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Full Length Article

Influence of hydrothermal treatment on filterability of fine solids in bitumen froth

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A B S T R A C T

Bitumen froth generated during the oil recovery operation from Athabasca oil sands needs to be cleaned to remove water and fine mineral solids for subsequent bitumen upgrading or pipeline transport. Two currently used bitumen froth cleaning methods, naphthenic froth treatment (NFT) and paraffinic froth treatment (PFT), either cannot generate market-spec bitumen froth (NFT) or causes losses of bitumen (PFT). In this study, a combination of hydrothermal treatment, venting and filtration was investigated to clean the bitumen froth. Laboratory hydrothermal treatment was conducted at 300–420 °C for 0–180 min. The filterability of fine solids was quantitatively characterized by room-temperature filtration or hot filtration at 200 °C. Mineralogical composition and particle size distribution of the untreated and treated fine solids were determined by quantitative X-ray diffraction using RockJock and focused beam reflectance measurement (FBRM) particle size analyzer. The microscopic observation of clay particle stacking behavior at the filter cake-filter medium interface was made by scanning electron microscope (SEM). The results show that hydrothermal treatment followed by venting and filtration is an effective way to remove water and fine solids from bitumen froth: the water content was reduced from 14 wt% to 0.03 wt%, and the fine solids content was reduced from 8 wt% to 0.08 wt% by hot filtration at 200 °C using a 0.5 μm pore size stainless steel filter medium. After hydrothermal treatment, no noticeable changes were observed to the clay mineralogy and fine solids particle size. However, the platy clay particles at the filter cake-filter medium interface turned from preferential orientation to random orientation due to the attachment of numerous ultrafine particles on the basal surface of the clay, increasing the porosity of the filter cake and facilitating the filtration. Such a change in the filter cake was hypothesized to be caused by the re-structuring of the organic-mineral aggregates into the ultrafine-particle-coated platy clays, releasing the organics and the ultrafine solids during the hydrothermal treatment. The released ultrafine solids then adsorbed onto the clay platelets. It was indeed observed that the total organic carbon content of the bulk fine solids decreased from 14.7 wt% to 10.3 wt%, but the carbon concentration on the fine solids surface increased from 35.6 at.% to 47.7 at.%.

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1. Introduction

The current oil sands operations in the Fort McMurray region in northern Alberta, Canada, use a warm-water extraction process which generates a bitumen froth as an intermediate product. Typical bitumen froth contains 60 wt% bitumen, 30 wt% water and 10 wt% fine solids [1]. The water may carry dissolved salts, which contribute to corrosion hazards in downstream operations [2]. The fine solids not only stabilize water-in-oil emulsions, but are also detrimental to downstream processes like upgrading and refining [3,4]. Transport of the bitumen by pipeline requires that contents of basic sediment and water (BS&W) be lower than 0.5 vol%, while water alone is limited to 0.3–0.5 vol% [5]. In order to be acceptable for pipeline transport, the water and fine solids in the bitumen froth must be removed.

Two technologies are currently used for cleaning bitumen froth, depending on the solvent used to dilute the bitumen froth and lower its viscosity [3,6]. When naphtha distillate is used, the emulsion is only partly broken and significant amounts of solids and water remain even after using inclined-plate settlers and centrifuges (Fig. 1a). In this case, the resulting bitumen can still contain 2–5 wt% water and 0.5–1 wt% fine solids [7] and cannot be transported by pipelines unless it is first processed by coking-

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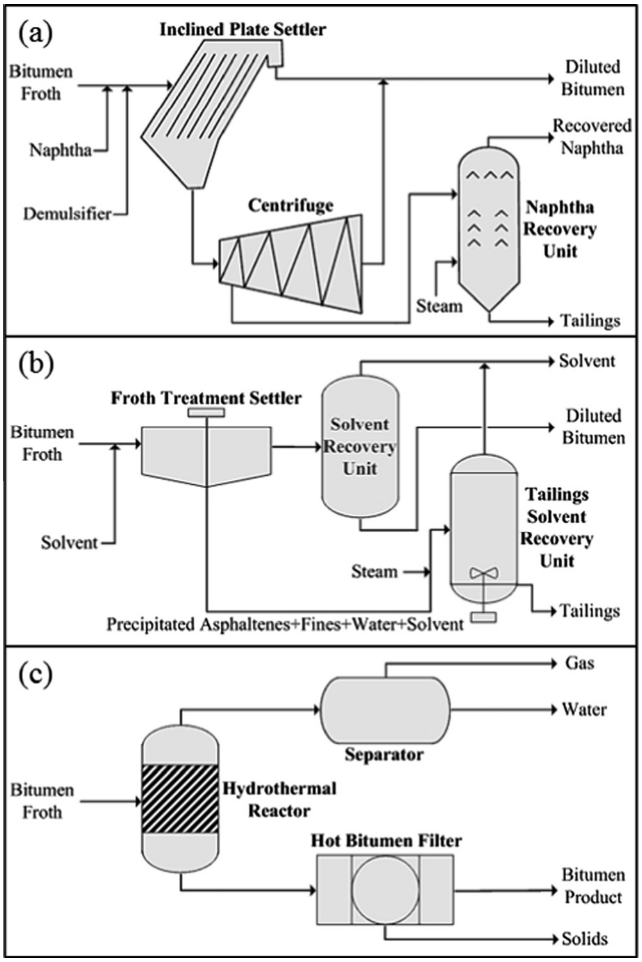

