TECHNICAL REVIEWERS' RATING SUMMARY

G-020-B

Enhanced Oil Recovery from the Bakken Shale Drainage Using Surfactant Imbibition Coupled with Gravity

Comment: Enhanced Oil Recovery from the Bakken Shale Using Surfactant Imbibition Coupled with Gravity Drainage

Submitted by University of North Dakota

Principle Investigators: Dongmei Wang

Request for $245,929; Total Project Costs $819,763

Rating Category	Weighting Factor	Technical Reviewer 20B-01	20B-02	20B-03	Average Weighted Score
Objective	9	4	3	4	33.0
Availability	9	5	3	3	33.0
Methodology	7	2	3	3	18.7
Contribution	7	2	3	4	21.0
Awareness	5	2	3	4	15.0
Background	5	4	4	5	21.7
Project Management	2	3	4	2	6.0
Equipment Purchase	2	4	4	1	6.0
Facilities	2	4	3	4	7.3
Budget	2	3	4	3	6.7
Average Weighted Score		167	161	177	**168.3**
Maximum Weighted Score					**250**

OVERALL RECOMMENDATION

FUND			
FUNDING TO BE CONSIDERED	**X**	**X**	**X**
DO NOT FUND			

Section B. Ratings and Comments:

1. The objectives or goals of the proposed project with respect to clarity and consistency with North Dakota Industrial Commission/Oil and Gas Research Council goals are: 1 – very unclear; 2 – unclear; 3 – clear; 4 – very clear; or 5 – exceptionally clear.

Reviewer 20B-01 (Rating: 4)

The objectives of the project are adequately stated.

Reviewer 20B-02 (Rating: 3)

More detail could be added on how they are structuring the field trials. Do they have some operators that wish to try the technique on an existing well? How do they plan to establish a control to determine if the technique provides incremental production gains?

Comment: Hess Corporation will participate in this project by reviewing results, providing core samples and direction to the project, and ultimately, if the research results look promising, consider applying the new technology in their wells (please see the support letter from Hess attached). We also intend to get one or more additional producers to participate.

Concerning the issue of control (or baseline for comparison) raised by Reviewer 20B-02, our laboratory experiments will provide a ranking of solutions and characteristics that promote imbibition and oil recovery versus those that do not. For the field applications, the exact basis for judgment of success will be established in cooperation with the field operator. Certainly, our ultimate goal is to enhance production rate. We plan to work with the field operator to develop tests for side-by-side comparison of surfactant and brine water. In view of field expenditures, the particular field operator will play a major role in deciding how many variations of the process can be field tested.

Reviewer 20B-03 (Rating: 4)

The goal of increasing oil production in the Bakken Formation by introduction of a surfactant is very straightforward.

2. With the approach suggested and time and budget available, the objectives are: 1 – not achievable; 2 – possibly achievable; 3 – likely achievable; 4 – most likely achievable; or 5 – certainly achievable.

Reviewer 20B-01 (Rating: 5)

No Comment

Reviewer 20B-02 (Rating: 3)

The goals would appear to be achievable. The field study could present problems with cost overruns.

Comment: Except for the time/salaries associated with the listed PI and project personnel, any money spent on actual field implementation will be provided by our industrial participants. The proposed project money will be spent on laboratory work, simulation model development, and gathering of field data from interested operators. Any money that will be spent on actual field implementation (i.e., acquisition of wells, surface facilities, and chemicals to be injected) will be separate from this specific project. We feel very comfortable that no cost overruns will occur. We assume that the funding agencies would not allow any cost overruns.

Reviewer 20B-03 (Rating: 3)

The overall project framework is defined, but many aspects of the proposal lack detail. How many Bakken samples will be analyzed, what types of samples (whole core, plugs, etc), the samples will be obtained from which Bakken member(s), and where will they come from within the Williston Basin? This proposal is difficult to evaluate without that level of detail and was downgraded because of it.

