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Resubmitted
~~May 28, 2021~~ 12/5/2021

Karlene Fine, Executive Director
North Dakota Industrial Commission
State Capitol – 14th Floor
600 East Boulevard Avenue
Bismarck, ND 58505-0840

Subject: "Development of Formulations for the Removal of Scale from Oil and Gas Wells in the Williston Basin," Proposal to the Oil and Gas Research Program by Dr. Ali Alshami, Principal Investigator

Dear Ms. Fine:

On behalf of the University of North Dakota, I am pleased to submit Dr. Ali Alshami's proposal on "Development of Formulations for the Removal of Scale from Oil and Gas Wells in the Williston Basin" for consideration by the Oil and Gas Research Program. Dr. Alshami is an Associate Professor in UND's Department of Chemical Engineering and is the Principal Investigator for this project. Dr. Alshami is proposing a three-year project with a total requested amount of ~~$699,627~~ $451,427. Dr. Alshami has put together a strong team to ensure his project's success. He has also made substantial arrangements for the cost-share requirements to be met as outlined in detail in his proposal; in fact the requested amount from your agency is only ~~40%~~ 39.18% of the project total of ~~$1,750,560~~ $1,603,163.

Please contact Dr. Alshami with any technical questions about the project at (701) 777-6838 or ali.alshami@und.edu.

The $100 application contribution is currently being processed as an electronic payment by UND and should reach your office in a timely manner.

Thank you for your consideration of this proposal.

Sincerely yours,

Karen Katrinak

Karen Katrinak, Ph.D.
Proposal Development Officer
Research and Sponsored Program Development

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May 27, 2021

Karlene Fine, Executive Director
North Dakota Industrial Commission
State Capitol – 14th Floor
600 East Boulevard Avenue
Bismarck, ND 58505-0840

Subject: Tax liability pertaining to UND's proposal, "Development of Formulations for the Removal of Scale from Oil and Gas Wells"

Dear Ms. Fine:

I am writing to you regarding the Tax Liability Statement which is a requirement for the University of North Dakota's proposal to the NDIC Oil and Gas Research Program. Dr. Ali Alshami is the UND Principal Investigator for this proposal entitled "Development of Formulations for the Removal of Scale from Oil and Gas Wells." As an Authorized Official of the University of North Dakota, I affirm that the University of North Dakota is a State entity and has no tax liability.

Please feel free to contact me at (701) 777-2505 or Karen.katrinak@und.edu with any questions.

Thank you for the opportunity to propose this project to the Oil and Gas Research Program.

Sincerely yours,

Karen Katrinak

Karen Katrinak, Ph.D.
Proposal Development Officer
Research and Sponsored Program Development

Oil and Gas Research Program

North Dakota
Industrial Commission

Application

Project Title: Development of Formulations for the Removal of Scale from Oil and Gas Wells in the Williston Basin

Applicant: Ali Alshami

Principal Investigator: Ali Alshami

Date of Application: 1 June 2021

Amount of Request: $451,427

Total Amount of Proposed Project: $1,603,163

Duration of Project: 2 years

Point of Contact (POC): Ali Alshami

POC Telephone: 701-777-6838

POC E-Mail Address: ali.alshami@und.edu

POC Address: 241 Centennial Drive, Grand Forks, ND 58202.

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Statement of Status on Another Project Funding

ABSTRACT

Objective:

The overall objective of this project is to advance the development of a novel oilfield antiscalant formulations specifically tailored to the predominant scalants found in the Williston Basin formation. The PI has successfully developed and tested three new formulations that have shown superior scale inhibition results compared to currently available commercial formulations. The proposed development involves formulations, synthesized via polymer grafting as inhibitors and a combination of chelating and converting agents, that are precisely aimed at inhibiting and removing calcium carbonate, halite, and pyrite scale. The chelating agents will be designed to eliminate the generation of sulfide gas when the dissolving liquids react with iron sulfide; therefore, hydrogen sulfide scavengers and other additives, such as corrosion inhibitors, will not be required during scale removal. Small quantities of the formulations will be introduced into the field injection water once compatibility is confirmed. The structures of the proposed formulations and converting agents will be optimized and screened using computational and standard experimental techniques. The reaction kinetics of the proposed system's scale will be experimentally studied using the typical field conditions of pH, pressure, and temperature. Optimum scale removal and inhibition system performance will be assessed in a flow loop to simulate dynamic well conditions. The proposed system's economic and environmental impact will also be evaluated.

Expected Results:

The proposed project will result in novel formulations development to inhibit and remove calcium carbonate, halite, and pyrite scale. The project's outcomes will greatly enhance oil recovery, prolong reservoir life, reduce operation cost, and substantially minimize environmental complications caused by discharged formation water laden with significant amounts of salts and chemicals. The proposed inhibitors and chelates will possess the following features: 1) high inhibition efficiency at low dosages, 2) high water solubility and compatibility with brines, 3) inhibition of various scale types, and 4) environmental friendliness. A scale type and property database for the Bakken and Three Forks formations will be built

via characterization techniques. Potential environmentally friendly and cost-effective formulations that meet oilfield operation conditions will be identified experimentally. This research study will increase capacity building at the University of North Dakota through faculty member and student participation during the planned tasks.

Duration:

The duration of the proposed project will be two years (05/16/2022 to 05/15/2024).

Total Project Cost:

The total cost of the project is $1,603,590. The amount requested from NDIC is **$451,427** (**39.18%** of total project cost). A combination of cash and in-kind co-funding totaling at least $1,152,163 will be obtained from Creedence Energy Services, Hess Corporation, Continental Resources Corp., the University of North Dakota (UND), and the UND College of Engineering and Mines (CEM).

Participants:

A UND research team comprised of UND Associate Prof. Ali S. Alshami (lead-PI), Prof. Vamegh Rasouli, Asset. Prof. Minou Rabiei, and Ph.D. students from the Chemical and Petroleum Engineering Departments at the University of North Dakota will participate in the project. Industrial partners Creedence Energy Services, Hess Corporation, and Continental Resources will support the project by providing samples and laboratory and field-testing capabilities.

PROJECT DESCRIPTION

Objectives:

All equipment involved in hydraulic fracking and drilling within the Williston Basin Formations are prone to scale due to the large amounts of water used; hence, scale formation is one of the ongoing top production problems. The currently available commercial formulations are limited, inefficient, and largely ineffective. This project addresses these problems by developing cost-effective and highly efficient formulations based on novel polymer grafting and a combination of chelating and converting agents. We aim to synthesize, develop, and optimize new functionalized polymeric formulations that would result in efficiencies significantly higher than the currently available commercial products. ***Preliminary bench-top and pilot-scale investigations for our developed formulations indicate performance efficiencies greater than 95% compared to the maximum efficiencies of 40-60% for the most popular commercial antiscalant formulations (*****Appendix D*****)***.

Methodology:

The proposed study consists of four work packages (**WPs**) that will be executed as illustrated in **Figure 1**.

WP1 focuses on a thorough scale analysis and characterization of procured samples from various oil fields in the Williston Basin formation, scale samples from surface equipment, and flow-back and injection water samples. The initial phase of this work has already begun in collaboration with our industrial partners.

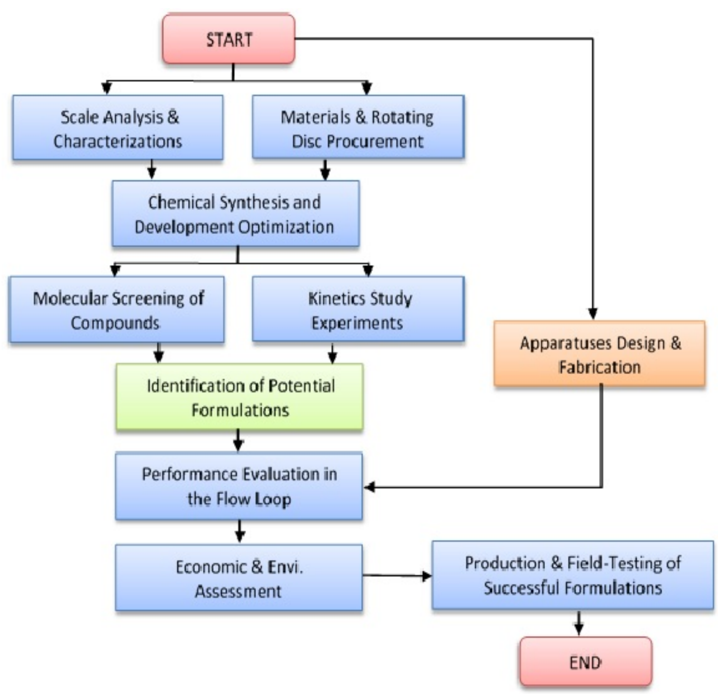

Figure 1. Flow diagram for the proposed work plan.

WP2 addresses the chemical synthesis, development, brine solution synthesis, and kinetic studies used to determine dissolution kinetics and identify the formulations and conditions that yield maximum inhibition and removal efficiency. The kinetics data on scale dissolution will be obtained using a rotating disc apparatus (RDA). The procurement of chemicals and the rotating disc apparatus will be completed by the lead PI and is not included in the work packages. **WP3** will focus on designing the flow loop and evaluating the performance of the potential formulations. Studies will be completed to determine the economic and environmental impacts of the new formulations. **WP4** involves molecular screening of the targeted scales to determine the optimal reactions conditions and study the adsorption abilities to identify the best dissolvers. Objectives of each task and deliverables timeline are outlined in this section and the detailed work description for all WPs is in **Appendix I.**

WP1: Samples Analysis and Characterization	**Duration: 4 months**

Scope and objectives of this work package

This work package focuses on understanding the nature and chemistry of scale types most common in the Bakken and Three Forks formations. Understanding the scientific basics will extend into the analysis and characterization of injection and flow-back waters. This knowledge will be used to create the appropriate brine solutions needed for testing and guide antiscalant chemical synthesis.

The specific objectives of this package are:

- Characterize scale and crystal morphology using FTIR, XRD, EDS, SEM, and TEM spectroscopy.
- Determine the mechanisms of scale formation and inhibition with morphological studies.
- Investigate produced and injected waters to draw parallels between studied scale and inferred formation mechanisms.
- Synthesize scaling and non-scaling brine solutions based on an analysis of field samples.
- Translate and integrate obtained analysis results into molecular screening tasks.

The work package is composed of three main tasks; the due dates are shown as month (M) and year (Yr.):

Task 1.1: *Procure various scale samples from the field. characterize and analyze using FTIR, XRD, EDS, SEM, and TEM, along with other potential techniques*.

Task 1.2: *Experimentally determine relationships between the analyzed scale and the composition of the injection and produced water*.

Task 1.3: *Use the results from the analyzed scale and water samples to prepare synthetic scaling and non-scaling brines*.

Deliverables	Title	Responsibility	Due Date
D0	Literature review.	All	M2, Yr1
D1.1	Complete analysis and characterization of procured scale from the Bakken and Three Forks formations.	UND/Creedence/ Hess/Continental	M4, Yr1
D1.2	Complete determination of the optimal synthetic brine composition for scale formation and inhibition studies.	UND/Creedence/ Hess/Continental	M5, Yr1
D1.3	Complete the analysis of field injection and produced water.	UND/Creedence/ Hess/Continental	M6, Yr1

WP2: Synthesis and Kinetic Studies	Duration: 8 months

Scope and objectives of this work package

The objective of this package is to generate the reaction kinetics data for the synthesized formulations under controlled conditions in a high-pressure, high-temperature, rotating disc apparatus that resembles the well-known stirred tank reactor. Reaction kinetics data will be used later in the design of the flow loop. The specific objectives of this package are:

- Study the reaction kinetics of various chelating agents with pyrite-iron sulfide scale in the rotating disc apparatus under constant temperature and pressure.
- Investigate the effects of compounds on the reaction kinetics of various formulations and chelating agents with the targeted scale.
- Identify the temperature and concentration of formulations and agents that yield the maximum inhibition and removal of the targeted scale.

This work package is composed of four tasks, with the due dates shown as month (M) and year (Yr.):

Task 2.1: *Synthesize polymer-based compounds and prepare brines. Produce at least three antiscalants and test in all prepared brines*.
Task 2.2: *Complete compatibility tests, analyze, and evaluate*.
Task 2.3: *Test the effects of four converters on the reaction rate of the chelating*

Deliverables	Title	Responsibility	Due Date
D2.1	Identify the dissolution kinetics data of scale in the presence of different antiscalants and chelating agents using K_2CO_3.	UND/Creedence	M10, Yr1
D2.2	Acquire kinetic data for scale dissolution using three converters.	UND/Creedence	M2, Yr2
D2.3	Develop the kinetic equations for scale dissolution for the different antiscalants, chelating agents, and converters.	UND	M4, Yr2

WP3: Flow loop design, performance evaluation of different formulations, and the economic and environmental impact of the proposed formulations	Duration: 12 months

Objectives of this work package

This package aims to design a new experimental setup to remove scale, such as calcium carbonate, halite, pyrite, and barite, from oil and gas wells. A new flow loop design will be introduced at laboratory scale, and we will develop novel formulations that can also be applied in the field.

The specific objectives of this package are:

- Build a flow loop for a scale removal apparatus for use in laboratory scale applications. Real scale samples from the field will be evaluated with different formulations at different temperatures.
- Use the flow loop to determine the amount of fluid flow scale removal due to friction by conducting static and dynamic tests.
- Determine the formulation's required volume and flow rate based on an ICP-OES analysis of the effluent samples.
- Perform an economic assessment of the proposed formulations.
- Perform an environmental assessment of the proposed formulations.

The work package comprises seven tasks:

Task 3.1: *Setting up the flow loop.*

Task 3.2: *Evaluating the scale removal efficiency of different formulations using the flow loop*.

Task 3.3: *Engineering design of iron sulfide removal using the flow loop.*

of downtime, repair, and other factors will be used for a given practical case. The cost of the chemicals used in the formulations, such as acid, anticorrosion agents, and H_2S scavengers, will be calculated.

Task 3.4: *Preliminary assessment of the environmental impact of different formulations will be performed.* The environmental risks associated with effluent disposal due to new formulation usage will be assessed.

Task 3.5. *Analyze the critical factors affecting the proposed solution's cost-effectiveness to guide ongoing research and development.*

Task 3.6 *Final Report*.

Deliverables	Title	Responsibility (institutes)	Due Date (end of)
D3.1	Design and fabrication of the flow loop setup.	UND	M6, Yr2
D3.2	Determination of the factors that influence the dissolution of scale in a flow system.	UND/Creedence	M8, Yr2
D3.3	Assessment of the different formulation's environmental impact.	Creedence/ Hess/Continental	M10, Yr 2
D3.4	Identification of the critical factors in research affecting the proposed solution's cost-effectiveness.	UND/Creedence/ Hess/Continental	M12, Yr2

WP4: Computational and Theoretical Studies	Duration: 24 months

Scope and objectives of this work package

The specific objectives of this package are:

- Perform molecular screening for selective reactions to determine optimal reactions conditions, such as molecular weight, reaction time, reaction temperature and others.
- Study the adsorption abilities of the inhibitors on calcite, halite, and pyrite.
- Identify the formulations that result in maximum scale dissolution.

This work package is composed of eight tasks, with the due dates shown as month (M) and year (Yr):

Task 4.1 *Determine the thermodynamic stability of cationic-anionic complexes involved using periodic density functional theory (DFT) calculations (VASP).*
Task 4.2 *Determine thermodynamic stability of the process water streams with respect to [Ca2+], [Na1+], pH, presence of other anions (or potential ligands), such as Cl-, OH-, CO32-, HCO3-, H2O, etc. by using cluster DFT calculations, including solvent (water) molecules explicitly or implicitly.*
Task 4.3 *Determine overall thermodynamics of the process water stream and the listed minerals. Input cluster DFT-data for periodic MD-model based on a Nano particle of the different minerals.*
Task 4.4 *Study the formation of S22- from possible S-sources (H2S, HS-, S2-, transition metal ions, surface transition metal ions etc.) as a function of process conditions.*
Task 4.7 *Based on the known performance of Fe(II) DPTA and Fe(HEDTA) complexes, new (biodegradable) N,O-ligands can be designed using cluster DFT.*
Task 4.8 *Input cluster DFT-data for periodic MD-model based on a nano particle of the different minerals and new pseudo-ligand/solvent potentials.*

Deliverable #	Title	Responsibility (institutes)	Due Date
D4.1	Identification of the conditions for thermodynamic stability of all Fe-S minerals	UND	M 6, Yr1
D4.2	Determination of the thermodynamic stability of the process water streams	UND	M 8, Yr1
D4.3	Determination of the overall thermodynamics of the process water streams	UND	M 10, Yr1
D4.4	Determination of the factors that influences the formation of S_2^{2-} from possible S-sources	UND	M 4, Yr2
D4.5	Molecular design of biodegradable ligands	UND	M 8 , Yr2
D4.6	Input cluster DFT-data for periodic MD-model based on a nano particle and new pseudo-ligand/solvent potentials.	UND	M 10, Yr2
D4.7	Final Report	UND/Creedence/ Hess/Continental	M12, Yr2

Anticipated Results:

The proposed project will result in the development of a new generation of antiscalant formulations for the most dominant scalants in the Williston Basin formations; namely, calcium carbonate, halite, barite, and pyrite. The project's outcomes will lead to higher oil recovery, prolonged reservoir life, reduced operation cost, and mitigated environmental complications caused by discharging formation water laden with significant amounts of salts and chemicals. A scale type and characteristics database for the Bakken and Three Forks formations will be built using XRD, XRF, and SEM techniques. Potential environmentally friendly and cost-effective formulations that meet oilfield operation conditions will be identified experimentally.

