Optimizing Perforations*

David J. Hatton[1] and Payam Kavousi Ghahfarokhi[2]

Search and Discovery Article #42159 (2017)**
Posted December 4, 2017

*Adapted from oral presentation given at AAPG Eastern Section 46th Annual Meeting, Morgantown, West Virginia, September 24-27, 2017

[1]Department of Petroleum and Natural Gas Engineering, West Virginia University, Morgantown West Virginia (David.Joshua.Hatton@gmail.com)
[2]Department of Geology and Geography, West Virginia University, Morgantown West Virginia

Abstract

The principal of perforation gun technology has not undergone vast modifications since its introduction to the petroleum industry. Perforation geometrical parameters, such as shots size, shape, approach angle, and "drilled" angle, influence the fluid pressure regime around the perforations. Three aspects of unconventional reservoirs can be optimized for a robust well performance: production, hydraulic fracturing, and proppant migration. To optimize production, the near-bore pressure losses must be minimized. Most of the pressure losses are because of perforations and tortuosity.

We modeled the reservoir pressure with losses vs. flow rate using nodal analysis (IHS Harmony Software) and decline curve analysis for a single well model (EXCEL); flowrate and ultimate recovery factor are significantly improved with minimizing pressure losses. Changing the shape of the perforation also affects the hydraulic fracturing process. Our computer simulation using ANSYS software for a homogenous media with eight perforations, using laminar and turbulent models shows that if the circle was changed to an oval that during injection high stress regimes would occur at the ends, in effect causing fractures to propagate from the ends. The use of fracturing ballistics gel experiment also shows a correlation between perforation shape and fracture width, length, and height. For vertically drilled well, if long ways of oval is vertical, fracture shows improved height gain. If oval is horizontal, fracture shows width gain. We also evaluated the flow streamline for two models: The first model has oblique shot penetration angle, while the other model has straightly penetrated shots. As the penetration angle becomes more oblique, pressure losses are seen to decrease. In conclusion, if parameters of a perforations are changed it gives the possibility to optimize a specific well to developer’s desires.

OPTIMIZING PERFORATIONS

An in-depth view of effects of perforations on a well during production, injection, and hydraulic fracturing

DAVID JOSHUA HATTON

B.S. Petroleum and Natural Gas Engineering, from West Virginia University

Contact:

E-mail: David.Joshua.Hatton@gmail.com

OUTLINE

1. History of perforating guns
2. Affects of pressure loss due to perforations
3. Estimating Pressure loss with ANSYS
4. Perforations and hydraulic fracturing
5. Injection
6. Conclusion
7. Discussion

MOTIVATION

Maximize production by changing the diameter size, shape, and bend angle of perforations in order to best fit the specific well.

PURPOSE OF PERFORATIONS

- Perforations are used to connect the flow-path of hydrocarbons from the formation to the cased wellbore.
- Target pay-zone or desire zone/depth
- Combined with casing and cement, allows successful hydraulic fracturing

HISTORY OF PERFORATIONS AND PERFORATING GUNS

- Bullet Guns affective in the 1930s
- Shape charge developed by military 1940s
- Late 1940s/ Early 1950s shaped charges became preferred perforating gun

PERFORATING GUNS TODAY

- Shaped charges are most dominate
- Punches (mechanical and hydraulic)
- Jets
- Arc
- Bullet guns
- Lazer

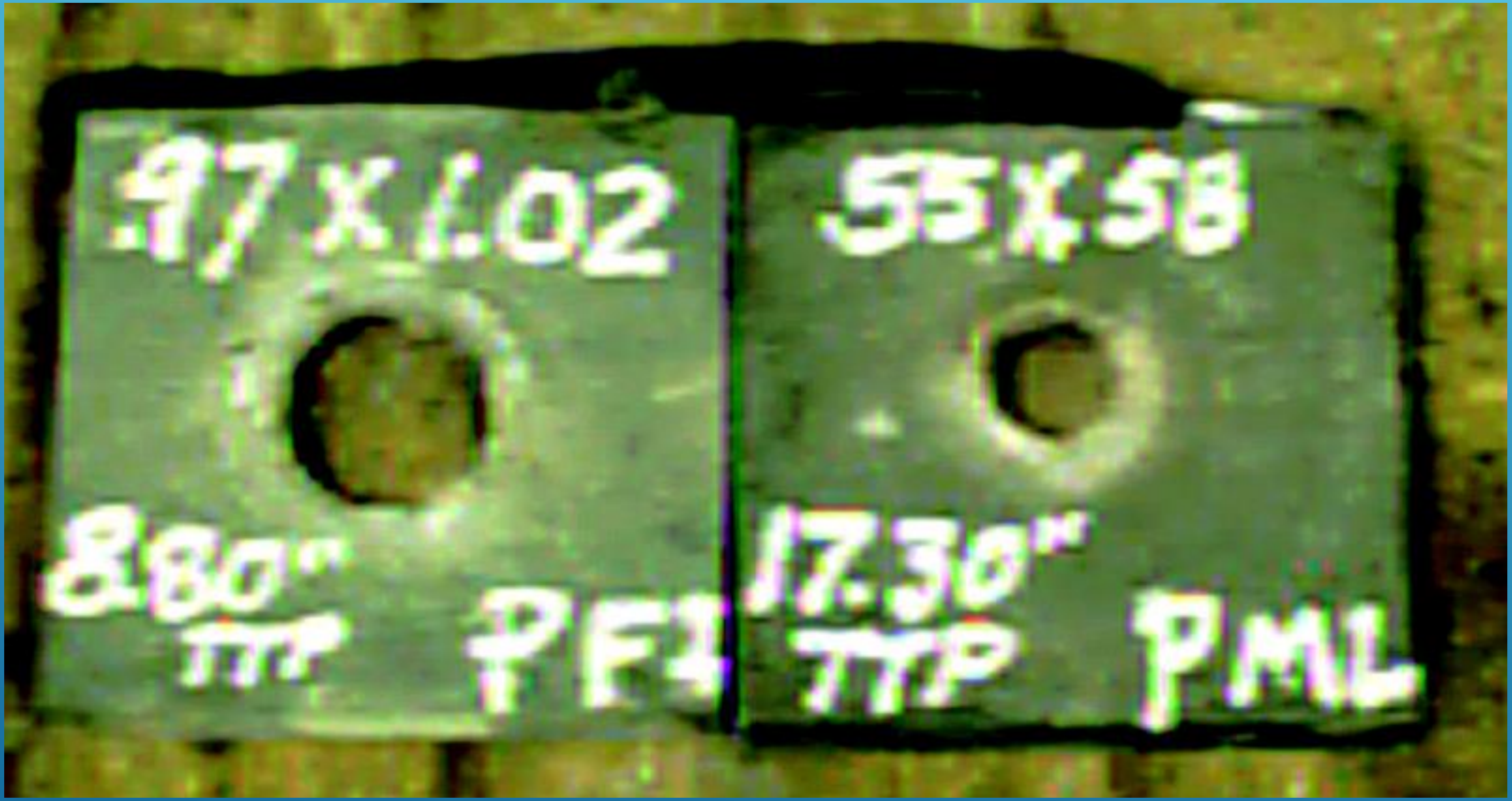
Unique / Uncommon

PERFORATION DESIGNS TODAY

Completions engineers place perforation guns in three categories

- Good: Larger perforation diameter
- Deep: Good penetration depth
- Combined: Mix between good and deep

