FIELD PILOT OF STEAM ADDITIVES TECHNOLOGY TO REDUCE GHG EMISSIONS INTENSITY IN SAGD
FINAL NON-CONFIDENTIAL OUTCOMES REPORT

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Executive Summary

Steam Assisted Gravity Drainage (SAGD) projects that develop and produce Alberta's oil sands are recognized as some of the highest cost and greenhouse gas (GHG)-intensive oil extraction operations in the world. The bulk of the cost comes in well drilling, completion, and construction of surface facilities. GHG emissions result from steam generation and suboptimal steam utilization in the reservoir. Improving the cost structure and environmental performance of existing and future SAGD expansion projects is critical to maintain and increase the attractiveness and competitiveness of Alberta's oil sands.

One of ConocoPhillips Canada's (CPC) active technology programs involved working jointly with InnoTech Alberta as part of the Steam Additives Industry Research Program (STEADi) to identify commercially available chemical additives to steam. These additives, specifically surfactants, have the potential to improve the performance of SAGD operations by increasing oil drainage rates while reducing energy losses. This results in improved thermal efficiency, reduced GHG emissions intensity, and incremental oil production.

Through STEADi, CPC identified a commercially available, low cost, chemical surfactant additive ready for 'first of kind' field demonstration. The proposed pilot sought to quantify the operational benefits and performance of steam additives and determine commercial operating requirements. Pilot success in addressing remaining uncertainties was expected to advance the technology to Readiness Level 9 by 2023.

Field pilot execution was conducted in four well pairs tied to existing facilities at the Surmont SAGD (end user) facility. GHG intensity reduction of 20%, equivalent to 15 kg-CO2e/bbl, or approximately 20,000 tCO2e/yr, were expected at the pilot area. The pilot achieved a reduction in GHG emissions intensity in the range of the expected reductions initially proposed.

The pilot aligns with the ERA strategic focus area to achieve cleaner oil and gas production, which is a GHG intensive sector. Using surfactants to reduce produced emulsion viscosities is an innovative approach to SAGD production and will enable GHG footprint reduction of Alberta's fossil fuel supply chain by more efficiently producing reservoirs, meaning tonnes of steam required for each unit of bitumen production are reduced resulting in a Scope 1 GHG emissions from natural gas combustion intensity improvement.

Technology Description and Background

Steam Assisted Gravity Drainage (SAGD) is the most widely used in-situ bitumen recovery method currently available. The underlying principle of SAGD involves the continuous injection of steam into a reservoir via horizontal wells. The steam permeates upwards and outwards through the formation, creating a 'steam chamber'. This significantly reduces the viscosity of the contacted bitumen, allowing it to be carried with the steam and condensed water to the edge of the chamber. Here the liquids drain under gravity and are extracted with a horizontal production well a few metres below the injection well.

This intermixing of steam, condensed water, and bitumen under conditions of high temperature, pressure and shear provides the conditions for bitumen emulsification to take place (refer to Figure 1 and Figure 2). Condensed water becomes dispersed as fine droplets throughout the bitumen-rich oil phase, and vice versa. Produced fluids from SAGD operations typically consist of mixed water-in-oil and oil-in-water (w/o + o/w) emulsions and sometimes multiple emulsions (e.g., water-in-oil-in-water (w/o/w)) are produced.

Heavy oils and bitumen have a natural tendency to form water-in-oil (w/o) emulsions owing to the presence of natural surfactants in the oil phase, and possibly also favoured by the viscosity ratio between oil and water. From the standpoint of production efficiency, formation of w/o emulsions is considered detrimental since these have higher viscosities and potentially drain less efficiently than the corresponding o/w emulsions. Drainage flow rate restrictions could be expected to arise from the formation of w/o emulsions, since these will be more viscous than the heavy oil or bitumen at any given temperature.

