

ecoENERGY Innovation Initiative
Research and Development Component

Public Final Report

Project: UOSE 014
Fundamentals of Non-Aqueous Extraction of Oilsands

July 23, 2016

1. R&D gaps in non-aqueous extraction of Alberta oil sands

One approach to avoid the wet tailings problem in the Alberta oil sands industry is the use of organic solvents, rather than water, to recover bitumen from the oil sands. The approach is effective for the recovery of bitumen, but it faces two crucial technical challenges: 1) the solvent must be recovered from the extraction gangue at very high efficiency. The residual concentration of solvent must be at most a few hundred parts per million (ppm) in order to avoid the environmental impact of solvents in the environment, and the cost of lost solvent. 2) the generated bitumen must contain little mineral solids in order to meet downstream processing requirements.

Preliminary research at the Institute for Oil Sands Innovation at the University of Alberta, prior to the award of the research project, indicated the promise and the challenges of non-aqueous extraction. Uhlík et al. (2009) [P. Uhlík, A. Hooshlar, O. Omotoso, T. H. Etsell, Qi Liu and D. G. Ivey, 2009. Characterization of clay minerals in the Alberta oil sands. 46th Annual Meeting of the Clay Minerals Society, Billings, Montana, June 5-11, 2009], and Hooshlar et al. (2009) [A. Hooshlar, P. Uhlík, T.H. Etsell, D.G. Ivey and Qi Liu, 2009. Behaviour of clay minerals in the Alberta oil sands during non-aqueous bitumen extraction. 14th International Clay Conference, Castellaneta Marina, Italy, June 14-20, 2009] performed a series of non-aqueous bitumen extraction tests using various ratios of toluene and heptane (representing aromatic and paraffinic organic solvents). They found such an extraction method to be very efficient, yielding high bitumen recovery even for low grade oil sands ores. Detailed mineralogical characterization was carried out and it was shown that the kaolinite-to-illite ratio increased significantly in the supernatant relative to the raw ore (Uhlík et al., 2009). The selective persistence of kaolinite over illite in the non-aqueous extraction supernatant could not be linked to particle size, because kaolinite is typically coarser than illite--smectite. Therefore, clay mineral segregation was related to the specific hydrophobic vs. hydrophilic surface properties of the clay minerals. The results pointed to the role of not only particle size but also particle surface properties (residual bitumen and organic coating) on the migration of the fine solids in bitumen-solvent solution product and potentially on the solvent retention by the extraction gangue.

2. Project initiation and evolution

The Institute for Oil Sands Innovation (IOSI) at the University of Alberta has been actively engaged in the development of breakthrough non-aqueous extraction studies since its establishment in 2005. In 2012, two IOSI projects, COSI 2010-04 and COSI 2010-06, were assembled into an application to a R&D project of the Natural Resources Canada (NRCan) ecoENERGY Innovation Initiative program, under the Unconventional Oil and Gas category. The project was awarded in March 2013, and given a project # ecoEII UOSE 014. The project was executed between March 2013 and March 2016, by IOSI at the University of Alberta. Imperial Oil Limited was the industrial partner of the project, who provided cash support to

cover 25% of the direct costs of the project as well as in-kind support through sample collection/shipment and project consultation/stewardship.

Murray Gray was the initial project manager. After his departure from IOSI and the University of Alberta in April 2014, Phillip Choi and Qi Liu took over the role of project managers from May 2014, with Phillip Choi overseeing project scope and execution and Qi Liu project reporting. The project had five principal investigators (PI), and they were Murray Gray, Phillip Choi, Qi Liu, Thomas Etsell and Douglas Ivey, all from the University of Alberta.

Under the project title “Fundamentals of Non-Aqueous Extraction of Oilsands”, the research was to address the challenge of recovering solvent from the non-aqueous extraction gangue. The project was divided into two main parts. Part One was to examine the type, concentration and effect of nano- and micro-sized minerals (inorganic) and kerogen (organic) in different oil sands petrological end members on non-aqueous oil sands extraction. Part Two was to examine the kinetic behavior of removing solvents from extraction gangue under different temperature and pressure conditions. Thomas Etsell was the lead PI for Part One, and Murray Gray (and Phillip Choi after Murray Gray left the University of Alberta) was the lead PI for Part Two.

