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Thermal Treatment of Petroleum Contaminated Soils by a Fluidized Bed Desorber

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Abstract–A novel type of fluidized bed desorber was developed for the remediation of petroleum-contaminated soils at low temperature with high efficiency. The performance of the fluidized bed desorber was experimentally investigated in two different operation modes. Results of continuous operation of fluidized bed indicated that the effect of the mass ratio of the fluidizing gas flow rate to the feed rate of contaminated soil was not significant at temperatures above 300 °C as long as proper fluidization was ensured. Periodic fluidization mode was tested aiming at reduction of off-gas volume. Effects of cycle time and split fraction on desorption efficiency were investigated. Within the range of experimental conditions, desorption efficiency decreased with increase of cycle time and split due to defluidization in the bed. With suitable choice of cycle time and split, periodic fluidization of the desorber enabled considerable reduction of off-gas volume without compromising desorption efficiency.

Key words : Thermal Desorption, Petroleum-Contaminated Soils, Fluidized Bed, Remediation

INTRODUCTION

Thermal treatment is widely applied to the remediation of petroleum-contaminated soils. Thermal desorption technology is preferred to incineration, because the volume of off-gas from the former is smaller than that from the latter [Kostecki and Calabrese, 1989]. The amount of off-gas in thermal treatment is important as the cost of off-gas treatment is one of dominant factors affecting total cost for thermal treatment of contaminated soils. A fluidized bed desorber has many advantages over a rotary desorber owing to higher heat and mass transfer, and no moving parts in the bed [Ayen et al., 1994].

In a fluidized bed system, a sufficient amount of sweeping gas is supplied into the bed continuously in order to maintain proper fluidization of soils [Yates, 1983; Lee and Park, 1987]. However, we recognized that a continuous flow of sweeping gas is not necessary and demonstrated that high desorption efficiency can be obtained using periodic sweeping gas flow through the fluidized bed desorber, thereby significantly reducing the amount of off-gas [Kim et al., 1997].

Fig. 1 shows schematically the concept of periodic gas flow together with the definition of cycle time and split.

The cycle time is defined as the time that elapses between repetition of the same input condition for gas flow. Split is defined as the fraction of cycle time during which sweeping gas does not flow into the bed. Thus each cycle consists of a fluidization period and a slump period. During the fluidization period sweeping gas is supplied into the bed and soils are fluidized. But during the slump period sweeping gas flow is completely cut off and soils are defluidized. In this paper we report results of a study on the performance of a fluidized bed desorber system that was operated in continuous operation mode and periodic operation mode at various cycle time and split for the remediation of soils contaminated with diesel oil.

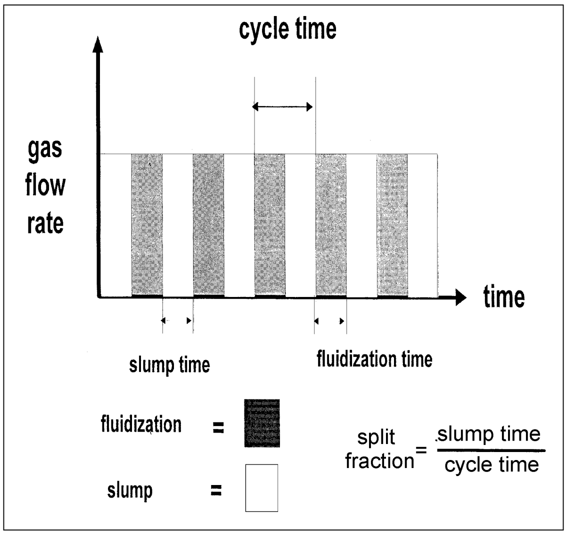

Fig. 1. Concept of periodic fluidization.

EXPERIMENTAL

One weight percent (1.0 wt%) diesel-contaminated soils used in this work were artificially prepared by physically mixing soils with diesel oil. Two different soils, designated here as clay and sand, were used. Their properties are listed in Table 1. A fluidized-bed with 0.057 m ID and 0.9 m length was set up to investigate desorption efficiencies at various operating conditions. The schematic diagram of the fluidized-bed system is shown in Fig. 2.

