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A systematic comparison of various upgrading techniques for heavy oil

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ABSTRACT

This study evaluates the economic viability of various post-production upgrading techniques for heavy oil. Heavy oils represent 60% of overall crude oil resources, worldwide. However, there are challenges associated with all phases of operation chain owing to high viscosity and low API. In this study, we present a comparative study of five post-production processing techniques in terms of their recovery factors, and economics.

We use five different techniques to study post-production processing of heavy oil: 1) dilution with lighter crude, 2) partial upgrading via visbreaking, and 3) wellsite mini-refinery with three various configurations. Two heavy oil samples are selected based on API gravity and sulfur content. Simulations have been conducted to study various processes for the chosen oil samples. Key parameters controlling each technique have been identified and impact of each parameter have been analyzed with sensitivity studies. Advantages and disadvantages of each process are compared to assess the performance at different operational conditions, including oil price.

Results indicate an overall net margin of $1 per barrel for blending, between $7 to $9 per barrel for partial upgrading technique, and between $13 and $20 per barrel for mini-refinery. Moreover, when production rate or the crude price is low, blending yields the best performance as it requires the lowest capital cost. Mini-refinery becomes profitable when production exceeds 20,000 barrel per day or oil price surpasses $ 50 per barrel. In addition, for dilution process operation cost has the largest impact on NPV calculations whereas interest rate and capital cost are most dominant factors for visbreaking and mini-refinery techniques.

The main contribution of this work is an economical comparison of different post-production heavy oil processing technologies to identify the optimal process under different conditions.

1. Introduction

Crude oil is a fossil fuel formed from organic remains which have accumulated at sedimentary environments over time, temperature and pressure. Heat and bacterial action transform the deposit into hydrocarbons, water, carbon dioxide, etc. (Robinson, 2006). What makes crude oil became heavy oil, in terms of geology, is the biological, chemical and physical degradation during migration after entrapment inside the pore space of the rocky reservoir. Heavy oil and bitumen is formed from the residue of light oil, whose light molecular weight components have been lost through microbial degradation, water washing and evaporation (Ancheyta, 2013). The extent of such degradation determines how heavy the resulting oil is.

As it is shown in Fig. 1, crude oil is classified based on key properties that determine not only its value once produced but also how it must be handled at the surface which includes transportation and upgrading or refining. These key properties are density, viscosity, and chemical composition. Based on API gravity and viscosity values heavy oil can be classified as light oil, medium oil, heavy oil, and extra heavy oil.

Heavy crude oil is defined as crude oil with an API gravity between 10° and 20° and with a viscosity greater than 200 cP (cP), where extra-heavy crude oil is defined as crude with an API gravity less than 10° (Smalley, 2000).

Production, transportation, and refining of heavy crude oil present special challenges compared to light crude oil (Speight and Ozum, 2002). These challenges have prompted producers to start looking for alternate options for upgrading bitumen in the field. The heavy oil can either be partially or fully upgraded based on certain economic factors. The decisions whether to upgrade heavy oil and subsequently to what extent to upgrade the feed depend on a number of key technical and economic factors:

- *Transportation of product.* Pipelines are the most cost-effective method to deliver oil to refineries; therefore, shipments are targeted to meet pipeline specifications for viscosity, solids content, and density.

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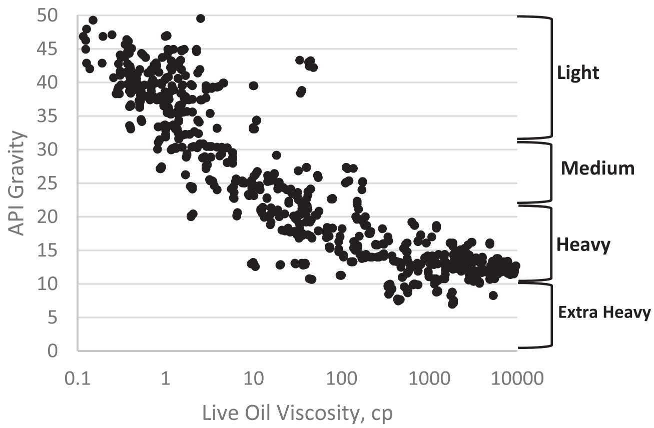

Fig. 1. Crude oil classification based on API gravity and viscosity (Smalley, 2000).

- *Physical properties of oil.* If the viscosity of the produced oil or bitumen needs to be reduced to meet pipeline standards, the ability to add a diluent without precipitating asphaltenes – which is often referred to as compatibility between the feed and diluent and subsequently the stability of the blend – will determine whether upgrading is required or optional.
- *Availability and price of diluent.* The cost and availability of condensate or other lighter hydrocarbons for use as diluent will determine the attractiveness of diluting heavy oil or bitumen for shipment.
- *Costs of upgrading.* Upgrading has three component costs: the capital investment (to build the facilities), the operation of the facilities, and the loss of oil volume as a result of upgrading. It should also be noted that although volume loss is typical in thermal cracking processes, volume gain can also happen in some catalytic processes (Pereira et al., 2001).

