Report on Naphthenic Acids and Their Regulations

Introduction

Minimized environmental impact in oil and gas production is an increasingly important goal for both government and industry. This is the result of society's growing awareness and concern for environmental degradation. Concern continues to increase due to the ever-expanding scale and production rates of oil sands tailings generation and the resulting increased safety risks to humans and the natural environment. Five stages of tolerance have been postulated within a cycle made up of an industry's opportunities and liabilities. This cycle is driven on one side by technological and economic capability, and on the other side by society wealth and environmental tolerance (1). The stages occur in the order of *Emergent, Production, Decline, Intolerant and Need to Tolerate*, after which they cycle back to the beginning when new technological developments occur within the industry, and continue through the stages based on social perception of the processes and concerns over the associated environmental impacts. At the present time, oil sands production appears to either be in or entering the *Decline Stage* of the cycle, whereby society is beginning to weigh the ultimate costs and benefits of industry processes. Based on this social pressure, government responds by expanding or developing legislation to create further restrictions to push industry to be more responsible and accountable in regards to environmental impact. Through the stages beyond this one, rules and regulation continue to develop. For this reason, it is important that technologies related to environmental assessment and analysis mature alongside industry in order to assist the adjustment to the increasingly stringent decree.

The 2011 iGEM team has decided to approach the Human Practices component of our report as a review of the regulations surrounding our target substance(s), Naphthenic Acid(s) (NA), and the use of synthetically created micro-organisms in the oil sands extraction industry. The intent is to paint a picture that describes where *Sensomonas nastytoxins* could potentially play a role in industry, based on current and impending future regulation. Comparison to the present industry standard will illustrate *Sensomonas nastytoxins'* potential to be marketable and have a competitive edge over current practices.

What does the current tailings pond situation look like?

In 2008, Alberta Energy Resources Conservation Board's (ERCB) reported that 0.1 cubic meter (m^3) of fine tailings is produced with the processing of one tonne of oil sands. After an initial tailings consolidation period of 3 to 5 years, this volume is further condensed to around 0.05 m^3 to 0.06 m^3 of mature fine tailings. For an average 100,000 barrel-per-day facility, approximately 195,000 tonnes of oil sands are processed, translating to nearly 20,000 m^3 of fine tailings per day as the byproduct (2).

There are currently more than 170 km^2 of tailings ponds covering the oil sands region of northern Alberta, 67 km^2 of which the Government of Alberta reports to be currently under active reclamation (3). This means that approximately 40% of the impacted land is currently receiving remediation attention. The challenge remains that oil sands mines may be active for decades, and following the end of operation, reclamation activities can take further decades to complete (3). When considering the lifetime of a project from its start to when the land is officially certified as "reclaimed", we can understand that the temporal profile involved is quite long. To date, only one tailings pond area has been acknowledged as reclaimed (3).

Why would detecting *NAs* through the use of synthetically created micro-organisms be useful in the marketplace?

- This particular product has been designed to allow for onsite detection of NAs in oil sands operations. This would be extremely useful for the quick and convenient identification of this prevailing tailings' toxin, saving the time, resources, and money that are all components of present testing methods.

What is currently being used to detect *NAs* in water?

- The current industry standard for the analysis of NAs in tailings samples is performed using Fourier Transform Infrared Spectrometer (FTIR). FTIR involves a filtered acidified sample of tailings that is put into a rotarytumbler apparatus, using hexane to extract NAs. The absorbance of the NAs sample is then compared to commercially available NA mixtures of known concentration. This particular quantification method measures the amount of carboxyl groups in the sample. Since the composition of the commercial mixture is not likely to match that of the sample, there remains some bias in the total NA value of the sample (4). Lab/analysis companies, such as Maxaam Analytics, charge around $200 per sample. This price may vary based on the amount of business supplied by the client, and so would be less for those companies practicing regular testing/analysis. The standard turnaround time is around 5 business days.

Why not just improve extraction processes in the field so that we don't have to worry about exposing the environment to NAs?

- It has been recognized that long-term operation and maintenance of tailings treatment systems (ponds) is the single largest burden that oil sands mining places on future generations (1). Improvement of technologies for the extraction process is an obvious solution that the whole industry should be working towards. However, it is an ongoing goal towards which industry continually strives. Other regulations need be met in the interim and as such, a demand for better/cheaper/more convenient testing methods and monitoring processes will remain.

