Introduction to Heavy Oil

An Online Continuing Education Course for Engineers

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1. Introduction

The world wants enormous new crude oil reserves. No economical, abundant substitute for crude oil is available nor will it become available within the next several decades. Maintaining the supply needed to support the economies of industrial countries and enable them to grow will require the development of significant additional crude oil reserves. Conventional (light and medium) oil reserves as of 2014, it is not widely questioned that oil production will be in decline after 2050. Additional resources will thus be primarily in the form of the sole alternative: heavy oil.

Heavy oil represents a large portion of the worlds unproduced discovered hydrocarbon resources. High density and viscosity at atmospheric conditions has traditionally made their recovery very energy demanding compared to lighter crudes, and has resulted in very low recovery factors. For this reason, heavy crudes are an abundant untapped potential energy source, which is expected to be a large contributor to the world's energy needs in the future. However, the technological costs per barrel are currently much higher than for conventional resources.

Due to the varying practices in reserve and resource reporting, efforts to chart the world's petroleum reserves by fluid properties are inherently challenging. Paradigm shifts in classification can cause rapid changes in reserve estimates, such as when Venezuela reclassified its' Orinoco heavy oil to proved reserves, bumping the nations' total reserves from 99, 4 to 211 billion barrels

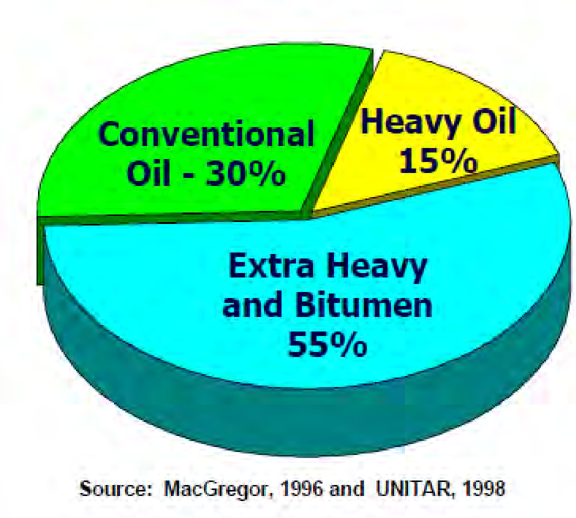


Figure 1: Total world oil reserves, heavy, extra heavy oils and bitumen make up about 70% the world total oil reserves

Figure 1 shows a frequently cited chart published in Oilfield Review, 2006. Out of the world's total remaining oil reserves, heavy, extra heavy oils and bitumen are expected to make up 70%. This number underlines the increasing importance of heavy oil production going forward, as conventional supplies are decreasing. Data presented by Saniere et al (2004) underline this message. As figure 2 shows, heavy oil reserves are higher than conventional reserves, but very little of the heavy oil has so far been produced compared to conventional resources. These numbers underline the potential gains from developing more effective extraction and production technologies for heavy oil.

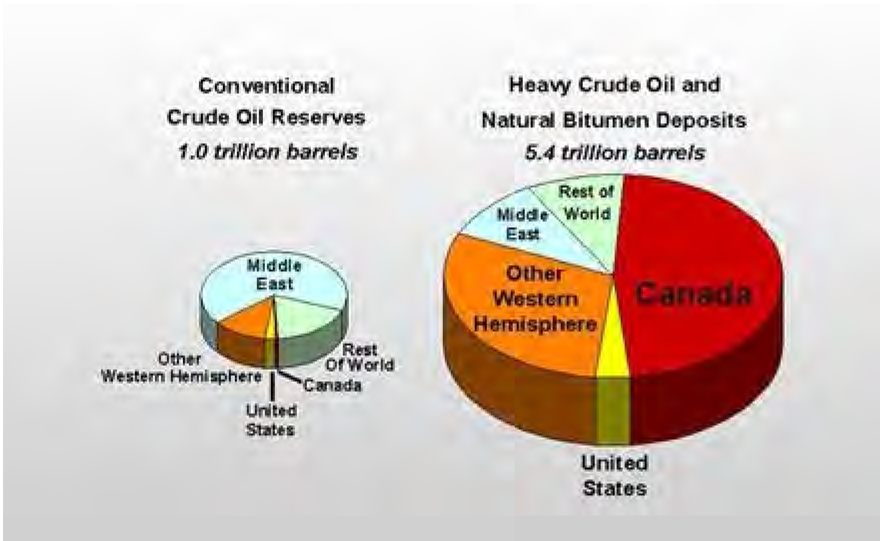


Figure 2: Worldwide Distribution of Conventional Crude Oil and Heavy Oil

Heavy oil is typically found in supergiant, shallow deposits. As a result, a few nations hold most of the world's resources and production of heavy oil and bitumen. Saniere et al (2004) reported that 87% of the heavy oil is located in Western Canada, Venezuela and Former Soviet Union states in Eastern Europe. Although the resource estimates are dated, the resource distribution reflects current estimates.

