Technical Feasibility of Solvent-Assisted Polymer Flooding to Improve Heavy Oil Recovery

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Outline

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Introduction

- Many of heavy oil reservoirs in Western Canada are thin so that thermal recovery techniques are not feasible options for them.

- Some of them were allowed to produce sand during oil production and as the result wormholes were formed.

- Unfavorable mobility ratio is the main parameter responsible for the poor sweep efficiency of waterflooding.

- The current arrangements of injectors and producers, available waterflooding facilities and many other factors are parameters making industry reluctant in choosing any other EOR technique that may need significant investment CAPEX.
Introduction

Therefore, one of the viable options is to improve the conventional waterflooding.

Obviously addition of polymer, which is not a new idea, could be an alternate solution.

However, polymer flooding is sometimes operationally difficult in heavy oil reservoirs due to the high injection pressure required.

In such a case increasing pressure can cause mechanical degradation and irreversible viscosity reduction.
To reduce the potential of mechanical degradation, oil viscosity must be slightly reduced so that lower injection pressure be sufficient.

We believed if solvent be injected after water, oil near the watered-out channels can be contacted and the oil viscosity will be lowered in these areas.

The lower viscosity oil then can be displaced by relatively lower viscosity polymer, leading to improve oil recovery at lower injection pressure.

Subsequent injection of a low-to-medium viscosity polymer can displace the oil and solvent mixture under more feasible operational conditions.
Also, injection of a slug of higher viscosity polymer (or gel) at the end of each stage may cause blockage of the displaced path and therefore allow the next cycle of water and solvent to contact other areas of the reservoir.
The main objective here is to examine the performance and applicability of water-solvent-polymer injection scheme in a heavy oil saturated system as a means of improved heavy oil recovery oil reservoirs.
Experimental Set-up
Experimental Set-up
Experimental Conditions

For all the experiments:

- The physical model (unconsolidated sand pack) is packed under same conditions, such as sand size and packing method, to minimize the initial discrepancy of the model.
- The porosity, permeability and initial oil saturation values were relatively consistent for all the experiments.
- The polymer solution (2000 ppm) used was made of high molecular weight polyacrylamide in 1% brine solution.
- All the experiments were performed at the same temperature, 27°C, which is typical value for Lloydminster region.
<table>
<thead>
<tr>
<th>Oil</th>
<th>Experiment #</th>
<th>Solvent</th>
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<tbody>
<tr>
<td>First Oil Sample</td>
<td>Experiment #1</td>
<td>No Solvent</td>
</tr>
<tr>
<td>(825 cP)</td>
<td>Experiment #2</td>
<td>Pure Carbon Dioxide</td>
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<td></td>
<td>Experiment #3</td>
<td>Pure Propane</td>
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<tr>
<td></td>
<td>Experiment #4</td>
<td>33% C&lt;sub&gt;1&lt;/sub&gt;, 34% C&lt;sub&gt;3&lt;/sub&gt;, 33% CO&lt;sub&gt;2&lt;/sub&gt;</td>
</tr>
<tr>
<td>Second Oil Sample</td>
<td>Experiment #5</td>
<td>Pure Propane</td>
</tr>
<tr>
<td>(5,000 cP)</td>
<td>Experiment #6</td>
<td>33% C&lt;sub&gt;1&lt;/sub&gt;, 34% C&lt;sub&gt;3&lt;/sub&gt;, 33% CO&lt;sub&gt;2&lt;/sub&gt;</td>
</tr>
</tbody>
</table>
Results and Discussions

- Oil Recovery
  - Waterflooding
  - Solvent Flooding
  - Polymer Flooding

- The Effect of Solvent Injection on the Build-Up Pressure of Polymer Flooding
Results and Discussions

- Recovery Factor of Experiment #4
  Water / Solvent / Polymer Flooding
  (Solvent: 33% C\textsubscript{1}, 34% C\textsubscript{3}, 33% CO\textsubscript{2})
Results and Discussions

Each experiment has a Recovery Factor vs. Pore Volume Injected graph with the same production trend:
Results and Discussions

Comparison between Oil Recovery Factor of each experiment

![Bar Chart]

- Exp. #1: 87.94%
- Exp. #2: 86.88%
- Exp. #3: 84.27%
- Exp. #4: 93.9%
- Exp. #5: 93.47%
- Exp. #6: 95.14%
Results and Discussions

Comparison between Oil Recovery Factor of each experiment:

- For the first oil sample (825 cP):
  Experiment #4 with the mixture of 33% $C_1$, 34% $C_3$, 33% $CO_2$ as the solvent showed the highest oil recovery.

- For the second oil sample (5,000 cP):
  Experiment #6 with the same solvent, mixture of 33% $C_1$, 34% $C_3$, 33% $CO_2$, showed the highest oil recovery.

