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New Production Techniques for Alberta Oil Sands

MAURICE A. CARRIGY

Low world oil prices represent a serious threat to expanded commercial development of the Canadian oil sands in the near term, as they do to all of the higher cost alternatives to crude oil such as oil shales and coal liquefaction. Nonetheless, research and field testing of new technology for production of oil from oil sands are being pursued by industry and government in Alberta. New production technology is being developed in Canada to produce synthetic oil from the vast resources of bitumen trapped in the oil sands and bituminous carbonates of northern Alberta. This technology includes improved methods of mining, extraction, and upgrading of bitumen from near-surface deposits as well as new drilling and production techniques for thermal production of bitumen from the more deeply buried reservoirs. Of particular interest are the cluster drilling methods designed to reduce surface disturbance and the techniques for horizontal drilling of wells from underground tunnels to increase the contact of injection fluids with the reservoir.

ALTHOUGH THE WESTERN WORLD APPEARS TO HAVE ABUNdant supplies of low-cost light oil at the present time, evidence suggests that these resources will be depleted in the not too distant future and the Western world will have to use a lower grade of hydrocarbon to satisfy its need for liquid fuel. Whenever this occurs, vast resources of heavy oil, extra heavy oil, and tar sand are available. In North America the largest concentrations of extra heavy oil and bitumen are located in the Province of Alberta, Canada, where more than 1×10^{12} barrels of bitumen are present at shallow depths in four major oil sand (tar sand) deposits (Fig. 1).

Most of this bitumen is in sands of Lower Cretaceous age buried too deeply for mining, but 10% is close enough to the surface to be mined by open-pit methods (*1*). In 1967, the first open-pit mining extraction and upgrading plant (designed to produce 45,000 barrels of synthetic oil per day) began production 390 km north of Edmonton, and in 1978 a second plant twice as large was built 10 km northwest of the first one. Subsequently, these plants have expanded, and together they now produce more than 170,000 barrels per day of synthetic oil, or 15% of Canada's total oil

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production. The reserves of synthetic oil available by using open-pit mining are estimated to be 26×10^9 barrels, roughly equal to the light oil reserves of the United States.

The more deeply buried deposits containing about 900×10^9 barrels of bitumen, or 90% of the total resource, have begun to produce significant quantities of raw bitumen by in situ methods of production. Because the bitumen is recovered from the reservoir without moving the sand, in situ techniques are in effect an extension of the current conventional crude oil recovery systems (Fig. 2). The major difference between conventional oil reservoirs and oil sands deposits is in the viscosity of the oil they contain. In oil sand, the oil is so viscous that it is almost solid at reservoir temperatures, and it is called bitumen. To extract bitumen through wells, it is necessary to reduce its viscosity and then keep it flowing through the reservoir until it is produced. In this process, hot fluids are injected into the reservoir to reduce the viscosity of the bitumen, which is then pumped up the same well or from a second well close by. The in situ and surface-mining methods of production are illustrated in Fig. 2. The current productive capacity from installed in situ wells in Alberta is roughly 75,000 barrels per day. Wells such as these will play an increasingly significant role in Canada's future oil production capability. Although the need for this relatively high cost heavy oil has been reduced by the current low cost of conventional oil, the ability of the Western world to tap these large resources of hydrocarbon will limit the price that can be charged for conventional oil by the Organization of Petroleum Exporting Countries. One of the strategies of the Alberta government therefore is to replace its declining light oil production with synthetic oil from the oil sands. To do this in an orderly and timely way, it has provided massive funding ($793 million, Canadian, over a 15-year period) for the development of new and improved technology for the production of synthetic oil and bitumen from its oil sands.