PERFORATION DESIGNS TODAY



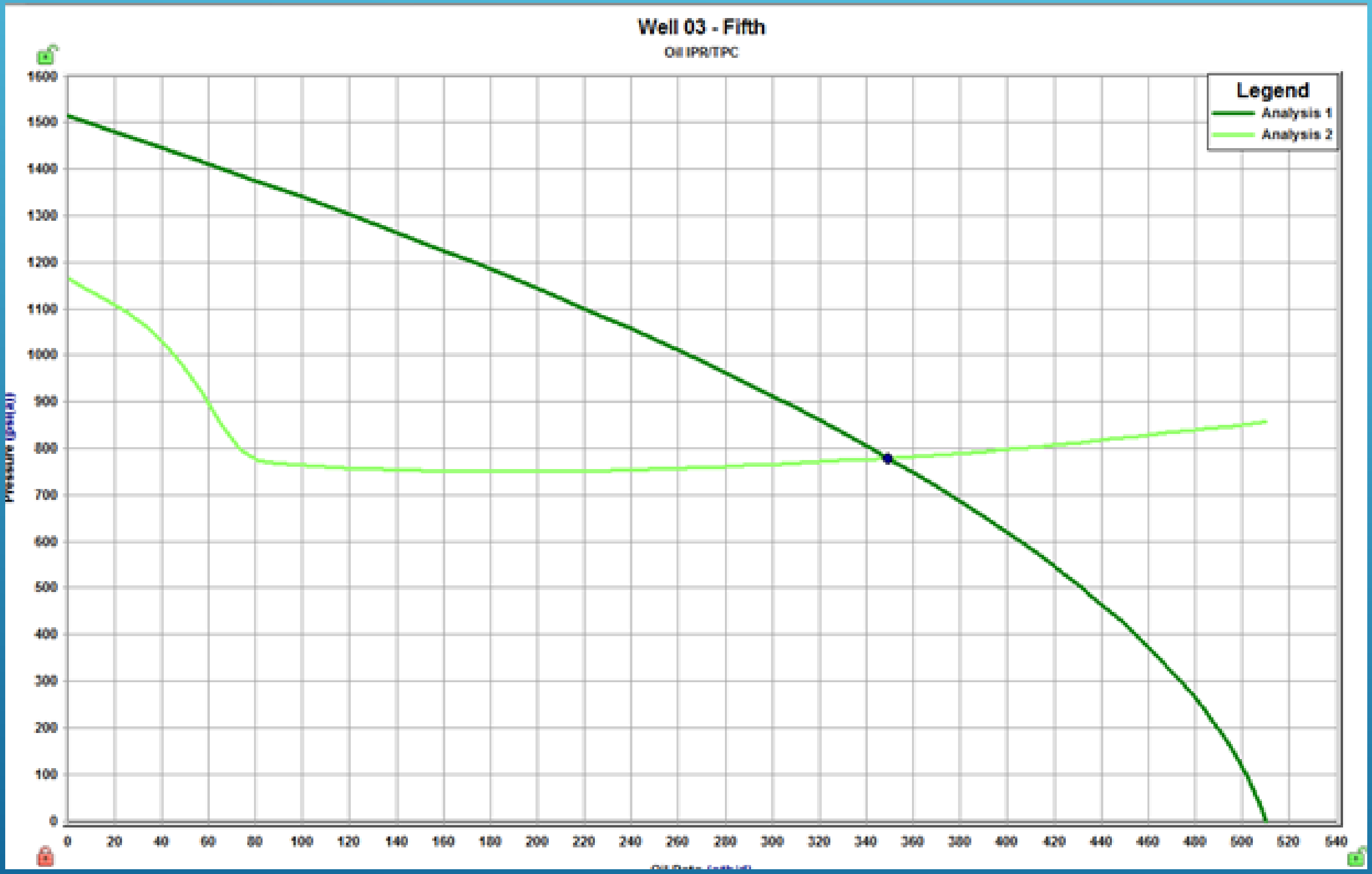
Good Perforation: Left

Deep Penetration: Right

TTP= penetration depth

AFFECTS OF PRESSURE LOSS

NODAL ANALYSIS



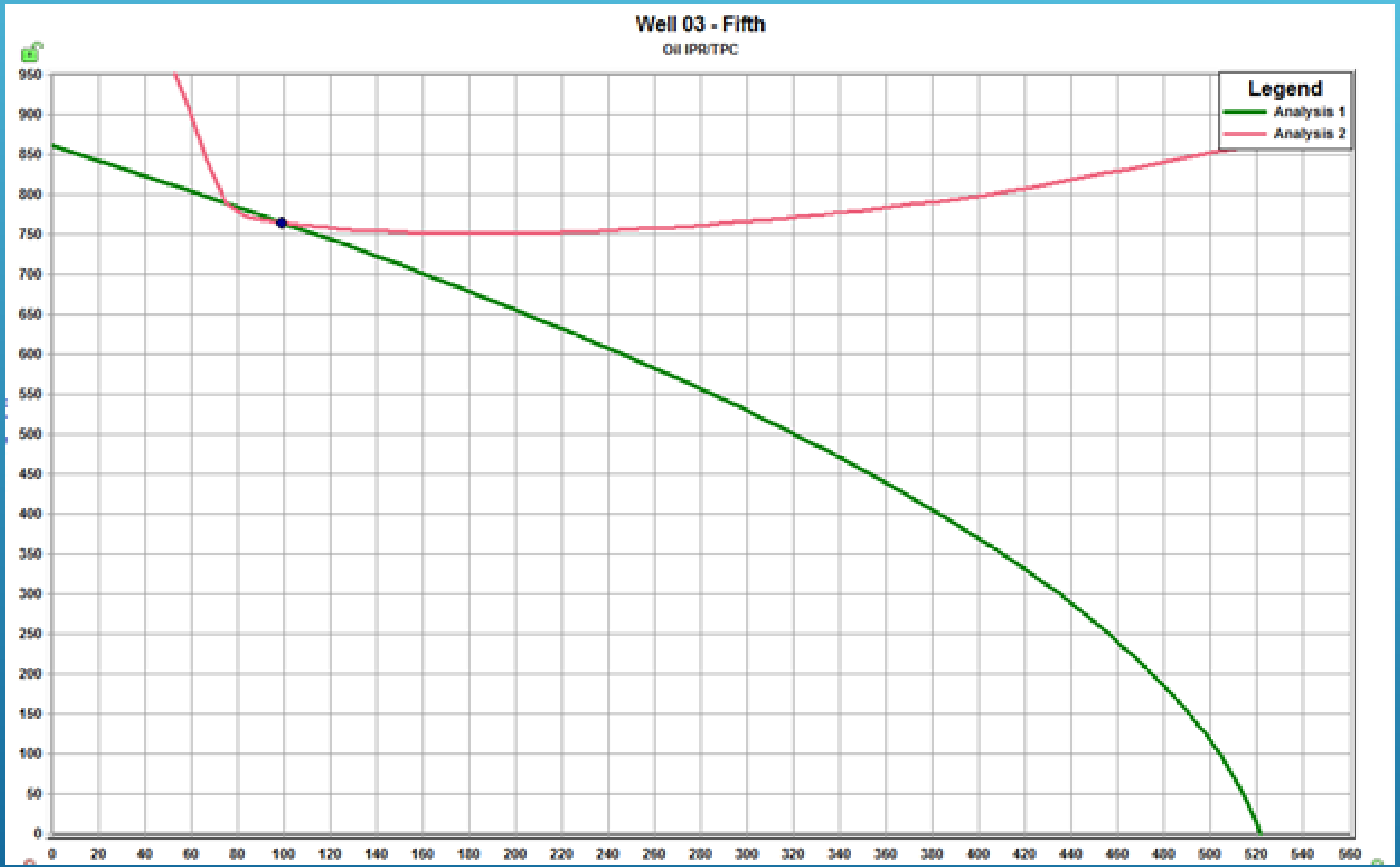
0psi additional loss

$$q_o = 349.2\ stb/day$$

$$P_{wf} = 779.42\ psia$$

$$P_R = 1513.11\ psia$$

NODAL ANALYSIS DEPLETED/PRODUCED



0psi additional loss

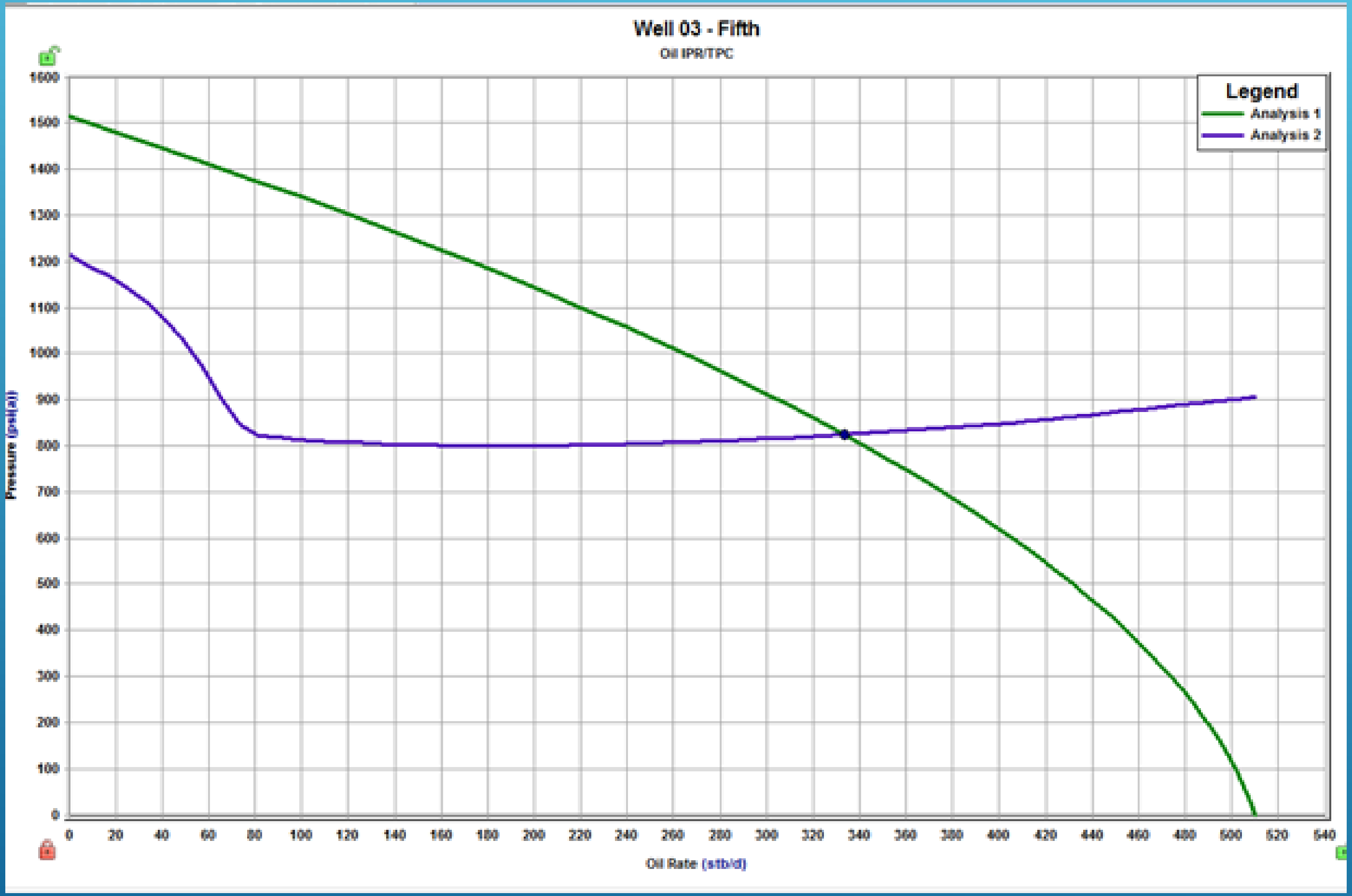
$$q_o = 99.3\ stb/day$$

$$P_{wf} = 764.28\ psia$$

$$P_R = 860\ psia$$

This is an estimate to what the reservoir pressure could be produced too w/o artificial lift or stimulation. Consistent data for all nodal analysis. Note considers homogenous reservoir pressure