Nitrogen gas was supplied through a perforated distributor (ratio of opening area 1.0%) at above minimum fluidizing gas

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Table 1. Properties of soils

Soil	Clay	Sand
Bulk density (g/cm^3)	0.89	1.32
BET surface area (m^2/g)	27.2	6.4
Mean diameter (mm)	0.151	0.341

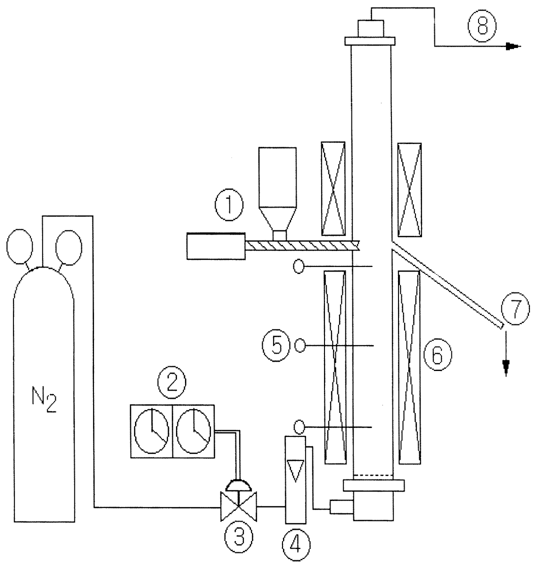

Fig. 2. Schematic diagram of fluidized-bed desorber.
1. Screw feeder
2. On-off twin timer
3. Solenoid valve
4. Rotameter
5. Thermocouples
6. Electric heater
7. Overflow
8. Ventilation

velocity which was previously determined as 7.5 cm/sec. An electrical heater supplied heat needed for desorption of diesel oil present in soil particles. A dust collector was installed to remove fine particles from exit gas, and an auxiliary heater was installed to avoid condensation of diesel oil at the upper part of the bed.

The fluidized-bed could be run either for continuous operation and periodic operation with regard to the flow of gas. For continuous operation, contaminated soils were fed into the fluidized-bed through a screw feeder at a predetermined rate, and decontaminated soils were continuously discharged through the outlet. For periodic operation, the sweeping gas could be intermittently fed into the bed by a set of two timers and a solenoid valve while all the other conditions including continuous feeding of contaminated soils into the bed were maintained the same as in the continuous operation.

The residual oils in the decontaminated soils were extracted by 2 ml methylene chloride at 40 °C in the sealed sonic extractor for 2 hours (EPA method 3550) and then analyzed by a gas chromatograph with a flame-ionization detector (GC/FID; Hewlett Packard 6890). The amount of residual contaminants in the discharged soils was also measured by detecting mass change with a Cahn-balance [Lee and Park, 1996].

RESULTS AND DISCUSSION

From a practical point of view, it is highly desirable to achieve required desorption efficiency with as little fluidizing gas as possible at the lowest temperature. In the continuous operation of the fluidized bed, therefore, two variables were chosen to investigate their effects on desorption efficiency. One is the ratio of the flow rate of fluidizing gas to the soil feed rate: Q (fluidizing gas mass flow rate)/F (feed rate of soil). The other is temperature of the bed. Effects of the temperature on desorption efficiency of contaminated sand and clay for the continuous operation are shown in Fig. 3. Desorption efficiency was sharply increased and then became flat with increase of bed temperature. A bed temperature of 250 °C or higher was required to desorb more than 90% of diesel oil from soils.

Effects of Q/F on desorption efficiency of contaminated clay and sand for the continuous operation are shown in Fig. 4 and

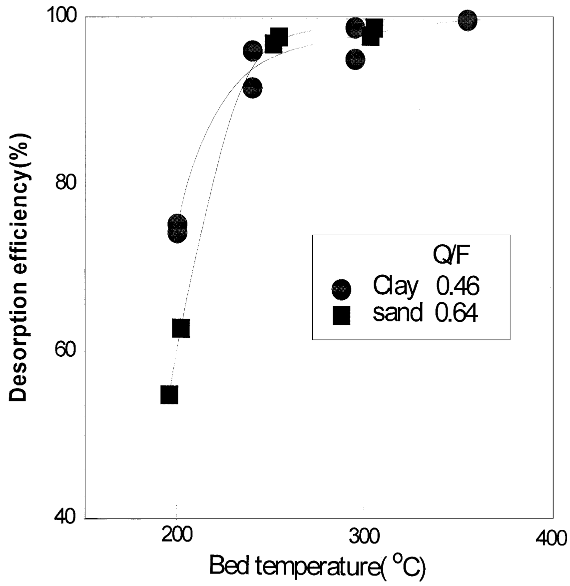

Fig. 3. Effect of temperature on desorption efficiency of the 1% diesel oil contaminated soils.

