

# 2010 Paul Fulton Scholarship Competition

## Modeling Hydraulic Fracture Propagation in the Marcellus Shale Formation

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### **Abstract:**

Shale formations can hold vast amounts of hydrocarbons and are currently very popular as producing formations. However, they must be stimulated in order to produce economically. The most prevalent stimulation technique is hydraulic fracturing. This paper details the design of three dimensional models for fracture propagation in a hypothetical Marcellus Shale well. Two models were developed, one for a user-defined treatment schedule and one for a software designed treatment schedule. These models were compared and parameters were varied to determine how to optimize fracture length and conductivity for each one. This paper also includes a rudimentary economic analysis and a brief word on environmental concerns.

## **Introduction**

The process of hydraulically fracturing a formation to increase the permeability has been in use for decades, but it has recently shot to the forefront of stimulation techniques. Production from low permeability shales has made hydraulic fracturing very important and very controversial.

Drilling a horizontal well and performing a hydraulic fracturing treatment is an extremely expensive process. Therefore, engineers need to be able to accurately predict the behavior of a fracture treatment. Advanced software packages, such as those offered by Meyer and Associates, are able to model predicted fracture propagation in a well, based on treatment schedules and formation properties. These models can then be used to optimize the treatment and get the most fracture benefit for a well.

The most important shale in the country right now is the Marcellus Shale, located primarily in western Pennsylvania. This formation boasts huge reserves of natural gas, but with its incredibly low permeability, this gas can only be unlocked and produced economically by horizontal drilling coupled with hydraulic fracturing. Well productivity is critically dependent on design of fracture treatments.

The objective of this research was to create a hypothetical Marcellus Shale well based on information from a producer survey, and then to apply the Meyer and Associates software package to create a three dimensional model of the well. This paper examines fracture models for a hypothetical well that features average Marcellus Shale well properties. Using these models, methods for optimizing Marcellus Shale fracture treatments can be determined.

## Methodology

Based on average Marcellus well data, provided anonymously via a survey presented to multiple producers at the SPE Unconventional Gas Conference in Pittsburgh in February 2010, a hypothetical horizontal Marcellus well was created. The survey presented is included in Appendix A. The properties of the well and the producing formation are summarized in the following table.

**Table 1. Well and Formation Properties**

True Vertical Depth	8,000 ft
Measured Depth	12,000 ft
Length of Lateral	4,000 ft
Casing Size	5.5 in
Tubing Size	2.375 in
Perforated Zones	10 zones with 5 perf. clusters per zone
Producing Zone Permeability	0.0001 md
Young's Modulus	$3.5 \times 10^6$
Poisson's Ratio	0.25

Based on this average data and on the survey responses, a general fracture treatment for this type of well was developed. The properties of this treatment are summarized in the following table.

**Table 2. General Fracture Treatment**

Fracture Fluid	Slickwater
Fluid Volumes	10,000 barrels per stage
Proppant Type	40/70 mesh sand
Proppant Concentrations	1.25 – 5 pounds per gallon
Number of Stages	10 stages

The hypothetical data summarized in Table 1 and Table 2 was entered into a three-dimensional fracture modeling software from Meyer and Associates, called MShale. Mshale is a discrete fracture network simulator designed to model fracture propagation in shale and for coal bed methane. The data was entered in two different ways. First, the data was entered using a typical Marcellus Shale well fracturing treatment schedule. Next, it was entered using an option for automatic fracture treatment design. The software can use a specific input (total fluid volume or total proppant volume) and calculate a treatment schedule that will reach that parameter. However, the automatic treatment design will only work for a single stage fracture treatment, so the fifth stage was chosen. The total slurry volume per stage from the typical treatment schedule was entered as the design parameter for the automatically designed treatment. The software was then able to simulate both treatments and prepare reports of the resulting fracture characteristics.

A powerful tool included in the Mshale software is the ability to produce three dimensional models of the fractures created in a well. A three dimensional model of the typical

treatment was obtained (showing all ten fracture stages), as well as a three dimensional model of the automatic treatments (showing only the fifth stage). Other outputs obtained from the software were reports of predicted fracture characteristics.

In this simulation, the well was modeled as 8,000 feet of vertical casing, a 90 degree bend, and then 4,000 feet of horizontal casing. In actuality, this well would feature a smooth curve from the vertical section to the horizontal section. However, to model just the fracture behavior in the horizontal lateral, it is effective to model the well as having a 90 degree bend.