NODAL ANALYSIS +50 PSI LOSS



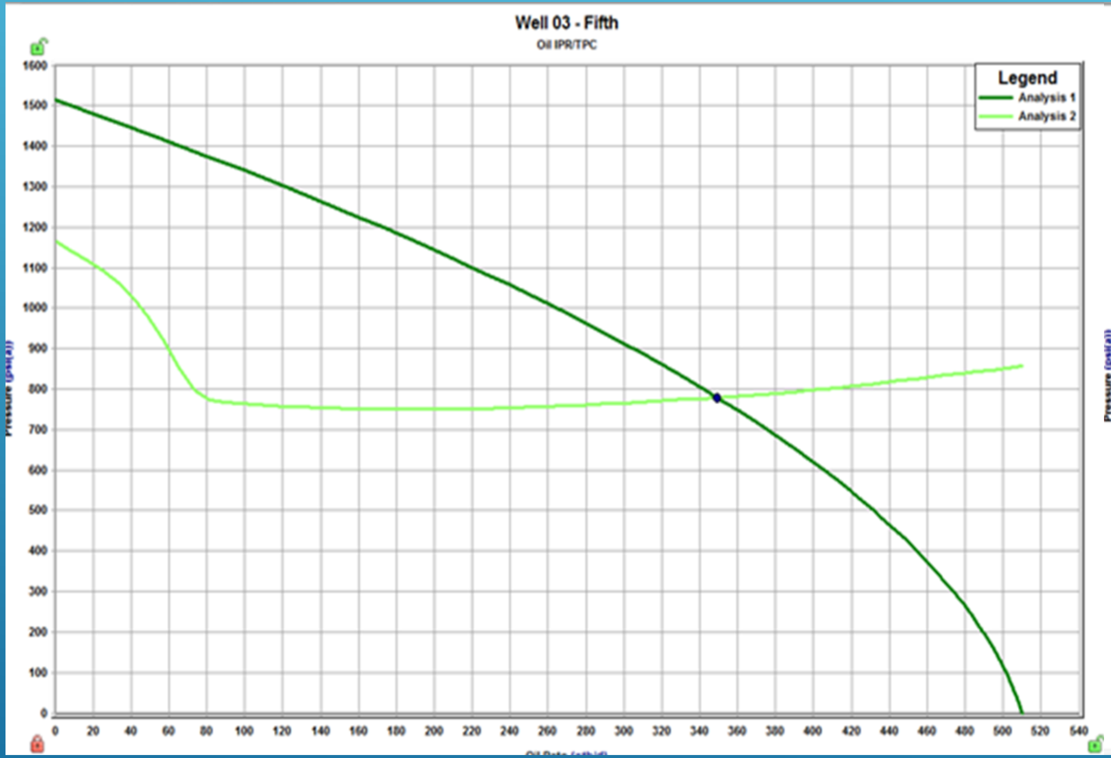
50psi additional pressure loss

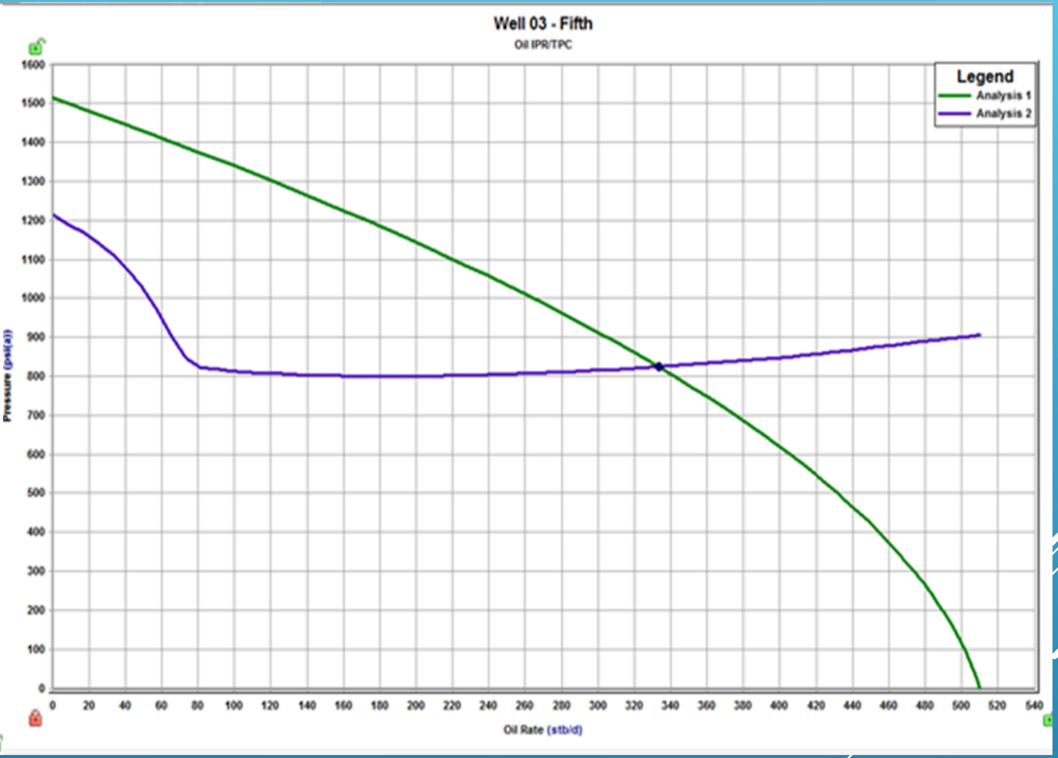
$$q_o = 333.3\ stb/day$$

$$P_{wf} = 824.52\ psia$$

$$P_R = 1513.11\ psia$$

COMPARISON

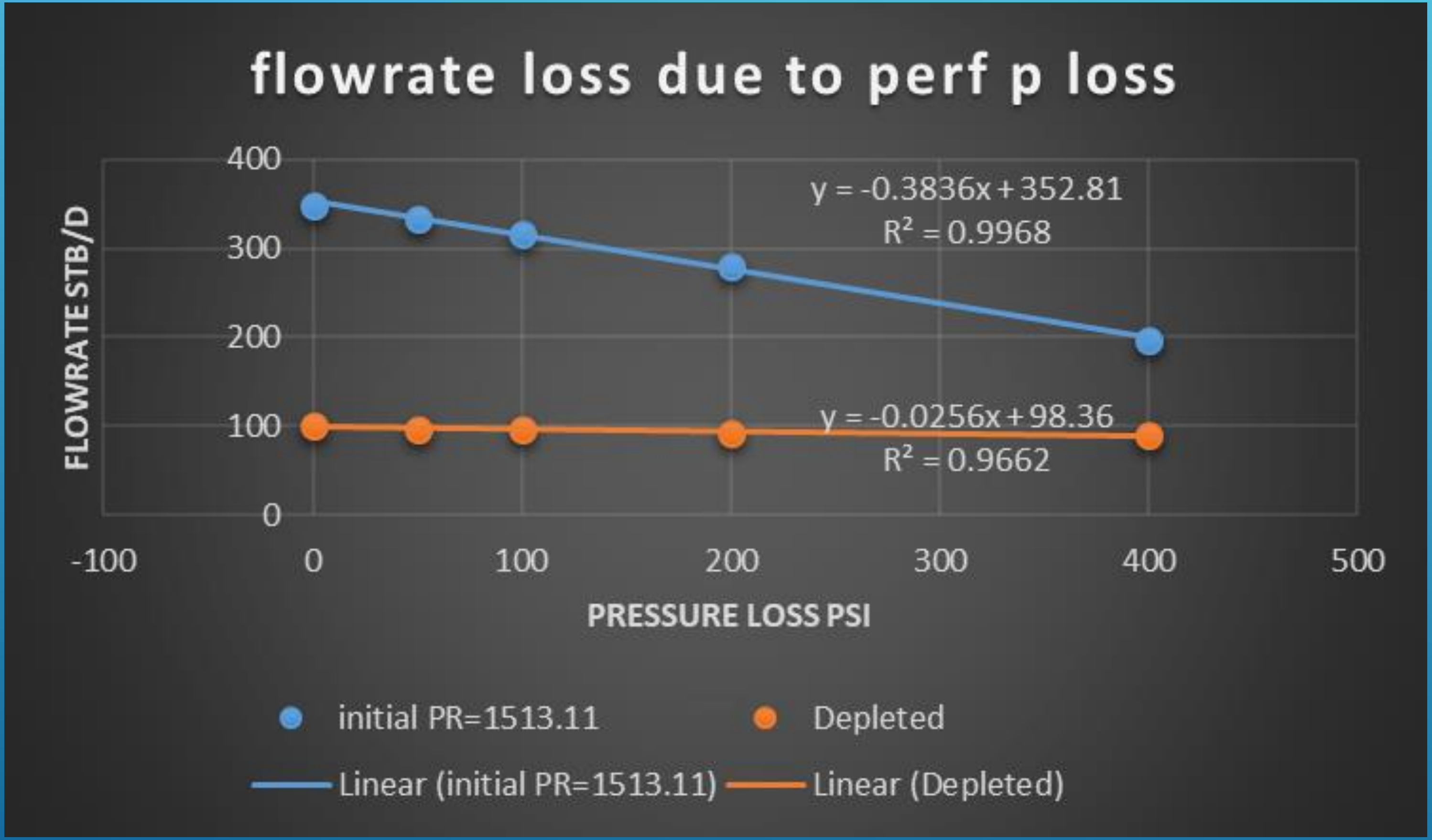




0psi pressure loss

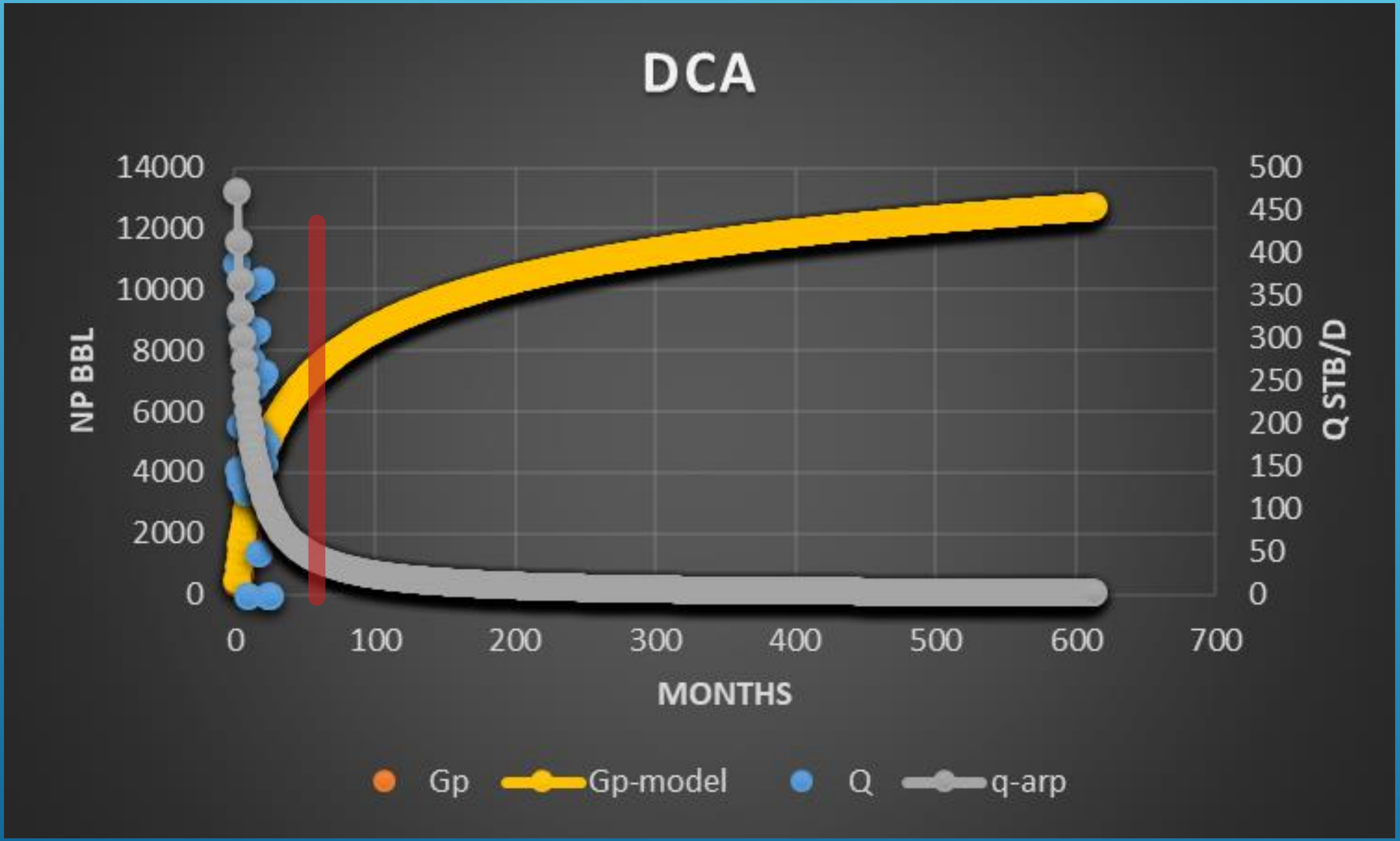
50psi pressure loss

RESULTS:



This graph shows initially for every psi saved results in .3836 more stb per day for this well
ex: 20 psi saved = 7.7 stb/d increase
ex: $50 bbl = $385/day increase.

