NDIC Contract No. G-045-89

Start Date of Contract: September 1, 2018

January 2019 Status Report

Vamegh Rasouli
Chair, Department of Petroleum Engineering, UND

Introduction:

This report serves as the first status report outlining the progress of the projects since the beginning of the above contract. According to the contract, the Department of Petroleum Engineering (DPE) at UND was expected to support 9 Ph.D. students from the NDIC funding, plus 6 additional students supported by the DPE to work on project topics proposed by the NDIC and listed in the contract as the followings:

- Big Data Analytics/UAS/Data Mining
- CO2-EOR
- Sulfate Deposition
- Machine Learning/Refracking

The DPE commenced its graduate program in Fall 2016, however, now serves as the largest graduate program at the College of Engineering and Mines (CEM) with currently 32 Ph.D. students and 20 Master students. This rapid growth could not happen without the strong support of the industry. The DPE has 30 representatives serving at the Industry Advisory Council (IAC) of the department and meet twice per year in fall and spring to discuss the state of the program and provide advice on how to expand and make the program stronger. Nearly all of our undergraduate students now receive job offers with the industry as soon as they are close to graduation, thanks to the support from the IAC.

Continuation of the Ph.D. program which supports directly the undergraduate program by providing the teaching assistance and mentoring roles is not possible without financial support. This NDIC contract has enabled the department to support 9 Ph.D. students who help the undergraduate students while they are expected to work on the research topics related to the industry problems in North Dakota as defined by the NDIC.

As the first progress report after 4 months since the commencement of the contract, the DPE has assigned a number of existing Ph.D. students and hired new Ph.D. students to work on projects related to the topics of this contract. Table 1 lists the topics of the 15 Ph.D. projects that have been identified by the faculty members (first 15 topics).

In addition to the 15 Ph.D. projects that the DPE is committed to assign to this contract, the title of additional 8 Ph.D. projects that are undertaken in the department is listed in the Table too in order to inform NDIC of other projects that the DPE is undertaking.

In the following a brief summary of each project proposal is given which outlines the statement of the problem, objectives, methodology, significance, project milestone and timing and the progress to date. It is hoping that each proposal provides a clear idea about the scope of each project and the plan forward. The DPE is providing all necessary support to the Ph.D. students to complete their program within 3 years, so the current financial support by the NDIC will end half way through the project life of the 15 Ph.D. students. We hope the contract can be renewed for the next term to provide financial support to the current students to complete their projects to the highest expected quality.

Industry Seminar:

In addition to the current report, as part of the requirements of the contract, we would like to organize a one-day industry seminar in April 2019 and invite the NDIC board to listen to the presentation of the projects progress by Ph.D. students. If agreed by the NDIC, we also would like to announce the event to the industry in North Dakota to attend this seminar to provide their technical feedback about each project. This will help us to ensure that the projects will carry the industry applications and give us the opportunity to discuss the technical aspects of each project with the industry and request their support in terms of providing data. We hope that NDIC is supportive of the proposed one-day seminar and provides possible dates in April 2019 for this event to take place.

List of current Ph.D. students' projects at the DPE

	Student	Advisor	Project Title	Project Area
1	Karthik Balaji	Rabiei	Enhanced Regulatory Compliance for Carbon Capture & Sequestration (CCS) using Data Mining & Algorithmic Regulations	Data Mining
2	Zifu Zhou	Rabiei	A Digital Solution for Supply Chain Management based on Blockchain Technology	Machine Learning/Block Chain
3	Matt Dunlevy	Rabiei/ Rasouli	Accelerating Pipeline Leak Detection Through Unmanned Aircraft Systems Based Routine Surveillance and Data Mining	UAS/Big Data Analytics
4	Xincheng Wan	Rasouli/ Rabiei	An integrated Data Mining and Simulation to Optimize Refracturing Design	Refracking/Data Mining
5	Olusegun Stanley Tomomewo	Jabbari	Studying the Mechanism of Barite Scales Formation & its Removal/Prevention in McKenzie and Williams Counties, Bakken Formation, ND	Barite Scales Formation
6	Abdulaziz Ellafi	Jabbari	CO2-EOR Application in Unconventional Rich Liquid Reservoirs (Bakken Petroleum System)	CO2 EOR
7	Nidhal Badrouchi	Jabbari	Bakken Tertiary Oil Recovery: Comprehensive Study of CO2-based solvent EOR	CO2 EOR
8	Ogochukwu Ozotta	Ostadhassan	Geomechanical Impact of CO2-EOR on the Bakken Formation	CO2 EOR
9	Hao Fu	Ling	Using Pressure Distribution to Detect the Blockage and Leakage in the Pipelines	Pipeline Leakage/UAS
10	Nejma Djabelkhir	Rasouli	Lattice Numerical Simulations of Near Wellbore Hydraulic Fracturing	Hydraulic Fracturing
11	Aldjia Djezzar	Rasouli/ Rabiei	Impact of Stress on the Characterization of Flow Units in the Complex Three Forks Carbonate Reservoir, Williston Basin	Machine Learning/ Petrophysics Three Forks

12	Dezhi Qiu	Rasouli/ Rabiei	Discrete Fracture Network (DFN) Modelling of Hydraulic Fracturing	DFN (Discrete Fracture Network)/Artificial Intelligent
13	Omar Akash	Rasouli	Simulations of Hydraulic Fracturing Through Perforations	Cased Hole HF
14	Lingyun Kong	Ostadhassan	Replicating Bakken Shale Rock for Petrophysical Experiments Using 3D Printing Technology	3D Printing Shale
15	Arash Abarghani	Ostadhassan	Multi-Scale Organic Material Characterization of the Bakken Source Rock	Organic Mat. Characterization
16	Hyeon Seok Lee	Ostadhassan	CO2 sequestration and EOR capacity of the Bakken Formation through Kerogen Molecular Modeling	Kerogen MM
17	Seyed Alireza Khatibi	Ostadhassan	Characterization of the Bakken Source Rock with Spectroscopy Methods	Spectroscopy
18	Siamak Koloushani	Rasouli	Lattice Numerical Simulations of Hydraulic Fracturing in High Permeable Formations	HF in High Permeable Formation
19	Sofiane Djezzar	Rasouli	3D Deterministic Models for Fracture Detection and Prediction in Unconventional Reservoirs for Finding Sweet Spot	Fracture Mapping
20	Yanbo Wang	Ling	Lab Experiments Using a Two-phase Flow Loop Unit and Numerical Simulations	Multiphase Flow
21	Foued Badrouchi	Rasouli	Cuttings Transportation Optimization: Lab Experiments Using a Large Scale Slurry Loop Unit and Numerical Simulations	Borehole Cleaning
22	Ahmed Ismail	Rasouli	Automated Directional Drilling: Lab Experiments and Numerical Simulation	Directional Drilling
23	Imene Bouchakour	Rasouli	Crack Geometry Prediction in Replicated Rock Samples During Triaxial Testing Using Velocity Data	Acoustic Emission

Enhanced Regulatory Compliance for Carbon Capture & Sequestration (CCS) using Data Mining & Algorithmic Regulations

Karthik Balaji
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

With rising concerns about controlling carbon emissions throughout the world the International Energy Agency identified Carbon Capture and Sequestration (CCS) as one of the significant technologies that could have a significant impact in controlling carbon emissions (IEA, 2011). The CCS technology is still in relatively with several pilot projects and few major commercial scale projects like the Petra-Nova plant in Texas (Congressional research Service, 2018). Like most new technology being transitioned from pilot projects to commercial-scale projects, CCS has several regulatory issues. Many of these regulatory issues are further explored by International Energy Agency (IEA, 2010). With North Dakota's entry in the sector CCS (EERC, 2016), it is essential to properly regulate CCS technology keeping in mind the rapidly evolving technological and economic environment.

This idea of algorithmic regulation-based compliance monitoring is gaining significant ground. Breaux, et al. (2012) used a concept known as parametric semantics to convert regulations into algorithms by breaking up legal language into basic components, which was used to check software compliance to regulations. Similarly, machine learning and datamining concepts are being increasingly used in the market to check compliance standards.

The proposed project will aim at one of the most pressing issues related to CCS regulatory framework, which relates to underground storage unit stability during CO_2 injection and post CO_2 injection phases. It is essential to monitor compliance of the injected CO_2 behavior for the reasons of safety and preservation of ground water reserves. The project will review the major areas of probable non-compliance by stakeholders. It will then review the legal and social aspects related to the areas of non-compliance, along with baseline studies. The legal aspects related to the area of non-compliance shall be systematically converted into a computer-code with related metrics to rate the performance of injection activity to follow the make-up of algorithmic regulations. Data from pilot CO_2 injection projects along with CO_2 enhanced oil recovery activities will be analyzed to better model the algorithms related to compliance monitoring using machine learning concepts. The eventual system would be able to predict circumstances of non-compliance in CCS projects. The project will be a move from responsive compliance to proactive compliance. This project will significantly help reducing cost of compliance for both the industry and regulatory bodies& will increase overall safety related to CCS activities.

Objectives:

- Identifying the point of maximum probability of non-compliance in the entire CCS life-cycle

- Formulate the optimum manner of accurately convert legal texts related to regulations to a code-based format
- Develop metrics related to performance of CCS activity related to area of maximum probability of non-compliance
- Use Machine-Learning and Data Mining in order to model data from CCS to check for non-compliance and to develop predictive model for identification of future non-compliance

Methodology:

- Analyze the risk factors in terms on non-compliance through the entire life-cycle (from land allocation to post-injection monitoring) of CCS (underground-storage)
- Identify point of maximum probability of non-compliance
- Collection of data around the point of maximum probability of non-compliance in CCS projects known as pain-point (pilot or commercial scale depending on availability including baseline studies)
- Convert legalese related to the statues available on the regulations related to the pain point in code to develop the algorithmic regulatory system using different available methodology such as parametric semantics and Goal-based algorithms and identify the optimum technique
- Develop metrics related the pain-point as a bridge between the algorithmic regulation and the data
- Use Machine-Learning and Data Mining in order to model data from CCS project (pilot or large scale depending on availability of data) in order to check performance based on metrics developed
- Generate Predictive model to identify cases of non-compliance in CCS activity and check the model against different sets of data generated from reservoir simulations at different timescales of CCS projects

Significance:

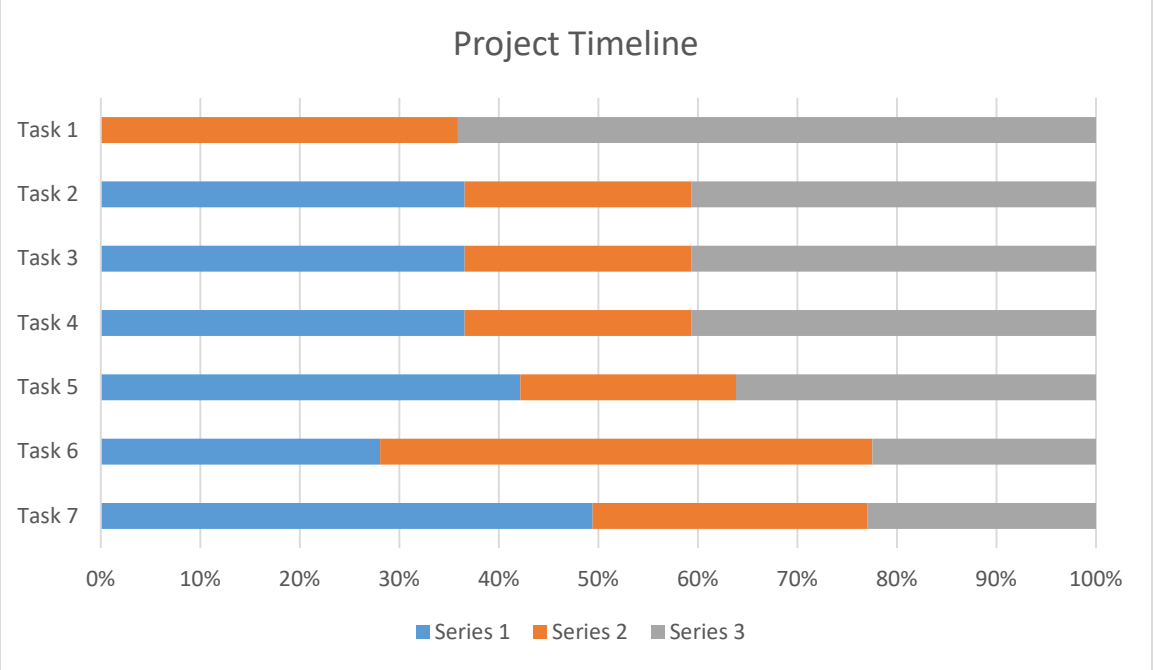
- Ability to identify the performance of specific regulatory laws implemented
- Significant economic gains for stakeholders in the CCS activities through reduction in cost in terms of regulatory compliance
- Reduction in rules complexity and adaptability to new technological advantage for regulations
- Help for regulatory bodies with problem of manpower
- Increase in general safety related to CCS activity
- Help to predict instances of non-compliance and prevent violations rather than react to violations of regulations

Project Milestone and Timing:

Time major milestone of the project Include the following tasks:

- Task 1: Literature Survey
- Task 2: Risk Assessment and Identification on pain points in CCS Project
- Task 3: Data Collection

- Task 4: Development of Legal Algorithms
- Task 5: Development of Metrics
- Task 6: Modeling of Data
- Task 7: Generation of Predictive Modeling Capability



Progress to date:

As of December 2018, a significant amount of literature has been reviewed in relation to CCS technology and regulations related to CCS technology. There has also been significant review of methodologies to convert legal text to code format and developing codes. Another significant part of the work till date, as has been the mapping of the methodology in order to achieve the objectives. A Major foreseeable problem would be related to obtaining of CCS related baseline data.

References:

International Energy Agency (2011). Carbon Capture and Storage and the London Protocol. https://webstore.iea.org/carbon-capture-and-storage-and-the-london-protocol

Folger, P (2018). Carbon Capture and Sequestration (CCS) in the United States. Congressional Research Service. 7-5700. https://fas.org/sgp/crs/misc/R44902.pdf

International Energy Agency (2010). Carbon Capture and Storage: Model regulatory Framework. https://www.iea.org/publications/freepublications/publication/model_framework.pdf

Breaux, T. D., Anton, A. I., Doyle, J. (2012) Semantic Parameterization: A process for Modeling Domain Descriptions. ACM Transactions on Software Engineering and Methodologies. Pp: 1-44

A Digital Solution for Supply Chain Management based on Blockchain Technology

Zifu Zhou

Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

When the price of crude oil is low, the high cost of upstream oil exploration and development coupled with downstream efficiency requirements forces most companies to reduce costs, almost to the point of sacrificing their future. The industry is facing unprecedented challenges in cost-effective information exchange system and supply chain management for various requirements. Given geographic, political and operational realities, along with the scale of investment required within the oil & gas industry, companies cannot exist in isolation and there will always be multiple suppliers throughout the supply chain. Many works have been done on designing the oil & gas supply chain. Gray et al. (2013) optimized crude oil supply chain by combining elements in transportation, refinery building and pipeline quality. Sahebi et al. (2014) reviewed mathematical programming models in context of crude oil supply chain by considering the strategic and tactical decisions and presented gaps of literature. However, all these traditional optimization analyses lost track on capitalizing on meaningful insight, cost take out and the associated transformation opportunities for a higher level of efficiency and longevity. The problem causing inefficient, expensive and cyber-attack vulnerable issue is that each participant in a supply chain must maintain their records, updated with their transactions and systems, which must then be reconciled among other participants in the networks. This time-consuming, manual reconciliation process is susceptible to errors, time delays, extra costs and manipulation of transactions. Sometimes issues become further complicated when third-party validation or intermediaries have to be brought in to resolve disputes. Industry networks also become more complex as the number of participants in them increases.

Blockchain technology has opened a range of new possibilities in which value and information can be directly transferred between participants without intermediaries or any centralized points of control. Blockchain, often referred to as the second generation of digital revolution, is a mechanism for safe storage of information based on a distributed ledger structure. A simple way to conceptualize blockchain is to picture a collection of linked blocks, similar to a database, where each block holds a number of records. These blocks are chained together using a cryptographic signature. These chained blocks work like a ledger, of which multiple copies run simultaneously across an authenticated shared network of nodes. These nodes can be distributed geographically and across many organizations or individuals. For a new block of data to be added to the network, all the nodes within the network must verify this transaction, and after that, all the nodes are updated with this new addition. Blockchain uses community validation to keep synchronization across multiple users, which is the key component in this step change for oil & gas industry that provides a data store of information replicated between peers and established across a large network from upstream to downstream. Once a contract is validated and deployed in blockchain-

based system, its execution is guaranteed. All transactions against the ledger require consensus across the whole network, where the provenance of information is not subject to misinterpretation and accessible to all participants. Compared with making some optimization models using linear or nonlinear algorithmic simulation, tokenization of oil & gas supply chain from reservoirs to customers through digital solutions supported by blockchain technology is the next foreseeable revolution. This research is focusing on the application of "Ethereum" and "Solidity" technologies to provide blockchain-based solutions for the future high-efficiency oil & gas supply chain application.

Objectives:

- Analyzing the supply chain in a specific operation to determine the various components and functions associated with this workflow.
- Identifying the key pain points within the supply chain workflow.
- Feasibility study on the application of different elements in blockchain and demonstrating the applicability of blockchain technology in supply chain management.
- Identifying the essential elements required for implementing an advanced solution to address identified the supply chain issues.
- Implementing a proof of concept for advanced smart contract, certification construction and transferring the knowledge to the key stakeholders.