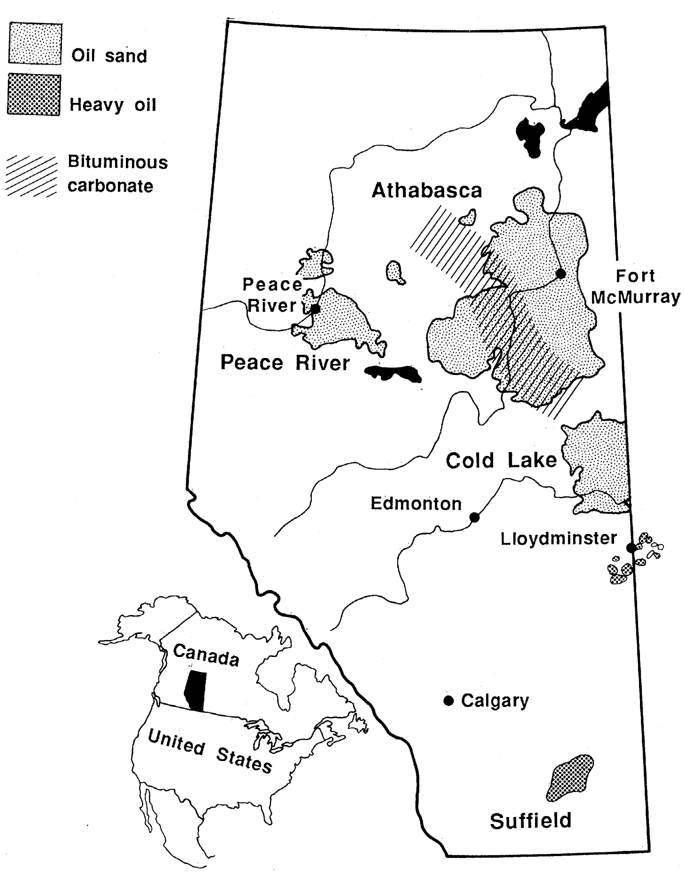

Fig. 1. Location of the four major oil sand deposits in Canada.

History of Oil Sands Technology Development

The challenge of extracting the 1.3×10^{12} barrels of very heavy, high-sulfur, sticky oil (bitumen) trapped above and below the Cretaceous-Devonian unconformity of northern Alberta has been met in many ingenious ways during the past 200 years. Where the oil sands can be seen in the outcrops along the Athabasca River west and north of Fort McMurray, the preferred method has been to remove the overburden mine and wash the bitumen out of the sand, and then return the clean sand into the pit. The technology to do this economically on a large scale took more than 50 years to commercialize. The process began in 1921 when Karl Clark was appointed to the Alberta Research Council and was assigned the task of finding a low-cost bitumen extraction process for the oil sands that outcrop along the Athabasca River. Clark and his colleagues developed the hot water extraction process, which in its most elementary form consists of mixing a small amount of hot water with the oil sand in a conditioning drum and then flooding the drum with hot water. The bitumen then rises to the surface, and the sand sinks. This simple procedure is being applied on a large scale in Canada in two commercial plants that are recovering about 200,000 barrels of bitumen per day. The hot water bitumen extraction process used today has two drawbacks in that bitumen recoveries from the low-grade oil sand (less than 10% by weight) are low, and the process produces large volumes of tailings sludge composed of oil, water, and clay that do not settle readily and have to be stored in vast tailings ponds. Several ways of solving these problems are being investigated, including (i) thermally retorting the whole oil sand, thus combining the extraction and primary upgrading into one operation and producing dry tailings sand that can be returned directly to the mine pit; (ii) finding secondary processes to recover the bitumen in the tailings stream and to accelerate the settling of the dispersed clay; or (iii) extracting the oil from the mined oil sand with solvents that would also produce dry sand tailings. These three alternative technologies are being actively pursued by government and private companies in Alberta and elsewhere in Canada.

Since less than 10% of the total Canadian bitumen resource is in locations favorable to surface mining and extraction technology, much of the money for research and technology development in Alberta is used to move the deeply buried bitumen above the ground where it can be upgraded to synthetic crude oil (*2*). This accomplishment could conceivably result in the addition of 200×10^9 to 300×10^9 barrels of synthetic oil to the Canadian reserves. Two methods of obtaining the bitumen are available: one uses heat, the thermal methods, and the other uses solvents or emulsifiers at reservoir temperatures.

Hundreds of techniques have been conceived and tried to recover the bitumen through wells. The thermal methods are divided into two types: (i) combustion processes that involve burning some of the oil underground to produce the heat, and (ii) steam injection, in which the fuel is burned above ground. Problems with the control of underground processes that use air to sustain the combustion have limited their application. However, some of these problems are being overcome by using oxygen instead of air. In certain reservoir situations, favorable results have been obtained with this technique.

Several cyclic steam-based processes are available. In one such process the steam is injected alternately, and the hot fluid is produced from the same well. In another, the steam is injected continuously down one set of wells, and the production fluids are produced from a second set of wells. Although cyclic steam stimulation has been the most successful thermal technique, only 20% of the bitumen in the reservoir can be recovered this way. Both the high cost of installing thermal wells and good conservation practice demand higher rates of recovery; recovering anything less than 50% of the oil in place should not be acceptable. This means that the cyclic steam production must be followed by a second treatment of either combustion, steam drive, or multiwell cyclic pressurization to conform with conservation practice.