Facilities:

Characterization techniques, such as XRD, XRF, and SEM, are required to investigate the mineralogy of the scale samples. A rotating disk apparatus (RDA) will be used to study the reaction kinetics of different scale types with the proposed polymeric formulations at reservoir conditions. A flow loop setup will be constructed to simulate the performance of the formulations. This setup will be housed at the University of North Dakota and used for research and teaching once the project tasks are completed. A detailed description of the available facilities and instrument capabilities is provided in **Appendix F**.

Resources:

UND Post-Doctoral Researchers and Graduate Research Assistants (GRAs) will be hired to perform the lab experiments. The project aims to develop the student's research skills by training them on state-of-art lab setups, such as RDA, DSL, and flow loops.

Techniques to Be Used, Their Availability, and Capability:

Characterization techniques, such as X-Ray Diffraction (XRD), X-Ray fluorescence (XRF), and scanning electron microscopy (SEM), are available at the University of North Dakota. A rotating disk apparatus (RDA) and flow loop will be constructed during the project stages.

Environmental and Economic Impacts while Project is Underway:

The proposed chemicals are environmentally friendly and safe to use in both lab and field conditions. A complete environmental and economic assessment will be completed at the end of the project to highlight optimum field conditions for functionalized polymeric formulation and chelating agent usage.

Ultimate Technological and Economic Impacts:

Technological impact: the application of grafted polymers capable of inhibiting and dissolving different scale types is relatively new. Iron sulfide inhibitors are still in development. A revolutionary technology for the oil and gas industry will be created if the synthesized inhibitors succeed in real field conditions.

Economic impact: Severe scale formation events will occur in 22 of 150 wells in the Bakken formation. Each of these events has a direct scale removal cost of approximately $2.5 M per operator, from just one well [1][2]. These costs surge to approximately $9 billion across the US, in addition to the significant indirect operating costs. The improvement of scale inhibition and removal efficiency will increase oil recovery rates worth billions of US dollars. Mitigating scale by 10% for one operator will yield $ 5.5M in savings, in addition to savings from operation cost.

This project will ultimately lead to:

- New advanced oilfield scale removal and inhibition technologies based on functionalized polymeric formulations.
- Improvements to the scale control procedures and protocols currently employed by oil and gas service companies in North Dakota.
- Creation of new business opportunities for end product commercial production.
- Reducing environmental concerns related to the disposal of produced water since it will be reinjected safely in oil and gas wells.
- Supporting higher education and research at the University of North Dakota by providing training and mentorship to the next generation of involved students.

Why the Project is Needed:

Oilfield scaling is a critical problem in the Williston Basin formation due to high salinity brines, see **Appendix B** for detailed information. Supersaturation and evaporation causes sodium chloride to precipitate and form a hard solid mineral, *halite*, when the brines are produced in the reservoir [4-5]. A recent article by the Wall Street Journal reported that roughly 43% (6,401 out of 14,888) of the current wells in the Bakken are experiencing an exponential decline after approximately 7 years of production [6]. Over 2,363 wells are experiencing discontinuous production records, and the remaining 1,279 new wells, with less than 12 months of production, have reported sporadic production disruptions. Mechanical equipment failure due primarily to scale formation is one of the principal causes for the cited production decline and disruptions. This project, therefore, will raise awareness of this problem in the Williston Basin formation, and the proposed materials will reduce the non-productive time and maintenance costs by implementing new techniques to inhibit scale build-up in reservoirs, near-wellbore areas, and well equipment.

STANDARDS OF SUCCESS

A complete research plan with specific tasks and deliverables has been prepared according to the project timeline and based on the annual reports submitted to the OGRP. The annual reports will include the achievements of the work packages and financial expenditures. The project comprises tangible outcomes, such as the synthesis of the proposed functionalized polymeric formulations and the creation of the lab setups. Intellectual property, scientific peer-reviewed paper publications in well-known, high-quality journals, will be included in the annual reports with links for the final published manuscripts. The success of this project will lead to developing new daily practice methodologies for oil and gas service companies, which will sustain productivity and minimize non-productive time and associated maintenance costs.

All North Dakota public and private sectors can use the project's outcomes. The proposed laboratory facilities will be available for future research and teaching activities at the University of North Dakota. The proposed chemical systems are environmentally friendly; therefore, using them in daily field operations will reduce the environmental side effects of high salinity formation water disposal. The technology readiness level of the proposed formulations is <u>high</u> and can be scaled up to field level after the completion of the economic and environmental assessments. The outcomes of this project assist in sustaining oil and gas production in North Dakota, and will increase education and research assets in terms of facilities and human resources at the University of North Dakota. Service and operating companies will be able to meet their current and future labor expenses when the new technology is implemented. The University of North Dakota will be capable of hiring lab technicians and research assistants to teach and perform research because of the laboratory and modeling facility availability. Finally, this project aligns with and meets the objectives of the OGRP, which aims to "Encourage, and promote the use of new technologies and ideas that will have a positive economic and environmental impact on oil and gas exploration, development, and production in North Dakota." The final report will summarize the technical and capacity-building achievements during the project period.

BACKGROUND/QUALIFICATIONS

Dr. Ali Alshami is an Associate Professor of Chemical Engineering at the University of North Dakota. He earned his Ph.D. in Chemical Engineering at WSU in 2006. He spent over ten years in the private sector working on R&D engineering projects at global chemical manufacturing and processing corporations prior to his involvement in academia. His specializations include material interfacial phenomena, polymer science and separations, and biochemical product development. He is currently managing projects in collaboration with the City of Grand Forks and AE2S Corp., to study the scaling of the membranes and associated piping in the city's newly constructed regional RO water treatment plant. He has managed multiple multimillion-dollar projects during his industrial work experience and currently leads a multidisciplinary team of Researchers and Ph.D. and M.S students, along with laboratory research associates.

Dr. Vamegh Rasouli, with over 17 years of consulting work with Schlumberger globally, will bring a strong industry support to this project. His expertise in drilling fluid lab testing and analysis will be of core support to this project.

Dr. Minou Rabiei has strong analytical and intelligent computer modelling experiences with emphasize in MLA and Data Mining applications in the oil and gas industry. Her contribution to this project will be in the computational studies, data analysis and some of the lab work.

MANAGEMENT

The lead principal investigator (LPI) will hold weekly video calls with the hired project personnel. Face-to-face meetings will be scheduled to discuss the project's results and any unresolved issues. A summary of the regular meeting discussions will be prepared for necessary follow-up actions. A Post-Doctoral Researcher and graduate students will be hired at the University of North Dakota to work with Dr. Alshami during the synthesis and testing. The LPI will make all efforts to deliver a high-quality end-product from this research.

The steps and procedures listed below will be followed for Quality Assurance:

- Tasks distribution in this project is based on each key personnel's skills and experience.
- LPI will have a weekly meeting with key personnel via online media such as WebEx or ZOOM, as well as regular emails and phone contact. All key personnel will submit a final monthly report at least five days before the end of the month so the project leader can make sure that the deliverable quality complies with the sponsor's requirements. All data from key personnel will be collected and stored. The final meeting will be arranged during the project's final phase before a final report is submitted to the funding agency.
- The PI on this project will be the primary coordinator for arranging the research team's weekly online meetings.

TIMETABLE

Project Schedule. WP1 (yellow), WP 2 (Red), WP 3 (blue),WP 4 (Orange), Final Report (Purple)

	Year 1						Year 2					
Del.	1-2mo	3-4mo	5-6mo	7-8mo	9-10mo	11-12mo	1-2mo	3-4mo	5-6mo	7-8mo	9-10mo	11-12mo
D0												
D1.1												
D1.2												
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BUDGET

Year	Project Associated Expense	NDIC's Share	Applicants Share (Cash)	Applicants Share (In-Kind)	Other Projects sponsor's Share
Year 1	634,079	252,499	0	279,713	101,867
Year 2	518,084	198,928	0	217,290	101,867
Total	**$ 1,152,163**	**$ 451,427**	**$ -**	**$ 497,002**	**$ 203,733**

Per the above table, the project total cost is **$1,152,163**. The requested amount is **$451,427** (**39.2%** of the total cost). Industrial collaborators, Creedence Energy Services, will provide a total of **$215,600**, Hess Corp. will provide **$45,000**, and Continental Resources Corp. is contributing **$45,000** as matching funds in the form of in-kind contribution, and UND will provide a cost-share of **$478,641** in the form of equipment, salary, benefits, and student tuition for UND participants. See **Appendix G** for Letters of support and **Appendix H** for detailed budget and justifications.

CONFIDENTIAL INFORMATION

There is no confidential information to disclose.

PATENTS/RIGHTS TO TECHNICAL DATA

An IP disclosure for the already developed three formulations is in the process of being filed. Additional formulations are expected to be patentable. The applicants wish to reserve the right of application for any future US patents.

STATUS OF ONGOING PROJECTS (IF ANY): N/A

Appendix A: References

[1] N. Ismail, **A. S. Alshami**, and I. A. Hussein, "Synthesis and evaluation of a novel polyacrylamide functionalized nano-silica as a calcium carbonate inhibitor in upstream applications," *J. Pet. Sci. Eng.*, p. 109864, Nov. 2021, doi: 10.1016/J.PETROL.2021.109864.

[2] Nadhem A. Ismail, **Ali S. Alshami**., " Development of a Novel Iron Sulphide Scale Inhibitor for Oilfield Application", ACS energy&fuel , Nov. 2021. (Submitted)

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[4] **Ali. Alshami**, T. Taylor, N. Ismail, C. Buelke, and L. Schultz, "RO system scaling with focus on the concentrate line: Current challenges and potential solutions," *Desalination*, vol. 520, p. 115370, Dec. 2021, doi: 10.1016/J.DESAL.2021.115370.

[5] Bradley, Rebecca Elliott, and M. Matthews. "Fracking's Secret Problem-Oil Wells Aren't Producing as Much as Forecast." The Wall Street Journal 2 (2019). http://www.orender.net/wayback/frackings-secret-problem.pdf

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[7] M. CRABTREE, D. ESLINGER, P. FLETCHER, M. MILLER, A. JOHNSON, G. KING, Fighting scale : removal and prevention, Oilf. Rev. 11 (1999) 30–45.

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Appendix B: WPs Work Description

WP1 :Description of work

The lead PI, Dr. Alshami, will collaborate with the UND Petroleum Engineering Drilling and Completion Laboratory (DRACOLA) to procure scale samples from various drilling equipment. Scale samples and injection and produced water samples will also be gathered from the field through industrial collaborators ***Hess***, ***Continental Resources***, ***EOG***, ***Marathon***, ***WPX***, ***Hunt Oil***, and ***Balon Valves***. These obtained samples will be examined with Fourier transform infrared (FTIR), electron scanning microscopy (SEM), transmission electron microscopy (TEM), X-ray powder diffraction (XRD), and energy-dispersive X-ray spectroscopy (EDS). An adequate number of samples will be obtained and analyzed since scale formation differs from one well to another and varies according to the depth of each well. The results from these analyses will be used to infer scaling tendency, such as the saturation index (SI) of the investigated scalants in the synthetic brines.

Two primary types of synthetic brines, scaling and non-scaling, will be used in this study. Scaling brine consists of a solution with at least one pair of scaling ions present in amounts above their saturation concentration, which promotes the formation of scale crystals. Scaling brines are typically prepared for scale inhibitor selection projects via the Dynamic Scale Loop or scale bottle tests. Non-scaling brine is a non-saturated brine used for compatibility tests, where all pairs of scaling ions are present in amounts below their saturation concentrations. Reagent usage will depend on the anticipated and targeted scale types based on brine composition. Different scale tests will require suitable reagents since the targeted environment is a mix of two or more scale types.

Non-scaling brines will be used for compatibility tests throughout this work. Sodium chloride, potassium chloride, magnesium chloride hexahydrate, sodium bicarbonate, and sodium sulfate will be the salt reagents used since the primary targeted scale minerals are calcium carbonate and halite. The reagent amounts used will depend on the interrelated ion concentrations. Scaling brines will be used for the static bottle inhibition and dynamic scale loop tests. The reagents used will be the same as those used for compatibility tests, but in different amounts. Two scaling brines will be prepared for the inhibition tests. Cationic and anionic brine solutions will be prepared separately using the species and concentrations listed in **Appendix C**.

WP2: Description of work

The chemical synthesis will continue to be executed in Dr. Alshami's laboratories at the UND Chemical Engineering Department. Developed formulation testing will be conducted using two different brines: scaling and non-scaling. Scaling brines will be prepared for scale inhibitor selection since they promote the formation of the scale crystals. The non-scaling brine used for compatibility tests is a non-saturated solution where all pairs of scaling ions are present in amounts below their saturation concentrations. This was changes because its repetitive (The same sentences are written in W1)

Reaction rate measurements will be completed using a rotating disk apparatus, which will be purchased for this project and located at UND. The rotating disc is composed of two chambers: the reactor and the reservoir vessels. Nitrogen will be used to flush the two vessels, scale disks will be fixed in the holder within the reactor vessel, and heat-shrinkable Teflon tubing will be used. The fluid mixture of antiscalants and chelating agents will be poured into the reservoir vessel and heated to the desired temperature.

Compressed N_2 will be applied to pressurize the reservoir vessel so the fluid can be transferred to the reactor vessel. The rotational speed will be set to the desired value, and the time will be recorded. The starting time will be recorded when the valve between the reservoir and the reactor vessels is opened. Two mL-sized samples will be withdrawn regularly every 20 minutes to determine the concentration as a function of time. A Perkin-Elmer atomic absorption spectrometer and ICP, or other analytical techniques, will be used for analysis. The following parameters will be investigated:

- Effect of temperature on scale removal efficiency.
- Impact of different chelating agents on scale removal efficiency.
- Impact of different converting agents on scale removal efficiency.
- Effect of the dissolving time.
- Effect of stirring speed on scale removal efficiency.
- Effect of additive salts on scale removal efficiency.
- Performance comparison of various chelating and conversion agents.
- Comparison of different scale type dissolution.
- Reaction kinetics of inhibitors and chelating agents with targeted scale.

The rotating disc apparatus will be used to study the reaction kinetics of the target scale with various inhibitors and chelating agents. The concentration of the formulations used in this study will range from 0.2 to 0.8 M. The experiments will be conducted at different rotational speeds, from 100 to 1,500 rpms, and the reaction rates will be determined. The chemical agent's diffusion coefficient will be determined from the plot of the reaction rate versus rpms. This plot will be constructed using four points at different rpm values, 100, 500, 1,000, and 1,500, with the corresponding four points of the reaction rate. These experiments will be completed at a fixed temperature and constant pressure: the temperature will be fixed at 100 ^{o}C with a pressure of 500 psi. The procedure will be repeated at different temperatures to study the effects of temperature and the formulation of the chemical agents on the scale's dissolution rate. The temperature will vary from 25 to 100 ^{o}C at four intervals. The engineering design for the removal process will use the diffusion coefficients determined in this task. The reaction rate for the scale inhibitors and chelating agents will be determined by collecting samples every two minutes and analyzing them for key cations. The number of species present will be converted to the dissolved amount of scale. The reaction area, or the surface area of the scale, will be determined and the reaction rate will be established based on the sample collection time. The following chelating agents will be investigated, along with in-house synthesized antiscalants:

- Diethylene triamine pentaacetic acid (DTPA).
- Ethylenediaminetetraacetic acid (EDTA).
- Hydroxyethyenediaminetriacetic acid (HEDTA).
- Glutamic acid diacetic acid (GLDA).
- Methylglycindiacetic acid (MGDA).

The number of chelating agents will be reduced to four, focusing on calcium carbonate and halite, then barite and FeS.

WP3: Description of work

- *Setting up the flow loop*

Scale removal will be tested by pumping the treating fluid through coiled tubing to the production tubing. The production tubing will be divided into sections and separated by production packers. The fluid will contact the scale in the production tubing and will flow back to the top through the annulus between the production and coiled tubing. A filtration system, either single or multistage based on the number of suspended particles in the fluid, will then be used to remove the suspended scale from the fluid so the fluid can be reused. The same lab-scale flow loop design can be used in field applications. A schematic diagram of the proposed design is depicted in **Figure 2**.

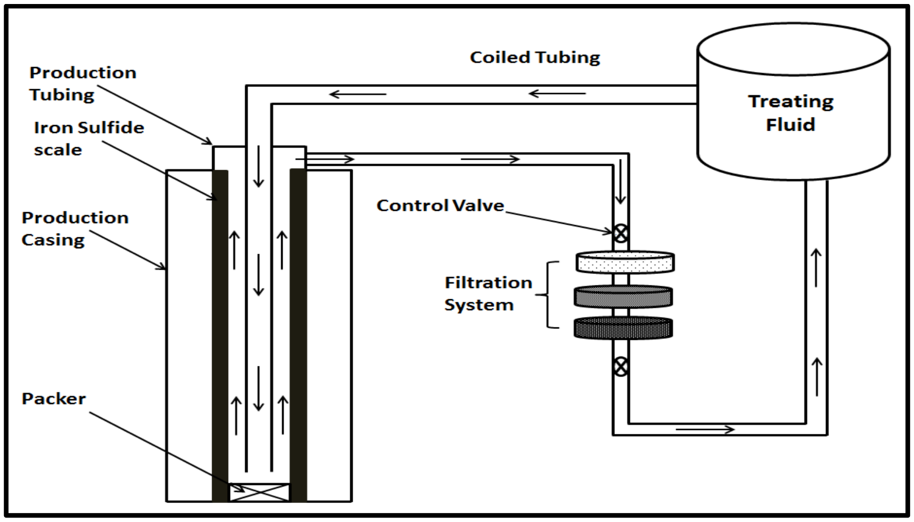

Figure I1. Schematic diagram of the proposed flow loop.

