Journal of Petroleum Exploration and Production Technology (2019) 9:663–668
https://doi.org/10.1007/s13202-018-0499-3

ORIGINAL PAPER - PRODUCTION ENGINEERING

Bench test on thermal desorption dispose of oily cuttings

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Received: 7 September 2017 / Accepted: 4 June 2018 / Published online: 8 June 2018

Abstract

A thermal desorption bench test device was assembled, and electromagnetic induction heating method was adopted. The obtained samples were tested at different terminal temperature and residence time, and the processing capacity of each test was about 15 kg. Total petroleum hydrocarbon (TPH) content dropped rapidly with the terminal temperature increasing from 200 to 400 °C, and the TPH removal rate reached 96% when terminal temperature rose to 400 °C. The terminal temperature should exceed the final boiling point of containing oil for effectively removal. The residence time increased from 20 to 30 min; drops of TPH content were obviously. Continued to increase the residence time after 30 min, the TPH content decrease became slowly. Results suggest that terminal temperature and residence time should be matched reasonably to achieve the best disposal effect. The residual oil content of solid slag reduced to 3 mg/kg under conditions of terminal temperature of 400 °C and residence time of 30 min. Low-speed stirring of the material in process was helpful to improve the disposal effect. In the process of removing oil, water contained was completely disposed. The sample quantity of bench test was much larger than that of laboratory experiment, and the results might be a direct guide for industrial applications.

Keywords Bench test · Electromagnetic induction heating · Terminal temperature · Residence time

Introduction

In drilling of unconventional oil and gas, oil-based drilling fluids have widely been used for its advantages of viscosity stability, heat resistance, shale adaptability, and lubricity (Jha et al. 2014). The use of oil-based drilling fluids would bring environmental pollution if drilling cuttings were discharged without oil removal treatment (Siddique et al. 2017; Melton et al. 2004). The cuttings' discharging standard of residual oil content has becoming stricter, though standards are different in different regions.

Thermal desorption dispose of oily cuttings is a feasible remediation method (Stephenson et al. 2004), and the removed oil can be recovered fully or partially (Eze et al. 2015; Shie et al. 2000). Indirect heating and direct heating have used for thermal desorption disposing of oily cuttings. Heat conduction oil heating and flue gas heating are the conventional heating methods (Pierce et al. 2006). The total heating efficiency is low and equipment is large in size. Heat generating by grinding cuttings with a hammer mill is a friction heating method for removing oil (Murray et al. 2008). Friction heating method is limited in heat production and temperature rise, which has strict requirements for liquids content of material. Microwave heating is an advanced direct heating method, which has used for thermal desorption (Júnior et al. 2017). The efficiency of microwave heating depends on microwave absorption of oil containing material. The texture and oxides present of material highly influence microwave absorption and contaminant removal (Falciglia and Vagliasindi 2015; Petri et al. 2017). Material selectivity is a disadvantage of thermal desorption by microwave heating. Electromagnetic induction heating is another method with high efficiency of energy conversion, compared with that of the traditional heat transfer heating method. Thermal desorption by electromagnetic induction heating has advantages of fast heating, nicety in controlling of temperature, and compact structure.

A bench test device for oily cuttings' disposal was developed, which used electromagnetic induction heating. The volume of thermal desorption unit (TDU) was 40 L, and handling capacity of single treatment was about 15 kg. The

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sample quantity of each test was much larger than that of laboratory experiments, and was closer to the industrial application. The test results might have directly guiding significance for industrial applications.

Device and experimental method

Experimental installation

The experimental installation is mainly composed of TDU, condensation unit, oil–water separator, sewage filter, noncondensable gas collector, and nitrogen purge equipment. The experimental system and process are shown in Fig. 1.

The core device of the experimental system is TDU, which structures are shown in Fig. 2. The volume of TDU is 40 L, and the single processing capacity is 15 kg by volume filling rate of 20%. A layer of heat insulating material was wrapped over the heating barrel, and electromagnetic induction coils were spirally wound around the heat insulating layer. The operating frequency of electromagnetic induction heating was 15 kHz, and the maximum power was 35 kW. The interior of TDU arranged a rotatable scraper. The scraper rotation can stir material evenly during heating, and prevent the material caked on the inner wall of barrel.

