

# Shale Gas Productive Volume Optimization



Adamu Umar Ibrahim and Berihun Mamo Negash

**Abstract** Recently, a modified mathematical model was presented in order to determine the productivity of multi-fractured shale gas wells. However, the considerable challenge of the model was assuming an average fracture width for the determination of the practical fracture geometry of the stimulated reservoir volume. This challenge led to over prediction of the gas well. Therefore, this paper presents a simple and accurate method using a pseudo-3D model to determine the fracture width in shale gas reservoirs. The method utilized the hydraulic fracturing propagation capacity of the MATLAB software to visualize the fracture geometry, which includes the fracture height, fracture length, and the fracture width. So, the obtained fracture width can be incorporated with analytical models to predict long term productivity for multistage fractured shale gas wells. An accurate result for the productivity will assist in determining the ultimate gas recovery, propped volume, optimal fracture length, fracture spacing and predict the future performance of the well.

**Keywords** Shale gas · Hydraulic fracturing · Fracture geometry

## 1 Introduction

The combination of horizontal drilling and hydraulic fracturing technologies has already boosted the exploitation of shale reservoirs by many countries around the globe [1]. This unconventional resource compliment the hydrocarbon demand all over the world. Therefore, these technologies are revolutionary and will remain vital in shale gas production [2].

One of the significant challenges in shale gas production optimization is the forecasting of long-term productivity of shale gas wells. Currently, three types of models

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are applied to predict productivity. These models are basically: analytical transient, numerical and empirical models [3, 4]. Recently, a simple model was presented, which successfully predict productivity with less than 3% over prediction. The analytical model is applied in pseudo-steady state flow conditions. However, the fracture width is assumed and computed as an average in the model [4]. Therefore, there is a need to find a more reliable way of obtaining a fracture width that will close the overprediction gap of the model. An accurate fracture width is vital to proper field performance prediction, fracture completion design and adequate placement of proppants in shale gas wells [5]. Also, this will give rise to designing a fracturing treatment that will propagate in a more optimal direction and avoid unnecessary damage to the subsurface environment.

This paper presents a simple and more accurate method using a pseudo-3D model to determine the fracture width in shale gas reservoirs. The model gives the visual result of the fracture geometry using MATLAB software. So, the obtained fracture width can be incorporated with the latest analytical model to forecast the long-term productivity of multistage fractured shale gas wells.

## 2 Methods and Procedures

Multistage hydraulic fracture in horizontal wells initiates many fractures from each perforation cluster. These change the formation stress field and affect the propagation of hydraulic fracture. Also, the low-viscosity fracturing fluid will leak off from the surface of hydraulic fracture into the reservoir, therefore, increasing its pressure. Consequently, the natural fractures will be stimulated by the induced stress. If the shear stress is greater than the shear strength, shear failure occurs [6]. Likewise, if the natural fractures inner pressure is greater than the tensile strength, tensile failure happens [7, 8]. Therefore, these increase the shale reservoir permeability. The fracture geometry, which has the fracture height, length, and width, directly control most of the productivity of the well [9, 10]. Proper design of these parameters aid in gas production optimization during fracturing treatment design.

Furthermore, it is good to visualize the fracture geometry using the pseudo-3D model in MATLAB software to determine the fracture width. The P3D model is compared with the well-known KGD and PKN models (Table 1).

Where,  $Q_g$  = production rate of the gas (MScf/D);  $n_f$  = number of fractures;  $\mu$  = viscosity of the fluid (cp);  $T$  = temperature of the formation ( $^{\circ}$ R);  $km$  = permeability of matrix (md);  $h$  = reservoir thickness (ft);  $p$  = average reservoir pressure (psia);  $p_w$  = wellbore pressure (psia);  $e$  = exponential function;  $xf$  = fracture half-length (ft);  $k_f$  = permeability of fracture (md);  $w$  = average fracture width (in);  $S_f$  = fracture spacing (ft).