- *Evaluation of the flow loop's removal efficiency*

Different formulations will be evaluated in this package, along with static solubility tests. Dynamic solubility will also be determined using the flow loop.

- *Engineering design of calcium carbonate, halite, pyrite, and barite removal using the flow loop*

A complete design of the field scale process will be developed for different tubing sizes, casing sizes, and scale volumes. Graphical designs will be provided based on the volume of scale determined by the production logging survey. The ICP-OES will be used to evaluate the removal ability at different flow rates, which will be determined based on the maximum removal efficiency of the formulation.

WP4: Description of Work

DFT-QSAR and Eco-toxicity prediction

The quantitative-structure-activity-relationship (QSAR) of the chelating agents (HEDTA, MGDA, EDTA and DTPA) and the polymeric inhibitors would be studied using Density Functional Theory (DFT). . The electronic structure molecular properties such as Frontier-Molecular orbitals (HOMO and LUMO), Hardness, Ionization potential, (η) global hardness and (χ) electronegativity would be calculated using quantum chemical calculations with the aid of the Gaussian 09 program (Frisch et al., 2013; Hamad et al., 2020). Understanding these parameters would provide insight on the inhibitory activity of the molecules based on the structure. These potential inhibitors (chelating agents and polymers) would be modified

using different functional groups particularly electron withdrawing groups such as -CN, CONH2. These QSAR properties of these modified inhibitors would be compared to their parent compounds to see if the modifications improved their scale inhibitory and/or removal properties.
Toxicity is a vital aspect in the design of new chemicals. Hence, the ecological-toxicity (eco-tox) properties of the inhibitors would also be predicted focusing on their biodegradability, eye and skin irritation, and effect on aquatic organisms with the aid of the ADMETSAR program (Cheng et al., 2012; Onawole et al., 2021). This will enable the selection of not just an effective corrosion inhibitor but also an environmentally friendly one.

Surface Model and Plane-wave DFT calculations

The surface models for calcite, halide and pyrite scales will be modeled with a slab containing a minimum of 5 layers to represent the bulk. The model of these scales will be based on the most stable facets based on miller indices. That is for calcite, the 104 surface (Abdulmujeeb T Onawole et al., 2020); for pyrite, 100 surface (Guanzhou et al., 2004; Abdulmujeeb T. Onawole et al., 2020) and 100 for the halide surface (Bruno et al., 2008) as depicted in Fig X. The surfaces would be equilibrated and a vacuum region of 12 Å would be placed above the surface to be able to place the inhibitors. Before studying the inhibitor adsorption and the corrosion process, the surface is first equilibrated with the bottom two layers been fixed to represent the bulk while the top three layers will be left free to relax. This will enable the mode of adsorption of the selected inhibitors from the previous task on QSAR and toxicity to be studied vis-a vis physisorption or chemisorption.

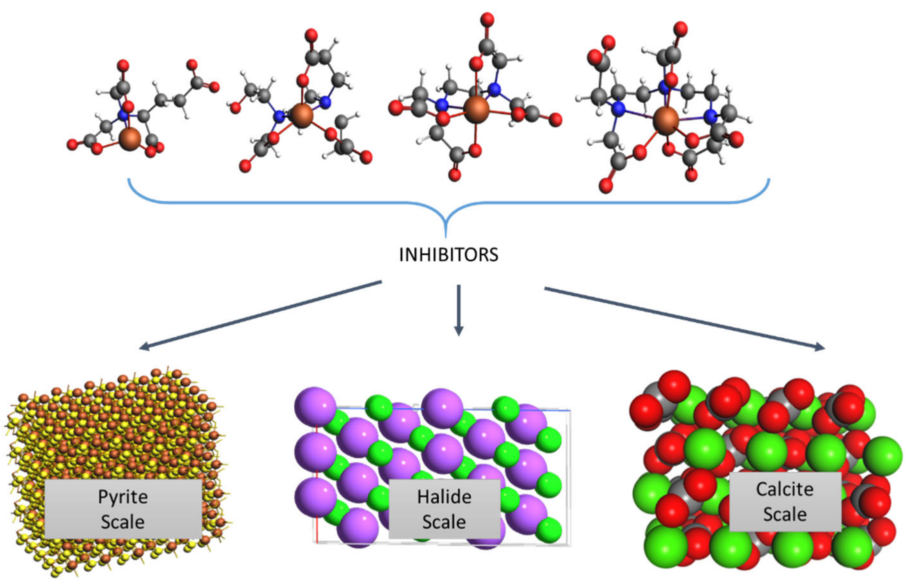

Figure I2: The structure of some chelating agents inhibitors above pyrite (100, halide (100) and calcite (104) surfaces.

The selected inhibitors would be placed on different positions on the slabs to find the optimum adsorption sites. This plane-wave density functional theory (DFT) calculations will be done with the exchange-correlation functional proposed by Perdew-Burke-Ernzerhof (Perdew et al., 1996). Periodic boundary condition (PBC) will be applied on all calculations. The projector augmented wave (PAW) method will be used to describe the core electrons of atoms, and the valence orbitals are represented with a plane wave basis set Electronic energies are calculated with the SCF tolerance of 10-4 eV using the Vienna ab initio simulation package (VASP) (Kresse and Furthmüller, 1996). The adsorption energies for all the listed inhibitors would be calculated using Equation (1). Subsequently, the inhibitors with strong adsorption energies will be identified. The inhibitor, which has a strong adsorption for all three scales, will be the most promising inhibitor. Adsorption of the inhibitors at various surface coverages will also be addressed to reveal the coverage effects on the corrosive phenomena. Charge density studies and Ab Inito Molecular Dynamics (AIMD) calculations would be carried out if the mode of adsorption were chemisorption to provide better insight to the mechanism of adsorption. Detailed analysis of the structural and electronic properties of the most promising inhibitor will be conducted to understanding the relationship between the adsorption strength and the structure of the inhibitors. This will provide a useful guiding principle for the design and development of novel inhibitors with superior anti-corrosion performance.

The most promising inhibitor(s) based on DFT-QSAR, Eco-toxicity, and Adsorption studies would then be synthesized and tested experimentally. This method shows the complimentary nature of molecular simulation in the design of new inhibitors particularly in saving cost. The flow chart (Fig. X2) denotes the work plan in this work package.

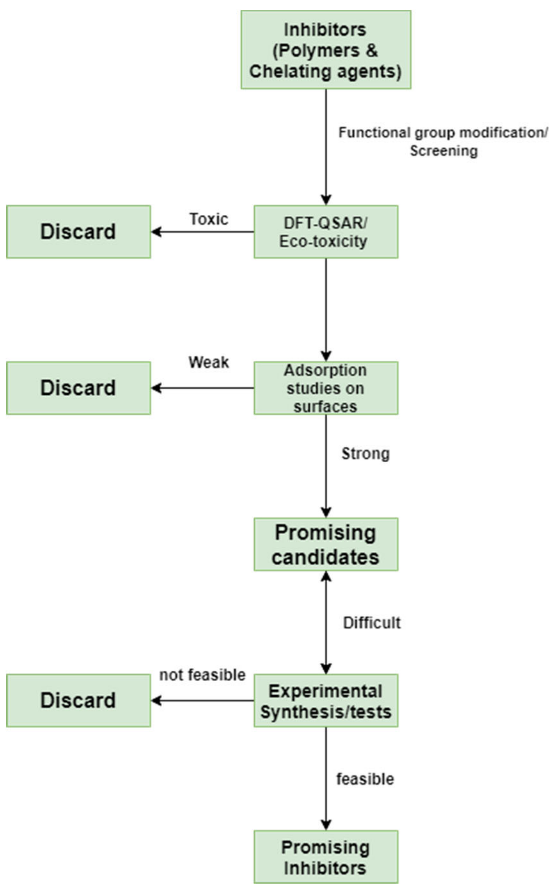

*Figure **I3**: The screening procedure for identifying superior inhibitors.*

Appendix C: RESULTS AND DELIVERABLES TIMETABLE

#	Results/Deliverable title	Responsibility	Type of deliverable	Delivery date
1	Literature review.	All	Report	M2 Y1
2	Scale analysis and characterization of the Bakken and Three Forks formation brines.	UND/Creedence/ Hess/Continental	Report	M4 Y1
3	Characterization of field injection and produced water.	UND/Creedence/ Hess/Continental	Report	M5 Y1
4	Brine formulation for scale formation and inhibition studies.	UND	Report	M6 Y1
5	Identification of the thermodynamic stability conditions for all minerals.	UND/ Creedence	Report	M10 Y1
6	Determination of the factors that influence scale formation and possible sources.	UND/ Creedence	Report	M12 Y1
7	Synthesis and optimization of functionalized polymeric formulations for scale removal and inhibition.	UND/ Creedence	Patent	M2 Y1
8	Solubility of the mixed scales in the functionalized polymeric formulations	UND/ Creedence	Report	M4 Y2
9	Investigation of the newly developed formulation's reaction kinetics and their ability to remove and inhibit scale build-up in the Williston Basin formation using an RDA setup.	UND	Report /Publication	M6 Y2
10	Identification of safe and environmentally friendly inhibitors based on eco-toxicological studies.	UND/Creedence/ Hess/Continental	Report	M6 Y2
11	Identify the structure-property relationship between the inhibitor molecules and the key corrosive processes.	UND	Report	M7 Y2
12	Design and fabrication of the flow loop setup.	UND/Creedence/ Hess/Continental	Experimental setup	M8 Y2
13	Determination of the factors that influence scale dissolution in a flow system.	UND/Creedence/ Hess/Continental	Report/publication	M9 Y2
14	Identification of the optimum conditions for scale removal in the flow loop.	UND/Creedence/ Hess/Continental	Report	M10 Y2
15	Cost determination for the commercialization of the new formulations.	UND/Creedence/ Hess/Continental	Report	M11 Y2
16	Assessment of the different formulation's environmental impact.	UND/Creedence/ Hess/Continental	Report	M10 Y2
17	Final Report.	All	Final Report	M12 Y2

Appendix D: Preliminary Work and Results [1-3]

UND Formulations vs Commercial Products

Partial preliminary bench-top study of performance and efficiency of the University of North Dakota anticalin inhibitors versus four commercial products currently used in the field resulted in the UND formulations significantly outperforming the commercial products as shown in Figure D1.

Table D1. UND Formulations vs Currently Available Commercial Products

Product	Description	Efficiency
1	Commercial 1	47.0%
2	Commercial 2	68.6%
3	Commercial 3	66.1%
4	Commercial 4	1.1%
5	**UND (locally synthesized and developed)**	**95.0%**

An overview of the University of North Dakota Technology is depicted in **Table D2**.

Table D2. UND Technology Overview

Synthesized Materials (UND)	Specific Application	Commercially Available
Code: **MAGP** Synthesized by grafting polymerization of malonic acid with acrylamide.	Works for scale inhibition. Was found it to be effective for several scale formations such as calcium carbonate and iron sulphide.	The commercially used anticalins are mainly phosphate compounds and polymer blends. Acids are also used. Example: **Sentinel X100** mixture of organic and inorganic antiscalants and inhibitors.
Code: **GAGP** Synthesized by grafting polymerization of Gallic acid with acrylamide.	Works for metallic corrosion. Was found to be effective for carbon steel corrosion inhibition at different environments conditions (PH and Temperatures)	Example: ZIP-ANTI-RUST, Example: **METCORE57, SP-350**, petroleum distillates, fatty acids, paraffin, naphtha, octane, nonane and dimers.
Code: **TAGP** Synthesized by grafting polymerization of Tannic acid with acrylamide.	Works for scale dissolution. Was tested towards a scale sample collected from the field.	Example: **Sentinel X300**. An aqueous solution of phosphate, organic heterocyclic compounds polymer and organic bases.

Biodegradability studies were also conducted with results showing UND formulations to range between 21 to 25 days for up to 23% biodegradability, compared to the commercial products orderability ranging from 28 to 35 days for only 17% biodegradability.

Compatibility tests

Compatibility tests must be completed before any inhibitors are tested. More than thirteen compatibility tests were completed for different chemical compounds. **Table D3** illustrates some of the chemicals tested and their responses.

Table D3: Compatibility tests

Product	t=0hr	t=1hr	t=24hr	Note
Graphene	√	χ	-	Small crystals formed.
Graphene+5% isopropanol	√	√	χ	Small crystals formed.
Graphene+15% isopropanol	√	√	χ	Small gathered crystals formed.
.	-	-	-	-
Grafted based polymers	√	√	√	No precipitation. Clear solution was observed.

An inhibitor is compatible if it does not form a precipitate in the synthetic brine. If a precipitate is formed, or a phase separation is formed, the inhibitor is incompatible and cannot be used for inhibition tests. **Figure D1** displays an example of a compatible inhibitor, grafted polymer-based, while **Figure D2** illustrates a non-compatible inhibitor, graphene-based, with small formed crystals.

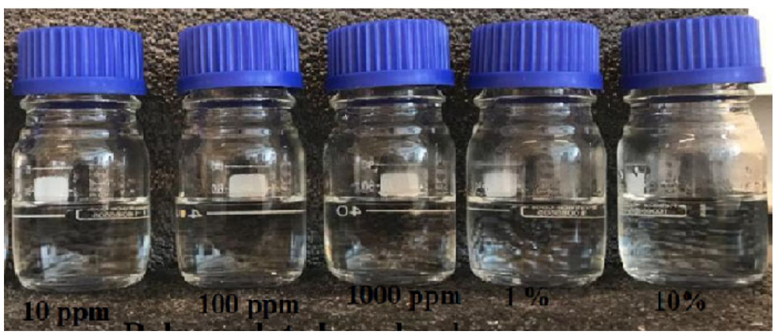

Figure D1: Grafting polymer-based inhibitor compatibility test.

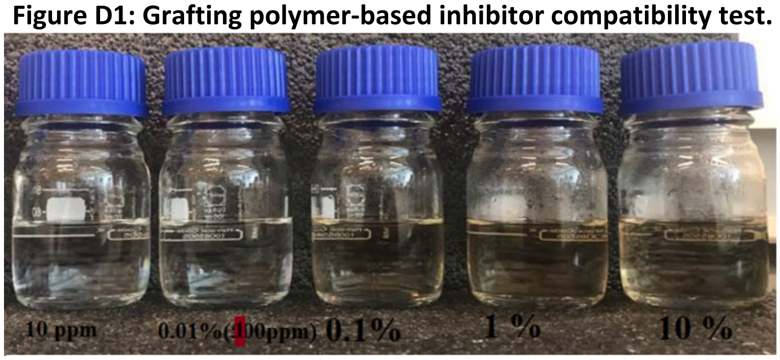

Figure D2: Graphene-based compatibility test.

Static bottle test

We were able to develop polymer-based inhibitors in previous experiments that provided up to 80% inhibition efficiency with iron sulfide scale. The inhibitors were tested with the static inhibition test procedure by injecting the antiscalant into the synthetic brine. The antiscalants were found to be effective at different concentrations once mixed with the synthetic brine resembling formation water. The setup used for iron sulfide inhibition is depicted in **Figure D3**.

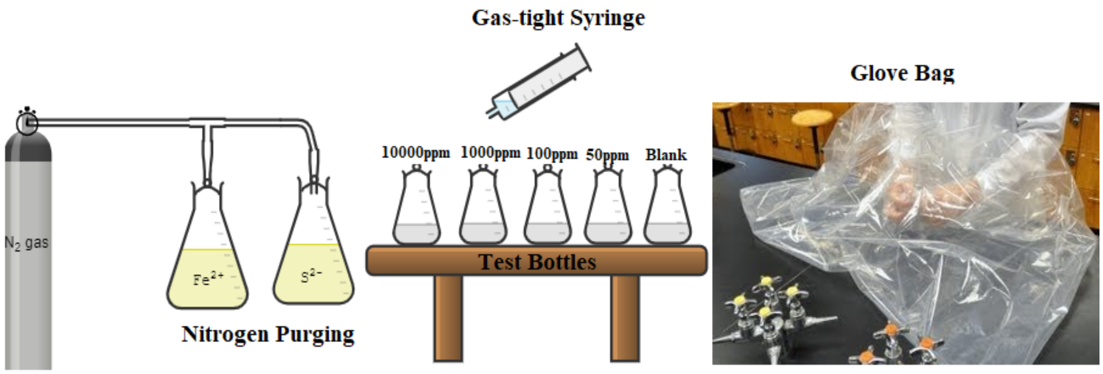

Figure D3: Schematic diagram of the FeS experimental setup.

Another antiscalant was also successfully synthesized and tested on calcium carbonate scale under anoxic conditions. The results were a remarkable 95% inhibition efficiency, which is greater than the highest reported value from commercial formulations: 68%. Static bottle inhibition tests were completed for four temperatures: 25, 40, 60, and 80 C (**Figure D4**). The highest inhibition percentage was at 80 °C with an inhibitor dosage of 20 ppm.