What is the need for a fast response?

- The production of test results in 24 hours or less would give *Sensomonas nastytoxins* a strong competitive edge in respect to onsite convenience. If it takes *Sensomonas nastytoxins* as long as FTIR (5 business days plus delivery time) to produce results for NA concentrations, it does not offer a time advantage to sending it to an analytics laboratory.

What other benefits could come from using *Sensomonas nastytoxins* for seepage monitoring purposes?

- Benefits will also come in the form of reduced costs of the analysis and regular transport of samples to (generally) municipally-based analytics labs. Further, the avoidance of long-term toxic seepage from the ponds protects the environment and its inhabitants, as well as avoids extraneous costs associated with long-term contaminated seepage collection and treatment, and/or increasing the area required to be remediated.

Which levels of authority are involved in industry regulation associated with environmental protection?

- The responsibility and power to protect Canada's environment is shared between various levels of government.
    - **International**

      Though NAs are not publicly reported in Canada, the United States Environmental Protection Agency (EPA) includes NAs on the hazardous substances list of the Comprehensive Environmental Response, Compensation and Liability Act, and this requires tracking (5). International standards and trends are often taken into consideration when assessing the potential danger of a substance (6).
    - **Federal**
        - *Canadian Environmental Assessment Act (CEAA), 1992*

          Under this act, there are no federal triggers whereby Environment Canada (EC) can issue approvals for oil sands projects. Instead, EC is a participant in the environmental assessment process as a Federal Authority, providing informative support to Responsible Authorities, such as the Department of Fisheries & Oceans (DFO), who do have chemical triggers by which to regulate industry. (7)

        - *Canadian Environmental Protection Act (CEPA), 1999*

          Currently there is no provincial legislation setting requirements related to the use of naturally existing micro-organisms in remediation or industrial applications (Gordon Dinwoodie, Land Reclamation Specialist for Alberta Environment, via email, July 22, 2011), much less those that have been synthetically created. As with chemicals used in similar ways, "products of biotechnology" fall under the *Canadian Environmental Protection Act, 1999* (8). With the goal of contributing to sustainable development, CEPA 1999 built a framework of guidelines for industry to follow in order to minimize their environmental footprint, while concurrently progressing as a business. This piece of federal legislation aims at protecting both the environment and human health by preventing pollution, specifically by addressing 'toxic' substances. Health Canada and Environment Canada share the responsibility of risk assessment and management of such determined substances (6).

Definition of CEPA-toxic (6)

A substance is considered "CEPA-toxic" if it enters or may enter the environment in amounts that may pose a risk to:

1. *human health;*
2. *the environment (such as fish or wildlife); and*
3. *the environment upon which life depends (such as water, soil, air)*

- *National Pollutant Release Inventory (NPRI)*

  The central effort of the federal government to track toxic substances or substances of concern in Canada is the NPRI, a program which is comprised of a database of pollutants used to support CEPA 1999 legislation. In the process of identifying and further monitoring sources of pollution, the NPRI provides a solid base on which to start, and can further be useful for the development of indicators for air, water and land quality. Publicly accessible, the NPRI is used by Environment Canada for chemical management programs. This mandatory reporting agency collects and tracks information from owners/operators of those facilities using, creating or disposing of the more than 300 listed "toxic" or "of-concern" substances. Judicial review of the NPRI program has resulted in reporting requirements for tailings water, whereby after 1999 they are applied to <u>all</u> those facilities that generate or dispose of tailings (9). As it is not currently listed as an NPRI substance, these facilities are not required to report NAs, though there are recent pushes to make this a reality (5). Environment Canada has indeed identified NAs as a primary source of toxicity in oil sands tailings (7).

- *Domestic Substances List (DSL)*

  Canada's DSL is a federal advisory which contains approximately 25 000 "substances" that have been identified for commercial-scale use in Canada, but that have not been assessed for toxicity or risk to human health or the environment. Once placed on this list, one-third of the "CEPA-toxic" assessment process is complete. This process is shared between Environment Canada and Health Canada. Inclusion of a substance on the

DSL can occur if an activity results or may result in a significantly greater quantity or concentration of the substance in the environment. Likewise, if there is a significantly different manner or circumstance of exposure of the environment to the substance, it may be included (8). Though technically NAs are naturally present in the environment, oil sands extraction processes bring them from their location deep in the ground, to the surface where they are not normally present in high concentrations. This exposes the environment to a harmful substance that it is not subjected in its naturally occurring state.

