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RESEARCH ARTICLE

Sensitivity Analysis of Geomechanics Influence on The Success of Hydraulic Fracturing in Shale Gas Reservoir

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Abstract

Shale gas has a permeability of <0.1 mD and a porosity of around 2% - 8% to produce gas that rises to the surface through hydraulic fracturing and horizontal drilling. Geomechanics is one of the important factors that influence the success of a hydraulic fracturing job. Technology in fractures makes geomechanics a clear factor in predicting the success or failure of rocks in deformation and knowing the properties that will be faced by fracture fluids which will later be used to see the effectiveness of fracture fluids in resisting fractures. High operational costs need to be studied further to determine the parameters that affect hydraulic fracturing work, especially from the geomechanical aspect to minimize production failures and work safety. The research conducted this time focuses on the sensitivity of geomechanical parameters by using CMG (GEM) reservoir simulations for reservoir models and conducting Response Surface Methodology (RSM) in selection and ease when applied in the field prior to the hydraulic fracturing process. In this sensitivity study carried out on 5 parameters namely stress, Poisson's ratio, Young's modulus, biot coefficient, and pore pressure. The geomechanical parameter that has the most influence on hydraulic fracturing work based on the sensitivity results carried out through 500 data sets using the Analysis of Variance obtained R2 = 0.99 with the results based on the importance value of the pore pressure variable of 3.8. Then Young's modulus is 0.28, stress is 0.12, Poisson's ratio is 0.08, and biot coefficient is 0.04.

Keywords: Hydraulic Fracturing, Shale Gas, CMG, Response Surface Methodology (RSM), Geomechanics.

1. Introduction

Currently, the development of Artificial Intelligence is very actively developing and entering into all aspects of life including the oil and gas industry. The application of Artificial Intelligence is very helpful and facilitates human life. This is because Machine Learning and Artificial Intelligence are more efficient and economical and fast when performing manual correlation and integration.

Shale gas has a very complex rock structure, so it is important to study rock mechanics and the factors that influence the direction of fracture in shale gas (Tao et al., 2021). Fracture directions can be determined based on design, fracturing fluids, and geomechanics (Bastos Fernandes et al., 2020). This parameter determines the success of the Hydraulic fracturing work. In addition, geomechanics is used to evaluate the interaction between rock stress and pressure, mechanical properties, and geometry. Geomechanics plays an important role in determining the design and optimizing the stimulation of hydraulic fracture in shale gas reservoirs (Nagel, 2019).

Technology in fracking makes geomechanics a clear factor in predicting the success or failure of rocks in deformation and knowing the properties that will be faced by fracturing fluids which will later be used to see the effectiveness of rocks against fracturing fluids in holding fractures. Development challenges and decision-making in the unconventional field are due to uncertainty in the sub-surface and economic factors so it is necessary to study geomechanical aspects to minimize production failures (Tamimi et al., 2020). A combination of reservoir simulation models and respon surface methodology an be used to analyze the sensitivity of parameters so that it becomes an alternative to optimize response (Liu et al., 2018).

This study focuses on predicting the parameters that affect rock geomechanics during hydraulic fracturing work which has previously been calculated using the Computer Modeling Group (CMG-GEM) Software and conducting a sensitivity test with the Response Surface Methodology.

2. Methodology

2. 1 Research Methodology

In order to meet the needs of the dataset that will be used to conduct sensitivity studies using the Response Surface Methodology (RSM). In this study, To begin, run a reservoir simulation with Reservoir Simulation Software (CMG) to model the basic case and CMOST to assist with modeling iterations.