Comment: Hess Corporation has agreed to provide us with Bakken cores from their operations in the Williston Basin. We have developed a method to make thin (1-5 mm thick, 25-mm diameter) shale slices that will be used for our initial evaluations. These thin slices will allow us to rapidly determine permeabilities for the low-permeability shales. They will also allow us to quickly assess whether a given formulation (either brine or surfactant formulation) is imbibing (through visual observation). When we identify formulations that appear promising, we will place many (perhaps up to 100) of these thin slices within an Amott cell to rapidly quantify imbibition rates and how much the oil saturation is reduced.

Guidance from Hess and other operators will be followed in determining exactly which parts of the Bakken shale will be evaluated. Currently, Hess has expressed a preference to focus on the Middle member and the associated shale members of Bakken formation.

3. The quality of the methodology displayed in the proposal is: 1 – well below average; 2 – below average; 3 – average; 4 – above average; or 5 – well above average.

Reviewer 20B-01 (Rating: 2)

In light of the project's goals and objectives, which naturally closely parallel those of the O&GRC, the lack of an economic model demonstrating the likely feasibility and value of the technique lessens the guidance and motivation to future workers who will be left with the actual field implementation of the technique should the process model prove promising. Likewise, 3 years is ample time to gain a greater understanding of the practical problems, pitfalls and steps to overcome them that have occurred in existing applications. An inferred implementation plan for field scale testing would be an asset to encourage continuation of work if the process model proves feasible. The staffing of this project seems top-heavy for the deliverables outlined, but that valuable collective experience should be applied to delivering such intellectual products as these.

Comment: We recognize that we must keep economics in mind during our research. Throughout the project, we will continually assess how the chemical costs, observed rates of imbibition, and rates of oil recovery will scale to field applications. Our numerical simulation efforts, in particular, will be directed at judging the economic viability of our new processes.

We understand that NDIC wants to encourage field development of the science and technology that we develop. We will keep this high within our awareness throughout this project. We currently have commitments from Hess, Tiorco/Stepan, and Champion to provide technical guidance of the project and to look for good opportunities for field application. We fully intend to make other North Dakota operators aware of our progress and to get them involved with our project, if appropriate. Of course, the implementation of field testing will have to evolve during the project.

Reviewer 20B-02 (Rating: 3)

The outlined lab experimentation looks very reasonable.

Reviewer 20B-03 (Rating: 3)

Methodology is not detailed to the degree that it should be. For example, are the cores to be tested in permeameters, column studies, etc? How is the gravity drainage aspect investigated? Is this simply gravity drainage of a solution through a rock column in a confined testing apparatus?

Comment: We recently purchased a special ISCO model 100DX pump. This pump can provide extremely accurate flow rates (over a very wide range) and pressures (up to 10000 psi). This pump is thermo-jacketed to provide fluids at whatever temperature that we desire (e.g., over 100 ˚C). We have also developed a core holder and method for accurately measuring oil or brine permeabilities for our shale samples. This apparatus will be used both to saturate our cores and measure flow properties. We believe that it is more accurate and versatile than other methods that

are currently available for characterizing the flow properties in Bakken shale. Of course, gravity drainage will be extremely slow from a nano-darcy to micro-darcy shale. We do not expect gravity to play an important role within the shale itself. The gravity drainage aspects will be evaluated for fluids within the fracture system using numerical simulation. The experimental studies will focus on determining and maximizing imbibition and oil displacement studies from the shale.

The last sentence on page 12 states "numerical simulation models will be set up to verify the core flooding results, …..". It is improper science to verify lab results with a model.

Comment: Reviewer, 20B-03 is correct. We should have said "scale the coreflooding results..." instead of "verify the core flooding results..."

I just arrived from China last July and my English is still pretty rusty. I will work hard to improve it.

What formula or formulas will the lab results be plugged into?

Comment: The key formulas to be used for the core studies will be (1) the Darcy equation and (2) literature correlations for imbibition rates.

Is a goniometer the most accurate method available when measuring water-oil contact angles?

Comment: Reviewer 20B-03 may be correct in their concern about the utility of the goniometer. We noted that Mohanty and Austad found it useful, so we thought it would be worth a try. Of course, if the method is not found to be useful, we will focus on other methods, especially the Amott method.

The numerical model should be dropped from this proposal. If the lab tests are successful, a follow up proposal requesting funding for the numerical model could be submitted to the Council.

