DECONTAMINATION OF DRILLED CUTTINGS BY A SEMI-INDUSTRIAL CONTINUOUS MICROWAVE DRYER

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RESUMO - The drilling fluids most commonly used in oil and gas drilling operations are synthetic fluids with low biodegradability. These fluids contaminate the drill cuttings, which must undergo decontamination before disposal. Microwave drying has been investigated as a remediation technique for drill cuttings. The objective of this work is to update the industry with experimental results of a novel cuttings drying technology based on microwave heating. The expectation is to provide a competitive technology for offshore applications. The motivation is to provide alternatives for efficient cuttings drying to reduce the environmental impact of offshore drilling operations. A semi industrial continuous microwave dryer was initially built to process oily cuttings at flow rates around 0.5 ton/hr. Construction parameters were based on extensive lab scale experiments previously and preliminary tests. Real cuttings and internal olefin based drilling fluids were used. A low field RMN technology was used to evaluate oil contents in inflow and outflow samples. Initial content of synthetic base on the drill cuttings, feed flow rate, residual content and specific energy were some of the variables investigated. Results obtained from preliminary tests and a 9 experiment test matrix show that the technology is able to reduce oil concentration in cuttings to values as low as 0.1% depending on operational parameters. The operational limits of the equipment were successfully pushed to allow processing a cuttings flow rate of 0.75 ton/h. The specific energy of this equipment proved to be competitive with other commercial equipment. The present experimental campaign encourages the continuation of the project signaling for studies to allow the construction of a field scale microwave cuttings dryer to operate either at a floating rig or at a dedicated ship that would be able to process cuttings generated by several neighbor drilling vessels.

Keywords: microwave drying, drill cuttings, internal olefin-base drilling fluid.

INTRODUCTION

Drill cuttings contaminated with drilling fluids are the waste of drilling operations. The cuttings generated by the action of the drill are carried to the surface by drilling fluids. Some types of drilling fluid, particularly synthetic-based fluids have low biodegradability. Therefore, cuttings contaminated with synthetic drilling fluid must be decontaminated before disposal (ASME Shale Shaker Committee, 2011; Caenn and Chillingar, 1996).

Drill cuttings and drilling fluid are separated by means of vibrating screens, hydrocyclones and centrifugal decanters (Njobuenwu and Wobo, 2007). However, these devices cannot reduce the residual content of drilling fluid in drill cuttings sufficiently to comply with the environmental limits established by Brazilian regulations. In Brazil, the disposal of materials contaminated with synthetic drilling fluids into the marine environment is allowed only when their organic content is less than 6.9 wt.%, this is the same limit established by the United States Environmental Protection Agency - US EPA (Pereira et al., 2013).

In 1997, the Norwegian government, concerned about the harmful environmental effects caused by the disposal of drill cuttings, established a target of zero disposal. However,
this target should be interpreted not as an obligation to stop all disposal in the region, but rather, as a goal to be achieved to improve the environmental management of wastes discharged from oil and gas exploration and production (Singaas et al., 2008).

A filtering centrifuge is often used in the treatment of oil and gas well drill cuttings to reduce their drilling fluid content to levels below those permitted by environmental regulations. However, this type of equipment has presented operational problems, particularly when it comes to the decontamination of particles with diameters smaller than 44 µm (Pereira et al., 2012; Seaton et al., 2006).

To improve the decontamination of cuttings and overcome the limitations of centrifugal filtration, the thermal process has emerged as a very interesting alternative technology (Ball et al., 2012; Carignan et al., 2007). Microwave heating has proved to be a promising technology to promote this decontamination (Robinson et al., 2010; Santos et al., 2014a; Shang et al., 2006). Drill cuttings obtained after microwave drying presented a residual oil content of less than 1 wt.% and the organic phase of the recovered drilling fluid showed no chemical changes, allowing its reuse in the formulation of a new drilling fluid (Robinson et al., 2012, 2009; Santos et al., 2014b).

Microwave heating has been used in several areas, e.g., in oxide sintering (Panda et al., 2006), endothermic chemical reactions (Gedhe et al., 1991), pyrolysis (Salema and Ani, 2012), food pasteurization (Lau and Tang, 2002), and coal drying (Çalışkan et al., 2012). This technology has presented numerous advantages over conventional heating, such as, selective heating of materials, fast start-up and stopping, and heating without physical contact (Haque, 1999).

An important parameter in microwave drying processes is specific energy (Equation 1). This parameter defines the amount of energy spent in a given time interval per mass unit (Santos et al., 2014a). In continuous drying processes, the specific energy ($SS$) is the ratio of applied power ($P_a$) and mass flow inlet ($\dot{m}$).

$$SS = \frac{P_a}{\dot{m}}$$

Another parameter used to verify the drying efficiency is the removal efficiency. This parameter shows the amount of a liquid is removed with respect to the initial amount on the sample. Equation 2 shows the equation to calculate this parameter. Thus, removal efficiency ($\eta$), initial content ($X_i$), residual content ($X_r$).

$$\eta = \frac{(X_i - X_r)}{X_i}$$

Therefore, it was developed a semi-industrial micro-wave dryer for drill cuttings treatment called Drill Cuttings Treatment Unit (DCTU). This equipment is a pilot prototype to study the technical and financial feasibility for its introduction in the industry.

