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Full Length Article

Effect of mixing and vapor residence time on thermal cracking of bitumen in a Mechanically Fluidized Reactor

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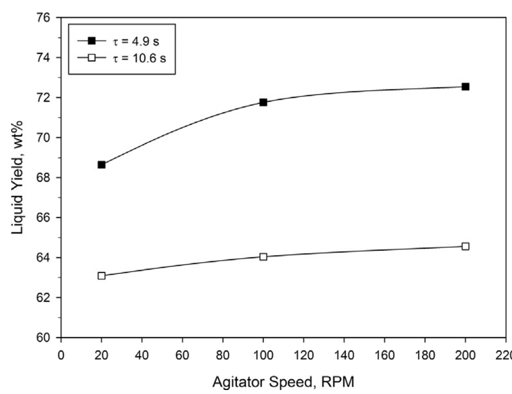
HIGHLIGHTS

- The Mechanically Fluidized Reactor can be used to study Fluid Coking.
- Improving liquid distribution on coke particles reduces the coke yield.
- Longer vapor residence time increases the conversion of vapors to gas.
- At short vapor residence times, improving liquid distribution increases the liquid yield.

GRAPHICAL ABSTRACT



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ABSTRACT

Fluid Coking™ is a non-catalytic carbon rejection process that is utilized to convert petroleum residues into more valuable light and middle distillates. In this process, heavy oil is sprayed into a fluidized bed of hot coke particles; the liquid heats up and undergoes endothermic thermal cracking to vapors, non-condensable gas and solid coke. This study shows that liquid distribution on hot coke particles affects the products yields and the liquid product quality. The vapor residence time also affects the products yields and the liquid product quality.

The Mechanically Fluidized Reactor has been successfully developed and implemented for Fluid Coking applications. Multiple vapor phase residence times can be investigated simultaneously while reducing intrinsic errors present in a complex system such as coking. The impact of applied bed mixing and vapor phase cracking on Fluid Coking yields, as well as on product oil quality can, thus, be accurately evaluated.

Applying mechanical mixing to the bed of coke particles results in better liquid distribution on coke particles and reduces coke yields. It also increases the yield of low viscosity, low molecular weight liquid at short vapor residence times. At long vapor phase residence times, however, vapors crack to gas, resulting in a concentration of higher viscosity, higher-molecular weight compounds in the liquid phase. The additional vapors that are produced in the bed thanks to enhanced mixing are more reactive and easily crack to gas at long vapor residence times. Realizing the full benefit of enhanced liquid distribution therefore requires minimization of the vapor residence time.

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1. Introduction

Historically, conventional light crude oil reserves have been a major contributor to worldwide petroleum production. However, their ubiquitous use has lead to a shift towards unconventional oil resources such as bitumen and heavy and extra heavy crude oil [1].

Bitumen is a complex mixture of high-molecular weight aromatic hydrocarbons which exhibits a high viscosity and semi-solid state. It is characterized by relatively high levels of impurities such as nitrogen and sulphur heteroatoms, and metals such as nickel, copper, and vanadium [2]. After extraction, bitumen is typically fed through atmospheric and vacuum distillation. The non-distillable fractions are referred to as residues that require significant processing in order to obtain useful fuels. Delayed Coking and Fluid Coking™ are the most common unit operations applied to these residues [3,4].

Fluid Coking™ is a non-catalytic carbon rejection process that is utilized to convert residues into more valuable light and middle distillates. The process involves the main reactor, stripping and scrubbing sections, as well as a burner unit (Fig. 1). The reactor section consists of a fluidized bed of hot coke particles into which bitumen is sprayed for thermal cracking into lower-molecular weight compounds. The scrubbing section is situated on top of the reactor and cools the product vapors, effectively recycling heavier components back to the reactor while allowing lighter, more valuable products to exit [4]. The stripping section is employed to minimize hydrocarbons carry-under to the burner vessel. The burner vessel is a fluidized bed in which coke is partially combusted with oxygen to generate the heat required to sustain the endothermic cracking reactions. Hot coke is then recycled back to the reactor to complete the heat balance while excess coke is quenched and stockpiled for future use [2].