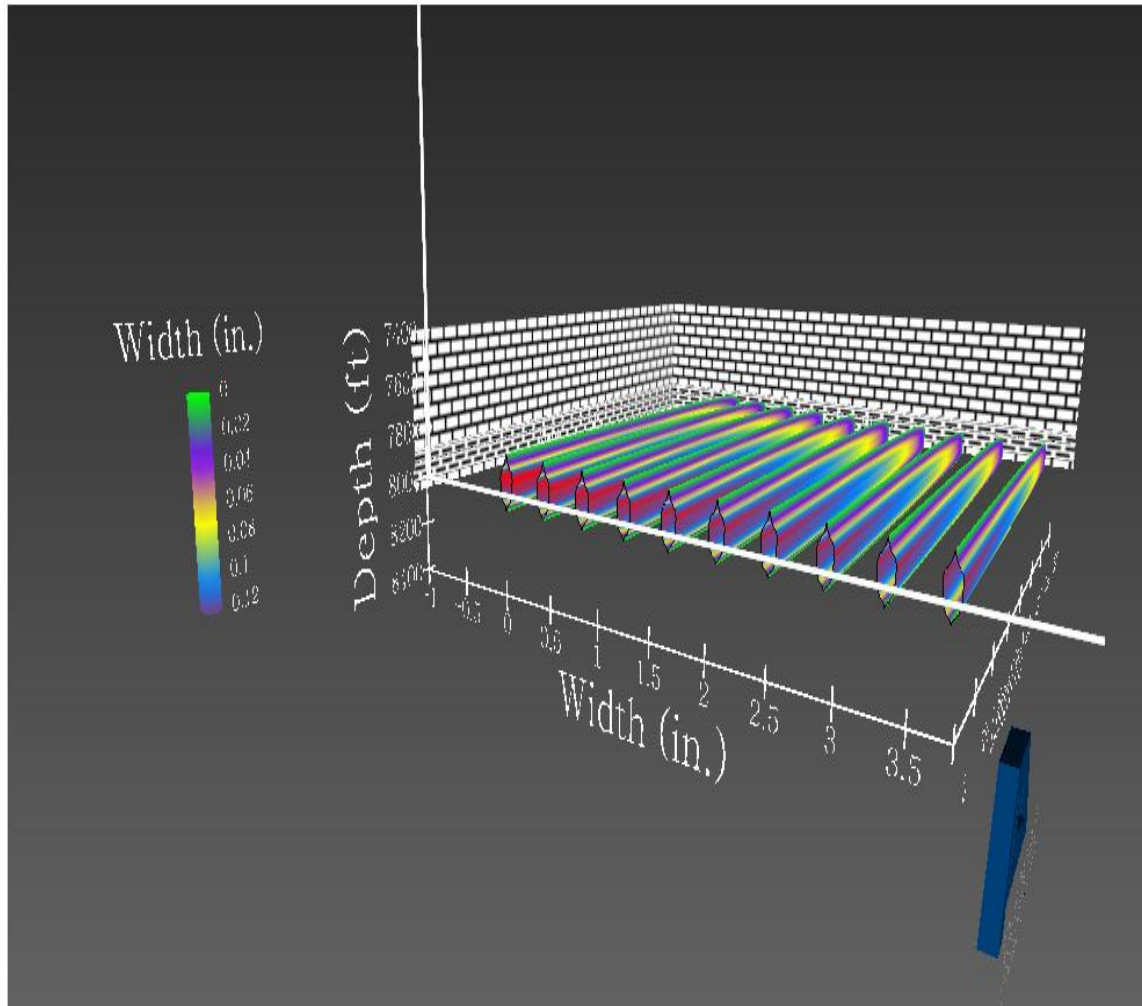
After the initial models and reports were obtained, various properties were varied and each simulation was re-run. First, proppant types and fluid types were varied. Several proppants and fluids were selected from the MShale software database, with the simulation being re-run after each change. Then, proppant concentrations were varied. First, proppant concentrations were cut in half for the entire treatment and the simulation was re-run. Second, the simulation was re-run with the proppant concentrations doubled for the entire treatment. Additional reports were obtained from the software for each variation.

## **Results**

The most important fracture characteristics to consider when determining economic viability are fracture length and width. These are used to determine fracture conductivity and increase in permeability. Fracture length is especially important in low permeability reservoirs, such as shales.