Methodology:

- Systematic collection of commercial/ public dataset
- Construct blockchain especially Ethereum project infrastructure based on several techniques (e.g. arrays mapping, refactoring deployment)
- Govern the behavior of dynamic dataset
- Analyze and visualize dataset using common data science packages (e.g. NumPy, Pandas, Matplotlib on Python)
- Deliver presentations and publications of blockchain technology in oil & gas industry

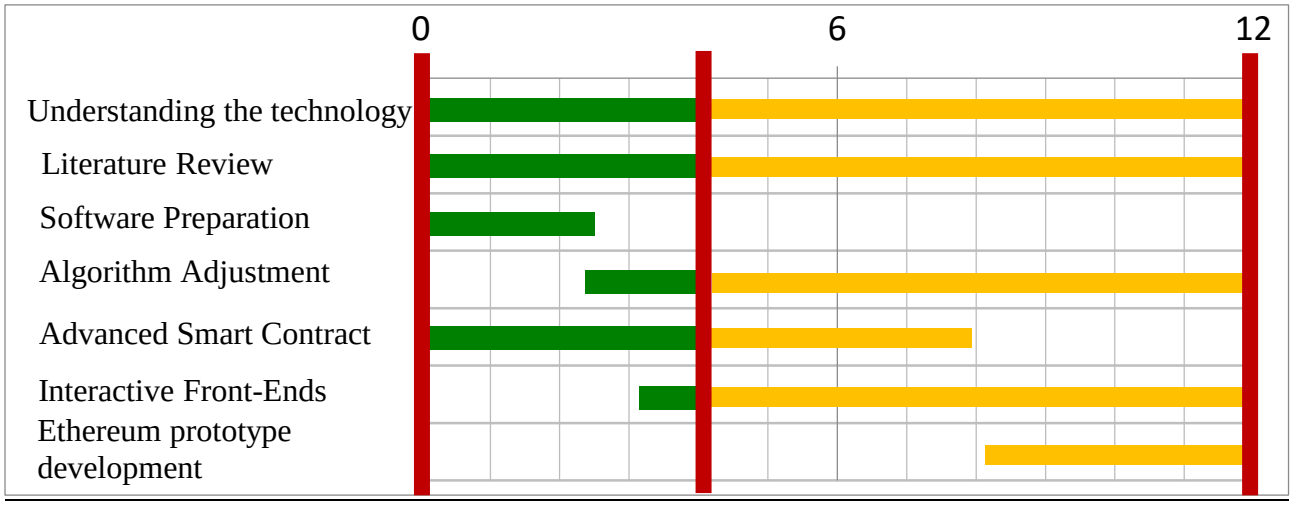
Significance:

Blockchain is one of the strongest tools associated with trustworthy development in the oil & gas industry. Decentralization, security, automation and immutability are the key characteristics for a blockchain system. Blockchain technology will allow companies across upstream, midstream and downstream to improve efficiency, reduce waste in time, optimize cost and control data transparency. Adoption of blockchain technology will enable faster, permissioned, immutable, transparent and auditable business-to-business interactions between companies and their suppliers, distributors, financial institutions and government regulators. Blockchain technology provides a strong tool and feasible solution to integrate various types of data, quantify uncertainties, preserve immutable information, reduce business cost, enhance transparency and build trust within public or private network. Tampering, fraud and cyberattack will be much more difficult because of the blockchain adoption and proper public education.

With the right mix of research, coding capability and collaboration on Solidity, the proposed algorithmic blockchain will provide an adaptable approach for supply chain integrity, data flow integrity and infrastructure protection. The value of blockchain is the combination of confidentiality and availability for both industry and government. Efficacy of running programs will definitely increase, information access and processing capabilities will improve, and monitoring expenses will diminish. Implementing blockchain technology into oil & gas industry is a perfect chance to promote new optimum distribution mechanisms in asset and information systemic management. Blockchain is more than a disruptive technology. It represents an opportunity for oil & gas industry to increase profitability in today's economic environment and well into the future. The understanding of what is required to move this next generation digital transformation forward is vitally important for the industry. In the future, as blockchain-based business transactions and supply chain become more sophisticated, business and industry networks could evolve into self-governing cognitive networks and reduce the cost and risk for a long term.

Project Milestone and Timing:

The start date of the project is from September 1, 2018. Midterm presentation is January, 2019.



Progress to date:

- Fully understand the blockchain concept and cryptocurrency application.
- A comprehensive literature review is underway to investigate the application of this technology in other industries.
- Have started writing code scripts on blockchain applications and using different blockchain-based techniques like transaction management and ether token generation.

Reference:

Gray. B., Jones, E.C., Weatherton, Y., Sunarto-Bussey. R., Armstrong, H., 2013. Utilizing Pipeline Quality and Facility Sustainability to Optimize Crude Oil Supply Chains. Int. J. Supply Chain Manag. 2 (4).

Sahebi, H., Nickel, S., Ashayeri, J., 2014. Strategic and Tactical Mathematical Programming Models within the Crude Oil Supply Chain Context-a review. Computer. Chem. Eng. 68, 56-77.

Azadeh, A., Shafiee, F., Yazdanparast, R., Heydari, J., Fathabad, A.M., 2017. Evolutionary Multi-objective Optimization of Environmental Indicators of Integrated Crude Oil Supply Chain under Uncertainty. Journal of Cleaner Production 152 (2017) 295 – 311.

Aste, T., Tasca, P., Matteo, T.D., 2017. Blockchain Technologies: The Foreseeable Impact on Society and Industry. IEEE Computer Society.

Accelerating Pipeline Leak Detection Through Unmanned Aircraft Systems Based Routine Surveillance and Data Mining

Matt Dunlevy
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

Pipelines leak an average of 76,000 barrels per year in the United States alone. Since 2010, over nine million barrels of oil have spilled out of American pipelines. The problem is so severe, that the United States Code of Federal Regulations mandates that the largest of the lines must be inspected regularly: *"PART 195—TRANSPORTATION OF HAZARDOUS LIQUIDS BY PIPELINE*
49 CFR § 195.412 Inspection of rights-of-way and crossings under navigable waters.

Each operator shall, at intervals not exceeding 3 weeks, but at least 26 times each calendar year, inspect the surface conditions on or adjacent to each pipeline right-of-way. Methods of inspection include walking, driving, flying or other appropriate means of traversing the right-of-way."

The cost of using manned aircraft to fly over these rights of way is higher and less safe than unmanned aircraft. Manned aircraft also do not collect minable data as UAS do. Using

Objectives:

- Study the current UAS applications for underground pipeline inspection procedures.
- Identify the applicable sensors that can be used to inspect the pipelines laid underground and assess their range of applicability.
- Identify viable combinations of UAS sensors with industry adopted external leak detection systems that could improve accuracy, reliability, and/or sensitivity of the current detection systems.
- Develop a comprehensive pilot program to demonstrate the technical feasibility of the UAS in pipeline inspection and run several drone test flights over the pipelines that will be simulated for the purpose of this study to get results in normal and difficult conditions.
- Applying Artificial Intelligence and big data analytics to large quantities of data obtained from inspection flights to gain a better insight into an identified location of incident faster, which will in turn improve the response time to the situation.
- Evaluate the financial viability and economic impact of utilizing the newly developed process in pipeline inspections especially in large scale projects.
- Establish a streamlined process for pipeline inspection using the pioneering UAS technology to save cost, increase safety, and enhance overall productivity.

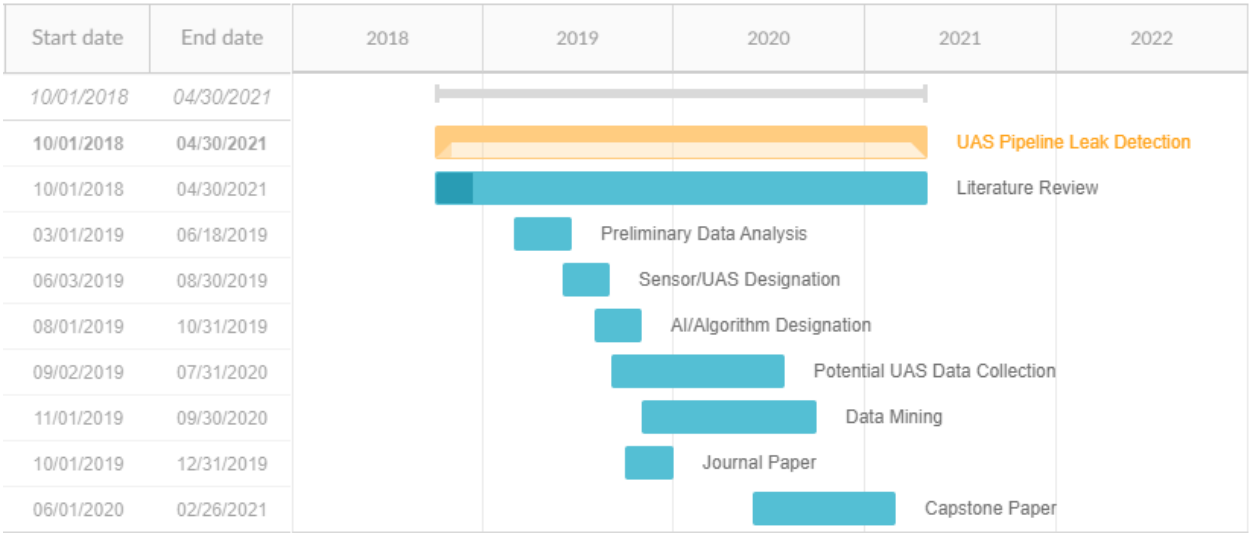
Methodology:

- Mainstream machine learning/AI initiatives will be applied to the data via university computing machinery in labs.
- The accuracy and repeatability of data mined throughout the project will be cross referenced with traditional methods and sensors of previous technological generations.
- If UAS flights occur, they would be conducted under 14 CFR Part 107 and within the parameters of any manufacturer's safety manual. They would not occur unless approved by the UND UAS Research Ethics and Privacy Committee.

Significance:

- Development of an intelligent drone-based pipeline inspection procedure for significant improvements in pipeline monitoring and management in North Dakota and the US.
- Demonstration of the cost/time-effectiveness of the proposed integrated leak-detection technology for pipeline companies operating in North Dakota.
- Maintaining healthy and safe environment by improving the response time to the identified locations with critical need for maintenance or potential safety concerns.
- Advancing compliance and regulatory strategies for pipeline companies by development of a preventive strategy for pipeline companies utilizing the wealth of data generated in surveys and applying advanced big data and AI methodologies.

Project Milestone and Timing:



Progress to date:

- I have become more well versed in stitching and processing software.
- There is a significant amount of literature on the topic available to me.
- My discussions with oil and gas industry leaders indicates interest in the topic.
- I have good networks with sensor providers.

An integrated Data Mining and Simulation to Optimize Refracturing Design

Xincheng Wan
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

Horizontal well drilling and hydraulic fracturing operation have significantly enhanced the shale oil production, stimulating economic growth and employment. However, fast production decline in the hydraulic fracturing wells potentially leads to lower profits during post production period. Drilling more wells may be one of the options, but during the downturn of the oil industry, the cost of drilling a new horizontal well may result in less NPV. An alternative technology that has been proposed during the last decade is the refracturing of an existing well.

Despite some successful trials of refracturing operations being reported, operators may still be concerned about the effectiveness of refracturing operation in their field. Production decline models can be used to predict the risk analysis, however, they are not based on fracture propagation and fracture fluid flow mechanisms. Numerical simulation takes both mechanisms into account. Numerous numerical studies have been done on simulation of hydraulic fracturing or hydrocarbon production, some studies have simulated fracture reorientation during refracturing treatments. However, no studies have been done on the integrated simulation of the hydraulic fracturing-production-refracturing-reproduction process. The data mining algorithms have been recently used for design optimization and selection of best candidate wells for hydraulic fracturing. This approach together with numerical simulations will be used in this study.

Objectives:

- Develop an integrated simulation and data mining based workflow for hydraulic fracturing-production-refracturing-reproduction process.
- Analyze different factors such as rock properties, in-situ stresses, and presence of natural fractures on hydraulic fracturing propagation.
- Simulate production rate decline and pore pressure and stress redistribution during the production process.
- Investigate how factors such as pore pressure, stress redistribution, and production history affect refracturing design.
- Predict production decline during the refracturing process.

Methodology:

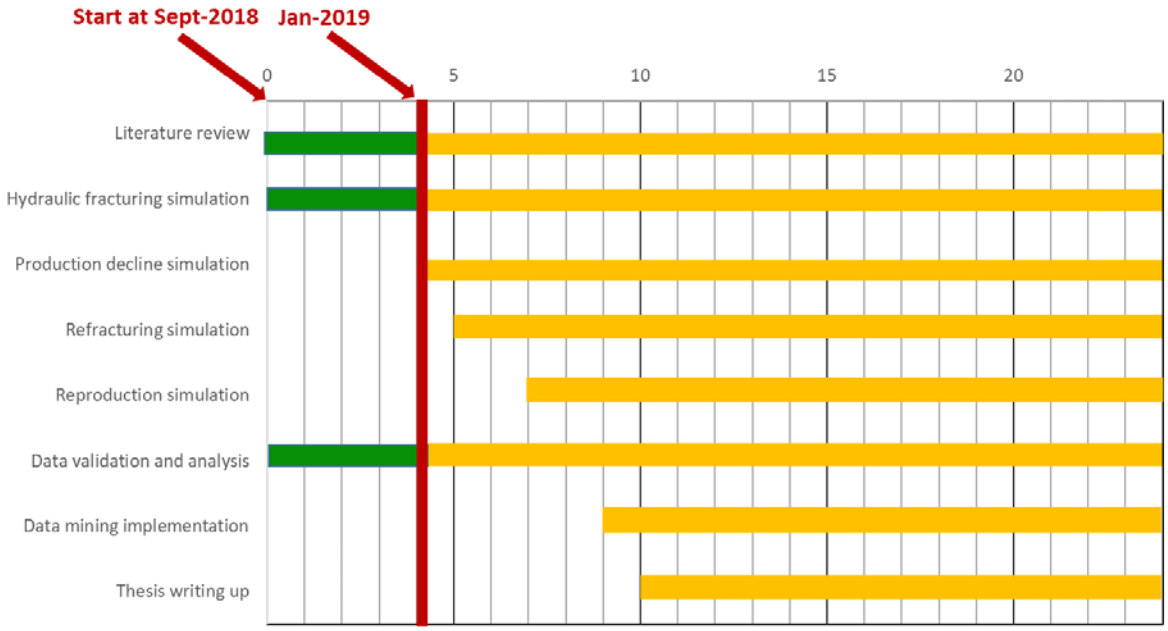
- Use XSite, a new grain based model software from the Itasca Consulting Company, to simulate hydraulic fracturing process.
- Import fracture geometry to FLAC3D, build production model using FLAC3D.
- Import pore pressure distribution back to Xsite to simulate refracturing.
- Import hydraulic fracture and refracture geometry back to FLAC3D to simulate production after refracturing process.
- Compare the simulation results in simple cases with some analytical solutions.

- Validate the simulation results with existing field data where possible.
- Apply data mining methods such as artificial neural network to optimize refracturing well candidate selection.

Significance:

- The lattice-based software XSite was designed by the Itasca Company for the purpose of hydraulic fracturing simulation. It has a strong physics background with high computational efficiency. Using XSite to simulate refracturing will potentially guide refracturing candidate selection and operation design in the field.
- The proposed integrated simulation workflow may help operators optimize refracturing design and improve production after refracturing treatment.
- Refracturing is one of the technology that is being developed and practiced in North Dakota. The results of this study will benefit the local industry.
- Data mining methods, which have been widely applied in other areas, will potentially improve selection of well candidates for refracturing operations. Moreover, its application may lead to a revolution in the petroleum industry in the future.

Project Milestone and Timing:



Progress to date:

- Built numerous models for hydraulic fracturing simulation using XSite.
- Built a model for production simulation using FLAC3D.
- Submitted an abstract on hydraulic fracturing-production-refracturing simulation to the 53RD ARMA SYMPOSIUM.

- Submitted one paper to the Rock Mechanics and Rock Engineering journal. The paper is about hydraulic fracturing simulation for the North Perth Basin.

Studying the Mechanism of Barite Scales Formation & its Removal/Prevention in McKenzie and Williams Counties, Bakken Formation, North Dakota

Olusegun, Stanley Tomomewo
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

Barium sulfate ($BaSO_4$) scale is one of the most annoying and costly problems encountered in oilfield operations, and it seems to be immeasurable. Scale deposition cost the industry billions of dollars in damage and lost production every year, and it is also known as the leading cause of production decline in some Bakken wells in McKenzie and Williams Counties, Bakken Formation. Unfortunately, all the methods of treating oilfield mineral scales that have been practiced to date would not work properly for barium sulfate because it forms small crystals that are non-adhering. The review of the literature of previous research showed that there is not enough information to adequately understand and treat the problem of barium sulfate nucleation under all the prevailing conditions in Bakken wells. Therefore, additional study is required mainly for the McKenzie and Williams Counties, before useful suggestions are made that can lead to an efficient way to treat this type of scale. In this project we will study the main aspects of Barium formation in Bakken wells and seek for improved prevention and prediction of Barium scaling in the Williston Basin, ND.

Objectives:

The overall objective of this project is to better understand the mechanism of the nucleation of barium sulfate scales and be able to predict the location where it would more likely form on production strings, from bottom hole all the way up to the surface towards the surface separation equipment. The second objective is to come up with methods of reducing scale potential and to also suggest a more efficient way to remove scale deposit if it eventually forms.

Methodology:

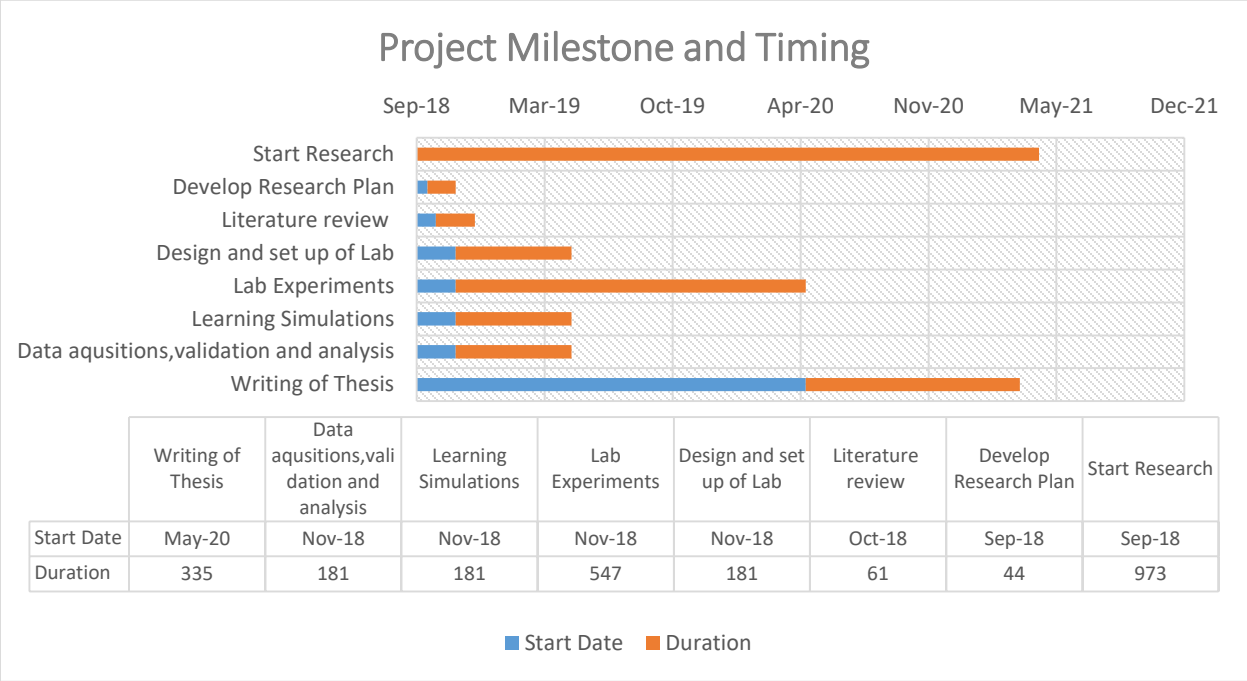
Combination of lab experiments and numerical simulations will be applied in this project to help understand the barium sulfate scaling forming tendencies. At the end of the research, a report will be compiled where all findings will be documented for public use.