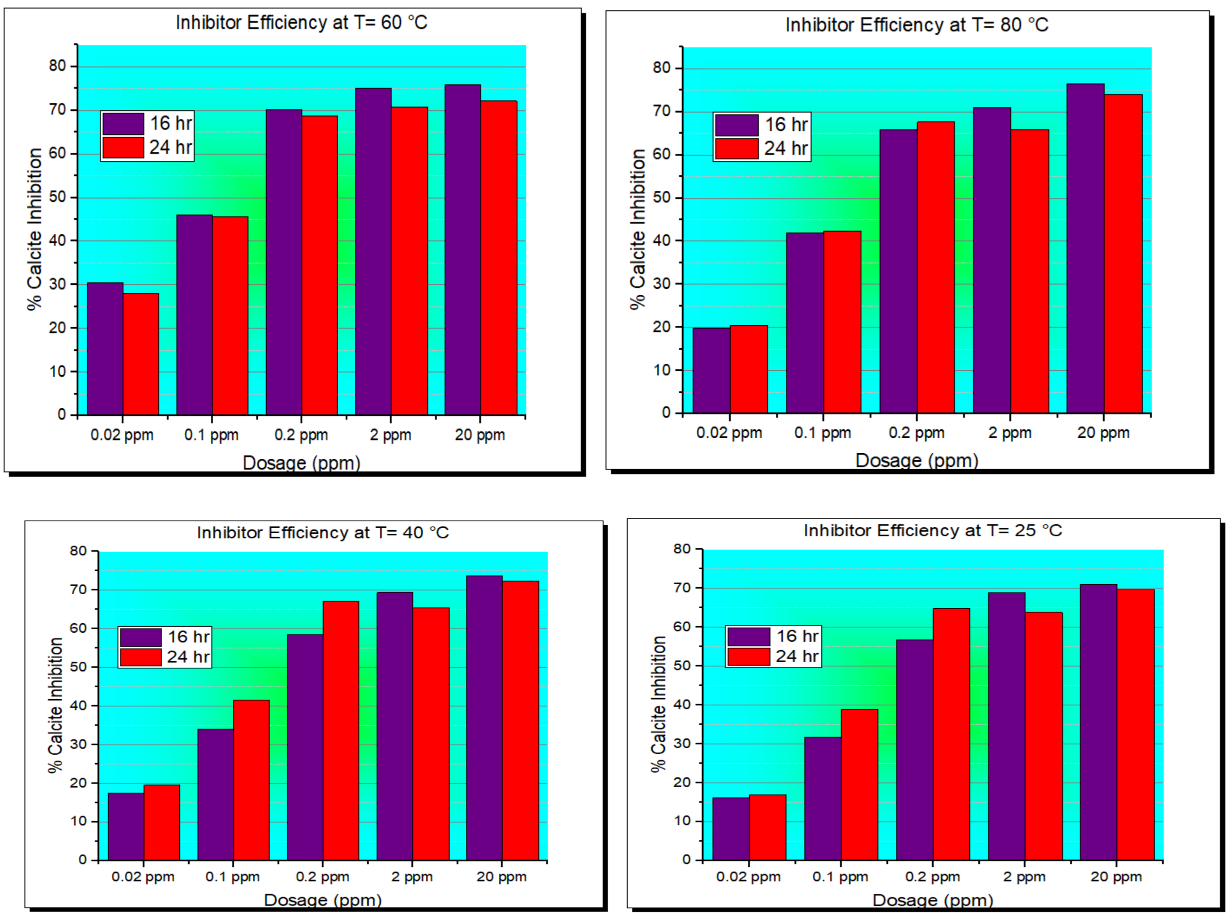

Figure D4: Inhibitor efficiency at different temperatures.

We aim to complete inhibitor synthesis and testing for other scales and scale matrices, or combined scales such as carbonate and sulfate. The developed inhibitors can be applied to fresh water and inhibit the precipitates that may potentially form. Successful inhibitor synthesis and evaluation will solve one of the most persistent problems within the oil and gas industry, and reduce the costs associated with scale formation.

Appendix E: Oilfield Scale Deposition and effects

During oil and gas production, scales form in the underground wellbore formation and downhole equipment. Downhole and surface equipment such as casings, production tubing, mandrels, and pipes are susceptible to damage by the build-up of scale. Whenever the wellbore produces water or when water injection is used to enhance the recovery of the natural resource, there is a possibility that scale will form. Several types of scales including carbonates, sulfides, sulfates, oxides, and hydroxides exist. Scales formed by iron sulfide compounds have a physical appearance of amorphous solid particles and they are capable of absorbing water and oil.

Formation of scale in the producer, injection, and supply wells causes many operational problems in the oil and gas industry. The deposits on the surface of conduits such as pipelines hinder the accurate determination of the pipeline integrity, and scale can affect the performance of downhole tools. Additionally, scale deposits increase the corrosion rates within pipeline networks and may interfere in the safe operation of pipeline valving systems, leading to potential catastrophic system failures which cause major economic losses. The deposits obstruct the flow of oil in wells, in the adjacent strata, and in the pipelines as well as in processing plants and refineries. Such deposits tend to stabilize oil-water emulsions that can form during secondary oil recovery. Scale causes loss of injectivity of water injectors, reduces the productivity of oil, gas, and water supply wells, decreases the efficiency of gas/oil separation plants, and enhances corrosion in well tubulars and surface facilities.

The formation of scale leads to damage near the wellbore, especially in high temperature, high-pressure wells. This build-up leads to damage early in the injection program. Scaling also leads to problems in production wells as it builds up near the perforation throat. Pressure drops can lead to runaway scale precipitation near the wellbore matrix. The incompatibility of injection water and formation water leads to scale precipitation in the formation matrix. **Figure B1** depicts scale damage to injection and production wells.

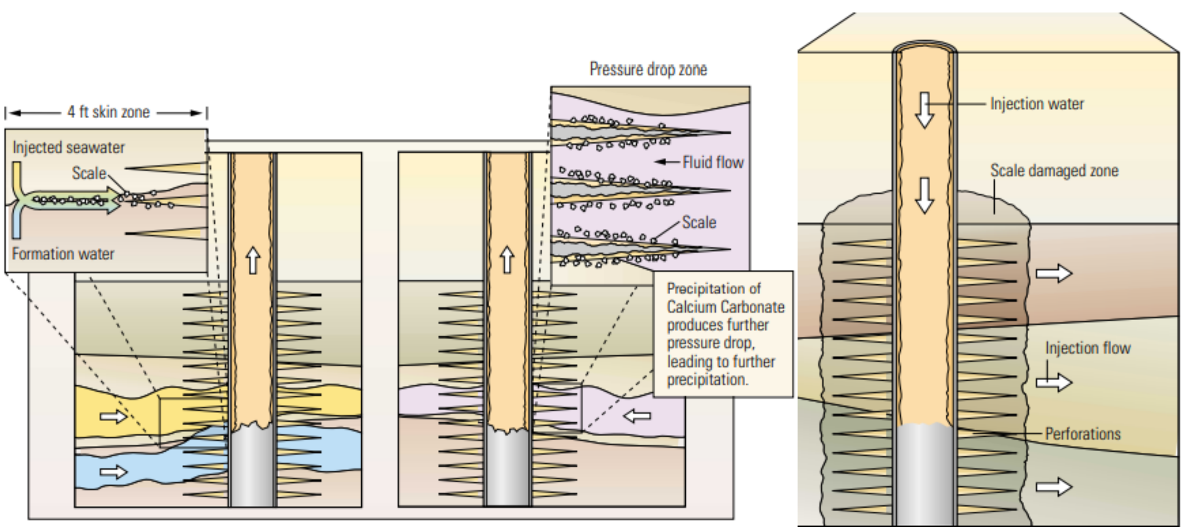

Figure B1: Scale damage to an injection well (right) and production well (left) [4].

Scale also causes damage to tubing and reduces well permeability. The scale build-up in the tubing can vary from the downhole equipment to the surface, where it restricts the flow by blocking nipples, safety valves, and gas-lift mandrels. The formed scale is often covered by a layer of wax or asphaltene coating.

Pitting corrosion is enhanced under this coating due to bacteria growth and sour gas capture, leading to damaged steel. Figure B2 illustrates scale deposition in tubing (left) and affected well permeability (right).

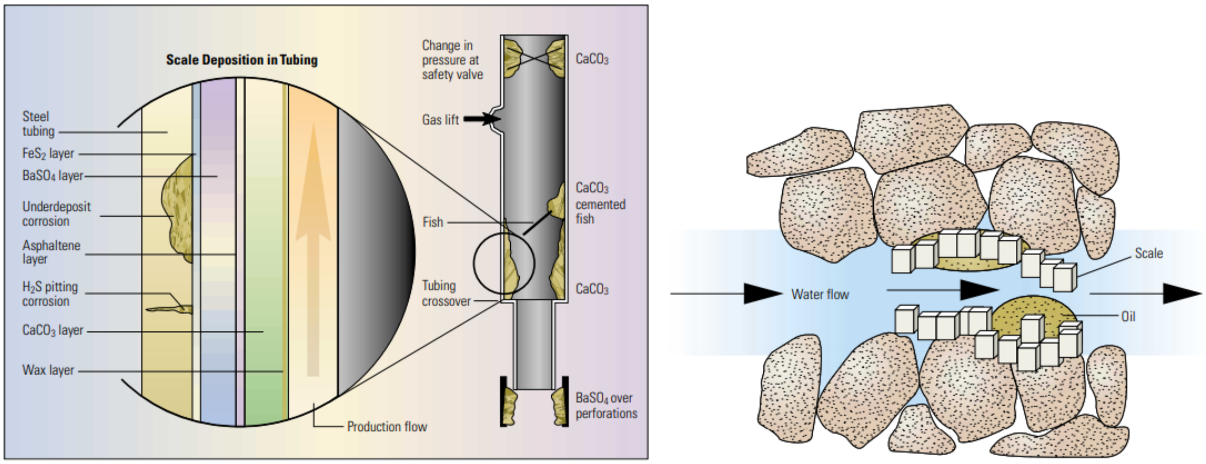

Figure B2: Scale deposition in tubing(left) and how scale affects permeability(right) [4].

Figure B3 depicts the severity of scale deposition on different surfaces, equipment and tools.

Figure B3: Scale deposition (left to right): in the pipeline, on a separator surface, on a clean separator surface, in downhole tubing, and in the riser pipe of a heating furnace. [6]

Appendix F: Concentrations Used for Compatibility and Inhibition Tests

Two primary types of synthetic brine, scaling and non-scaling, will be used in this study. Scaling brine will be a supersaturated solution in which at least one pair of scaling ions is present in an amount above its saturation concentration, promoting the formation of scale crystals. Scaling brines are typically prepared for scale inhibitor selection projects via the Dynamic Scale Loop or scale bottle tests. Non-scaling brine is a non-saturated brine where all pairs of scaling ions are present in an amount below their saturation concentration, used for compatibility tests. The reagents used in the brine's preparation procedure are in Table C1, based on the scale of interest.

Table C1. Reagents used for brine preparation

Cation chloride salts	Sodium anion salts	PH Adjustment Reagents
NaCl	$NaHCO_3$	1 M acetic acid solution
KCl	Na_2CO_3	0.1 M sodium hydroxide
$MgCl_2.6H_2O$	Na_2SO_4	-
$CaCl_2.2H_2O$	$Na_2S.9H_2O$	-
$SrCl_2.6H_2O$	NaF	-
$BaCl_2.2H_2O$	$NaC_2H_3O_2$anhyd	-
$FeCl_2.4H_2O$	$CH_3COONa.3H_2O$	-
($ZnCl_2$)	-	-
$PbCl_2$	-	-
$MnCl_2.4H_2O$	-	-
LiCl	-	-

Not all reagents in **Table C1** will be used. The reagent usage will depend on the targeted scale type or brine composition. Different scale tests require the use of suitable reagents; therefore, the targeted environment may be a mix between two or more types of scale.

Non-scaling brines will be used for compatibility tests. Since the primary targeted scales are calcium carbonate and halite, the salt reagents used will be sodium chloride, potassium chloride, magnesium chloride hexahydrate, sodium bicarbonate, and sodium sulfate. The amount of reagent used depends on the interrelated ion concentrations. The ion concentrations and respective reagent amounts are listed in **Table C2**. These concentrations and amounts may change depending on the results acquired from the water analysis in WP1.

Table C2. Ion concentrations for the compatibility tests

Ion	Conc. (ppm)	Source(salt)	g-Salt(for 500 ml)
Na^+	19,047	NaCl	24.56
K^+	703	KCl	0.67
Mg^{2+}	1,286	$MgCl_2.6H_2O$	5.38
Ca^{2+}	3,942	$CaCl_2.2H_2O$	7.23
Sr^{2+}	62	$SrCl_2.6H_2O$	0.09

Cl^-	39,119	-	-
SO_4	1,847	Na_2SO_4	1.37
HCO_3	500	$NaHCO_3$	0.34
TDS	66,530		39.64

Scaling brines will be used for static bottle inhibition tests and dynamic scale loop tests. The reagents used will be the same as those used for compatibility tests, except in differing amounts. Two scaling brines will be prepared for inhibition tests. Cationic and anionic brine solutions will be prepared separately using the species and concentrations listed in Table C3. These concentrations and amounts are also susceptible to change according to the results from the water analysis.

Table C3. Ion Concentrations for the inhibition tests

Salt	CW (g)	AW(g)	MIX(g)
NaCl	8.83	43.254	52
KCl	2.268	-	2.268
$MgCl_2.6H_2O$	4	-	4
$CaCl_2.2H_2O$	39.12	-	39.12
Na_2SO_4	-	0.46	0.46
$FeCl_2.4H_2O$	0.01	-	0.01

Appendix G: Relevant UND Facilities

The research team has access to advanced laboratory facilities both internal and external to perform the proposed research. Access to instrumentation in the UND Department of Chemical Engineering, Department of Petroleum Engineering, Department of Chemistry is not restricted and is not currently charged. The access to the Materials Characterization Laboratory and the Environmental Analysis Research Laboratory at UND are not restricted and a nominal laboratory service fees have been budgeted in this proposal.

The **PI's Laboratory** has a dedicated setup for synthesis of antiscalants. The laboratory is fully equipped for all synthesis studies required and has ample desk space, internet/phone connection for students, fellows, and staff. The static bottle test setup is also available which will be used for screening the synthesized antiscalants before doing thorough testing at different thermodynamic conditions using advanced equipment such as the Dynamic scale loop and the core-flooding system. An anaerobic chamber equipped with purging Nitrogen and Argon gases, gloves, and gas tight syringes is also available in the lab to be used for iron supplied scale inhibition screening tests. Totally anoxic condition needs to be achieved when testing towards iron sulfide scale to prevent the formation of iron oxide which will interfere and change the inhibition efficiency results.

The **Key personnel** drilling fluids labs can test all fluid properties including density and viscosity at different temperature and pressure. The core-flooding system(CFS) will be used to simulate the scale formation and the application of the antiscale at real field pressure and temperature. The CFS series flawlessly performs single and multiphase core flood studies at reservoir-representative conditions of temperature and pressure. Notably the device allows the evaluation of critical parameters such as brine sensitivity, return permeability, critical flow velocity and various secondary and tertiary EOR methods, including water flooding, polymer injection, ASP injection, miscible and immiscible gas flooding, acid treatments and microbial flooding. Relative permeabilities at irreducible water saturation, residual oil saturation, displacement efficiency and incremental oil recovery after implementation of the EOR process, can be determined. The computer-controlled system is provided with a unique software that allows both manual and automated operation where all key components can be controlled including pumps, valves, video capturing and data acquisition. A test sequencer also permits automated elaborate test sequences. The core holder, air operated valves, produced fluid separator if selected and necessary plumbing are mounted in an isothermal convective air bath that has been designed to provide easy access to all main components.

The Drilling and completion lab (DRACOLA): This is a key lab for this project, especially for work package 3. DRACOLA facilities include a wellbore simulator pressure vessel, a full-scale drill rig and mud pumping capabilities for measuring the performance, wear, deviation and dynamics of full-size drill bits tested at overbalanced or underbalanced drilling conditions at simulated depth. The effects of drilling and coring fluids and drill-bit hydraulics on drilling performance, bit balling, formation damage, coring and core fluid invasion, and many other areas can be determined.

Full size rig floor Drilling and Well Control Simulator DrillSIM-5000: The new DrillSIM-5000 'conventional' drilling simulator replicates a real drill-floor environment in exacting detail, providing a real-life experience for students, researchers and professionals alike. The simulator allows for setting up any drilling and well control scenario based on actual events experienced in the field. Training on full- scale simulators is a practice well known to many industries including commercial aviation, military, and motorsports and other industries operating in potentially hazardous situations and has been shown to be a much more effective tool for knowledge retention and effective long-term skills training than traditional study methods.

Computing: In addition to personal computer stations provided to faculty, Postdoctoral fellows and graduate students, the department of Petroleum Engineering hosts local high-speed computation facilities, with high capacity RAM and processors available to researchers on request. The research team will also have access to the University of North Dakota (UND) Computational Research Center (CRC). CRC houses its computational systems in North Dakota University System (NDUS) data center, located on the University of North Dakota campus. The data center has been built to criteria of a Tier 3 data center as defined by the Uptime Institute. Data center features include 5000sqft (currently 3,000 sift built out with power, cooling and racking) of machine room space, redundant power and cooling systems, as well as dual fiber networks connecting the data center to the UND campus network, Internet1, and Internet2 through the North Dakota Statewide Technology Access for Government and Education network (STAGEnet) and Northern Tier Network (NTN). The data center network is designed with up-to-date routing and switching, next generation security appliances, and application delivery solutions. Network connectivity, security, and management is provided in a highly redundant configuration for secure and reliable service delivery. STAGEnet and NTN research networks currently operate offer 10 Gbps capacity but are scheduled to be upgraded to 100 Gbps service in the next 12 months, with 100Gbps ScienceDMZ features to be added at that time under the NDILLI project (NSF Award #1826993).