Comment: We appreciate that our proposal is ambitious and we understand the suggestion to focus the work on the experimental portion. However, we feel that the simulation studies will provide very valuable guidance to the experimental program. By using simulation to scale up our laboratory results, we can rapidly determine whether our findings are in the right ball park for a potential field application.

4. The educational contribution of the proposed work to specifically address North Dakota Industrial Commission/Oil and Gas Research Council goals will likely be: 1 – extremely small; 2 – small; 3 – significant; 4 – very significant; or 5 – extremely significant.

Reviewer 20B-01 (Rating: 2)

See comment under item 3. The project's findings as proposed have the potential for significance; however, there are the deficiencies noted above that decrease the likelihood of this information being used to proceed to application. The applying agency will likely verbally present results at venues that may or may not attract sufficient interest to fund the next phase – either through them or otherwise. The insight referred to in the comment above should be presented in a more permanent and tangible form. Again, the strengths of the human resources planned for this project seem underutilized in the present proposal.

Comment: For Reviewer 20B-01 for Question 4, we recognize that we need to have a concerted effort to communicate our results to interested industrial parties and to assimilate their guidance into our work. That is the most efficient path that will lead to effective field application. That is why we have Hess, Tiorco/Stepan, and Champion involved in the project. (Incidentally, we will not be paying for their contributions.) Also, as mentioned earlier, we will try hard to get as many North Dakota operators interested in our work as possible.

Reviewer 20B-02 (Rating: 3)

If the goals are achieved, the contribution could be significant to enhanced recovery in the Bakken.

Reviewer 20B-03 (Rating: 4)

This work would obviously be of significant value if it could contribute towards a means of increasing Bakken production.

5. The principal investigator's awareness of other current educational efforts being conducted by other persons or entities related to the proposal is: 1 – very limited; 2 – limited; 3 – adequate; 4 – better than average; or 5 – exceptional.

Reviewer 20B-01 (Rating: 2)

I assume from the PI's background that familiarity with unpublished research and those individuals and organizations conducting research related to the proposal is evidently more extensive than the text of this proposal suggests. This project needs to be materially strengthened by utilizing all available human knowledge to "model" all aspects of a likely positive outcome of this phase. Extensive interaction with researchers and the people actually implementing the technology elsewhere in the world is vital to this project. If this level of PI knowledge isn't in place prior to this proposal, a plan to gain and model this information to the greatest degree possible should a task of the proposal. It is an appropriate and crucial step that would merit inclusion. Its inclusion wouldn't reflect negatively on the PI but would, instead, would reflect wisdom and full insight into the ultimate project goal. These criticisms suggest that the project application may have far more potential than is shown and proposed by its present form.

Comment: Concerning Question 5, the three reviewers were concerned about our awareness of previous work with imbibition in fractured systems. This criticism has a degree of truth that we will work hard to rectify. Since our primary experience is in enhanced oil recovery, we cannot claim to be intimately familiar with efforts in ground-water remediation. We are aware that Hiraski and Pope and others have performed "traditional" displacement-type surfactant floods for ground-water remediation, but were not aware of an imbibition focus.

We are also aware of a large body of work on surfactant flooding in general for oil recovery. In fact, the PI was actively involved with some of the largest field surfactant and ASP floods in the Daqing field in China. However, imbibition was not a dominant theme during most of that work.

We are aware of a large body of literature on imbibition and wettability, especially the work of Norm Morrow, Jill Buckley and their associates. However, most of that work was directed at more permeable formations.

The primary literature that we are familiar with that is directly applicable to surfactant imbibition in very low permeability formations is that of Mohanty, Hirasaki, and Austad. As the reviewers suggest, we will work hard during our project to learn of all relevant work by others in these areas. If you have specific literature sources that we missed, we would greatly appreciate learning of them.

Thank you for you kind comments.

Reviewer 20B-02 (Rating: 3)

I would like to have seen more detail on the prior use of surfactants in other fractured formations.

Comment: Please refer to 20B-01.

Reviewer 20B-03 (Rating: 4)

They have referenced international papers that have attempted or are attempting to introduce surfactants into oil reservoirs (chalks, etc). I would have rated this area as excellent had they referenced papers where surfactants have been successfully used in groundwater remediation. Information derived from groundwater remediation studies in fractured aquifers may be applicable.

