Fracture Geometry Characterizations through Physical Modeling

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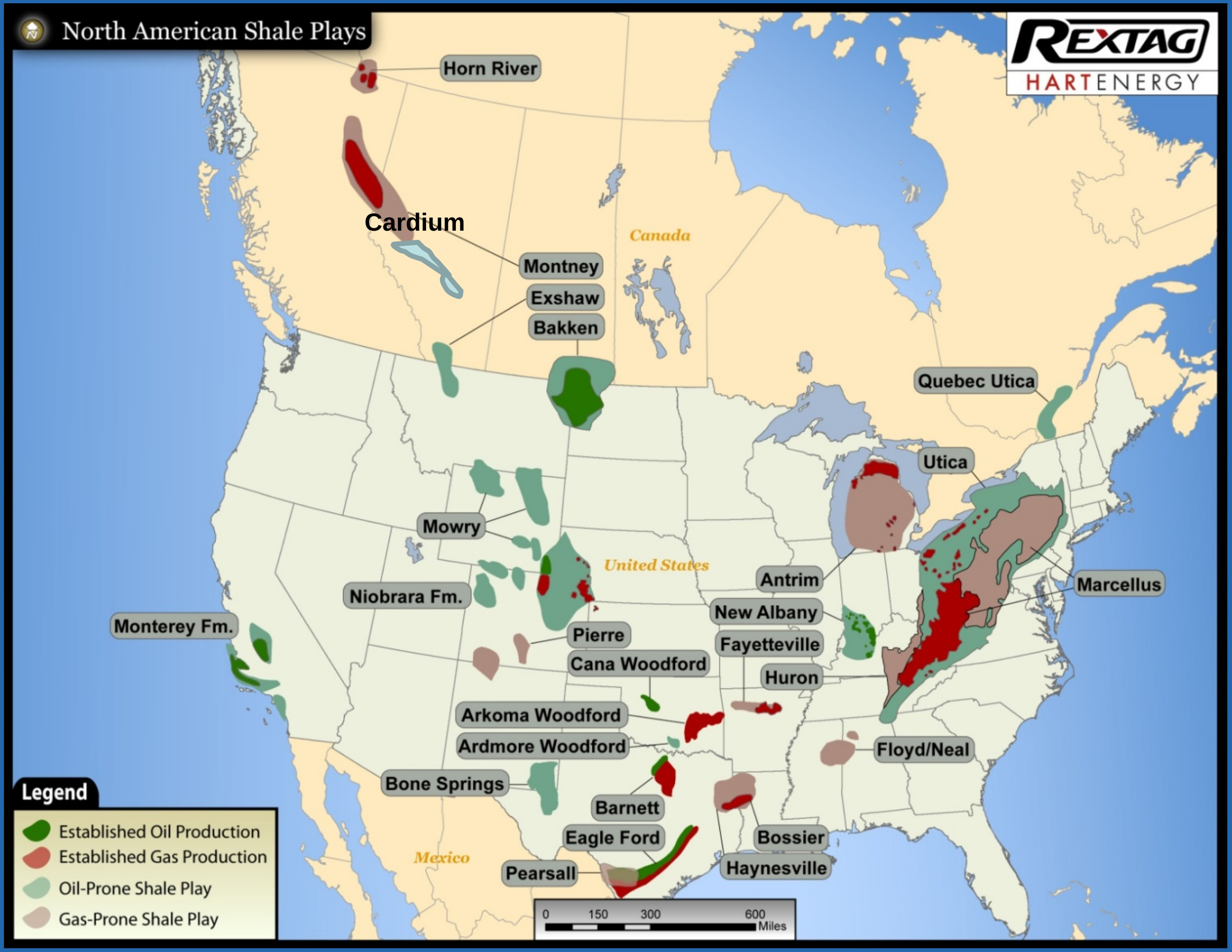
Presentation contents

- Objective.
- Introduction.
- Literature review.
- Fracture Geometry Characterization methodology.
- Present the main findings.
- Present the main conclusions

Global Shale Plays

North American Shale Plays



Source: Hart Energy Data and Mapping Service

Sample Shale Gas Plays

Country	Shale	TOC %	Thickness Meters
Argentina	Los Molles & Vaca Muerta Shales Neuquén Basin	1.6 - 5.0	up to 1,200
Colombia	La Luna Simiti Shale Middle Magdalena Basin	3.1	800
China	Ordos Basin Permian Shale	2.0 -20.0	250
Sweden	Alum Shale Lower Saxony Basin	1.7 - 16.0	200
India	Cambay Basin Shale	2.6 - 5.0	1,150 - 1,350
Australia	Goldwyer Shale Canning Basin	3.9 - 62	100 - 500
Poland	Graptolitic Shales Baltic Basin	6.0 - 10.0	460
Germany	Posidonia Shale Lower Saxony Basin	2.0 - 8.0	up to 530
Saudi Arabia	Qusaiba Hot Shale Arabian Basin	4.0 - 12.0	20 - 70
South Africa & Botswana	Ecca Formation Karoo Basin	0.7 - 1.3	46
Ukraine	Rudov Shale Dnieper-Donetsk Basin	2.0 - 13.0	8 - 70

Sample Shale Oil Plays

Country	Basin	Shale	TOC wt%	Prospective Area mi^2
Australia	Beetaloo	Kyalla	2.0-3.0	5,400
New Zealand	East Coast	Whangai	.7-1.7	1,500
Colombia	Middle Magdalena	La Luna	1.0-6.0	2,000
China	Songliao	Qingshankou	5.0	11,700
Spain	Basque-Cantabrian	Liassic	9.0 (max)	9,145
Jordan	Arabian	Hiswa	1.0	na

Objective

- The overall objective of establishing the fractured reservoir physical model research is to study the impact of fractures geometry and their distribution on reservoir performance.

- The study proposes detailed and integrated characterizations using six different characterizations of fracture parameters:
  1. Length,
  2. Aperture (width),
  3. Orientation **(to the flow),**
  4. Density,
  5. Spacing, and
  6. Porosity.

Introduction

- Fractures have been known to exist in reservoirs for the last half century,
  - Yet the practice of characterizing fractured reservoir system has been extremely slow.
- Why is this so?
  - Because fractured reservoirs are extremely complex.
- The complexity is attributed to vast number of both dependant and independent geometrical variables that dictates final reservoir response.