Other Resources: XSEDE & Midwest Big Data Hub: Aaron Bergstrom, UND Advanced Cyberinfrastructure Manager is available to consult with UND researchers as the university's campus champion to assist with access to XSEDE cluster allocations for those projects that require HPC resources beyond those that are available locally. Mr. Bergstrom also serves as the university's coordinator with the Midwest Big Data Hub and can aid with accessing hub expertise in data science.

Appendix H: Budget and Justifications

The following four tables contain the detailed breakdown costs for all personnel and non-personnel during Years 1 and 2. We request a total of $**467,373** (direct costs: $349,192; indirect costs: $118,181) from the NDIC-OGRP to perform this critical study. The majority of the funds will be used for personnel expenses incurred while developing promising scale prevention and mitigation strategies. The development of these strategies is essential and will ultimately enhance oil recovery in the Williston Basin; however, it will require a significant amount of efforts and time. These funds include summer support for the PI, two key personnel, a post-doctoral researcher, and three graduate students. Salaries and benefits are approximated using the increasing rate of 5% per annum from 2022 to 2024. UND policy requires a 41% overhead to cover the facilities and other support provided by the institution.

Table H1. Budget Summary

Expenses, personnel	**Year 1** NDIC Share	**Year 1** UND Share	**Year 1** Industry Sponsor Share	**Year 2** NDIC Share	**Year 2** UND Share	**Year 2** Industry Sponsor Share
Alshami,PI	28,426	28,426		29,847	29,847	
Vamegh Rasouli	8,430	18,886		8,430	18,193	
Minou Rabiei	5,466	12,957		5,466	12,957	
Post-doc	-			-	-	
Three Graduate students	84,840	46,450		84,840	46,450	
Total Personnel	127,162	106,718		128,584	107,446	
Expenses, Nonpersonnel	65,000	48,000		12,500	3,000	
Supply/Materials-Professional	15,000		101,867	6,500		101,867
Equipment>$5,000	45,000	45,000			-	
Lab fees: Mat Charact Lab @UND	1,000			1,000		
Travel, Meetings, Conferences	3,000	3,000		4,000	3,000	
Office Supplies	1,000			1,000		
Tuition	-	61,560		-	61,560	
Total Nonpersonnel	65,000	109,560		12,500	64,560	
Total Direct Expenses	192,162	216,278		141,084	172,006	
F&A (41% of Direct Costs)	60,337	63,434		57,844	45,283	
TOTAL EXPENSES	**$ 252,499**	**$ 279,713**	**$ 101,867**	**$ 198,928**	**$ 217,290**	**$101,867**

Table H2. Year 1 Budget

	Year1,NDIC Share			Year1,UND Share			Industrys Sponsor's Share
Expenses, Personnel	**Salary**	**Benefit**	**Tuition**	**Salary**	**Benefit**	**Tuition**	
Alshami,PI	$ 23,692	$ 4,733		$ 23,692	$ 4,733		
Vamegh Rasouli	$ 6,848	$ 1,582		$ 15,420	$ 3,465		
Minou Rabiei	$ 4,900	$ 566		$ 11,846	$ 1,111		
Post-doc	$ -	$ -					
Graduate students	$ 84,000	$ 840		$ 45,990	$ 460	$61,560	
Total Personnel	$119,441	$ 7,721	$ -	$ 96,949	$ 9,769	$61,560	
Expenses, Nonpersonnel							
Supply/Materials-Professional	$ 15,000						$ 101,867
Equipment>$5,000	$ 45,000			$ 45,000			
Lab fees: Materials Characterization Lab@UND	$ 1,000						
Travel, Meetings, Conferences	$ 3,000			$ 3,000			
Office Supplies	$ 1,000						
Total Nonpersonnel	$ 65,000			$ 48,000			
Total Direct Expenses	$192,162			$216,278			
F&A (41% of Direct Costs)	$ 60,337			$ 63,434			
TOTAL EXPENSES	$252,499			$279,713			$ 101,867

Table H3. Year 2 Budget

	Year2,NDIC Share			Year2,UND Share			Industrys Sponsor's Share
Expenses, Personnel	**Salary**	**Benefit**	**Tuition**	**Salary**	**Benefit**	**Tuition**	
Alshami,PI	$ 24,877	$ 4,970		$ 24,877	$ 4,970		
Vamegh Rasouli	$ 6,848	$ 1,582		$ 15,420	$ 2,772		
Minou Rabiei	$ 4,900	$ 566		$ 11,846	$ 1,111		
Post-doc	$ -	$ -					
Graduate students	$ 84,000	$ 840		$ 45,990	$ 460	$61,560	
Total Personnel	$120,626	$ 7,958	$ -	$ 98,134	$ 9,313	$61,560	
Expenses, Nonpersonnel							
Supply/Materials-Professional	$ 6,500						$ 101,867
Equipment>$5,000	$ -						
Lab fees: Materials Characterization Lab@UND	$ 1,000						
Travel, Meetings, Conferences	$ 4,000			$ 3,000			
Office Supplies	$ 1,000						
Total Nonpersonnel	$ 12,500			$ 3,000			
Total Direct Expenses	$141,084			$172,006			
F&A (41% of Direct Costs)	$ 57,844			$ 45,283			
TOTAL EXPENSES	$198,928			$217,290			$ 101,867

A. PERSONNEL

Dr. Alshami, **PI**, will be responsible for the overall coordination and supervision of all aspects of the study along with the successful execution of the project, including supervising staff and students, coordinating team member efforts, scheduling and staff assignments, and quality control and project management. The PI will lead the efforts of each task, assist with data analysis, and be responsible for reporting the study's findings. The PI requests two months of summer salary and associated benefits for each year. The total salary request for Dr. Alshami $48,570 and $9,703 in benefits. UND will provide the same amount as a cost-share match: two months' worth of salary and benefits (see UND commitment letter).

Dr. Vamegh Rasouli, key personnel, will participate in the WP 1 – Characterization of Bakken scale, injection water, and formation water samples. He will also assist in project report preparation. Dr. Rasouli will receive a **$13,697** salary and the associated benefits of **$3,164** during the **two years** of the project.

Dr. Minou Rabiei, key personnel, will participate in WP 3 – Flow loop design and performance evaluation for different formulations, and the economic and environmental impact of the proposed formulations**.** He will perform experimental study, experimental data analysis and interpretation, computer modeling, and report preparation. The salary for Dr. Rabiei will be **$9,801 during the two years** of the project and associated benefits of **$1,132**.

B. OTHER PERSONNEL

Three **Ph.D. students**, two from the chemical engineering department and one from the petroleum engineering department, will be recruited for this project. Each research assistant will be hired for the 24 calendar months of the project. These individuals will be trained by key personnel to contribute to experimental work, data analysis, and report preparation. The salary and benefits for two of these students will be supported with funding from UND. The 24 months of salary requested from the NDIC for **½-time three graduate students is $169,680**, with the associated benefits of $1,680.

C. MATERIALS AND SUPPLIES

General Research supplies are approximated at **$21,500 to purchase the materials** necessary for synthesizing the grafting polymer-based inhibitors, chelating agents, reagent grade salts, gases, glassware, flow loop parts, sampling equipment, and piping.

D. EQUIPMENT

A variety of advanced laboratories at UND are equipped with most of the instruments needed for the proposed study. Funds are requested to **purchase one dynamic scale loop ($45,000),** vendor quotation provided in Appendix K. The dynamic scale loop with completely anaerobic conditions and adjustable temperature and pressure controls is essential for real field condition experiments, such as inhibition screening tests on different scale types.

E. LABORATORY FEES

Most of our scale and injection and formation water characterization experiments will be conducted at UND's Materials Characterization Laboratory and the Environmental Analytical Research Laboratory (EARL). Both laboratories are supportive of this proposed project and will charge an institutional service fee. A budget of **$2,000** is earmarked for this purpose. XRD, SEM, EDS, and TEM studies will provide critical insights on the Bakken scale and brine samples. These insights are essential to synthesize suitable formulations for different scale samples and injection-formation water concentrations.

F. TRAVEL

Travel is estimated based on UND travel policies, which can be found at https://und.edu/financeoperations/accounting-services/travel-employee.cfm. Travel may include site visits, visits to industrial collaborator's laboratories, professional meetings, and conference participation, as indicated by the scope of work and budget. The estimated travel costs are **$7,000**, which will enable travel to professional conferences and the presentation of findings associated with this investigation.

G. OFFICE SUPPLIES

Office supply estimates are based on prior experience. The cost of office supplies for the proposed project is estimated at **$2,000**.

Appendix I: Letters of Support

UNIVERSITY OF NORTH DAKOTA
COLLEGE OF ENGINEERING & MINES

UND.edu

Office of the Dean
Upson II, Room 165
243 Centennial Dr Stop 8155
Grand Forks, ND 58202-8155
Phone: 701.777.3411
Fax: 701.777.4838
engineering.UND.edu

MEMORANDOM

To: UND Grants Office

From: Brian Tande, Dean

Date: 20 May 19, 2021

RE: Cost Share Commitment

The College of Engineering and Mines agrees to use one month of Dr. Ali Alshami's salary, one-half month of Dr. Vamegh Rasouli's salary, one-half month of Dr. Minou Rabiei's salary and $72,582 in tuition waivers as cost share for three years for the proposal entitled "*Development of Formulations for the Removal of Scale from Oil and Gas wells in the Williston Basin*" which is to be submitted to the North Dakota Oil and Gas Research Council.

B. Te
Brian Tande
Dean College of Engineering & Mines

5/20/21
Date

21 Central Ave East
Minot, ND 58701

5930 16th Ave West
Williston, ND 58801

CREEDENCE ENERGY SERVICES

www.creedence-energy.com
contact@creedence-enrgy.com

Kevin Black
CEO
Creedence Energy Services
21 Central Avenue East
Minot, ND 58701

18 May 2021

Ali Alshami, Ph.D.
Associate Professor
Department of Chemical Engineering
University of North Dakota
Grand Forks, ND 58202

Dear Dr. Alshami

Creedence Energy Services is very pleased to support your proposed project entitled "***Development of Formulations for the Removal of Scale from Oil and Gas wells in the Williston Basin***", and looks forward to adding all the support it can to the advancements of this innovative oilfield scale inhibitors and dissolution formulations technology.

The Williston Basin continues to be prone to scale due to large amounts of water used for hydraulic fracking, making scale formation one of the current top production problems. These problems are in need for the development of value-added solutions that safely, efficiently, and cost-effectively improve production operations. Creedence strongly believes that the proposed efforts in this project adequately address these problems and present plausible potential solutions. Thus, Creedence is excited to be part of these efforts and a contributor to the solutions.

Specifically, Creedence with its experienced team in the field will play a key role in facilitating an understanding of the challenges operators regularly face and assist in delivering not only the developed products, but also the service to enhance well performance. Creedence's team understands the challenges of analyzing the complexities and matrix effects of high TDS fluids and will transfer this knowledge through collaboration to the UND teams to result in a robust array of inhibitors to provide both broad and highly targeted solutions to calcium, barium, and iron scales. Creedence, therefore aims to collaborate with UND teams to develop economic and long-term solutions uniquely tailored to the issue at hand for optimal production and increased oil recovery.

Creedence in-kind contribution will include the provision of our analytical and technical services, capability to design appropriate evaluation methods and determine proper metrics for performance assessment, field testing and evaluation, training of UND researchers, and consulting services to both UND researchers and the end-users. The contribution of our technical services and consultation is at least $129,600, the analytical and laboratory work is worth at least $71,000, and student's training valued at least $15,000. Our three years' contribution will be at a value of **$215,600** in total.

Creedence commitment is, of course, contingent on Alshami's attainment of the necessary funding from NDIC-OGRC. Please do not hesitate to contact me if you need further clarification or would like to discuss this effort further.

Sincerely,

Kevin Black

CEO
Creedence Energy Services

24 May 2021

Ali Alshami, Ph.D.
Associate Professor
Department of Chemical Engineering
University of North Dakota
Grand Forks, ND 58202

Dear Dr. Alshami,

Hess Corporation is pleased to support your proposed project entitled "***Development of Formulations for the Removal of Scale from Oil and Gas wells in the Williston Basin***" and looks forward to supporting the effort to advancement oilfield scale inhibitors and dissolution formulations technology.

Hess recognizes that oilfield scaling in the Williston Basin is one of the most persistent and costly flow assurance issues in the basin. With the development of hydraulic fracturing and recent improvements in completions technology, produced water production and the resulting scaling is an ever-increasing issue. Produced water from the Bakken and Three Forks formations is also notably high in TDS, which leads to many well maintenance issues related to scaling. Various scale types present different challenges that require effective mitigation and control options. Hess believes that the proposed work might potentially result in cost effective options to scale control and we are pleased to support this research.

Hess therefore is offering an in-kind contribution to this project that includes provision of our engineering and technical support, field testing and evaluation, and consulting with both UND researchers and the end-users. The time and material contributions are valued to be approximately $15,000 per year with our three years' contribution to be valued at approximately $45,000 in total.

Hess commitment is, contingent upon Dr. Alshami's attainment of the necessary funding from NDIC-OGRC. Please do not hesitate to contact me if you need further clarification or would like to discuss this effort further.

Sincerely,

Brent Lohnes

Brent Lohnes
General Manager – North Dakota
Hess Corporation
1501 McKinney Street
Houston, TX 77010

Continental
RESOURCES

28 May 2021

Ali Alshami, Ph.D.
Associate Professor
Department of Chemical Engineering
University of North Dakota
Grand Forks, ND 58202

Dear Dr. Alshami:

I am writing in support of your research proposal entitled "***Development of Formulations for the Removal of Scale from Oil and Gas wells in the Williston Basin***". Continental Resources, Inc. continues to be a strong supporter of oil and gas developments in North Dakota and looks forward to adding all the support it can to the advancements of this innovative oilfield antiscalant formulations technology.

Continental understands the fact that oilfield scaling in Williston Basin continues to be one of the most persistent flow assurance issues in the oilfield. Halite scale, in particular, has come into focus in the Basin increasingly over the last two decades for both gas and hydrocarbon wells due to hydraulic fracturing. Produced water from the Bakken and Three Forks formations is also notably high in TDS, which leads to many well maintenance issues related to scaling. With our awareness raised, various scale types are identified as flow assurance challenges that require effective mitigation and control options. Continental strongly believes that the proposed work offers these very much needed options, and is pleased to be part of the solution.

Continental, therefore, welcomes the opportunity to collaborate with the University of North Dakota and is offering an in-kind contribution to this project that may include technical services, field testing and evaluation, and consulting services to both UND researchers and the end-users of these novel formulations.

Continental Resources' commitment is, of course, contingent on your attainment of the necessary funding from NDIC-OGRP. Please do not hesitate to contact me if you need further clarification or would like to discuss this effort further.

Sincerely,

Bradley A. Aman

Bradley A. Aman, PE
Vice President, President & Completion
Continental Resources, Inc.

20 N Broadway, OKC, OK 73102
(405) 234-9000 • Fax (405) 234-9253 (Human Resources)

Appendix J: Resumes of key personnel

CURRICULUM VITAE

ALI S. ALSHAMI
Associate Professor, Department of Chemical Engineering,
University of North Dakota, Grand Forks ND 58202-7101
Phone: (701) 777-6838 | E-mail: ali.alshami@und.com

1. EDUCATIONAL BACKGROUND

Ph.D. Chemical Engineering Science, Washington State University, Pullman, WA	2007
M.S. Biochemical Engineering Science, Washington State University, Pullman, WA	2001
B.S. Chemical Engineering, Washington State University, Pullman, WA	1996

2. PROFESSIONAL EXPERIENCE

University of North Dakota, Associate Professor	2019-present
University of North Dakota, Assistant Professor	2014-2019
King Fahd University of Petroleum and Minerals, Assistant Professor	2010-2014
Pace Intl/Valent Biosciences, Engineering and Services Manager	1996-2010
Eaton/Cutler-Hammer Corp, Technology Development Engineer	2000-2003
Canon USA, Application Engineer	1997-1999

SYNERGISTIC ACTIVITIES

- Thirteen (13) years industrial R&D management in roles of increasing responsibility at various global corporations focused on materials development, separations and purification processes.
- National/International collaboration: On-going collaboration with teams at Los Alamos National Laboratory, NASA-ARC, NASA-Langley, Penn State University, King Fahd University of Petroleum and Minerals (KFUPM), Environmental and Energy Research Institute (QEERI), Qatar University; formal agreements to bring sustainable treatment technologies for water and natural gas treatment and purification (2010-present).
- Research Infrastructure: Developed a fully equipped and functional membranes research laboratory for water and gas separations at the University of North Dakota.