Table 1. Reservoir and Fracture Properties

Properties	Unit	Value
The Model Dimensions	Grid	66 x 20 x 3
The Model Dimenssions	Ft	9900 x 4000 x 45
Reservoir Pressure	Psi	2950
Reservoir Temperature	F	150
Matrix Porosity	Fraction	0.06
Matrix Permeability	MD	0.00015
Rock density	lb/ft3	120
Fracture half length	Ft	300
Rock Comparability	psi-1	$3x10^{-6}$
Fracture Spacing	Ft	100
Fracture Conductivity	Md.ft	1
Bottom Hole Pressure	Psi	500

Source: (Jamshidnezhad, 2015; Roussel & Sharma, 2011).

In order to meet the needs of the dataset that will be used to conduct sensitivity studies using the Response Surface

Methodology (RSM). In this study, the authors first carried out reservoir simulations using Reservoir Simulation Software (CMG) to model the base case (Fig.1) and CMOST which functioned to help carry out modeling iterations.

This study uses secondary data on Barnett's field obtained from (Jamshidnezhad, 2015; Roussel & Sharma, 2011) as the base case. The data are as follows (Table 1 and Table 2).

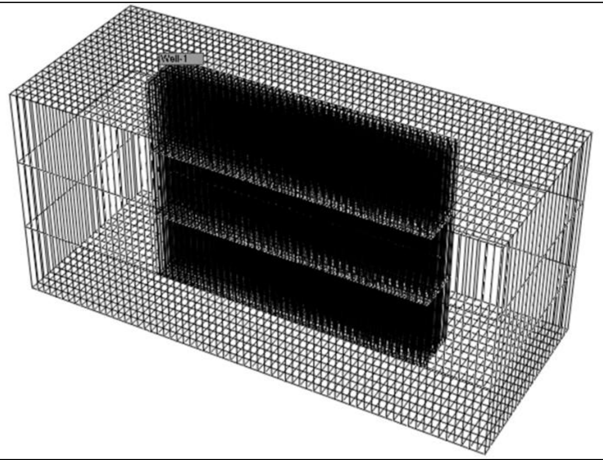

Fig 1. Reservoir Model

Table 2. Value Parameter

Properties	Value	
Stress	6000	(T. H. Kim et al., 2016)
Poisson Ratio	*0.25*	(T. H. Kim et al., 2016)
Modulus Young	*7.3 x10^6*	(Roussel & Sharma, 2011)
Biot Coefficient	0.7	(Jamshidnezhad, 2015)
Pore Pressure	5463	(Jamshidnezhad, 2015)

Response Surface Methodology is a set of statistical techniques that improve and optimize processes (Myers, R.H.; Montgomery, 2009). According to (Liu et al., 2018), a combination of reservoir simulation models and RSM can be used to analyze the sensitivity of parameters. In this study, a sensitivity analysis of geomechanical parameters was carried out using a response surface methodology with upper and lower values limited to 30% of the actual value based on the research conducted (Nguyen-le & Shin, 2019). The data are as follows in Table 3.

Table 3. Value Parameter Geomechanics

Properties	Lower	Upper	Unit
Total Stress	4200	7800	psi
Poisson Ratio	0.175	0.325	*v*
Modulus Young	5.11x10^6	9.49x10^6	psi
Biot Coefficient	0.49	0.91	α
Pore Pressure	3824	7101	psi

After running the input data according to the range that has been determined using the CMG CMOST, there will be a total of 500 simulation data scenarios that will be reused for analysis by RSM.

2. 2 Hydraulic Fracturing

The hydraulic fracturing method is by injecting fracturing fluid to expand the fracture and then inserting a buffer so that the fracture does not close again on condition that the proppant has permeability.

The fracture direction is determined based on rock mechanics, overburden pressure, and formation depth. If the stress is the smallest and has a vertical direction, the fracture will form horizontally and vice versa.