The reactor operates in the range of 510–565 °C, with maximum liquid yields occurring in the range of 510–530 °C [5]. Pressures are maintained close to atmospheric. The vapor-phase residence time ranges from 10 to 30 s depending on where the vapors are liberated in the bed [6]. With bitumen being a complex mixture of high-molecular weight hydrocarbons, resins, and asphaltenes, the chemical reactions are highly complex [7].

Ariyapadi et al. [8] investigated the injection of gas-liquid jets into fluidized beds using non-intrusive digital X-ray imaging techniques. They found that agglomerate formation occurs at the end of the jet region. Agglomerates of 5–40 mm were observed in the low-shear regions of the jet, where the jet liquid contacts slower-moving particles [8].

Agglomerate formation in fluidized beds is a complex phenomenon impacted by various physicochemical properties of the bed material and liquid injection, as well as operating parameters of the equipment [9]. There is practical operating evidence that poor liquid injection results in poor distribution of the liquid on the coke particles, which in turn leads to loss of bed fluidity, entrapment of feed liquid in large agglomerates, reduced liquid yields, and severe fouling of reactor internals, all of which are detrimental to the performance of the Fluid Coking process [5,10].

The first purpose of this study was, thus, to determine how liquid distribution on hot coke particles affects the products yields and the liquid product quality. An important objective was to achieve nearly ideal liquid distribution to determine the best possible liquid yield and quality. Because regular bubbling fluidized beds cannot provide a very good liquid distribution [5,11], a new reactor was developed to provide nearly ideal mixing conditions. The second purpose was to determine the impact of the vapor residence time on the products yields and the liquid product quality. This required the development of a new system that to provide a much more precise measurement of the impact of the vapor residence time on thermal cracking than could be obtained in a regular bubbling bed pilot plant.

2. Materials and methods

2.1. Materials

The feed to the reactor was Athabasca vacuum topped bitumen. This feed represents the non-distillable residue from vacuum dis-

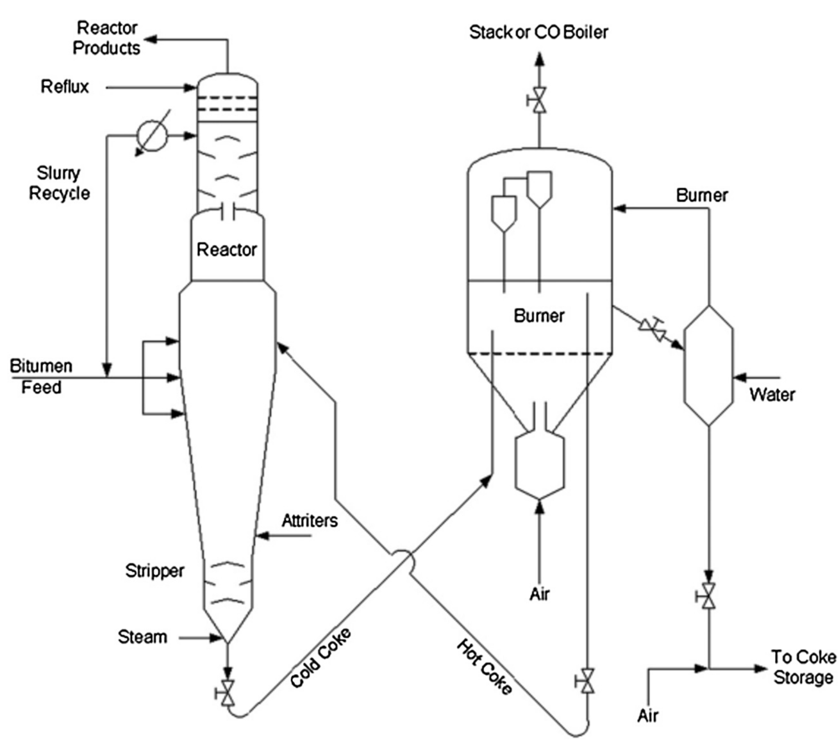

Fig. 1. Fluid Coking Reactor.