Pilot Test on Oily Solid Waste Disposal by Thermal Desorption of Moving Bed

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Abstract. Oil-contained solid wastes subsidiary produced in process of oil and gas exploration and production are classified as hazardous wastes. Oily solid waste is necessary to reduce the total petroleum hydrocarbon (TPH) content to required targets before discharging. A thermal desorption test equipment of electromagnetic heating in moving bed was set up, and estimated processing parameters of thermal desorption unit (TDU) based on thermal calculation. Constant wall temperature of heating bed was helpful for rapid thermal desorption disposal, and power output of heating bed was not constant on each section. Rapid thermal desorption tests of two samples were carried out on pilot equipment. Under the residence time of 12.5 minutes, sample #1 was processed at bed wall temperature of not less than 450 \textdegree C, TPH content could be reduced to 1%, and to achieve the same disposal effect, sample #2 should be processed at bed wall temperature of not less than 500 \textdegree C. The residence time was reduced to 7.2 minutes, TPH content of treated sample #1 could be reduced to less than 1% at bed wall temperature of 500\textdegree C, while the disposal effect of sample #2 was fail to reach the standard.

1. Introduction

In oil and gas drilling, the use of oil based drilling fluid brought great convenience to drilling operation, but also produced a considerable amount of oily cuttings. And in process of production, another amount of oil-contained solid wastes were produced in oil fields and processing plants. In many countries, solid wastes containing mineral oils belonged to hazardous solid wastes\textsuperscript{[1, 2]}, which brought serious impacts on the environment\textsuperscript{[3, 4, 5]}, and needed to reduce the TPH content to required targets before discharging. On the other hand, mineral oils in solid wastes could be partially or completely recycled\textsuperscript{[6]}, and disposal methods generally took into account the recycling of petroleum hydrocarbons\textsuperscript{[7, 8]}.

Compared with disposal methods of centrifuge separation, chemical treatment, microbial decomposition, solidification and incineration, thermal desorption has characteristics of strong process versatility, oil removal efficiency and convenience of hydrocarbons recovery\textsuperscript{[9, 10]}. Brandt NOV and Therma-Flite adopted thermal desorption to disposal oily drilling cuttings by thermal oil indirect heating\textsuperscript{[11]}, and Halliburton Baroid used mechanical friction heating technology and was successfully applied to harmless treatment of oily drilling cuttings\textsuperscript{[12]}.

A moving bed thermal desorption system was developed in this study. TDU adopted indirect heating of electromagnetic induction and double helix transportation, which could control heating temperature and residence time nicely.
2. Experimental equipment and samples

The experimental system is mainly composed of TDU and post processing system. TDU is the core device, which includes feeder, heating and desorption system, discharging and cooling system, steam purging and air lock system, the process and structures are shown in figure 1. A moving bed of double screws in TUD is used to transporting wet raw material. Both the barrel and two screw shafts are adopt super-audio frequency electromagnetic induction heating, and temperatures are controlled independently.

![Figure 1. Structures and process of TDU.](image)

The raw material is preheated in feeder by vapors from desorption, and the temperature rise to about 60℃. Discharging and cooling system adopts forced convection cooling by jacket heat exchangers, and the discharge temperature of disposed material is less than 80℃. Air locks at feed and discharge terminals ensure no oxygen invasion in TDU, the residual air in temporary barrels of inlet and outlet is replaced by steam purging.

TPH and water contents of obtained samples are shown in table 1. Sample #1 was oily cuttings obtained from shale gas well drilling site in Chexi, Yichang (China). Sample #2 was oilfield sludge obtained from treatment plant located in Penglai (China). TPH content of samples was measured by mass difference after soxhlet extraction with petroleum ether, and water content was measured by mass difference in condition of 105℃ drying.

| Samples | Solid (%) | Water (%) | TPH (%) |
|---------|-----------|-----------|---------|
| #1      | 71.9      | 9.4       | 18.7    |
| #2      | 72.9      | 13.9      | 13.2    |

3. Processing parameters of TDU

3.1. Residence time

The residence time \( t_R \) of material in TDU is related to revolution speed of screw shaft, as in equation (1). According to the screw shaft size of TDU, the material residence time of different screw revolution speeds is shown in figure 2.

\[
t_R = \frac{60L}{nS} \quad (1)
\]

where \( L \) is length of heating bed; \( n \) is revolution speed of screw shaft and \( S \) is pitch of screw conveyor.
3.2. Heating calculation and phases content estimation

Arrangement of two screw shafts and material in barrel is shown in figure 3. Barrel and two screw shafts of TDU are all heated by electromagnetic induction. Wall temperatures are controlled at constant value during heating in order to enhance heat transfer, compared with constant power heating. The maximum wall temperature of heating bed can be set to 550°C.

