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# Thermal Remediation of Tar-Contaminated Soil and Oil-Contaminated Gravel

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Pilot plant studies were carried out to evaluate the feasibility of remediation of coal tar-contaminated soil and oil-contaminated gravel by incineration, with environmentally acceptable performance.

High-temperature treatment has the advantages of reliability and high capacity in decontamination of polluted materials.

Besides adequate decontamination and emission control, effort was devoted to treating the special feedstocks with difficult handling properties by use of conventional combustion and feeding systems.

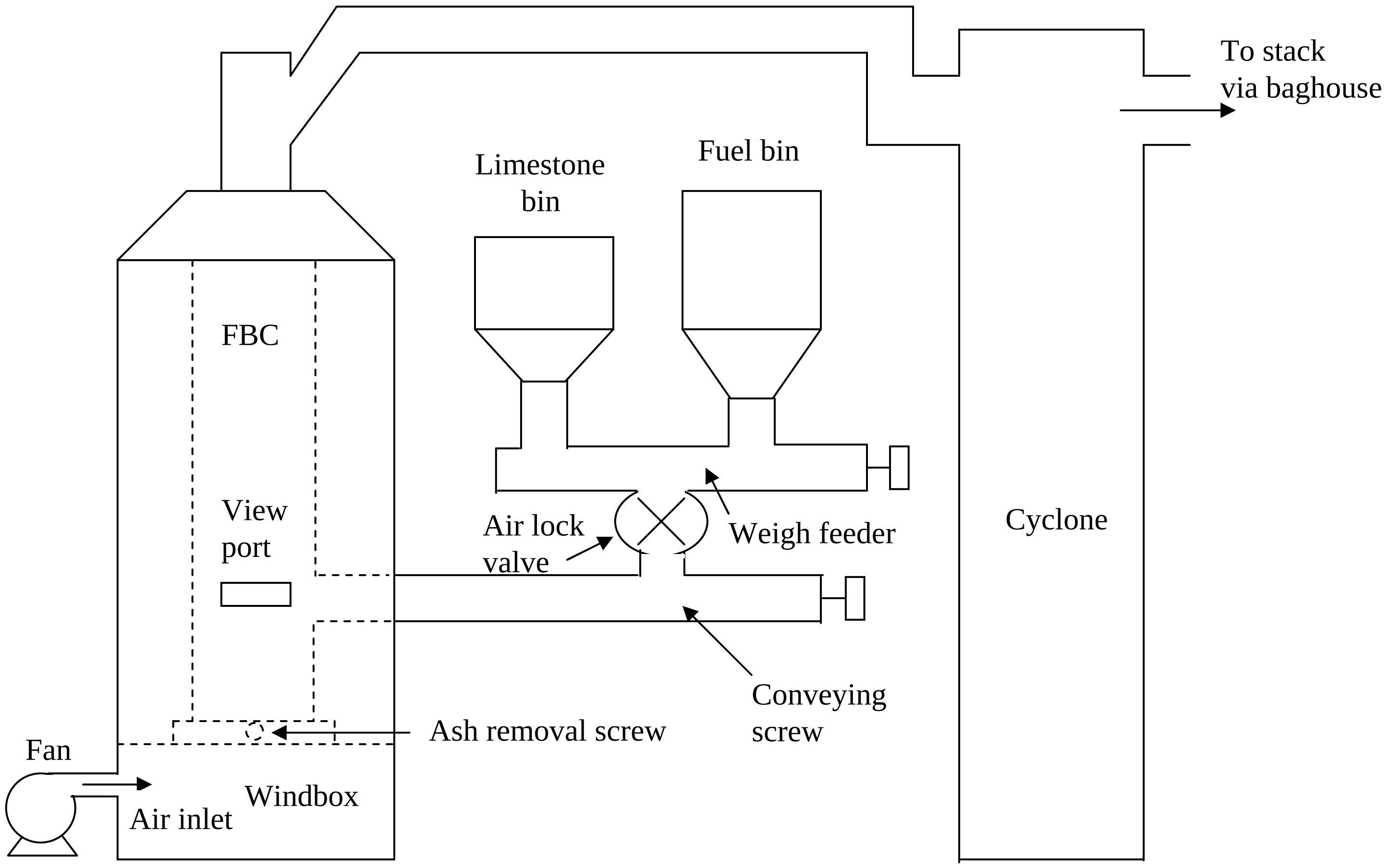


**Fig. 1.** Schematic of the pilot plant fluidized combustor used for remediation of oil-contaminated gravel.

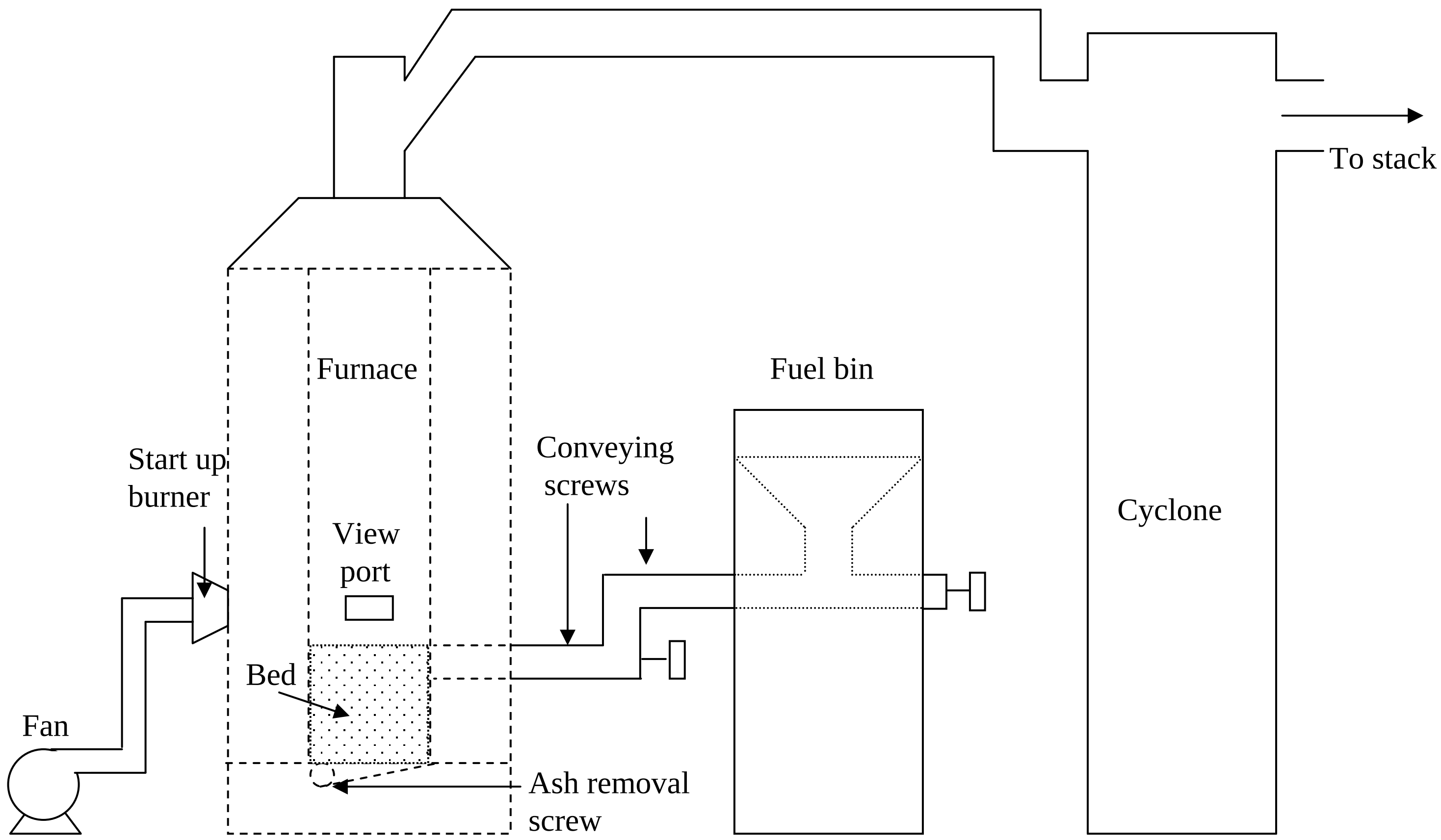


**Fig. 2.** Modified pilot-scale furnace for incineration of coal tar-contaminated soil.

**Table 1. Analytical data for coal tar-contaminated soil samples**

| | Sample 1 | Sample 2 | Sample 3 |
|---|---|---|---|
| **Proximate analysis** (wt %) | | | |
| Moisture | 19.40 | 13.80 | 30.20 |
| Ash | 22.57 | 23.96 | 47.32 |
| **Ultimate analysis** (wt %) | | | |
| Carbon | 46.51 | 51.72 | 17.20 |
| Hydrogen | 3.83 | 4.47 | 1.43 |
| Nitrogen | 0.58 | 0.67 | 0.38 |
| Sulphur | 0.56 | 0.72 | 0.49 |
