MPC-420
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Project Title:
Environmentally Benign Extraction of Bitumen from Oil Sands for Pavement Binder

University:
University of Utah

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Research Needs

Oil sands are an aggregate of clay, sand, water, and bitumen, the last being a black, heavy hydrocarbon solid that is extracted and processed into crude oil (see Oil Shale and Tar Sands Programmatic EIS Information Center). Only Alberta of Canada, the world's largest oil sands deposit, produces oil from oil sands at a significant level, currently over 50% of oil production and increasing. Bitumen can be readily used as a binder for pavement. The largest US oil sands deposit, estimated to contain over 30 billion barrels, resides in Utah and it remains undeveloped. With diminishing light oil supply, increasing oil price, and energy security reasons, oil sands resources have attracted attention. However, development of Utah's oil sands with current hot water extraction technology as practiced in Canada (Misra et al., 1981; Dai and Chung, 1996) will exact a very high cost in environmental quality.

Current hot water extraction technology obtains bitumen by contacting excavated oil sands with hot water, which separates the clay and sands and allows the bitumen to float to the water surface. It demands a large amount of water and results in large amounts of tailing and contaminated process water that are very difficult to treat and dispose of in an environmentally acceptable manner. We have provided a more detailed review of oil sands processing and needs recently (Hong et al., 2013). Other solvent-based technologies have been attempted and none have shown to be commercially viable owing to their different sets of barriers. To date, Utah oil sands resource remains virtually untapped. Any new development of the oil sands resource must address critical issues such as cost effectiveness, byproducts of process water and tailings, and water availability especially in arid regions.

We have demonstrated a new way of extracting bitumen from Utah oil sands (Hong et al., 2013) without using caustics that lead to problematic tailings and contaminated water. We have also shown the incorporation of bitumen as a binder into pavement materials (Hong et al., 2012). The HOSE (heightened oil sands extraction) process involves adding oil sands to hot water in a closed vessel and subjecting the mixture to rapid, successive cycles of pressurization and depressurization with a gas. A pressure cycle begins when air or another gas (e.g., CO_2) is introduced allowing the gas to dissolve in water and the reactor headspace to build to designate pressure (e.g., 100 psi) – the compression stage. Once the specified pressure in the headspace is reached, it is released by venting – the decompression stage. The complete cycle consisting of the compression and the decompression stages is rapidly repeated to a prescribed number of times to achieve release of the bitumen from the sands, typically within 20 min. The process requires no chemical additives and produces high quality and yield of bitumen without the problematic tailings and water. HOSE offers advantages in high bitumen yield (95%), high quality froth (35% bitumen), and low extraction temperature (65 ^{o}C), rapid processing (20 min), and no caustics or other chemicals being used.

To deploy HOSE, we must first determine its potential impact on the environment through discharges. We propose here a program to determine the quality of process wastes including the process water and spent sands, the presence of trace organics in wastes, and the recyclability of the water. The water demand and costs will be determined for the new process.

Research Objectives

The objectives are to:

1) optimize extraction and determine optimal conditions,
2) determine the quality of the process water and spent sands,
3) determine the extent of treatment required for reuse and discharge of the water, and
4) performed the cost analysis of producing the bitumen as pavement binder based on the above outcomes.

Research Methods

A laboratory experimental approach will be carried out. Extraction will be performed in a pressure vessel used previously (details in Hong et al., 2013; Hong and Xiao, 2013). Bitumen yields will be determined under varied extraction parameters (described in work plan). Waste products (water and sand) will be determined for its inorganic and organic contaminants. Pressure-assisted ozonation and sand filtration (Hong and Xiao, 2013) will be used to treat the water as necessary and determine the treatment conditions required for process reuse and discharge. The spent sands will be ascertained not to leach using toxicity characteristic leaching procedure (TCLP). Performance data and required treatment results from above will be used for cost analysis to produce the pavement binder.

Expected Outcomes

These research outcomes will be available:

1. optimal conditions for bitumen yield using HOSE,
2. qualities of the water and sand,
3. qualities of the water and sand after required treatment, and
4. process cost to produce bitumen binder from oil sands.