Fig. 1. Schematics of bitumen froth treatment processes: (a) simplified naphthenic froth treatment, (b) simplified paraffinic froth treatment and (c) conceptual hydrothermal treatment.

type upgrading plants. When a poor solvent such as hexane is used, 4–10% of the bitumen fraction, mostly asphaltene, precipitates, flocculating and removing with it almost all water and fine solids [8] (Fig. 1b). Both the froth cleaning processes require distillation to remove the large volumes of solvent from the bitumen product, and solvent recovery units to recover the residual solvents from the fine solids and water. Inefficiencies in solvent recovery are a major contribution to solvent losses into the tailings ponds [3].

Alternative technologies for froth cleaning are desirable if they can reduce the equipment cost, reduce energy consumption, and reduce environmental impact. The bi-wettable fine solids stabilize water-in-oil emulsions, which, in turn, makes solids and water removal from bitumen froth extremely difficult [9]. Hence, any technology which can alter the surface properties of the fine solids may be a potential choice for froth cleaning. Hydrothermal treatment is direct thermal processing of bitumen froth at elevated temperature (up to 450 °C) rather than the current approach of froth treatment followed by upgrading. After the hydrothermal treatment, the wide range of the surface properties of the initial fine solids particles with a high disparity of wettability was made uniformly hydrophobic [10].

Filtration is a well-established method for solid–liquid separation [11]. Although bitumen is viscous at room temperature, at the elevated temperatures that follow hydrothermal treatment its lowered viscosity may enable filtration. In related studies, Yoshida et al. [12] performed hot filtration of coal liquids at 360 °C by using 0.5 μm pore size stainless steel filters to produce ash-free material. They found that a high extraction yield can be achieved under hot filtration with addition of organic solvents such as methylnaphthalene. Filtration at high temperature offers many advantages, such as increased overall efficiency, improved product quality, recovery of thermal energy, and integration of filtration into the overall process [13,14]. Advances in filter media have provided materials such as sintered metal and porous ceramic filter media that are readily available and suitable for hot filtration at temperatures up to 900 °C [15–17].

To employ filtration in bitumen froth cleaning process, the filterability of the fine solids is of great significance. No systematic studies have examined the filtration behavior of the fine solids after hydrothermal treatment. A filter cake can be described as a packed bed of particles with a complex system of interconnected inter-particle voids [18]. The stacking of microscopic particles inside the filter cake is directly related to the macroscopic filtration performance. In this regard, any changes in the pore structure of the filter cake due to particle rearrangement will affect the flow behavior within the filter cake and in turn change the filterability.

We hypothesize that hydrothermal treatment will improve the filterability of the fine solids in bitumen froth by disrupting the original stacking of clay particles. In this study, a conceptual bitumen froth cleaning approach is proposed, as shown in Fig. 1c, which combines the hydrothermal treatment of bitumen froth, water separation by venting and solids removal by hot filtration. Our objectives were to study the influence of hydrothermal treatment at 300–420 °C for up to 180 min on the filterability of the fine solids in bitumen froth and to test the feasibility of solids removal from bitumen froth by hydrothermal treatment followed by hot filtration at the laboratory scale.

2. Materials and methods

2.1. Bitumen froth

The bitumen froth sample was obtained from CanmetENERGY, Devon, Alberta, courtesy of Imperial Oil. The sample contained 78 wt% bitumen, 14 wt% water and 8 wt% fine solids as determined by Dean–Stark extraction.

2.2. Hydrothermal treatment and water removal

The hydrothermal treatment, venting and solids hot filtration were carried out using the laboratory set up shown in Fig. 2. The treatment temperature and time are optimized by conducting hydrothermal treatment at 300–420 °C for 0–180 min. The hydrothermal treatment was performed using a 500 mL 4575B Series Parr reactor (Fig. 2a). To carry out the hydrothermal treatment, a bitumen froth sample weighing 165 g was loaded into the Parr reactor for each run. The reactor was then pressurized with nitrogen to 0.7 MPa and placed in a heating mantle to heat to the desired temperature. When the temperature reached 100 °C, the stirring was turned on and fixed at 300 rpm. It took about 40 min for the reactor to reach the target temperature. The reactor was left at the target temperature for certain treatment time (the heat-up time was not included in the reported treatment time). The following conditions were investigated: 300, 330, 350, 370, 390, 400, 410 and 420 °C for 30 min, and 390 °C for 0, 10, 30, 60 and 180 min. In this context, a treatment time of 0 min means heating the reactor to 390 °C then immediately cooling it without holding the temperature at 390 °C. The pressure under different treatment conditions was in the range of 8.6–19.3 MPa. After the hydrothermal treatment, the reactor was cooled down to 270 °C by turning off the heating mantle and circulating cooling water in the coil inside the Parr reactor. The vapors inside were vented out at 270 °C and

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