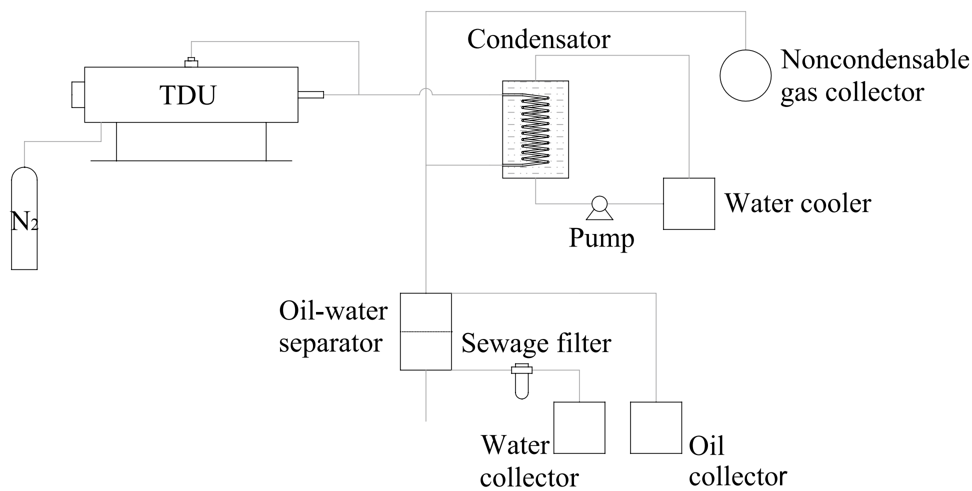

Fig. 1 Thermal desorption experiment system and process

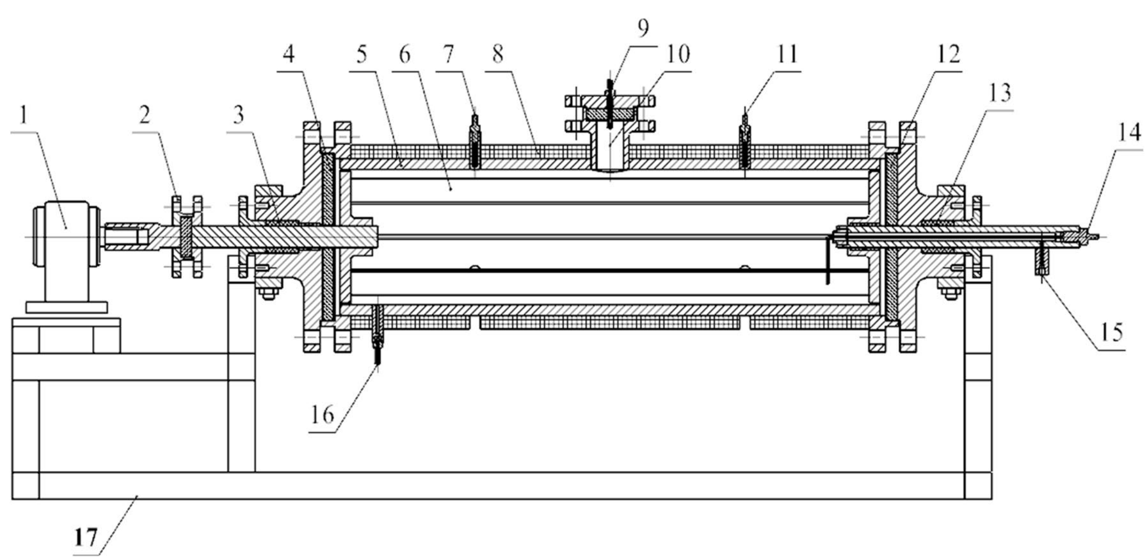

Fig. 2 Detailed structures of TDU (1 reducer; 2 heat insulation coupling; 3 packing seal; 4 heat shield; 5 barrel; 6 rotary scraper; 7 thermocouple; 8 electromagnetic induction heating and insulation layer; 9 exhausting connector; 10 feeding/sampling port; 11 thermocouple; 12 heat shield; 13 packing seal; 14 thermocouple; 15 exhausting connector; 16 nitrogen connector; 17 support platform)

