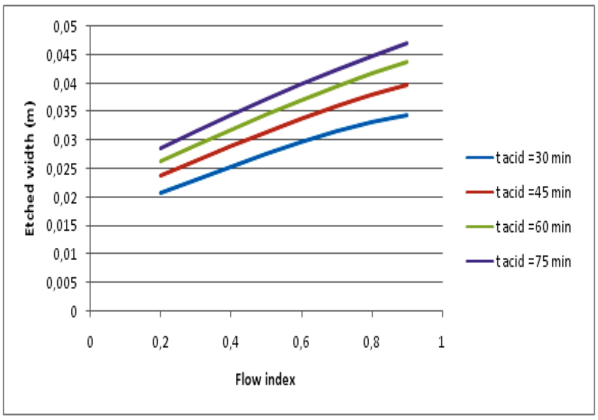

Fig.7 Etched width as a function of flow index

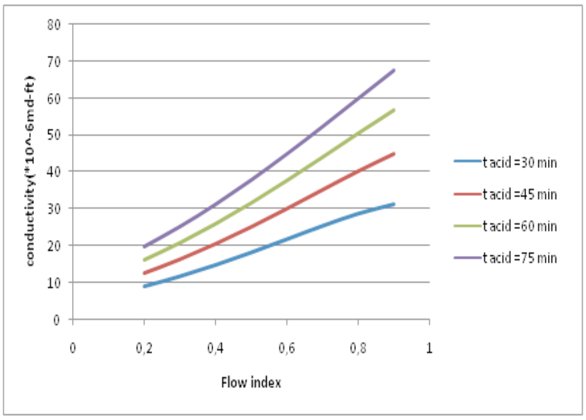

Fig.8 Conductivity as a function of flow index

CONCLUSION

The use of fracture propagation KGD model can provide a clearer understanding of the effects different parameters on the fracture geometry and the conductivity. The effects of fluid rheology represented by the flow index on the fracture half-length, average fracture hydraulic width, average fracture etched width, acid penetration, and initial oil flow rate can help determine a reasonable optimum value of the flow index. The effects of fluid injection rate on fracture half-length, average fracture width, average etched width, and initial oil flow rate can also facilitate the task of the designer to determine the operating value of injection rate and the duration of the stimulation operation for specific objectives of treatment by acid fracturing. The effects of both fluid injection time and acid contact time on the initial oil flow rate and productivity index ratio were also studied fruitfully, which allows the possibility of improving production. Finally, a comparison of different acids was offered, allowing the selection of the most appropriate.

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