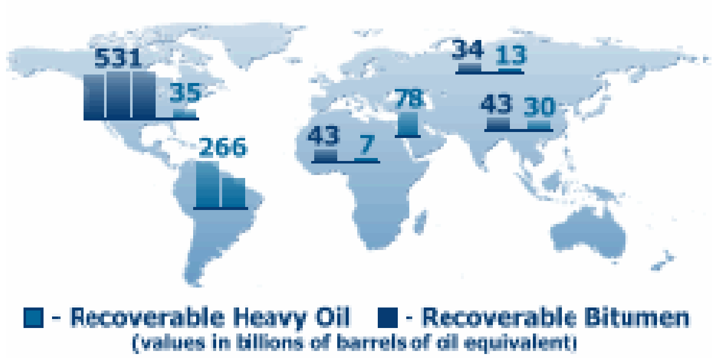


Figure 3: Worldwide Heavy Oil Statistic

Interestingly, very little of the world's heavy oil resources are found in the Middle East. This sets the stage for geopolitical motivations in the development of heavy oil technology. If significant advancements were made in heavy oil production technology, it might lessen the OECD (Organization for Economic Co-operation and Development) countries' dependence on imported oil from this region. This may be seen in the same light as how new fraccing technology for shale formations is turning the U.S. into a net exporter of oil and gas.

The Western Hemisphere has 69% of the world's technically recoverable heavy oil and bitumen, with an estimated 800 billion barrels of oil. From a global perspective, a few of the large heavy-oil-deposit areas include the Athabasca, Canada deposits; Peace River, Canada deposits; Cold Lake, Canada deposits; Orinoco South America deposits; Volga Russia deposits; Bohai Bay Penglai China deposits; Baghewala oilfield in Rajasthan, India; Frade offshore Brazil; and Bakersfield, California, USA deposits.

The Grane Oil Field is the first heavy oil field producing on the Norwegian Continental Shelf. It is operated by Statoil and has been producing since September 2003. It is one of the largest discoveries on the Norwegian continental shelf, and is expected to produce more than 750 million barrels. The produced oil has a 12 cP viscosity and 19^o API rating, which makes it heavy by Norwegian standards, but fairly light compared to heavy oil deposits in other countries. This makes it possible to use gas injection to boost oil recovery. 60% of the original oil in place is expected to be recovered by the end of field life, a large value even for conventional oil fields. The produced oil is exported to an onshore terminal through a 28", 212 km pipeline.

So far, Grane remains the only heavy oil field producing on the Norwegian Continental Shelf (NCS). There is, however, heavy oil activity in the British sector of the North Sea, with Statoil set to develop the Mariner & Bressay fields. These fields generally contain heavier crudes than Grane, with $12\text{-}14^o$ API gravity and viscosity up to 1000 cP. Production is expected to start in 2017, with plateau rates at 55 000 bbl/d for the first three years.

Heavy Oil – Key Properties

Low API's and High Viscosity
Heavy and extra-heavy crude oils and bitumens are petroleum or petroleum-like liquids or semisolids occurring naturally in porous and fractured media. Bitumen deposits are also called tar sand, oil sand, oil-impregnated rock, and bituminous sand.

These crude oils and bitumens may be characterized first by viscosity and then by density. The term "Heavy Oil" is a reference to the high density (API Gravity) of those oils. The measurement that we care most about today is viscosity since that is the property that governs well productivity. Viscosity is not synonymous with Gravity. There is a positive, but very loose correlation between gravity and viscosity that is specific to a given oilfield – but any quantitative transform from API Gravity to Viscosity is a rough approximation at best, and there are no transforms or rules of thumb for oils in general.