DCA



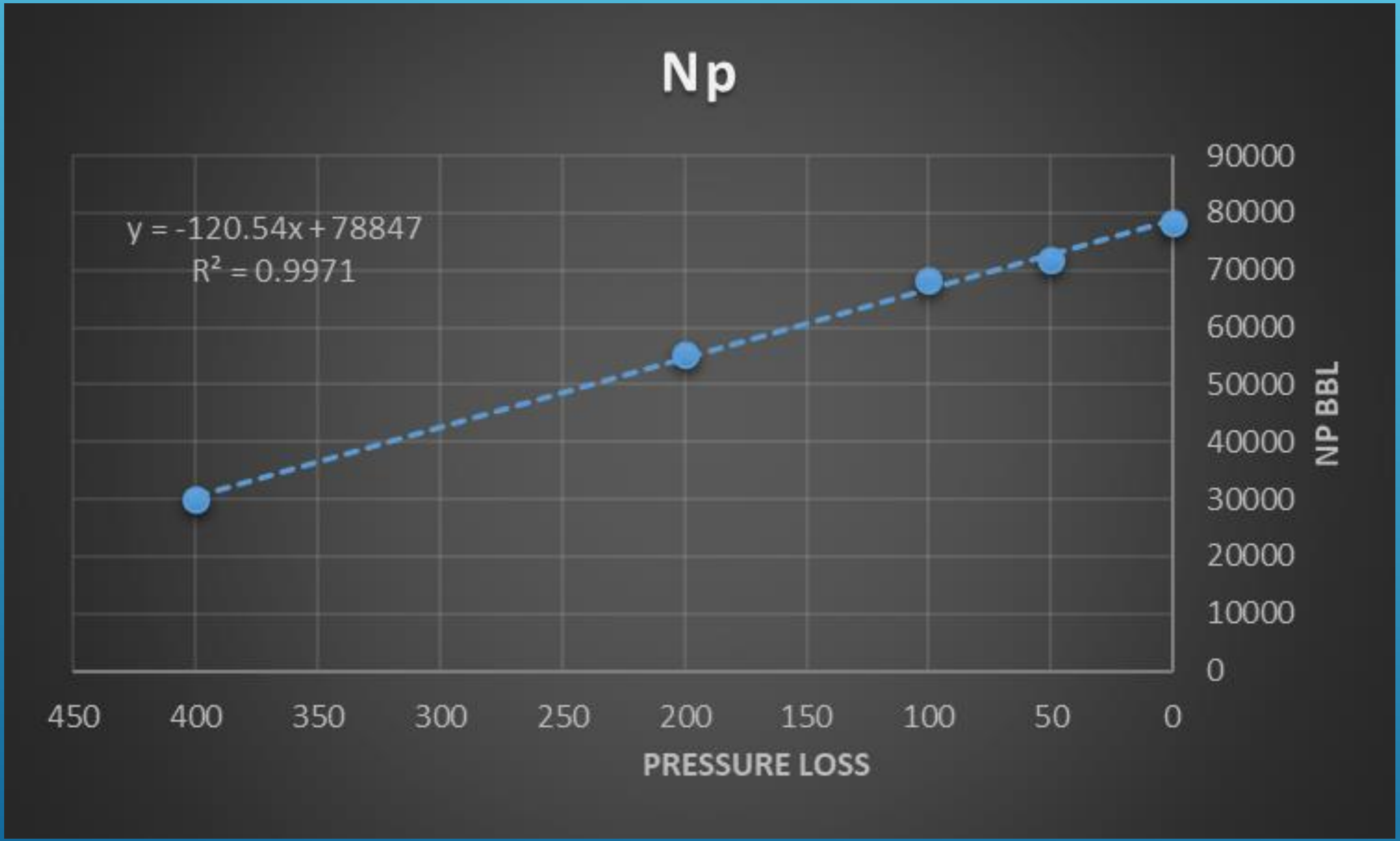
Decline Curve Analysis using production history. Barrels produced could be estimated with depleted flowrate found by nodal analysis (shown by red cutoff line)

ARPs method

Di and b values constant

Qi changes

RESULTS:

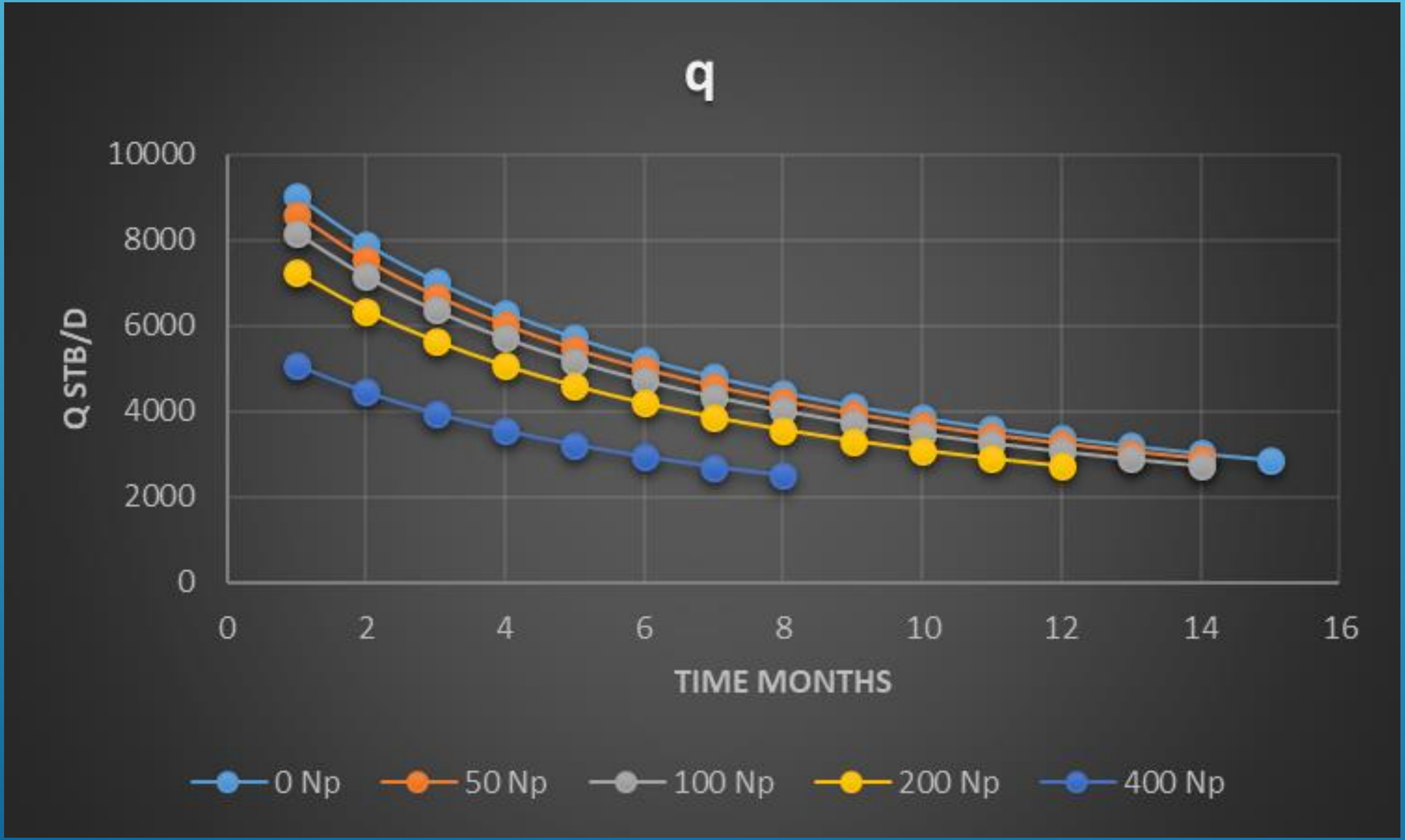


In This well we see a 120.54 stb increase for every 1 psi conserved

ex: 20psi saved= 2410bbl

ex: $50/bbl = $120,540

RESULTS:



