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Comparative analysis of quartz sand and detritus effects on thermal behavior and kinetics of heavy crude oil

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ABSTRACT

This work aimed at conducting the comparative effect analysis of quartz sand and detritus on thermal behavior and kinetics of heavy crude oil by thermogravimetric (TG) tests with multiple heating rates. The results indicated that during the whole heating process, oil, oil + quartz sand and oil + detritus experienced three main regions, i.e. low temperature oxidation (LTO), fuel deposition (FD) and high temperature oxidation (HTO). When the detritus and quartz sand were added, the FD range was shortened and HTO region was shifted to a lower temperature one, especially for the detritus. Generally, the detritus played a positive role of catalytic effect and surface area effect for oil oxidation in different reaction regions. The relation of activation energy versus conversion rate for oil alone and its mixtures was presented, which is expected to add new insights to oxidation mechanism and catalytic mechanism. Compared with oil only and oil + quartz sand, oil + detritus gave the lowest activation energies which were varied between 32–81, 63–161 and 63–133 kJ/mol at the LTO, FD and HTO stages, respectively.

1. Introduction

A descending oil production from mature reservoirs has attracted appreciable attention on improved oil recovery (IOR) to meet ever-increasing energy demand. Quite a few laboratory investigations and oil field practices have validated that thermal recovery techniques are significantly promising, notably for the heavy oil reservoirs [1–4]. Generally, thermal recovery methods involved in situ combustion (ISC), steam injection, supercritical water, in situ electrical heaters, binary mixtures, etc. With regard to ISC, there are parallel, competitive and consecutive physical processes and chemical reactions with a small quantity of the oil in place and oxygen in the injected air or oxygen-enriched gas. The considerable heat produced by combustion accelerates to displace the oil into production wells. However, approximately 80% of the ISC projects have been proved to be economic failures because of a limited understanding of the processes [5].

For the past few years, the thermal behavior and kinetics of heavy crude oil and mixtures of oil and sand/detritus had been studied widely using a series of thermal analysis instruments such as TG/differential scanning calorimetry (DSC), accelerating rate calorimeter (ARC), combustion tube (CT), small batch reactor (SBR), etc. [6–10] As reported by most peers, the reactions during ISC are usually identified as LTO, FD and HTO [11–13]. Pu et al. [14] analyzed the thermal behavior of Tahe heavy oil by TG analysis. It was claimed that the LTO region was narrowed while the FD stage was expanded with the addition of detritus. The detritus drastically lowered the HTO activation energy determined by Arrhenius equation on the basis of TG data of single heating rate. Also, it was considered that quartz sand held negligible catalytic effect. Ranjbar [15] reported that the reservoir rock promoted FD during the pyrolysis process and catalyzed fuel oxidation, as indicated by the results of CT. In addition, with the clay content in the matrix, an increase in the amount of fuel formed was noted, accompanied by a decrease in the activation energy. Varfolomeev et al. [16] observed that the addition of clay to porous matrix significantly affected the thermal effect caused by crude oil oxidation. Yu et al. [17] investigated the effect of three types of clay minerals involved in the detritus on LTO of heavy oil during ignition process using SBR. The results elucidated that the clay minerals boosted the reaction rate, thermal release rate and oxygen consumption rate in the LTO stage. Based on a sequence of ARC results, Greaves et al. [18] proved that the

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