| **Calorific analysis** ($MJ \cdot kg^{-1}$) | 20.13 | 22.50 | 6.50 |

**Table 2. Analytical data for the lignite coal (dry basis) which was mixed with the coal tar-contaminated soil**

| | |
|---|---|
| **Proximate analysis (wt%)** | |
| Ash | 16.72 |
| Volatiles | 37.27 |
| **Ultimate analysis** (wt%) | |
| Carbon | 63.32 |
| Hydrogen | 3.86 |
| Nitrogen | 1.17 |
| Sulphur | 0.63 |
| Oxygen (by difference) | 14.30 |
| **Calorific analysis** ($MJ \cdot kg^{-1}$) | 23.93 |

**Table 4. Test conditions and results of flue gas emissions and opacity observation for treating the coal tar-contaminated soil**

| | Test 1 | Test 2 | Test 3 | Test 4 [a] | Test 5 [b] | Test 6 |
|---|---|---|---|---|---|---|
| Feed Rate (kg·h$^{-1}$) | 23.2 | 40.0 | 20.0 | 32.7 | 34.5 | 20.4 |
| Lignite-soil ratio | 75/25 | 50/50 | 75/25 | 50/50 | 75/25 | 80/20 |
| Gas temperature (°C) | 793 | 966 | 872 | 1078 | 929 | 872 |
| Bed temperature (°C) | 318 | 204 | 222 | 368 | 121 | 231 |
| Gas residence time (s) | 4.9 | 3.2 | 5.1 | - | 3.7 | 5.0 |
| Bed depth (mm) | 100 | 200 | 200 | - | 130 | 150 |
| $O_2$ (%) | 5.0 | 4.4 | 4.1 | 2.5 | 4.6 | 5.7 |
| $CO_2$ (%) | 10.7 | 12.0 | 11.7 | 11.0 | 11.3 | 8.3 |
| CO (ppm) | 112.0 | 124.0 | 186.0 | 206.0 | 78.0 | 130.0 |
| $SO_2$ (ppm) | 354.0 | 345.0 | 388.0 | 197.0 | 109.0 | 214.0 |
| $NO_x$ (ppm) | 115.0 | 166.0 | 169.0 | 58.0 | 151.0 | 108.0 |