Complexity of Fractures

- Fractures are present in all rock subsurface formations.
- Fractured rocks that comprise the reservoirs are formed in variety of geometric shapes due to dynamic diagenesis.
- The physical character of these fractures is dictated by:
  - Their mode of origin,
  - The mechanical properties of the host rock, and
  - Subsurface diagenesis.
- These factors combine to develop a feature that can either increase or decrease reservoir porosity and permeability.
- Fractures when they occur in sufficient spacing or length that their effect on fluid flow becomes important.
- To accurately assess this effect (either negative or positive) it is important to know the fluid flow properties of individual fractures and how many of these fractures of a given orientation exist in a given reservoir volume.

Current Fracture Characterizations

- The origin of fracture system is postulated from data **(if available)** on fracture dip, morphology, relative abundance.

- Often times, these data obtained from:
  - Full-diameter oriented core,
  - Borehole imaging tools, and
  - Applied empirical models of fractures generation.

- Available fracture models range from tectonic to of primarily digenetic origin.

- The interpretation of fracture system origin involves a combined geological/ rock mechanics approach to the problem.

Several obstacles are identified w/ current fracture characterizations

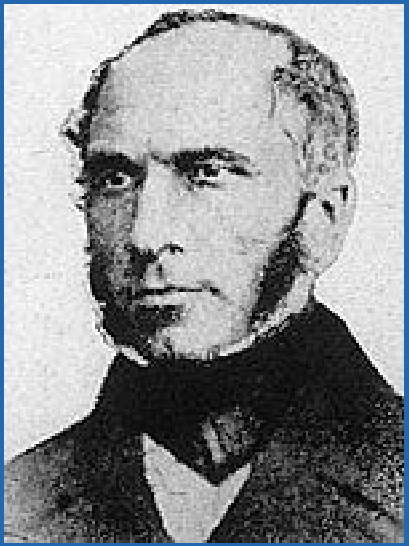
1. A lack of in-depth quantification approaches to describe these fractures.
2. Failure of geologists and engineers to recognize fracture geometry, regularity and their distribution.
3. Over-simplistic approaches in the description of fracture distributions and their morphologies.
4. The need for deterministic solution to model fluid flow in fractured porous media.
5. Physical modeling a complex phenomenon is not easy, it will inherent data limitation, which will force geologists and engineers toward stochastic solutions.

Important thoughts

- These obstacles are approached by the use of many techniques, at best, developed for finding fractures.
- An important research thought is: "**finding fractures is not enough**."
- Detecting fractures or predicting their existence is important, but evaluating them is the key to have better economical producing strategy.

Literature review

- The first quantitative description of fluid flow through porous media was by Darcy (1856).
- In his general equation (derived for laminar, incompressible, single phase, Newtonian flow in a continuous, homogeneous, porous material), the permeability through porous media was discovered.

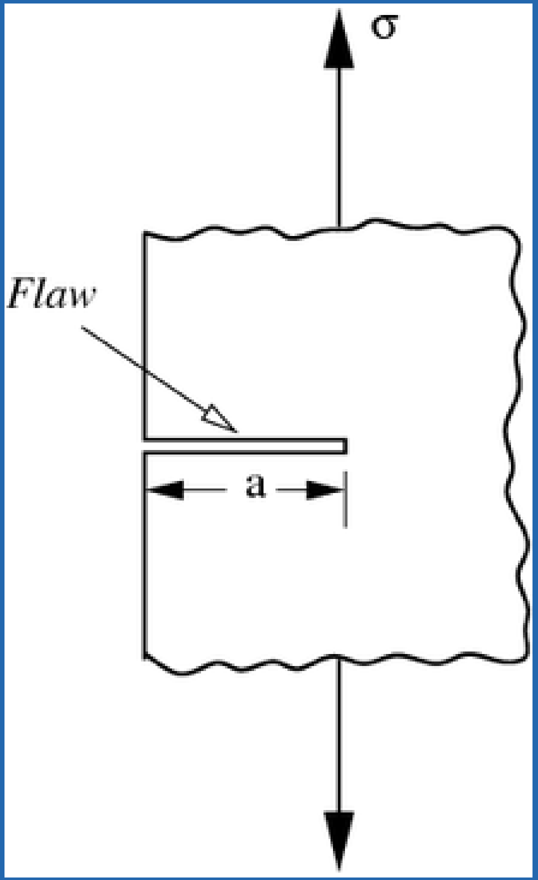


84 years Later

- Hubbert (1940) showed that the resultant dimensions of the permeability (k) are (length)^2.

1950's - Today

- Griffith's work after World War I on cracks on materials designed for airplanes, It was later realized that the intrinsic permeability could not be defined for flow along a fracture.
- Therefore, in an attempt to model the fractures, the parallel-plate theory of flow was developed.
- However, flow in this theory is assumed to occur between two smooth parallel plates separated by a distance.
- This work has led later to the equations as used by Huitt (1955), Lamb (1957), Snow (1965 and 1968), Sharp (1972), and others.



Cont’d

- All work describes only portion of the total flow through a fractured-porous rock; for example, Darcy’s equation describes only the intact-rock portion of the system, others describe the parallel-plate theory for the fractures.
- The next upgrade to determine the total flow was to combine these equations (Parsons, 1966). This work assumes that: flow is laminar between smooth, nonmoving, parallel-plates.
- Fluid flow across any fracture/ matrix surface does not alter the flow of either system, and fractures are homogeneous with respect to orientation, width, and spacing.

This Fracture Study is Different

- This study is different than other fracture studies in terms of studying the origin of fractures.
- This study is concerned with studying the effect of the petrophysical determinations of the rock matrix in which the fracture system resides.
- It is also to determine the reservoir properties as that is detrimental to the fluid flow.

The new problems associated with this study

- In order to conduct this complex work, three problems has to be solved.
  1. Provide a fracture free rock.
  2. Finding the apparatus that will host the rock media, and finally
  3. Making and controlling the geometry of fractures.

Reservoir media

- An alternate rock is suggested for this study.
- The standard Calcium Silicate Brick also known as the Sand-Lime Brick will be the reservoir media.
- The specification of this brick, from sand and lime, is intended for use in masonry.
- The scientific terminology is C-1209.