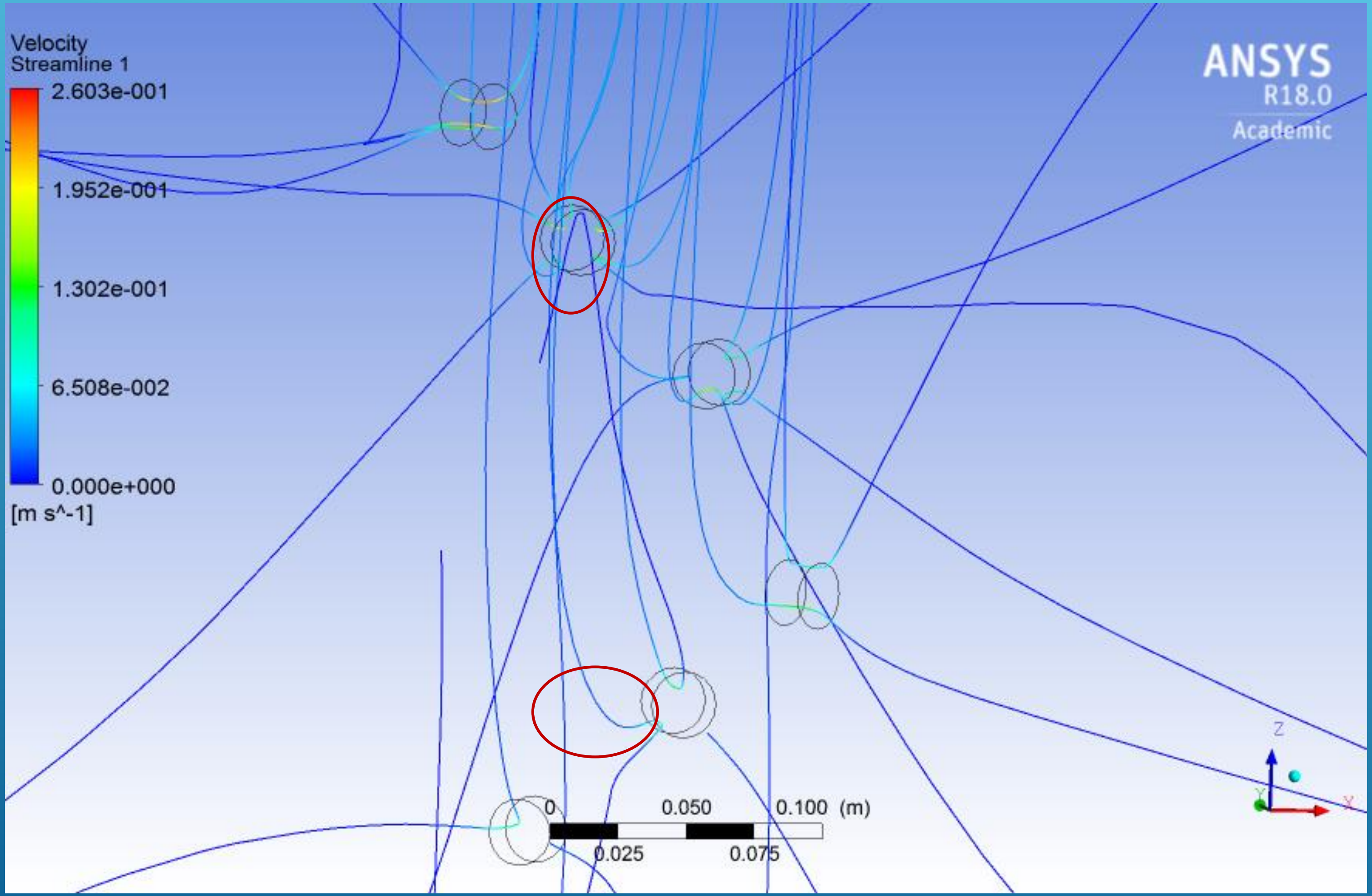
This graph shows the change of expected flowrate over time for each pressure loss

CALCULATING PRESSURE LOSS

ANSYS SET UP:

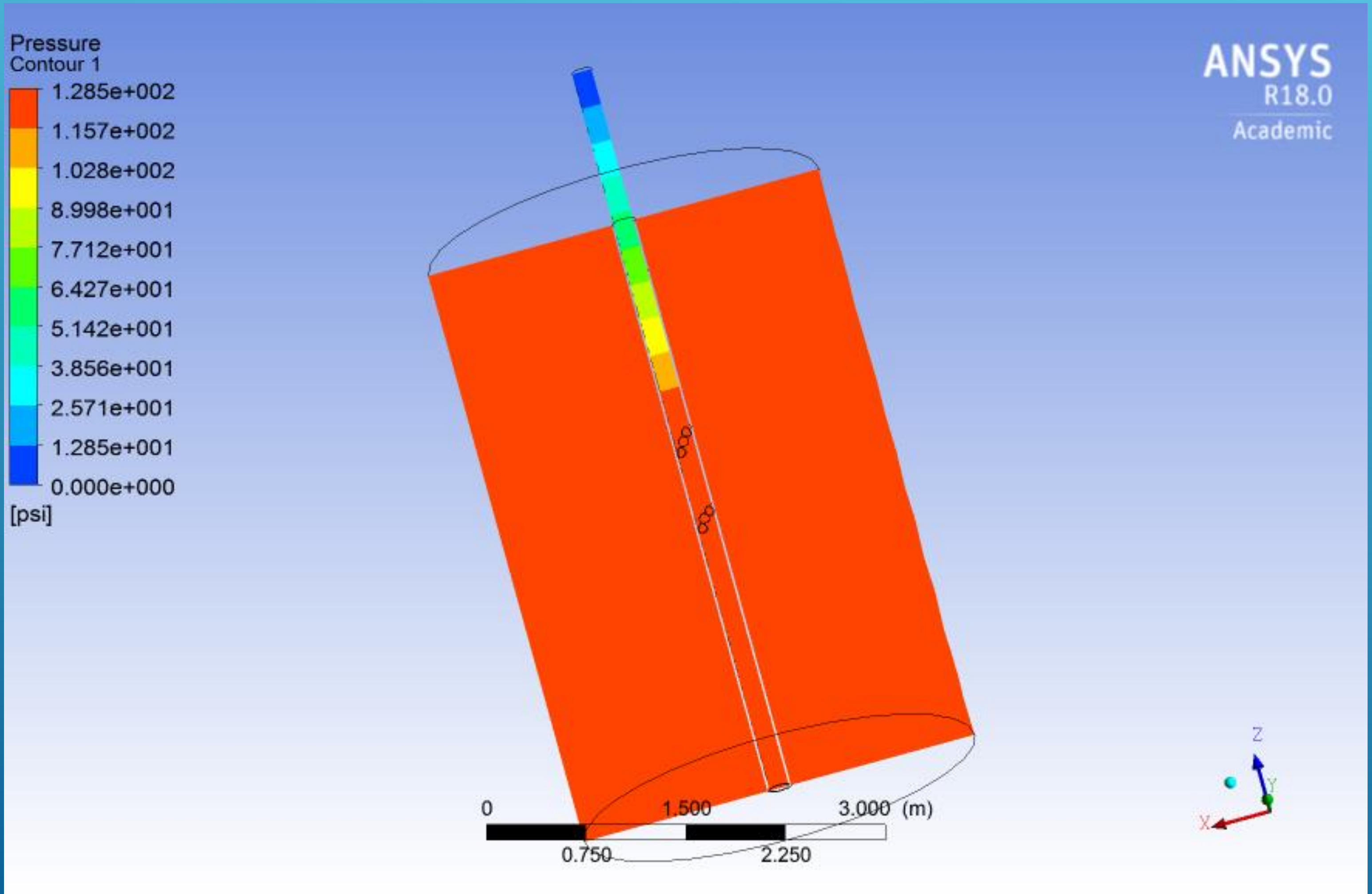
- Data consistent with Nodal analysis.
- Flowrate 300bbls/d , open flow (Consistent with Harmony)
- Reservoir pressure = 1513 psi
- Casing inner diameter = 6”
- Casing and cement thickness = 1”
- Ansys Octane values where used for fluid.
- 24 perforations 6 SPF

ANSYS CONTROL:



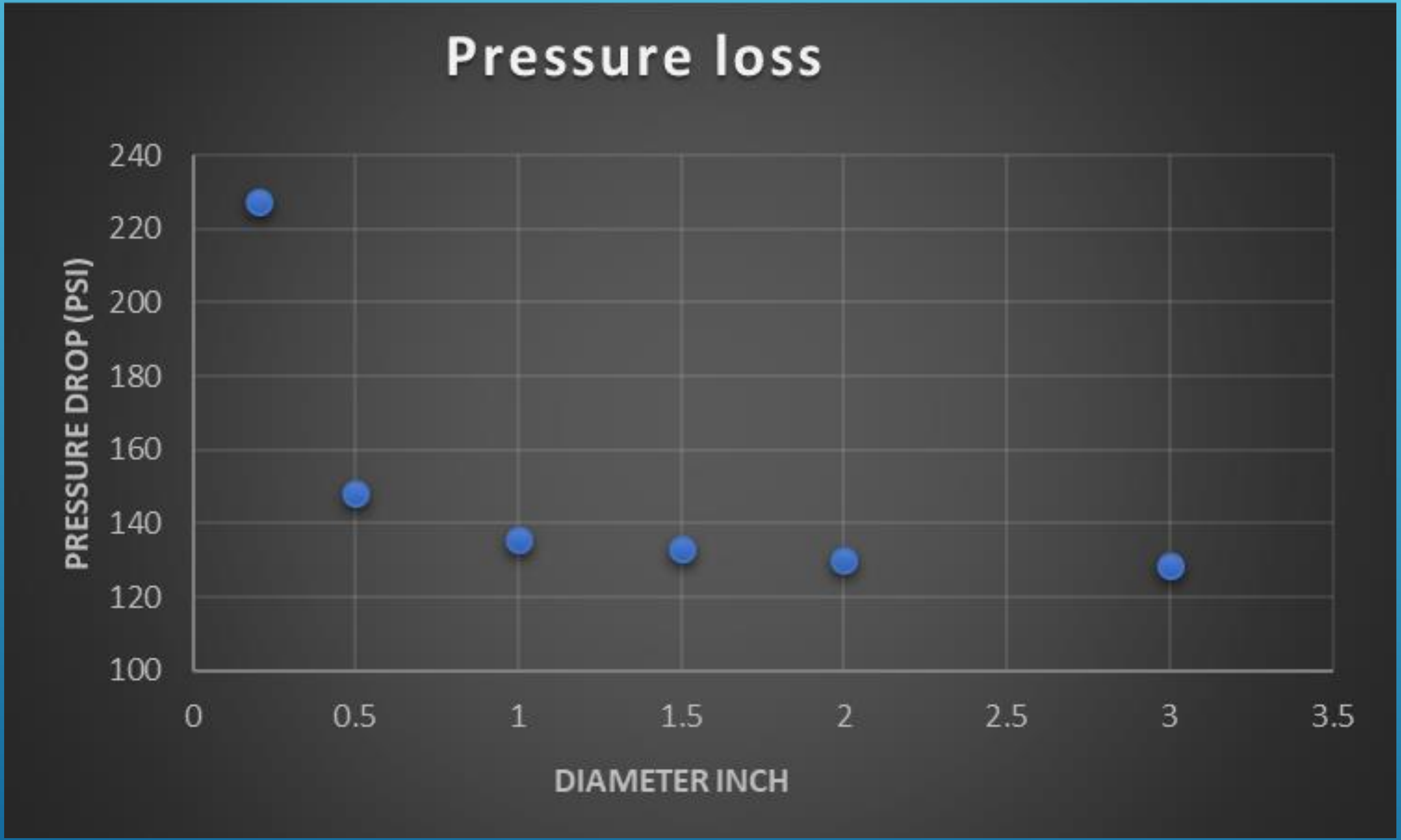
Sharp turns like circled cause additional pressure drop