| Hydrocarbons (ppm) | 0.0 | 0.0 | 4.6 | 3.5 | 19.0 | 10.0 |
| Opacity | very slight to nil | invisible | slight | - | slight | slight |

[a] During this run the conditions were unstable and clinkering in the furnace occurred. The removal of ash and char residue from the furnace bottom was difficult and eventually stopped; see text.

[b] With the batch that was lean in tar content.

Table 5. Analysis of ash samples after incineration of coal tar-contaminated soil

| **Proximate analysis** (wt%) | **Test 1** | **Test 2** | **Test 3** | **Test 4** | **Test 5** | **Test 6** |
|---|---|---|---|---|---|---|
| Moisture | 2.23 | 3.53 | 0.91 | 1.55 | 6.91 | 4.59 |
| Ash | 55.60 | 39.93 | 42.90 | 36.16 | 41.02 | 33.02 |
| Volatiles | 10.57 | 20.12 | 10.49 | 19.53 | 24.56 | 26.35 |
| Fixed carbon | 31.60 | 36.42 | 45.70 | 42.76 | 27.51 | 36.02 |

$$\frac{dY}{dz} = -\frac{A}{Q} k_s Y \qquad (1)$$

$Y$ : fraction of the unburned combustibles
$z$ : bed height
$A$ : cross-sectional area
$Q$ : volumetric flow rate of the solids
$k_s$ : apparent rate coefficient for the solids

$$Y = Y_0 \exp\left(-\frac{A}{Q} \bar{k}_s z\right) \qquad (2)$$

$$\bar{k}_s = \frac{\int_0^Z k_s dz}{Z} \qquad (3)$$

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When both bed height and feed rate are varied, the unburned combustible fraction can be given as a function of the ratio *z/Q*,

