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Comparison of Vapour Emissions from Remediation by *Ex*-Situ Excavation and Landfill Disposal 2013 Summary Report

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1.0 INTRODUCTION

Under the authorization of the Petroleum Technology Alliance Canada (PTAC), Millennium EMS Solutions Ltd. (Millennium) conducted an assessment of the environmental significance of vapour emissions during *ex-situ* remediation activities. The work was conducted under the Alberta Upstream Petroleum Research Fund (AUPRF), under the direction of the Canadian Association of Petroleum Producers (CAPP) and the Explorers and Producers Association of Canada (EPAC). The following report documents the results of the assessment, and has been updated to reflect work completed as of 2013.

1.1 Background

The purpose of the study was to conduct a life cycle analysis of emissions from one time *ex-situ* remediation as compared to landfill disposal for soils contaminated with volatile petroleum hydrocarbons (*e.g.* condensate). *Ex-situ* remediation and landfill disposal were compared using approaches as similar as possible in order to ensure the comparison was meaningful. The objective of the project was to be able to meaningfully assess the relative human health and environmental impacts of the two approaches in order to determine whether *ex-situ* remediation may be an appropriate approach at a specific site.

A literature review was conducted to identify relevant models to estimate emissions of volatile organic chemicals (VOCs), criteria air pollutants and particulates from both *ex situ* remediation and landfill disposal. The most appropriate available model for each process was selected based on scientific basis, defensibility, regulatory acceptance, applicability to Canadian conditions, and ability to meet project objectives. The selected models were combined into a single recommended modelling approach capable of predicting lifecycle emissions of all emissions evaluated, as well as short-term emissions of VOCs for the evaluation of human health and environmental effects using regulatory air dispersion models. The model was developed into a simple spreadsheet-based calculation tool for screening-level evaluations.

In 2012 further research into the use of biofilters with *ex situ* remediation, including evaluating the lifecycle emissions from ex situ remediation with and without biofilters was completed. This included consideration of the production and fate of the biofilters and the effects of biofilters on ambient air quality. A sampling program to collect real-world emission data from *ex situ* remediation was completed in order to calibrate and confirm the modelling assumptions. A second sampling program with similar objectives was completed in 2013. A hypothetical comparison, for various concentrations of contaminants above regulatory guidelines, was also completed in order to determine when exceedances of ambient air quality objectives were predicted to occur.

2.0 MODELLING APPROACH

There are three general approaches to estimating exposure concentrations in air: (1) ambient air monitoring, (2) emission measurements coupled with dispersion modelling, and (3) emission modelling coupled with dispersion modeling (USEPA, 2006). The development of a scientifically defensible model to quantify remedial emissions during *ex-situ* activities would allow upstream oil and gas to more accurately estimate their emissions and define the associated risks.

2.1 Lifecycle Assessment

To complete the assessment a life cycle approach was used considering assessment damages that included the accounting of predicted pollutant emissions including greenhouse gases, and criteria air contaminants. To simplify the comparison, only aspects of the techniques that were quantifiable, comparable and specifically related to the remediation processes were considered. The assessment was considered a 'gate to grave' assessment and the environmental impacts of fuel production, equipment production, preceding site visits *etc.* were not considered, but rather the time scale began when remedial activities began on-site.

2.2 Contaminant Fate Modelling

Contaminant fate and transport models have historically been used in a variety of applications including risk assessment, analysis of remedial system performance, cost-benefit assessment and contaminant life cycle analysis (Benson et al., 1993; Poulsen *et al*., 2001). To enable a quantifiable comparison, kinetic or mass transfer equations were applied because of their conceptual and mathematic simplicity. The environmental effects associated with petroleum hydrocarbons are encountered at different length and times scales, so the various categories of human health and other adverse impacts were divided into a more manageable length-time scale. For the purposes of this life cycle assessment, the time scale considered begins when remedial activities commence and concludes when the mass of contaminant is completely removed from the soil media.

2.3 Conceptual Model and Processes Considered

For purposes of modelling, a conceptual model was produced for each scenario to represent the processes and sources involved.