ANSYS RESULTS:



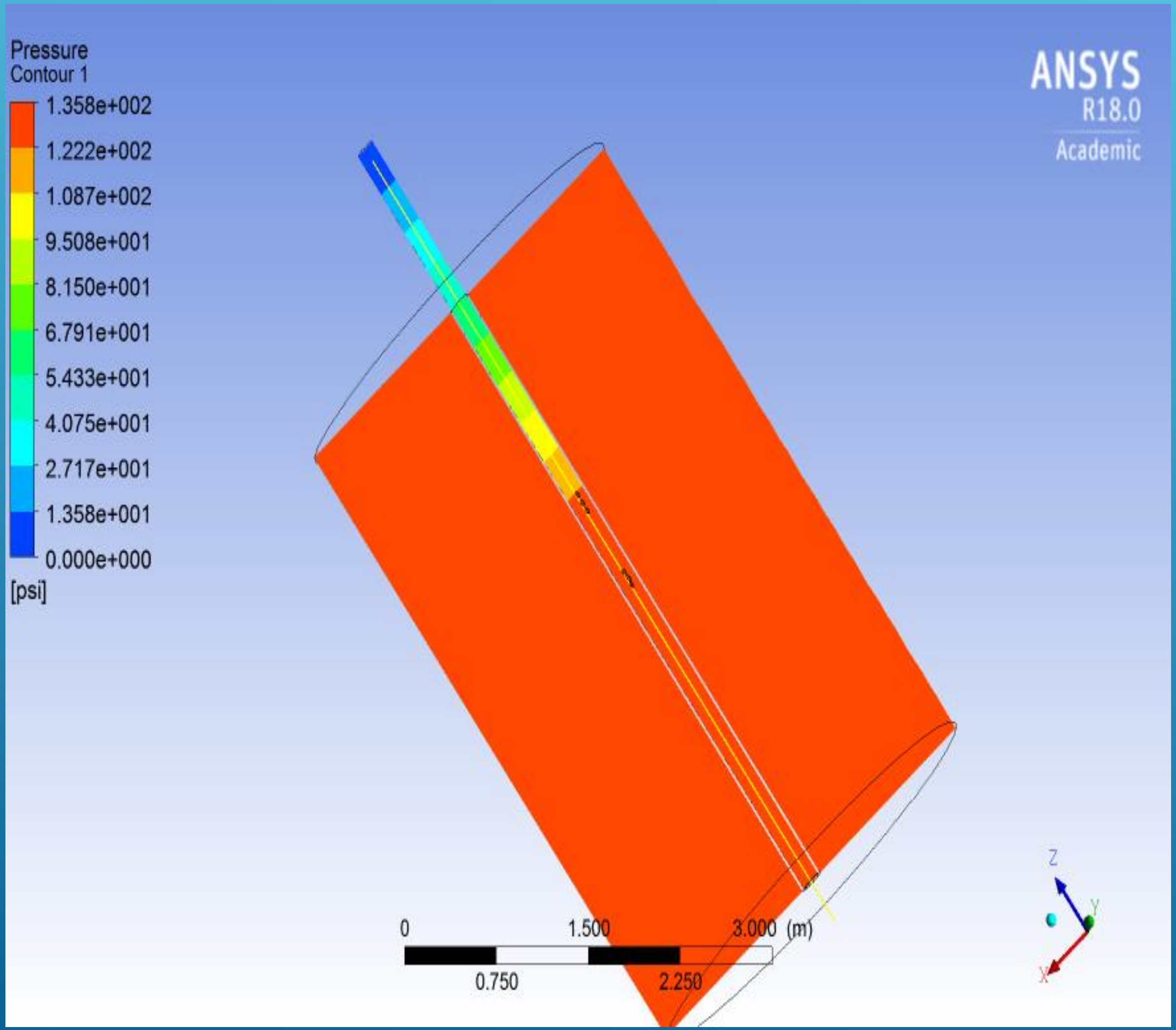
Ansys results show pressure of reservoir is 128.5 psi higher than the wellbore

RESULTS



Graphical anlysis of pressure loss due to perforation diameter. 3 inches would be almost impossible with a 6 inch wellbore.

ANSYS RESULTS 135° AND PHASING APPROACH:



Pressure difference between wellbore and reservoir for both approaches shows no gain or loss in pressure.

NOTES:

- This study is for conventional reservoirs. Horizontal wells will have many stages to compensate for pressure loss.
- Pressure loss is dependent on viscosity and density of liquid produced. Ex: Methane has less pressure loss than octane
- Pressure loss is not dependent on bend angle or phasing

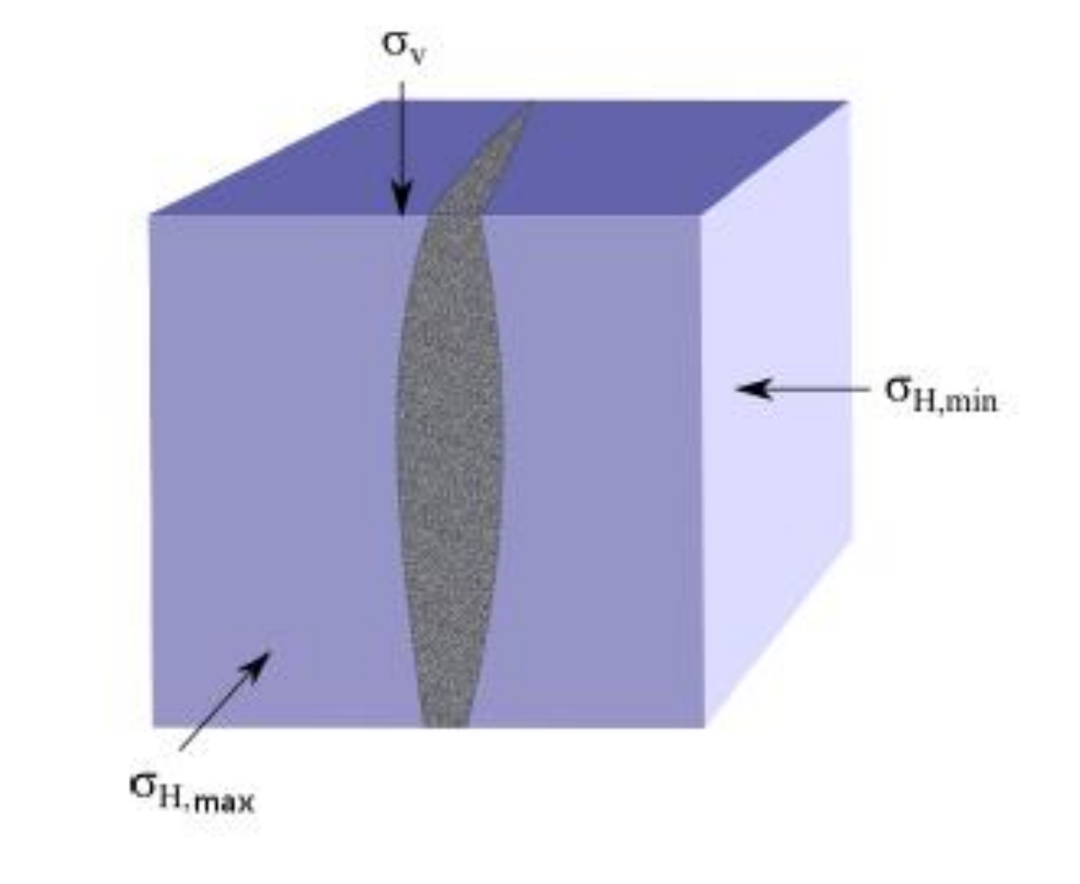
HYDRAULIC FRACTURING

OPTIMIZED FRACTURES ACCORDING TO LITHOLOGY

Low Permeability(shale): Long and narrow fracture

High Permeability(sandstone/conventional): Short and wide Fracture

HOW FRACTURES PROPAGATE



Height is limited to vertical stress or change in lithology.

Width opens parallel to horizontal min stress.

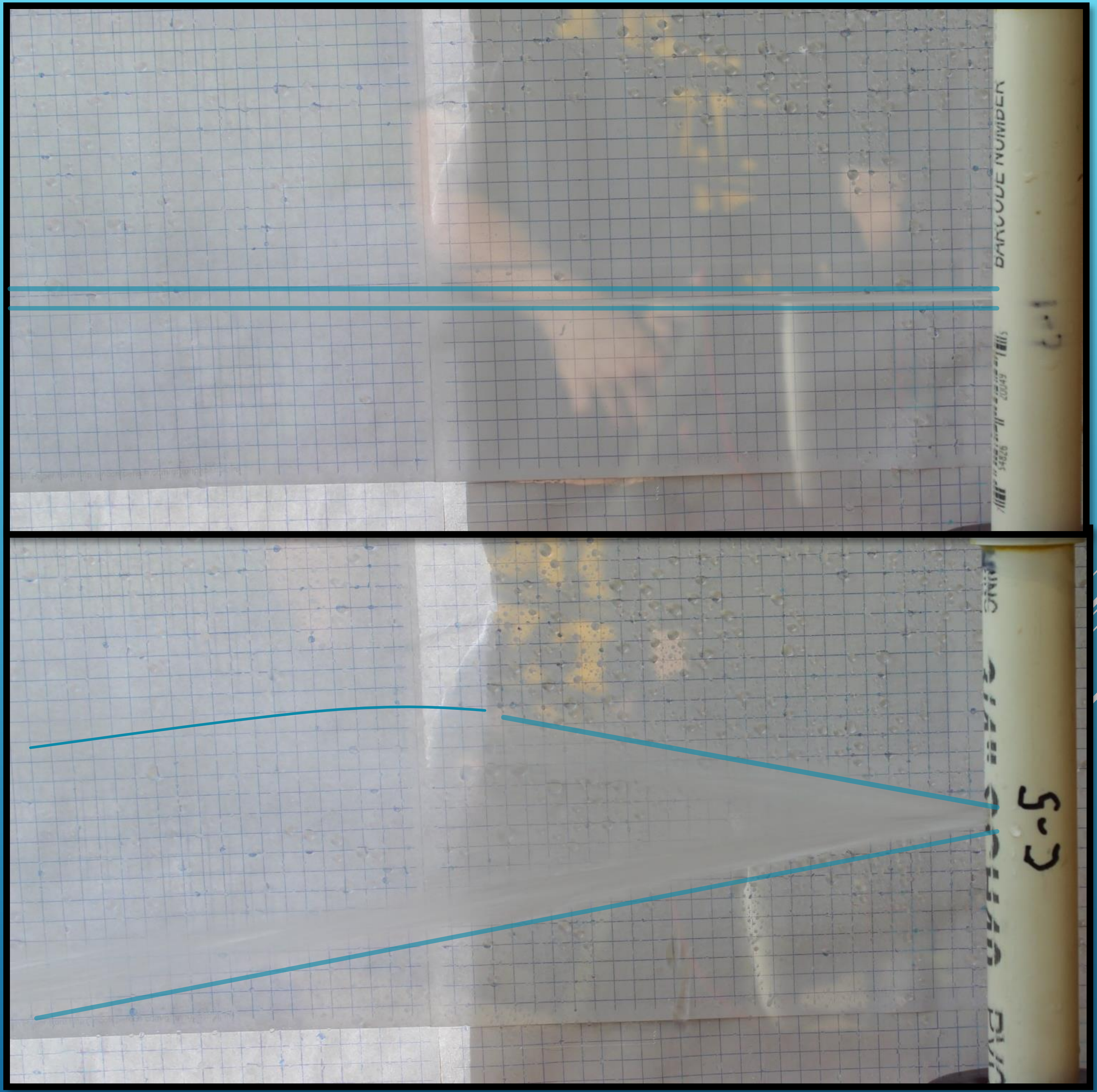
Length grows perpendicular to horizontal min stress

