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An Integrated Soil Respiration Model for Assessing Hydrocarbon Biodegradation Activity in Cold-Region Site Soils

Jihun Kim and ***Wonjae Chang*** (wonjae.chang@usask.ca) (University of Saskatchewan, Saskatoon, SK, Canada)

Background/Objectives. On-site soil respiration data have been frequently used for assessing microbial enhancement during the bioremediation of petroleum hydrocarbon-contaminated soils. Various soil respiration models, including the Generalized Respiration model (GRESP), have been formulated in order to account for site-specific rate-limiting factors for bioremediation, such as site soil temperatures and soil water content. Due to the limited accessibility of northern cold-region sites in Canada (~2 to 4 months), soil respiration activity (O_2 and CO_2 gas) in aerobic soil bioremediation systems is an important on-site indicator for verifying that microbial enhancement is occurring in response to soil treatments at such sites. However, soil respiration models for cold-region site soils under variable low temperature regimes that include sub-zero temperatures have not been extensively developed. The objective of this study was to develop an integrated soil respiration model that couples the effects soil temperatures and unfrozen water content in contaminated soils at cold sites, and to validate the model with experimental data.

Approach/Activities. The Michaelis-Menten microbial kinetic equation was incorporated into the GRESP model to introduce the correlation between soil respiration activity and unfrozen water content variations in cold-region site soils. The temperature and unfrozen water dependencies of microbial activity during seasonal thawing, which are specific to each site soil, were addressed through sensitivity analyses of the modified GRESP model. A numerical soil thermal model (TEMP/W) was employed to predict soil temperatures and unfrozen water content in soils subjected to seasonal, site-representative low temperatures. The predicted temperature and water content data were transferred to the calibrated modified GRESP model to generate a predictive soil respiration dataset (O_2 and CO_2 gas). The predicted soil respiration data and the associated respiration quotients (RQ) were validated with experimental respiration data and RQ values determined for site soils during bioremediation under seasonal thawing.

Results/Lessons Learned. The developed soil respiration model closely approximated changes in the soil respiration activity associated with variable unfrozen water content during seasonal thawing in field-aged, petroleum hydrocarbon-contaminated soils undergoing bioremediation. Existing GRESP models did not accurately predict soil respiration activity at soil temperatures near and below 0 °C. Accurately modelling soil respiration activity in soils when soil temperatures are near 0 °C can improve our understanding of hydrocarbon biodegradation activity under the zero-curtain effect in cold-climate soils, and can help identify the seasonal activation of the microbial activity of cold-adapted hydrocarbon-degrading bacteria in remote cold-region site soils. Using the determined RQ values, the specificity of the soil respiration activity to hydrocarbon biodegradation can be assessed. Using both the soil thermal model (TEMP/W) and the modified GRESP model, the predicted soil temperatures, unfrozen water contents, O_2 and CO_2 soil gas concentrations, and RQ values were all in good agreement with the experimental data obtained from the site soils. This study indicated the necessity and feasibility of developing a reliable, integrated bioremediation assessment framework that can predict soil respiration activity for contaminated sites in remote cold regions. The outcomes of the study are meaningful in the context of planning, managing and monitoring bioremediation in remote cold climates.