If any "significant new activity"[1] uses a substance that is listed on the DSL, and a minister suspects that it has the potential to produce adverse effects to human health or the environment, it may be expedited through the assessment process.

Micro-organisms currently constitute one category of the DSL. As of April 4, 2011, there are 4 species, made up of 9 strains of *Pseudomonas* bacteria comprising this list (10). Risk assessments of substances on the DSL are based on the apparent organismal (both human and non-human) health and/or environmental impact of a substance, as well as its exposure potential (8). If there is a high probability of human exposure of substance, or if it is determined to be persistent or bio-accumulative *and* inherently toxic to organisms, it may be placed on a priority substances list and subsequently categorized "toxic", which does not control the substance at this authority level, but aids the government in regulation decisions (8). It should furthermore be noted that an organism being used in research and development in a closed facility[2] is not required to be considered for the DSL and acceptable for industrial use if present in amounts of less than 250 liters at any given time (11).

Provincial

- Alberta's *Environmental Enhancement and Protection Act, 2010*
    - Under this Act, environmental assessments must be completed in order to obtain various licenses/permits and approvals from Government of Alberta agencies, including the Waste Control Regulation (WCR) and the Energy Resources Conservation Board (ERCB). With the intention of minimizing the costs related to waste analysis and classification, a framework called the *Alberta User Guide for Waste Managers* was created to assist producers in determining their footprint. By this guide, Alberta Environment holds producers of potentially hazardous wastes (or

[1] "Significant new activity" is defined as any activity which in one calendar year involves 100 kg or more of the suspect substance. (6)

[2] "Contained facility" is defined as "an enclosed building with walls, floor and ceiling, or an area within such a building, where the containment is in accordance with the physical and operational requirements of a level set out in either the Laboratory Biosafety Guidelines or Appendix K of the NIH Guidelines." as found in sub-section 1(1). (14)

a consultant on their behalf) responsible for classifying their own waste and further determining if is prohibited from being deposited into landfills (12) or similar types of disposal practices. Once classified, it is local regulation agencies which oversee waste disposal. Alberta has a zero-discharge policy for the residual water of oil sands extraction processes, and so tailings water must be stored (5). NAs have been identified by Alberta Environment as the primary source of toxicity among the other toxins found in tailings (13).

- It has been reported that Alberta Environment is in the mid-development of a Tailings Management Framework, an integrated management approach which will direct assertive plans to deal with pre-existing tailings. The framework is to include a performance criteria outline to aid in minimizing the environmental impact caused by tailings storage (3). All plans for the creation of new ponds will be undergoing thorough professional review prior to construction, and are required to be constructed with ground-water seepage-capture facilities that are under close monitoring (3).

Local Regulatory Authorities

- The Energy Resources Conservation Board (ERCB)

The ERCB regulates oil sands mining and processing operations, as well as operational discards, including tailings. The Board's *Directive 74* lays out performance criteria that will hold mineable oil sands operators accountable for their own tailings management. It dictates that "operators must demonstrate to the satisfaction of the ERCB that sufficient monitoring, measurement, and sampling are available to measure and report on the status and properties of DDAs" (dedicated disposal areas) (15). Beginning this year, an annual compliance report must be submitted to the ERCB which includes (but is not limited to) details of geotechnical monitoring, as well as the identification of any deviations from the DDA plan, including sampling frequencies (15). From 2009 forward, annual tailings management plans that include projections related to impoundment structure integrity and lifespan, and a current "summary of tailings water chemistry, seepage water chemistry, and seepage water rates into the groundwater from reports of groundwater and tailings monitoring programs provided to AENV" (Alberta Environment) (15).

How can the use of products of synthetic biology continue until all risks of this relatively new technological approach have been thoroughly investigated and *Sensomonas nastytoxins* deemed safe?