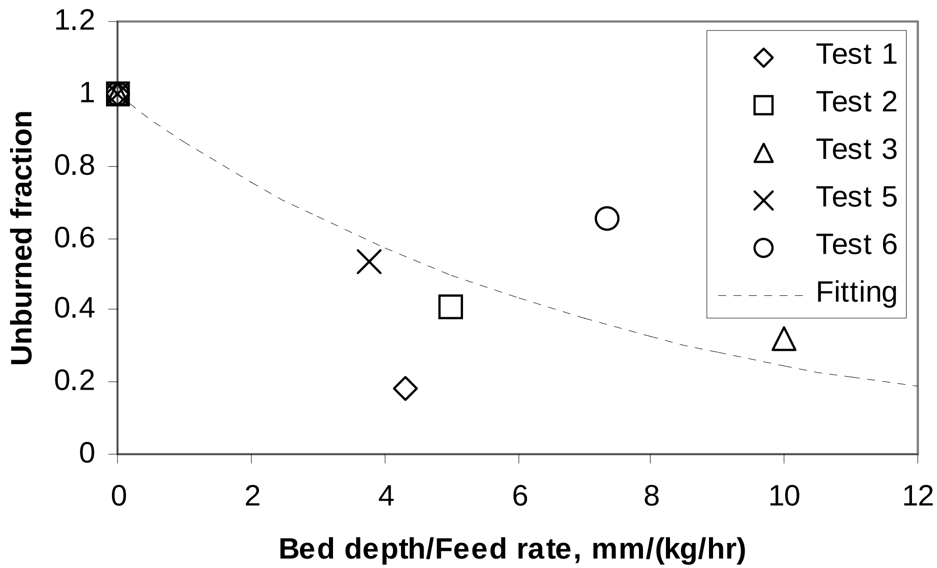
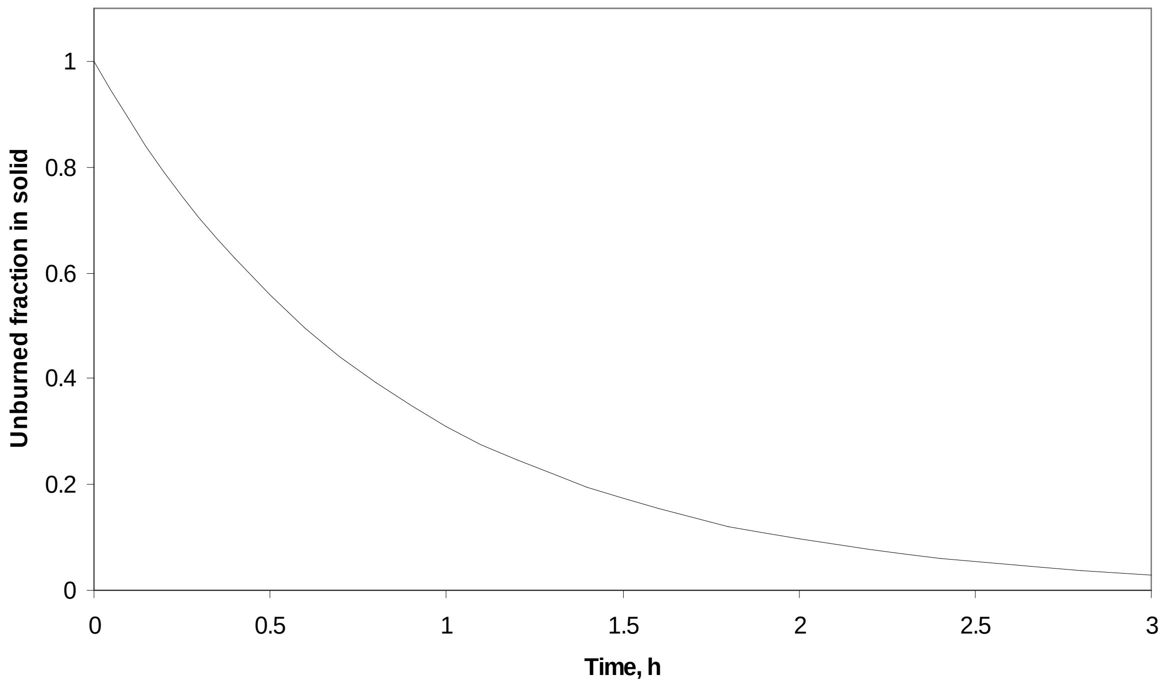