3. PROFESSIONAL EDUCATION/CONSULTANT ACTIVITIES

- Distillation and Separation Engineering Short Course for Saudi Aramco Process Engineers
- Bioinstrumentation and Control for Pace Internal llc field engineers and technicians
- Six Sigma Green Belt Trainer for Eaton/Cuttler-Hammer Corp. new employees

4. ACADEMIC AWARDS

- 2019 Dean's Award for Excellence in Collaborative Faculty Research, UND.
- 2017 Dean's Award of Excellence for Outstanding Public Service, UND.
- 2012 Excellence in Advising Award, Chemical Engineering, KFUPM
- 2006 Outstanding Teaching Assistant Award, Washington State University
- 2005 Outstanding Graduate Student Scholarship, Washington State University
- 2004 WSU GS Fellowship, Washington State University
- 2003 NIH National Needs Fellowship

5. RESEARCH ACTIVITIES

Project Title	Organization	Date	Funds	Role
Surfactant-polymer-alkaline system interactions and their effects on the physicochemical characteristics of chemical enhanced oil recovery fluids	ACS-PRF	16-Aug-14	$110,000	PI
2,3-Butanediol recovery from gaseous fermentation broth	UND RD&C	24-Oct-14	$25,000	PI
Laboratory Research Equipment Program	CEM Dean	23-Aug-14	$50,000	PI
Surfactant-polymer-alkaline system interactions in chemical enhanced oil recovery fluid flooding	AURA ND EPSoR	3-Feb-15	$10,000	PI
Biobutanediol from Waste Carbon Dioxide	SSARC	25-Sep-15	$25,000	PI
Microwave-Assisted, Immobilized Lipase Treatment of Municipal Wastewater	NSF CBET - Environmental Engineering	20-Oct-15	$330,000	PI
Bio-based 1,3-Butadiene Production via Fermentation of SYNGAS from Lignite Gasification	ND EPSCoR	7-Jan-16	$35,152	PI
Exploration and Development of Biomimetic Water Purification Membrane	ND EPSCoR	7-Jan-16	$20,000	PI
2,3-Butanediol Production via Fermentation, an Alternative Route to Chemical Synthesis, Using Synthesis Gas from Lignite Coal Gasification	Research ND	19-Feb-16	$100,000	PI
Biomimetic Membrane Development for Water Purification Purposes	NSF CBET - CAREER	21-Jul-16	$586,515	PI
Bio-inspired Membrane for Ultrapure Water Generation	ND NASA EPSCoR	14-Oct-16	$40,000	PI
Bio-Based Dielectric Substrate based on Sunflower Seed Shells for Radio Frequency Antennas	EPSCoR Track-1	27-Oct-16	$35,000	PI
Development of Sunflower Seed Shells Dielectric Substrates for Antennas and Radio Frequency Devices	Research ND	18-Mar-17	$100,000	PI
Ethanol dehydration using aquaporin based biomimetic membranes	UND -VPR	15-Nov-17	$20,000	PI
Mixed-Matrix-Membrane Consisting of Activated Carbon from Biochar for Gas Separation	DOE NETL-UCFER	8-Jan-18	$200,000	PI

Production of USP-Grade Carbon Dioxide Using Biomimetic Gas Separation Membrane	ACS- GCIPR	31-May-18	$25,000	PI
Metamatrial development for molecular mass diffuion and separation	3M	8-Oct-18	$45,000	PI
Gas separation of N2 from CH4 Using metamaterial-based membrane	ACS-PRF	19-Oct-18	$110,000	PI
Natural Gas Purification and Upgrading Using Metamaterial-based Membranes	UND-VPR Post-doc program	5-Jan-19	$45,000	PI
Grand Forks Water Treatment Plant Concentrate Line Scaling, Potential Plugging, and Methods of Prevention Study	City of Grand Forks	8-Nov-18	$50,000	PI
Size Controlled Synthesis of Graphene/Graphene Oxide from Lignite for Use as a Membrane Separations Material	DOE NETL-UCFER	6-Feb-19	$300,000	PI
Biodegradable and Inexpensive CH4/CO2 Sensor/Antenna System to Measure Gas Emissions in the Arctic	NSF-SitS EAGER	13-Apr-18	$200,000	PI
Membranes development for CH4/N2 and CH4/CO2 gas mixture separation	NSF-CBET CAREER	18-Jul-19	$500,000	PI
Gel Permeation Chromatography (GPC) Analytical System for Polymers Research and Development	ND EPSCoR	16-Sep-19	$72,000	PI
Carbon Dioxide Removal from Air Using Graphene/Graphene Oxide Membranes from Lignite	DOE NETL-UCFER-RFP05	9-Oct-19	$437,500	PI
Bioethanol Production via fermentation, an alternative route to chemical synthesis, using synthesis gas from lignite coal-gasification	Research ND-Venture Phase II	8-Nov-19	$200,000	PI
Mixed-Matrix-Membrane for CO2 Separation and Capture	DOE NETL-UCFER-RFP06	10-Jun-20	$252,430	PI
Binary gas diffusion and separation in dual-layer metamaterial	ACS-PRF	16-Oct-20	$110,000	PI
Virtual Lab IV Experiments	ND EPSCoR	12-Sep-20	$6,000	PI
NSF MRI: Acquisition of NMR UND	NSF	19-Jan-21	$973,296	co-PI
Graphene Oxide Membrane to Enhance ECLSS Water Purification (White Paper)	NASA	10-Feb-21	$281,456	PI

6. REFEREED PUBLICATIONS (Last 4 Years)

1. Jeremy Lewis, Ali Alshami, Ademola Owoade, Sagheer Onaizi. Agglomeration tendency and activated carbon concentration effects on AC-PSF mixed matrix membrane performance: a design of experiment formulation study. *Journal of Membrane Science*. 14-Sept-2020. (SCI indexed, Impact Factor: 7.38. SCImago Journal Ranking: 2.5, Q1)
2. Jiselle Thornby, Ali Alshami, Meysam Haghshenas. A Review on the Influence of Processing Methods on Corrosion Rates of Mg-CNT Nanocomposites. *Current Nanomaterials*, 28-Sept-2020. (SCI indexed, Impact Factor: 2.188. SCImago Journal Ranking: 0.554, Q1)
3. Sagheer A. Onaizi1, Mohammed Alsulaimani1, Mohamed Mahmoud, **Ali Alshami**. Crude Oil/Water Nanoemulsions Stabilized by Biosurfactant: Extremely Stabile but Easy to Switch with pH-Swing. *Journal of Petroleum Science and Engineering*, Accepted 12-Aug-2020.
4. Lewis, Jeremy, Mark Miller, Jake Crumb, Maram Al-Sayaghi, Chris Buelke, Austin Tesser, and Ali Alshami. "Biochar as a filler in mixed matrix materials: Synthesis, characterization, and applications." *Journal of Applied Polymer Science* (2019): 48027. (SCI indexed, Impact Factor: 2.188. SCImago Journal Ranking: 0.554, Q1)
5. Buelke, Christopher, Ali Alshami, James Casler, Yi Lin, Mike Hickner, and Isam H. Aljundi. "Evaluating graphene oxide and holey graphene oxide membrane performance for water purification." *Journal of Membrane Science* (2019): 117195. (SCI indexed, Impact Factor: 7.24. SCImago Journal Ranking: 2.1, Q1)
6. Lewis, Jeremy , A. Q. Al-sayaghi, Maram , Buelke, Chris , Alshami, Ali. (2019). Activated carbon in mixed-matrix membranes. Separation & Purification Reviews. 1-31. . (SCI indexed, Impact Factor: 4.174. SCImago Journal Ranking: 0.5, Q1)
7. Al-Sayaghi, Maram AQ , Jeremy Lewis , Chris Buelke , and Ali S. Alshami. "Physicochemical and thermal effects of pendant groups, spatial linkages and bridging groups on the formation and processing of polyimides." *International Journal of Polymer Analysis and Characterization* 23, no. 6 (2018): 566-576. (SCI indexed, Impact Factor: 1.426. SCImago Journal Ranking: 1.2, Q1)
8. Buelke, Chris , Ali Alshami, James Casler, Jeremy Lewis, Maram Al-Sayaghi, and Michael A. Hickner. "Graphene oxide membranes for enhancing water purification in terrestrial and space-born applications: State of the art." *Desalination* 448 (2018): 113-132. (SCI indexed, Impact Factor: 6.566. SCImago Journal Ranking: 1.6, Q1)
9. Alshami, Ali S., Juming Tang, and Barbara Rasco. "Contribution of Proteins to the Dielectric Properties of Dielectrically Heated Biomaterials." Food and Bioprocess Technology 10, no. 8 (2017): 1548-1561. (SCI indexed, Impact Factor: 3.032. SCImago Journal Ranking: 1.222, Q1)
10. Jeremy Lewis, Ali Alshami. “Factorial study on activated carbon mixed matrix membrane formation for aniline blue filtration,” *Desalination* (/7/2019), (SCI indexed, Impact Factor: 6.566. SCImago Journal Ranking: 1.6, Q1)
11. Al-Sayaghi, Maram AQ , Jeremy Lewis , Chris Buelke , and Ali S. Alshami. "Structure-Property-Function Connections Underlying Performance of Polybenzoxazole Membranes

Derived from BisAPAF Polyimides." *Polymer* 182(2019)-121825. (SCI indexed, Impact Factor: 3.77. SCImago Journal Ranking: 1.04, Q1)

12. Woock, Tucker , Stacy Bjorgaard, Brian Tande, and Ali Alshami. "Purification of natural gas using thermally rearranged polybenzoxazole and polyimide membranes–a review: part 1." *Membrane Technology* 2016, no. 9 (2016): 7-12. (SCI indexed, Impact Factor: 0.321 SCImago Journal Ranking: 0.163, Q1)
13. Woock, Tucker , Stacy Bjorgaard, Brian Tande, and Ali Alshami. "Purification of natural gas using thermally rearranged polybenzoxazole and polyimide membranes–a review: part 2." *Membrane Technology* 2016, no. 10 (2016): 7-12. (SCI indexed, Impact Factor: 0.321 SCImago Journal Ranking: 0.163, Q1)
14. Austin Tesser , Ala Alemaryeen , Jeremy Lewis , Ali Alshami1, Meysam Haghshenas, Sima Noghanian. "Synthesis and Use of Bio-Based Dielectric Substrate for Implanted Radio Frequency Antennas," IEEE-Access, 5/29/2019, manuscript ID is Access-2019-10931 (Accepted). (SCI indexed, Impact Factor: 4.098 SCImago Journal Ranking: 0.609, Q1)

National /International Presentations (since joining UND)
(*graduate student; **under-graduate student; Corresponding author underlined)

1. Ali A. Alshami, Ammar Jamie, Zuhair O. Maliabari, Muataz Ali Ateih, Immobilization and Catalytic Activity of Lipase on Modified MWCNT for Oily Wastewater Treatment. AIChE Annual Meeting, Salt Lake City, UT. November 2015.
2. Ali A. Alshami. Simulation-Aided Characterization of Biomimetic Separation Membrane for Water Purification. AIChE Annual Meeting, Atlanta, GA. November 2014.
3. Ali A. Alshami. "Mixed-Matrix Membranes Loaded with Activated Carbon For Gas Separations," North American Membrane Society (NAMS), Boston, MA on June 2nd, 2015.
4. Ali A. Alshami. "Comparison of the permeabilities and selectivities of polybenzoxazole membranes thermally rearranged from hydroxyl-polyimides formed from different dianhydride precursor," AIChE Annual Meeting, San Francisco, CA. November 2016.
5. Janguala, Jamison**, Alshami, Ali. "Analysis of Clostridium Autoethanogenum Bacteria Growth with D-xylose as a Carbon Source and Subsequent Preliminary Work for Synthesis Gas Fermentation." ND EPSCoR, Fargo, ND Spring 2016.
6. T Taylor*, A Alshami, "Preliminary Growth Kinetics with D-xylose," ND EPSCoR State Conference, Grand Forks, ND April 19th, 2016.
7. T Taylor*, M Mann, A Alshami. "Growth Kinetics and Modeling of 2, 3-Butylene Glycol Fermentation Using Carbon Monoxide," AIChE Annual Meeting 2017 (October 30, 2017).
8. A. Alshami, A Tesser**, S Noghanian, M Mirzaee*. "Bio-based Dielectric Substrate for Radio Frequency Antenna," AIChE Annual Meeting 2017 (October 30, 2017).
9. M Al-Sayaghi*, A Alshami. "The Effect of Bridging Group of Dianhydride Precursors on Resulting Thermally Rearranged Polybenzoxazole for Natural Gas Purification," AIChE Annual Meeting 2017 (October 30, 2017).

10. T Taylor*, A Alshami. “Preliminary Growth Kinetics with Carbon Monoxide,” ND EPSCoR State Conference 2017 (April 12, 2017).

11. P Stack*, and A Alshami. “Using Aquaporin-Type Membranes to Purify Contaminated Drinking Well Water in Fracking Regions,” ND EPSCoR State Conference 2017 (April 12, 2017).

12. M Al-Sayaghi*, A Alshami. “The Effect of Bridging Group of Dianhydride Precursors on Resulting Thermally Rearranged Polybenzoxazole for Natural Gas Purification,” ND EPSCoR State Conference 2017 (April 12, 2017).

13. Ali Alshami and Chris Buelke*. “Investigating Graphene Oxide and Holey Graphene Oxide Membrane Properties for Water Purification,” 2018 AIChE Annual Meeting (ISBN: 978-0-8169-1108-0)

14. Maram Al-Sayaghi* and Ali Alshami. “The Synthesis of Thermally Rearranged Polyimide Membranes for Natural Gas Separation Using Four Different Dianhydride Precursors,” 2018 AIChE Annual Meeting (ISBN: 978-0-8169-1108-0).

15. Jeremy Lewis*, Keith M. Forward, and Ali Alshami. “Formation of Activated Carbon/Polymer Bilayer Membranes by Solution Electrospraying for Water Purification,” 2018 AIChE Annual Meeting (ISBN: 978-0-8169-1108-0).

16. C Buelke*, A Alshami, J Casler. “Enhancing Water Purification for Terrestrial and Celestial Applications,” North American Membrane Society (NAMS). 27th Annual Meeting, June 9, 2018.

17. Taylor*, A Alshami. “Biokinetics & Preliminary Reactor Conditions to Produce 2,3-butanediol & Ethanol,” ND EPSCoR 2018 2018 (4/17)

18. M. Noghanian, Sima, Alshami, A, Alemaryeen, Ala*, Tesser, A**, Lewis, J*, Haghshenas. M. “On the development of a bio-based dielectric material,” International Symposium on Electromagnetic Theory (EMTS), San Diego, CA. May 2019.

DR. VAMEGH RASOULI
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Department of Petroleum Engineering, University of North Dakota (UND)
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Professional Timeline (all-inclusive 18 years old to present, in reverse chronological order)
July 2017–Present: Director, Jodsaas Centre for Leadership and Entrepreneurship, College of Engineering & Mines, UND. Responsibilities include offering different activities for nearly 3,000 Engineering students in the College to learn set up and run small business, practice teamwork and leadership skills and do collaborative projects within the College and other Schools in cluing the business School.
March 2015–Present: Department Chair, Continental Resources Distinguished Professor, Department of Petroleum Engineering, UND. In addition to teaching courses at undergrad and grad level and advising grad students and doing research project, the Chair responsibilities include quality assessment of the program, ABET accreditation coordination, hiring faculty, staff and grad students, fundraising and securing scholarship, engage the industry advisory council to support the department, attract industry and research fund, increase enrolment and retention for both undergrad and grad programs, expand on existing teaching and research labs and add new labs and manage all financial aspects of the department. Overall budget management including all the external fund change from $5M-$10M per annum. Total student numbers of nearly 250 in the department and 12 faculty and staff plus over 15 visiting scholars and researchers are working in the department on average on an annual basis.
January–February 2015: Perth, Australia. Preparing for move to the USA to join my new job appointment at UND as the Chair of Petroleum Engineering program.
August 2012–Present: Part-Time Instructor, Schlumberger's Network of Excellence Training (NExT) Program. The courses delivered face to face and online. Delivering industry short courses for international oil and gas companies worldwide.
July 2008–July 2010: Part-Time Consulting Engineer, Schlumberger Oil and Gas Service Company, Perth, Australia. Conducted several industry projects related to oil and gas drilling and Geomechanics.
August 2006–December 2014: Senior Lecturer, Associate and Full Professor (Acting Head and Head of Department), Department of Petroleum Engineering, Curtin University, Perth, Australia. Similar responsibilities to my current position at UND in terms of teaching and research and duties as the department Chair. Total number of students 500, faculty and staff and visitors 20 in the department.
November 2004–August 2006: Part-Time Consulting Engineer, Schlumberger Oil and Gas Service Company, Tehran, Iran. Conducted several industry projects related to oil and gas drilling and Geomechanics.
February 2003–August 2006: Assistant Professor, Acting Head of Department, Amirkabir University, Tehran, Iran. In addition to teaching undergrad and grad level courses to Mining, Chemical and Petroleum Engineering students, I was appointed as the Deputy of the newly established Petroleum Engineering Department to build the Undergraduate and graduate program, raise fund to build a new building and labs, and other responsibilities similar to my current Chair position at UND. Total number of students 300, faculty and staff 40 in the department.

September 2002–January 2003: Traveled from United Kingdom to Tehran, Iran, after completing Ph.D. and settling down before commencing new job.
January 2000–August 2002: Ph.D. Candidate, Imperial College, University of London, London, United Kingdom.
March 1997–December 1999: Preparation for overseas Ph.D. exam competition and move to United Kingdom, Tehran, Iran.
September 1995–February 1997: M.Sc. Candidate, Engineering Rock Mechanics, Tehran Polytechnic University, Tehran, Iran.
September 1991–August 1995: B.Sc. Candidate, Mining Engineering, Yazd University, Yazd, Iran.
July 1990–September 1991: Preparation for university entrance exam, Tehran, Iran.

Qualifications
Ph.D., Imperial College, University of London, London, United Kingdom, 2002.
M.Sc., Engineering Rock Mechanics, Tehran Polytechnic University, Tehran, Iran, 1997.
B.Sc., Mining Engineering, Yazd University, Yazd, Iran, 1995.