Ex-situ remediation aims to remove contaminant mass from soil media through the physical manipulation of the contaminated soil volume, encouraging partitioning from soil to air by exposing soil particle surfaces to air. Increasing soil exposure to air through physical manipulation, is the minimum requirement to be considered *ex-situ* remediation, however, this is often coupled with other techniques to encourage volatilization. *Ex-situ* remediation is considered to involve the following processes:

- Mobilization/demobilization of equipment to the site.
- Excavation of contaminated soils.
- Onsite treatment of contaminated soils and replacement in the excavation.
- Long-term *in situ* degradation of residual contamination

Hydrocarbon contaminants disposed in a landfill undergoes both aerobic and anaerobic biological transformation. The rate of gas production is a function of waste composition, age of waste (time since emplacement), climate, moisture content, particle size, compaction, nutrient availability, and buffering capacity (USEPA, 2005). Landfill disposal is considered to include the following processes:

- Mobilization/demobilization of equipment to the site.
- Excavation of contaminated soils.
- Transport of contaminated soils to a landfill and placement in the landfill.
- Long-term degradation of contamination at the landfill.

2.4 Selection of Emissions Models

All processes thought to be directly involved in contributing emissions from *ex-situ* remedial activities, including criteria air contaminants and greenhouse gases, were considered. As no individual model was ideally suited to all aspects of the remediation scenarios, multiple models were utilized that were best suited to specific processes.

Models with some form of regulatory acceptance, particularly federal regulatory acceptance that would be broadly applicable were preferred. Models that specifically considered Canadian conditions, or were developed or endorsed by Canadian regulators, were also preferentially considered. A list of selected models for emission quantification requirements can be seen below in Table 1.

Table 1 Models for Various Emissions Quantification Applications

Emissions Type	Model
Ex-situ contaminant emission	Mass Transfer
Landfill gas emission	CCME Biosolids Emission Estimation
Combustion emissions (particulates, criteria air contaminants and greenhouse gases)	GHGenius NRC Model
Equipment process particulate emissions	US EPA Construction Particulate Emissions, 1993
Vehicular transport particulate emissions	Environment Canada NPRI Toolbox Estimating Road Dust Emissions

2.5 Spreadsheet Model

A spreadsheet tool was developed for Microsoft Excel that contains the full emission model developed by Meridian (2010). The inputs for the tool require information related to site conditions, contaminant concentrations, and remediation method. Additional secondary inputs for more complex parameters may also be used to refine estimates if site specific data is available. Default and/or recommended values were provided where applicable for input parameters based on expected site conditions in Alberta, current regulatory guidance, and common remedial strategies. The output of the tool includes a screening-level air quality assessment and comparative life cycle emissions for *ex-situ* treatment and landfill disposal options.

3.0 BIOFILTER EVALUATION

3.1 Background

A typical biofilter uses a three-phase system, consisting of a gas phase transporting the target chemicals through the reactor, a liquid phase which contains an aqueous biofilm, and a solid phase substrate on which the microorganisms are present.

The gas phase often consists of ambient air, with the typical open biofilter being exposed to the atmosphere and limited by the rate of ascending gas flow. Biofilms are populations of microorganisms attached to the solid biofilter substrate surfaces through polymeric substances, and the biofilm matrix will contain: water, microbial cells, polymers, absorbed nutrients, and metabolic by-products. The solid substrate, or filter bed, is generally in the form of inert packing material, and is required to increase the available area for surface transfer between phases. At this time most commercial biofilters operate using indigenous microbial populations.

3.2 Treatment Rates

Removal efficiencies over 99% have been obtained for BTEX in lab tests and complete removal of hexane in a compost biofilter; however, lower removal efficiencies closer to 80% are often encountered in practice. Treatment rates are typically limited by the rate of mass transfer between phases in a biofilter, and are influenced by the initial concentration of microbes and the air flow rate through the biofilter.

3.3 Applicability to Emissions Model

Actual removal efficiency will vary between contaminants and result in changes to the composition of volatile contaminants. Therefore application of an overall removal credit should be based on the lowest expected removal efficiency in order to account for difficult to degrade chemicals and the potential for inhibitory interactions between compounds. Based on a review of published literature on biofilter treatment of petroleum hydrocarbons, a minimum expected efficiency of 60% is considered reasonable for difficult to treat compounds.

4.0 MODEL VALIDATION

4.1 2012 Program

In order to calibrate the model, soil concentrations and volatile emissions from one *ex-situ* remediation project were measured as a pilot test. Candidate sites were provided by the PTAC Project Manager. The available reports from these sites were evaluated to identify the site with the highest concentrations of volatile contaminants and appropriate remediation technology. The remediation project selected was a wellsite located near Sundre, Alberta.