Significance:

This project is vital because its overall objective is to come up with more efficient ways to prevent, control and treat barium sulfate menace in other to improve production of oil, that will reduce production cost for the Operators on McKenzie and Williams Counties.

Project Milestone and Timing:

The chart 1.0 below described the milestones breakdown, start date, and the estimated duration to achieve each. All activities will be done simultaneously.



	Writing of Thesis	Data aqusitions,validation and analysis	Learning Simulations	Lab Experiments	Design and set up of Lab	Literature review	Develop Research Plan	Start Research
Start Date	May-20	Nov-18	Nov-18	Nov-18	Nov-18	Oct-18	Sep-18	Sep-18
Duration	335	181	181	547	181	61	44	973

Chart 1.1- Project Milestones and Timing

Progress to date:

The chart below described progress made so far on the Milestones described above.

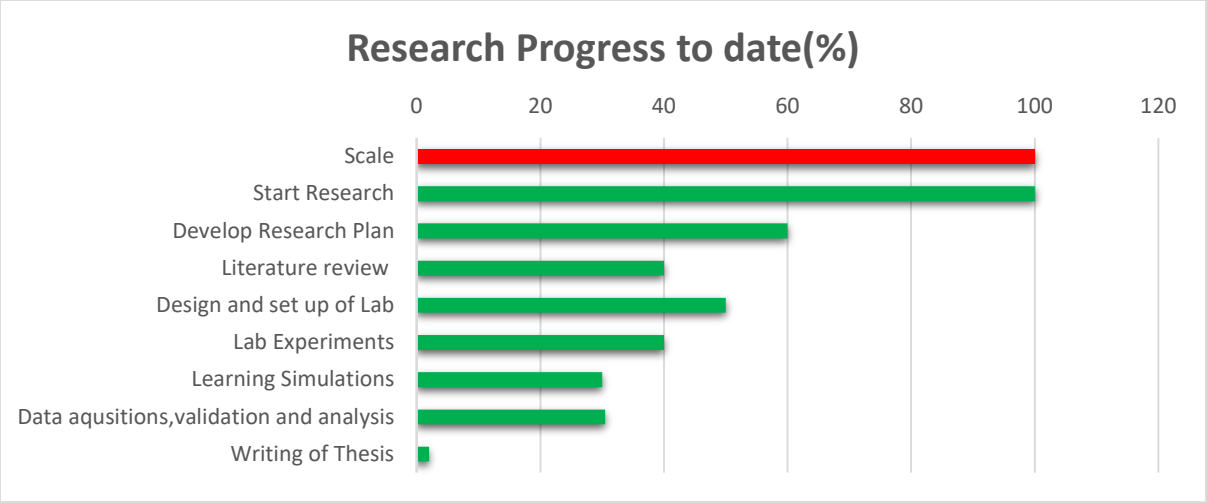


Chart 1.2- Current Project Progress

CO2-EOR Application in Unconventional Rich Liquid Reservoirs (Bakken Petroleum System)

Abdulaziz, Ellafi,
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

The primary hydrocarbon recovery in the Bakken Formation is estimated to be in the range of 3-10 % according to many studies in the literature. This main problem results from the production sustainability due to reservoir characteristics in the Bakken Formation (i.e. ultra-low permeability and low porosity), where the initial production level in the producing wells starts with a high flow rate. Then, the production rate declines sharply and reaches the stabilization period at the low flow rate. The main reason behind the fast decline in production rate is the quick depletion in the natural fractures while slow to no recharge from the rock matrix that represents the main oil storage. Subsequently, around 4-7 billion barrels of oil can remain isolated in the reservoir by the complex heterogeneity of the reservoir properties without using unconventional applications, such as CO_2-EOR. Recent studies evaluated a large number of scenarios that showed positive results in terms of long-term oil productivity in the Bakken formation from CO_2-EOR applications. In this project we will study core samples from Bakken wells, and analyze well logs, geology, pressure and rate transient tests to investigate the main aspects of CO_2-EOR in the Williston Basin, ND.

Objectives:

- Construct a comprehensive literature review to build a bank of data and general guidelines.
- understand of geology, lithology, mineralogy, thermal maturity, fluid properties, and pore structures & connectivity in order to obtain reliable assessment of CO2-EOR.
- Evaluate CO2-EOR injection performance in the Bakken Formation core samples and the optimal potential to improve oil recovery.
- Understand the physical, chemical mechanisms, and key parameters affecting the effectiveness of CO2 injection for enhanced oil recovery in the Bakken formation.
- Quantify the amount of CO2 that can be adsorbed onto and diffused into shale (Upper, and Lower Members).
- Perform nanoscale simulation of shale transport properties in the Bakken Formation to obtain pore network, pore scale modeling, the velocity field of the reconstructed porous media, dynamic properties (k & tortuosity), and simulating fluid flow.

Methodology:

- Gathering data from previous works by reviewing science journals, conference papers, PhD dissertations, and reports.
- Designing lab work experiments.
- Performing reservoir simulation models using CMG simulator.
- Using computer programing language (VBA-Excel and/or MATLAB coding)

Significance:

- The significance of this research is a comprehensive study in more details that includes both the laboratory experiment works and reservoir simulation studies to have a better understanding of physical and chemical reactions in the subsurface system. As a result, this study solves previous work issues in the field scale and provide general guidelines to have successful CO2-EOR application.

Project Milestone and Timing:

Tasks	Semesters								
	F-18	SP-19	S-19	F-19	SP-20	S-20	F-20	SP-21	S-21
Courses									
Comprehensive Literature Review									
Ph.D. Qualifying Exam									
Experimental Works									
Simulation Studies									
Validate Results									
Ph.D. Comprehensive Exam									
Final Draft of Dissertation									
Final Defense									
F: Fall, SP: Spring, and S: Summer									

Progress to date:

- Through Fall 2018, I performed some lab works:
    1. Sampling core plug from the Middle Bakken Member,
    2. Cleaning the cores,
    3. Measuring the absolute reservoir permeability, and the velocity V_P and V_s to determine the geomechanical parameters.
- In the simulation part, I have constructed:
    1. Two different compositional simulation models (Dual Porosity /Dual Perm),
    2. Representative PVT model.
    3. Sensitivity analysis and history match using CMOST software.
    4. Optimization process by performing CO2-EOR injection.

Bakken Tertiary Oil Recovery: Comprehensive Study of CO_2-based solvent EOR

Nidhal, Badrouchi,
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

The Bakken Formation is an extremely tight formation with ultra-low permeability that generated about 200 to 400 billion barrels of oil in place, which makes it an attractive petroleum exploration target in North America. Although, the technology advances in horizontal drilling and multi-stages hydraulic fracturing has enabled an economic recovery throughout the basin, the production rates quickly decline after a few months of production and that the recovery factors remain very low. Thus, EOR solutions need to be considered to push more oil out of matrix into the stimulated reservoir volume in order to increase the recovery factor and provide a sustainable production trend. Because of the nano-scale pores in such an unconventional reservoir, the effect of capillary pressure and interfacial tension must be investigated more in details. It has been proven that the amount of residual oil in tight formations mainly depends on existing interfacial tension and the prevailing capillary forces. In this project we intend to investigate the aspects of CO2-EOR that contribute into fluid transport and rock/fluid interactions to study potential EOR applications in the Bakken Formation, Williston Basin, ND.

Objectives:

- Investigate CO2 EOR viability in Bakken Formation
- Solvent design to obtain first contact miscibility
- Determine key performance points for CO2 EOR
- Study the effectiveness of the combination of solvent and wettability alternation surfactant
- Deliver innovative solutions for a successful CO2 application

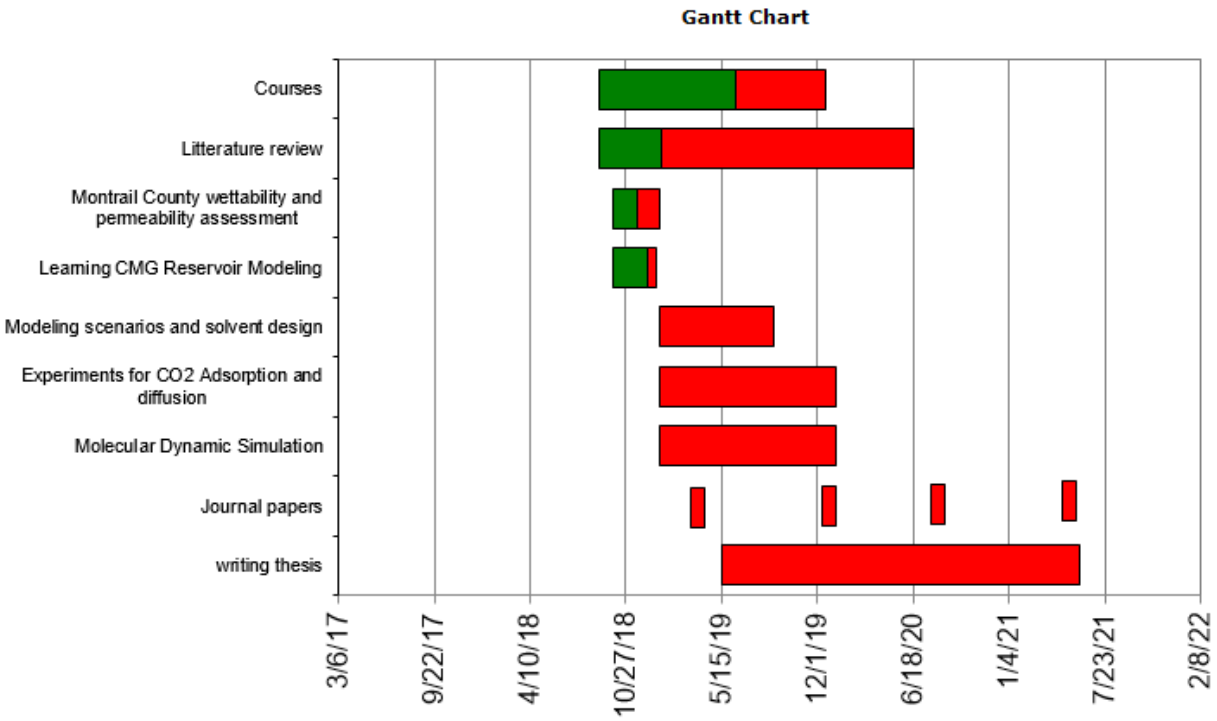
Methodology:

- Literature review
- CMG Reservoir Modeling for solvent design and forecasting optimization scenarios.
- Solvent adsorption and diffusion assessment using molecular simulation
- Design of lab experiment to determine the amount of solvent Adsorbed in a Bakken Samples.
- Using molecular dynamic simulation for a better understanding of Rock-Solvent interaction.

Significance:

- Combine between numerical field simulation and core sample lab experiments
- Multi-purpose CO2-Solvent use:
  - CO2 hybrid Fracturing
  - CO2 and surfactant injection
- Discuss solvent design in extend
- Evaluation of application parameters (Soak time, Injection time and period, etc.)

Project Milestone and Timing:



Progress to date:

- Reservoir fluid characterization
- PVT model in Winprop
- Reservoir model in CMG
- Permeability, wettability and rock Vp&Vs measurements.

References

Larry W. Lake . (2014). Petrophysics and Petrochemistry, Fundamentals of enhanced oil recovery (83-84). Society of Petroleum engineers.

Janet K. Pitman, Leigh C. Price, and Julie A. LeFever, 2001, Diagenesis and Fracture Development in the Bakken Formation, Williston Basin: Implications for Reservoir Quality in the Middle Member, U.S. Geological Survey.

Geomechanical Impact of CO2-EOR on the Bakken Formation

Ogochukwu Ozotta,
Ph.D. Student, Department of Petroleum Engineering, UND

Statement of problem:

Bakken Formation is considered as unconventional tight formation, due to low porosity and low permeability which makes recovery of hydrocarbons to be very low. For this reason, horizontal drilling and hydraulic fracturing is required to increase production. Additionally, recent studies have shown that the Bakken Formation can be a target for enhanced oil recovery with injection of CO_2. Although injection of carbon dioxide may increase production, its impact on mechanical properties of the formation and pore structures have been addressed or investigated. This study aims to expose samples from the Bakken Formation, all three members to CO_2 for certain period of times, also with a mixture of gas and brine to examine how it would affect, the formation in terms of either changing modulus of individual mineral and the whole sample or altering pore structures.

Objectives:

1- Understanding nanoscale geomechanical properties of the Bakken Formation and relate individual mineral modulus before and after the exposure.
2- Upscaling geomechanical characteristics of the formation through different methods such as effective medium theory and compare it to before and after exposure.
3- Understanding the effects of exposure time and fluid mixtures on individual minerals and the rock unit through upscaling and data analytics methods.
4- Studying pore structure of the sample, prior and after exposure under the SEM for deeper insight into changes that can occur with exposure to EOR fluids.

Methodology:

- Prepare small chips of rock and polish them to make a smooth surface for nano scale rock mechanics measurements/nanoindentation.
- Saturate the samples by CO2, brine and both using core flooding machine for extended period of time from 2 days, to two months for different solutions of fluids.

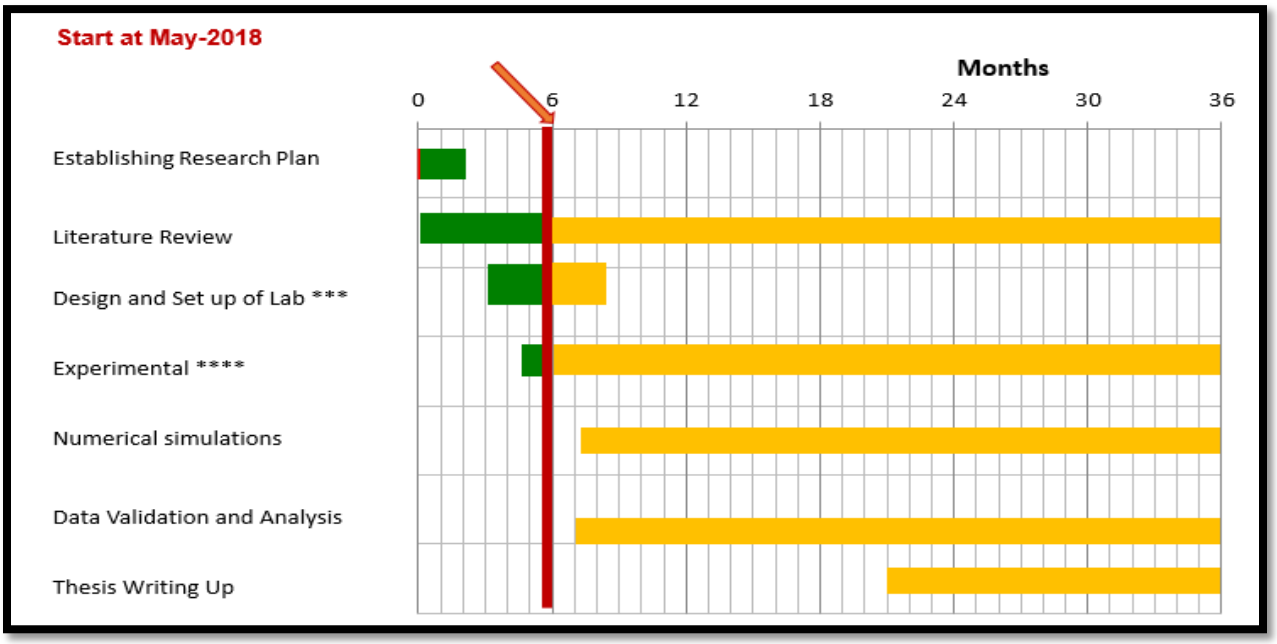
- Using nanoindentation test to measure young's modulus and hardness of the samples prior to and after the exposure.
- Using XRD to analyze the mineral compositions.
- Using data analytics method/deconvolution techniques to relate mechanical measured data to existing mineral assemblages.
- Using SEM (Scanning Electron Microscope) to see changes of pore structures before and after the exposure.

Significance:

This Study is Application of:

- Modulus and hardness are important values that should be input for more accurate fracturing simulation, by monitoring the changes that can occur through exposure such models can be improved.
- Stress analysis of the formation should be reevaluated after getting more accurate data from modulus of each mineral with the effects of fluid exposures.
- EOR is main part of production in Bakken Formation to improve oil recovery which depends on rock and fluid mechanics, properties and pores structures. Pore size and shape (structures) will impact fluid recovery micromodels which will be revealed through this study.