Change in one stress/force alters entire fracture

Concept check

Small Perforation
High velocity
Low pressure
Narrow path/fracture
Long path/fracture

Large Perforation
Low velocity
High pressure
Wide path/fracture
Short path/fracture



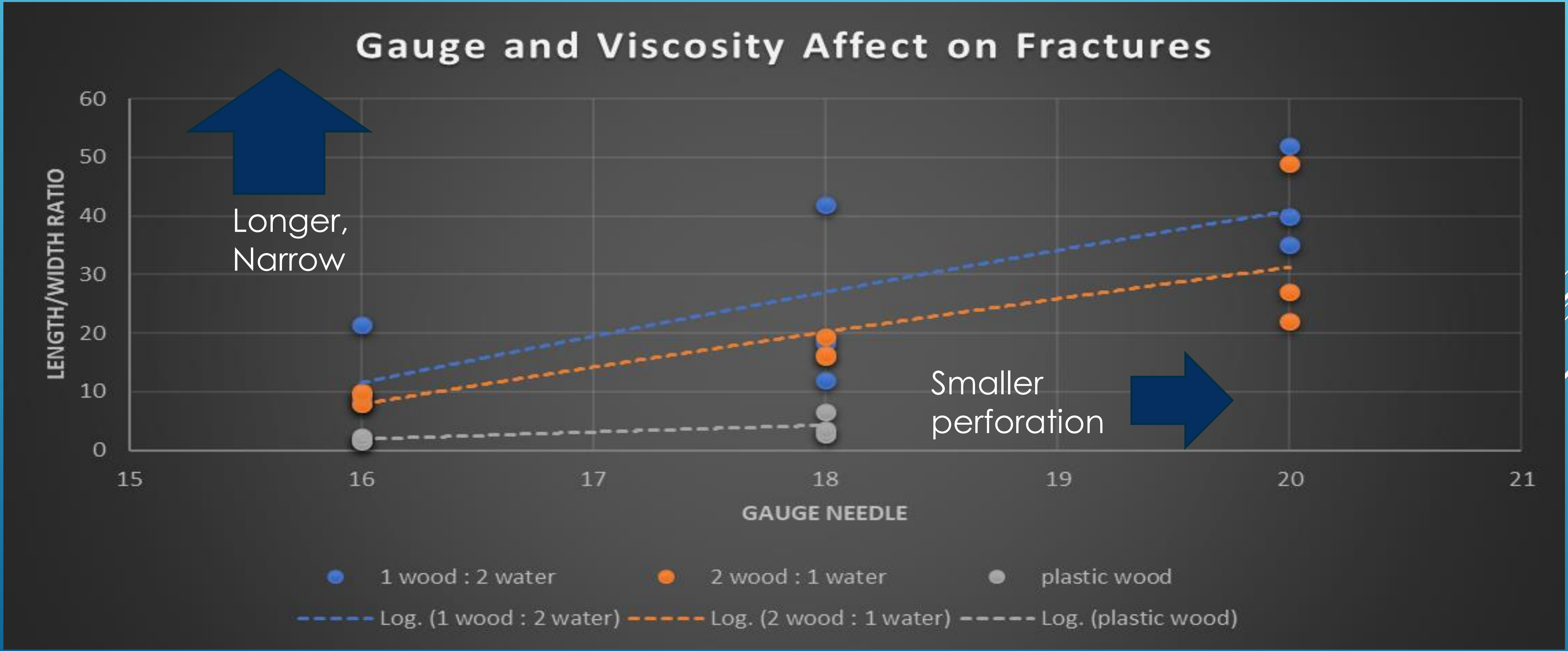
EXPERIMENT

- Plastic wood used as slick-water very viscous
- To change viscosities plastic wood is mixed with water (2:1, 1:2)
- Inject constant 1 cc of slick-water
- Average needles are used to represent diameter changed (gauge16-20)

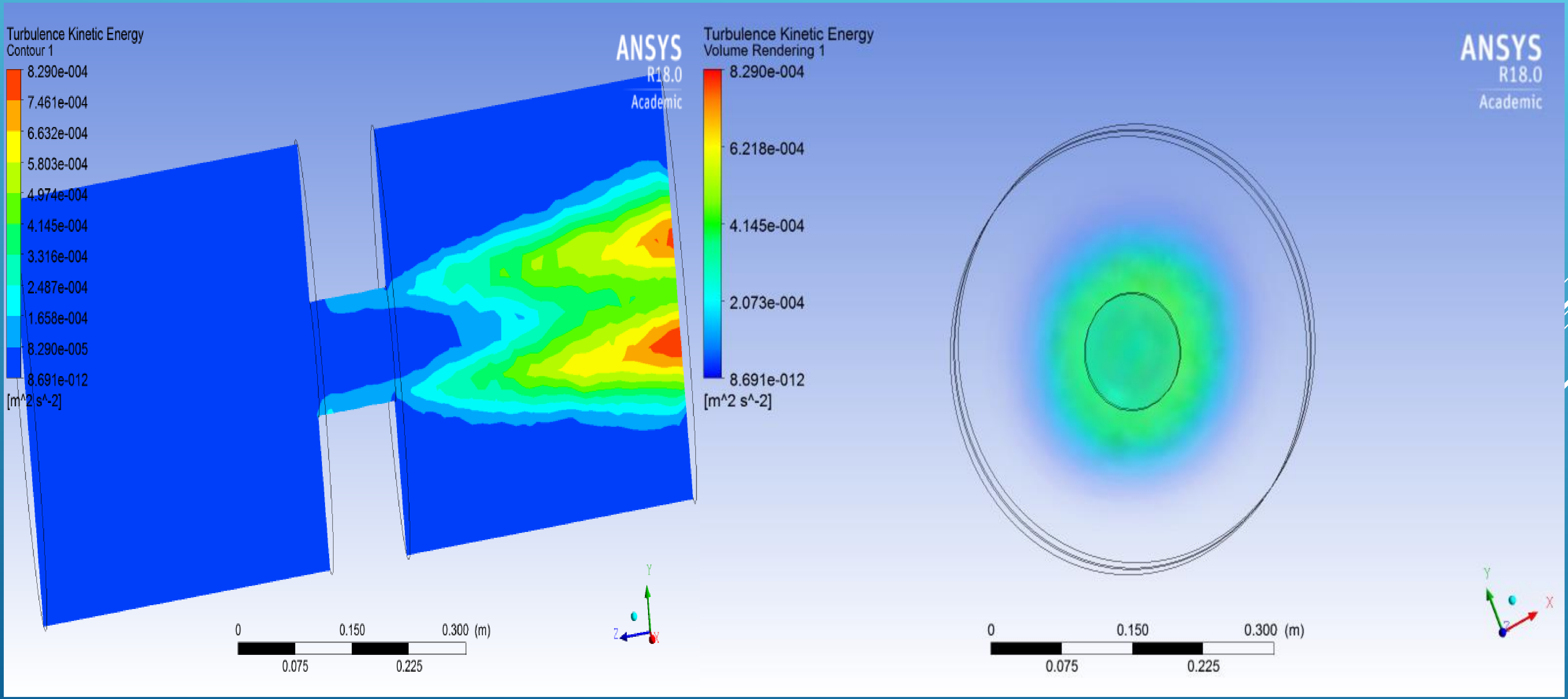
EXPERIMENT NOTES

- Length and height are equal since vertical stress and max horizontal stress are equal.
- Plastic wood besides being viscous also used because it will harden to be removed and measured.
- The more Viscous the slick-water is the higher surface pressure was needed.

