Heavy Oil Exploitation

Contents

Preface

The petroleum industry contains a number of disciplines and specialties working together to locate, produce, and refine the various petroleum products that ultimately make it to both the industrial and consumer markets. For those working in the industry, it is easy to spend your entire career working or specializing in a particular area without ever being aware of or understanding the technical challenges your colleagues face every day, let alone having a general understanding of the industry. While some of our colleagues benefit from frequent travel or relocation to various gas- and oil-producing regions around the world, most improve their technical understanding through conferences, technical journals and books, and short courses targeting midcareer personnel. All of our authors have benefited from taking as well as preparing and teaching technical short courses to midcareer personnel. The idea for this book originated from a course for nontechnical professionals that we prepared and gave repeatedly over the past few years. The material was updated before almost every course as we learned more about the industry, especially from great student questions that required us to go back and research the topics in more depth.

Like the course, this book attempts to encompass all aspects of heavy oil exploitation from geology to production to transport to upgrading. As such, the book provides a very broad overview of the full life cycle of heavy oil development. While the material does demand a basic understanding of organic chemistry as well as petroleum, mechanical, and chemical engineering, the intent is to provide an overview that would benefit both technical and nontechnical professionals working in the petroleum industry, as well as university students who require an introductory text on heavy oil exploitation. In line with providing a broad overview for both technical and nontechnical professionals, we have attempted to keep the technical details and use of equations or discipline-specific terminology to a minimum. Since technical terminology cannot be completely avoided, we have provided as many definitions as possible throughout the text. For those who are inspired to dig deeper into specific technical aspects of heavy oil exploitation, we have also attempted to provide as many valuable references as possible.

The material is organized into eight chapters, roughly divided by the major elements in heavy oil exploitation. Chapter 1 provides an introduction to how heavy oil is defined relative to other types of oil, the types of geology and geochemistry that give rise to heavy oil deposits, and the challenges in developing these deposits, with an emphasis on the major heavy oil regions of Venezuela and Canada.

Chapter 2 gives an overview of the chemistry and related fluid phase behavior and properties that one can expect to encounter throughout the heavy oil exploitation process. Understanding the fluid characteristics of heavy oil is key to making good design decisions in the different aspects of production, transport, and refining.

Chapter 3 summarizes the mechanisms and criteria of different heavy oil recovery processes and how these processes are being applied in different heavy oil fields around the world.

In chapter 4 we describe various aspects of constructing and completing a heavy oil well. While a number of the approaches are similar to conventional oil well completions, the specific configuration used in heavy oil development will depend on the chosen recovery mechanism. This chapter also includes completion best practices from around the world.

Chapter 5 provides information about common production and sand management techniques used in heavy oil production, including heavy oil–specific reservoir and well characteristics that may influence the selection of lifting techniques.

Following up on the different aspects of recovery, chapter 6 provides an overview of the common gathering and processing techniques used to handle the heavy oil once it has been produced to the surface. This includes discussions on separating gas, heavy oil, water, and solids into separate flow streams, and subsequent treatments required to meet commercial and regulatory specifications prior to transportation.

Chapter 7 discusses various options for the transportation of heavy oil. Due to its highly viscous nature, various methods have been developed to reduce the viscosity of heavy oil in order to reduce the effort and energy required to transport the oil over long distances.

Finally, chapter 8 concludes the book with an overview of processing, upgrading, and conversion. To improve market value or quality, heavy oils are subjected to chemical conversion. This chemical conversion is applied to enhance the quality of the oil to meet a higher level of technical specification.

1

Introduction

The petroleum production and processing industry has seen a rise in the volume of crude oils coming from unconventional sources, namely crude oils that are economically more difficult to extract due to one or more technical challenges. Examples of production from unconventional sources include light crude oil production from kerogen-bearing rock (i.e., shale oil), crude oil production from rock composed of very small pore spaces (i.e., tight rock), and the production of high viscosity, high density crude oils from shallow reservoirs (i.e., heavy crude oils, including bitumen). As the title implies, the aim of this book is to provide a high-level overview of the production, transportation, and refining of heavy crude oils.

Heavy crude oils have a unique chemical nature that gives rise to a number of technical challenges. The most obvious is the high viscosity of heavy crude oils, which often requires the development of new techniques to make the viscous liquid flow more easily through porous rock and through pipelines. However, less obvious are the effects on well site unit operations from high viscosity and near-water density, effects such as the separation of gas, sand, and water from the crude oil. Further downstream, the presence of higher concentrations of highly aromatic compounds requires the use of additional unit operations, namely upgraders, to convert much of the heavy crude oil into lighter, more valuable hydrocarbon compounds. The presence of higher concentrations of sulfur, nitrogen, and heavy metals in heavy crude oils also introduces processing challenges in removing these elements from the refinery products.