One method to reduce the formation of w/o emulsions, and hence increase SAGD efficiency, is through the addition of a small amount of surfactant co-injected with steam. When injected with steam in SAGD operations, surfactants are expected to reduce the formation of w/o emulsions, and promote the formation of o/w emulsions, which have lower viscosity, resulting in more efficient drainage of oil from the reservoir. By reducing the emulsion viscosity, like the addition of solvents, oil drainage rates and the productivity of SAGD wells increases. The increase in drainage rates also reduces the time in which energy from the steam chamber is lost to the produced emulsion, hence improving thermal efficiency specifically, production efficiency overall, and reducing GHG emissions.

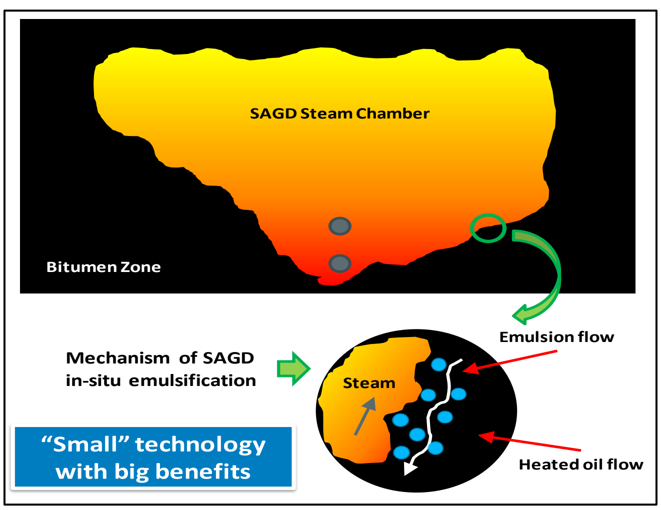

Figure 1. Mechanism of SAGD In-situ Emulsification

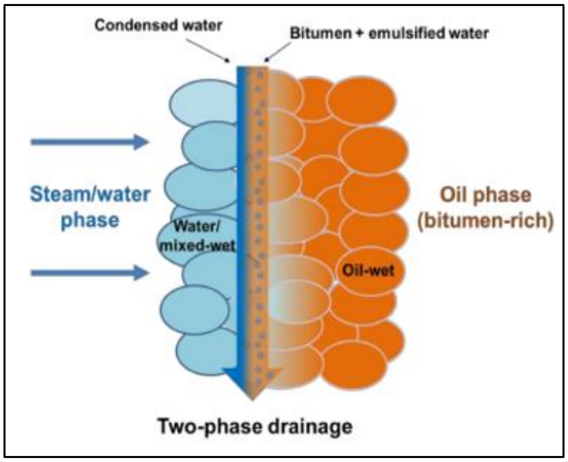

Figure 2. Schematic of Drainage and Formation of w/o Emulsions at the Steam Chamber Wall

ConocoPhillips and its partners have been investigating steam-additives for over 10 years. Initially, steam-additives were hydrocarbon-based and focused on reducing the viscosity of bitumen in-situ. Over time, CPC's efforts shifted to looking at other chemistries to reduce viscosity of in-situ generated emulsions. Other operators have performed pilots using additives focused on more conventional applications of surfactants such as: 1) shifting wettability, 2) reducing residual oil saturation, and 3) reducing interfacial tension. While CPC certainly notes these could be factors influenced with the use of chemicals, CPC believes these are second order effects compared to the applied technology in this project.

Surfactants have been applied in both thermal (e.g., steam flooding) and non-thermal processes in the past. However, application of surfactants in SAGD is poorly understood because of the high temperatures involved, and because surfactant-bitumen and surfactant-rock interactions have not been fully characterized for the McMurray formation.

In 2016, CPC first began exploring chemical additive (surfactant) co-injection in SAGD. As part of the preliminary evaluation of this technology, CPC joined the STEADi Joint Industry Program (JIP) with InnoTech Alberta. The STEADi JIP focused in studying the formation and flow of emulsions in porous media in the presence of chemical additives in SAGD. A series of comprehensive studies focused on emulsion viscosity behaviour and fluid displacement in porous media was performed. The experimental conditions for both viscosity measurement and coreflooding tests were representative of the pressure and temperature at the edge of the steam chamber in the pilot area.