Project and Time:



Progress to date:

Literature review is done and samples are picked and prepared. The setup for exposure of the samples to fluids is being put together and exposing samples to carbon dioxide will stat before the end of the year (2018)

Using Pressure Distribution to Detect the Blockage and Leakage in the Pipelines

Hao Fu
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

The pipeline is a very efficient way to transport oil and gas over long distances. However, the blockage and leakage phenomena commonly occur when the pipes have been running for a long time. Existing blockage and leakage detection methods include physical inspections and mathematical models. Physical inspection consists of fluid sampling, soil monitoring, flow rate monitoring, acoustic, optical, satellite-based hyperspectral imaging. Usually, physical inspection results in accurate detection of the location and size of the blockage and the leakage, but at the high expense and long-time test. Mathematical model detects the leak by solving the governing mass conservation, momentum conservation, and energy balance equations thus lead to a quick evaluation at a much lower cost. The literature review indicated that no model is available to detect blockage and leakage without inlet or outlet rate or pressure, and no mathematical model was available to evaluate several block sections and multi-leak points in looped or parallel pipelines. This project is to fill these gaps.

Objectives:

- To apply new methods to detect blockages and leakages in petroleum pipelines.
- Using daily recorded transportation data such as pressure, temperature, the flow rate to locate and estimate the severity of the blockage and leakage.
- To estimate blocked section length and detect blockage with incomplete flow parameters.
- To detect the single leak and multiple leaks in looped or parallel pipelines.
- To detect blockages and leakages through mathematical models and numerical modeling.
- To incorporate our detection models in the monitor systems of pipeline companies to better monitor pipelines operation.
- Objective in phase 2 of the project: To use controlled transients such as water hammer waves that travel in the pipe system to obtain the health information of the pipes.

Methodology:

- • In the Hess Lab, to use the flow loop to observe the pressure drop through the blockage or leak point. To control variables to find the effect of each variable to the pressure drop through the blockage and leakage. Blockage length, size, and location were studied. The leak location and leak rate were tested under multi-flow rates.
- • To make the CFD model to figure out the impact of elements to the pressure drop and its gradient distribution based on the obstruction and leakage.
- • To build the mathematical model to predict the blockage and leakage based on pressure distribution in the pipeline by MATLAB.

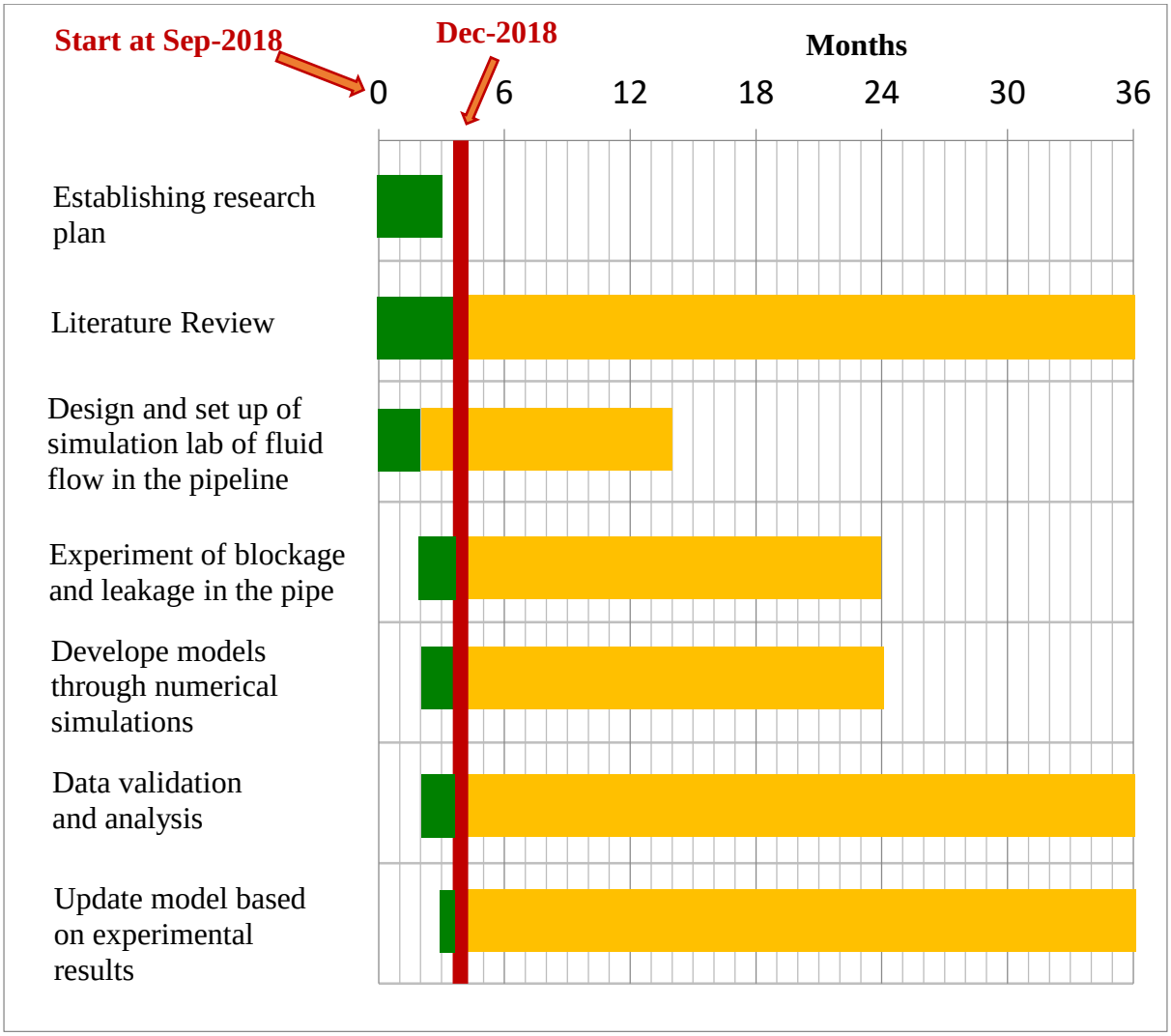
- • Methodology in phase 2 of the project: To figure out the analytical solutions of governing equations for the detection methods of the blockages and leakage.

Figure 1: The Simulation Lab of Fluid Flow in the Pipeline System

Significance:

- • Our detection methods can help locate the blockages and leakages through the pipelines.
- • To ensure the safety of transportation through pipelines in North Dakota.
- • To reduce the energy consumed by the pump in the transmission of long distance.
- • Quick detection will not only reduce the loss of oil and gas but also reduce the damage to facilities, possible loss of life, and the extent of environmental pollution.
- • Significance in phase 2 of the project: Once confirmed by lab experiments and successful field pilot tests, the new detection technology will be adopted by pipeline companies to monitor pipeline operations in real time.

Project Milestone and Timing:



Progress to date:

By the end of December 2018, I clarified the purpose and significance of the experiment, mastered the methods of experimental operation, and had ideas for future research. I expect a deeper understanding of numerical simulation and mathematical modeling for the pipeline in the future.

Lattice Numerical Simulations of Near Wellbore Hydraulic Fracturing

Nejma, Djabelkhir

Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

Hydraulic fracturing is the principal stimulation technique applied to improve oil and gas recovery and enhance production from unconventional resources. Better understanding of these reservoirs and advanced tools make the production economically viable and more efficient. Unconventional reservoir has a very specific characteristic, such as complex mineralogy, lateral and vertical heterogeneity as well as anisotropy. These characteristics require detailed characterization and right exploitation technologies.

Hydraulic fracturing near wellbore is complex and influenced by several parameters. The induced stress distribution around the wellbore, the damaged zone around the wellbore during drilling and/or production phase and other factors results in hydraulic fracture initiation and propagation pressure to be different than what is expected. Fracture tortuosity, multiple fracture growth and propagation of the fracture in direction different than what is expected are examples of the complexities that are part of the goal of this study. We use the XSite software, which is a grain based numerical simulator, introduced by the Itasca Consulting group in this work and demonstrate the advantage of using this software for simulation of hydraulic fracturing. Figure below shows an example output simulation from the XSite.

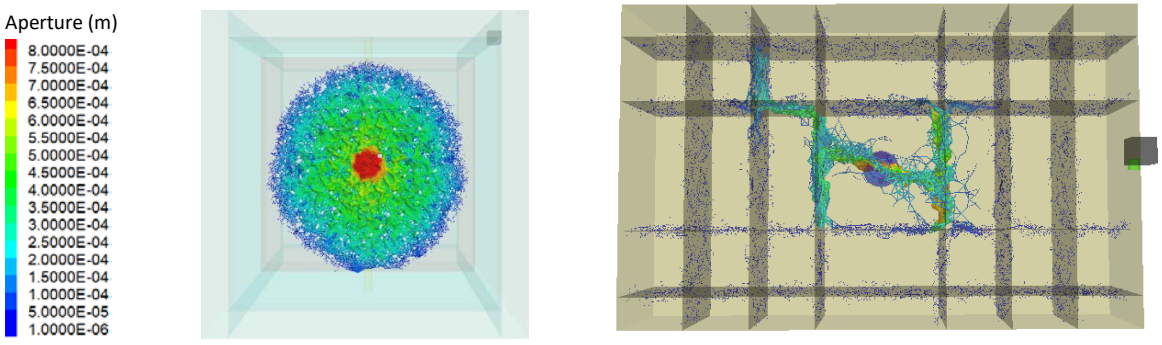


Figure: Penny Shape hydraulic fracture (left) and preferred fracture propagation plane in presence of two sets of natural fractures (right) using the XSite software

Objectives:

- Demonstrate the advantages of using grain based numerical simulator for modeling hydraulic fracturing
- Simulate near wellbore stresses and strains
- Simulate hydraulic fracture initiation and propagation near wellbore and identify the impact of rock properties, fluid characteristics and skins
- Validate the simulation results versus lab experimental work done in presence of three principal stresses
- Establish the workflow for simulation of near wellbore stress analysis and hydraulic fracture initiation and propagation in the XSite software

Methodology:

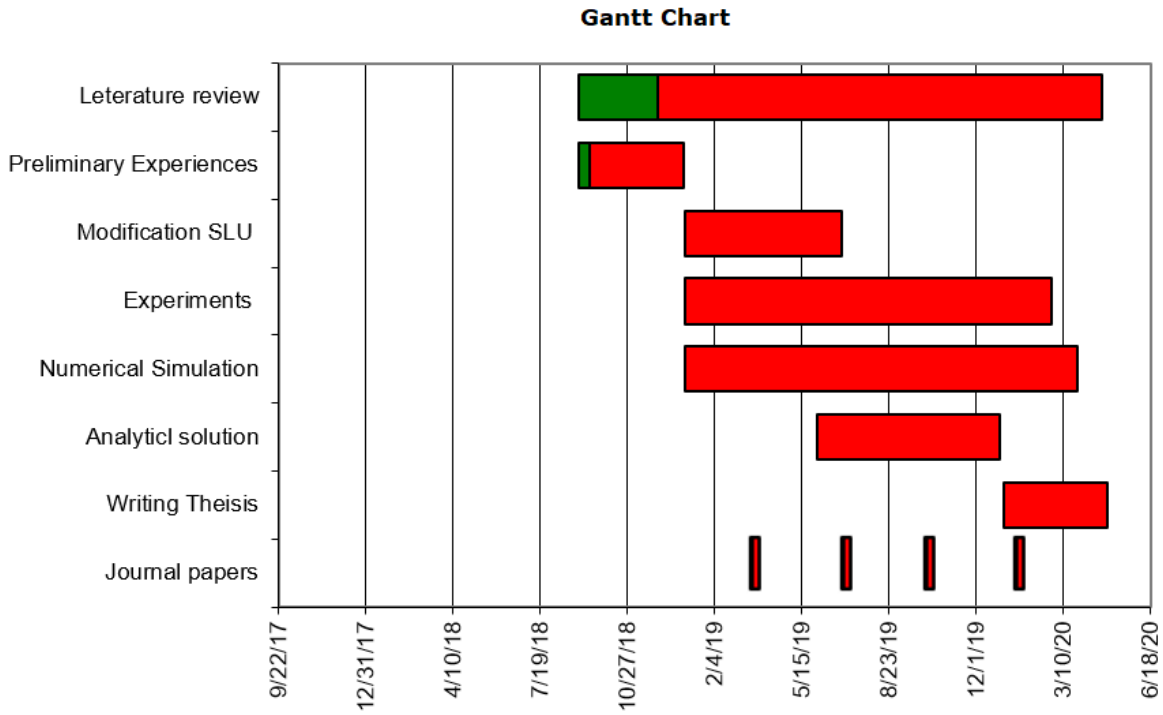
- We use the results of hydraulic fracture experiments done on 10 cm cubical mortar samples in this study for simulation purposes
- We use the newly developed XSite software by the Itasca group for this study. This simulator works based on the physics of the granular material and designed specifically for simulation of hydraulic fracture
- the analytical simulations available for determination of near wellbore stresses and strains will be used to compare with the simulation results
- The impact of hydraulic fracture near wellbore in terms of bypassing the damaged zone and increasing the productivity will be studied and compared with analytical solutions
- The impact of rock properties, state of stresses and fluid rheology are defined using the sensitivity analysis of various parameters

Significance:

- Hydraulic fracturing is the primary method of improved recovery in North Dakota. This study will provide in-depth studies on hydraulic fracturing process as occurs around the wellbore.
- Initiation of hydraulic fracturing around the wellbore is significantly important to be understood. Tortuous fracture path, multi branch of fractures and formation damage can influence the hydraulic fracturing process near wellbore. This study will investigate the impact of different parameters on near wellbore fracture initiation and propagation.

- A calibrated numerical simulator is essential for design purposes as lab experimenting and field testing are expensive and time consuming and does not allow easy sensitivity analysis of different parameters. This is while cross checking of the numerical simulation with lab or field data is important.
- This study introduces one of the first grain based hydraulic fracture simulations and the results will present the advantages of this modelling comparing to other existing numerical methods including continuum and discontinuum models.

Project Milestone and Timing:



Progress to date:

- The analysis of the lab experiment results is on going
- The literature review is being carried out on different stages of this study
- The collaboration with ITASCA team is made to improve and validate the results
- Learning different features of the XSite software

Impact of Stress on the Characterization of Flow Units in the Complex Three Forks Carbonate Reservoir, Williston Basin

Aldjia Boualam Djezzar
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

The objective of this study is to investigate the impact of the reservoir quality and the state of stresses on the characterization of hydraulic flow units in the complex Three Forks (TF) formation. The first phase of the research focuses on reservoir characterization and difficulties associated with petrophysical analysis. The primary complexity concerning formation evaluation of the TF is the presence of the thin beds, which can result in large anisotropy of resistivity and high water saturation (Sw). The second phase of the research will focus on the laboratory studies. The main objective is to investigate the stress dependent permeability and porosity for a set of rock samples from Upper and Middle TF. Through this analysis, we will investigate if there is any correlation between changes in effective stress with porosity and permeability and understanding the permeability hysteresis, which plays a significant role in tight reservoir production.

Objectives:

- Characterization of the thin beds in TF formation.
- Water Saturation estimation using advanced well logging.
- Water saturation prediction using machine-learning algorithms.
- Minerals and fluids volumes quantification using multi-mineral solver.
- Prediction of the porosity-permeability relationship.
- Identification of hydraulic flow units using different methods.
- Understanding permeability hysteresis.
- Identification of the factors controlling stress dependent porosity and permeability.
- The impact of stress on the characterization of the hydraulic flow units.

Methodology:

- An integrated approach will be used to evaluate the reservoir characteristics and the effect of stresses on the hydraulic flow unit characterization.
- The first alternative approach to thin beds petrophysical model is the integration of the advanced logging in petrophysical analysis such as elemental capture spectroscopy (ECS), nuclear magnetic resonance (NMR), multifrequency array dielectric measurements, and triaxial induction resistivity in conjunction with core analysis.
- Developing reservoir petrophysical model using multi-mineral solver (Quanti-Elan).
- The lithological model is derived from the elemental dry weight fractions quantified by ECS, which are used in combination with neutron porosity, bulk density, and photoelectric factor to define the complex lithological model (Illite, chlorite, quartz, dolomite, calcite, K-feldspar-anhydrite and pyrite), and estimate the porosity.

- The permittivity array is used as an input in the model. In addition, the water-filled porosity from the array dielectric in combination with total porosity from petrophysical analysis provides an estimation of the water saturation independent of resistivity.
- Quantification of the minerals and fluids volumes will be carried out.
- The outputs of the petrophysical model are compared with special and routine core analysis (XRD/XRF, porosity and water saturation).
- Machine-learning algorithm will be used to predict the water saturation model at any point in the reservoir, and generate synthetic logs for uncored wells with a conventional data set (GR, Resistivity, Neutron, Density and Sonic).
- The permeability-porosity relationship of the formation will be used for identification of reservoir hydraulic flow units using different methods (e.g. Winland, Reservoir Quality Index , FZI*). The probability plot clustering technique will be apply to better identify the hydraulic flow units.
- Core samples selection will be done based on hydraulic flow units and petrography (XRD, SEM) from Upper Three Forks -perpendicular and parallel to lamination.
- Experiments will be conducted using the Autolab equipment by first gradually increasing the confining pressure from 500 to 5000 psi or more. Then subsequently reducing it back to 500 psi where the porosity and permeability will be measured at each step (SEM-300).
- Micro CT Scan or SEM of the samples will be done before and after the experiments.
- Correlations between changes in effective stress with porosity and permeability will be investigated.
- Factors (pore geometry, content and location of clay particles, grain-contact type, and grain size) that control the changes in permeability as a function of reservoir effective stress will be identified.
- The impact of the effective stress on the characterization of hydraulic flow units will be studied.