2. 3 Geomechanic

In designing well maintenance, rock mechanics has an important role as a controller of fracture geometry. Geomechanics is a scientific discipline that integrates rock mechanics, geophysics, geology, and petrophysics to analyze quantitatively how a rock responds to a disturbance caused by the influence of drilling activity, fluid flow, formation pressure, in-situ stress, and formation temperature (Anis, 2008). In the case of a geomechanical model with compaction, it can affect flow because the permeability of the formation changes. Reserves without a geomechanical model will be different from the presence of a geomechanical model, this is influenced by the nature of the rock. Geomechanics is very useful for analyzing overpressured reservoirs with the main effects given such as the effect on permeability which is pressure dependent (Yilmaz and Nur correlation) and the effect of formation comparability depending on pressure (Dobrynin correlation) (Temizel et al., 2020).

Rock mechanics consists of stress and strain, Poisson ratio, shear modulus, bulk modulus, Young's modulus, and overburden pressure. According to (Liu et al., 2018), most reservoir simulation studies do not address the effects of geomechanics on fracturing. In addition, differences in rock types affect the value of rock mechanics such as influencing the value of pore pressure, young modulus, passion ratio, fracture pressure, maximum vertical stress, minimum stress, and strength.

a) Stress and Pore Pressure

According to (Hu et al., 2016) shear and strain affect the strength of the rock when a fracturing fluid is injected. If the differential stress is greater then the shear in the rock will collapse. So it is necessary to pay attention to minimize the differential stress due to the greater bottom hole pressure. Then, pore pressure becomes an important part of hydraulic fracturing to control the final stimulation of the fracture geometry (Arias Ortiz et al., 2021).

b) Biot Coefficient

One of the parameters to determine and minimize geomechanical effects during the process fracturing job is the biot's coefficient. If, less than 0.1, the better in minimizing the failure of geomechanical effects on the fluid (Joridis, 2014). According to (Belyadi et al., 2016) when a rock has high porosity, the rock compatibility value is close to 1. If the porosity is low, the value is close to 0. So, the equation is as follows:

$$\alpha = 1- (Cmatrix/Cbulk) \quad (1)$$

If the value of a rock does not have a porosity value and a geomechanical value can be calculated using the following equation:

$$\alpha=0.64+0.854 \times \boldsymbol{\theta} \quad (2)$$

c) Modulus Young and Poisson Ratio

A high modulus young may reduce the fracture gap due to limited deformation and vice versa, leading the fracturing fluid to reach the tip fracture quickly and provide high conductivity. Furthermore, according to research conducted shows an effect Young's modulus and the Poisson ratio control the length of the fracture, which grows longer and wider before shrinking. (Ye and colleagues, 2020) The knowledge that it raises the ratio of stress horizontal minimum becomes an important aspect of measuring the fragility of a rock. As the stress horizontal minimum increases, the fragility index decreases.

2. 4 Recovery Factor

The recovery factor or recovery factor is a ratio between the amount of hydrocarbons that have been taken with the total amount of hydrocarbons before being taken (initial). In the gas reservoir, the recovery factor can be formulated as follows:

$$RF = \text{Retriveable Vgas/ Initial Gas} = 1 - P_2Z_1/P_1Z_2 \quad (3)$$

2. 5 Computer Modeling Group

CMG, or Computer Modelling Group, is a reservoir simulation company based in Calgary, Canada. This simulation is used for reservoirs with one or more phases and can be employed in two or three dimensions. On CMG, the simulator types include IMEX, STAR, and GEM. The distinction between the three is in the sort of fluid to be imitated. CMG-GEM is often used to model pressure changes in fluids and gases. The benefit of adopting CMG is that it is typically less expensive than competitors. Furthermore, simple usage (Computer Modeling Group Ltd, 2018).

2.6 Modde 5

Modde 5 is a single application window that generates and evaluates statistical experimental designs. The purpose is to conduct an investigation factor that has a significant impact on the outcomes, the optimal factor of a system, and anticipate results.

2.6 Respon Surface Methodology Algorithm

ML and AI are gaining ground in the oil industry as they generate precise information using the integration of logs and core data. One of these methods is very important in predicting the geomechanical properties of shale which is considered as the most heterogeneous rock with wettability which is unfavorable for hydrocarbons to flow (Syed et al., 2021).