Initial screening type experiments were conducted in twelve different surfactant additives to help narrow down the selection of additives that would undergo more comprehensive experimentation. Three of the most important tests in this screening process were interfacial tension (IFT) reduction, thermal stability, and static rock adsorption. Given the SAGD operating conditions, only thermally stable chemicals can survive the harsh subsurface environment of the process and still be effective when reaching the steam condensation front. Based on the surfactant structure, some of the components may break and degrade into other products once the molecules are exposed to high temperatures. These thermally reformed structures may still be surface active. Hence, in combination with thermal stability tests, IFT lowering of the surfactants before and after exposure to high temperatures was also evaluated.

Baseline IFT performance of the additives was conducted using the pendant drop IFT technique to measure interfacial tension of the fluids at high temperature and pressure. Following IFT baselining, five surfactant additives were selected for the thermal stability tests, and their thermal degradation was evaluated as a function of time.
Additionally, given the small volume of additives co-injected with steam, disaggregated reservoir rock static adsorption tests were conducted. The static adsorption test was designed to measure the amount of chemical adsorbed on the reservoir rock surface at equilibrium under SAGD conditions.
After the initial screening experiments were finalized, three surfactant additives were selected to evaluate their impact on oil drainage rates in a core soaking test under SAGD conditions. Following the soaking tests, two surfactant additives were selected to further evaluate their impact on emulsion viscosity. Experiments with both surfactant additives exhibited considerable reductions in emulsion viscosity at water cuts approximate to those of typical SAGD operating conditions (60-80%). From this, it was decided to carry a coreflooding experiment with the additive that showed the highest emulsion viscosity reduction. From this, the additive was finally selected for field implementation in the project trial summarized in this report.

Project Objectives & Success Metrics

Described below were the original project objectives as described in the contribution agreement.

- Advance the technology to TRL 9 in a bid to enhance the SAGD recovery technique of Steam Assisted Gravity Drainage (SAGD)
- Confirm operationally the expected GHG intensity reductions.
    - Confirm laboratory results which show reduced viscosity of water-oil emulsions formed during SAGD.
    - Validate the hypothesis that the premised higher drainage rates result in improved thermal efficiency.
    - Confirm the Steam Additives are efficiently transported sub-surface to the condensation interface.
    - Observe and record any unanticipated negative impact to surface facilities and/or additional costs.
- Determine the commercial viability of surfactant co-injection in SAGD contexts (both brown- and green-field green applications)
- Identify commercial operating requirements for broader application of the technology.

Strategic Objectives Success Metrics:

The proposed pilot sought to quantify the operational benefits and performance of steam additives and determine commercial operating requirements. Pilot success in addressing remaining uncertainties was expected to advance the technology to Readiness Level 9 by 2023. A commercial path forward for both brown- and green-field applications is expected to result in GHG intensity reductions of at least 10% and 20%+, respectively.

Field pilot execution was proposed in four well pairs tied to existing facilities at the Surmont SAGD (end user) facility. GHG intensity reduction of 20%, equivalent to 15 kg-CO2e/bbl, or approximately 20,000 tCO2e/yr, are expected at the pilot area.

Project Work Scope

Facilities Construction

Once the steam additive chemical selection process had been completed, a pilot location evaluation was conducted, resulting in four wells being selected for the trial.

The major equipment required was:

- Pump building: VFD-controlled pumps
- Mass flow metering
- Heated tank for chemical
- Truck-in station
- Emergency shower and eye wash
- Heat tracing
- Injection quill

Construction work packages were issued for construction in 2020 Q4, and the trial was ready for operations and the end of 2021 Q1. No major issues were encountered at the construction phase for pilot facilities.