- For all tests utilizing solvent in conjunction with polymer:
  The best performance resulted for the heavier oil system; this could be due in part to the fact that the initial waterflood performed slightly better in the lighter oil system.
Results and Discussions

Comparison between Oil Recovery Factor for first cycle of each Experiment, 825 cP Oil:

![Bar chart showing comparison of oil recovery factors for different methods and solvent types.](chart.png)
Results and Discussions

Comparison between Oil Recovery Factor for first cycle of each Experiment, 5,000 cP Oil:

- Solvent: Pure C3
- Solvent: 33% C1 - 34% C3 - 33% CO2

Waterflooding
Solvent Flooding
Polymer Flooding
Results and Discussions

- **Waterflooding:**
  - The recovery factor for waterflooding part of all the tests for each sample was in the same range, but consistently higher for the lower viscosity oil.
  - By comparing the results produced for waterflooding of the experiments with the same solvent:
    It is obvious that the less viscous oil produced a higher oil recovery factor by 6-10% over the more viscous oil system.
Results and Discussions

Solvent Flooding:

- The observation made during the tests suggested that the addition of propane and methane to the mixture of solvent increased the oil recovery compared to the injection of pure CO$_2$.

- The main objective of solvent flooding for these tests was to use the solvent to reduce the oil viscosity and therefore allowing the low-viscosity polymer to displace the oil and create more production.
Results and Discussions

Polymer Flooding:

For all the experiments conducted, the oil recovery with polymer flooding was higher for the more viscous oil. This behaviour was not expected because the lower oil should have a more favourable mobility ratio between the injected polymer solution and displaced oil.

However these results showed that under the same conditions, the solvent flooding can affect the higher viscosity oil to a greater degree than the less viscous oil.
Results and Discussions

Polymer Flooding:

- By comparing the results produced for polymer flooding of the experiments with the same solvent: It is obvious that the viscous oil produced a higher oil recovery factor by 15% over the less viscous oil system.

- In Experiment #5 and Experiment #6, which were conducted on 5,000 cP oil, polymer flood was able to double the oil recovery in comparison to a baseline waterflood.
Results and Discussions

The Effect of Solvent Injection on the Build-Up Pressure of Polymer Flooding:

- A certain start-up pressure was required to mobilize the trapped oil after waterflooding. The more viscous the oil, the higher the start-up pressure.

- The results obtained from these series of experiments showed that by injecting the solvent before polymer flooding:
  - The polymer requires a lower build-up pressure to initiate recovery
  - The flowing pressure drop after polymer break was much lower
Results and Discussions

- Differential Pressure: Polymer Flooding, Experiment #1
  (Conventional Polymer Flooding)
Results and Discussions

- Differential Pressure: Polymer Flooding, Experiment #2 (Solvent: Pure Carbon Dioxide)
Results and Discussions

- **Differential Pressure: Polymer Flooding, Experiment #3 (Solvent: Pure Propane)**

![Graph showing differential pressure over time for Water/Solvent/Polymer Flooding and Conventional Polymer Flooding.]

- A significant decrease, around 50%, during the build-up pressure by using pure propane as the solvent (825 cP Oil).
Results and Discussions

- Differential Pressure: Polymer Flooding, Experiment #4 (Solvent: 33% C\textsubscript{1}, 34% C\textsubscript{3}, 33% CO\textsubscript{2})

![Graph showing differential pressure over time for Water/Solvent/Polymer Flooding and Conventional Polymer Flooding.]

- The mixture of gases showed a more significant decrease in the build-up pressure compared to that of pure carbon dioxide (825 cP Oil).
Results and Discussions

- A significant decrease, around 50%, during the build-up pressure by using a compositional mixture of 33% C$_1$, 34% C$_3$, 33% CO$_2$ as the solvent (Experiment #6).

- It is obvious from the pressure profiles that using the mixture of gases as the solvent showed a more significant reduction in the build-up pressure compared to that of pure propane as the solvent (Experiment #5 vs. Experiment #6).
Conclusions I

Based on the sets of experiments conducted, under experimental conditions used for heavy oil samples with viscosity 825 cP and 5,000 cP:

- Using cyclic procedure of water-solvent-polymer flooding led to an increase in heavy oil recovery factor.

- The results represented that alternating polymer flooding with solvent flooding could improve the overall recovery factor and the injection of 2000 ppm polymer solution displaced the oil and solvent mixture under applicable operational conditions.
By performing solvent flooding before polymer flooding, the build-up pressure during the initial injection stages for a polymer flood was decreased.

Higher viscosity oil showed more significant increase in oil recovery and decrease in build-up pressure compared to the less viscous oil by using water-solvent-polymer flooding scheme.
Future Works

- More tests will be performed to investigate the effect of:
  - PV Injected
  - Pressure
  - Permeability
  - Solvent Composition

- Additional tests at several other operating pressures would allow for determination of the effect of more specific solvent compositions.

- Attempt will be made to simulate the results.
Acknowledgements

The financial support for this research was provided by:

- PTRC
- BL-NCE Secretariat
- BP Exploration (Alaska) Inc.
- Canadian Natural Resources Limited
- Husky Oil Operations
- Nexen Inc.
- Saskatchewan Ministry of Energy and Resources

I would like to thank all of them for continuous support and encouragement.
Thank You For Your Attention