Experimental procedures

Oily cuttings samples were obtained from shale gas well-drilling site in Chexi, Yichang (China), and samples' appearance was shown in Fig. 3a. The average TPH content of samples was 18.7% and the average water content was 9.4%. The experimental steps were as follows:

1. The weighed samples were poured into the barrel from the feeding port, then closed the cap, and sealed the feeding port.
2. The nitrogen was injected into the barrel for displacing the air thoroughly to prevent oxidation disturbance in the process of thermal desorption.
3. Stopped the nitrogen purging and sealed the nitrogen inlet, and then started the electromagnetic heating module.
4. The temperature of barrel inner wall rose to the set point and remained for a specified period of time.
5. After heating, samples were taken out and cooled to 60 °C in sealed sampler, and then analyzed residual TPH content and moisture content.

Tests repeated according to the different requirements of temperatures and times. For operating safety, nitrogen needed to be injected into barrel to replace vapors before sampling.

After being treated by thermal desorption, raw samples became greyish white solid slag, as shown in Fig. 3b.

Measuring methods

There were five temperature measuring points in the heating barrel. Four measuring points were uniformly distributed on the inner wall of the heating barrel for measuring the inner wall temperature. The inner wall temperature was controlled by electromagnetic induction heating module. The material temperature in the cavity was measured by a probe axially inserted into the barrel.

The terminal temperature was the material temperature reached before sampling time, and was measured directly by the thermocouple.

The heating time was equal to the sum of the preheating time and the holding time. The preheating time was the time used for inner wall temperature heating to the set value. When inner wall temperature reached the set value, hold the temperature unchanged by the heating controller. Then continued to heat for a period, this duration time was the holding time.

Defining the holding time as the residence time, that is, the duration time after inner wall temperature reached the set value.

TPH content of cuttings was measured by mass difference method after soxhlet extraction, and petroleum ether (60–90 °C) was used as extraction solvent. The moisture content of cuttings was measured by mass difference method under 105 °C drying condition.

Results and discussion

Effects of terminal temperature on TPH content after disposal

TPH residual content and moisture residual content of solid slag at different terminal temperature are shown in Fig. 4. TPH content dropped from 4.6% to below 1%, with the terminal temperature increasing from 200 to 350 °C. The terminal temperature continued to rise from 350 °C to over 400 °C, the TPH content continued to decrease, but the drops were very small. The TPH content almost unchanged when terminal temperature varied from 400 to 415 °C.

The base oils of oil-based drilling fluid in obtained samples were mainly diesel and mineral oil. The distillation range of diesel is about 180–360 °C, and mineral oil

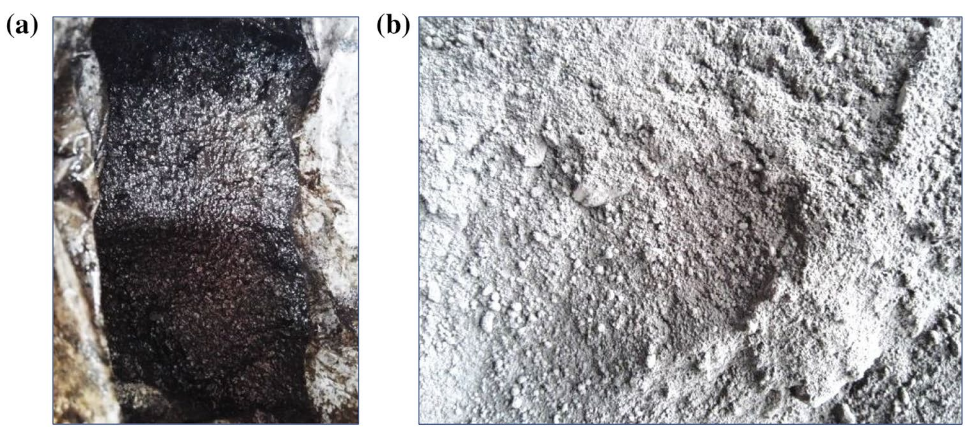

Fig. 3 Sample appearance (**a** raw samples; **b** treated samples)