Pilot Start-up, Monitoring Plan and Operations

Pilot start-up was achieved on Q1, 2021. The plan involved co-injection of the chemical additive directly to the individual steam line for each well in the pilot, and a co-injection concentration of 3000ppm was used for start-up operations, based on information obtained through the laboratory research phase, as well as simulation results used for dynamic baseline of the system. A subsequent plan to trial a reduced concentration was implemented in a second phase of the project, in an effort to understand the benefits at reduced chemical volumes and capture associated cost reduction for improved business case economics.

Overall, co-injection of steam additives in the pilot wells was achieved for a period of 21 months from project start to project completion date, and the pilot has been expanded post project completion date to further understand the level of impact to surface treating facilities under an expanded co-injection scheme. This work is still in the project execution phase, but it is key to fully address one of the main project objectives defined as part of the success metrics for the technology: “Observe and record any unanticipated negative impact to surface facilities and/or additional costs.”

The pilot monitoring plan consisted of typical key performance indicator (KPI) metrics, including:

- Well Rates (injection / production)
- Chemical Additive concentrations and volume.
- Pressures & Temperature (injection / production)
- Ratios: Steam/Oil Ratio (SOR), Water/Oil ratio (WOR), Water cut.
- Pump Performance metrics.
- Emulsion sampling @ test separator (pH and additive return, water cut for meter calibration) for Pilot and neighboring wells – included baseline sampling.
- Emulsion sampling @ CPF.

Soon after co-injection started, it was detected that the pilot wells had coalesced with wells from a neighboring pad operated under a lower pressure regime. This was observed from emulsion sampling analysis in the laboratory, as well as 4D seismic monitoring data from late 2021. This coalescence required an expanded monitoring area for performance analysis and impact from the additive’s co-injection.

Pilot Operations and Results

The project timeline allowed the team to evaluate two distinct operational phases in the trial. Initially, a production uplift phase characterized by sustained pressure within the system reservoir. And a second operational phase to trial steam reduction in the system, with the goal to achieve sustained oil rates at lower chemical injection. The rationale for this strategy relates to trialing the flexibility the technology can provide to the development of the asset in the future. The steam reduction strategy implied a system pressure decrease in the reservoir to achieve a targeted new steam rate in the pilot wells. This methodology was sustained for approximately one year of continuous operation.

Through this phase, a production uplift and SOR reduction in line with the range of expected KPIs was achieved from the pilot planning phase.

Project Work Scope - Reservoir Modelling

As the field trial of steam additives was being executed, a concurrent reservoir modeling project was kicked off, with the objective to achieve a history-matched model of the wells and predict performance for evaluation of actuals. The following reservoir modelling methodology was conducted:

- Performed Pad history match to ensure actual performance data from the wells in this pad is captured and performance predictability optimized.
- Developed a steam additives modeling methodology.
- Forecasted well performance under low, medium, and high effectiveness of the additive's cases, calibrated from levels of reservoir adsorption and thermal degradation from the experimental laboratory phase.
- Included leak-off well proxy to mimic system coalescence and additive migration to neighbor pad.

Based on the results observed from the "Out of Box" model, additive migration from steam coalescence was observed in the model, between wells in the same pad. Although inter-pad coalescence wasn't explicitly modeled, this additive migration phenomena with steam helps corroborate the observed coalescence impact in the actual pilot areas.

To better understand the performance impact from the system, which includes areas between two pads, a leak-off study was conducted in the model to match the amount of water (in the form of steam) had migrated to the coalesced wells, and the volume of active chemical being carried by that steam. With this proxy, a better match for oil rates from the original pilot wells was achieved.

The modeling methodology proved effective to understand the benefits of the technology that can now be applied to static models from other producing or new areas in the field and provide a range of possible outcomes for SAGD optimization with steam additives under different geological environments and operation conditions and, including the combination of technologies within a single model for further optimization (i.e. NCG co-injection).

Further sensitivities in the model were conducted to better understand the impact of additive concentration in the steam chamber, as well as the impact in rates that the level of maturity at time of additive injection start-up would have in an uplift case.

