Unconventional Oil Ores around the World: A Review

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Abstract. With the increasing demand of the conventional oil and gas, unconventional oils are playing an increasingly important role in global energy supplying. Unconventional oil ore (such as oil sands, asphalt rocks) has been widely used in the industry. The bitumen recovered from the unconventional oil ore can be used for the production of synthetic crude oil. Canada has the world's largest oil sands deposits in Alberta. Since the discovery of the Athabasca oil sands, many technologies have been applied to recovery the bitumen in industry, and the daily production of unconventional oil has reached $10.9 \times 10^6$ barrels in 2018. However, the Chinese oil sands has not been applied to the industry due to the complex characteristics. Much more attention will be paid to the fundamental research and process development of the unconventional oil ores.

1. Introduction

With the increasing demand of the conventional oil and gas, much more attention has been paid to the development of alternative energies. Unconventional oils are the new alternative and emerging sources of petroleum fuels, which differ significantly from conventional crudes. Unconventional oil includes extra-heavy oil and bitumen, tight oil, gas to liquids, coal to liquids, kerogen oil and additives, as shown in Figure 1. The proven unconventional oil reserves are about $4.023 \times 10^{12}$ barrels, accounting for about 65% of total oil reserves. At the same time, unconventional oil production is increasing year by year. In 2018, the daily production of unconventional oil was about $10.9 \times 10^6$ barrels, accounting for 11.5% of global oil production. Exploitation and development of unconventional oil resources are of great significance for the improvement of the current situation of tight energy demand.
2. Unconventional oils and oil ores

Unconventional oils are rich in reserves, and various forms of unconventional oil resources are distributed all over the world. As shown in Table 1, North America has the largest reserves of tight oil, heavy oil and bitumen, and kerogen oil. Both Eurasian and Asia-Pacific regions have tight oil reserves of more than 70 billion barrels. Central and South America and Eurasia are rich in heavy oil and bitumen resources.

| Oil resources (billion barrels) | Conventional crude oil | Tight oil | NGLs a | EHOB b | Kerogen oil | Proven reserves | Resources |
|--------------------------------|------------------------|-----------|--------|--------|------------|----------------|----------|
| North America                 | 244                    | 177       | 141    | 802    | 1000       | 240            | 2364     |
| Central and South America     | 246                    | 60        | 50     | 494    | 3          | 288            | 852      |
| Europe                        | 60                     | 19        | 29     | 3      | 6          | 15             | 116      |
| Africa                        | 310                    | 54        | 86     | 2      | -          | 125            | 452      |
| Middle East                   | 913                    | 29        | 152    | 14     | 30         | 836            | 1138     |
| Eurasia                       | 241                    | 85        | 60     | 552    | 18         | 145            | 956      |
| Asia Pacific                  | 129                    | 72        | 67     | 3      | 16         | 52             | 287      |
| World                         | 2142                   | 496       | 585    | 1870   | 1073       | 1700           | 6165     |

a NGLs refers to natural gas liquids.
b EHOB refers to extra-heavy oil and bitumen.

Heavy oil and bitumen are important forms of unconventional oil resources. As of 2018, the global recoverable reserves of heavy oil and bitumen are $1.87 \times 10^{12}$ barrels, and the reserve of heavy oil and bitumen accounts for more than 54% of unconventional oil resources. According to data of the International Energy Agency, the output of heavy oil and bitumen has grown rapidly year by year from 2000 to 2015, with an average annual growth rate of 9%. In 2018, the daily production of Canadian oil sands bitumen was $3.0 \times 10^6$ barrels, and the daily production of Venezuelan heavy oil was $0.8 \times 10^6$ barrels. In recent years, with the increasement of oil production in Saudi Arabia and Russia and the decline in oil prices, the exploitation of unconventional oil resources (represented by American shale oil and Canadian oil sands bitumen) has been severely impacted, resulting in the decline of the growth rate of heavy oil and asphalt production. To this end, the Alberta in Canada has implemented a production reduction order from January 2019 to match the oil sands bitumen production with the available pipeline capacity. Venezuela’s heavy oil production is affected by multiple domestic politics and economy, and major new projects have been delayed to varying degrees. Affected by the Corona Virus Disease 2019 (COVID-19) in early 2020, international crude oil prices fell sharply. Whiting Petroleum of the United States submitted bankruptcy protection to the court in early April and declared bankruptcy, becoming the first shale oil company to go bankrupt after the decline in crude oil prices affected by the COVID-
19. Nevertheless, heavy oil and bitumen will still be extremely important unconventional oil resources. It is estimated that the daily output of oil sands bitumen in Canada will reach $4.5 \times 10^6$ barrels in 2040, and the production of heavy oil in Venezuela will also reach $1.2 \times 10^6$ barrels

Unconventional oil ore (such as oil sands, asphalt rocks, etc.) is an important form of heavy oil and bitumen in nature. It is a complex mixture of heavy oil (or asphalt), sand, clay and a small amount of water. The formation of the unconventional oil ores can be explained as: the mineral solids were impregnated by the oil seepage or asphalt caused by the fault and compression action from geological movement, and the unconventional oil ores formed after the evaporation of light components due to million years of the natural weathering and biodegradation.