Professional Experience
July 2017–Present: Director, Jodsaas Centre for Leadership and Entrepreneurship, College of Engineering & Mines, UND.
March 2015–Present: Department Chair, Continental Resources Distinguished Professor, Department of Petroleum Engineering, UND.
August 2012–Present: Instructor, Schlumberger's Network of Excellence Training (NExT) Program.
July 2008–July 2010: Part-Time Consulting Engineer, Schlumberger Oil and Gas Service Company, Perth, Australia.
August 2006–December 2014: Senior Lecturer, Associate and Full Professor (Acting Head and Head of Department), Department of Petroleum Engineering, Curtin University, Perth, Australia.
November 2004–August 2006: Part-Time Consulting Engineer, Schlumberger Oil and Gas Service Company, Tehran, Iran.
February 2003–August 2006: Assistant Professor, Acting Head of Department, Amirkabir University, Tehran, Iran.

Research Projects Completed

From	To	Project Title	Organization	Role & Fund Amount
June 2020	May 2023	ND CarbonSAFE Phase III - Site Characterization and Permitting	DOE, Jointly applied with the EERC	Co-PI $129,438
Mar 2020	Feb 2023	Support Petroleum Engineering Research at UND	North Dakota Industrial Commission (NDIC)	PI: $2,778,000
Oct 2020	Dec 2020	Study to Determine the Feasibility Oo Developing Salt Caverns for Hydrocarbon Storage in Western North Dakota	North Dakota Industrial Commission (NDIC)	Co-PI: $20,000
Jan 2020	Dec 2023	Safety Reporting Action Program for Offshore Oil and Gas Industries in the Gulf of Mexico	National Academies of Sciences, Engineering and Medicine (NAS)	Co-PI: $750,000
Jul 2019	Feb 2019	Enhancing Reservoir Productivity Through a New Hydraulic Fracturing Approach	State Energy Research Center (SERC)	Co-PI: $70,000
Mar 2020	Oct 2020	Simulation of refracturing for EOR	SERC	Co-PI: $70,000
Sep 2018	Feb 2020	Refracturing and data analytics for EOR in Bakken	NDIC	PI: $600,000
Oct 2018	Oct 2020	Joint Inversion of TimeLapse Seismic Data	U.S. Department of Energy (DOE), DE-FE0031540	Co-PI: $102,302
Apr 2017	Apr 2018	An Integrated Software Package for Data Processing, Modeling, and Simulation of Unconventional Reservoirs	Research North Dakota	Co-PI: $100,000
Oct 2016	Oct 2019	Field Demonstration of the Krauklis Seismic Wave	DOE, DE-FE0028659	Co-PI: $167,000
Jan 2016	Jan 2017	Postdoctoral Research Fellow Grant	UND	PI: $40,000
Jan 2013	Dec 2014	Design and manufacture of a large-scale true triaxial stress cell to study geomechanical aspects of CO_2 sequestration	National Geosequestration Lab (NGL), Australia	Co-PI: $3,000,000

2013	2014	Next-Generation Drilling Technologies	Deep Exploration Technology Cooperative Research Centre (DET CRC) of Australia	PI: $300,000
Jan 2012	Dec 2013	Upscaling laws for hydraulic fracturing of tight reservoirs based on reproducible true triaxial laboratory testing	Australian Research Council linkage research project (ARC LP)	PI: $607,000
Oct 2011	Oct 2013	A study of shale gas geomechanics in the Perth basins	MERIWA, Western Australia	PI: $619,000
Feb 2011	Feb 2014	Predicting CO_2 injectivity properties for application at CCS sites	ANLEC R&D, Western Australia	Co-PI: $653,000
2010	2011	Geomechanics and Drilling Design of Tight Gas Wells	WAERA, Western Australia	PI: $140,000

Industry Projects Completed

From	Project Title	Organization	Fund Amount
2012–Present	Delivered over 70 industry courses in Drilling, Geomechanics, & Unconventional Reservoirs	Schlumberger’s NExT Training Program	Instructor
Mar 2014–Sept 2014	Review and Study the Proposed Hydraulic Fractured Well for shale gas production from Canning Basin	An independent review project funded by Buru Energy, Australia	$32,000
Jan 2012–May 2012	Estimation of state of in situ stresses in an injection site in Australia	Buru Energy, Australia	$25,000
Apr 2011–Oct 2011	Mud weight design and wellbore stability analysis for Mountain Bridge Well	Norwest Energy, Australia	$30,000
Sep 2011–Dec 2011	Mud weight Design, wellbore stability analysis and hydraulic fracturing studies of Arrowsmith 2 Shale Gas Well	Norwest Energy, Australia	$40,000
Jan 2010–May 2010	Rock Mechanical Modelling and Wellbore Stability Study for Well Mondarra 1	APA Australia	$20,000
Jun 2010–Dec 2010	Rock Mechanical Modelling and Hydraulic Fracturing Study of Well Corybas-01 in Elegans Area	AWE Australia	$40,000
Apr 2009–Aug 2009	Geomechanical Study of Mondarra Field, Australia. Phase-1: Data review	APA Australia	$15,000

Jan 2009–Aug 2009	Rock Mechanical Modelling and Hydraulic Fracturing Studies for Woodada-5 & 6 Wells	AWE Australia	$40,000
Feb 2009–Dec 2009	Wellbore stability study and Mechanical Earth Modelling of Blacktip Field, PNG	Schlumberger	$55,000
Jul 2009–Dec 2009	Wellbore stability study and Mechanical Earth Modelling of Blacktip filed, ENI Australia	Schlumberger	$30,000
Mar 2009–Sep 2009	Reservoir Geomechanics Study of Enfield field, Woodside Petroleum	Schlumberger	$12,000
Oct 2006–Dec 2006	Wellbore stability study in Anaran field	Schlumberger	$70,000
Oct 2006-Dec 2006	Wellbore stability study in Mehr field	Schlumberger	$70,000

Professional & Other Services

Year	Project Title	Organization
Apr 2015–Present	Established Petroleum Engineering Labs (including Teaching, Research, Virtual Reality, Drilling Simulator, Drilling Rig, Slurry Loop)	UND
Sep 2006-Aug 2010	Coordinated an international dual degree Master of Petroleum Engineering program for 4 years at Curtin University with National Oil Company, Iran	Curtin University
Oct 2012-Jul 2014	Developed several labs (ultrahigh-speed drilling rig, flow loop, True Triaxial Stress Cell [TTSC])	Curtin University
Feb 2007-Oct 2009	Developed and designed a unique TTSC for advanced Petroleum Geomechanics lab experiments.	Curtin University
Sep 2007	Established Curtin Petroleum Geomechanics Group (CPGG)	Curtin University
2007–Present	Advised over 20 Ph.D. students, 100 Master's students	Curtin University, UND
Oct 2006–Present	Member of Society of Petroleum Engineers	SPE
Sep 2010–Present	Member of editorial board, Journal of Petroleum Engineering & Technology	Journal Board
Jul 2014–Present	Member of editorial board, Rock Mechanics Rock Engineering	Journal Board
Oct 2013–Present	Member of editorial board, Journal of Petroleum & Environmental Biotechnology	Journal Board

Publications

<u>2021</u>

- Adesina, F., Rasouli, V., and Ling, K., 2021. Modelling flow for finite conductivity in long horizontal oil wells. Energy Exploration an Exploitation.
- Ashena, R., Rabiei, M., Rasouli, V., Mohammadi, A.H., Mishani, S., 2021. Drilling Parameters Optimization Using an Innovative Artificial Intelligence Model. J. Energy Resour. Technol. 1-19.
- Benouadah, N., Djabelkhir, N., Song, X., Rasouli, V., and Damjanac, B., 2021. Simulation of Competition between Transverse Notches versus Axial Fractures in Open Hole Completion Hydraulic Fracturing. Rock Mechanics Rock Engineering.

<u>2020</u>

- Minaeian, V., Dewhurst, D., and Rasouli, V., 2020. An Investigation on Failure Behaviour of a Porous Sandstone Using Single-Stage and Multi-stage True Triaxial Stress Tests. Rock Mech Rock Eng.

- Boualam, A., Rasouli, V, Dalkhaa, C, Djezzar, S., 2020. Stress-Dependence of the Permeability and Porosity of Thin Bed Reservoir, Three Forks, Williston Basin. 54thUS Rock Mechanics/Geomechanics Symposium held Golden. Colorado, USA, 28 June-1 July. ARMA 20–1742.
- Boualam, A., Rasouli, V, Dalkhaa, C, Djezzar, S.,2020. Advanced Petrophysical Analysis and Water Saturation Prediction in Three Forks Reservoir, Williston Basin. SPLWA–750.
- Djezzar, S., Rasouli, V., Boualam, A., Rabiei, M. (2020). An integrated workflow for multiscale fracture analysis in reservoir analog. Arab J Geosci 13, 161. https://doi.org/10.1007/s12517-020-5085-6
- Ellafi, A., Jabbari, H., Wan, X., Rasouli, V., Geri, M.B., and Al-Bazzaz, W., 2020. How Does HVFRs in High TDS Environment Enhance Reservoir Stimulation Volume?, International Petroleum Technology Conference
- Wan, X., Rasouli, V. Damjanac, B., Yu, Wei, Xie, H., Li, N., Rabiei, M., Miao, J., and Liu, M., 2020. Coupling of fracture model with reservoir simulation to simulate shale gas production with complex fractures and nanopores. Journal of Petroleum Science and Engineering 193, 107422.
- Wan, X., Rasouli, V., Damjanac, B., and Pu, H., 2020. Lattice simulation of hydraulic fracture containment in the North Perth Basin, Journal of Petroleum Science and Engineering 188, 106904, 1, 2020
- Ashena, R., Elmgerbi, A., Rasouli, V., Ghalambor, A., Rabiei, M., and Bahrami, A., 2020. Severe wellbore instability in a complex lithology formation necessitating casing while drilling and continuous circulation system. J Petrol Explor Prod Technol 10, 1511–1532. https://doi.org/10.1007/s13202-020-00834-3.
- Rasheed, Z., Raza, A., Gholami, R., Rabiei, M., Ismail, A., and Rasouli, V., 2020. A numerical study to assess the effect of heterogeneity on CO_2 storage potential of saline aquifers. Energy Geoscience, Vol 1, p.p. 20-27.
- Gholami, R., Raza, A., Rabiei, M., Fakhari, N., Balasubramaniam, P., Rasouli, V., and Nagarajan, R., 2020. An approach to improve wellbore stability in active shale formations using nanomaterials, Petroleum, https://doi.org/10.1016/j.petlm.2020.01.001

- Zhou, N., Mei, Y., Li, X., Chen, B., Huang, W.Q., Rasouli, V., Zhao, H.J., and Yuan, Z.J, 2020. Numerical Simulation of the Influence of Vent Conditions on Hydrogen Flame Propagation. Combustion Science and Technology. ISSN: 0010-2202.
- Guana, S., Gholami, R., Raza, A., Rabiei, M., Fakhari, M., Rasouli, V., and Nabinezhad, O., 2020. A nanoparticle based approach to improve filtration control of water based muds under high pressure high temperature conditions. Petroleum, Vol. 6, Issue 1, p.p. 43-52.
- Zhang, K., Cha, J.H., Kirlikovalie, K.O., Ostadhassan, M., Rasouli, V., Farhae, O.K., Jang, H.W., Varma, R.S., and Shokouhimehr, M. Pd modified prussian blue frameworks: Multiple electron transfer pathways for improving catalytic activity toward hydrogenation of nitroaromatics. Molecular Catalysis Volume 492.

2019

Raza, A., Gholami, R., Rasouli, V., Rezaee, R., Bing, C.H., and Nagarajan, R., 2019. Chapter 1. An Introduction to Carbon Capture and Storage Technology. From: Membrane Technology for CO_2 Sequestration and Separation. ISBN: 13: 978-1-138-50450-9.

E Bakhshi, V Rasouli, A Ghorbani, MF Marji, B Damjanac, X Wan, 2019. Lattice numerical simulations of lab-scale hydraulic fracture and natural interface interaction. Rock Mechanics and Rock Engineering 52 (5), 1315-1337.

R Ashena, G Thonhauser, A Ghalambor, V Rasouli, R Manasipov, 2019. Determination of Maximum Allowable Safe-Core-Retrieval Rates. SPE Reservoir Evaluation & Engineering 22 (02), 548-564.

A Raza, R Gholami, M Rabiei, V Rasouli, R Rezaee, 2019. Greenhouse Gas Emissions and Energy Transition in Pakistan. International Journal of Big Data Mining for Global Warming, 1950006.

A Raza, R Gholami, M Rabiei, V Rasouli, R Rezaee, 2019. Injection rate estimation to numerically assess CO_2 sequestration in depleted gas reservoirs. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 1-10.

E Bakhshi, V Rasouli, A Ghorbani, M Fatehi Marji, 2019. Lattice numerical simulations of hydraulic fractures interacting with oblique natural interfaces. International Journal of Mining and Geo-Engineering 53 (1), 83-89.

A Tohidi, A Fahimifar, V Rasouli, 2019. Effect of non-Darcy Flow on induced stresses around a wellbore in an anisotropic in-situ stress Field. Scientia Iranica 26 (3), 1182-1193.

E Bakhshi, V Rasouli, A Ghorbani, M Fatehi Marji, 2019. Hydraulic fracture propagation: analytical solutions versus Lattice simulations. Journal of Mining and Environment 10 (2), 451-464.

J Wang, H Song, V Rasouli, J Killough, 2019. An integrated approach for gas-water relative permeability determination in nanoscale porous media. Journal of Petroleum Science and Engineering 173, 237-245.

A Raza, R Gholami, G Meiyu, V Rasouli, AA Bhatti, R Rezaee, 2019. A review on the natural gas potential of Pakistan for the transition to a low-carbon future. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects.

A Raza, R Gholami, R Rezaee, V Rasouli, M Rabiei, 2019. Significant aspects of carbon capture and storage–A review. Petroleum 5 (4), p.p. 335-340.

A Raza, R Gholami, R Wheaton, M Rabiei, V Rasouli, R Rezaee, 2019. Primary recovery factor as a function of production rate: implications for conventional reservoirs with different drive mechanisms. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects.

B Tokhmechi, J Nasiri, H Azizi, M Rabiei, V Rasouli, 2019. Wavelet Neural Network: A Hybrid Method in Modeling Heterogeneous Reservoirs. International Journal of Mining and Geo-Engineering 53 (2), 203-211.

A Raza, R Gholami, M Rabiei, V Rasouli, R Rezaee, N Fakhari, 2019. Impact of geochemical and geomechanical changes on CO_2 sequestration potential in sandstone and limestone aquifers. Greenhouse Gases: Science and Technology 9 (5), 905-923.

CX Liew, R Gholami, M Safari, A Raza, M Rabiei, N Fakhari, V Rasouli, 2019. A new mud design to reduce formation damage in sandstone reservoirs. Journal of Petroleum Science and Engineering 181, 106221.

B Tokhmechi, V Rasouli, H Azizi, M Rabiei, 2019. Hybrid clustering-estimation for characterization of thin bed heterogeneous reservoirs. Carbonates and Evaporites 34 (3), 917-929.

A Boualam, S Djezzar, V Rasouli, M Rabiei, 2019. 3D Modeling and Natural Fractures Characterization in Hassi Guettar Field, Algeria. 53rd US Rock Mechanics/Geomechanics Symposium.

F Badrouchi, N Badrouchi, M Rabiei, V Rasouli, 2019. Estimation of Elastic Properties of Bakken Formation Using an Artificial Neural Network Model. 53rd US Rock Mechanics/Geomechanics Symposium.

S Djezzar, V Rasouli, A Boualam, M Rabiei, 2019. A New Method for Reservoir Fracture Characterization and Modeling Using Surface Analog. 53rd US Rock Mechanics/Geomechanics Symposium.

S Djezzar, V Rasouli, A Boualam, M Rabiei, 2019. Size Scaling and Spatial Clustering of Natural Fracture Networks Using Fractal Analysis. 53rd US Rock Mechanics/Geomechanics Symposium.

N Djabelkhir, X Song, X Wan, O Akash, V Rasouli, B Damjanac, 2019. Notch Driven Hydraulic Fracturing in Open Hole Completions: Numerical Simulations of Lab Experiments. 53rd US Rock Mechanics/Geomechanics Symposium.

F Badrouchi, X Wan, I Bouchakour, O Akash, V Rasouli, B Damjanac, 2019. Lattice Simulation of Fracture Propagation in the Bakken Formation. 53rd US Rock Mechanics/Geomechanics Symposium.

X Wan, V Rasouli, B Damjanac, M Torres, D Qiu, 2019. Numerical simulation of integrated hydraulic fracturing, production and refracturing treatments in the Bakken formation.53rd US Rock Mechanics/Geomechanics Symposium.

2018

Bakhshi, E., Rasouli, V., Ghorbani, A. et al. Rock Mech Rock Eng (2018). https://doi.org/10.1007/s00603018-1671-2.

Gholami, R., Rabiei, M., Aadony, B., and Rasouli, V., 2018. A methodology for wellbore stability analysis of drilling into presalt formations: A case study from southern Iran. Journal of Petroleum Sci. & Eng. 167 (2018) 249–261.

Guan, O.S., Gholami, R., Raza, A, Rabiei, M., Fakhari, N., Rasouli, V., and Nabinezhad, O., 2018. A nanoparticle-based approach to improve filtration control of water based muds under high pressure high temperature conditions, Petroleum. doi: https://doi.org/10.1016/j.petlm.2018.10.006.