The aims of this study were to do some preliminary tests on the DCTU to set some optimized operating conditions to obtain a better decontamination and improved the safety. Furthermore, the feed flow rate and the initial content of synthetic base were changed in three levels to analyze the drying and energy efficiency.

**MATERIALS AND METHODS**

**Experimental Set-up**

The development and construction of DCTU was made in partnership with the Faculty of Chemical Engineering at the Federal University of Uberlandia and ONDATEC Ltda., with financial support from PETROBRAS S.A. The Figure 1 shows the experimental apparatus (DCTU), which consists of five subdivisions: feed unit (1), cavity (2), condenser unit (3), dry drill cuttings discharge unit (4) and purge liquid unit (5).

The drill cuttings contaminated with drilling fluid was fed into the hopper located in the feed unit. The drill cuttings down to a bulkhead and with the movement of the conveyor, it was generated a layer of drill cuttings under the microwave issues, performing the drying. There are three scrambles to promote homogenization of the drill cuttings during drying. The conveyor moves the layer under the microwave issues, performing the drying. There are three thermocouples to promote homogenization of the drill cuttings during drying. The conveyor moves the layer under the microwave issues, performing the drying. There are three thermocouples to promote homogenization of the drill cuttings during drying. The conveyor moves the layer under the microwave issues, performing the drying. There are three thermocouples to promote homogenization of the drill cuttings during drying. The conveyor moves the layer under the microwave issues, performing the drying. There are two line blind valves (pressure relief), three thermocouples to bet temperature and three thermocouples to steam temperature, and a manometer to the pressure control. The DCTU operates in continuous feed and in the steady state, samples are taken for determination of the residual content utilizing a low field RMN technology.
Materials Characterization

The drill cuttings used in these experiments came from the PETROBRAS S.A. waste treatment center, in Carmópolis, Sergipe, Brazil. The drill cuttings, initially contaminated with n-paraffin base, were homogenized and stored in bags. It was taken a sample for characterization of drill cuttings physical properties. It can be viewed in the Table 1.

The additional contamination of drill cuttings was done using internal olefin-based drilling fluid, which was donated by PETROBRAS S.A. In this work, it was use an additional contamination to achieve a higher initial content of synthetic base. The received drilling fluid was stored in 1 m³ container. After being homogenized, some samples of drilling fluid were taken for characterization. It can be viewed in the Table 2.

Experimental Procedure

Feed preparation: For the feed preparation, the drilling fluid must be added in the drill cuttings until it reaches an initial content of synthetic base of each test. To estimate the volume of drilling fluid required, it was need to make a low field RMN test to determine the initial content of synthetic base on the drill cuttings.

For mixing the drill cuttings and drilling fluid was used an industrial cement mixer. It was added 200 kg of drill cuttings inside the mixer with a calculated amount of drilling fluid. The mixer was performed for fifteen minutes and it was subsequently feed into the feed unit.

Operating conditions: Preliminary tests aimed at obtaining operating conditions to increase the drying efficiency, safety equipment useful life and decrease energy costs. For this, they were tested as parameters: number of open exhaust lines, operating temperature, operating pressure, and thickness bed layer.

Therefore, for preliminary tests was used a condition of 500 kg/h of feed flow rate contaminated with 21.3% of initial content of drilling fluid, i.e. a contamination of 12.5% of synthetic base (internal olefin + n-paraffin).

To analyze the drying performance and energy expenditure was used the optimized operating conditions of the preliminary tests, except the feed flow rate and initial content of synthetic base. It was used an experimental design at three levels, which were changed the parameters of feed flow rate and initial content of synthetic base. Operating conditions of this part or work are shown in Table 3.

Table 1 – Physical properties of drill cuttings

<table>
<thead>
<tr>
<th>Drill Cuttings</th>
<th>real density [kg/m³]</th>
<th>bulk density [kg/m³]</th>
<th>n-paraffin content [%]</th>
<th>water content [%]</th>
<th>solids content [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2683.2</td>
<td>1299.8</td>
<td>9.43</td>
<td>7.71</td>
<td>82.87</td>
</tr>
</tbody>
</table>

Table 2 – Physical properties of drilling fluid

<table>
<thead>
<tr>
<th>Internal Olefin-base Drilling Fluid</th>
<th>real density [kg/m³]</th>
<th>olefin content [%]</th>
<th>water content [%]</th>
<th>oil/water ratio [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1010.5</td>
<td>44.8</td>
<td>28.2</td>
<td>61/39</td>
</tr>
</tbody>
</table>
The operating conditions of drying performance tests are shown in Table 3. Therefore, the operating temperatures used in regions I, II and III were 200°C, 220°C, 250°C, respectively.