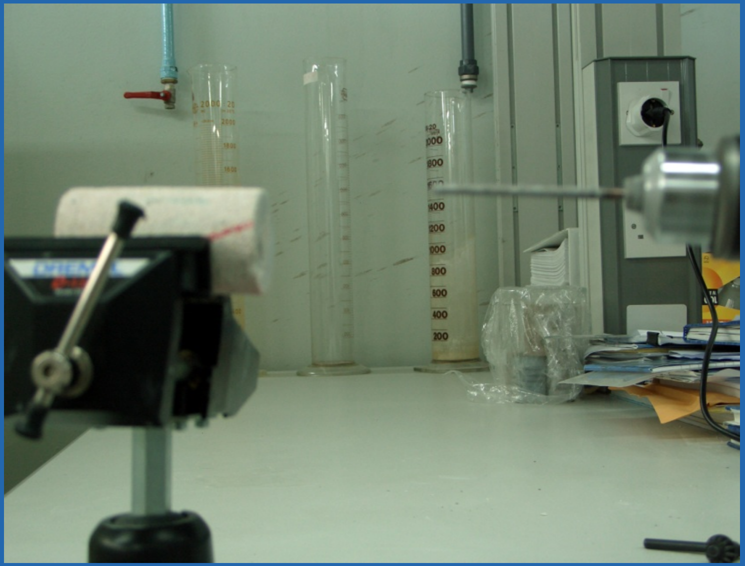
The perfect rock media

- The brick is soundly-compacted and free of fractures and any other defects.
- It has strength of 4500 psi and water absorption of 15 lbs/ ft3.

Media physical parameters

- The rock strength is sufficient to introduce various morphological a parent 1.5 inches core plugs and daughter-fractures without shattering the surrounding mother matrix.

- Each plug has approximately:
  - 1.5 inches diameter,
  - An average core length between 6 to 8 centimeters.
  - The core air-porosity is measured to be 27.25%.
  - The air-permeability is measured to be about 5 md.



Apparatus description

- A bench top core flood system is used to measure the liquid permeability for the Sand-Lime Brick of different fracture designs.
- The permeability system has a coreholder that can host a 1.5 inches in diameter for a cylindrical core material with up to 8 inches in length.
- The sleeve material is Viton that can tolerate maximum pore pressure of 5,000 psi and maximum confining pressure of 9,950 psi.
- **This study uses 700 psi as an overburden/ confined pressure on the plug sample.**
- **The system's coreholder is oriented in a horizontal position.**
- The system is integrated with a computer based for the pump operation and for the pressure data acquisition.
- The pump can operate up to 100 cubic-centimeters per minute.
- **However, this study uses a fixed flow rate of 3 cc/ min or 0.05 cc/ sec.**
- There are two digital delta-pressures gauges assigned for this system, high-pressure gauge (10 to 1000 psi) to honor pressures of the tight permeability matrix type and low-pressure gauge (0 to 10 psi) to honor pressures of open fracture permeability.
- These pressure tools are interchangeable during the flow experiment.

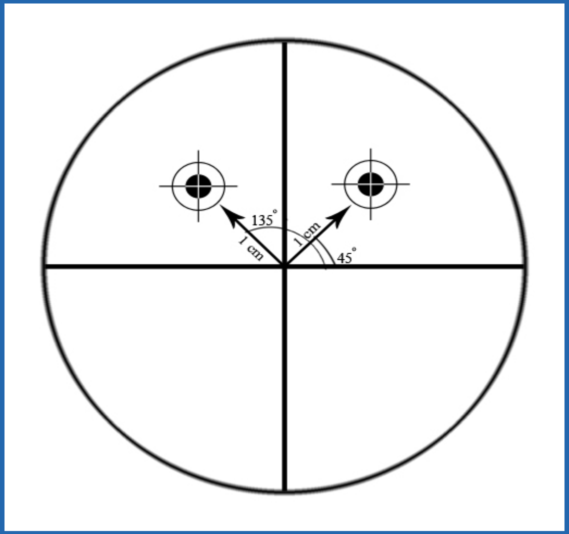
Fracture description

- A controlled morphology of the fracture is attainable by simple milling of the reservoir matrix using a masonry drilling device is how the fracture is introduced to the system.

- The drilling action will make a cylindrical hole that will be interpreted as the controlled fracture.

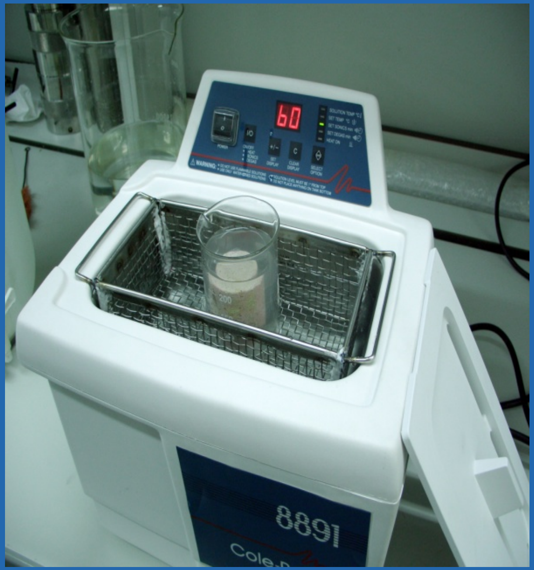
- The cylinder-fracture will have controlled:
  - Length,
  - Aperture/ circular area,
  - A fixed orientation,
  - A number (e.g. one hole, two holes…etc.) that will represent the density,
  - The spacing between fractures (2 fractures or more), fixed porosity, and distribution in the mother rock matrix.

- The rock matrix is the Sand-Lime Brick that is designed to withstand milling actions.