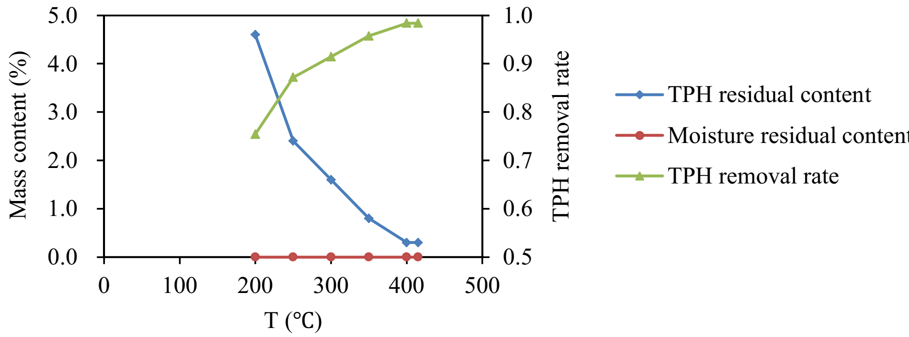

Fig. 4 Residual content of TPH and moisture in solid slag at different terminal temperatures (the residence time of 30 min)

is generally the fraction from 250 to 400 °C in the crude oil. TPH content decreased rapidly when the cuttings temperature was higher than the initial boiling point of oil contained. The TPH removal rate reached 96% when terminal temperature rose to 400 °C. It can be inferred that diesel and mineral oil have been removed after terminal temperature reached 400 °C. There was still a small amount of residual oil (3 mg/kg) in solid slag might be high boiling point oil from oil bearing formation, and might require higher temperature to dispose.

After terminal temperature above 200 °C, the water has been completely distilled, that is, moisture content was zero. It was easy to remove water in cuttings after terminal temperature exceeded water boiling point.

Effects of residence time on TPH content after disposal

TPH residual content and moisture residual content of solid slag at different residence time are shown in Fig. 5. Under the condition of terminal temperature of 350 °C, the TPH content decreased rapidly during the residence time increased from 20 to 30 min, and continued to increase the residence time, the TPH content decrease became slowly. The TPH removal rate was above 95% when residence time reached 30 min. After 1 h, the increase of residence time did not affect the content of TPH. It can be considered that to further improve the oil removal rate is less significant by increasing residence time when the residence time reaches the certain duration.

The residence time and terminal temperature should be matched reasonably to achieve the best disposal effect. To improve the processing efficiency and for saving energy, the residence time should not be too long. Compared to Figs. 4 and 5, it is found that when the residence time (30 min) unchanged, the terminal temperature rises from 300 to 400 °C, the TPH content drops by more than 20%; when the terminal temperature (350 °C) unchanged, the residence time increases from 30 to 60 min; the TPH content decrease is less than 10%.

It can be inferred that the terminal temperature determines whether the oil contained in cuttings can be evaporated, and the residence time determines the processing efficiency. For the obtained samples of oily cuttings, the best disposal effect of tests is residual oil content of 3 mg/kg, under conditions of terminal temperature of 400 °C and residence time of 30 min.