<table>
<thead>
<tr>
<th>test</th>
<th>mass flow inlet [kg/h]</th>
<th>initial content of synthetic base [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>250</td>
<td>7.5</td>
</tr>
<tr>
<td>2</td>
<td>500</td>
<td>7.5</td>
</tr>
<tr>
<td>3</td>
<td>750</td>
<td>7.5</td>
</tr>
<tr>
<td>4</td>
<td>250</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>500</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>750</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>250</td>
<td>12.5</td>
</tr>
<tr>
<td>8</td>
<td>500</td>
<td>12.5</td>
</tr>
<tr>
<td>9</td>
<td>750</td>
<td>12.5</td>
</tr>
</tbody>
</table>

### RESULTS AND DISCUSSION

Preliminary tests were conducted to define the optimized operating parameters and they were obtained some values to increased drying efficiency of the equipment and to decreased energy expenditure. Table 3 shows the results of residual content and specific energy of original conditions, without optimized conditions, and optimized conditions.

The optimized conditions decrease the residual content of synthetic base (72%) and water (57%). The specific energy also decreased by approximately 17%, thereby encouraging the use of optimized operating conditions.

In optimized conditions, the operating pressure was -50 mmH₂O, a layer thickness bed of 90 mm, all three points of exhaustion open. The operating temperature was divided in regions, which the region I, II and III can be seen in Figure 1. Therefore, the operating temperatures used in regions I, II and III were 200°C, 220°C, 250°C, respectively.

Once defined the optimized operating conditions in preliminary tests, this conditions were used in drying performance tests. The results of residual contents of synthetic base in drill cuttings are shown in Figure 2. The results of drilling fluid removal efficiency are shown in Figure 3.

The results in Figure 2 show that have two conditions (test 8 and 9) proposal by Table 2, that the equipment failed to reduce the synthetic base content to levels below the Brazilian environmental legislation (6.9 wt.%). Test 1 was showed a residual content of synthetic base very low and near the equilibrium residual content (0.11%) found by Petri (2014).

Analyzing the results, as can be seen that the equipment developed could processing a feed flow rate between 500-250 kg/h keeping the residual content of synthetic base below 2.7%. This means a reduction of about 255% over the residual content currently stipulated by the Brazilian environmental legislation.

### Table 3 – Results of preliminary tests

<table>
<thead>
<tr>
<th></th>
<th>original conditions</th>
<th>optimized conditions</th>
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</thead>
<tbody>
<tr>
<td>water residual content [%]</td>
<td>1.25</td>
<td>0.54</td>
</tr>
<tr>
<td>synthetic base residual content [%]</td>
<td>9.74</td>
<td>2.70</td>
</tr>
<tr>
<td>specific energy [kWh/kg]</td>
<td>0.239</td>
<td>0.235</td>
</tr>
</tbody>
</table>

![Figure 2](image-url) – Results of residual content of synthetic base in drying performance tests
Figure 3 shows that there is good removal efficiency when using a lower feed flow rate. This efficiency decreases as the feed flow rate is increased. For the feed flow rate which generate a drill cuttings allowed for disposal (500-250 kg/h), the DCTU removed the synthetic base with 68-99% efficiency, depending on the initial content of synthetic base contained in the drill cuttings.

Figure 4 shows the specific energy results for each test. As can be seen that the specific energy results, per kg of drill cuttings treated, was between 0.12-0.34 kWh/kg. For the feed flow rate range of 250-500 kg/h, the specific energy was between 0.21-0.34 kWh/kg. As the feed flow rate increases, specific energy decreases, so the relationship between specific energy and the removal efficiency is directly proportional, so to obtain a good removal efficiency is necessary to spend a large specific energy.
CONCLUSIONS

The results show that it was possible to obtain optimized operating conditions to improve drying efficiency and reduce specific energy.

The equipment was able to operate at a feed flow rate of 250–750 kg/h, but it was only at a rate of 250–500 kg/h which the residual content of synthetic base below 2.7%, regardless of initial content used. This content is about 255% less then currently provided by Brazilian environmental legislation (6.9 wt.%).

The removal efficiency, using a feed flow rate between 250–500 kg/h, was between 68–99%. And the specific energy, in these same feed flow rates, was between 0.21–0.34 kWh/kg. These results show that both the equipment and technology have the potential for industrial use.

The device also proved to be able to reduce levels to below 0.1%, which shows how good the technology provides. The specific energy of DCTU remained close to the levels of commercial equipment and may be commercially competitive.

Currently, there is not many equipment that reach residual content close to equilibrium content with a high feed flow rate (250 kg/h). Specific energy and removal efficiency show the effectiveness of technology in decontamination drill cuttings.

They will be made some structural improvements, which it is expected that the equipment can work with a larger feed flow rate, getting residual levels close to equilibrium, with lower specific energy.

REFERENCES


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