**Fig. 3.** Unburned fraction of combustibles in the ash withdrawn from the bottom of the furnace as a function of the ratio of bed depth to feed rate. The dashed curve represents the description by Eq. (2).

$$Y = Y_0 \exp(-\frac{A}{Q}\bar{k}_s z) \longrightarrow Y = Y_0 \exp(-\bar{k}_s t)$$

The unburned combustible fraction will be negligible after 2 to 3 hours at much higher temperature.



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| Lignite-soil ratio | 75/25 | 50/50 | 75/25 | 50/50 | 75/25 | 80/20 |
| Gas temperature (°C) | 793 | 966 | 872 | 1078 | 929 | 872 |
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| Gas residence time (s) | 4.9 | 3.2 | 5.1 | - | 3.7 | 5.0 |
| Bed depth (mm) | 100 | 200 | 200 | - | 130 | 150 |
| $O_2$ (%) | 5.0 | 4.4 | 4.1 | 2.5 | 4.6 | 5.7 |
| $CO_2$ (%) | 10.7 | 12.0 | 11.7 | 11.0 | 11.3 | 8.3 |
| CO (ppm) | 112.0 | 124.0 | 186.0 | 206.0 | 78.0 | 130.0 |
| $SO_2$ (ppm) | 354.0 | 345.0 | 388.0 | 197.0 | 109.0 | 214.0 |
| $NO_x$ (ppm) | 115.0 | 166.0 | 169.0 | 58.0 | 151.0 | 108.0 |
| Hydrocarbons (ppm) | 0.0 | 0.0 | 4.6 | 3.5 | 19.0 | 10.0 |
| Opacity | very slight to nil | invisible | slight | - | slight | slight |

[a] During this run the conditions were unstable and clinkering in the furnace occurred. The removal of ash and char residue from the furnace bottom was difficult and eventually stopped; see text.

[b] With the batch that was lean in tar content.

$$\frac{dC}{dt} = -k_g C$$

$$C = C_0 \exp(-\bar{k}_g t)$$

$$C = \gamma F \exp(-\bar{k}_g t)$$ $\gamma$ : proportionality coefficient; $F$ : unburned fraction of fuel