Relevance to Strategic Goals

The new HOSE technology produces asphalt materials from an abundant oil sand resource in Utah that will address transportation needs of pavement materials and potential fuel. The process produces them in an environmentally benign manner, significantly removing the burden to the environment in oil sands development such as contaminated water and tailings that challenge the industry today. Thus, this research will contribute to DOT's strategic plan to deliver a desirable outcome of increasing environmentally sustainable practices and materials in the transportation sector. In particular, this research contributes to more sustainable transportation materials, construction, and infrastructure; it promotes practices in construction and maintenance of highways that increase sustainability of transportation. The reduced environmental impact of HOSE makes it more sustainable, as lifecycle analysis enabled by this research will show.

The potential to meet the strategic goal of economic competitiveness in terms of economic returns from investment on the project technology is enormous, as it provides an environmentally benign way of accessing a vast resource of pavement binder and fuel in Utah oil sands. The University of Utah holds intellectual property rights of HOSE invented by the PI.

Educational Benefits

This project will engage one graduate student to perform environmental engineering research as part of his/her research thesis. The research will create knowledge in lessening environmental impacts such as water and land pollution resulting from energy development. It will demonstrate that an innovative technology approach will not only enable development of an existing resource that otherwise would remain inaccessible but also can be executed in an environmentally friendly manner.

While a strong, existing water -energy nexus is well recognized, technologies that address both at the same time are critically needed. This research will lead to new knowledge of treatment and reuse of water in the energy sector, which can be incorporated into sustainability topics in environmental engineering courses. The clean process will be demonstrated to prospective students regularly visiting the University from high schools; it will excite them with possibilities and environmental stewardship of an engineering education.

Work Plan

The following major tasks will achieve project objectives identified above:

1. Preparation

Oil sands samples will be procured from Asphalt Ridge, Utah and reactor set up for experimentation (reactor details in Hong et al., 2013).

2. Optimize extraction conditions

Extraction with HOSE and yields will be evaluated under different conditions: gas composition (CO_2/air), temperature (60 ^oC – boiling), contact time (10-60 min), water-to-solid volume ratio (1 – 5), agitation intensity (without agitation and agitation at various velocity gradients impacting gas transfer kinetics), pressure (50 – 150 psi), number of pressure cycles (3 – 30), compression speed (10 – 60 s), decompression speed (5 – 60 s). The compression speed is relevant because it affects the duration that affects the extent of equilibrium for gas dissolution, while the decompression speed/duration affects the rate of formation, growth, and duration of the microbubbles. The results will be useful for identification of an optimal combination of operation conditions.

3. Analysis of process wastes

Waste products (water and sand) will be determined for its inorganic and organic contaminants. Inorganic contents of process water and spent sands will be determined by conductivity, solids measurements (TS, VS, VSS, DS, FS), ion chromatography (IC). Organic contents will be determined by GCMS after liquid-liquid extraction/solid phase extraction of the process water and after Soxhlet extraction of the spent sands.

The ease in water removal (dewatering) and remaining organics in the spent sand will determine disposal options and required treatment before reuse in the extraction process. Preliminary analytical results of spent oil sands following extraction with pressure cycles indicate the sands have been essentially free of organics (as determined by ignition test at 550 ^{o}C), which may suggest alternative use of the spent materials such as in road construction. The remaining organics in the spent oil sands will be determined and its use potential assessed.

4. Treatment of process wastes

Pressure-assisted ozonation and sand filtration were found useful for produced water treatment (Hong and Xiao, 2013); they will be employed to treat the process water as necessary. Based on the constituent analysis in Task 3, treatment will be prescribed (such as ozone dose, contact time, filtration velocity) and carried out accordingly to evaluate the extent of treatment required for reuse in the extraction process as well as for discharge.

Spent sand of the new process are not expected to leach and remained much as before extraction albeit devoid of the bitumen. However, the leaching potential of the spent sand will be spot-checked by toxicity characteristic leaching procedure (TCLP).

Recommendations of treatment for reuse and disposal of the water and handling and final disposal of the solids will be made.

5. Cost analysis

Based on the extraction results, a pilot plant with necessary processes and equipments will be designed. Cost analysis to produce bitumen will be performed. Recommendations on how to implement the new extraction process will be made.

Project Cost:

Total Project Costs: $128,895

MPC Funds Requested: $60,123

Matching Funds: $ 68,772

Source of Matching Funds: University of Utah and Utah State Economic Development Office

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