Effects of stirring speed on TPH content after disposal

The outer edge of rotary scraper is very close to inner wall of the barrel. The revolving scraper can remove the dry layer of material caked on the inner wall of barrel. The dry layer will

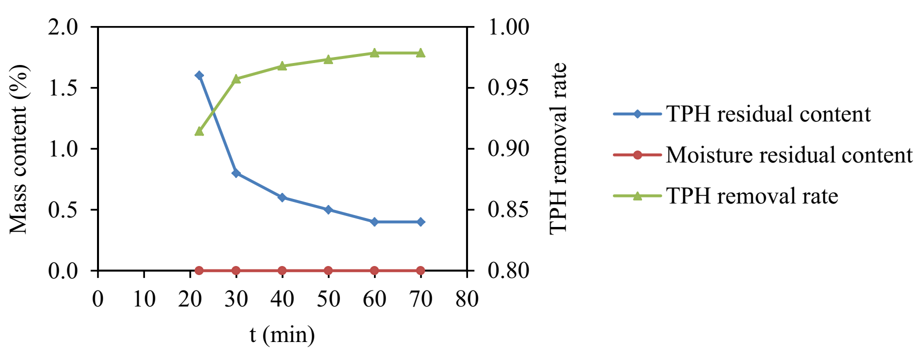

Fig. 5 Residual content of TPH and moisture in solid slag at different residence time (the terminal temperature of 350 °C)

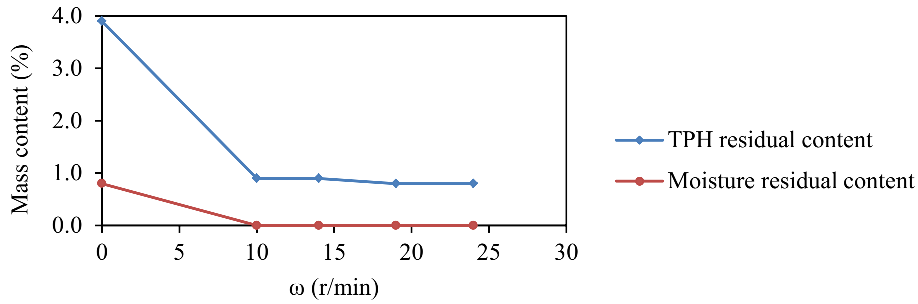

Fig. 6 Residual content of TPH and moisture in solid slag at different stirring speed (the terminal temperature of 350 °C and the residence time of 30 min)

increase thermal resistance and affect heat transfer efficiency between the barrel wall and the material. At the same time, the revolving scraper has stirring effect on the material in barrel, and could accelerate vapors diffusion after liquids evaporation, and is beneficial to vapors discharge.

TPH residual content and moisture residual content at different stirring speed of the scraper are shown in Fig. 6. Compared with the static state, low speed of stirring could improve the removal efficiency of liquids. However, the increase of scraper rotary speed (10–25 rpm) has a little effect on liquids content change. It can be inferred that low-speed stirring can improve heat transfer condition and liquids removal efficiency, but the changes of scraper rotary speed on TPH and moisture removal rate are not remarkable.

Conclusions

1. Terminal temperature setting of thermal desorption disposal is related to the distillation range of oil containing components. TPH content of obtained samples dropped obviously when the terminal temperature increases from 200 to 400 °C. Residence time should be sufficient to ensure a better disposal effect. TPH content decreases rapidly within the residence time of 30 min. While the terminal temperature is too low, only increasing residence time could not effectively improve the oil removal rate.
2. Terminal temperature and residence time are two important factors that affect the removal rate of TPH in process of thermal desorption. The two factors should be matched reasonably to achieve the best disposal effect and for saving energy. The best disposal effect of tests is residual oil content of 3 mg/kg, under conditions of terminal temperature of 400 °C and residence time of 30 min.
3. The low-speed stirring in TUD is helpful to improve results of thermal desorption, but the changes of stirring speed have a little effect on the TPH removal rate.
4. The method of electromagnetic induction heating with fast temperature rise and easy temperature control is a good choice for thermal desorption dispose of oily cuttings.

Acknowledgements The authors wish to thank Chuanglian (Hubei, China) Petroleum Technology Co. Ltd., for assembling and testing the experimental equipment, and providing experimental condition and technical support.

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