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Case Study

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SCALE-UP FACTORS WHEN APPLYING BIOVENTING RESULTS TO THE FIELD

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1 BIOVENTING SCALE-UP

Soil contamination with petroleum and its by-products is an on-going problem in the entire the world. This contamination is caused frequently by leaking underground storage tank systems, accidental releases during transportation, or improper disposal of petroleum hydrocarbon wastes. Bioventing is an important technology that is used to remediate sites contaminated with petroleum hydrocarbons. It is a low cost non-destructive in-situ method that uses natural occurring microbiology to degrade the contaminants. The challenge in using bioventing is the determination or estimation of the biodegradation rate, as the remediation conditions vary greatly from site to site due to changes in environmental conditions, as well as site-specific conditions, like the type of soil, presence of degrading bacteria, physiochemical properties, and the concentration of contaminant. Consequently, crude estimations of the biodegradation rate are made, or expensive, time-consuming bench- or pilot-scale measurements for each site are completed.

Eyvazi and Zytner (2009) developed an empirical correlation using six different soils to provide a simple and reliable tool to estimate the degradation potential for different sites without undertaking expensive and time consuming laboratory studies. The correlation given in Equation 1 has a significance level of 95%:

$$\ln(k)=2.803\cdot PDP+0.210\cdot Sand+4.886\cdot OM-0.094\cdot Clay-0.004\cdot(SW\cdot Sand)-0.021\cdot(Sand\cdot PDP)-0.632\cdot(OM\cdot PDP)+0.004\cdot(SW\cdot Clay)-23.4997 \quad (1)$$

where, k is the biodegradation rate constant (1/d); PDP is the logarithm of initial population of hydrocarbon-degrading microorganisms in soil (log cfu/g); SW is the soil water content (%); Sand is the soil sand content (%); OM is the soil organic matter content (%); Clay is the soil clay content (%).

Development of Equation 1 showed that the soil organic matter and initial population of hydrocarbon-degrading microorganisms were the major factors affecting the biodegradation rate of synthetic gasoline in soil. It was also seen that the biodegradation rate of the gasoline was independent of the initial concentration, up to 8700 mg/kg soil for the study completed, indicating that this level of petroleum hydrocarbon contamination had no inhibitory effect on the activity of microorganisms.

Having the an estimated degradation rate for different site conditions is important as predictions on the time to closure could be completed, but the question arises as to whether the value determined from a soil sample of 200 g in size is appropriate for a site having tonnes of contamination. Accordingly it was decided to evaluate the scale-up factor to transfer the lab results to the field. Khan et al. (2015) completed work with 4 kg reactors to refine Equation 1 for a large scale and determine a scale-up factor.

Khan et al. (2015) monitored biodegradation in the 4 kg reactors with radial flow under similar environmental conditions to that studied by Eyvazi and Zytner (2009). It was determined that under ideal bioventing conditions, nutrients, temperature and oxygen, the degradation rate followed a two stage model, with the second stage of degradation representing degradation conditions that were similar to Equation 1. Equation 2 is the resulting stage-2 correlation developed by Khan et al. (2015):

$$lnk_{Stg2} = 0.0231 \times Silt - 0.0355 \times Clay - 0.383 \times OM + 0.825 \times PDB_8 - 0.048 \times SW - 6.774 \quad (2)$$

where, lnk_{Stg2} is biodegradation rate constant (1/d); PDP_8 is the logarithm of initial population of hydrocarbon-degrading microorganisms in soil (log cfu/g) after 8 days; Silt is silt content (%).

Comparing the degradation rates determined from Equations 1 and 2 for the various soils tested gave an average scale-up factor (SF) of 1.8 ± 0.5. This scale-up factor showed that the increase in volume of soil from the 200 g micro-reactors to the 4 kg meso scale reactors increased the rate of hydrocarbon degradation by almost a factor of two. The increased degradation rate was mainly attributed to improved oxygen supply to the microorganisms.

Based on the findings of Khan et al. (2015), Mosco and Zytner (2017) undertook a bioventing study with a 80 kg soil reactor system to further explore scale-up conditions. The 80 kg system consisted of a climate chamber for water control in the soil, low flow venting system and an off gas capture device. Sandy and clayey soils were tested after being spiked with synthetic gasoline. Results showed that a two stage degradation system still existed, with the second stage degradation rate similar to that obtained by Khan et al. (2015) when comparing results from identical soils. Further review of the results showed that there was statistical difference between the degradation rates measured for the identical soils. However, when comparing all the scale-up factors determined for the 80 kg reactor, and comparing the results with the 200 g degradation results, an average scale-up factor of 2.3±0.4 was obtained. Completing a statistical analysis on the scale-up factors determined for the 80 kg and 4 kg reactor degradation rates when compared to the 200 g reactor showed no statistical difference.

1.1.1 Significant Findings

Similar soils were tested under similar environmental conditions at various scales: 200 g, 4 kg and 80 kg. The 200 g bioventing tests showed a single stage degradation, while the 4 kg and 8 kg reactors demonstrated two stage degradation patterns. These degradation patterns were attributed to the ideal bioventing conditions induced from the radial flow induced in the larger reactors, with the second stage degradation rate matching the single stage degradation determined for the 200 g soil. Comparing all the degradation rates gave scale-up factors that averaged to 2.1±0.5, with no statistical difference. This indicates that there is no significant advantage in completing bioventing experiments at the larger 80 kg scale. As such, the Equation 1 can used as the base correlation for estimating the degradation rate, provided that a scale-up factor of approximately 2 is applied. Doing so can help remediation consultants estimate the length of time it will take to reach closure and evaluate if environmentally viable.

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