Significance:

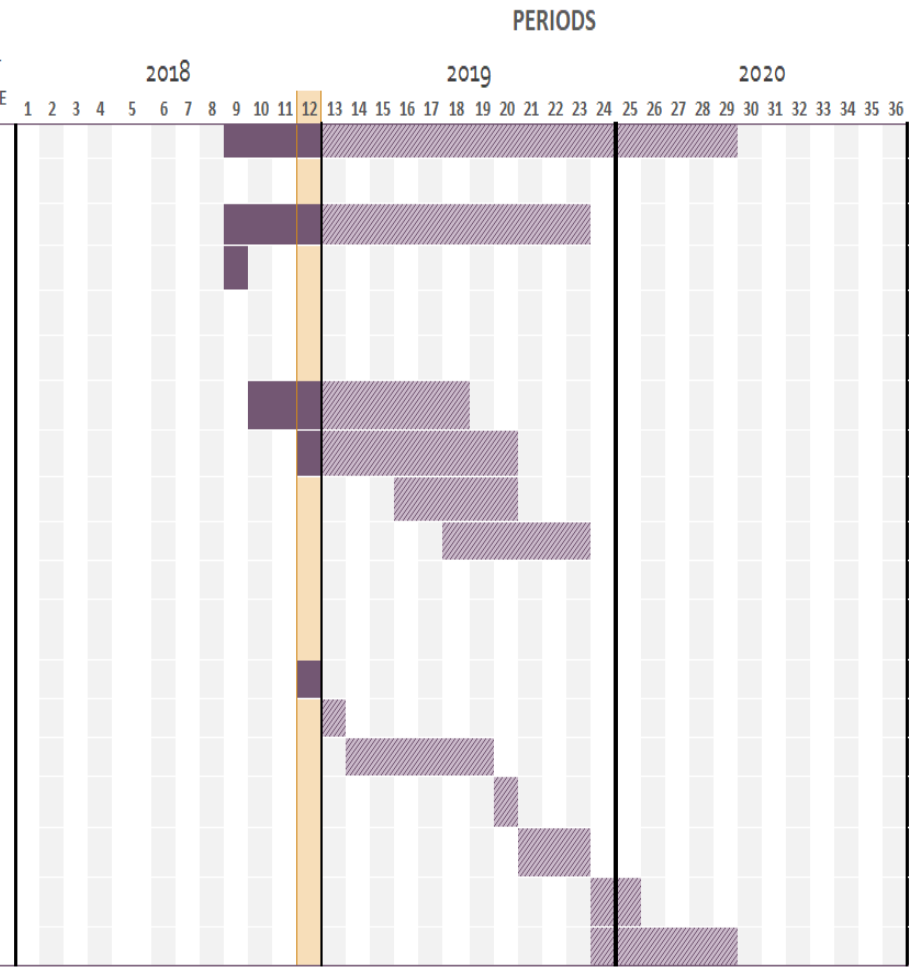
- Thin beds reservoir with thickness of less than the resolution of the conventional tools can result in large anisotropy of resistivity and high water saturation (Sw). The practical impact is the underestimation of the net pay thickness and reserves. Similar studies are rarely done due to the complexity of the reservoir.
- Since the discovery of the Three Forks reservoir, there have been more than three thousand wells drilled and completed with conventional logs. Due to the complexity of the reservoir, full cores were acquired across the TF and logged advanced logging tools in some wells. The application of machine learning algorithm for water saturation prediction using the conventional logs can be a meaningful tool across the entire basin. In addition, to low cost comparing to the advanced logging and coring. This work is one of the first attempt that will be done for TF formation.
- Understanding the permeability hysteresis and the factors that control the changes in permeability as a function of reservoir effective stress can leads to better production. This topic has not been studied in TF before and will be done in this study.

Research and Study Schedule

Select a period to highlight at right. A legend describing the charting follows.

Period Highl 12 | Plan Duration | Actual Start | % Complete

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Research plan	9	21	9	21	20%
Literature Review/Study					
Phasel : Reservoir Characterization	9	15	9	15	30%
- Data Availability (NDIC):	9	1	9	1	100%
*Data Loading & QC					
*Well Tops /por-perm					
- Advanced Petrophysical Analysis (30 wells)	10	9	10	9	35%
- Sw Prediction(machine learning)	12	9	12	9	15%
- Por-perm relationship	16	5	16	5	0%
- Hydraulic Flow Units	18	6	18	6	0%
Phase II : Laboratory Studies					
- XRD/XRF	12	1	12	1	100%
- SEM / micro CT Scan ?	13	1	13	1	0%
- Permeability & porosity hysteresis experiments	14	6	14	6	0%
- Micro CT Scan ?	20	1	20	1	0%
- Factors that control changes in permeability	21	3	21	3	0%
- Impact of stress on the hydraulic flow units	24	2	24	2	0%
- Thesis proofilment	24	6	24	6	0%



Discrete Fracture Network (DFN) Modelling of Hydraulic Fracturing

Dezhi, Qiu
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

Fracture networks usually serve as the main pathways for fluid transport in matrix rocks, especially when the matrix is impermeable compared to the fractures, in case of unconventional reservoirs such as shale plays. In unconventional plays, hydraulic fracturing is the main operation which enhances production. If this operation is designed correctly in areas with natural fracture networks, known as sweet spots, in can take advantage of the existing fracture pathways and results in larger fold of increase (FOI). Therefore, characterization of the natural fracture networks is significantly important in order to characterize the fracture network geometry and the impact it may have on the hydraulic fracture. In addition, the fracture network geometry is used to estimate the storage capacity of the reservoir and to understand physical phenomena concerning fluid flow through fractures.

The past research studies have identified crossing, arresting and opening, as the three main interaction mechanisms when a hydraulic fracture intersects a single plane of natural interface (i.e. natural fracture, bedding plane or any other interfaces). Many analytical solutions have been proposed to predict the interaction modes. Also, lab experimental works have been done to study the interaction modes. However, the network of natural fractures in real field are far more complex than a simple fracture pattern, which makes it difficult to use the analytical solutions or study in simple lab set up. A more accurate investigation of hydraulic fracture propagation in a fractured media requires fracture network modelling which represents the hydromechanical characteristics of the field as closely as possible. Discrete Fracture Network (DFN) has been widely applied to characterize fracture network geometry and to study the permeability and mechanical behavior of fractured rocks. Statistical, geostatistical and stochastic DFN models have been proposed in the past to simulate the interaction mechanism and to estimate permeability. In this study, we investigate the use of artificial intelligent (AI) and other advanced models in data mining to propose a DFN model to characterize natural fracture geometry. Then we study the effect of the fracture geometry on the preferred fracture propagation (PFP) direction of hydraulically induced fracture in addition to several other parameters that may affect the PFP such as the state of the field stresses and rock properties.

Objectives:

- Present a new DFN model based on the new advanced methods in data mining including the Artificial Intelligent (AI) algorithms.
- Compare the applications of the new DFN model with the existing statistical and stochastic models.
- Apply the new DFN model to characterize the fracture networks in Bakken or Three Froks formations.

- Conduct hydraulic fracturing simulations using a new grain based simulator to study the PFP path in the modeled DFN media.
- Investigate the impact of different fracture geometries and more importantly the effect of the scale of fractures on the PFP direction.
- Study the impact of in-situ stresses, formation mechanical properties and injection fluid rheological parameters on PFP direction.

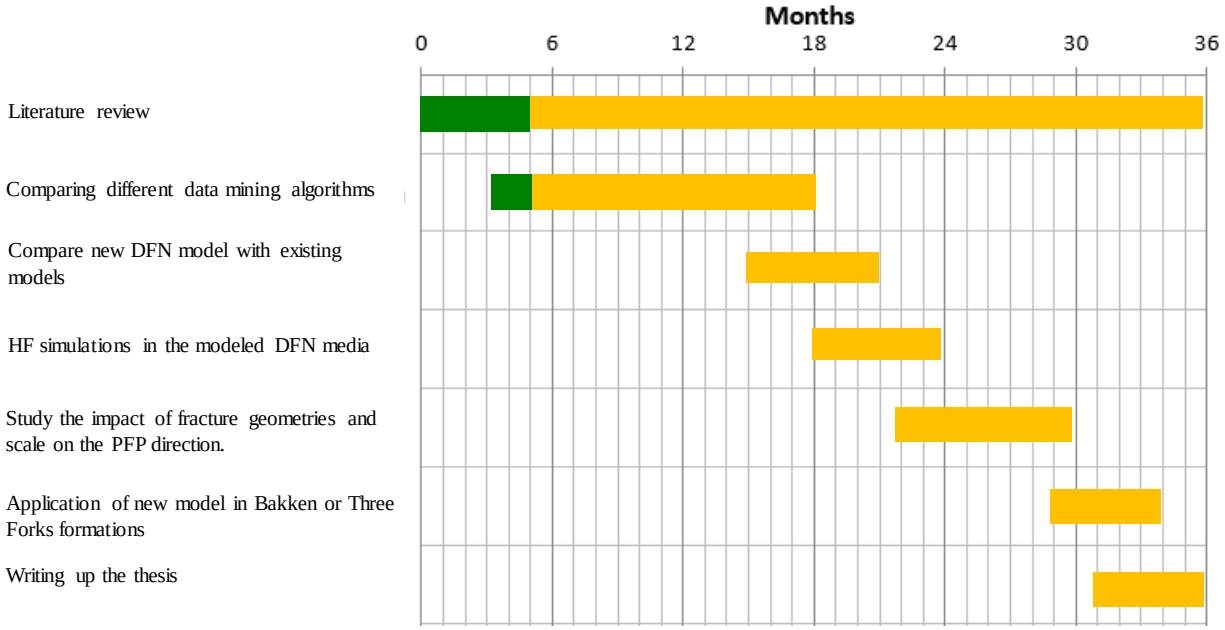
Methodology:

- Data mining based models including AI will be used to develop a new DFN model and compare with existing methods including stochastic and statistical approaches.
- Log data, including the image logs, seismic and various field reports from Bakken or Three Forks will be used to capture the natural fractures at different scales.
- XSite, a new grain based model software, developed by the Itasca group, will be used in this study to simulate the interaction modes and the PFP direction in modelled DFN media.
- Analytical solutions will be used in case of simplified cases to compare the interaction modes with the simulation results.

Significance:

- The use of data mining methods used in this study to develop the DFN is relatively new and offers several advantages.
- XSite is a newly developed hydraulic fracture simulator based on the physics of granular material. This software is used in this study.
- Hydraulic fracturing is the main stimulation technique used in North Dakota, so the results of this study is expected to present practical applications.

Project Milestone and Timing:



Progress to date:

- Literature review is being carried out on different data mining models and other methods for modeling the DFN.
- FracSim 3D software has been used to generate some preliminary DFNs for initial modelling and practice.
- Hydraulic fracturing modelling using XSite has been practiced and simple models with two natural fractures have been simulated to predict the interaction modes.

Simulations of Hydraulic Fracturing Through Perforations

Omar, Akash
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

Hydraulic fracturing is a commonly used technique to stimulate hydrocarbon production in low permeability formations. The near wellbore stress state may affect the initiation and propagation of the fracture and this will have direct effect on hydrocarbon production rate. Operation of hydraulic fracturing in cased holes through the perforation is one of the topic which requires detailed studies. Many studies are available in the literature that focuses on near wellbore problems in a cased hole perforated wellbore. Among the observed near wellbore issues are T-shaped fractures, multiple parallel fractures, sand production, tortuosity, and reoriented fractures. In this study, we simulate hydraulic fracturing from perforations using a new grain based numerical model. The simulations are performed firstly for some lab experiments which were carried out elsewhere to calibrate the numerical model. Then we expand the applications to field scale.

Objectives:

- Summarizing the state of the art in perforations design.
- Address challenges related to hydraulic fracturing from perforations.
- Study numerically the best perforations geometry and locations.
- Determine, in the case of multiple perforations, what is the optimum number, spacing and orientation.
- Using existing analytical models optimize the parameters related to perforations design.
- Study the tortuosity effect and how to reduce it.
- Determine the location of fracture initiation along the perforation tunnel.

Methodology:

- Using numerical simulation software Xsite which is a grain based model.
- Using analytical equations and solutions in the literature to verify simulation results.
- Using experimental results available in literature and comparing it with simulation results.

Significance:

- While there are several similar studies done in the past, there are little or no report on the grain based simulations, comparing to continuum and discontinuum based models. This is the approach which will be used in this study and its advantages will be highlighted.
- We will use a number of existing analytical solutions to compare with simulation results and determine the range of their applicability. This will provide means for quick analysis.
- In this study we will conduct simulations of a number of lab experimental studies, whose data are available to us, and this should provide a strong means to calibrate the numerical simulation models before we apply to field scale.
- The results of this study has direct applications to the ND oil and gas industry where hydraulic fracturing operations are the major improved recovery method to produce from low permeability shale oils.

Project Milestone and Timing:

			Months			
	6	12	18	24	30	36
Establishing Research Plan						
Literature Review						
Review of Experimental Work						
Numerical Simulation						
Validation of Simulation Results						
Thesis Writing						

Progress to date:

- Established a research plan.
- Practiced the simulation software that will be used in the study.
- Literature review of analytical models.

Replicating Bakken Shale Rock for Petrophysical Experiments Using 3D Printing Technology

Lingyun Kong,
Ph.D. Student, Department of Petroleum Engineering, UND

Problem Statement:

Bakken Formation during petrophysical and geomechanical experiments, especially core flooding and geomechanical measurements, showed high heterogeneity, anisotropy and microstructure complexity. Destructive experiments would prevent the same rock sample for further measurements and multiple testing for better modeling and simulation. To solve this problem, traditional manufacturing methods have attempted to mimic the shale rock using a mixture of versatile mineral components and cementations, while limited by the design in regards to the levek they can achieve in complexity of pore/fracture structures. 3D printing, also known as additive manufacturing, is currently revolutionizing many industries and academia, especially biomedical engineering and aircraft industry. In the area of petroleum engineering and geosciences where porous medium plays a major role, 3D printing has been utilized to reinvent conventional experimental methods since 2015. When we would be able to create similar samples without being worried about losing them for several experiments like, core flooding, geomechanical experiments, the whole process will enhance the efficiency, as well as save the expenses since it will make our dependency to number of rock samples less.

Objectives:

1) Introducing *3D printing* which has been used previously to replicate sandstone and carbonates for replicating unconventional reservoir rocks and testing their physical properties using different printing technologies. The properties are as follows:
    - Porosity, Permeability
    - Pore size distribution
    - Geomechanical properties
2) In the next phase of the study, high-resolution 3D printer will be used to:
    - Replicate shale samples of the Bakken using similar components
    - Test in the core flooding and geomechanical experiments.
    - Substitute Bakken shale rock for various experimental models under variable scenarios.

Methodology:

Additive manufacturing (3D printing):

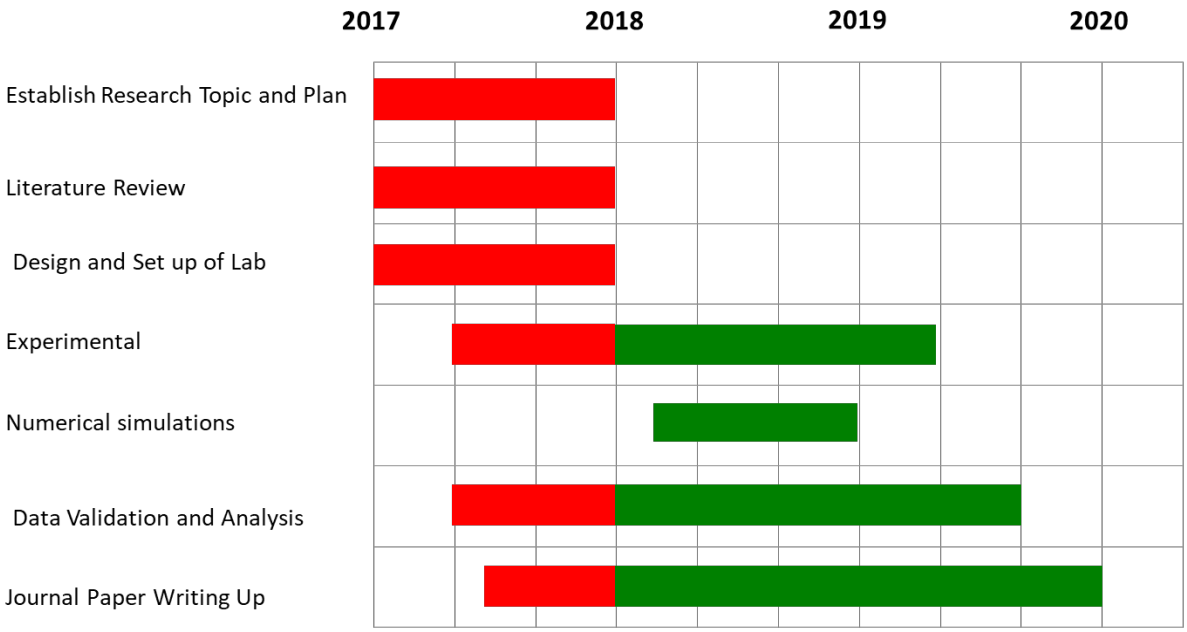
- Creating and transforming digital rock models to tangible rock analogues.
- Attempting three different 3D printing technologies, including gypsum-powder, silica sand, resin SLA then ccomparing the performance and optimizing the strategy.
- Performing SEM, micro-CT, EDS, MICP, Geomechanical experiments, on created samples to find the one with the most similarity with natural rocks in terms of pore structures.

- Examining the properties of the Bakken reservoir rock, create digital models, print them and compare it with 3DP samples to examine existing rock physics, geomechanics and geophysical models.

Significance:

- 3D printing can improve the efficiency of rock core experiments. Reducing the cost of drilling the core plugs by performing analogues replicas for unlimited experiments design and modeling.
- 3D printing can also manufacture macroscale rock models to perform hydraulic fracturing and acoustic emission (microseismic) experiments.
- 3D printing has the potential to revolutionize the traditional laboratory experiments and conduct infinite number of experiments on validating and calibrating the theories in petroleum industry that are being used under lots of assumptions.

Project Milestone and Timing:



Progress to date:

The characterization of petrophysical (transport and storage capacity) 3D printed rocks have been conducted on three different technologies and materials, which means the first objective has completed. All the results and conclusions have been published in journal articles and presented in multiple world-known academic conferences.

Multi-Scale Organic Material Characterization of the Bakken Source Rock

Arash Abarghani,
Ph.D. Student, Department of Petroleum Engineering, UND

Problem Statement:

The Bakken petroleum system in Williston Basin is one of the most important unconventional shale plays in North America. During past decades, the Bakken was the subject of various research and studies. However, most of those studies have focused on the Middle Bakken and its petrophysical properties as reservoir and the productive zone of the Bakken Formation. In this regard, studies that would address the Upper and Lower Shale members' characteristics, such as constituent organofacies, organic petrology and geochemistry are limited, specifically on the American side of the basin. For instance, in the scarcity/absence of vitrinite macerals, most researchers have used the Barnett Shale or the Duvernay Formation T_{max} to vitrinite models to estimate equivalent vitrinite reflectance for the Bakken due to lack of such a models for the Bakken source rock. However, our studies have shown that the Bakken not only has a significantly different thermal maturity trend with those mentioned formations but also each member has its own thermal maturity trend. Considering the fact that, there are lots of wells in the Bakken Formation with a complete set of wireline log data, establishing a robust model to relate petrophysical properties from the logs to the main geochemical characteristics of the source rock such as total organic carbon (TOC) or thermal maturity across the basin will be very beneficial. Extensive organic petrology and geochemistry studies and analysis on individual macerals and kerogen could give us a solid understanding of the source rock capabilities in the large scale. In the micro and nano-scale, appropriate samples from the previous stage will be analyzed utilizing advanced techniques such as AFM based Infrared (IR) spectroscopy, to provide a better insight of the source rock characteristic and potential. By the combination of the outcomes of the multi-scale analysis, it will be possible to construct continuous geochemical logs which lead to a 3D model for the source rock thermal maturity and richness evaluations, basin wise. This model can help to better understand source rock and carry out more accurate petroleum system evaluation and finally reserve estimation.