Comment: Please refer to 20B-01.

6. The background of the investigator(s) as related to the proposed work is: 1 – very limited; 2 – limited; 3 – adequate; 4 – better than average; or 5 – exceptional.

Reviewer 20B-01 (Rating: 4)

Better than average bordering on exceptional

Reviewer 20B-02 (Rating: 4)

The investigators certainly appear to be qualified.

Reviewer 20B-03 (Rating: 5)

Wang is a leader in her field; Drs. LeFever and Gosnold have strong backgrounds relating to subsurface research in the Williston Basin.

7. The project management plan, including a well-defined milestone chart, schedule, financial plan, and plan for communications among the parties involved in the project . is: 1 – very inadequate; 2 – inadequate; 3 – adequate; 4 – very good; or 5 – exceptionally good.

Reviewer 20B-01 (Rating: 3)

No plan or system outline for coordination and interaction among the investigators is formalized. It can be assumed that such interaction occurs but that assumption cannot be taken for granted in any organization. Clearer specification of deliverables (referred to as tasks in this section) in addition to their completion as milestones is needed to materially improve the chart, Table 1, and understanding of the contractural terms of the proposed award. This portion is adequate bordering on inadequate.

Comment: Concerning Question 7, we appreciate the criticisms from the reviewers about the lack of clarity on the project management plan. We apologize for that. Some of this is still developing. My current thoughts are as follows: We hope to hear favorable responses from NDIC and RPSEA by March or April. If accepted, soon after contracting, we will have a "kick-off" meeting with all interested parties in Grand Forks. That meeting will involve all listed project personnel, the funding agencies, Hess, Tiorco/Stepan, Champion, and any other interested party. Thereafter, we will provide quarterly reports. At least once per year, we will provide a project review (also held in Grand Forks).
We fully expect a number of trips where the PI will travel to Houston, Austin, Socorro, Laramie, certain North Dakota locations and/or other places to discuss issues that are directly related to the project. We expect visiting scientists and

engineers from the various participating organizations to come to Grand Forks also. However, these trips are not formalized yet.

Concerning communication between the University of North Dakota participants, the PI will take responsibility for effective communication. We are a small, close-knit group, so month-to-month communications will be very common. If formal, regular (e.g., weekly) meetings are necessary, we will implement whatever process is most efficient to make good progress. In addition to relying on their expertise in the areas of geology, chemistry, and engineering, the senior-level personnel have valuable industrial contacts that will considerably help in disseminating our results, in obtaining project guidance, and ultimately in facilitating field applications.

Reviewer 20B-02 (Rating: 4)

The time line schedule appears to be detailed. Will preliminary findings be released as major milestones are obtained?

Comment: Please refer to 20B-01.

Reviewer 20B-03 (Rating: 2)

The schedule chart documents the hours per individual per quarter, but there is no discussion on the plans for communication between the Co-PIs. I would like to see a paragraph or two specifically outlining the anticipated contributions from each Co-PI regarding the selection of cores, evaluation of various results, etc. How will the four Co-PIs spend 2 ½ weeks per year on this project, in monthly meetings, quarterly meetings, reviewing lab results, etc? The hard tasks and responsibilities are outline in the proposal, but not described.

Comment: Please refer to 20B-01.

8. The proposed materials and media to be developed or used are: 1 – very inadequate; 2 – inadequate; 3 – adequate; 4 – very good; or 5 – exceptionally good.

Reviewer 20B-01 (Rating: 4)

Equipment usage seems reasonable and cannot be evaluated further due to this reviewer's lack of familiarity with the experimental methodologies proposed.

Reviewer 20B-02 (Rating: 4)

I assume most of the lab equipment already exists.