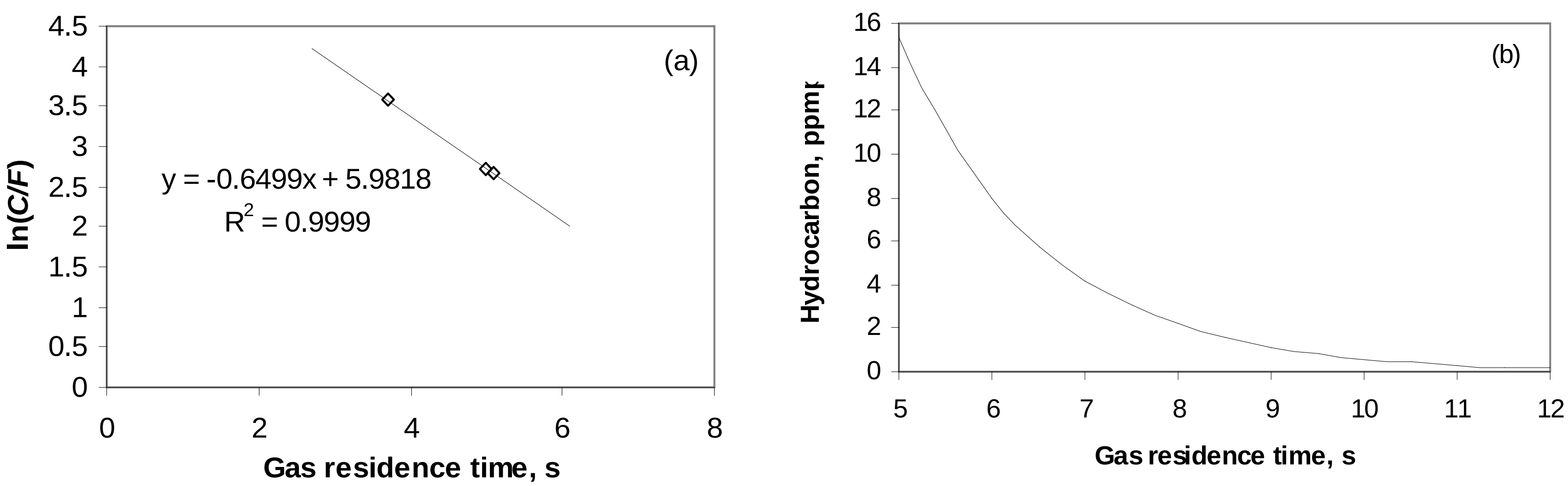


**Fig. 4.** (a) Logarithm of the ratio of gaseous hydrocarbon to unburned combustibles in the solids as a function of gas residence time. The equation is for the trend line and $R^2$ is the square of the correlation coefficient. (b) Projected gaseous hydrocarbon concentration, based on the information from (a), as a function of the gas residence time.

**Table 3. Analytical data for Saudi crude oil**

| | Fresh Saudi oil | Weathered Saudi oil |
|---|---|---|
| **Ultimate analysis** (wt%) | | |
| Carbon | 84.8 | 85.3 |
| Hydrogen | 13.0 | 12.5 |
| Nitrogen | 0.1 | 0.1 |
| Sulphur | 1.94 | 2.29 |
| Oxygen | < 0.5 | < 0.5 |
| **Calorific value** ($MJ \cdot kg^{-1}$) | 44.64 | 43.92 |

**Table 6. Test conditions and results of emissions measurements and oil residue analysis for incineration of the oil-contaminated gravel**

| | Test 1 | Test 2 | Test 3 |
|---|---|---|---|
| Feed | gravel/fresh oil | gravel/oil emulsion | weathered gravel/oil |
| Average bed temperature (°C) | 877 | 840 | 824 |
| Feed rate ($kg \cdot h^{-1}$) | 50 | 50 | 50 |
| Superficial gas velocity ($m \cdot s^{-1}$) | 2.2 | 2.1 | 2.0 |
| $O_2$ (%) | 10.4 | 12.0 | 11.8 |
| $CO_2$ [a] (%) | 14.7 | 16.0 | 15.4 |
| CO [a] (ppm) | 50 | 56 | 71 |
| $SO_2$ [a] (ppm) | 100 | 119 | 119 |
| $NO_x$ [a] (ppm) | 56 | 59 | 66 |
| $N_2O$ [a] (ppm) | 0.52 | 0.59 | 0.57 |
| PAH [b]($ng \cdot m^{-3}$) | 636 | 1022 | 755 |
| PCDDs/PCDFs [b](TEQ, $pg \cdot m^{-3}$) | 3.28 | 4.85 | 4.09 |
| Oil remaining on gravel (by Xylene extraction) | Nil | Nil | Nil |