4 Classes based mainly on downhole viscosity :

- ***A Class : Medium Heavy Oil*** *25°> d°API > 18°*
  100 cPo >μ > 10 cPo, mobile at reservoir conditions
- ***B Class : Extra Heavy Oil*** *20°> d°API > 7°*
  10 000 cPo >μ > 100 cPo , mobile at reservoir conditions
- ***C Class : Tar Sands and Bitumen*** *12°> d°API > 7°*
  μ > 10 000 cPo, non mobile at reservoir conditions
- ***D Class : Oil Shales***
  Reservoir = Source Rock, no permeability
  Mining Extraction only

In determining the international resource base, viscosity should be used first to differentiate between crude oils, on the one hand, and bitumens, on the other. Subsequently, density should be used to differentiate among extra-heavy crude oils, heavy crude oils, and other crude oils. Viscosity at reservoir temperature, which determines how easily oil flows, is often the most important measure to an oil producer. Density, a better indicator of the yield from distillation, may be more important to an oil refiner. Unfortunately, no clear correlation exists between the two: Medium-density or light crude with high paraffin content in a shallow cool reservoir can have a higher viscosity than heavy, paraffin-free crude in a deep hot reservoir. Viscosity varies greatly with temperature, while density varies little. Density has become the more commonly used oil field standard for categorizing crude oils.

To see how viscosity changes, here's a table of liquid viscosities at 20 degrees Celsius:

Table 1: Viscosity of various substances

Product	Viscosity, cp	Product	Viscosity, cp
Acetone	0.3	Honey	3,000
Water	1.5	Molasses	5,000
Beer	1.8	Hershey Chocolate Syrup	10,000
Milk	3.0	Heinz Ketchup	50,000
Antifreeze	15	French's Mustard	60,000
Mazola Oil	70	Cold Lake Crude	100,000
SAE 5W30 Oil	100	Peanut Butter	250,000
Maple Syrup	200	Foster Creek Crude	1,000,000
SAE 60 Oil	1,000	Athabasca Oil Sands	5,000,000

Density is usually defined in terms of API (American Petroleum Institute) gravity, which is related to specific gravity—the denser the oil, the lower the API gravity. API gravities for liquid hydrocarbons range from 4°, for tar-rich bitumen, to 70°, for condensates. Heavy oil occupies a range along this continuum between ultra heavy oil and light oil. The U.S. Department of Energy defines heavy oil as having API gravity between 10° and 22.3°. Nature does not recognize such boundaries, however: In some reservoirs, oil with gravity as low as 7° or 8° is still considered heavy rather than ultra heavy, because it can be extracted by heavy oil production methods. Density of oil is measured using the American Petroleum Institute, API definition:

API gravity (degrees) = $\frac{141.5}{\gamma_o}$ - 131.5

Where γ_o = oil specific gravity at 15°C and 101 kPa, fraction

The specific gravity (density of fluid divided by density of water) is measured relative to water whose specific gravity is 1.0.

Recall that the oil density, ρ_o, is then given by

$\rho_o = 1000\,\gamma_o$ kg/m^3
= γ_o g/cm^3

Thus, the API of oil is inversely related to its density. It can also be seen that the API of fresh water is 10°. The API of motor oil is 40°. The API is always referred to 15°C and 101 kPa. Because the density of water and heavy oil is similar, they are difficult to separate.

API gravity is not perfectly correlatable to viscosity, this is because the gravity depends on how the oil was created, reservoir temperature etc. There may be two orders of magnitude variation in viscosity for the same value of °API.