Raza, A., Gholami, R., Rezaee, R., Rasouli, V., Bhatti, A., A., and Bing, C., H., 2018. Suitability of depleted gas reservoirs for geological CO_2 storage: A simulation study. Greenhouse Gas Sci Technol. 0:1–22 (2018); DOI: 10.1002/ghg.

Raza, A., Gholami, R., Meiyu, G., Rasouli, V., and Bhatti, A., A., 2018. A review on the natural gas potential of Pakistan for the transition to a low-carbon future. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. https://doi.org/10.1080/15567036.2018.1544993.

Raza, A., Meiyu, G., Gholami, R., Rezaee, R., Rasouli, V., Sarmadivaleh M., Bhatti, A., A., 2018. Shale gas: A solution for energy crisis and lower CO_2 emission in Pakistan. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. https://doi.org/10.1080/15567036.2018.1544993.

Wang J., Song, H., Rasouli V., Killough, J., 2018. An integrated approach for gas-water relative permeability determination in nanoscale porous media. Journal of Petroleum Science and Engineering. Volume 173, February 2019, Pages 237-245.

Tokhmechi, B., Rasouli, V., Azizi, H., and Rabiei, M., 2018. Hybrid clustering-estimation for characterization of thin bed heterogeneous reservoirs. Carbonates and Evaporites. https://doi.org/10.1007/s13146-018-0435-0.

Ashena, R., Thonhauser, G., Ghalambor, A., Rasouli, V. & | Manasipov, R., 2018. Determination of Maximum Allowable Safe Core Retrieval Rates. SPE-189480-MS. SPE International Conference and Exhibition on Formation Damage Control, 7-9 February, Lafayette, Louisiana, USA.

Tokhmechi, B., Nasiri, J., Azizi, H., Rabiei, M., and Rasouli, V., 2018. Wavelet Neural Network: A Hybrid Method in Modeling Heterogeneous Reservoirs. International Journal of Mining and Geo-Engineering.

Tokhmechi, B., Azizi, H., Rabiei, M., and Rasouli, V., 2018. A New 2D Block Ordering System for Wavelet-Based Multi Resolution Up-Scaling. International Journal of Mining and Geo-Engineering.

Tokhmechi, B., Rasouli, V., Azizi, H., and Rabiei, M., 2018. Hybrid clustering-estimation for characterization of thin bed heterogeneous. Carbonates Evaporites. DOI 10.1007/s13146-018-0435-0.

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EDUCATION

PhD, Reservoir Engineering-Applied Statistics May 2007 – July 2012
Curtin University of Technology, Perth, Australia
MSc, Advanced Information Technology Oct 1999 – Mar 2002
London South Bank University, London, England
BSc, Mining Engineering Oct 1994 – Oct 1998
Amirkabir University of Technology, Tehran, Iran

PROFESSIONAL HISTORY

ASSISTANT PROFESSOR, University of North Dakota Mar 2015 – Present
ASSOCIATE LECTURER, Curtin University June 2014 – Mar 2015
SESSIONAL ACADEMIC, Curtin University Feb 2009 – June 2010
ACADEMIC POLICY AND RESEARCH ANALYST, Tehran University, Iran Aug 2005 – Aug 2006
STRATEGIC RESEARCH ANALYST, Iranian Institute of Minerals Research & Application Sep 2004 – Aug 2005
PROJECT ANALYST/COMMERCIAL MANAGER, Aria Paper & Film Industries, Iran Sep 2003 – Sep 2004
PROJECT OFFICER, Zaminkav Gostar Consulting Company Jan 2003 – Sep 2003

FUNDED GRANTS

Year	Title	Agency	Amount
2021	Advanced Autonomous Systems for Industries	NSF EPSCoR Track II	Senior Personnel $3,999,979 (Pending)
2020	NDIC Funding to Support Research of Petroleum Engineering Program at University of North Dakota (UND)	NDIC	Co-PI $2,788,000
2019	Refracturing, Data Mining and CO2 EOR Research Studies in Unconventional Reservoirs	NDIC	Co-PI $400k in 2019
2019	Hydraulic Fracturing Project	SINOPEC	Co-PI $220k
2018	A Case-Based Reasoning Approach for Harnessing Big Data in Unconventional Petroleum Projects	UND Early Career Research Award	PI $20,000
2018	Enhancing Regulatory Compliance by Capitalizing on Big Data Analytics and Artificial Intelligence: A Mutually Beneficial Regulators-Industry Collaboration	UND Energy & Environmental Sustainability-White Papers	PI $8,500
2017	An Integrated Software Package for Data Processing, Modelling and Simulation of Unconventional Reservoirs	Research North Dakota Venture Grant	PI $100,000
2017	A New Approach to Quantifying Adsorption/Diffusion Characteristics of Shale Formations through 3D Printing Technology	ACS (American Chemical Society)	C-PI $110,000

2017	Simulation of Hydraulic Fracturing and Re-fracturing Operations to Enhance Oil Production from Bakken and Three Forks Formations	Research North Dakota	Co-PI $300,000
2016	Postdoc Funding Program	VP Res & Econ Dev	PI $60,000
2016	iPELAB: A Technology-Based Teaching and Learning Approach for Petroleum Engineering Teaching Labs	FDIC Summer SIDP	Co-PI $8,000
2016	An Integrated Software Package for Data Processing, Modelling and Simulation of Unconventional Reservoirs	Research North Dakota – Venture Grant	PI $100,000
2016	Simulation of Hydraulic Fracturing and Re-fracturing Operations to Enhance Oil Production from Bakken and Three Forks Formations	Research North Dakota	Co-PI $300,000
2015	EPSCoR Startup Fund for new Faculty	ND EPSCoR Startup fund	$150,000

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Appendix K: Vendors Quotation

Techbox Systems

Document Title	**Quotation - Dynamic Scale Loop (H200/H400)**
Client	University of North Dakota
Document Number	1818
Number of Pages	8
Client Contact	Nadhem Ismail
Author	James Preston

Issue Number	Issue Date	Details
1	28/05/21	Proposal

Techbox Systems Limited, Aspen Lodge, Braemar Road, Ballater, Aberdeenshire AB35 5RQ UK Tel +44(0)1339 755856

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1 Introduction

Originally formed in 1998 as Sky High Services to design and manufacture specialist laboratory equipment, Techbox Systems has gained valuable experience building bespoke test equipment primarily, but not exclusively, for laboratories in the oil and water industries. With over 20 years specialist knowledge of equipment to test scale deposition and wax in these industries. Techbox also provide a bespoke design and manufacture service in addition to repair, maintenance and calibration services.

We are well known within the oil industry with various major clients.

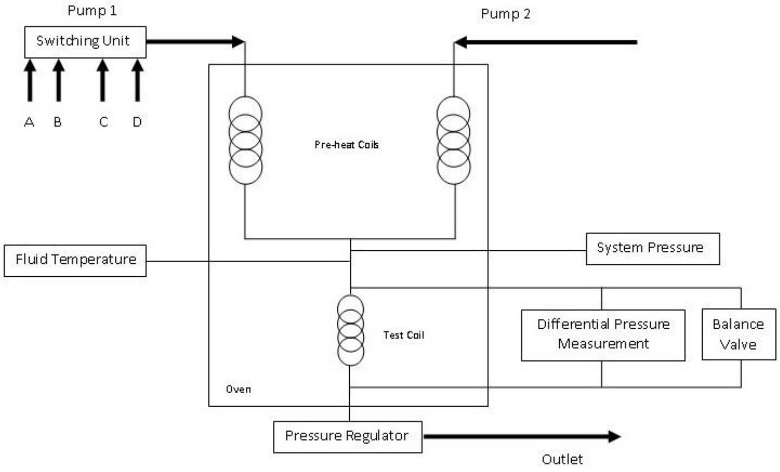
2 Description

Techbox Systems latest Dynamic Scale Loop (DSL) H200/H400 utilises our latest software to fully control and automate the testing process. In the standard machine two pumps are used to mix the brines. One pumps the Cation, the other is fed from a switching unit which can provide either Anion, Anion with inhibitor or cleaning solutions.

This enables a series of automatic tests to be undertaken. Initially a high concentration of inhibitor is mixed with the anion and run for a set period of time. If the test coil does not block the test is re-run with a lower concentration of inhibitor, this is repeated until the differential pressure increases indicating the test coil starting to block with scale. From this the MIC can be calculated.

The program can also be set to perform a pre-scale prior to the test run.

Once the test has completed the system can automatically clean itself.



H200/H400 Schematic

Techbox Systems

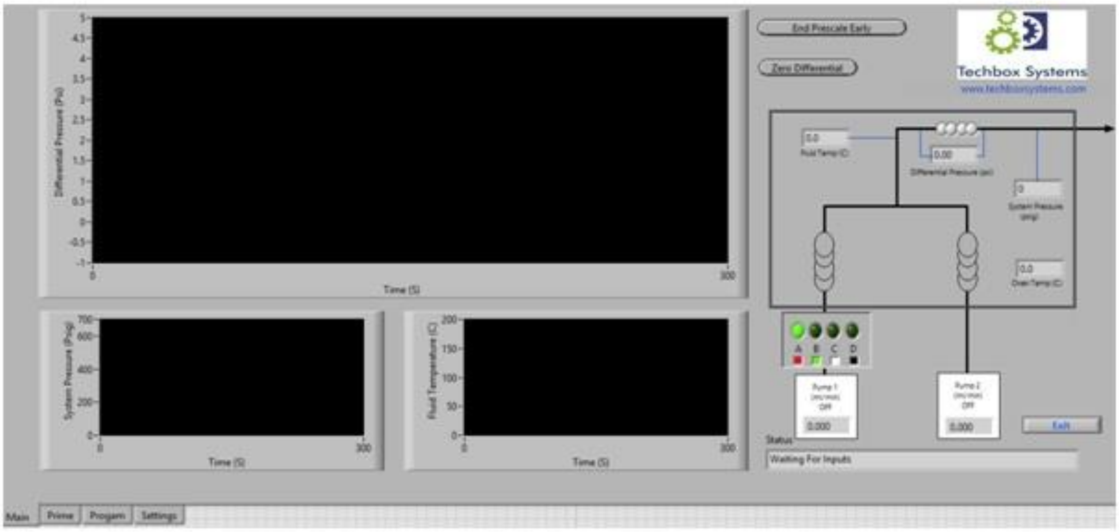
H200/H400 (optional 3rd pump shown)

3 Pumps

Two HPLC pumps are utilised, both fully controlled from the PC. Each with a maximum flow rate of 10 ml/min (20ml/min system total) and a standard pressure of 200 bar (2900 psi) H200 and 400 bar (5800 psi) H400.

4 Software/Hardware

Our latest software is utilised (as shown below) incorporating a full schematic and the ability to save run details thus removing the need to input flow rates/times for each test, this we believe to be a first in the industry. This is linked to high accuracy logging and control hardware.



H200/H400 Software

5 Solenoid Valve

A Solenoid valve is incorporated in the system to protect the differential transducer from damage. This is controlled by the software to open in the event of the coil becoming severely blocked.

6 Transducers

Two transducers are utilised; a highly accurate differential unit which detects the slightest change in pressure across the test coil and also a system transducer monitoring the overall pressure.

7 Safety

The unit is constructed with safety in mind. The pumps contain over pressure circuitry in addition to pressure relief valves built into the flow system.

8 Oven

As standard, tests can be undertaken up to 250°C. (Higher available on request)

9 Temperature

The system contains two accurate temperature probes, one measuring oven temperature and the other the fluid temperature. Both are displayed and recorded on the PC.

10 Dimensions/Power Requirement

The overall footprint of the standard unit is approximately 130cm x 60cm

The standard power requirement is 240V or 110V (240V 50Hz 2500W (Max))

11 Coils

The oven contains two pre-heat coils and one test coil. Each pre-heat coil is 2M x 1/8" od. The test coil is 1M x 1/16" od (1mm id). Standard coils are 316 stainless steel. Alloy 400 (Monel) is an option for the pre-heat coils and fittings within the oven.

12 Costs (All UK Pounds)

The standard two pump H200 unit supplied with computer and software pre-installed (200bar, 2900psi)	£35,600
The standard two pump H400 unit supplied with computer and software pre-installed (400bar, 5800psi)	£41,400

50% payment with order, 50% on shipping.

Options

Spares pack Containing various pump spares, coils and fittings	£1,500
Packaging / freight (CIF) (Customer can arrange collection if preferred)	@ Cost
Inline PH measurement in low pressure outlet	£1,400
Alloy 400 (Monel) Pre-heat coils and fittings in heated areas	£2,200
3rd Pump option Including additional pre-heat coil and safety PRV	£4,200

Delivery

Shipping for standard H200/H400 is currently approximately 4 to 6 weeks from receipt of formal order and initial payment.

Techbox Systems

TERMS AND CONDITIONS

1. Definitions

Buyer	the person who buys or agrees to buy the goods from the Seller.
Conditions	the terms and conditions of sale as set out in this document and any special terms and conditions agreed in writing by the Seller.
Goods	the articles which the Buyer agrees to buy from the Seller.
Price	the price for the Goods, excluding VAT and any carriage, packaging and insurance costs.
Seller	means Techbox Systems Ltd of Braemar Road Ballater.

2. Conditions

2.1 These Conditions shall form the basis of the contract between the Seller and the Buyer in relation to the sale of Goods, to the exclusion of all other terms and conditions including the Buyer's standard conditions of purchase or any other conditions which the Buyer may purport to apply under any purchase order or confirmation of order or any other document.

2.2 All orders for Goods shall be deemed to be an offer by the Buyer to purchase Goods from the Seller pursuant to these Conditions.

2.3 Acceptance of delivery of the Goods shall be deemed to be conclusive evidence of the Buyer's acceptance of these Conditions.

2.4 These Conditions may not be varied except by the written agreement of [a director of] the Seller.

2.5 These Conditions represent the whole of the agreement between the Seller and the Buyer. They supersede any other conditions previously issued.

3. Price

The Price shall be the price quoted on the Seller's confirmation of order. The Price is exclusive of VAT and any other relevant taxes, which shall be due at the rate in force on the date of the Seller's invoice.

4. Payment and Interest

4.1 Payment of the Price and VAT shall be due within [30] days of the date of the Seller's invoice.

4.2 Interest on overdue invoices shall accrue from the date when payment becomes due calculated on a daily basis until the date of payment at the rate of [8%] per annum above the Bank of England base rate from time to time in force. Such interest shall accrue after as well as before any judgment.

4.3 The Buyer shall pay all accounts in full and not exercise any rights of set-off or counter-claim against invoices submitted by the Seller.

5. Goods

The quantity and description of the Goods shall be as set out in the Seller's confirmation of order.

6. Warranties

The Seller warrants that the Goods will at the time of delivery correspond to the description given by the Seller in the confirmation of order. [Except where the Buyer is dealing as a consumer (as defined in section 12 of the Unfair Contract Terms Act 1977), all other warranties, conditions or terms relating to fitness for purpose, quality or condition of the Goods are excluded]. The warranty is offered only on a return to base basis for a period of 12 months.

7. Delivery of the Goods

7.1 Delivery of the Goods shall be made to the Buyer's address. The Buyer shall make all arrangements necessary to take delivery of the Goods on the day notified by the Seller for delivery.

7.2 The Seller undertakes to use its reasonable endeavours to despatch the Goods on an agreed delivery date, but does not guarantee to do so. Time of delivery shall not be of the essence of the contract.

7.3 The Seller shall not be liable to the Buyer for any loss or damage whether arising directly or indirectly from the late delivery or short delivery of the Goods. If short delivery does take place, the Buyer undertakes not to reject the Goods but to accept the Goods delivered as part performance of the contract.

7.4 If the Buyer fails to take delivery of the Goods on the agreed delivery date or, if no specific delivery date has been agreed, when the Goods are ready for despatch, the Seller shall be entitled to store and insure the Goods and to charge the Buyer the reasonable costs of so doing.

7.5 All delivery times are ex-works.

8. Acceptance of the Goods

8.1 The Buyer shall be deemed to have accepted the Goods [48 hours] after delivery to the Buyer.

8.2 The Buyer shall carry out a thorough inspection of the Goods within [48 hours] of delivery and shall give written notification to the Seller within 5 working days of delivery of the Goods of any defects which a reasonable examination would have revealed.

8.3 Where the Buyer has accepted, or has been deemed to have accepted, the Goods the Buyer shall not be entitled to reject Goods which are not in accordance with the contract.

9. Title and risk

9.1 Risk shall pass on delivery of the Goods to the Buyer's address.

9.2 Notwithstanding the earlier passing of risk, title in the Goods shall remain with the Seller and shall not pass to the Buyer until the amount due under the invoice for them (including interest and costs) has been paid in full.

9.3 Until title passes the Buyer shall hold the Goods as a custodian for the Seller and shall store or mark them so that they can at all times be identified as the property of the Seller.

9.4 The Seller may at any time before title passes and without any liability to the Buyer:

9.4.1 repossess and dismantle and use or sell all or any of the Goods and by doing so terminate the Buyer's right to use, sell or otherwise deal in them; and

9.4.2 for that purpose (or determining what if any Goods are held by the Buyer and inspecting them) enter any premises of or occupied by the Buyer.

9.5 The Seller may maintain an action for the price of any Goods notwithstanding that title in them has not passed to the Buyer.

10. Carriage of Goods

Carriage will be chargeable on all sales at cost (packaging + freight) +10%.

11. Notes

All components within our products comply with current European standards. It is the customers responsibility to ensure this is suitable for their needs. It is the responsibility of the operator to ensure that the equipment is operated in a safe manner, especially with respect to chemical testing where hazardous gases can be produced.