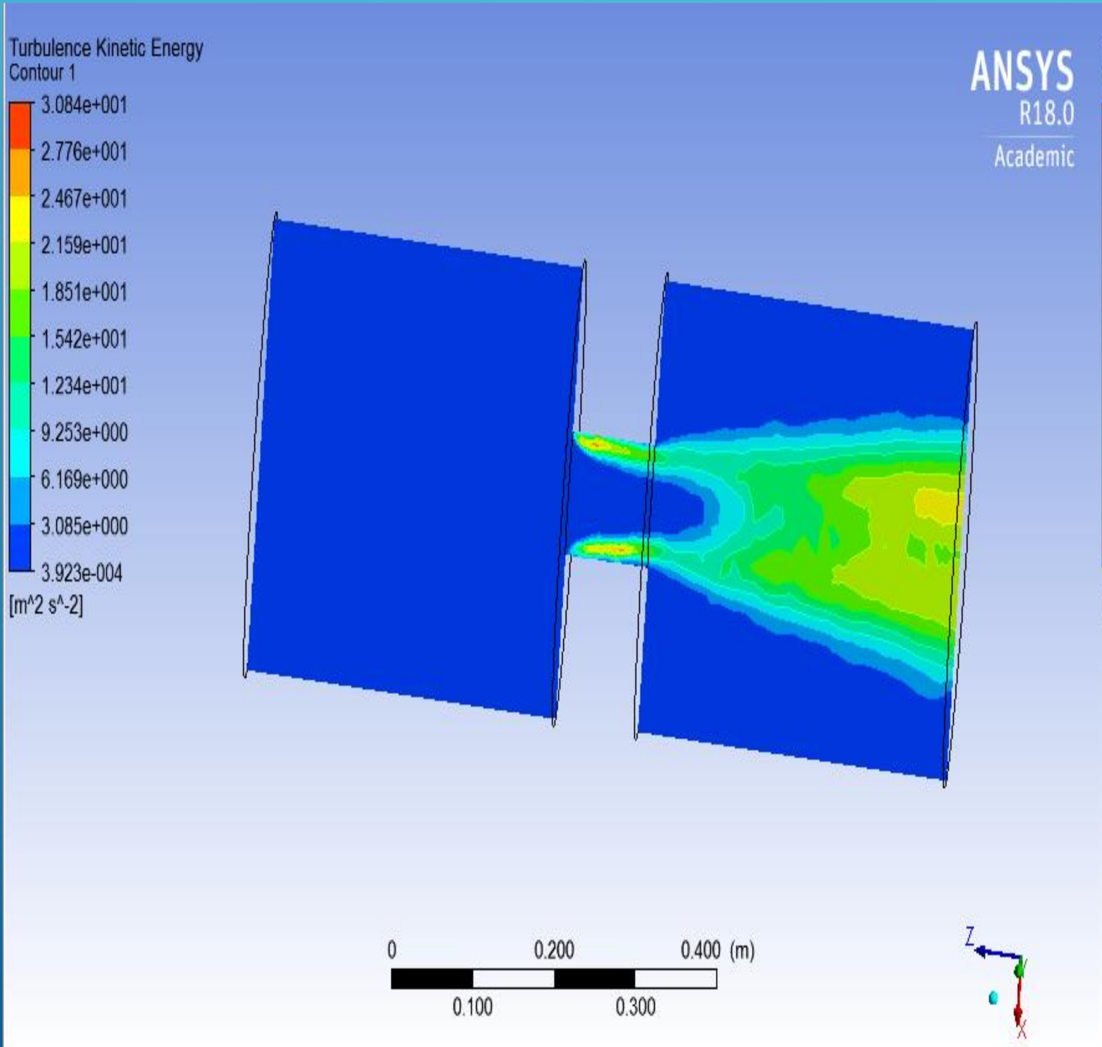
EXPERIMENT RESULTS

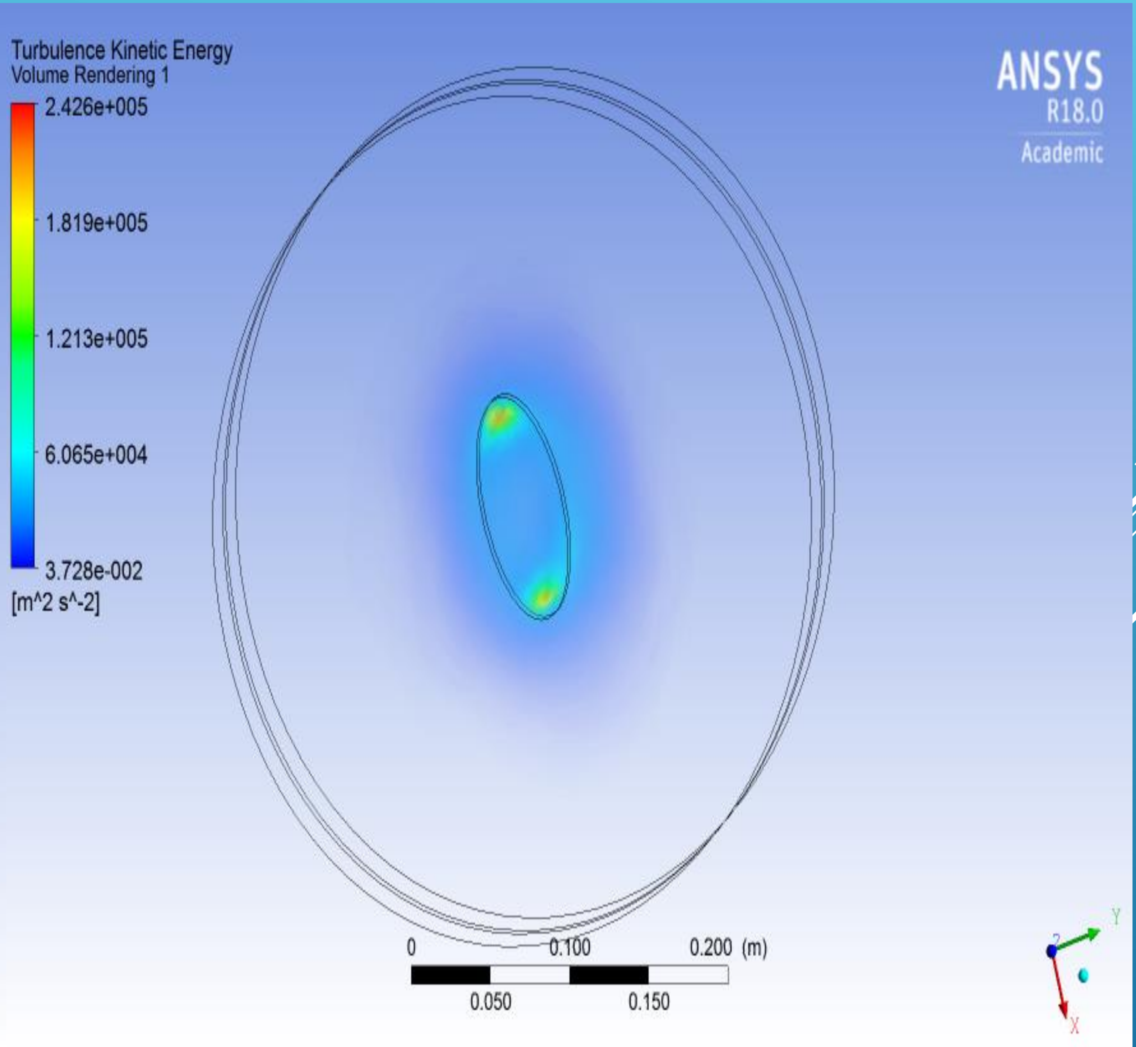


CONTROL ANSYS RESULTS:



OVAL/ELONGATED ANSYS RESULTS:





OPTIMIZING PERFORATION FOR FRACKING

Shale: small perforations

- Lower SPF : a bleeding affect between perforations was seen when simulated on ansys.

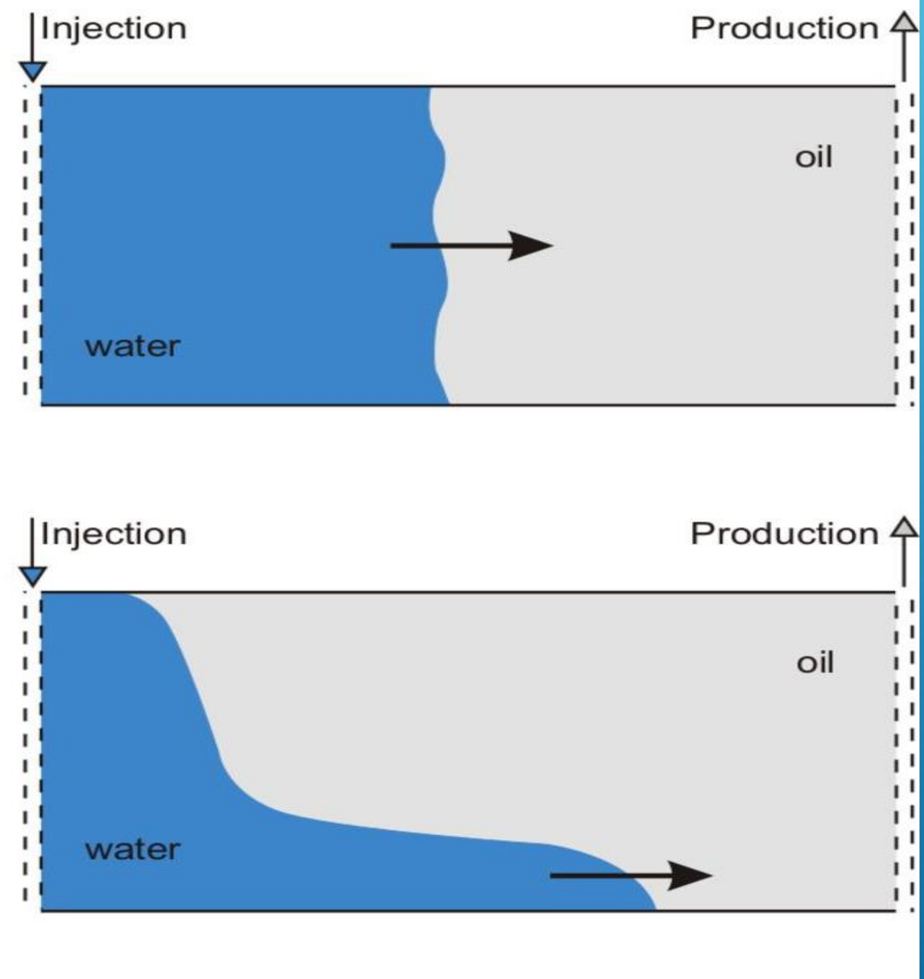
Conventional: Large perforations

- If an oval is produced perpendicular to horizontal min stress a wider fracture would be experienced.

Note: Slurry is very corrosive and will effect results, however the initial fracture is believed to affect on final result.

INJECTION

AFFECT ON INJECTION



Consider homogeneous well

High pressure low velocity = higher recovery factor

Low pressure high velocity = lower recovery factor

CHOOSING PERFORATIONS / CONCLUSION

CONSIDERATION 1:

Type of well

- Injection: Minimize pressure loss, Larger perforation diameter, Higher SPF
- Conventional production: Minimize pressure loss, Larger perforation diameter, Higher SPF, Oval
- Unconventional production: Optimize fracture, Smaller perforations, Lower SPF

CONSIDERATION 2:

Formation lithology

High Permeability: short but wide fracture, Oval or large perforation diameter, Large perforation diameter, Higher SPF

Low Permeability: Long fracture, Smaller perforation diameter, Lower SPF

CONSIDERATION 3:

Type of hydrocarbon

- Dry-Gas: Optimize Fracturing
- Wet-Gas: Optional
- Liquid: minimize Pressure Loss

DISCUSSION

Could a perforation be optimized for proppant migration and if so how?

What other shape could be used for optimization?