Objectives:

- Selecting at least 20 different wells with a good areal distribution throughout the North Dakota portion of the Williston basin in order to better exploit the complete maturation series existing in the basin.
- Extensive organic petrology study of the Bakken source rock, the study of individual maceral, kerogen typing, vitrinite/bitumen reflectance, source rock geochemical screening using SRA and Rock-Eval 6, X-ray fluorescence, restoration of the original geochemical properties using empirical and mathematical methods in order to identify constituent organofacies basin wise.
- Establishing a new relationship between vitrinite reflectance and Rock-Eval driven T_{max} for the Upper and Lower Shales separately. These models could be used in the future research and industrial purposes instead of using the Barnett or Duvernay Shale models.

- Establishing a new relationship between Bitumen reflectance and a combination of different petrophysical log in order to the quick prediction of thermal maturity and be able to generate continuous geochemical logs which could be used for the source rock screening basin wise in three dimensional models.
- Employing advanced analytical instruments such as AFM-NanoIR2 for geochemical and geomechanical characterization of the source rock in Nano-scale to provide a better understanding of the effects of thermal maturity on the macerals transformation and petroleum generation.

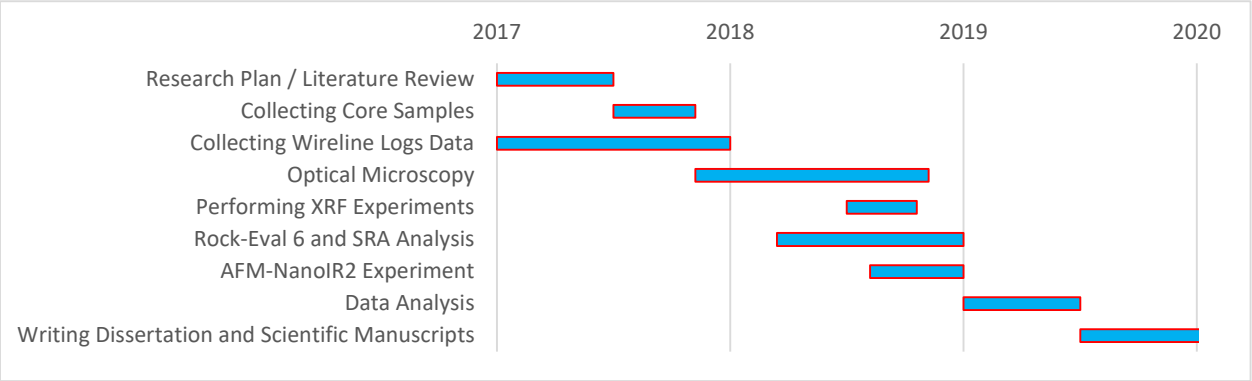
Methodology:

- Picking up appropriate core samples from the North Dakota Geological Survey Core Library.
- Optical microscope LEICA DM 2500-P equipped with a J&M Imager for the purpose of organic petrography studies using white and UV lights. Vitrinite and solid bitumen reflectance measurements and kerogen typing.
- X-Ray fluorescence analysis in order to the reconstruction of the sedimentary environment from the anoxic/euxinic condition point of view.
- Extensive geochemical analysis of the samples using the Rock-Eval 6 and SRA instruments both vertically and horizontally in order to accurately screening of the source rock and thermal maturity trend studies.
- Collecting all the available wireline log data include of Sonic (Shear and compressional), Formation Density, Neutron Porosity, and Gamma Ray in order to find a possible relationship between these logs and bitumen reflectance.
- Analyzing appropriate samples utilizing AFM-NanoIR2 in order to the geochemical and geomechanical investigation of the individual macerals and, their transformation to petroleum and bitumen.

Significance:

- A comprehensive multi-scale study of the source rock from the basin-scale down to Nano-scale could provide a solid understanding of the source rock capabilities in generating and expelling petroleum. Since the existence of organic carbon will lead to a decrease of the rock stiffness, an accurate distribution 3D map of the total organic carbon could provide a roadmap to find appropriate locations for fracturing operations.
- From the exploration point of view, the source rock screening is the base of any successful prospect evaluation and can reduce the cost of the operation significantly by excluding no-potential source rocks.

Project Milestone and Timing:



Progress to date:

We have carried out various analysis and research simultaneously to keep progress going for the overall project. Some experiments have done on the samples include of organic petrology and XRF analysis. Some others in progress and I am trying to extend the samples amount size and cover more portion of the basin to get a solid understanding of the whole basin of the Bakken source rock. some results were already published, and some are under review in the peer-review journals. More outcomes are anticipated to be published soon.

CO_2 sequestration and EOR capacity of the Bakken Formation through Kerogen Molecular Modeling

Hyeon Seok Lee
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

Computational molecular modeling has been increasingly utilized to study kerogen or amorphous organic material. Additionally, simulation techniques have been acquired to analyze phenomenon that involves organic matter such as the adsorption/desorption process (EOR). This is happening due to the attention that organic matter is receiving in regards to its role in exploiting shale plays and carbon sequestration in rock layers with an abundance of organic matter. Kerogen models are continuously being developed but still require further research due to its complexity and variability which will increase the accuracy of modeling and simulation results in organic rich shale plays. This study demonstrates organic rich shale response, particularly the Bakken Formation, when the organic matter chemical properties are coupled with the electrostatic interactions for selectivity of in CO_2/hydrocarbons/brine for the purpose of EOR and sequestration applications. The structural features and mixed-gas sorption properties of the Bakken organic matter show that it would be possible to combine equilibrium and kinetic adsorption selectivity in the same porous material to facilitate effective CO_2 separation (EOR) and capture (Sequestration).

Objectives:

1) Construction the Bakken organic matter models through 3D macro-molecular structure characterizing by inputting realistic chemical & physical substances of the Bakken source rock in terms of:
   - CO2, N2 gas adsorption isotherm
   - Raman/IR spectroscopy calculations
   - X-ray photoelectron spectroscopy (XPS) analysis
   - 13 C NMR data
2) In the next phase of the study, estimate the response of the Bakken in terms of Enhanced Oil Recovery (EOR) and CO2 sequestration:
   - Understand adsorption/desorption characteristics and interactions between kerogen and CH_4, CO_2 gas in saline solutions.
   - Estimation of mechanical properties (simulation for atomic stress) of the organic matter for better estimation of hydraulic fractures when its mixed with various fluids.

Methodology:

1) Molecular Dynamics Simulation (MDS):

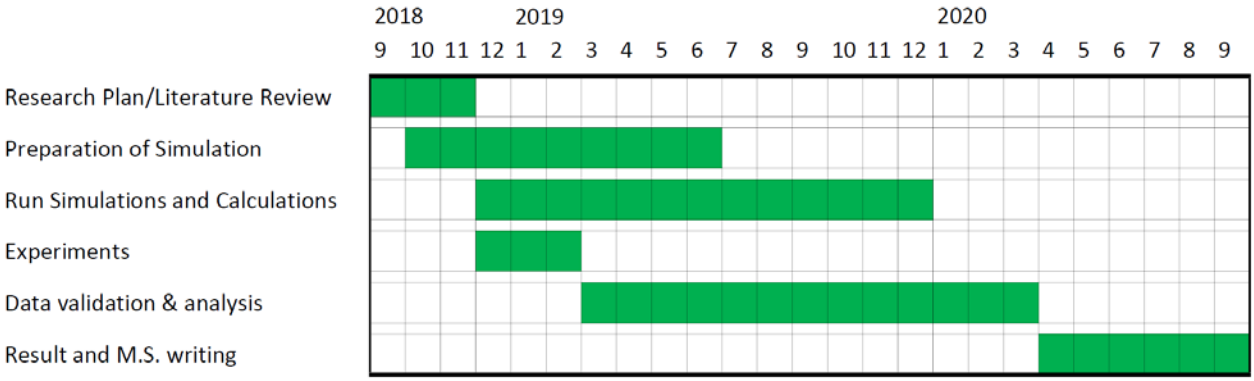
- In a multicomponent single-phase system, molecular dynamics simulation through molecular simulator, LAMMPS will be utilized to build organic matter molecular model.
- Electrostatic interactions between the fluids and kerogen surface will be modeled and compared with experimental data.
- Transport phenomena of desired molecules in the Bakken kerogen pores will be predicted.
- Evaluating thermodynamic instantaneous and fluctuation properties (Kinetic/Potential Energy, Heat capacity etc.) of organic matter.

2) Quantum mechanics calculation:
   - Geometric optimization of kerogen molecular model.
   - Calculation of partial charge of all atoms
   - Advanced theoretical spectroscopy calculation & analysis (NMR, Raman, IR)
3) Experimental analysis
   - X-ray photoelectron spectroscopy (XPS) and 13C NMR data will be gathered to analyze existing functional groups and chemistry of the sample at various maturities and update MDS models via experimental data.

Significance:

1) This study will enable us to understand thermodynamic, mechanical and physio-chemical properties of the organic matter to improve hydrocarbon recovery from the Bakken and estimate sequestration capacity of the formation simultaneously via optimal adsorption and desorption properties of organic rich shales.
2) Computational molecular dynamics overcome the experiment limitations (extremely high temperature and pressure) with desired/real reservoir environments that cannot be achieved in the lab.

Project Milestone and Timing:



Progress to date:

1) The initial computational kerogen 3D molecular structure models for the Bakken were developed by using molecular simulation and quantum mechanics calculation. The models have a good overall agreement with real Bakken sample in the adsorption isotherm from previous laboratory experiments. To build the model, XPS and NMR data were input in the MDS software from limited studies that was found in the literature.

2) Currently the QM software (ORCA) is calculating in theoretical Raman/IR spectroscopy of the Bakken kerogen models, then the outcome is going to be compared with the Bakken Kerogen samples IR and Raman spectra on physical samples.
3) The simulation models have been prepared in terms of the selectivity between CH_4/CO_2/Brines and their mixtures for further analysis of EOR and sequestration capacity of the formation.
4) XPS experiments are being conducted and physical Bakken samples which are at different maturity levels that are estimated from Rock-Eval pyrolysis. Then, molecular Bakken kerogen models are going to be upgraded and corrected iteratively.

Characterization of the Bakken Source Rock with Spectroscopy Methods

Seyedalireza Khatibi,
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

Although organic-rich oil-producing unconventional reservoirs have been studied extensively during the last decade, kerogen (organic matter), as one the main constituents of them, is not thoroughly understood. Quantity of hydrocarbon generation from unconventional shale plays is a function of kerogen content and type also its maturity. As primary vitrinite is absent in sedimentary formations older than the Devonian, such as the Bakken in ND, USA, conventional vitrinite reflectance analysis can be difficult. Furthermore, since kerogen is not as stiff as inorganic minerals, its presence can have a significant impact on the initiation and propagation of fractures in kerogen-rich formations that should undergo stimulation. But, as kerogen is dispersed within the matrix, pinpointing a location that contains solely kerogen would be challenging. Considering, such complexities in unconventional reservoirs leads to use new analytical tools for better characterization of shale reservoirs.

Objectives:

1) Introduction of *Raman spectroscopy* which has been used previously to characterize various chemicals substances as a promising, rapid and non-destructive method to evaluate Bakken source rock in terms of:
    - Thermal maturity
    - Rock-Eval properties
    - Mechanical properties
2) In the next phase of the study, high frequency *NMR spectroscopy* was used to:
    - Study fluid typing in shale samples of the Bakken
    - Relate physical properties of samples to its geochemical properties for better understanding of unconventional reservoirs

Methodology:

Raman spectroscopy:

- Perform Raman spectroscopy on different samples with different maturity levels
- Perform solid bitumen reflectance (SBRo) measurements and also Rock-Eval pyrolysis on the same samples
- Establish a correlation between maturity, and other geochemical properties of organic matter with Raman spectroscopy bands
- Using the correlation exist between maturity and Young's modulus of organic matter to correlate Young's modulus of organic matter to Raman bands as a new method to measure source rock mechanical properties
- Use obtained mechanical data to get more accurate hydraulic fracturing simulation results in organic rich members of the Bakken Formation compared to existing models

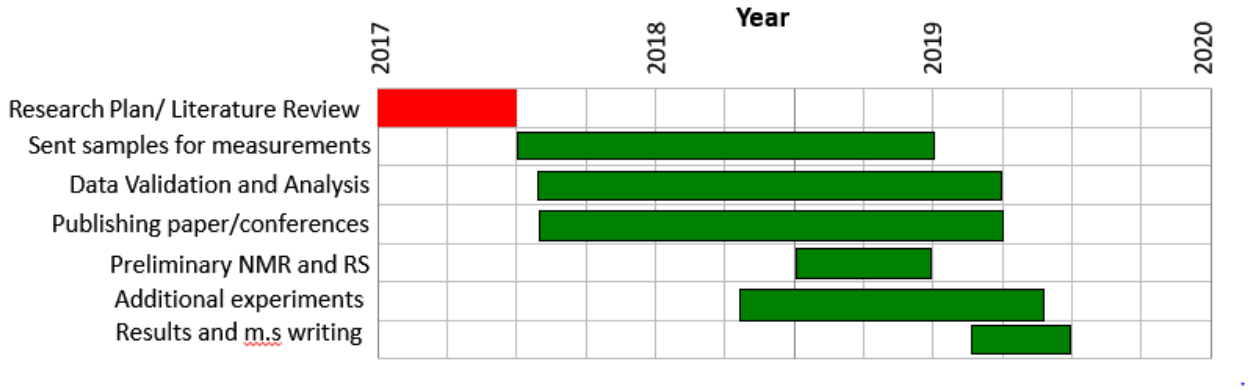
NMR spectroscopy:

- Distinguish different hydrogen populations in shale rock samples including water, oil and solid organic matter
- Using the intensity of hydrogen population on T1-T2 map to predict geochemical properties of organic matter and relate that to geochemical characteristics from programmed pyrolysis

Significance:

- The benefit of using Raman spectroscopy in organic matter characterization is the speed of analysis, and non-destructive approach without dependency of large samples, while in conventional methods sample preparation needs time and might not be available.
- The benefit of using the proposed method via NMR is that we understand various components that exist in the shale sample and separate them clearly for updated OOIP and Production Potential estimation.
- Using core flooding systems along with NMR spectroscopy on shale samples can detect the movement of hydrocarbons from small pores to larger ones and extend the idea to Enhanced Oil Recovery (EOR) operations

Project Milestone and Timing:



Progress to date:

I have performed preliminary and limited lab experiments and established a correlation between Raman and NMR spectroscopies with respect to the organic matter geochemical properties obtained from Rock Eval pyrolysis. I am working on preparing additional lab experiments on more samples and write several manuscripts to submit for publication in journals and conferences.

Lattice Numerical Simulations of Hydraulic Fracturing in High Permeable Formations

Siamak Koloushani
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

Conventionally, hydraulic fracturing is used as a technique for enhanced recovery of tight formations with very low permeability. Hydraulic fracturing in high permeable formations is known to be not practically successful, as the fluid pressure is lost due to a large fluid leak-off into the formation. However, the industry has used hydraulic fracturing in high permeable formations for some specific applications. Frac packing has been used to improve the economic returns of the reservoirs through the reduction of formation damage and controlling sand production from unconsolidated formation. In this technique the gravel (large size proppant, usually 6-10 times larger than the size of producing sand) are placed around a perforated screen and inside the hydraulic fracture that has penetrated to the unconsolidated formation. The screen will hold the gravel in place and the gravels stop the producing sands much earlier before they reach close to the wellbore along the fracture plane.

During the Frac & Pack job a fracture created by the injection of viscous fluid with pressure greater than formation break down pressure followed by the injection of slurry of fluid with proppant. When the large volume of the injected proppant reaches the tip of the created fracture the fluid leaks off to the formation and the dehydrated proppant accumulates and forms a bridge at the fracture tip and its perimeter. This avoids further growth of the fracture length. Continuous injection of slurry causes the fracture width to increase as the pressure increases leading to balloon the fracture and that the fracture length cannot increase any longer. At the Tip Screen Out (TSO) point, the slurry velocity drops suddenly and this will result in rapid increase of the slurry viscosity, which helps to increase the fracture width with less opportunity for the high viscos slurry to leak into the formation. The higher the slurry concentration in the fracture, the greater the proportion of the created aperture that will be propped open. Figure 1 shows the evolution of the TSO.

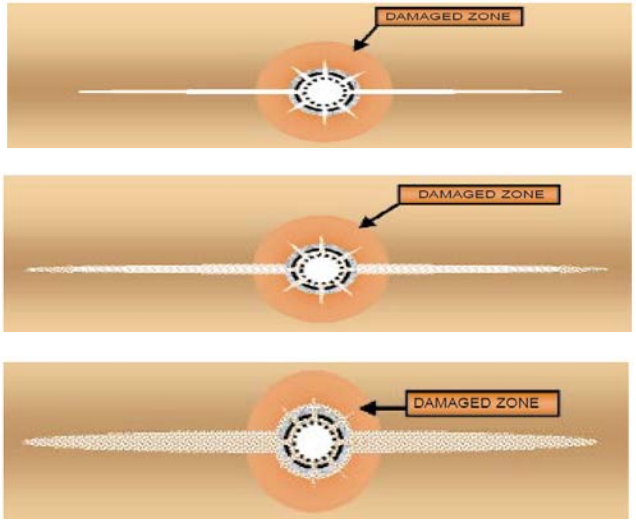


Figure 1: Major stages of a TSO. Pad pumped without proppant extends initial fracture past near-wellbore damage (Top). Proppant screens out at tip of fracture, arresting fracture extension (Middle). Continued pumping with high concentrations of proppant extends fracture width and increases proppant loading. Perforation tunnels, screen/casing annulus, and near wellbore are tightly packed with proppant (SPE 39232).