Reviewer 20B-03 (Rating: 1)

$6,000 is shown for equipment in year 1 on Table 2, but equipment is not mentioned in the text of the proposal. Although this purchase would represent only a small percentage of the overall budget, I had to give it the lowest possible rating because the purchase was not explained or justified.
Comment:

Comment: Concerning Question 8, because of space limitations, we did not include the detailed equipment list. Through the generosity of the University of North Dakota, we have already obtained an ISCO 100 DX pump, our core holder, equipment/glassware for Amott cells, a Brookfield viscometer, vacuum pump, pH meter, glassware, tubing, and fittings, and a number of other necessary items. The $20000 that we included in the equipment budget of the proposal (of which we hope that $6000 will come from NDIC and $14000 from RPSEA) will be for a spinning drop interfacial tensiometer.

I apologize for not providing this information in the original proposal.

9. The materials and media available and to be purchased for the proposed educational effort are: 1 – very inadequate; 2 – inadequate; 3 – adequate; 4 – notably good; or 5 – exceptionally good.

Reviewer 20B-01 (Rating: 4)

There should be very good material resources available for this project as it is proposed.

Reviewer 20B-02 (Rating: 3)

More investigation on any field equipment for the field trials might be needed.

Comment: Concerning Question 9, Reviewer 20B-02, please recognize that the currently proposed funding for this project will not involve any field equipment.

Reviewer 20D-03 (Rating: 3)

I have to assume that the laboratory facilities at the University of North Dakota are well suited for this type of project.

Comment: Please refer to 20B-03 of Question 8.

10. The proposed budget value relative to the outlined work and the financial commitment from other sources is of: 1 – very low value; 2 – low value; 3 – average value; 4 – high value; or 5 – very high value. (See below)

Reviewer 20B-01 (Rating: 3)

Since the funding sought is a fractional interest in the total project budget, greater value due to the synergy of external resources must be assumed. But, the absolute value to O&GRP goals must still be considered. There seems to be an underutilization of the experience and talent funded in this project. The intuitive conclusion is that more could be done with the human resources provided by the budget to 1) address the concerns outlined above and 2) otherwise enhance the deliverables – including possibly taking the project into the initial stages of field tests within the time frame outlined.

Comment: Concerning Question 10 and the comment from Reviewer 20B-01, we understand your concern about optimizing our talent pool to have the greatest impact. In particular, we sense your need to make sure that we are developing a process that can be implemented as rapidly as possible to recover oil from the Bakken formation in North Dakota. We will keep this very high on our priority list.

Reviewer 20B-02 (Rating: 4)

The proposed project could be of high value for enhanced recovery. Even if the technique should be proven to be of limited value or uneconomic, it still should be investigated for merit.

Reviewer 20B-03 (Rating: 3)

Not knowing the number of cores or the number of tests that will be run on each core it is not possible to determine a unit cost and to effectively evaluate the budget value. The cost to the Industrial Commission does not appear exorbitant when you consider that Dr. Wang alone will be donating 80% of her time to this project

Comment: Please refer to 20B-01 of Section 7.

No matching funds are documented for this project. As such, I do not believe the project proposal, as written, is eligible for funding. If they are planning to match it with RPSEA funds the $573,835 in matching funds (total project amount minus request to the Oil and Gas Research Council) should be incorporated into Table 2. If this is indeed the case, than funding from the Oil and Gas Research Council would have to be contingent upon RPSEA awarding an equal or greater amount of funding. If instead they are planning on matching with Center of Excellence funds, those amounts should be shown in Table 2.

Comment: Concerning the comment from Reviewer 20B-03, yes, we also recognize that RPSEA must accept and approve this project before it can go forward. Unfortunately, this is a reality with co-funding of research today--we must submit the proposal to both parties at roughly the same time and hope for the best.

[1] "Value" – The value of the projected work and technical outcome for the budgeted amount of the project, based on your estimate of what the work might cost in research settings with which you are familiar.

<u>Financial commitment from other sources</u> – A minimum of 50% of the total project must come from other sources to meet the program guidelines. Support less than 50% from Industrial Commission sources should be evaluated as favorable to the application.

Section C. Overall Comments and Recommendations:

Reviewer 20B-01

Research effort in the area of this specific topic certainly merits funding and in that general sense the project should be funded. However, a first approximation of an economic model for implementation of the process (assuming of course successful experimental and modeling results), and a review and model, or algorithm, of field application of similar or analogous techniques would be deliverables of comparable value to the process modeling. It is recommended that the proposal be modified to include these deliverables. The greatest value will come to O&GRC if maximum motivation is in place to stimulate industry and other funding sources to test and ultimately bring the technology on line.