The advantage of RSM is that it can interpret results with few factors. However, the drawback is that it is difficult to interpret more than 3 factors. RSM is particularly successful in reducing costs and increasing efficiency in shale gas reservoirs with unknown reservoirs. In RSM the technique used to understand system response is to develop a regression model (interaction regression). linear squared) and sequential factors (F test, fit test, and R-squared value) were then checked and analyzed for variance (ANOVA) (Myers, R.H.; Montgomery, 2009). The study's (Liu et al., 2018) findings were analyzed utilizing the Response Surface Methodology. a mix of simulation models Reservoir and RSM can be used to examine the sensitivity of parameters, which can then be used to optimize the response to this problem.

Wang et al., 2016 investigated the sensitivity using RSM of 7 parameters which included thickness, cohesion, dip angle, spacing, friction angle, IR, and SD through 46 designs obtained the most influential results in maximizing stimulation volume reservoir (SRV) in the thickness. This research is one of the reasons for using RSM because RSM is easy to implement with fewer factors with the result of carrying out a combination of data using machine learning and artificial intelligence later it can be known the influential parameters to provide an overview of exploration and development shale gas.

4. Result and Discussion

4.1 Respon Surface Methodology CMOST

Modeling was carried out using CMG-GEM by entering a dataset of 500. Parameters tested included stress, Poisson ratio, modulus young, biot's coefficient and pore pressure as input and output are recovery factors, formed from a random sample using upper and lower bounds. Data dissemination utilizes continuous real distribution, where the parameter value cannot be estimated (Fu et al., 1991). The sensitivity test was carried out to obtain results where the geomechanical parameters have an effect on when a hydraulic fracturing job is carried out.

4.2 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is a statistical test to detect differences in group means when there is one parametric dependent variable and one or more independent variables. Predictive modeling is done to see the accuracy of the data. R^2 explains the level of confidence and explain the value of the data from the independent variable or model input. R^2 has a value of 0 to 1 which means that the closer to 1 the better and does not have an error large (Hair et al., 2014).