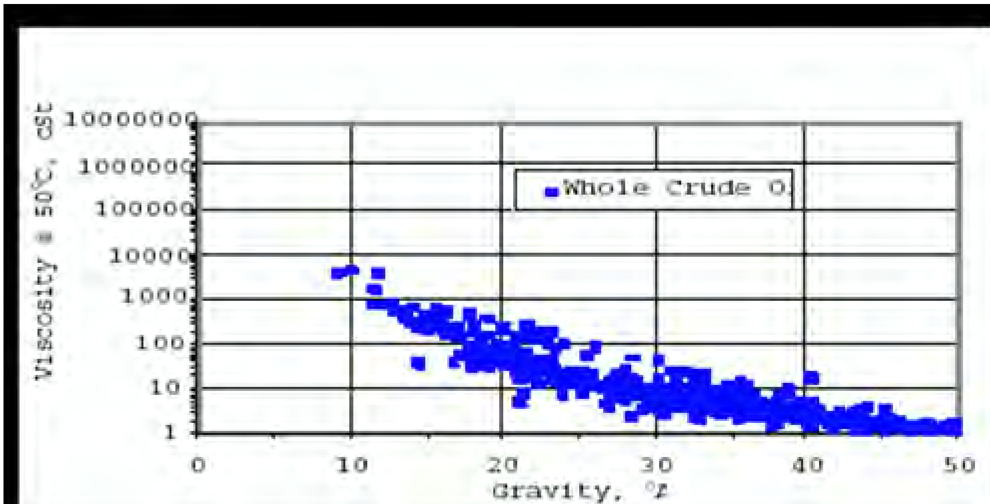


Figure 4 Gravity-Viscosity Relationship — Crude Oils

Bubble Point Pressure, P_b
This is the first pressure where, at constant temperature, where the oil system releases a small bubble of gas. This gas can affect the oil recovery.

Oil Formation Factor, B_o
B_o relates a reservoir volume of oil to a surface volume. The reservoir volume includes dissolved gas, while the surface volume is essentially dead oil and does not include the released gas. It has units of reservoir cubic meters (barrels) of oil (with solution gas) per stock tank cubic meter (barrel) or (bbl/STB). B_o includes any gas dissolved at a given pressure; the dissolved gas is considered to be part of the oil. As a function of pressure, B_o increases to the bubble point as the pressure is reached and decreases from the bubble point. Shrinkage is equal to $1/B_o$.

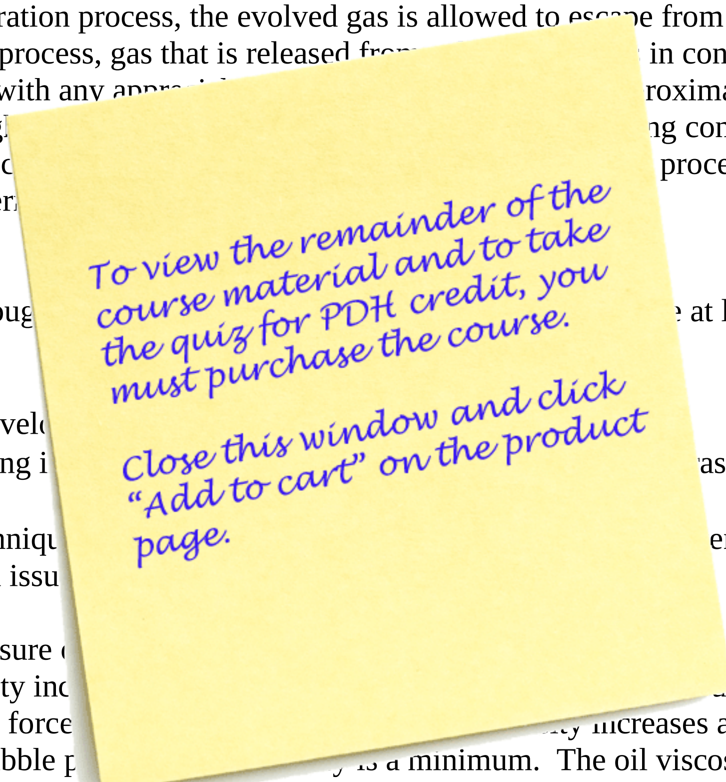
Solution Gas-Oil Ratio, R_s
R_s is a measure of the gas dissolved in the oil at any given condition. Its units are standard cubic meters of gas per stock tank cubic meter of oil, or standard cubic feet per stock tank barrel (scf/STB) or thousands of standard cubic feet per stock tank barrel oil (MCF/STB).

As a function of pressure, R_s is constant above the bubble point, and decreases with decreasing pressure below the bubble point as gas is released to become free gas.

Two types of gas liberation processes may occur:

a) differential
b) flash

In a differential liberation process, the evolved gas is allowed to esc... from contact with the oil. In a flash liberation process, gas that is released fr... in contact with the oil. Flows in reservoirs with any appr... roximate a differentiable process; flow throug... ng continuous shales will approach a flash proc... process will be slightly higher than that deter...



Viscosity
Heavy oil flows throug... at lower rates than light oil wells.

- Heavy oil devel...
- Water flooding i... ast between heavy oil and water
- Thermal techniqu... ery but energy balance is an issu...

Viscosity is the measure ... elow the bubble point, the oil viscosity inc... bble point, the liquid molecules are force... increases as the pressure increases. At the bubble p... is a minimum. The oil viscosity is strongly dependent on temperature, ... exponentially with increasing temperature.