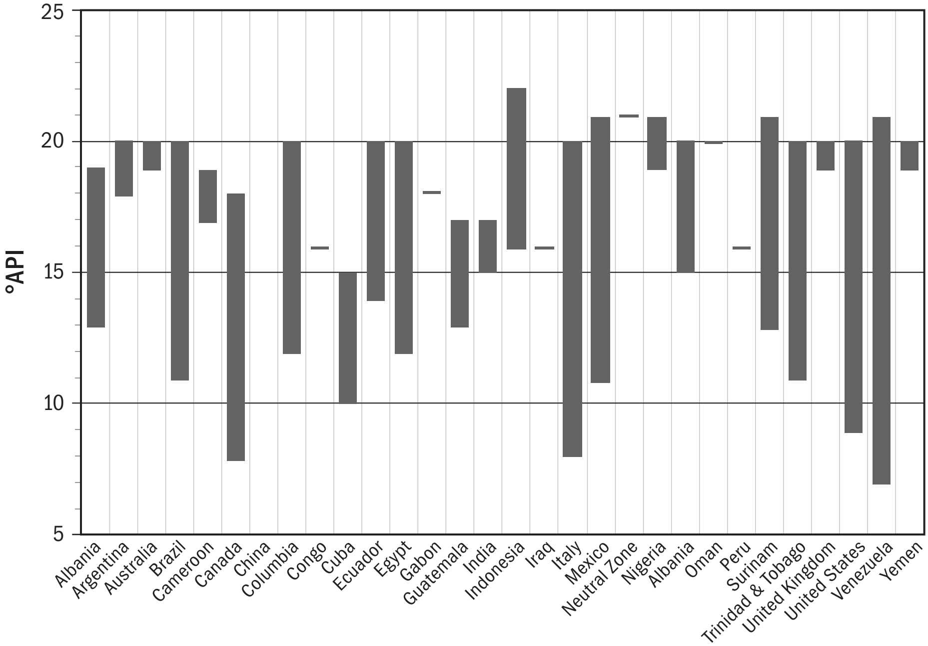

Fig. 1–3. API range of heavy oil worldwide
Courtesy of Schlumberger.

Heavy Oil Characteristics—Mobility and Viscosity

One of the keys to heavy oil exploitation is understanding the differences between heavy oil and conventional (light and medium) crude oils, in particular the high viscosity and low mobility associated with heavy oil relative to conventional oils. Typical oil viscosity in a mobile heavy oil reservoir—a reservoir capable of production under its own driving energy—is in the order of 1,000 mPa·s. Typical oil viscosity in an immobile extra-heavy oil and bitumen reservoir ranges from 10,000 to 10^6 mPa·s.

To better understand mobility, let's take a brief look at the Darcy equation. Darcy's law is a simple proportional relationship between the flow rate of a fluid through a porous medium, the viscosity of the fluid and the pressure gradient of the flow, which is the pressure drop over a given distance (equation 1–1). The total fluid volume flow or discharge (e.g., oil or water), q_i, in volume per unit time is equal to the product of the permeability of the fluid, k_i, the cross-sectional area to flow, A, and the fluid pressure drop, ΔP_i, all divided by the viscosity of the fluid, μ_i, and the length the pressure drop is taking place over, Δx. The permeability of

Collecting Fluid Samples

Prior to making any design or operational decisions, we need data and often that means collecting a sample of heavy oil. However, not just any sample will do since the quality of the data is only as good as the sample. For example, if you are creating a field development plan, you will need multiple samples from across the field to understand the vertical and aerial variations of fluid properties across the formation. If you are planning a surface upgrading process, you need to know the composition and properties of the heavy oil entering the upgrading plant. The quality of data depends on collecting a sample of heavy oil that has a composition and associated properties as close as possible to the fluid you expect to see at that point in the process. This approach to collecting fluids is often referred to as “representative sampling.”

