Journal of Environmental Management 196 (2017) 659–665

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Microwave drying remediation of petroleum-contaminated drill cuttings

Irineu Petri Júnior [a], André Leibsohn Martins [b], Carlos H. Ataíde [a,*], Cláudio R. Duarte [a]

[a] Federal University of Uberlândia, Faculty of Chemical Engineering, Av. João Naves de Ávila, 2121, Bloco 1K, 38408-100 Uberlândia, MG, Brazil
[b] PETROBRAS, Rua Horácio Macedo, 950, Ilha do Fundão, Cidade Universitária, 21941-915 Rio de Janeiro, RJ, Brazil

ARTICLE INFO

Article history:
Received 13 September 2016
Received in revised form
16 March 2017
Accepted 22 March 2017
Available online 30 March 2017

Keywords:
Microwave drying
Crude oil
Drill cuttings
Oil reservoir
Microwave remediation

ABSTRACT

The oil reservoir drilling phase generates contaminated cuttings with oil formation itself. These cuttings must be subjected to a decontamination process before being disposed of in the environment. Several technologies are cited in literature for the remediation of soil contaminated with oil or diesel, but none have been reported to remedy drill cuttings contaminated with oil from reservoir. The reservoir drill cuttings are a problem because its discharge is not allowed. The drying technology using microwave has shown promise in the decontamination of cuttings with non-aqueous base drilling fluid, conciliating good robustness and high removal efficiency. Considering the aspects mentioned previously, the application of heating and drying technology using microwave in the remediation of oil contaminated cuttings from well drill was studied. The influence of temperature, specific energy and initial content of water in the drying operation of the reservoir cuttings and of the drilling cuttings artificially contaminated with oil were analyzed. The results showed an influence of temperature in the drying of the cuttings, being necessary to reach the boiling temperature of heavier hydrocarbons to reach an efficient removal in the operation. The specific energy has a strong influence, reaching a total decontamination using 2.67 kWh/kg. The initial water content was effective in removing oil, reducing the residual level of oil with the increase of initial content of water. It also modifies the temperature profiles of the kinetic-warming of the contaminated cuttings. Both the technology and the equipment used proved effective for obtaining total decontamination of oil from the cuttings.

1. Introduction

The consumption of petroleum products increases every day and as a result there is a growing demand for improvements in well and oil refining drilling operations. The drilling operation is not simply based on drilling the rock; there are other steps that should be added to the process. One of these steps is the control system for solids which aims to separate the rock fragments from the drilling fluid, which is injected into the well to assist in the drilling process and also promote the transportation of particles.

Synthetic based drilling fluids are made from the emulsion of an organic synthetic base and water, with additives (emulsifying agent, weighting agent, alkalinizing agent, etc.) to promote the stability of physical properties. The synthetic base drilling fluids are widely used because it has greater advantages over other types of fluid. Due to the high cost and presence of the organic phase, drill cuttings with synthetic based drilling fluids must be separated and recovered in solids control system (Petri et al., 2015).

When dealing with a drilling fluid with a synthetic basis, the solids control system is usually formed by a set of solid-liquid separation equipment, each responsible for separating a particle size range of cuttings. At the end of these separation steps, there are basically two trends: the first consists of all the recovered drilling fluid which is re-injected into the well to give continuity to the drilling operation; the second stream is formed by all the cuttings removed from the pit (Pereira et al., 2014). The cuttings originating from this separation is sent to the cuttings dryer, which has the premise to reduce the organic phase solids content below 6.9% by weight so as to be discarded into the environment, according to the current standards of the US Environmental Protection Agency (EPA).

The cuttings dryer is a crucial piece of equipment for making the

* Corresponding author.
E-mail addresses: irineupetri@gmail.com (I.P. Júnior), aleibsohn@petrobras.com.br (A.L. Martins), chataide@ufu.br (C.H. Ataíde), claudiofequfu@gmail.com (C.R. Duarte).

http://dx.doi.org/10.1016/j.jenvman.2017.03.068
0301-4797/

organic or synthetic residual fluid content acceptable, having in mind the disposal of these cuttings. In literature one finds various types of dryers such as thermal desorption (Wait and Thomas, 2003), thermo-mechanical desorption (THERMTECH, 2006), supercritical extraction (Eldridge, 1996), filter centrifuge (Reddoch, 2004) and microwave (Robinson et al., 2010; Santos et al., 2014). The microwave drying technology has shown to be quite effective and viable for the decontamination of drill cuttings with synthetic base fluid.

In the drilling of oil wells the drill passes through various types of rock and the first phase of the drilling is through less compact and less hard or softer rock. As the drill penetrates in the well, the rock structure is getting harder and drill penetration rate decreases. As a last stage in drilling one meets the reservoir rock, which is comprised of a certain amount of oil. This rock is brought to the surface through the drilling fluid, and it is necessary to remediate same for disposal into the environment (ASME, 2011).

Alternative methods are used for the remediation of soil contaminated with oil, such as bioremediation (Qin et al., 2013) and phytoremediation (Merkl et al., 2005a,b). There are also soil remediation methods using chemical products and solvent extraction (Do et al., 2009; Gan et al., 2009). However, these methods have low processing capability due to the long duration of the biological reactions, high cost for the separation and recycling of the solvent after treatment (Lim et al., 2016).