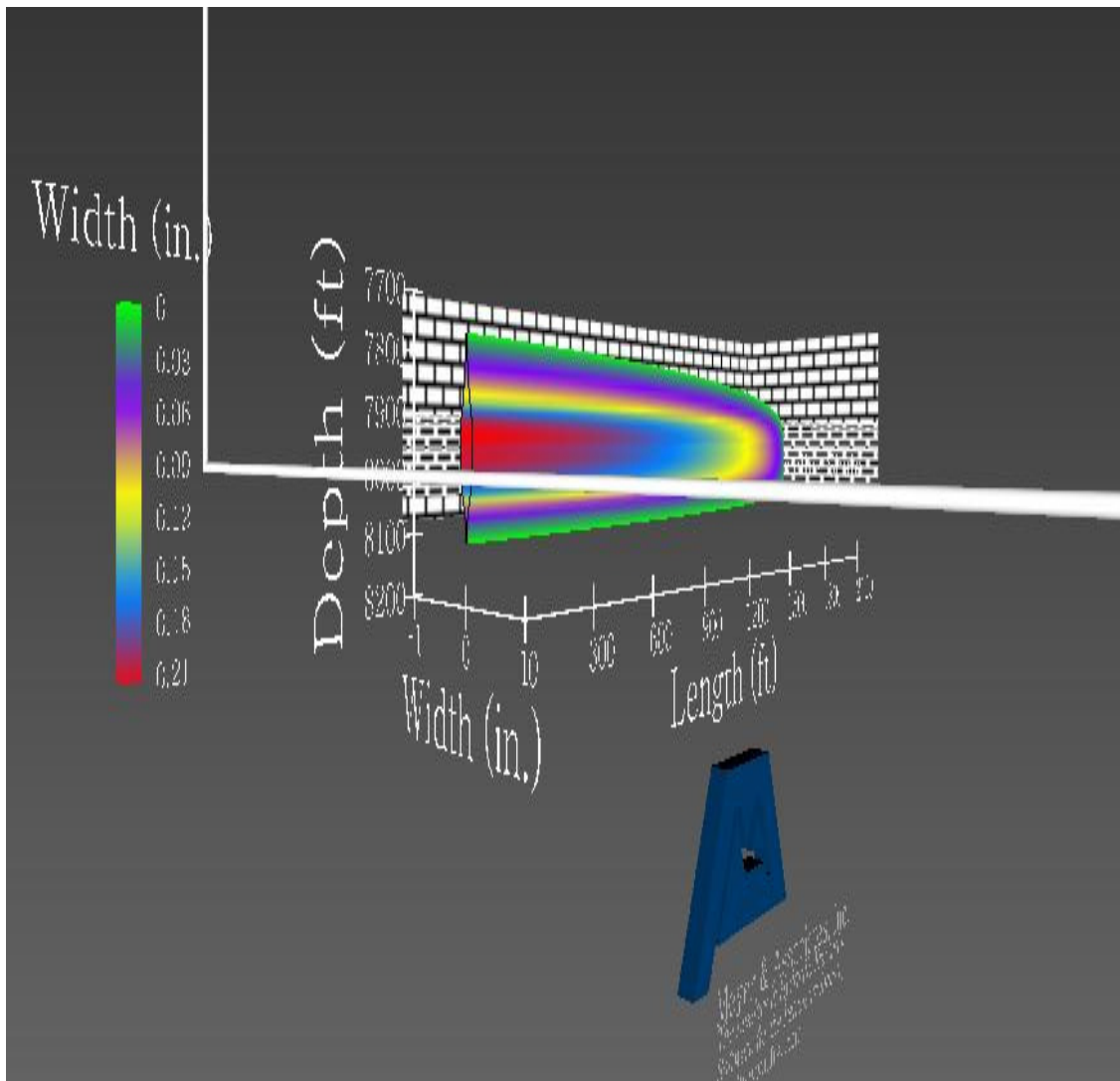
Utilizing the general fracture treatment parameters, the model predicted a fracture half length of 3,454 feet and an average fracture width of 0.075 inches. This predicted length is the length on one side of the wellbore; the total length of each fracture would be 6,908 feet.

**Fig. 1. Model for Typical Treatment Schedule**



Using a total slurry volume equal to the slurry volume per fracture from the typical treatment, the automatic treatment for stage five predicted a fracture half length of 1,915 feet, or a total length of 3,830 feet. Also predicted was an average fracture width of 0.105 inches. While the width is somewhat larger for this fracture than for the typical treatment fractures, the length is nearly half as much. This suggests that the typical treatment schedule is more effective than the automatically designed schedule.

**Fig. 2. Model for Automatic Treatment Schedule**



- **Fluid Types**

The use of various fracture fluids from the MShale software database, in the place of the typical slickwater, resulted in either no change in fracture length or a significant decrease in fracture length.

- **Proppant Size**

As long as proppant remains the same size, any material can be used without affecting the fracture length. Also, different proppant sizes do not affect fracture length. For all proppant types and sizes chosen, the predicted fracture half length for the automatically designed treatment remained 1,915 feet.

- **Proppant Concentration**

Reducing the proppant concentrations by 50% for the typical fracture treatment only minimally affects the fracture properties. Half as much proppant reduces the fracture half length to 3,393 feet, from the original 3,454 feet. While this hardly affects the initial fracture propagation, it could affect how well the fractures stay open.

Similarly, doubling the proppant concentrations for the typical treatment minimally affects fracture properties. Double the amount of proppant increases the fracture half length to 3,574 feet.