4.1.1 Data Collection

Soil and air samples were collected simultaneously after a brief warm-up period for the operators and equipment. Pre-treatment soil samples were obtained directly from an excavator bucket containing approximately 1 m^3 of contaminated soil before aeration and trommel treatments. The material in the excavator bucket was then aerated and run through the trommel. Post-treatment soil samples were then obtained directly from the fine material ejected from the trommel after all the soil had passed through. Air samples were obtained from locations identified as "background," "source," and "downwind."

4.1.2 Data Evaluation

The soil data were used to estimate the mass of contaminants lost to the atmosphere during the 1-hour remediation period. This data was incorporated into the previously developed Meridian emission model (2010) and emission outputs were compared to measured air concentrations obtained from the source and downwind air sampling location.

As the downwind sample did not contain detectable PHCs, a qualitative comparison to the laboratory detection limits was made instead. Concentrations of several parameters were below laboratory detection limits and could not be included in the model comparison. Based on the measured concentrations and observations on site activities, it appears that a significant portion of the volatile contaminants had been lost prior to obtaining the pre-treatment samples, either through excavation and handling disturbances or gradual volatilization to the atmosphere over time.

4.1.3 Model Comparison

Measured concentrations of PHC contaminants in soil were used as inputs for the Meridian (2011) model, and predicted air exposure concentrations were compared to the measured air concentrations. The model significantly over-predicted exposure concentrations for all parameters with data available, by up to a factor of 200. While this over-prediction ensures that the model is conservative when considering worker exposure to contaminants during *ex-situ* remediation, it is likely that the previous loss of volatile mass was a major factor as well. Due to the limited amount of data available, no adjustments to the original model were recommended.

4.2 2013 Program

In order to complete validation of the original *ex-situ* emission model, additional candidate sites undergoing remediation of volatile petroleum hydrocarbons were identified. One suitable candidate site (a former gas plant) was identified.

4.2.1 Data Collection

Soil and air samples were collected simultaneously after a brief warm-up period for the operators and equipment, following similar procedures to the 2012 program. A total of ten soil samples and three air samples were collected. Soil samples were collected as grab samples either before or after treatment, and air samples were collected with flow-regulated summa canisters over a period of 1-hour from locations adjacent to the onsite emission sources, 10 m from the onsite emission sources, and at a background location upwind of onsite vapour sources.

4.2.2 Data Evaluation

The soil data were used to estimate the mass of contaminants lost to the atmosphere during the 1-hour remediation period. This data was incorporated into the previously developed Meridian emission model (2010) and emission outputs were compared to measured air concentrations obtained from the source and downwind air sampling location.

4.2.3 Model Comparison

The spreadsheet model over-predicted PHC concentrations, suggesting that it is conservative. It may be possible to adjust the model to reflect this over-prediction with additional data.

4.3 Hypothetical Model Runs

Three hypothetical model runs were undertaken in order to determine when exceedances of the ambient air quality objectives are predicted to occur. These models runs used concentrations of PHCs at two, five, and ten times the regulatory guidelines and assumed that *ex-situ* treatment was able to reduce concentrations to the applicable Tier 1 guidelines. Initial soil concentrations, model predicted 1-hour ambient air concentrations, and the soil concentration which resulted in predicted ambient air quality exceedances during treatment are shown below in Table 2. All input parameters other than PHC soil concentrations were left at the default model values, and ambient air quality objectives are based on 8-hour occupational exposure limits recommended by ESRD. The 1-hour Alberta ambient air quality objective is also provided for reference.