Thermal desorption has as its principle the vaporization of volatile oil components by means of any heat source. Falciglia and Vagliasindi (2015) and Li et al. (2009) studied the remediation of rocks with diesel using heating by microwave and found that this alternative is the best choice for remediation of soil contaminated with diesel when compared to other treatment processes: biological, physical, chemical and thermal desorption with conventional heating. Chien (2012) developed a pilot drying unit by means of microwave for the remediation of soil contaminated by oil in which was detected its robustness and high efficiency in cleaning rocks, reaching extremely low levels of oil concentration.

Several studies show that treatment by microwaves has potential for use in the remediation of soils contaminated with oil. However, literature still lacks information as to remediation of reservoir cuttings and drill cuttings artificially contaminated with petroleum. The reservoir cuttings are naturally contaminated with petroleum in intraparticle pores.

For this reason, the present work is innovative as it aims to study and validate the use of microwaves in the remediation of reservoir cuttings and drill cuttings which are contaminated naturally and artificially, respectively, with oil. In addition, a study as to the influence of temperature and specific energy in the remediation operation of these cuttings was made, generating determinant results that will be useful in scale-up process for industrial equipment. Finally, the influence of the initial water content in the cuttings contaminated with oil was analyzed, as this level varies significantly in the same reservoir.

2. Materials and methods

2.1. Experimental set-up

In this work a domestic microwave oven which was adapted to perform the drying of drill cuttings by batch regime was used. This unit has two magnetrons with 800 W output power each (total 1600 W), frequency of 2450 MHz and a cavity with dimensions of 330 × 330 × 181 mm (19.7 L). Fig. 1 shows a microwave oven scheme together with the adjustments made to promote the decontamination of drill cuttings.

This unit has a pressure gauge (1) for pressure measurement in the interior of the cavity and a hot wire anemometer (2) which has the function of registering the inert gas velocity (3) injected into the cavity through a hole (4). The inert gas (industrial nitrogen) has the basic function of assisting in the purging or removal of organic vapors within the cavity and thereby prevent explosion hazards. An exhaust fan is also shown (5) which causes the suction of vapors generated during the drying process and a rotating disc (6) to improve the distribution of electromagnetic waves. It also has K-type thermocouples for measurement of vapor temperature (7) and of the gravel bed (8). The second thermocouple has its tip inserted in the packaged sample in the porcelain container (9). The thermocouple rod was protected by a stainless steel tube called thermowell.

The acquisition of temperature and pressure signals was made through an NI USB-6009 plaque and the monitoring, control and recording of such data were developed in LabVIEW 2015 software.

2.2. Material characterization

2.2.1. Characterization procedure

The oil and water content was obtained by using the hybrid method of the Retort FANN 50 ml and Soxhlet extraction with isopropyl alcohol. The drill cuttings density and composition were obtained through helium gas pycnometer in the Micromeritics AccuPyc 1331 equipment and X-Ray Fluorescence Spectrometer Shimadzu EDX 720, respectively.

The size distribution of these cuttings were obtained using two methods. Sieve analysis for particles greater than 2000 μm and laser diffraction with the MASTERSIZER 2000 equipment using isopropyl alcohol as a means of dispersion and the calculation methodology proposed by Franhoufer, for particles smaller than 2000 μm.

The oil present in the reservoir cuttings was extracted using a Soxhlet extractor with isopropyl alcohol and subsequent distillation of the solvent using a rotary IKA RV 10 Control evaporator for the concentration of the recovered oil. The chemical composition of these two oils was obtained by means of a chromatographic analysis of the samples.

The chromatography analyzes of crude oil and oil from reservoir cuttings were performed using a gas chromatograph coupled to a mass spectrometer of the Shimadzu brand, GCMS-QP2010 model, with a Rxi-1ms model column of 30 m. Carbon disulfide was used as a diluent, according to international ASTM D2887 standard, with a 0,2 μL injection. Heating ramp of 40 °C to 250 °C was used at a heating rate of 10 °C/min, and remaining for 10 min at the final temperature ramp. The temperatures of the injector and detector were 300 °C and 250 °C, respectively.

2.2.2. Drill cuttings

The two types of cuttings used were collected from the well drilling in Brazil. The reservoir cuttings used in this work are rock fragments from onshore well drilling with initial content of 6.78% oil and 25.21% water. The actual density of the reservoir cuttings is 2572.6 kg/m^3 and the results of sieve analysis showed that 14.7% of the reservoir cuttings particles passed through the sieve of 4000 μm and were retained in the sieve of 2000 μm. The parameters n and $d_{63.2}$, of particle size distribution, represented by Rosin-Rammler model was 0.82 and 24.0 μm, respectively.

The other cuttings used are derived from the drilling of oil wells in an offshore environment at an intermediate depth (2000–3000 m). These cuttings do not contain oil in their composition and were subjected to a cleaning process by means of Soxhlet extraction for the complete removal of organic phase and water resulting from synthetic based drilling fluid used in drilling. After cleaning, the cuttings were mixed with a stable emulsion of