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NUMERICAL MODELLING OF SMOULDERING COMBUSTION TO OPTIMIZE EX SITU SOIL TREATMENT SYSTEM DESIGN

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ABSTRACT

There is widespread soil contamination at thousands of cites in Canada resulting from the historical improper storage and disposal of industrial liquids (Story et al., 2014). Large financial resources are allocated to remediation efforts due to the human and environmental health risks associated with exposure to such contamination, with over $582 million CAN spent on remediation in 2014-15 by the Canadian government alone (Treasury Board of Canada, 2016). Our scientific understanding of site remediation has evolved greatly over the past decades and it is now widely accepted that remediation of the contaminant source zone is necessary to achieve a high level of long-term remediation (Kueper et al., 2014). Non-aqueous phase liquids, or NAPLS, are one of the most prevalent contaminants at contaminated sites and are challenging to remediate due to their highly recalcitrant nature (Kueper et al., 2003). Although many remediation technologies have been developed over the past decades, the challenge in source zone remediation of NAPLs persists.

The application of smouldering combustion to treat NAPL contaminated soils has been proven as an effective technology with both the laboratory experiments and applied in situ at a field site (Switzer et al., 2009, Pironi et al., 2011, Switzer et al, 2014, Salman et al., 2015, Scholes et al., 2015). This technology, titled "Self-sustaining treatment for active remediation", or STAR, utilizes the high calorific value of NAPLs to ignite and sustain a smouldering oxidation reaction, effectively destroying the contaminant in the process. A phenomenological model developed by MacPhee et al. (2012) uniquely combined a multiphase flow model, perimeter expansion model, and analytical expression for the forward smouldering front velocity. This model is able to predict the propagation of the reaction front in response to the interplay between a heterogeneous distribution of permeability and the time-dependent distribution of air flux. After subsequent calibration by Hasan et al. (2014), the model was shown to correctly predict the ultimate extent and time of remediation during treatment for 2D lab scale experiments.

Recently, STAR is being developed as an ex-situ treatment for above ground soils and for sludge intentionally mixed with sand (STARx). Two configurations, or modes of application, are being evaluated: a metal reactor and a "hot pad/soil pile". This work presents the results of calibration and optimization simulations in support of the engineering design process. Model calibration against intermediate pilot tests (~ 2 m^3) was first conducted to ensure the rate of treatment and the final position and time of extinction of the smouldering front were modelled correctly. The calibrated model was then used to complete a suite of simulations to determine the effects of key system design parameters on the extent and time required for remediation. Contaminant pack configuration, NAPL saturation, airflow rate, system dimensions, the influence of heterogeneity, and the effects of impermeable walls and clean sand caps were investigated. The influence of scale was also explored by simulating intermediate scale, large pilot scale, and full field scale applications. The findings from these simulations will be used to influence the optimal STARx

design, maximizing NAPL destruction rate and minimizing the volume of untreated soil. The final design is expected to be tested at the field pilot scale, in 2016.

Keywords: Numerical modelling, source zone remediation, smouldering combustion

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