## **Economic Analysis**

Net Present Value (NPV) is a measure of the economic viability of a project, and it is commonly used to evaluate engineering projects. NPV is generally defined as the present value of revenues from a project at some interest rate minus the present value of costs at some interest rate (Stermole and Stermole 111). For a hydraulic fracturing treatment, NPV can be defined as

the revenue from a fractured reservoir minus the revenue from the same reservoir without fractures minus the cost of the fracture treatment (Meyer et al. 37).

The Meyer and Associates software package also includes tools to perform Net Present Value analysis. Two software programs, MProd and MNpv, are used in conjunction to determine the economic effects of fracturing.

However, since economic data was not a part of the research, the performed economic analysis is only useful for comparison purposes. Costs of fluids and proppants were arbitrarily chosen. Then, using MProd and MNpv, coupled with the automatically designed fracture treatment and entirely fictional pressure and production data, it was determined that a fracture can contribute significantly to total revenues. One of the main outputs of MNpv is Additional Fracture Revenue. In this particular fictional case, the additional fracture revenue was a small amount compared to the total cost, but this was for a single fracture. In a multi-stage fracture treatment, the additional fracture revenue becomes large enough to make the fracture treatment profitable.

A more useful economic analysis could be performed if actually or average economic data were acquired. The results obtained from this simulation serve only to show that hydraulic fractures can make a financial impact.

## **Environmental Concerns**

In March 2010, the Federal Environmental Protection Agency began a multi-million dollar study of the effects of hydraulic fracturing on the environment, with emphasis on pollution of drinking water (Howell). Even though fracturing has been used for decades, it is now

receiving significant protests because it is going on in heavily populated areas like Pennsylvania and New York.

Hydraulic fracturing is generally perceived as nothing more than injecting large quantities of unknown chemicals into the ground near sources of drinking water, which is why the EPA study may actually be a good thing for the oil and gas industry. Industry groups, such as the American Petroleum Institute, believe the study will conclude that fracturing is safe and, in turn, put to rest some of the controversy (Howell). While federal government scrutiny is generally unwanted, in this case, providing that the EPA study is unbiased and peer reviewed, it may actually help to ease the situation for producers looking to tap into the Marcellus Shale.

## **Conclusions**

The results obtained from the fracture models indicate that the way the Marcellus Shale is being stimulated in an effective manner. The typical fracture treatment being used created fractures that were nearly twice as long as what was created by the software designed treatment. Also, variations in fluid and proppant properties had negative, if any, affect on the fracture characteristics. Therefore, industry experience is still a better tool than computer software, and engineers are not yet obsolete. Modeling software is a powerful tool, but engineers cannot rely solely upon it.

Hopefully, environmental concerns regarding hydraulic fracturing will be lessened following the EPA study. Public outcry, and not technology, may be the biggest obstacle facing producers in the Marcellus Shale. The Marcellus Shale can only become economically significant if producers are free to produce from it.

In the future, more actual data should be obtained and a study could be focused on a specific geographic area of the Marcellus or any other shale. This research was performed with average Marcellus Shale properties, but the actual properties within the reservoir vary from location to location.

Overall, it seems that hydraulic fracturing is currently being done the proper way. It needs to continue and to grow in the Marcellus and other shale formations, in order to boost the oil and gas industry.

**Appendix A. Producer Survey Presented at SPE Unconventional Gas Conference**

**Marcellus Shale Information Sheet**

- Well Depth \_\_\_\_\_
- Casing Size \_\_\_\_\_
- Number of Perforated Zones \_\_\_\_\_
- Depths of Perforated Zones \_\_\_\_\_
- Fluid Types \_\_\_\_\_
- Fluid Volumes \_\_\_\_\_
- Producing Zone Permeability \_\_\_\_\_
- Formation Properties (Young's Modulus, Poisson's Ratio, Critical Stress, etc.) \_\_\_\_\_  
\_\_\_\_\_
- Fluid Loss Data (Leak-off Coefficient, Spurt Loss, etc.) \_\_\_\_\_  
\_\_\_\_\_
- Proppant Types \_\_\_\_\_
- Proppant Concentration (mass per area) \_\_\_\_\_
- Number of Treatment Stages \_\_\_\_\_
- Other \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

• Tubing Size \_\_\_\_\_

• Length of Horizontal Section \_\_\_\_\_

• Total Slurry Volume \_\_\_\_\_

## Works Cited

Howell, Katie. "EPA Begins Study of Fracturing's Affects on Water Supplies." *New York Times* 18 March 2010. Web.

Meyer, Bruce R. et al. "Optimization of Multiple Transverse Hydraulic Fractures in Horizontal Wellbores." SPE 131732. *SPE Unconventional Gas Conference*, 2010.

Stermole, Franklin J. and John M. Stermole. Economic Evaluation and Investment Decision Methods. 12th ed. Lakewood: Investment Evaluations Corporation, 2009.