The debris

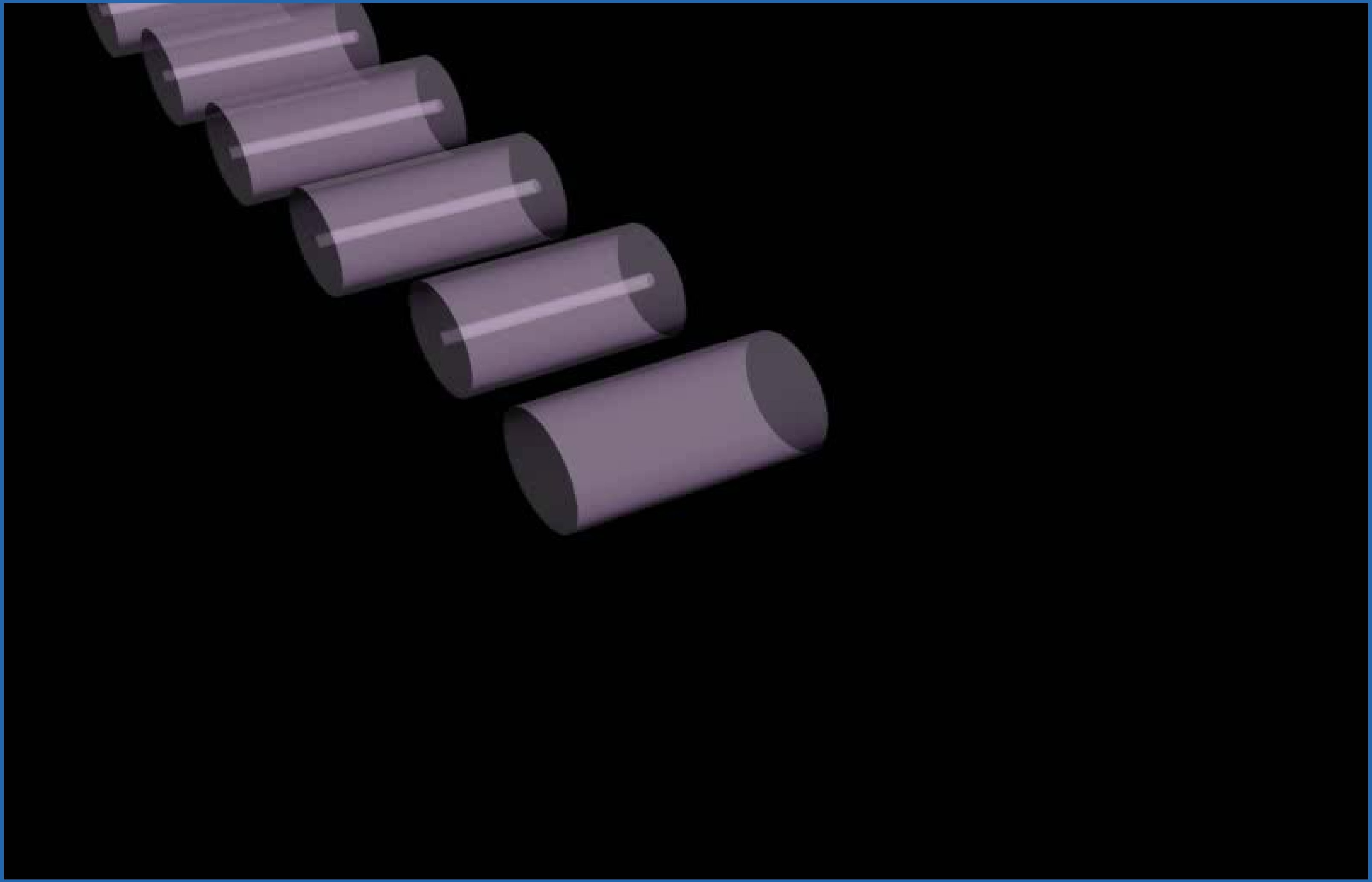
- The fracture is introduced after the core-plug is 100% saturated with deionized water.
- The debris resulted from the milling action is divided into two sections:
  - Debris-I is removed outside the core by the drill bit itself, and this portion is the majority of the rock mass that has been removed.
  - Debris-II is fines that are plugging the pores along the cylindrical wall of the fracture.
- Debris-II is problematic because it has the ability to obstruct fluid flows from the fracture to the matrix or vise-versa.
- This problem is treated by a sonic warm bath treatment to the plug sample.
- The bath temperature used for this purpose is 39°C and the sonic run time used here is approximately 60 minutes.



Experiment design

- To explain the complexity of the fracture morphology arrangements in the rock matrix, a combination of all six parameters with their all possible arrangements must be considered at the same time.
- As a result, a full factorial experiment must design this problem.
- Six possible fracture factor and about three runs in each arrangement will yield a 3^6 possibilities equivalent to 720 experiments.
- These numbers of experiments is impossible to carry in laboratories with limited resources.
- Also, full factorial designs are not recommended for 5 or more factors; however, more realistically, a one-factor-at-a-time method will be designed for the physical model. As a result, all six factors with their possible morphological setup will be evaluated independently.
- In this study-design, the one-factor-at-a-time method is hard to reproduce measured results phenomenon. Therefore, comparisons between fracture-cases are much more reproducible and are used.
- This study compares the permeability of a fracture system against a standard case without-fracture system that acts as baseline.
- The total number of experiments, therefore, is twenty four experiments.

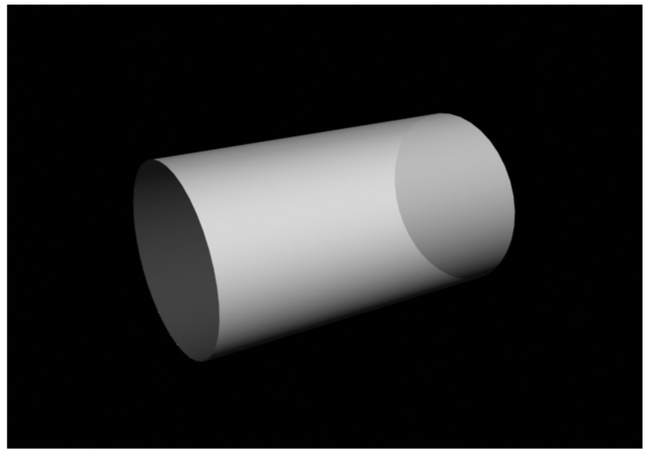
The Demo



The baseline case

Case:

Without Fracture



Fracture

Fracture Dia (cm): N/A

Fracture Length (cm): N/A

Fracture Φ (%): N/A

Oeriention (^{o}): N/A

Fracture Density: N/A

Fracture Spacing (cm): N/A

Core Plug

Length (cm): 7.25

Diameter (cm): 3.805

Porosity Φ (%): 27

K_i without Frac (md): 5.13

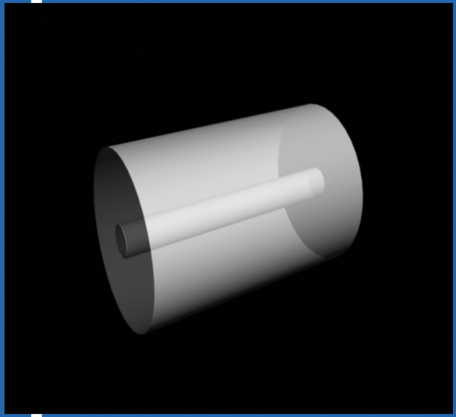
Total

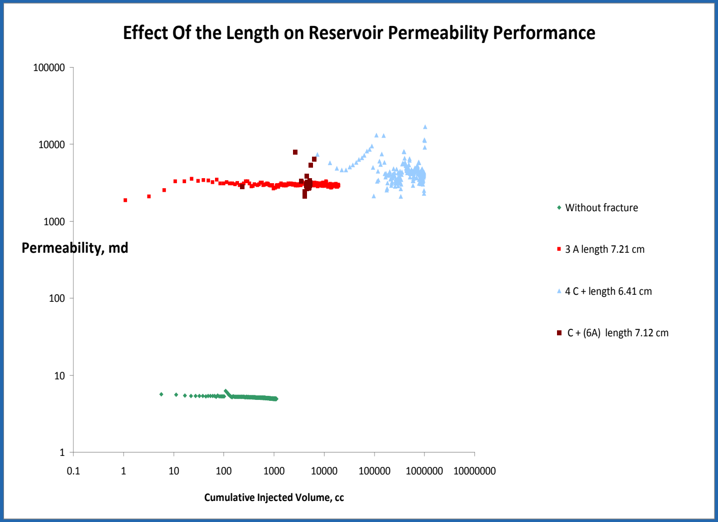
K_f (md): N/A

$\varepsilon=(K_f/K_i)x100$ (%): N/A

The fracture length

Controlled parameters: One fracture, 0° fracture, Diameter is 0.5 cm, Fracture is 100% open				
Case Items	Length (cm)	Possible Location	Possible fractures Per matrix	Total Experiments
1	6.41	1	1	1
2	7.12	1	1	1
3	7.21	1	1	1
			Total Experiments	3

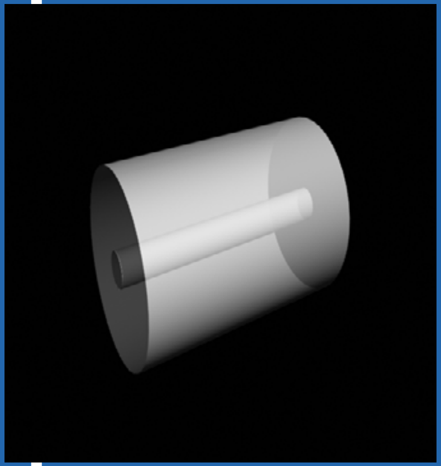


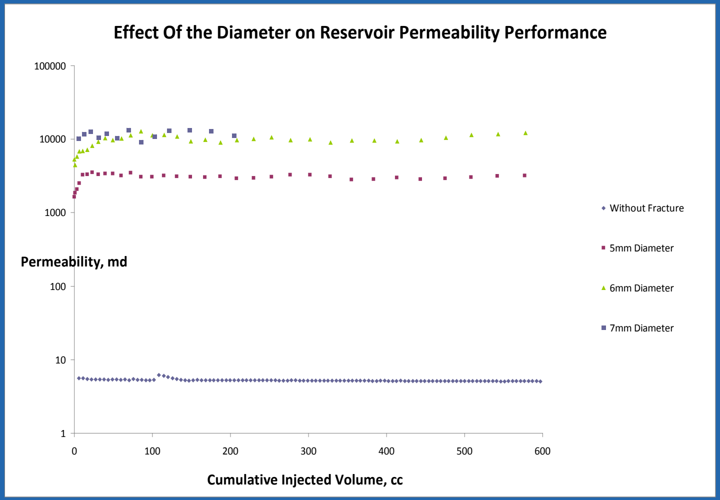


Fracture Length (cm)	Plug+Fracture perm Kf (md)	Flow Efficiency ε (%)
No Fracture	5	0
6.41	4,521	90,420
7.12	2,970	59,400
7.21	2,977	59,540

The fracture width

Controlled parameters: One fracture, Length is 5 cm, 0° fracture, Fracture is 100% open				
Case Items	Diameter (mm)	Possible Location	Possible Fractures Per matrix	Total Experiments
4	5	1	1	1
5	6	1	1	1
6	7	1	1	1
			Total Experiments	3

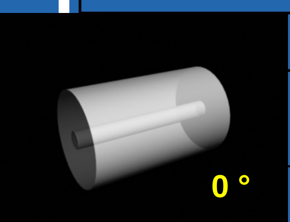


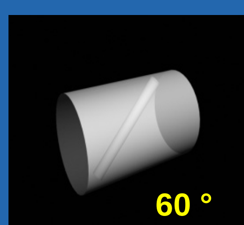


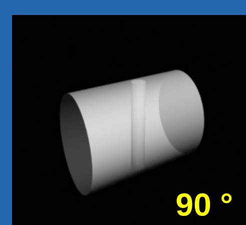
Fracture Width (mm)	Plug+Fracture perm Kf (md)	Flow Efficiency ε (%)
No Fracture	5	0
5	4,977	99,540
6	11,375	227,500
7	11,667	233,340

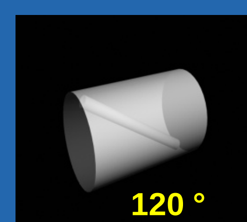
The fracture orientation

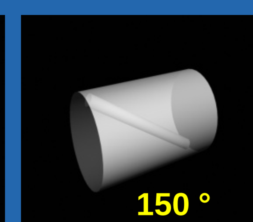
Controlled parameters: One fracture, Length is 5 cm, Diameter is 0.5 cm, Fracture is 100% open				
Case Items	**Orientation**	**Possible Location**	**Possible fractures Per matrix**	**Total Experiments**
7	0°	1	1	1
8	30°	1	1	1
9	45°	1	1	1
10	60°	1	1	1
11	90°	1	1	1
12	120°	1	1	1
13	135°	1	1	1
14	150°	1	1	1
			Total Experiments	8