Unconventional oil ores are rich in reserves and are widely distributed all over the world. Unconventional oil ores deposits are mainly distributed in Canada, Venezuela, the United States, Russia, Indonesia, China and other places. The reserves and distribution of unconventional oil ores deposits around the world may vary somewhat with the geological structures and formation conditions. Among them, Canada's oil sands resource reserves rank first in the world and have a long history of process development.

Since the discovery and exploitation of the Athabasca oil sands in Canada, unconventional oil ores are playing an increasingly important role in global energy supplying. The bitumen recovered from the oil sands can be used for the production of synthetic crude oil, which is widely used in the energy supply after being upgraded using delayed coking, or hydrotreating. Great efforts have been made in the recovery of heavy hydrocarbon from oil sands with the increasing demand for petroleum fuels. Since the discovery of the Athabasca oil sands, many technologies have been applied to recovery the bitumen. Both the in-situ technology and the ex-situ technology had been applied in commercial use. In the ex-situ process, hot water extraction process was used to recovery the bitumen from oil sands. This method was first successfully applied in large scale commercial use in 1967 by the Great Canadian Oil Sands (now Suncor Energy Inc.) \(^4\). After been crushed, the oil sands were mixed with the hot alkaline water in the stirred tanks. The conditioned oil sands slurry is introduced to hydro transport pipelines, where the oil sands are sheared and the bitumen is liberated from the sand grains. The oil production from oil sands in Alberta reached 2.45 million barrels per day in 2016, more than 54 percent of the Alberta's oil sands were produced using in situ methods. The bitumen from the Athabasca oil sands would become an important alternative to meet the need of the oil in Canada.

In general, the unconventional oil ores can be divided into two categories: carbonate type and silicate type. The main mineral solids in silicate oil ores is the silicate minerals, such as quartz and kaolinite. At the same time, the main minerals in carbonate oil ores is carbonate minerals, such as calcite and chalk. The Athabasca oil sands is the silicate oil ores, and the main mineral solids in Athabasca oil sands is quartz. The carbonate oil ores are quite different from the silicate oil ores, such as Indonesian asphalt rocks. On the other hand, the oil sands can be divided into the water-wet oil sands (Athabasca oil sands) and the oil-wet oil sands (Utah oil sands and Indonesian asphalt rocks) depending on the hydrophilicity of the mineral solid. There is a notion that a thin layer of water surrounds individual sand grains separating them from the bitumen in Athabasca oil sands \(^5\), and the water film was calculated to be about 10 nm.

3. Oil sands deposit in Canada
The oil sands in Canada are mainly distributed in the northeastern of Alberta. The proven reserves of oil sands in Alberta are approximately 165.4 billion barrels (geological reserves of crude oil) \(^6\). Relying on the advantages of oil sands resource reserves, Canada's petroleum resource reserves rank third in the world, after Venezuela and Saudi Arabia \(^6\). Alberta’s oil sands are mainly distributed in the three core oil sands mining areas in the north. As shown in Figure 2, the three major mining areas are the Athabasca mining area, the Cold Lake mining area and the Peace River mining area. The mining area covers an area of 142,200 km\(^2\).
The three major mining areas are all covered by sandstone, shale, moss swamps and moraines, each mining area has its own differences. The Athabasca mine is named after the Athabasca River which flows through the area, and its center is the northern town of Fort McMurray. The Athabasca mining has the largest area of the three mining areas, about 93,000 km$^2$, and the thickness of the oil sands in some places reaches 150 m. The Cold Lake mining area occupies an area of about 18,000 km$^2$, and the oil sand reservoir is 300 to 600 m below the surface. The Peace River mine area is about 29,000 km$^2$, and the oil sand reservoir is located about 300 ~ 770 m underground.

Only the reservoir with the depth less than 75 m can be exploited by ex-situ mining, and the reservoir below the surface more than 75 m requires the in-situ mining technology. The Athabasca mining area has about 4800 km$^2$ of reservoirs that can be mined by the ex-situ mining method, and this area only accounts for 3.4% of the total area of the oil sands mining area in Alberta. Correspondingly, only about 20% of the oil sands can be mined and separated by ex-situ mining technology. Since the oil sands reservoir depth is far more than 75 m in the other two mining areas, and both of them must be exploited through in-situ technology. In-situ mining technology is suitable for deep oil sands, avoiding the impact of tailings and wastewater on the environment during surface mining. In recent years, in-situ mining technology has been widely used and developed. As shown in Figure 3, the daily output of oil sands bitumen produced by in-situ technology in Alberta reached 1.5468 million barrels in 2019, accounting for about 49.9% of the total output.
The oil sands geological resources in China is 5.97 billion tons, ranking fifth in the world. However, Chinese oil sands have a low oil content and water content, and the sand grains in Chinese oil sands are apparently hydrophobic due to the presence of directly coated bitumen on the surface\textsuperscript{10-11}. The complex relationship between the oil and minerals (e.g., silica, calcite, illite) in Chinese oil sands makes it much tougher for the bitumen recovery. The hot water extraction method which has been applied in Athabasca oil sands can’t be effectively used to Chinese oil sands. Until now, none of the separation process has been applied to the Chinese oil sands for industry application. Much more efforts should be paid to the fundamental research and process development.

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