Taking one pitch of screw conveyer for analysis, material storage volume ($V_s$) calculation is shown in equation (2), and heat flux ($\Phi$) calculation is shown in equation (3).

\[
V_s = \frac{2\pi D_{mid}}{\cos \beta} (S \cos \beta - e) h \varphi
\]

(2)

where $D_{mid}$ is middle diameter of spiral blade; $\beta$ is helix angle at the middle diameter; $e$ is blade thickness; $h$ is spiral groove depth; $\varphi$ is filling coefficient of material.

\[
\Phi = 4\pi \lambda \varphi S \left( \frac{1}{\ln(D/D_{min})} + \frac{1}{\ln(D_{min}/d)} \right) (T_w - T_{min})
\]

(3)

where $\lambda$ is thermal conductivity of material; $T_w$ is bed wall temperature; $T_{min}$ is the minimum temperature of material in thickness; $D$ is diameter of barrel inner wall; $d$ is root diameter of blade; $D_{min}$ is the corresponding diameter of $T_{min}$.

The factors affecting thermal conductivity of raw material are complicated, generally required to be tested by experiments. The thermal conductivity of two raw samples in Table 1 is between 0.37 and 0.41, and that of dry solid slags after thermal desorption is about 0.45. The influence of moisture and oil contents on thermal conductivity is relatively obvious. In order to facilitate calculation, the coefficient of thermal conductivity is estimated according to volume fractions of solid phase, water and oil.

In process of thermal desorption, the mass change of water is equal to the amount of evaporation. For oil phase, mass change is not only caused by evaporation phase change, but also a part of mass change caused by pyrolysis of heavy oil. For material holdup in one pitch spiral groove, the energy consumed ($Q$) at any time is calculated by equation (4).

\[
Q = \sum C_{pi} m_i \Delta T + \sum \Delta m_j H_j
\]

(4)

where $m_i$ is retained mass of each phase; $C_{pi}$ is specific heat capacity at constant pressure; $\Delta T$ is average change of temperature; $\Delta m_j$ is mass of phase transition; $H_j$ is phase transition or reaction heat.

The estimated contents of TPH and water change with residence time are shown in figure 4. Increasing bed wall temperature and prolonging residence time are propitious to thorough disposal, but
too long residence time may increase energy consumption. The residence time should be matched with the terminal time of liquid phases removed. According to the different heating temperature, the residence time is appropriate between 7.2 and 12.5 minutes for sample #1.

![Figure 4](image)

**Figure 4.** Liquids content change with residence times (a. TPH content of samples #1; b. water content of samples #1).

By calculating, changes of material temperature with residence times are shown in figure 5. D0–D6 are isometric points in thickness direction of material, D0 is contact point of the heating wall, and D6 located at the minimum temperature point of material (approximately located at the middle position of the thickness). It should be noted that temperatures in figure 5 does not take into account transient changes at the material feeding times. Liquids evaporation requires fairly large amounts heat absorption, and material temperature is basically unchanged, as shown in straight section of figure 5, which is the main stage of thermal desorption. When the evaporating of liquid phases becomes very small, material temperature gradually increased, and finally approached wall temperature.

![Figure 5](image)

**Figure 5.** Material temperatures (samples #1, setting bed wall temperature of 550°C).

![Figure 6](image)

**Figure 6.** Power density along the length of heating bed (samples #1)

### 3.3. Heating power

In order to ensure constant wall temperature of the heating bed, power supply should meet the energy requirements in processing of thermal desorption. In the length direction of heating bed, material temperature and content of liquid phases are all different, so output power density of heating bed is also different. The heating power output density \( \rho \) is calculated by equation (5).
The power density distributions of heating bed are shown in figure 6, without consideration of heat loss. The electromagnetic induction coil should be segmented design, and power output of different segment is controlled by electric current. It can be seen from figure 6, the higher the wall temperature is, the greater the power density required for the front part of the heating bed. The power density distribution of heating bed becomes uniformity with the setting of wall temperature reducing.

4. Test and results
Two samples were tested for thermal desorption, adopting constant wall temperature heating. The appearance of samples before and after thermal desorption are shown in figure 7.

![Figure 7. Samples appearance (a. raw samples; b. treated samples).](image)

TPH and water contents of two samples after treated by thermal desorption are shown in figure 8. The influence of heating temperature on disposal effect is obvious. In the limited length of TDU, the wall temperature of heating bed should be no less than 450℃, and TPH content of samples #1 can be less than 1% after disposal. While for sample #2, to achieve the same disposal effect, the bed wall temperature should be no less than 500℃.

![Figure 8. TPH and water contents of samples after disposed (a. screw speed of 2.0rpm and residence time of 12.5 minutes; b. screw speed of 3.5rpm and residence time of 7.2 minutes).](image)
sludge, while sample #1 obtained from oil-based drilling cuttings in which main oil component is diesel. Higher temperature and more residence time are needed for processing samples #2.

5 Conclusions
Two different samples were tested by rapid thermal desorption on developed equipment with electromagnetic heating in moving bed, and the TPH content of solid slag could be less than 1% by adjusting process parameters.

Heating bed temperature and residence time are two key process parameters. The heating temperature is related to the evaporation temperature of oil containing components and the pyrolysis temperature of heavy oil contained, and residence time is related to liquids content and material thickness on heating bed.

The process parameters are studied by calculation model. It is considered that the constant wall temperature heating could reduce the residence time and help to realize the rapid treatment. The heating method of electromagnetic was a better way to control bed wall temperature of TDU. In this way, the output power of each section of heating bed is different, which is helpful for energy-saving design of TDU.

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