One of CEPA 1999's guiding principles is based on *precautionary principle*. The principle, which states that "where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (6). Without implying threat or serious consequences from the use of synthetic organisms, it remains that synthetic biology is a relatively new area of science. In particular, considering that by its very nature, the broad-spectrum technology may be employed for an exhaustive number of very specific applications, it is difficult and still controversial to determine the technology as *generally* safe. Instead, case-by-case assessment of the safe-use of applications may be more logical. As it remains, the overall technology still requires much time and testing to prove its safe-use, and this is an obstacle that could very well have to be overcome even before individual applications are investigated. Since the Government of Canada operates on the *precautionary principle,* the use of synthetic biology, in this case *Sensomonas nastytoxins,* within closed industrial facilities (i.e. not physically released to the environment) may continue simultaneously to its impact assessment, so long as a compelling preliminary assessment and competitive cost can be established.

Conclusion

Table 1: Comparison of FTIR to *Sensomonas nastytoxins*

Component	FTIR (Current)	*Sensomonas nastytoxins* (Future)
Instrumentation	Specific Expensive Large, stationary	Non-specific Inexpensive Small, relatively transportable
Location of Analysis Procedures	Analytics Lab – offsite, usually located in an urban centre	Onsite closed lab facility (ex. a trailer/non-permanent building)
Technician/Analyst Training	Extensive	Minor
Tailings Sample Preparation	Significant NA extraction process	(TBD) – little to none
Time Required for Results	5 business days	(TBD) – less than 24 hours
Cost	$195/sample	(TBD) – comparitively inexpensive
Accuracy	Very accurate	(TBD)*
Quantified Molecular Group	Carboxyl	(TBD)

TBD = to be determined

* For the intended purposes of seepage-monitoring, the accurate determination of a sample's concentration is not as important as identifying if NA concentrations are higher than ambient concentrations (ex. Present/not-present)

After some discussion, the team has decided that currently the most practical and marketable use of *Sensomonas nastytoxins* in the oils sands industry is for pond-leakage monitoring. With the current push to track toxic NAs as well as ensure environmental protection, *Sensomonas nastytoxins* would be a cheap (TBD) and convenient way for companies to conduct on-site regulatory monitoring of pond containment. The University of Calgary's iGEM team sees a future in regulatory monitoring that complies with Alberta Environment's zero-discharge policy. In order to meet this team vision, a fast response is pertinent to *Sensomonas nastytoxins'* success in the market. Circumventing tailings ponds, sample wells are drilled to assess the surrounding groundwater stores. Water samples from these wells are tested regularly to ensure that leakage is not occurring from the ponds into the environment. The extreme toxicity of tailings makes it necessary for immediate action to be taken to discover the source of fault and fix it. For this reason, a procedure whereby results could be obtained in less than a day would be extremely valuable. Further, the cost of regularly analyzing multiple samples from every pond**,** has the potential to become very expensive, very quickly. Water samples could be collected and returned to an onsite laboratory for testing to occur. Further, samples could be mixed with *Sensomonas nastytoxins* and other required reagents in vials/test chambers as samples are collected, further reducing the time required to obtain results. It should be noted that by using *Sensomonas nastytoxins* as a biosensor for water samples, the synthetic organism is not actually released to the environment, but would completely contained during sampling as well as in the lab, and properly disposed of (destroyed) after testing is complete, including for the disposal of test chambers. NAs exist in the environment naturally in concentrations of less than 1-2 mg/L, but may exceed 100 mg/L in tailings (16) (S.S. Leung et al, 2003). Thus, even if NAs themselves are not being monitored, their presence alone in slightly elevated concentrations produces a unique signature that would be an unfaltering indication of pond leakage. Thus by using *Sensomonas nastytoxins*, industry would embrace the unique and innovative opportunities to decrease production costs and promote technological advances. Additionally, they will be able to easily meet the regulatory requirements that are currently overseen at the level of local authority, but which are likely to soon move up the in the legislative hierarchy. Future bioremediation applications of synthetic biology would require larger-scale application of synthetic organisms with correspondingly increased risk of release into the environment. By applying synthetic biology to the relatively easily contained biosensor application first, it would lay the framework for advancing the use of synthetic microorganisms for bigger and more direct bioremediation applications in the future.

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