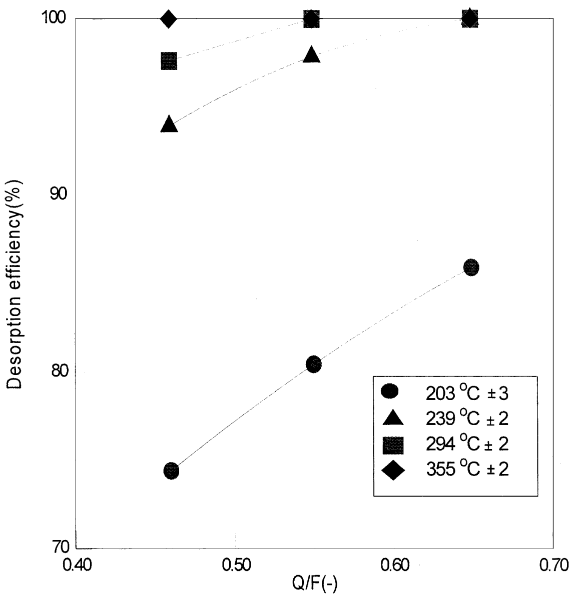

Fig. 4. Effect of ratio of gas flow rate to clay feed rate (Q/F) on desorption efficiency.

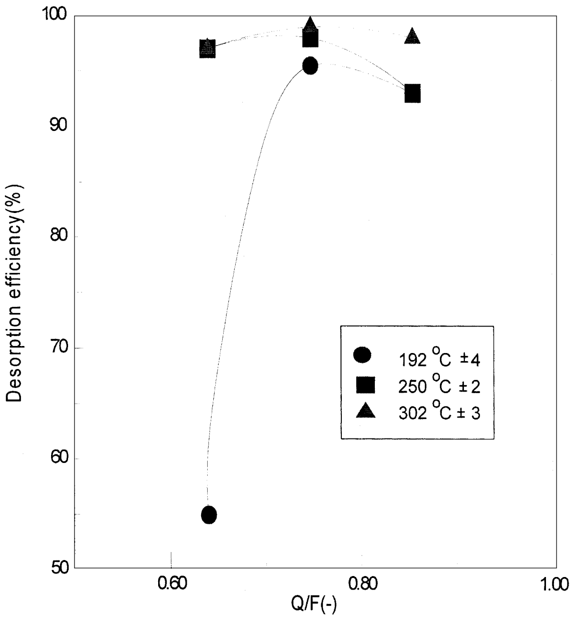

Fig. 5. Effect of ratio of gas flow rate to sand feed rate (Q/F) on desorption efficiency.

5, respectively. Desorption efficiency for clay increased with Q/F indicating promotive effect of sweeping gas on desorption of oil from soil particles. But the effect of Q/F decreased with increase of bed temperature. Notice that desorption efficiency increased sharply with bed temperature so that there was less room for further increase of desorption efficiency with higher values of Q/F. At a bed temperature of 355 °C desorption efficiency was almost 100% regardless of Q/F value. At a low bed temperature of 192 °C, however, desorption efficiency increased with gas flow rate. A similar trend was observed for sand (Fig. 5). However, the effect of Q/F for sand was much higher at a low bed temperature of 192 °C. A small increase of Q/F from 0.64 to 0.75 incurred a large increase of desorption efficiency from 55% to 95%. But desorption efficiency dropped a little bit with further increase of Q/F. At higher bed temperatures (250 °C and 302 °C) the effect of Q/F was insignificant up to a Q/F value of 0.75. However, desorption efficiency decreased with further increase of Q/F. The reason for this is not clear, but a change in fluidization characteristics with increase of Q/F is suspected. Differences in desorption behavior between clay and sand are believed due to the difference in surface area as shown in Table 1.

Results of periodic operation for clay are shown in Fig. 6. Here the split was set to 0.33 and cycle time was varied from 30 seconds to 120 seconds. In periodic operation, gas flow rate during fluidization was the same as in continuous operation. Compared to continuous fluidization, therefore, the time averaged gas flow rate for periodic operation was smaller by the value of the split.

As shown in Fig. 6 desorption efficiency decreased slightly with increase of cycle time but was still more than 99% for all cycle times. GC/FID analysis indicated that heavier components of diesel oil remained in clay after thermal treatment. For continuous operation as well as periodic operation of short cycle time (60 seconds or less), only hydrocarbons with carbon number from 21 to 25 (C21-C25) were detected in treated clay discharged from the desorber. Notice that their amount increased with cycle time. With further increase of cycle time above 60 seconds, less heavy components of C16-20 began to show up. Effects of split and cycle time on desorption efficiency are shown in Fig. 7 and Fig. 8. For fixed cycle times desorption efficiency decreased with increase of split due to longer slump time. Notice that average gas flow rate decreases with increase of the split. For the same value of split, the effect of cycle time was insignificant except for a split of 0.667. The desorption efficiency for the split of 0.667 decreased sharply with increase of cycle time, which was probably due to improper mixing in the bed with increase of slump time.