3. Project objective

The objective of this project is to investigate the key chemical and physical interactions that control the non-aqueous extraction of bitumen from the Alberta oilsands. Efficient recovery of solvent from the extracted gangue requires a clear understanding of the interactions of the solvent with the components in the oil sands matrix, and an appropriate design of a solvent. The purpose of this project is to provide data on the recovery of solvents by evaporating from dry extraction gangue, after the removal of bitumen, and to define how the mineral and residual organic components control solvent recovery. Information on residual solvent concentrations, as a function of process conditions and ore type, will allow selection of solvent, define environmental impact, support the design of solvent recovery equipment, and help to define the process costs.

The research would build on the knowledge base associated with the existing water-based technology for oilsands extraction, by investigating key issues for application of solvents. The range of components of the ores are well defined from past work, but their interactions in a solvent-rich environment are not. The research will provide the fundamental scientific insights and engineering data to support successful scale-up and application of non-aqueous extraction of the oilsands. This research will support the development of new non-aqueous extraction processes, rather than an existing commercial technology.

4. R&D activities performed

The major R&D activities of this project include developing a laboratory non-aqueous oil sands extraction protocol. Collection and characterization of the suspended fine solids in the bitumen-solvent product after different settling periods from 1 min to 48 h. Isolation and characterization of kerogen from the oil sands and studying its effect on non-aqueous extraction. Solvent recovery from the extraction gangue under varying temperature and pressure, using either re-constituted gangue or real extraction gangue from solvent extraction of the oil sands ore in the laboratory. Study of the affinity of the clays and mineral solids to different organic solvents using intelligent gravimetric analyzer.

5. Challenges encountered

Non-aqueous extraction of Alberta oil sands has been investigated since the 1970s, and the barrier that was identified was the solvent losses to the extraction gangue. Through this project, we have also identified the second barrier, which was the quality of the resulting bitumen-solvent product. The product needs to contain less than 0.03 wt% inorganic solids in order to feed directly to refineries.

The two technical barriers have not been overcome by the current project UOSE 014. It was suggested that further R&D is required to study these issues. The paths forward have been identified.

6. Conclusions (non-confidential)

Through this NRCan sponsored R&D project, ecoEII UOSE 014, cyclohexane was identified as a potential solvent due to its relatively high solubility product (which ensures high bitumen dissolution and recovery) and vapor pressure (which ensure its easy recovery). The results were published in Canadian Journal of Chemical Engineering, Vol. 91 (2013), 1153. Many associated investigative studies were carried out to examine the effects of ore grade and blending with alkane on bitumen recovery and cyclohexane recovery from the extraction gangue. The identification of this solvent makes the R&D work along this line more focused.

It was found that during cyclohexane extraction of oil sands, the ore lumps were disintegrated so that the solvent could access and recover the bitumen. While the hydrophilic fine minerals and clays could be agglomerated by connate water, the hydrophobic or partially hydrophobic fine solids remain suspended in the bitumen-solvent product. These inorganic solids could not be removed by gravity settling even after 48 h.

Recovery of the solvent (cyclohexane) from the extraction gangue is governed by both thermodynamics and kinetics. Stationery bed drying was studied by varying temperature and pressure. It was found that residual bitumen or toluene-insoluble organics (such as kerogen) on the particle surface increased its affinity to solvent, while the migration of

residual bitumen by the solvent inside pores and the deposition of the bitumen on the gangue surface when the solvent evaporates make solvent recovery both thermodynamically and kinetically unfavorable.

7. Benefits and outcomes

Non-aqueous extraction is not a commercial oil sands extraction process at this point, but it is an attractive alternative to the current commercial hot-water extraction process which is plagued with many environmental problems. The identification of cyclohexane, the observation of the fine solids migration in the non-aqueous extraction, and the observation of residual bitumen migration during solvent recovery from the extraction gangue, will guide further R&D effort in non-aqueous extraction studies so that they are more focused.

8. Next steps for R&D in this area

Although cyclohexane could ensure greater than 90% bitumen recovery from low grade ores and greater than 94% for rich grade ores, two challenges were identified from this project that need to be overcome to make the non-aqueous extraction of Alberta oil sands commercially possible. These are 1) the cleanup of the bitumen-solvent product, 2) recover the solvent from the extraction gangue so that it meets regulation.