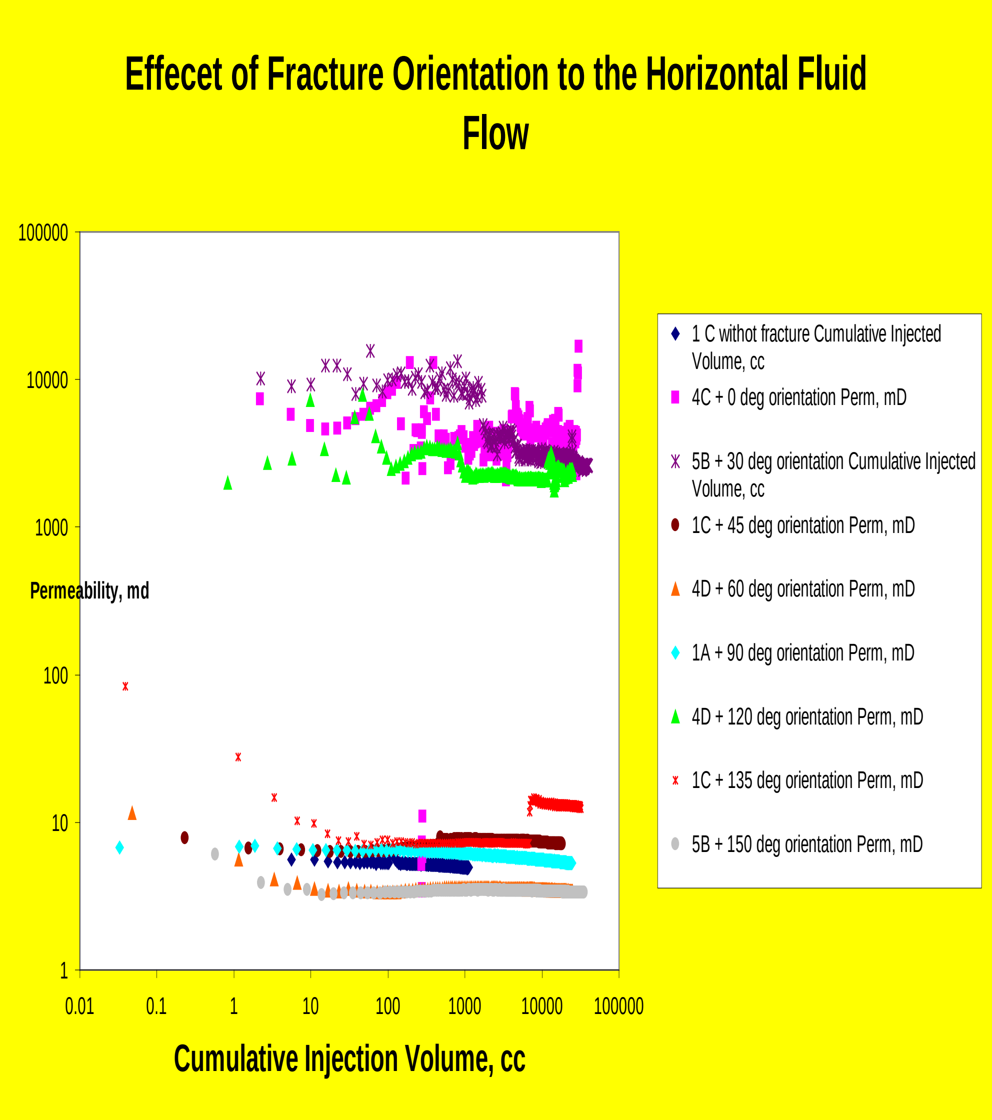








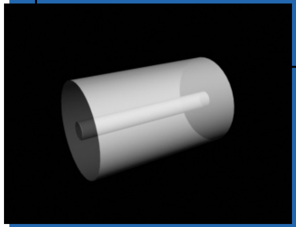
The fracture-orientation effect on the total system flow efficiency, showing two scenarios: the direct to flow fractures (0°, 30°, and 120°)on top of the graph, and opposite to flow fractures (45°, 60°, 90°, 135°, and 150°) at the bottom of the graph.

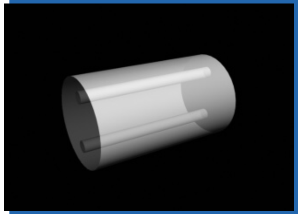


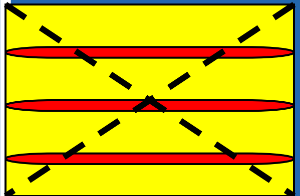
Fracture Angle To the Flow	Plug+Fracture permKf (md)	Flow Efficiency ε (%)
No Fracture	5	0
0° (Horizontal)	4,977	99,540
30°	4,340	86,800
45°	7.32	1.46
60°	3.55	-0.71
90° (Vertical)	5.8	1.16
120°	2,488	49,760
135°	11	2.20
150°	3.41	-0.68

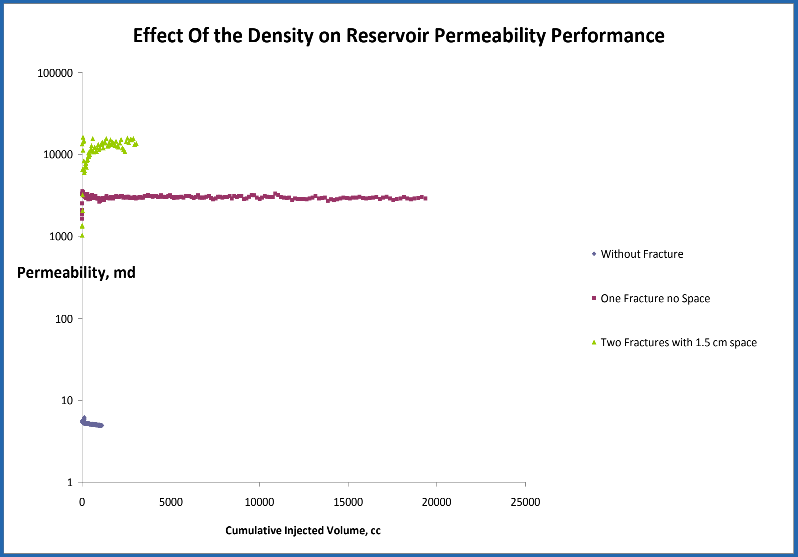
The fracture density

Controlled parameters: Length is 5 cm, 0° fracture, Diameter is 5 mm, Fractures are 100% open				
Case Items	Density	Possible Location	Possible Fractures Per matrix	Total Experiments
15	1	1	1	1
16	2	1	2	1
17	3	1	3	1
			Total Experiments	3