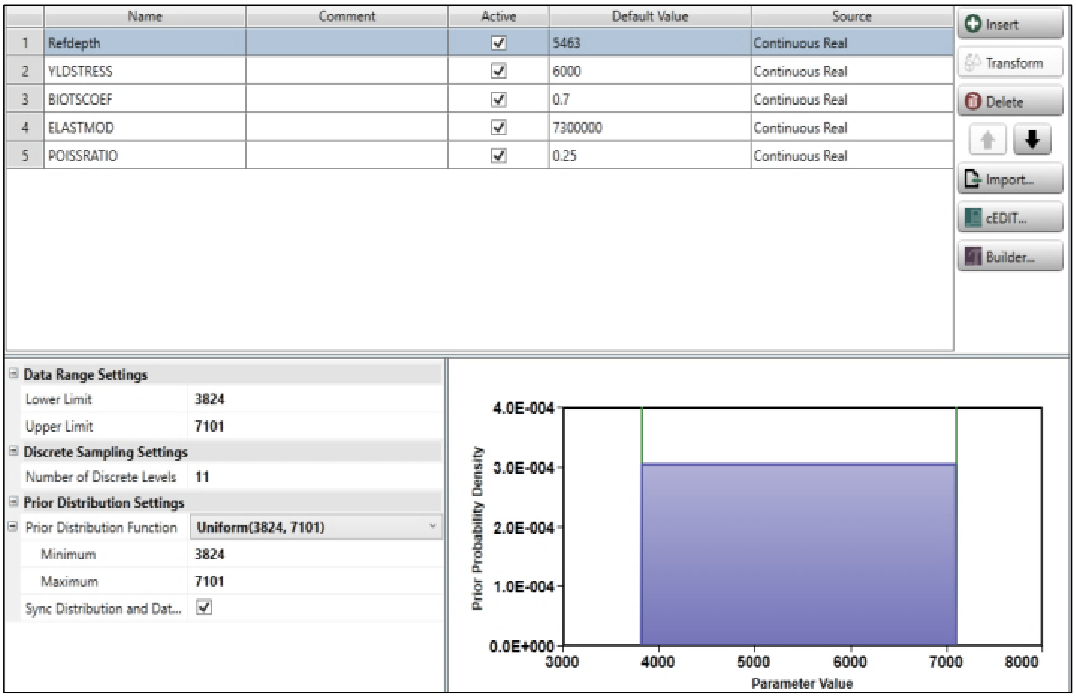

Fig 2. Distribution continuous real

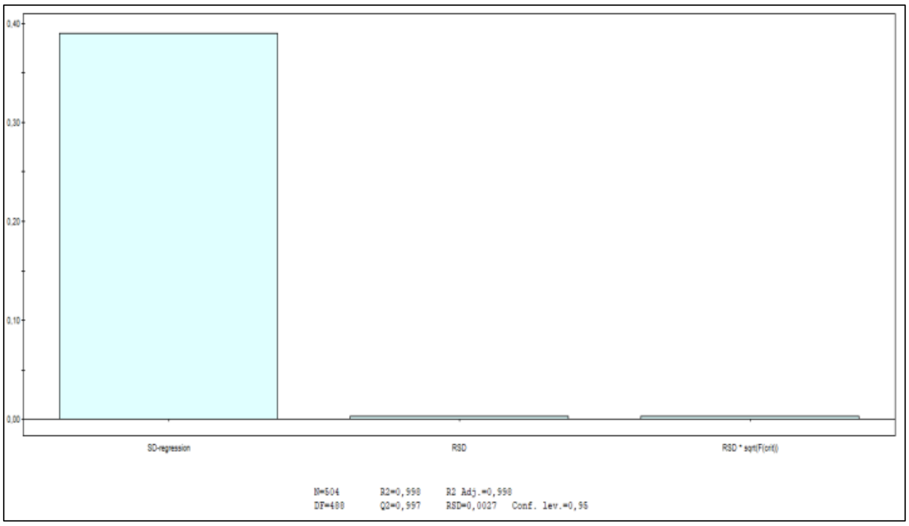

Fig 3. Plot ANOVA

R2 = 0.99 demonstrates the outcomes. The R2 statistic can be used as a benchmark to determine whether a regression model is robust enough to be used with a value higher than 0.85.

To further analyze the impact of parameters on recovery factors, ranking parameters are used (Mousavi et al., 2020).

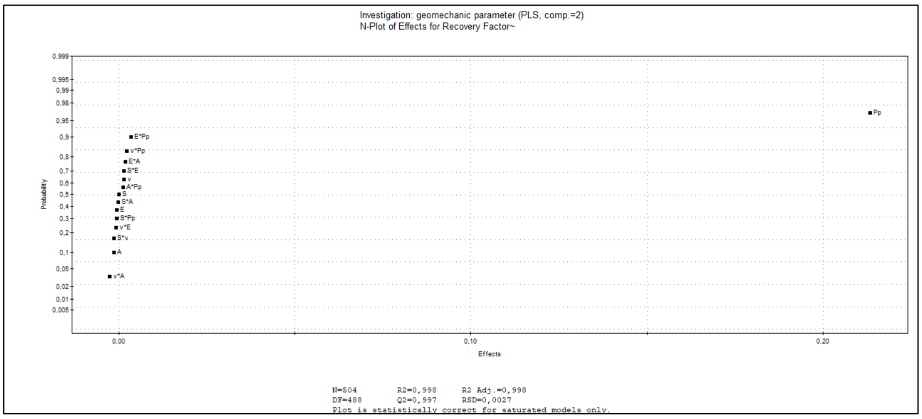

Fig 4. N-Plot of Effect for Recovery Factor

Effects plotted on a cumulative normal probability scale can only be used to determine important effects with at least a model with 10 effects. This plot is based on parameters that are robust and normally distributed so that effects significantly different from 0 will be outside the normal line.