[a] Values normalized to 3.5% oxygen

[b] Sampled and measured by Environment Canada

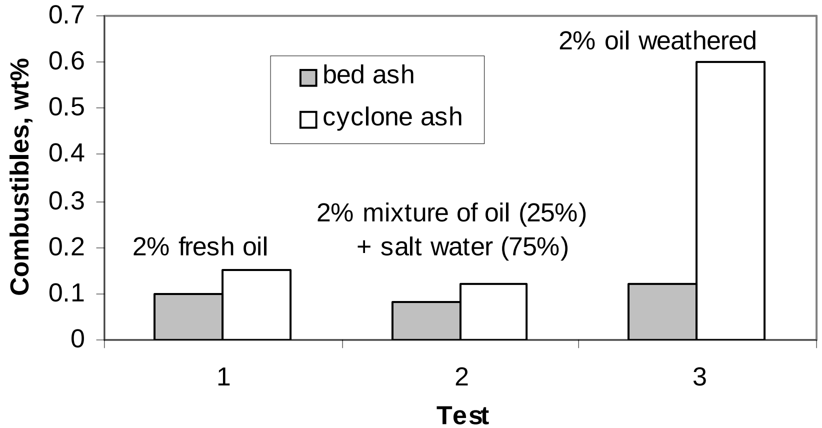


**Fig. 5.** Content of combustibles in the incineration ashes of oil-contaminated gravel.

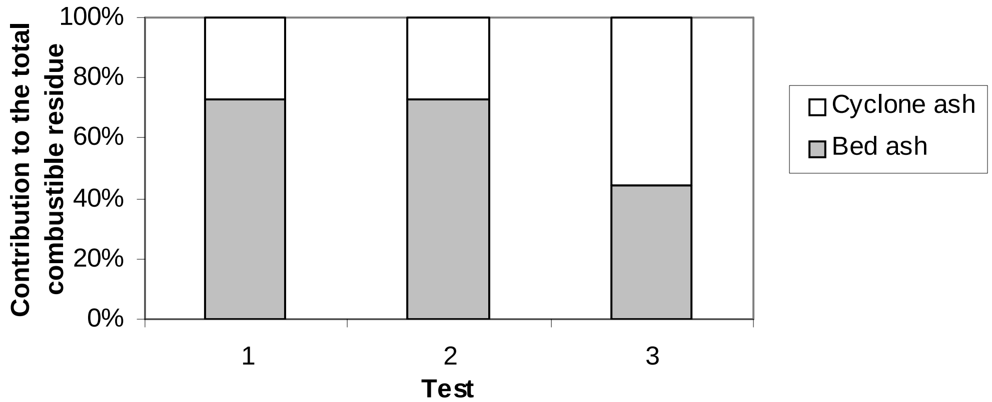


**Fig. 6.** Contribution from bed ash and cyclone ash to the total combustible residue in incineration of oil-contaminated gravel. (Test 1 = 2% fresh oil; test 2 = 2% mixture of oil (25%) and salt water (75%); test 3 = 2% weathered oil)

$$R = \dot{M}(X_0 - X_{ash})/V \qquad (7)$$

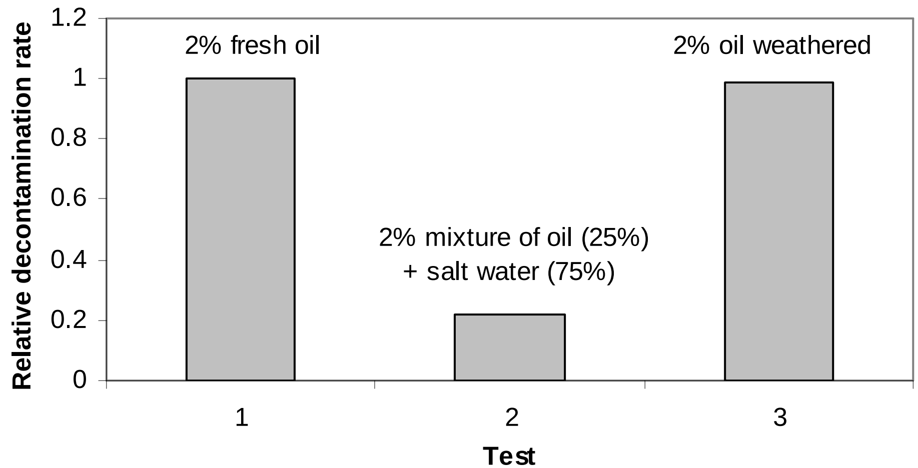


**Fig. 7.** Relative decontamination rate in the bed in incineration of oil-contaminated gravel. The rate of test 1 (2% fresh oil) is taken as the reference value.

## Summary

- The remediation tests targeted treatment of two types of contaminated materials using two representative incineration technologies. In both cases promising results were obtained.

- Based on the test results for the tar-contaminated soil, complete burning of the combustibles in a rotary calciner is expected.

- The oil-contaminated gravel was effectively decontaminated in the fluidized bed combustor. However, weathering of the gravel and addition of salt water could lower the decontamination rate. This effect is important in remediation of oil-contaminated shoreline gravel

## Acknowledgments

The study was partly funded by Environment Canada. Important contributions to the work by D.L. Desai, I. Lau and D. McLaughlin are recognized. The authors also appreciate greatly the support from D. Cianciarelli and D. Rose of Environment Canada, and R. Mortazavi of Natural Resources Canada.