Comment: we hope that our comments above show our sensitivity to your concern about rapid transfer of our developments to interested field operators. We promise to do our best!

Reviewer 20B-02

The lab portion of the proposal looks strong. However, I would like to see more detail and planning on the field trial. If the project can be successfully transferred from the lab to the field then I would recommend funding.

Comment: Please refer to 20B-01 of Section C.

Reviewer 20B-03

How much of this work was done on the Bakken in the 1980s or 1990s? Was any applicable work done on the Green River Formation?

Comment: Concerning Overall Comments from Reviewer 20B-03, we are not aware that any of our proposed work has been performed earlier with the Bakken formation. If you are aware of some work, we would certainly be interested in learning of it. We would hope that developments from our project will be applicable to other low-permeability formations.

The general idea of using surfactants to release more oil from the Bakken has merit and the proposed project may be a good way to test this, but the methodologies and Co-PI involvement need to be better defined. As previously noted, this should include the approximate number of cores, the members to be tested, whole cores vs. plugs, the formula or formulas that the will be test results be plugged into, etc.

Comment: We hope that our comments above have provided acceptable additional clarification of our research plans and methodologies. We apologize that space limitations did not allow us to provide enough of this for you in the original proposal.

Will the Bakken shales imbibe fluid?

Comment: That is the key question of our research. We want to do everything that we can to identify fluids that will imbibe.

Should consider SEM analysis of pore throat diameters to further characterize rock.

Comment: Thank you for the suggestion of using SEM analysis. I believe that we have the capability to do this at the University of North Dakota, and we will look into doing this.

Is the gravity drainage scenario suggested on page 9 with the surfactant injected in the lower part of the reservoir and a producer in the upper part of the reservoir valid for an over-pressured reservoir?

Comment: Concerning the question about the validity of our process in an over-pressured reservoir, we recognize that the rate of oil production due to our imbibition process must be compared with the production rate due to the driving force associated with the shale being over-pressured. That will be an important part of our simulation work as well.

Although it did not affect the scoring, the proposal had not been carefully proofed and there were a number of grammatical errors and a handful of sentences that did not make sense.

Comment: Concerning the grammar errors, again, I apologize. As I said, I just arrived from China in July, and English is not my native language. I will work hard to improve!

Finally, we are very grateful to all three reviewers for the excellent and detailed examination of our proposal!

December 11, 2009

Dongmei Wang, PhD
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81 Cornell Street, Stop 8358
Grand Forks, ND, 58202
LETTER OF SUPPORT: Enhanced Oil Recovery from the Bakken Shale Using Surfactant Imbibition Coupled With Gravity Drainage

Dear Dr. Wang:

Hess Cooperation is highly supportive of a phased approach to the research described in the proposed RPSEA Small Producer Program Research Project, "Enhanced Oil Recovery from the Bakken Shale Using Surfactant Imbibition Coupled with Gravity Drainage." We would support the following lab testing as Phase 1:

1. Wettability testing on the Middle Bakken and Three Forks
2. Relative permeability measurements (oil-gas, oil-water)
3. Capillary pressure measurements
4. Geo-mechanical measurement

Methods and technologies to improve oil production from the tight Bakken Formation are worth researching to insure future recoveries are maximized. We feel gathering the basic data will be a good 1st step to your research and that the data gathered is important and of significant interest to Hess and the oil industry. We offer our support and participation in Phase 1. Technological advances that improve production from the complex Middle member and associated shale members of the Bakken by even a small amount have the potential to contribute significantly to world energy supplies in the future.

In support of this project:

1. Hess will provide samples of cores of Bakken materials and samples of oil and formation water from Bakken wells. This is dependant on the availability of core material and priority assigned to the work by Hess. Details of samples needed for research testing (i.e. petrophysical, geomechanical, etc.) and study will be worked out.
2. Hess scientists and engineers are available to advise and participate in this research, review the results, and provide direction for development of the project at various stages

Sincerely,

Nancy Dedora

Nancy Dedora
North Dakota Subsurface Manager
Hess Corporation