**Table 1** KGD, PKN & P3D models comparison

MODEL: KGD/2D	Assumptions
$L = 0.48 \left( \frac{8GQ^3}{(1-\nu)\mu} \right)^{1/6} .t^{2/3}$ $W_0 = 1.32 \left( \frac{8(1-\nu)Q^3\mu}{G} \right)^{1/6} .t^{1/3}$ $Pw = \sigma_{min} + 0.96 \left( \frac{2G^3Q\mu}{(1-\nu)^3L^2} \right)^{1/4}$	<ul style="list-style-type: none"> <li>• Height is constant</li> <li>• A plane strain fracture in the horizontal plane</li> <li>• Viscous and Newtonian fracturing fluid</li> <li>• Elasticity theory used</li> <li>• No leak off into the formation</li> </ul>
<p>MODEL: PKN/2D</p> $L = \left( \frac{Q}{\pi c_1 h} \right) t^{1/2}$ $W_0 = 4 \left( \frac{2(1-\nu)Q^2\mu}{(1-\nu)\mu} \right)^{1/4} .t^{1/8}$ $Pw = 2.5 \left( \frac{G^4Q^2\mu}{(1-\nu)^4h^6} \right)^{1/5} .t^{1/5}$	<ul style="list-style-type: none"> <li>• Plane strain fracture</li> <li>• The fracture toughness does not influence the fracture geometry</li> <li>• No leak off into the formation</li> </ul>
<p>MODEL: PSEUDO-3D</p> <p><i>Penetration depth</i>(R) =</p> $0.548 \left( \frac{GQ^3}{G} \right)^{1/9} .t^{1/9}$ $W_0 = 1.32 \left( \frac{8(1-\nu)Q^3\mu}{G} \right)^{1/6} .t^{1/3}$ $Pw = \sigma_{min} - \frac{5}{4\pi} \frac{GW_0}{R} \ln \left( \frac{r_w}{R} \right)$ <p>G = shear modulus (psi); Q = pumping rate (bbl/min); W<sub>0</sub> = maximum width (ft); ν = poisson ratio; L = fracture length (ft); r<sub>w</sub> = wellbore radius (ft); σ<sub>min</sub> = minimum stress (psi); μ = fluid viscosity (cp)</p>	<ul style="list-style-type: none"> <li>• The vertical stress distribution is uniform</li> <li>• The shape of fracture is elliptical</li> <li>• No leak off into the formation [11]</li> </ul>
<p>MULTIFRACTURED SHALE GAS WELLS PRODUCTIVITY</p>	$\frac{5.87 \times 10^{-5} n_f k_m h (\dot{p}^2 - p_w^2)}{\mu T S_f \sqrt{c} \left[ \frac{1}{(1-e^{-\sqrt{cx_f}})} - \frac{1}{(3x_f \sqrt{c})} \right]}$ $c = \frac{96k_m}{k_f w S_f}$

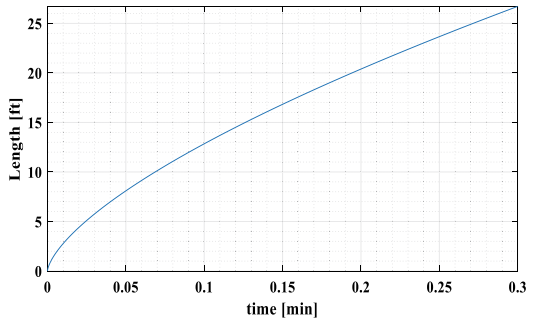
### 3 Results and Conclusions

The single hydraulic fracture propagation is first shown to compare a P3D model with the conventional KGD and PKN model. The visualized fracture width provides the quantitative result of the width, which makes it easy to be applied in the productivity model.

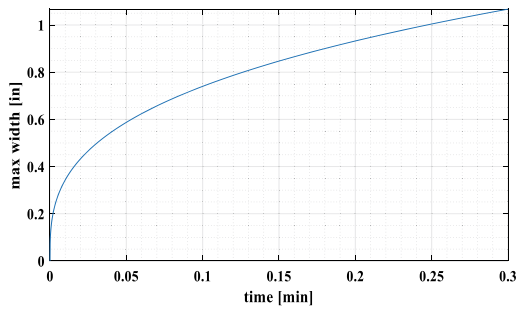
### 4 Discussion

From Figs. 1, 2, 3, 4, 5, 6, 7 and 8, it is shown that the length of the fracture improves with greater rate than the fracture width of the fracture, which increases

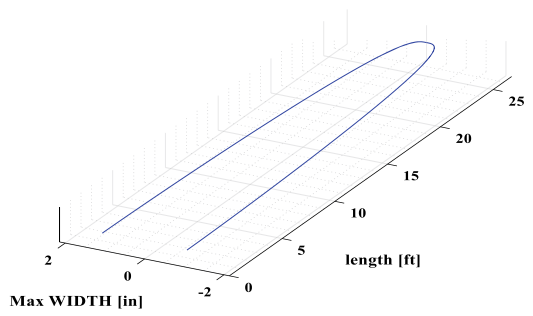
**Fig. 1** Fracture length against time (KGD)



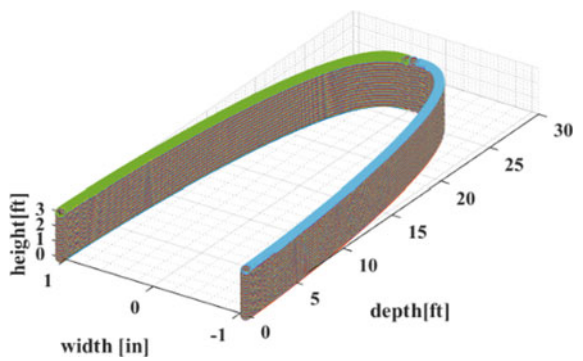
**Fig. 2** Max width against time (KGD)