Objectives:

- Simulation of hydraulic fracturing in high permeability formations using grain based numerical modelling.
- Sensitivity analysis of parameters affecting the onset of the TSO and identify the most important ones in generation of the largest aperture width.
- Use the pumping schedule applied in real field applications (an example is given in Figure 2) to simulate the TSO and compare the predicted fracture geometry and anticipated pressure data with field observations.
- Extend the findings of this study to establish the best practice to create an optimum fracture near wellbore to bypass the formation damage zone to enhance productivity.
- Compare the results of numerical simulations with analytical solutions where possible.

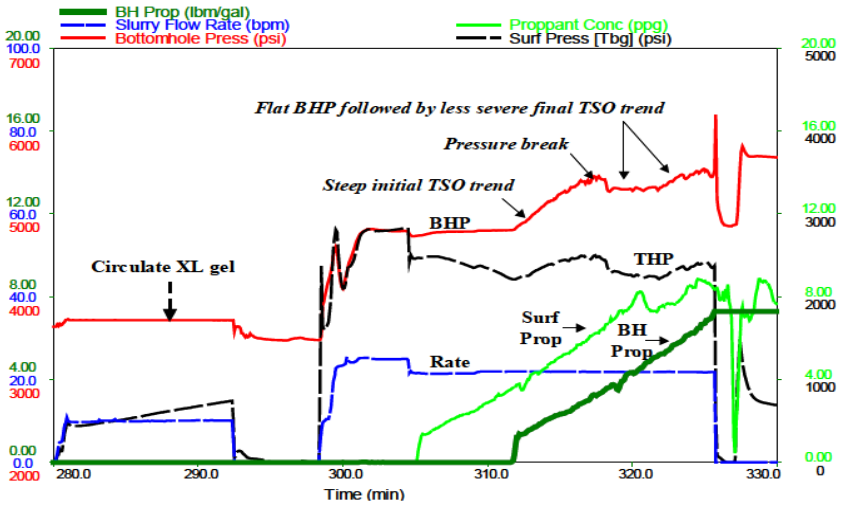


Figure 2: Wellbore C5 Frac-pack job, SPE 95514

Methodology:

- Use existing analytical and other models developed to design the pumping schedule corresponding to TSO and fracturing high permeability formations.
- Use XSite, a grain based simulator developed by the Itasca Consulting Group, to simulate hydraulic fracturing in high permeability formations. Figure 3 shows an output example of the XSite).
- Comparing the numerical simulation results versus analytical solutions.
- Simulate one real field case data to compare the results with field observations.

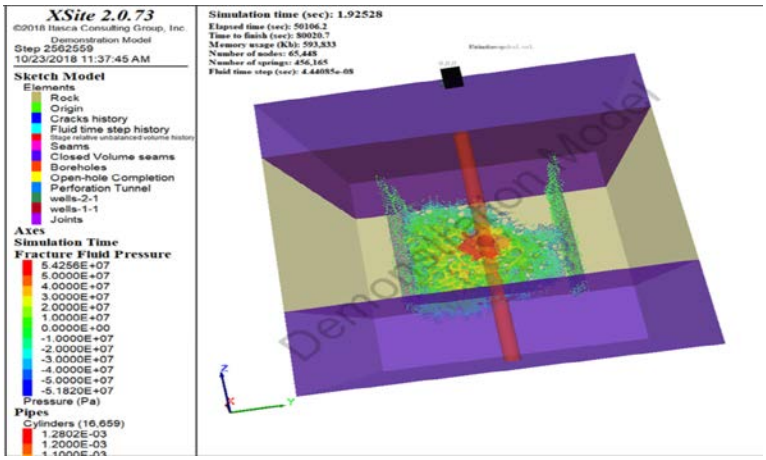
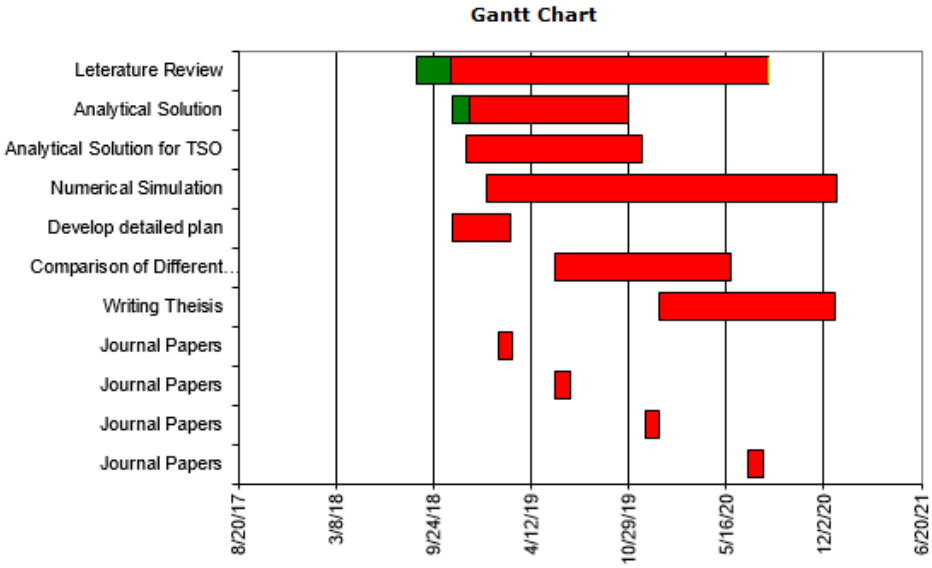


Figure 3: Fracture aperture simulation im Middle Bakken using the XSite

Significance:

- This study presents one of the first applications of the XSite software for applications of hydraulic fracturing in high permeability formation and TSO design.
- Combination of numerical simulations with analytical solutions is an integrated approach to investigate this problem and this carries a novelty in this work.
- Applications of the proposed study is not limited to the TSO design, but can be extended to fracture design in high permeability sand formations for different purposes. An example of this application in North Dakota is to design the optimum induced fracture in Dakota Sand which may assist in higher water storage capacity, as this formation is used to store the produced water during oil production from Bakken.

Project Milestone and Timing:



Progress to date:

- Literature review is being carried out on different hydraulic fracturing modelling.
- Started learning XSite software to generate simple models.
- Tried to learn HF2D06 Excel Based Macro for pumping schedule in hydraulic fracturing.
- Technical exchange with Itasca Consulting Group engineers who are providing assistant in this study for simulation purposes.

3D Deterministic Models for Fracture Detection and Prediction in Unconventional Reservoirs for Finding Sweet Spot

Sofiane Djezzar
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

The Cambro-Ordovician in the Algerian Saharan platform is characterized by tight sandstone formations with very low petrophysical characteristics whither the natural fractures play an important role in their productivity. The Mouydir basin is the less explored basin in Algeria where no 3D seismic data is available and only few wells and old seismic 2D survey exist to characterize these reservoirs. This basin is close to Ahnet basin, which is considered as the main important gas province in the western part of the Saharan plate-form. Both basins have the same petroleum system where the Cambro-Ordovician in Ahnet basin produces tremendous quantity of gas trapped in natural fractures. However, the few wells drilled in the Mouydir basin did not show any sign of gas. Because of the lack of data, the study of the Cambro-Ordovician analog becomes necessary to analyze the natural fractures that affect this basin to guide the exploration and the drilling of prospective wells. The study of the Cambro-Ordovician analog helps to understand the fracture distribution, connectivity, and the fractures kinematics in order to predict their length and frequency in subsurface. The Cambro-Ordovician formations are characterized by stiff tectonic style, showing a dense net of faults and folds which affected the Paleozoic. The outcomes are the determination of fault sets, length distributions, correlation coefficients, power law coefficients, and fractal dimensions. The 3D deterministic fault model is built to illustrate the fractures distribution in space, determine their origin, their relationship, their kinematics, and illustrates the impact of the basement's faults on the sedimentary cover.

Objectives:

- Fracture characterization and modeling using outcrops data (satellite images, geological maps, digital elevation model).
- Characterization and modeling using subsurface data (seismic 2D, core, gravity and magnetism data).
- The merge between the surface and subsurface models to understand the spatial and temporal distribution of fractures.
- Analysis of the relation between fractures and petrophysical parameters (porosity, permeability).
- Understand the reason for wells with no productivity in the basin.
- Analysis of borehole imagery in Ahnet basin to determine typology of fractures and maximum horizontal stress.
- Analysis of 2D/3D seismic data to analysis the major faults in the Ahnet-Mouydir basins' boundaries.
- Determine the orientation of prospective new wells in the area of study based on the fracture distribution and the maximum horizontal stress.

Methodology:

- A new workflow for reservoir fracture characterization and modeling using surface analog.
- Analysis of geological maps, satellite images and digital elevation model on Global Mapper software.
- Introduction of seismic attributes (curvatures and illumination) of fault recognition applied on digital elevation model.
- Digitalization of faults and joint at different scales.
- Faults sets and length distribution analysis.
- Fracture connectivity and fractures kinematics analysis.
- Size scaling and spatial clustering of natural fracture networks using fractal analysis by determining the power law distribution and some statistical parameters.
- Analysis of gravity data and aeromagnetic data.
- Analysis of 2D/3D seismic data.
- Analysis of porosity vs permeability core data.
- Analysis of borehole imagery data by determining typology of fractures and maximum horizontal stress.
- Analysis of core data by quantifying the length and aperture of fractures.
- 3D modelling and natural fractures characterization by merging 3D surface and subsurface fracture models.

Significance:

- The proposed workflow is an innovative and integrated approach merging surface and subsurface data.
- The reservoir analog is localized in the south edge of the basin, which gives information that is more significant that can be applied on the reservoir in the subsurface.
- Application of different seismic attributes such as curvatures on the digital elevation model to enhance and recognize fractures.

Progress to date:

- Data collection
- Fracture and length analysis
- Fractal analysis
- 3D deterministic fault models

Project Milestone and Timing:

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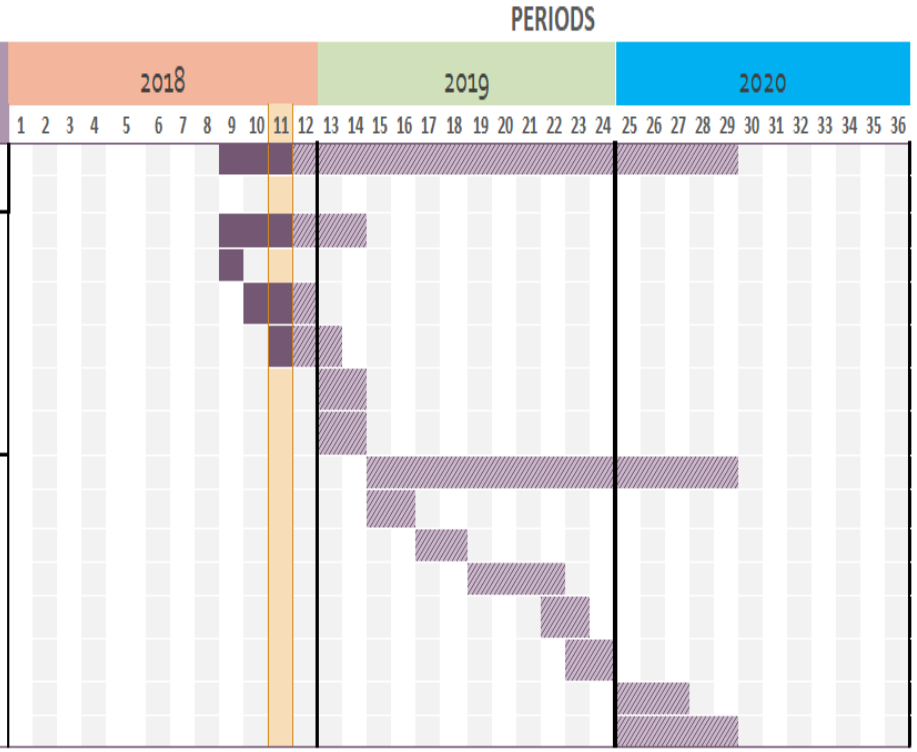
Period Highl 11 | Plan Duration | Actual Start | % Complete

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Research plan	9	21	9	21	15%
Phasel : Outcrops Characterization	9	6	9	6	50%
- Data Collection	9	1	9	1	100%
- Fracture & Length Analysis	10	3	10	3	75%
- Fractal Analysis	11	3	11	3	30%
- 3D Deterministic Models	13	2	13	2	0%
- 3D stochastic Models	13	2	13	2	0%
Phase II : Sub-Surface Characterization	15	15	15	15	0%
- Gravity Analysis	15	2	15	2	0%
- Aeromagnetic Analysis	17	2	17	2	0%
- Seismic 2D/3D Analysis	19	4	19	4	0%
- Borehoe Analysis	22	2	22	2	0%
- Core Analysis	23	2	23	2	0%
- DFN & 3D Modeling	25	3	25	3	0%
- Thesis proofilment	25	5	25	5	0%



Lab Experiments Using a Two-phase Flow Loop Unit and Numerical Simulations

Yanbo, Wang
Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

In the oil industry, after the wellbore is drilled into a reservoir, oil and gas will flow into the bore hole and can be transported to the earth's surface through tubing. Two-phase flow will take place in the pipe and two-phase flow will also causes the pressure fluctuation, which will influence the whole processing system. In this process, there are several factors will affect production rate such as flow regime changing, pressure-drop, and liquid loading.

The wellbore is deep enough to generate all kinds of flow regime. Firstly, the study of flow regime changing in this project could help us predict the pressure-drop, and better control the production rate. Secondly, it is normal to shut-in or restart a well when we want to test the well or service the well. These procedures easily caused the pressure oscillation and affect the operation. In this proposal, a two-phase flow loop unit that recently built in the Department of Petroleum Engineering at UND will be used to simulate shut-in well pressure-drop and could also clearly see the flow pattern changing through transparent PVC pipes. At last, the liquid loading problem in gassy well will also be studied, with changing the diameter of tube and the liquid/gas inlet flow rate to find out the critical velocity then compared results with the exist prediction models like Turner model, Coleman model and Li model to develop more accurate models.

In all these studies, commercial software ANSYS-FLUENT will be used for numerical simulation and the results will be compared with experiment results.

Objectives:

- Study the change of flow regime in vertical upwards pipe and horizontal pipe.
- Investigate the impacts of tube diameter and liquid/gas fluid flow rate on fluid flow pattern.
- Evaluate the impacts of tube diameter and liquid/gas fluid flow rate on pressure-drop.

- Simulate how the flow pattern and the pressure drop change inside the tube after shut-in or reopen.
- Find liquid loading critical velocity in the tube with different tube size and fluid flow rate.
- Use existing analytical models to optimize the parameters.
- Run numerical simulations using ANSYS-FLUENT to simulate lab scale experiments and calibrate the simulator.
- Compared the lab results with numerical simulation result
- Develop new models to predict liquid loading.

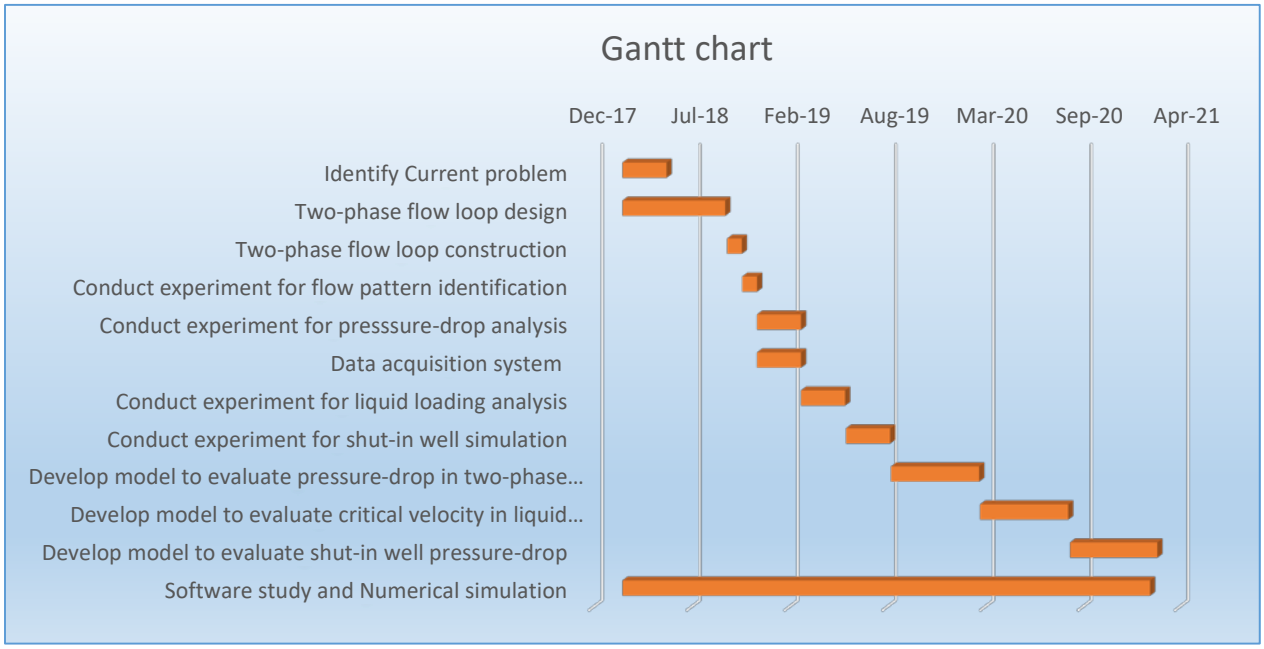
Methodology:

- Controlled-variate method will be use in this experiment
- ANSYS-FLUENT numerical simulations will be conducted to simulate lab scale experiments and calibrate the results.
- The results of lab experiments and numerical simulations will be checked to see whether they match.

Significance:

- There have been some lab experiments carried out to study two-phase flow, the new flow loop built has some advanced features such as simulate shut-in well in the industry and have larger fluid flow range.
- Only few numerical simulations have been reported for time-step simulation using ANSYS-FLUENT.
- Compare exist models with lab experiment results and numerical simulation results, and develop more accurate models, this helps us to get more reasonable conclusions.