This project evaluates and compares different techniques to determine the most cost-efficient method for a range of oil price. Objective of this study is to screen various existing technologies to upgrade heavy oil and extra-heavy oil, evaluate these technologies and propose the ones suit to the given conditions. Two field examples with different API and sulfur content are chosen and five determined upgrading techniques are simulated using Aspen Hysys commercial software. The key steps of this project are as follow; (1) Identify several post-production upgrading techniques and simulation modelling of each chosen upgrading technique; (2) Economic evaluation of chosen heavy oil samples to determine the feasibility of implementing the technology vs. the oil price.

2. Heavy oil post production upgrading techniques

The primary purpose of this paper is to determine a cost-efficient technique for different crude oil price ranges by comparing various upgrading methods. The chosen and modeled heavy oil upgrading configurations are as follow; (1) Heavy oil dilution: blending the heavy oil with lighter oil at the wellsite to reduce the viscosity to minimum transportation specification, (2) Visbreaking as partial upgrading technique: visbreaking of the heavy oil at the wellsite to reduce the viscosity to minimum transportation specification, (3) Mini refinery configuration: atmospheric and vacuum distillation of heavy oil representing mini refinery at the wellsite, (4) Mini refinery with additional visbreaking unit, and (5) Mini refinery with additional delayed coking unit.

Heavy oil dilution or blending is performed in around 60% of heavy oil operations around the world. Heavy oils cannot be transported via pipeline without a prior reduction of their viscosity. By mixing of a light oil with the heavy incoming oil, viscosity can be reduced and additionally API gravity of the final mixture will increase. This operation can be performed in-situ or post-production to reduce the incoming heavy oil feed to the required transportation specifications to ensure flow assurance. Blending involves a comparatively simpler and cheaper setup than other upgrading techniques and avoids the issue of fluid instability associated with thermal treatment (Hart, 2013; Hasan et al., 2010).

As an alternative, partially upgrading techniques have been developed from a desire to minimize costs to the producer and a subsequent focus on reducing viscosity to meet specifications for pipeline transport (Colyar, 2009; Fukuyama et al., 2010). Partial upgrading techniques can include techniques like aquaconversion, visbreaking, high-conversion soaker cracking and distillation but only to the extent that the API gravity is raised roughly to the range of 15–25 and viscosity is reduced from, typically, greater than 10,000 cP to about 350 cP. Visbreaking is one of widely used partial upgrading techniques. Visbreaking, or viscosity reduction is a mild thermal cracking process, which improves the viscosity of the residue at low cost, without altering the distillates significantly (Speight, 2012; Radovanovic and Speight, 2011). In this work, as a partial upgrading technique, soaker visbreaking is considered and modeled.

Next selected method is mini-refinery which is consistent of atmospheric and vacuum distillation columns. Modular mini-refineries are considered as cost-effective and flexible options for crude oil producers. The refining capacity of a mini-refinery typically ranges from 4000 barrels per day (bpd) to 30,000 bpd. These units can upgrade heavy oil feedstocks fully at a given rate in barrels per day and are typically considered, economically, upon cost per capacity basis – cost per barrels per day. These units are characterized by the ability to be built and located or relocated in short time spans. The benefit of a mini refinery is that in remote areas more finished products can be produced more readily; this is particularly useful in areas where little infrastructure exists for subsequent transport or refining of produced heavy oil.

Mini-refinery with visbreaking unit is modified configuration of base mini-refinery scenario with additional visbreaking unit added to further processing of vacuum residue. Mini-refinery with delayed coking is an alternate mini-refinery option, which vacuum residue is processed with delayed coking unit instead of visbreaking unit.

3. Simulation models

In this work, two different heavy crude oils with different API and sulfur content and one light crude oil for blending option are chosen. The light oil is from Egypt field, Zarif light oil, has an API gravity of 28.3 and viscosity of 22 cp at standard conditions. The first chosen heavy crude oil is owned by Chevron, Bozhong crude, which is produced offshore in Bohai Bay, China. Bozhong is a heavy crude oil which has an API gravity of 16.9, viscosity of 13,140 cp at 60 F temperature. Next chosen heavy oil is Bachaquero from Venezuela, with API gravity of 12.3 and 2.8% sulfur content. Viscosity at 60 F for Bachaquero heavy oil is 62,946 cp. Table 1 details the specifications of chosen heavy crude oils. For this study, Aspen Hysys was used to model chosen five different upgrading techniques.

During heavy oil dilution procedure, it is considered to simply blend heavy oil with lighter crude to get deserved viscosity at 60 F and sell as mixed crude. For blending method, it is assumed that, chosen light oil is compatible with heavy crude oils and crude mixture will be stable at any condition.

In case of partial upgrading option, visbreaking is modeled, as

Table 1
Crude oil specifications.

Property	Bozhong	Bachaquero
Gravity, API°	16.9	12.3
Molecular Weight	413.6	361.2
Sulfur, wt%	0.29	2.8
Viscosity (60 F), cp	13,140	62,946
Total Nitrogen, ppm	4 993.6	2 525
Vanadium, ppm	0.74	428.6
Nickel, ppm	15	64
Asphaltene, (H.C7) wt%	8.2	7.5