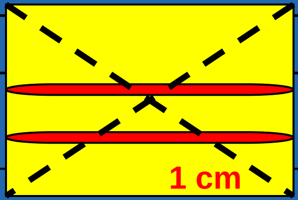


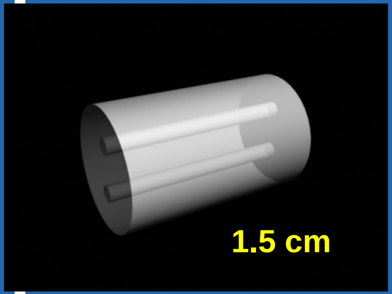


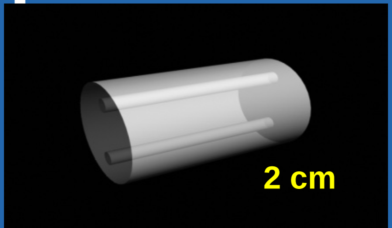
Fracture Density (#/ plug matrix)	Plug+Fracture perm Kf (md)	Flow Efficiency ε (%)
No Fracture	5	0
1	4,977	99,540
2	5,681	113,620
3	N/ A	N/A

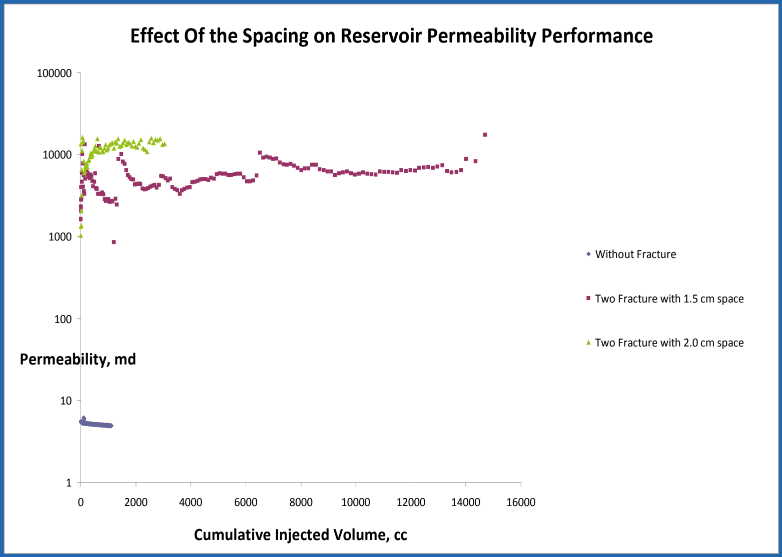
The fracture spacing

Controlled parameters: Two fractures, Length is 5 cm each, 0° fracture each, Diameter is 5 mm each				
Case Items	Spacing	Possible Location	Possible fractures Per matrix	Total Experiments
18	1 cm	1	2	1
19	1.5 cm	1	2	1
20	2 cm	1	2	1
			Total Experiments	3





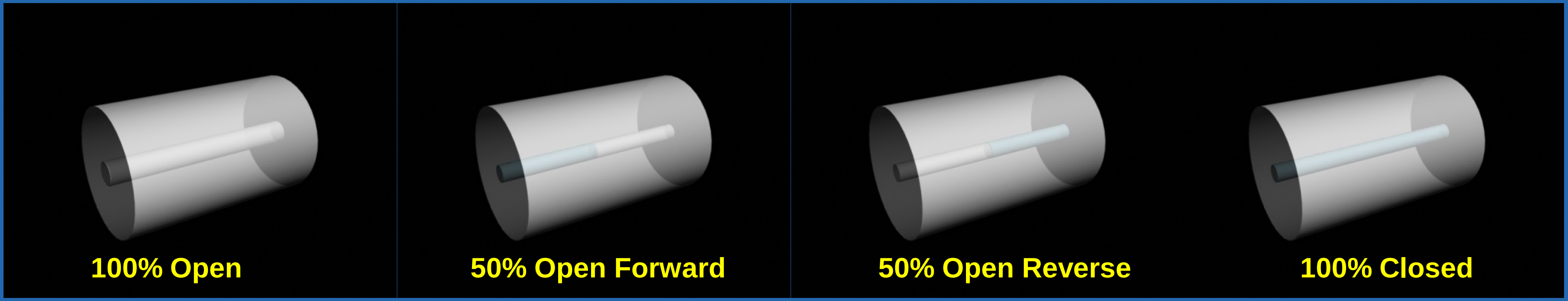




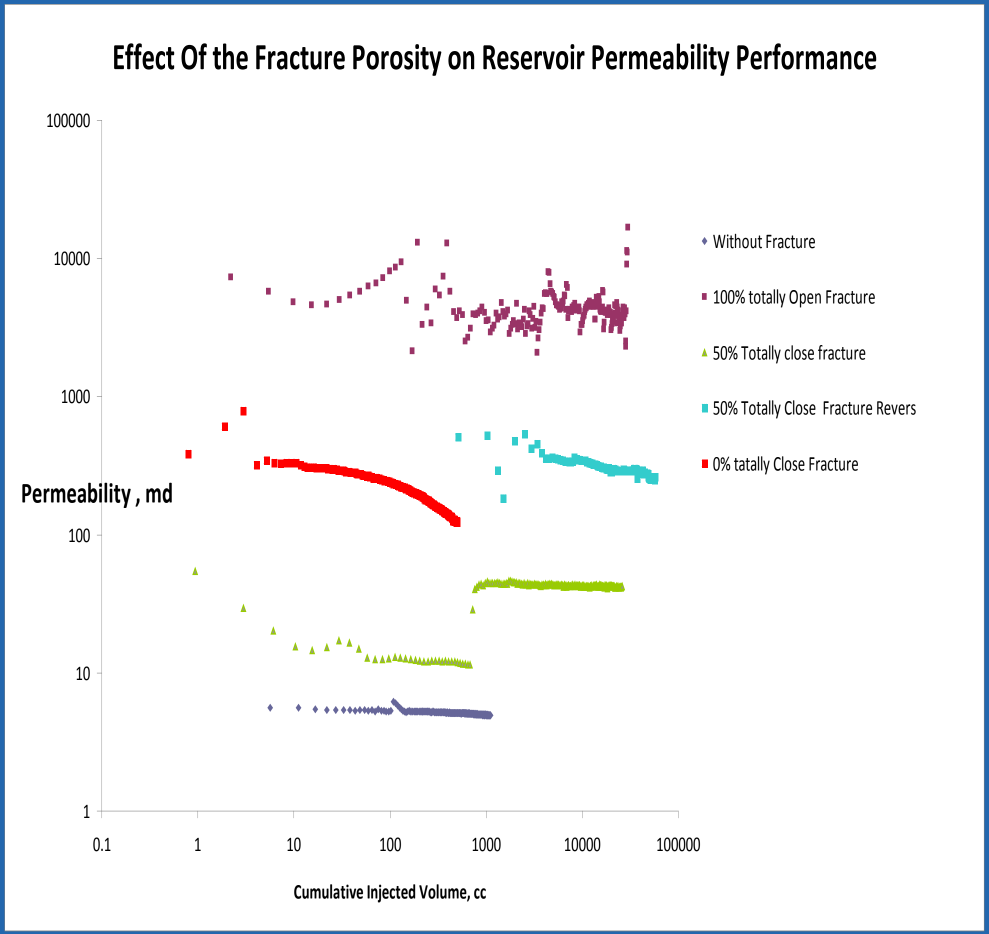
Fracture Spacing (cm)	Plug+Fracture perm Kf (md)	Flow Efficiency ε (%)
No Fracture	5	0
1	N/ A	N/A
1.5	5,681	113,620
2	11,325	226.500