Project Milestone and Timing:



Progress to date:

- The two-phase flow loop is already set up in the lab commissioned and I am setting up data acquisition system.
- Literature review is being carried out on liquid loading and shut-in well.
- Continue learning Ansys-fluent software and try to generate simple models to simulate experiment.

Cuttings Transportation Optimization: Lab Experiments Using a Large Scale Slurry Loop Unit and Numerical Simulations

Foued, Badrouchi

Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

Complex well trajectories are widely used in the development of oilfields and especially for unconventional reservoirs with long horizontal sections. Effective cuttings transportation or better hole cleaning during drilling operations can increase the rate of penetration (ROP), and mitigate various drilling associated problems such as high drag and torque and pipe sticking.

Analytical solutions, lab experiments, numerical simulations and field studies are different approaches that may be used to study cuttings transportation. There are advantages and limitations with regards to each of these methods. However, a combination of different methods allows cross validation of the results. In this proposal, a large scale slurry loop unit that recently has been built in the Department of Petroleum Engineering at UND will be used to study different parameters affecting cuttings transportation. Grain based numerical simulations will also be conducted to do sensitivity analysis.

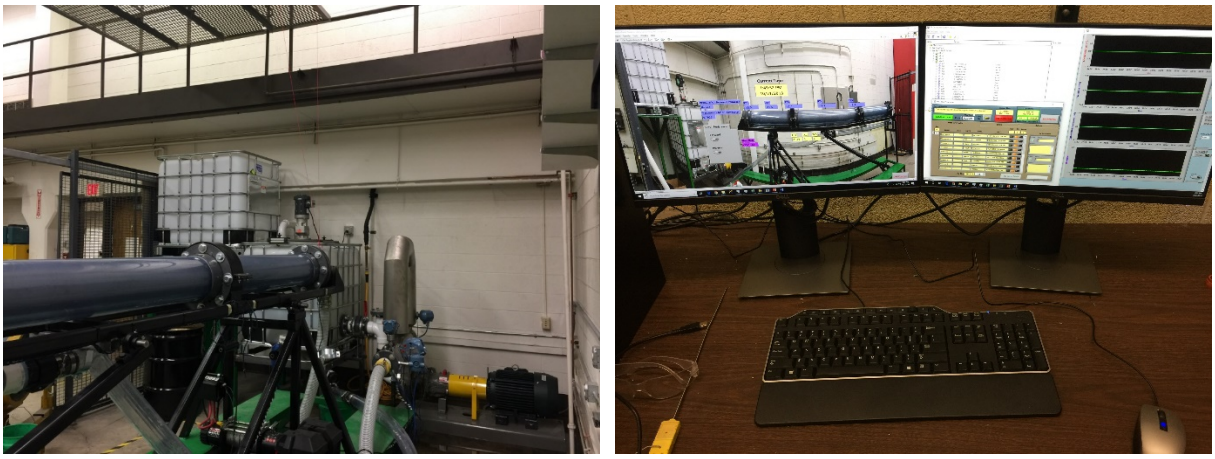


Figure1: Slurry Loop Unit with data acquisition system (Project Leader: Foued Badrouchi)

Objectives:

- Study the change of wellbore deviation on hole cleaning efficiency.
- Impact of fluid rheology (density, viscosity) on effective cuttings transportation.
- The impact of cuttings geometry, density, roundness and sphericity on hole cleaning efficiency.
- How the existence of hardware inside the wellbore, such as stabilizers, will affect the effectiveness of hole cleaning and how the impact can be minimized.
- Monitor and record various data during the lab experiments, including pressure drops, flow rate, temperature and solid concentration.
- Use existing analytical models to optimize the parameters affecting cuttings transportation.
- Run grain based numerical simulations using particle flow code (PFC) to simulate lab scale experiments and calibrate the simulator.
- Upscale the lab results to field scale through numerical simulations.

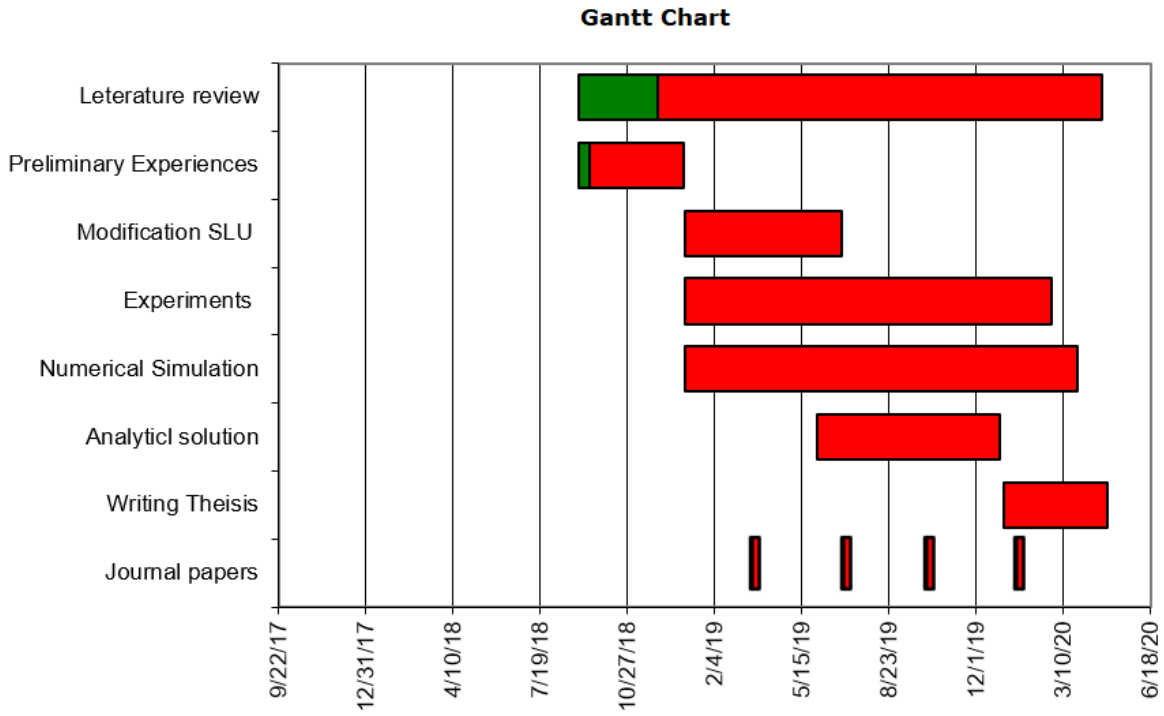
Methodology:

- The slurry loop will be extensively used in the lab for the purpose of this study.
- PFC 3D numerical simulations will be conducted to simulate lab scale experiments and calibrate the results.
- Upscaling models will be used to extend the lab test results to field scale.
- The results of lab experiments and numerical simulations will be checked against existing simple analytical solutions for comparison purposes.

Significance:

- While lab experiments have been carried out to study cuttings transportations, the new slurry loop built has some advanced features which allows us to run some specific simulations such as studying the effect of stabilizers on hole cleaning.
- Only few numerical simulations have been reported for cuttings transportation using PFC or similar grain based software.
- With the interest of local industry in North Dakota, it is expected that we will be receiving field data to calibrate and compare the results with lab experiments.
- Combination of lab experiments, numerical simulations and comparison with analytical solutions is an integrated approach to investigate this problem and this carries a novelty in this work.

Project Milestone and Timing:



Progress to date:

- The slurry loop is fully commissioned during the past few months and is ready for simulations.
- Literature review is being carried out on different cuttings transportation modelling.
- Started learning PFC software and how to generate simple models.
- Communicated with Halliburton drilling team who indicated great interest in collaborating in this project and provide support to this study.

Automated Directional Drilling: Lab Experiments and Numerical Simulation

Ahmed Ismail

Ph.D. student, Department of Petroleum Engineering, UND

Problem Statement:

Directional drilling can be the only feasible option available for many applications such as unconventional reservoirs and offshore drilling from a platform. Complex well trajectories and the number of hyper parameters in drilling unconventional reservoirs make directional drilling a big challenge. Automation of the drilling process with such a challenge is a very complex process. The complexity of the process is from design and operational perspectives. Optimization of the drilling process through the hyper parameters affects cost, energy and time. Finding the appropriate techniques and technologies to optimize this complex process is quite challengeable. The Petroleum Engineering Department at UND is working on building an automated lab scale drilling rig (see Fig. 1, the initial set up) that is capable of drilling directional wells. This lab scaled rig is the first step of the study, where upscaling the automated directional drilling process is planned to simulate the field scale operations. This type of lab work would help examining to see the effect of different parameters on drilling performance through sensitivity analysis. The lab set up would allow us to simulate the drilling operation and compare the results to the available analytical solutions and calibrate the numerical models before we use them for large scale simulations. The observational ability of the rock sample pre- and post- drilling in the lab allows a great opportunity to inspect the sample and assess the drilling performance based on the design. The large volume of the data generated from many lab experiments can be used to develop a Machine Learning Algorithm which can be used for efficient and optimized automated drilling operation.

Figure 1: Lab-scale Automated drill Rig tested drilling a vertical Hole

Objectives:

- Establishing an automated drilling rig that is capable of controlled directional drilling;
- Studying the effect of Changing the drilling parameters (weigh on bit, torque and drag, rate of penetration, mud density and rheology, drilling fluid flow rate, and others) on the directional drilling performance and efficiency;
- Studying the effect of changing the directional drilling parameters on maintaining the hole quality;
- Studying the effect of the lithology on building and holding the angle;
- Visualizing the effect of changing various directional drilling parameters by examining the rock sample;
- Optimizing the bit selection;
- Optimizing the directional drilling process based on mechanical specific energy (MSE), rate of penetration (ROP) and costs;
- Selecting the most fit-for-purpose directional drilling technique;
- Analyzing the results to ensure a quality automated system;
- Upscaling the results to field scale.

Methodology:

- The lab work will be conducted using the lab-scaled rig being built;
- Analytical models and numerical simulation will be used to simulate the lab experiments and calibrate the results;
- Comparison of the lab results against the analytical models available will be conducted;
- Upscaling the lab results to field scale will be performed.

Significance:

- To the best of our knowledge, this is one of the first type of lab scale directional drilling attempts which will provide a great platform to investigate different parameters affecting the directional drilling performance;
- All wells in North Dakota and other unconventional reservoirs nowadays are drilled horizontally making the outcome of proposed study of a wide application in oil field industry. The lab set up put together as a result of this study can be used by the industry in

ND to investigate various type of practical issues that they are facing in real field conditions and find potential solutions;

- The study may result in a novel directional drilling technique or improving the existing technologies;
- The optimization process can result in saving millions of dollars/ year.

Project Milestone and Timing:

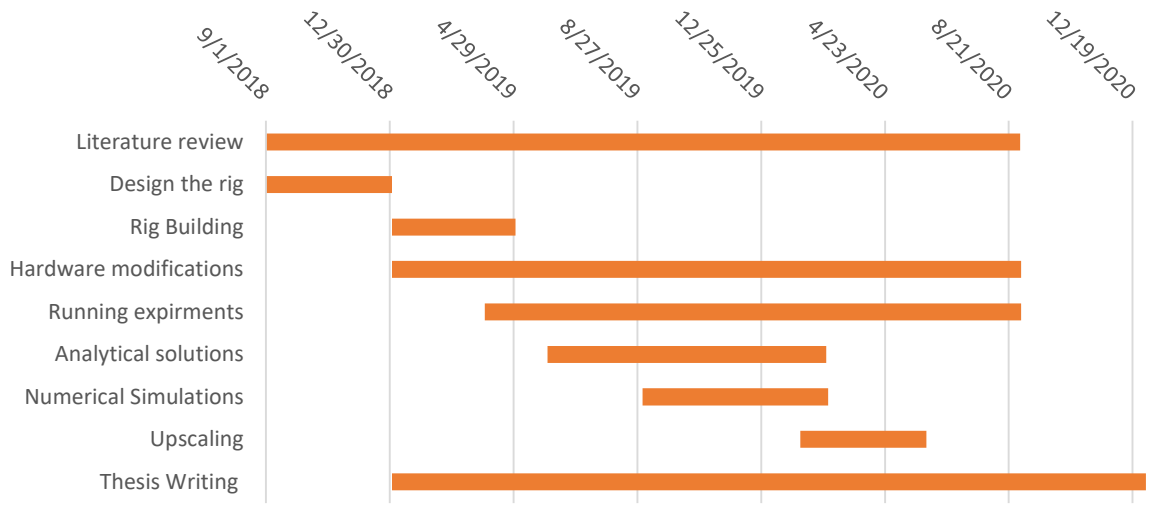


Figure 2: Project Gantt Chart

Progress up to date:

- The drilling rig developed to date can drill vertical holes;
- Literature related to the topic of research is being reviewed;
- Rig design is being modified for directional drilling;
- Some preliminary ideas for directional drilling are being tested in the lab.

Crack Geometry Prediction in Replicated Rock Samples During Triaxial Testing Using Velocity Data

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Problem Statement:

Failure mechanism of fractured rocks is very complex and sometimes is the result of mixed failure modes. Part of this complexity is due to heterogeneity and anisotropy of the real rocks. So, to understand the failure mechanism, studies have been done on samples having a single crack, and the evolvement of crack geometry under different loading conditions have been monitored indirectly using compressional and shear waves velocities measured during lab experiments. In recent years, experimental testing using a 3D-printed replica of a real rock sample has shown to have promising applications in rock engineering. Using 3D printed technique, the location of the crack and mechanical properties of the sample is accurately controlled and known. It removes the uncertainties associated with rock inhomogeneity when interpreting the crack geometry evolution and failure mechanism.

In this study, triaxial laboratory experiments will be conducted using Autolab1500 apparatus on several 3D-printed samples with elastic and strength properties similar to sandstone type rocks. P- and S- velocity data, recorded in each experiment, will be extracted and imported into Insite software to visualize the crack and to study the evolution of crack geometry. Numerical simulation is also performed using PFC software, based on the bonded-particle method (BPM), which is often used in the rock engineering field and validated by many works in the literature to study the mechanism of failure.

Figure 1. AutoLab 1500

Resin-based 3DP rock

DOI : 10.1016/j.ijrmms.2018.04.022

Objectives:

- Explore the use of 3D printed sample for studying the mechanical properties and failure mechanism.
- Simulate the rupture mechanisms under different reservoir conditions using PFC, based on BPM algorithm.
- Simulate the Acoustic Emissions (AE) using Insite software, which is based on source location mechanism.
- Validation of the numerical results with experimental results.
- Develop quantitative and qualitative methods to predict the fracture geometry due to failure of the sample.

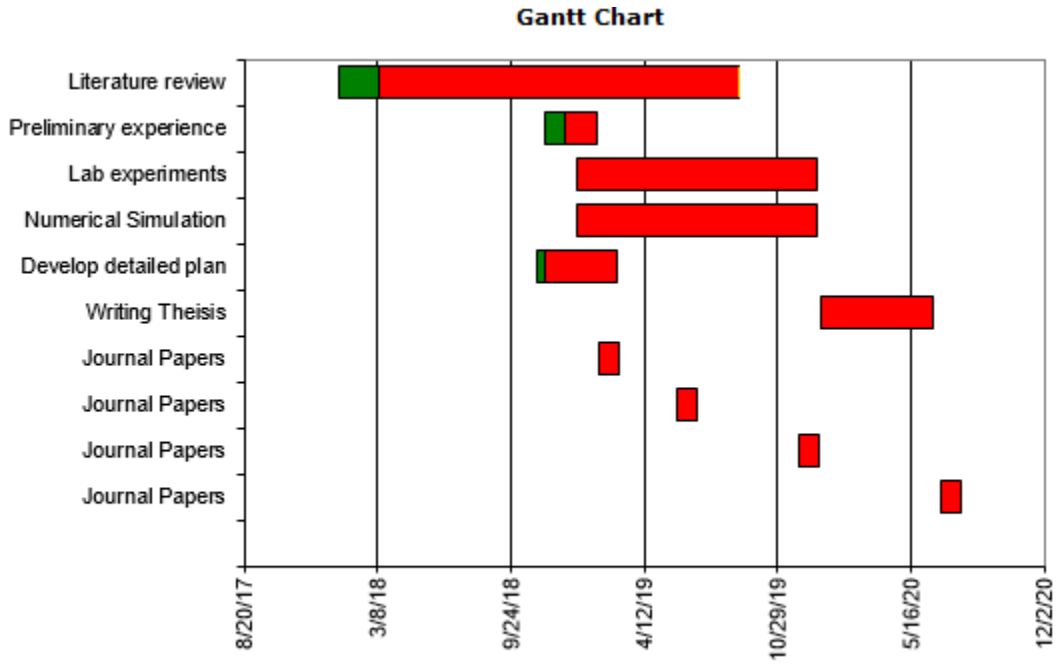
Methodology:

- Create 3D Printed (3DP) powder-based and resin-based samples, of size 1-inch diameter and 2-inch length and with an internal macro-crack oriented at 60 degrees.
- Conduct lab testing experiments on the 3DP sample using AutoLab1500 apparatus to measure the mechanical properties (Young's Modulus, Compressive strength, Poisson's ratio, etc.) and record the P- and S-waves velocities under different loading and reservoir conditions (confining pressures, fluid injection, depletion, the presence of fractures).
- Analyze the fracture failure mechanism observed in the 3DP sample (establish the stress-strain curves and analyze the failure modes and patterns).
- Perform two numerical modelings, the first a simulation model using PFC software, and second, using Insite.
- Analyze the numerical modeling of the fracture failure behavior and compare the result with the experimental work.

Significance:

- Investigate the different factors that affect crack geometry and rock failure.
- Identify a new approach that will improve the understanding of fracture propagation in complex reservoirs and inform about more efficient oil and gas extraction techniques.

Project Milestone and Timing:



Progress to date:

- A literature review is being carried out on 3D printing techniques and fracture growth and geometry.
- The collaboration with ITASCA team expert is made for support, advice, and discussion of issues on numerical modeling and software capabilities.
- Learned How to use the Autolab1500 apparatus for my experimental test.
- Investigated the 3D printed material and technology necessary for studying fracture failure mechanism.
- Execution of hydraulic fracturing simulation using Xsite software.
- Learning Insite software and PFC to use for this project.