Any successful data collection exercise requires planning, which means understanding what measurements are to be completed and what volume of heavy oil is required to complete them, and identifying the optimal location and technique for collecting a representative sample. The optimal solution for sampling will depend on the data accuracy required and, of course, the budget available to collect and analyze the heavy oil sample. There are a number of options available for collecting heavy oil and bitumen fluid samples, including extraction of fluid from core samples, collecting samples from temporary or permanent surface facilities, and collecting downhole samples from open- or cased-hole wells.

The unique properties of heavy oil reservoirs introduce a number of challenges in sampling. One common challenge for all sampling techniques is the high viscosity of heavy oils. The high viscosity means collecting the sample can be a slow process and, in the case of bituminous fluids, nearly impossible using conventional sampling techniques due to the immobility of the oil. In these extreme cases, alternative extraction techniques that rely on some form of fluid manipulation, such as heating, mechanical extraction, or water-based extraction, are required. The remainder of this section will briefly review the typical options for collecting heavy oils samples.

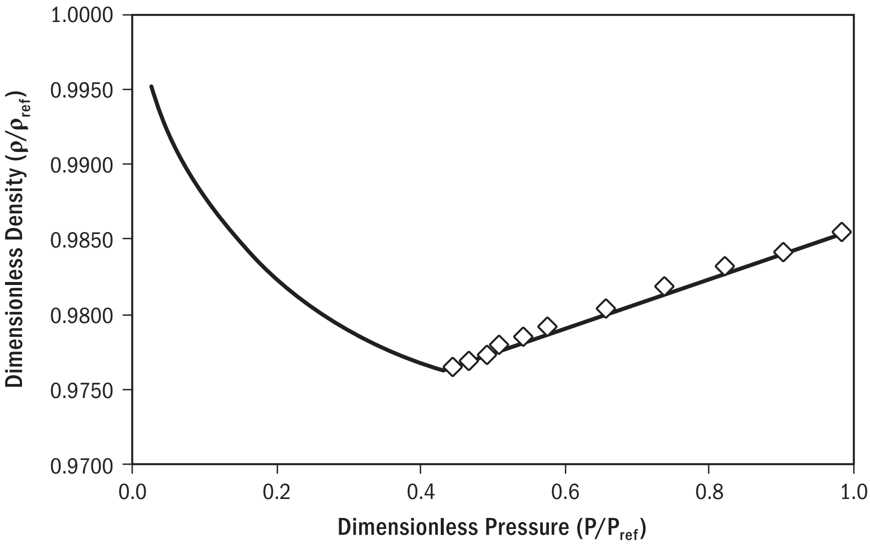

Fig. 2–12. Typical curve for change in liquid density during depressurization of a heavy oil. Note the increase in liquid density below the bubble point.

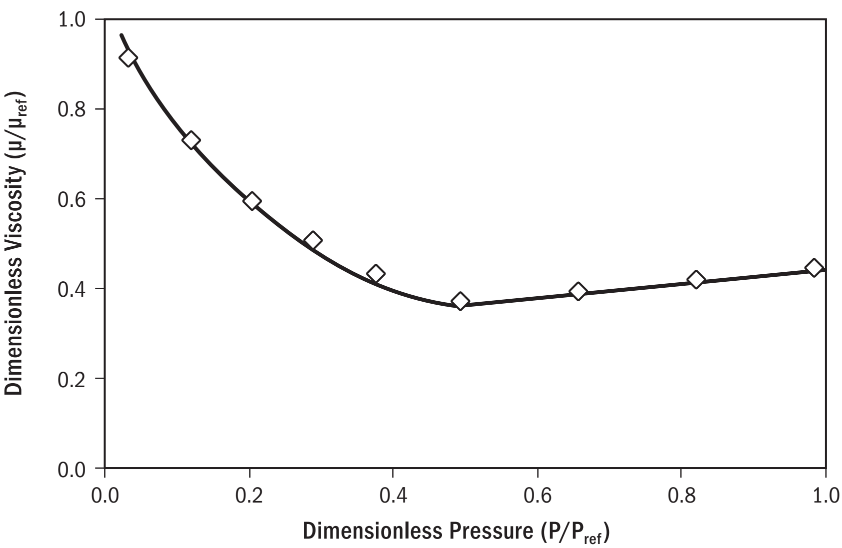

Fig. 2–13. Expected change in liquid viscosity during depressurization of a heavy oil. The liquid viscosity increases significantly below the bubble point.

m; oil viscosity at reservoir conditions of <2,000 mPa·s; oil saturation of >0.5; water-oil ratio (WOR) of <10; horizontal permeability of >200 md and vertical permeability of >100 md.