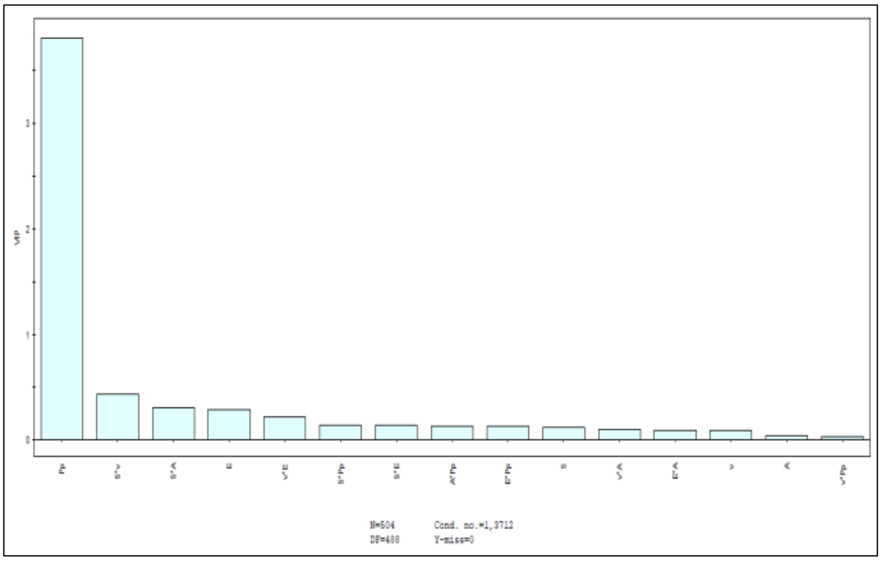

Fig 5. Variable Importance Plot

Variable Importance Plot helps visualize the strong relationship between features and the predicted response while considering all the features present in the model (Wei et al., 2015). VIP with the highest 5 in this study, pore pressure 3,8. Young's modulus is thus 0.28.stress is 0.12, passion ratio is 0.08, and biot coefficient is 0.04 (Table 4). Thus, the results obtained from this study are the dominant geomechanica parameters contained in the parameters of pore pressure. Then the second stage and so on there are parameters stress, young modulus, Poisson ratio, and biot coefficient. When pore pressure and stress increase causing excessive deformation which causes blow out happens so it needs monitoring when hydraulic fracturing will be carried out (Zhao & Huang, 2021)

Table 4. Variable Importance Parameter

	VIP (cum)	**Coeff Recovery Factor~**
Pp	3,80404	0,067349
S*v	0,436132	-0,000264751
S*A	0,304498	-3,8785e-005
E	0,285323	-0,000152669
v*E	0,220132	-0,000153699
S*Pp	0,144606	-0,000101427
S*E	0,136605	0,000306946
A*Pp	0,12722	0,000271854
E*Pp	0,127144	0,00069356
S	0,123577	2,15349e-005
v*A	0,0994813	-0,000503091
E*A	0,0929126	0,000369517
v	0,08863	0,000439638
A	0,0411581	-0,000429696
v*Pp	0,0343111	0,000448073
N = 504	Cond. no. =	1,3712
DF = 488	Y-miss =	0
Comp. = 2		

5. Conclusion

Based on the findings and analysis of the research, it can be said that pore pressure (3.8) had the greatest influence on geomechanical parameters during hydraulic fracturing operations using 500 data sets and the Analysis of Variance (R2 = 0.99). Thus, Young's modulus is 0.28, stress is 0.12, passion ratio is 0.08, and biot coefficient is 0.04.

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