Table 2 Model Results

Case	Benzene	Toluene	Ethylbenzene	Xylenes
Tier 1 Guideline (mg/kg)	0.073	0.49	0.21	12
8-Hour Occupational Air Guideline (mg/m^3)	1.6	188	434	434
Predicted Air Concentration at 2x Soil Guideline (mg/m^3)	0.043	0.29	0.12	7.0
Predicted Air Concentration at 5x Soil Guideline (mg/m^3)	0.11	0.72	0.30	18
Predicted Air Concentration at 10x Soil Guideline (mg/m^3)	0.21	1.4	0.61	35
Soil Concentration Resulting in Occupational Air Quality Exceedances (mg/kg)	5.5	640	1500	1500

4.4 Applicability to Dispersion Modelling

An additional purpose of the model was to generate inputs for air dispersion models to determine potential offsite impacts. As a demonstration, emission rates calculated by the model were used as an input for the US EPA Screen3 Gaussian dispersion model using a volume source area and a default meteorological data set. The remaining Screen3 inputs were based on default assumptions of the emission model, including: assuming a 2 m height for an allu (TM) bucket 1 m wide, receptors at 1 m height, and operation in a rural area. The concentrations predicted by Screen3 at multiple discrete receptors were used to calculate attenuation factors were for predicted air concentrations for a variety of distances from the source. Attenuation factors are presented in Table 3.

Table 3 Emission Attenuation Factors Calculated Using Screen3 Model

Distance From Source (m)	Attenuation Factor
10	0.78
20	0.61
30	0.47
40	0.37
50	0.29
100	0.082
500	3.7×10^{-6}

These attenuation factors could be applied to the Alberta Ambient Air Quality Objectives when determining if remediation would be predicted to result in exceedances to offsite receptors.

5.0 RECOMMENDATIONS

The model is considered ready for more general use, with existing data supporting its conservative nature. We recommend that users collect pre- and post-treatment soil data and air quality data when performing ex situ treatment and share these data with PTAC/CAPP in order to increase the confidence in the model conservatism and potentially build a case for model adjustment in the future. Pre-treatment samples should be collected from the most heavily contaminated areas and represent worst-case concentrations at the site, while also allowing for a determination of an average concentration of the material to be treated. Post-treatment soil samples should be obtained immediately after treatment at regular intervals. It is recommended that for each case, a minimum of f samples would be needed for this data to be useable. Air samples should be collected from a location immediately downwind of the treatment process and a background location, during the same period as when the post-treatment soil samples are collected.

6.0 LIMITATIONS OF LIABILITY AND CLOSURE

This report has been prepared under the Alberta Upstream Petroleum Research Fund (AUPRF), under the direction of the Canadian Association of Petroleum Producers (CAPP) and the Small Explorers and Producers Association of Canada (SEPAC). Quantitative and qualitative environmental modelling and fate analysis involves a number of uncertainties and limitations. As a consequence, the use of the results presented herein to develop site management strategies may either be overly protective or may not necessarily provide complete protection of human and environmental receptors or prevent damage of property in all circumstances. The work presented herein was conducted in accordance with generally accepted protocols. Given the assumptions used herein, the modelling approach is believed to provide a conservative estimate of the risks involved. The services performed in the preparation of this report were conducted in a manner consistent with the level of skill and care ordinarily exercised by professional engineers and scientists practising under similar conditions.

Yours truly,

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7.0 REFERENCES

Benson, D.A., D. Huntley, P.C. Johnson. 1993. Modeling Vapor Extraction and General Transport in the Presence of NAPL Mixtures and Non-ideal Conditions. Groundwater. 31(3):437-445.

Meridian Environmental Inc. 2010. Review of Approaches for Modelling Vapour Migration into Trenches and Excavations. Prepared for the Canadian council of Ministers of the Environment.

Meridian Environmental Inc. 2012. Vapour Emissions During Ex-situ Remediation Activities: Model Calibration, Evaluation of Biofilters, and Screening Tool Development. AUPRF Reference #09-9190-50.

Poulsen, T.D., M. Christophersen, P. Moldrup, P. Kjeldsen. 2001. Modeling lateral gas transport in soil adjacent to old landfill. J. Environ. Eng. 127(2):145-153.

US EPA (United States Environmental Protection Agency) 1993. Air Superfund National Technical Guidance Study Series: Models for Estimating Air Emissions Rates fro Superfund Remedial Actions. Office of Air Quality Planning and Standards. EPA-451/R-93-001.

US EPA (United States Environmental Protection Agency). 2005. Guidance for Evaluating Landfill Gas Emissions for Closed or Abandoned Facilities. Office of Research and Development. EPA-600/R-05/123a.

US EPA (United States Environmental Protection Agency). 2006. AP-42 – Miscellaneous Sources, Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, Unpaved roads. Office of Air Quality Planning and Standards. Available at: http://www.epa.gov/ttn/chief/ap42/index.html.