The fracture porosity

Controlled parameters: One fracture, Length is 5 cm, 0° fracture, Diameter is 5 mm				
Case Items	Fracture Porosity, ϕ_f	Possible Location	Possible fractures Per matrix	Total Experiments
21	100%	1	1	1
22 & 23 (Forward and Reverse)	50%	2	1	2
24	0%	1	1	1
			Total Experiments	4



The fracture-porosity effect on the total system flow efficiency.



Fracture Porosity Øf (%)	Plug+Fracture perm Kf (md)	Flow Efficiency ε (%)
No Fracture	5	0
100% Open	4,977	99,540
50% Open Forward	299	5,980
50% Open Reverse	38	765
100% Closed	191	3820

Result 1

- The baseline case (Experiment 0) has no fractures and the permeability came to be 5.13 md.

- This will be the baseline case, of which the following experiments will be benchmarked against. The c-1209 lime-brick was an excellent rock regarding its solid material that is free of fractures even when preparing the core-plug for measurements.

- It has also proved to withstand the milling activities necessary for making the fracture's geometry.

- The low permeability of around 5 md is a favorable simulation of a tight carbonate reservoir.

Result 2

- The suite of the fracture-length experiments show that the overall permeability of the rock increases as the fracture-length increases.

- The 6.41 cm fracture and the 7.12 have a 0.79 cm length difference and about a 14 cc difference in the fracture open space; therefore, the permeability improvement by this gain is 59,400% - 3,820% = 55,580%. So, it is deducted that the fracture-length is an important parameter to improve the flow efficiency.

Result 3

- **The suite of fracture-diameter experiments is found to result in a significant improvement to the flow efficiency.**

- The relationship between fracture-diameter and flow efficiency is also directly proportional.

- Length fractures give great efficiencies, and diameter fractures also demonstrate great flow efficiencies. However, the argument about which parameter dominates the other for improving flow efficiency--fracture-length or fracture-diameter--is unresolved.

- A clear distinction between length and diameter is difficult for these experimentations.

Result 4

- The relationship of the aspect ratio of width over length is proved to be useful for fracture-length-diameter evaluations.
- There is a direct proportional relationship between fracture-length and fracture-width.
- The higher fracture-diameter to length (D/L), the higher the total permeability will become; hence higher flow efficiency.

Experiment No.	Length (cm)	Diameter (cm)	Aspect Ratio (D/L) (%)	Kf
4	7.21	0.5	6.9	4,977
5	5.31	0.6	11.30	11,375

Result 5

- The suite of fracture-orientation experiments is found to have two scenarios for the flow efficiency:
  - First, the fracture angles of (θ = 0°, k = 4,977, ε = 99,540%), (θ = 30°, k = 4,340, ε = 86,800%), and (θ = 120°, k = 2,488, ε = 49,760%) show great improvement to the flow efficiencies.
  - Second, the fracture angles of (θ = 45°, k = 7.32, ε = 146%), (θ = 60°, k = 3.55, ε = 71%), (θ = 90°, k = 5.80, ε = 116%), (θ = 135°, k = 11, ε = 220%), and (θ = 150°, k = 3.41, ε = 68%) demonstrate little improvement effects on the total system flow efficiency.

- The 1st type fractures meet the flow right at the end-face of the core plug. As a result, the flow will be enhanced by the fractures.

- The 2nd type orientations (even though they are 100% open) are considered barriers to flow more than fluid-flow highways. These fractures can be good for fluid storage, but the host fluid acts as a resisting body to the incoming fluid.

- This observation confirms that the fracture-orientation to the flow direction is an important factor to consider for fracture-matrix flow efficiency simulations.

Result 6

- The suite of fracture-density experiments is found to have a direct proportionality relationship in regards to the flow efficiency.
- The more fractures that exist in a core plug, the more efficient the fluid flow will become. This result was expected, but now it is confirmed.
- A reminder to audience: the type of fracture-orientation used in this suite of experiments is 0°, which is horizontal to the flow direction.
- Therefore, studies about the geometry of fracture-populations in conjuncture of fracture-orientations are not investigated.

Result 7

- The suite of fracture-spacing experiments is found to have a direct proportionality relationship in regards to the flow efficiency.

- The efficiency is almost doubled in the 2 cm spacing fractures because the interference in this distance is relatively larger when compared to the interference that occurs in the 1.5 cm fractures.

- The 2 cm fracture spacing, in their action of sweeping, are helping each other. While the 1.5 cm fracture spacing, in their action of sweeping, are knocking out each other.

- Therefore, the larger the distance between fractures, the lower the interference effect; hence, the larger the volume sweeping.

Result 8

- In the fracture porosity suite, there are four scenarios for the flow efficiency; all show relative improvement to the flow efficiencies.
- First, the fracture porosity of (Ø = 100%, k = 4,977 md, ε = 99,540%) shows the expected result of greater flow efficiency improvement.
- Second, (Ø = 50% forward, k = 299 md, ε = 5,980%) shows two observations: one is the expected outcome of the efficiency improvement and the second is the location of the opening part of the fracture in regards to the flow direction. The beginning of the open fracture is a better conduit to flow than late in its flight.
- Third, (Ø = 50% reversed, k = 38 md, ε = 765%) shows the opposite outcome of the 50% open forward fracture. The outcomes of scenarios 3 and 4 confirm that the location of the sealing cement inside the fracture against the direction of the flow is also a controlling factor to remember in total reservoir efficiency studies.
- Last, (Ø = 0%, k = 191 md, ε = 3,820%) shows unexpected improvement from the baseline experiment of no fracture. This unexpected outcome is the result of a poor sealing job by the silicon impregnation that lead to not confirming the 0% open status, which created small openings between the sealing agent and the wall of the fracture that allowed the fluid to flow.

Thank You For Your Attention