Based on laboratory observation, the benefit of TTHW as compared to conventional waterflooding with vertical wells is the increase in ultimate oil recovery and the increase in water injectivity.[5] Also, the well configuration can easily be applied in the field by converting existing vertical wells that are being waterflooded. Since the water breakthrough is at the toe, the TTHW process is relatively easy in terms of monitoring and process control. The process is less sensitive to rock heterogeneity since the drive mechanism is dominated by gravity and the driven fluid (i.e., oil) is only travelling in a short distance, which is less than the thickness of the pay zone.

Waterflooding with additives (e.g., CO_2) can improve heavy oil recovery through the alteration of phase behavior, in terms of CO_2-hydrocarbon miscibility, swelling (caused by gas, CO_2, water-in-oil emulsions), and gas exsolution. Additives can also result in the alteration of relative oil-water and oil-gas flow rates caused by the reduction in oil viscosity and interfacial tension (IFT). The IFT can be altered by the addition of surfactant and caustic. The mobility ratio is also altered by the addition of polymers and solvents. The relative flow rates are altered by plugging the pores with foams, gels, and gel-foams. The chemicals can change the wettability of the rocks, improving recovery.

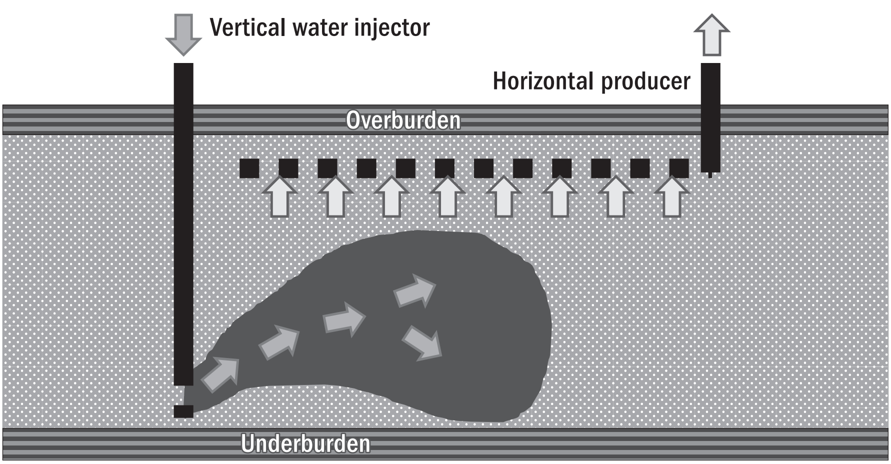

Fig. 3–8. Concept of TTHW

Source: A. Turta, F. Wassmuth, V. Shrivastava, and A. K. Singhal, Toe-to-heel waterflooding with progressive blockage of the toe region, US Patent 7,328,743B2, filed September 22, 2006, and issued February 12, 2008.

cold regions ahead of the combustion front, and to overcome the impact from reservoir heterogeneity on production performance.

THAI field pilot. The THAI process has been pilot tested in western Canada.[28] The Whitesands THAI Pilot, with three vertical/horizontal well pairs, is designed to produce 300 m^3/day (1,800 bbl/day) of partially upgraded bitumen from the Athabasca oil sands. The project area is around 20 ha (50 acres) with a horizontal well length of 500 m and horizontal well spacing of 100 m. Air injection rate per well pair is 3 MMscf/day.

The field pilot was operated from 2006 to 2011 with the following observations and conclusions given by Whitesands:

- The pilot consistently improved the quality of the produced oil with both increased API gravity and a reduction in viscosity relative to the initial oil properties.
- The produced oil had a significantly higher concentration of volatiles and saturates due to thermal cracking.
- The produced oil had a notable reduction of resins and asphaltenes due to partial upgrading. However, this reduction was only observed at the later stage of the production.
- With the increase in surface temperature, the produced fluid demonstrated an increased carryover of lighter ends to the secondary separators.
- Overall, the produced oil from the THAI field pilot process has a higher quality than that produced using SAGD.
- The produced gas had no oxygen, but contained up to 8% hydrogen.
- The produced gas had up to 9% of hydrocarbons (C_1–C_5) with a heating value of 85–120 Btu/scf, which is suitable for use in low–British thermal unit (Btu) steam generators. The CO_2 and CO contents and their ratios were consistent with those of a high temperature combustion process.
- The H_2S levels were stable in the produced gas and consistent with the expected value as a result of the reduction of sulfur in the produced oil.