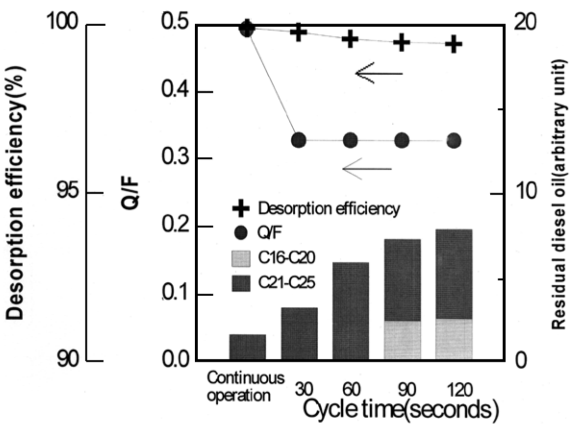

Fig. 6. Diesel oil components after thermal desorption, desorption efficiency, and Q/F (the ratio of mass flow rate of fluidizing gas to soil feed rate) with various cycle times with split of 0.33. Desorption temperature of 320 °C.

CONCLUSIONS

Effects of operating parameters were investigated for the ther-

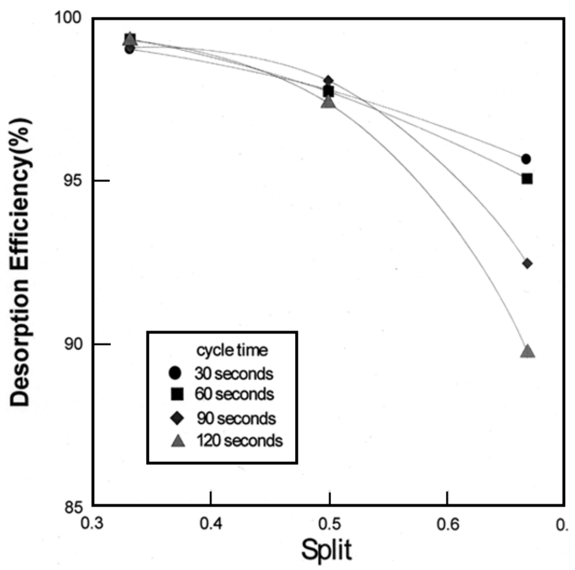

Fig. 7. Effect of cycle splits on desorption efficiency at various cycle times. Desorption temperature of 320 °C, Q/F of 0.57.

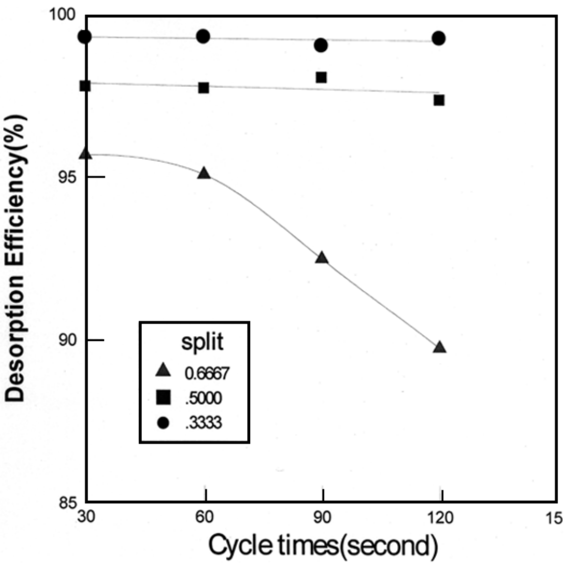

Fig. 8. Effect of cycle times on desorption efficiency at various cycle splits. Desorption conditions as Fig. 7.

mal treatment of diesel oil contaminated clay and sand in a fluidized bed desorber. During the continuous operation, the operating temperature must be kept over 294 °C to accomplish desorption efficiency over 95%. The ratio of gas flow rate to soil feed rate, Q/F, did not significantly influence desorption efficiency in this system at high temperatures (over 300 °C) as long as appropriate fluidization was maintained. This indicates that feed rate of soil, F, could be increased to some extent, thereby enhancing the treating capacity of a fluidized bed system. It is highly desirable to have some means to decrease the amount of fluidizing gas, while maintaining suitable conditions for proper thermal treatment, in order to lower the treatment cost for exhaust gas.

Employment of periodic operation of fluidizing gas provides a possibility to reduce the volume of off-gas significantly, i.e., off-gas volume could be reduced by the value of the split. Effects of split and cycle time on desorption efficiency were experimentally studied for clay and sand contaminated with diesel oil. It was found that desorption efficiency could be maintained nearly as high as in continuous operation with proper choice of split and cycle time while realizing significant reduction of off-gas volume.

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