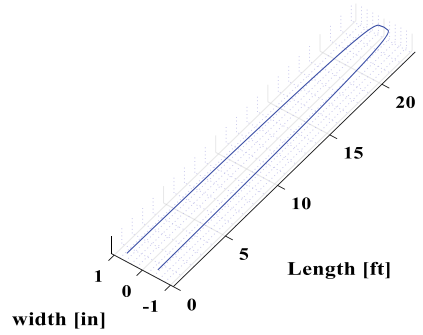
**Fig. 3** Max width against length (KGD)



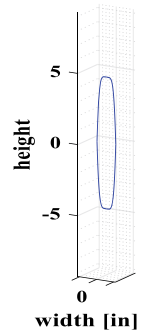
**Fig. 4** KGD in 3D



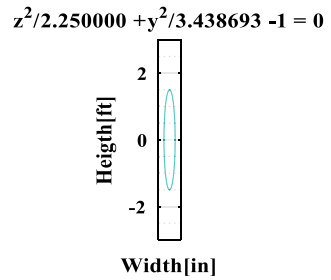
**Fig. 5** Fracture width against length (PKN)



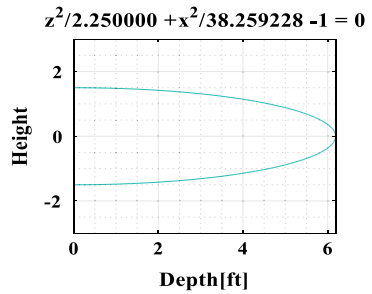
**Fig. 6** Fracture width against height (PKN)



**Fig. 7** Fracture height against width (P3D)

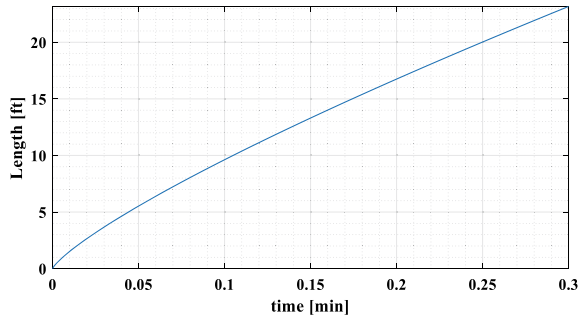


**Fig. 8** Pseudo-3D model

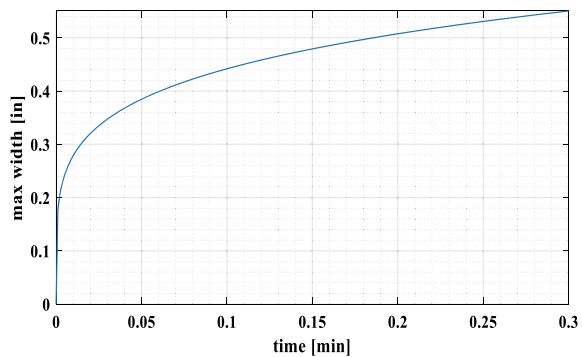


in proportional to  $t^{1/3}$ . These models show a curvy tip which indicates that in the KGD model, the effect of the tip of the fracture is not large. Both KGD and PKN showed an approximation the width of the fracture and length. The pseudo-3D model forecasts a complete ellipsoid in 3D space at a time which can be seen in Figs. 9, 10 and 11. Therefore, the P3D model is good for fracture propagation modelling. The model can display the variation of the fracture height with length as the fracture propagates.

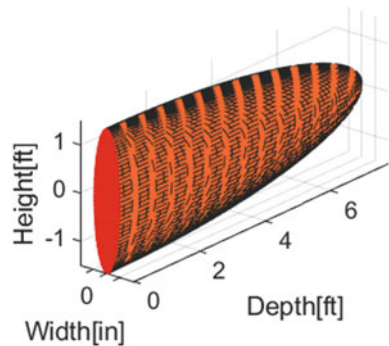
**Fig. 9** Fracture length against time (PKN)



**Fig. 10** Max. width against time (PKN)



**Fig. 11** P3D predicted shape



The fracture width is directly taken from the visualized fracture geometry and subsequently inputted in the multi fractured shale gas wells. This method is more dependable to determine the fracture width of a fractured shale gas reservoir to determine the productivity of gas wells. Also, it can be applied in order to optimize production by adequate fracture spacing and proppant placement.

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