Commercialization

As a result of the Project implementation, sufficient data has been gathered and analyzed to understand the subsurface impact of the technology. However, there continue to be areas that require further understanding that could ultimately set the technology behind commercial implementation if not resolved. A current area of highlighted interest is the impact to surface emulsion treating facilities.

Typically, SAGD facilities rely on emulsion breaker (EB) chemistry to aid in oil and water emulsion separation, however the concentration of EB used and the location for EB injection in the pipeline (affecting retention time) are variables that would play a role in the process. On the contrary, the working mechanism for the steam additives promotes the emulsification of oil in water for a lower viscosity continuous phase flow in the reservoir. This same action could adversely affect the surface process where an effective oil/water separation is required.

ConocoPhillips Canada continues evaluating this phenomenon before commerciality of the technology can be declared. While a commercial implementation has not been sanctioned, the deployment of this technology is part of the portfolio analysis process for the asset, to further understand the possible benefits on application for both brown-field and green-field pads in Surmont. ConocoPhillips continues to believe that steam additives can effectively optimize the SAGD process, however the full cycle economics for an implementation scheme could widely vary if add-on troubleshooting measures need to be implemented.

Further and additional to these efforts, continuing the line of sight to broader market adoption, ConocoPhillips Canada is concurrently kicking off a new laboratory screening phase in collaboration with other industry peers, as part of a COSIA innovation opportunity, to understand if there are any new chemistries that can provide another level of optimization at reduced overall costs or while minimizing any possible surface impacts. ConocoPhillips continues to believe that most other SAGD operators in Alberta would benefit from the application of steam additives technology, given its potential to be rapidly deployable as a mitigation tool to reduce SOR and associated GHG emissions, from all SAGD producing areas, and serve as a bridge for future energy transition technologies that are considerably more capital intensive and have a longer timeline for implementation.

Environmental Benefits

GHG Emission Reductions Impact

The Steam Additives pilot project was executed off existing SAGD wells, to evaluate the potential to improve the performance of SAGD operations by increasing oil production rates and/or reducing the steam rate of the system at sustained oil rates. From this, the technology was expected to result in a reduction in the GHG intensity of produced bitumen through an ultimate reduction in SOR. **The pilot achieved a reduction in GHG emissions intensity in the range of the expected reductions as initially proposed.**

Overall Conclusions

Steam Additives co-injection was applied at Surmont under a trial phase to evaluate performance impacts in both subsurface and surface environments.

The field pilot has been operated in four well pairs tied to existing facilities at the Surmont SAGD (end user) facility. **The pilot achieved a reduction in GHG emissions intensity in the range of the expected reductions as initially proposed.**

Enough data was gathered to understand the metrics in terms of production uplift or steam reduction, both key in improving the steam/oil ratio of the process and associated GHG emissions intensity. However, further evaluation and analysis of surface facilities impact from stronger or difficult to break emulsions is required before a sanctioning of commercial expansion application can be achieved. The project team has defined a continuation of the pilot to further evaluate these metrics and allow for troubleshooting activities if it is deemed that the used steam additives in the project affect surface facility processes.

For next steps, an expansion plan is being executed to increase co-injection of the chemical additive to the full pilot pad. The project team believes that this expansion will help solidify the right implementation plan for the asset, as well as more extensively evaluate a possible negative outcome that could bring the technology to a re-defining stage, if surface treatment issues are exacerbated from increased additives injection.

ConocoPhillips Canada, as part of the COSIA alliance, is in constant communication with its industry peers to find avenues for knowledge sharing opportunities related to technology advancement. Although the findings from this pilot remain under confidentiality terms for ConocoPhillips, joint industry projects (JIP) are legal ways explored to allow for such sharing activities. A current JIP between three of COSIA's participants, including ConocoPhillips Canada, is being advanced as a follow-up project, for the continued screening of new/alternate chemistries in the form of steam additives that could provide enhanced results to those observed through this pilot.