Six years ago no commercial in situ recovery plants were operating in Alberta (*1*). Esso Resources Canada Limited had applied to the Alberta Energy Resources Conservation Board to construct a 140,000-barrel-per-day synthetic crude oil plant based on in situ bitumen production from steam stimulation, but Esso abandoned the application in 1981 because of high interest rates, high inflation, and government indecision. However, a new strategy for in situ oil sands development soon emerged that sidestepped the difficult problems of financing megaprojects by building the capacity in 20,000-barrel-per-day stages (*3*).

In the past 6 years the production of bitumen from in situ operations in Alberta has increased sevenfold from less than 10,000 barrels per day in 1980 to nearly 75,000 at the end of 1985. In situ production of bitumen rather than synthetic crude oil is generally more amenable to staged development than production by integrated surface mining and upgrading plants because of its lesser sensitivity to economies of scale, although this situation may change with new developments in mining and extraction technology.

Much progress is being made toward lower costs, higher bitumen recoveries, and reduced environmental impact for in situ operations. Research and field testing are proceeding in drilling and production technology, establishment and enhancement of interwell communication, mobilization of bitumen and prevention of formation damage from swelling clays, and reuse of produced water for steam generation. Some of the most interesting advances are in drilling technology.

New Drilling Technology

It was recognized in the early 1970's that if in situ production of bitumen was to be applied widely in Alberta, the vast arrays of closely spaced vertical wells would have resulted in the clearing of native vegetation from very large tracts of land. This prospect has been modified by applying innovative drilling techniques. By drilling clusters of up to 28 wells from a single pad and deviating them to their bottom hole locations, the injection and production facilities can be concentrated in a relatively small area (*3*) (Fig. 3). An extension of this technology involves drilling the holes at an angle and is called slant hole drilling (Fig. 3). This technique is particularly effective where there is not sufficient depth to allow the well to be deviated from the vertical to its bottom hole location (*3–5*). Most of the methods used to recover bitumen from oil sands have already been used for offshore drilling for conventional oil. The novelty in drilling and production technology for oil sands is in the adoption of these techniques for installing shallow thermal wells at low cost.

The location and spacing of injection and production wells are critical to the efficient recovery and economic success of in situ processes to recover the bitumen from the oil sands. In most cases the drilling patterns are designed to heat and sweep a portion of the reservoir, and the wells are placed at optimum distances to recover a certain amount of oil in a fixed period of time. If the pattern of the wells is too small, there may be insufficient oil recovered to pay the cost of the facilities, even if the recovery is good. However, if the wells are spaced too far apart, it may be difficult to establish communication, and the production rate may be too slow and too low to pay for operations. Thus the spacing and productivity of the wells are crucial to any successful in situ operation.

The Athabasca deposit is the largest and richest of the Alberta oil sands deposits, but it has proven to be the most difficult area for oil production by in situ methods because of the high viscosity of the oil and the reservoir heterogeneity. Several experimental pilot projects have shown that it is possible to produce oil from very closely spaced vertical wells by thermal in situ methods. However, as the distance between wells increases, the steam and combustion gases tend to rise to the top of the reservoir before reaching the production wells, leaving the lower portions of the reservoir unheated. To prevent this situation, it has been suggested that closely spaced horizontal wells placed near the bottom of the reservoir, steamed at below fracture pressure, and drained from a lower set of parallel horizontal wells would achieve good recoveries from the whole reservoir. Another suggestion is that these horizontal wells could be placed more accurately and at a lower cost by drilling them from tunnels in, or below, the reservoir (*6, 7*). Underground drilling techniques were tested at an outcrop in the Athabasca deposit in 1979 (*8–10*), and these tests were followed up by feasibility studies (*11, 12*). Finally, to prove the perceived advantages of the underground system, the Alberta Oil Sands Technology and Research Authority (AOSTRA) began building an underground test facility in 1983 (*13*). The facility consists of two vertical shafts, 3 m in diameter and 213 m deep, leading to a series of tunnels (5 by 4 m) that are driven into the limestone beneath the oil sands. From the tunnels a series of wells will be drilled up into the oil sands and

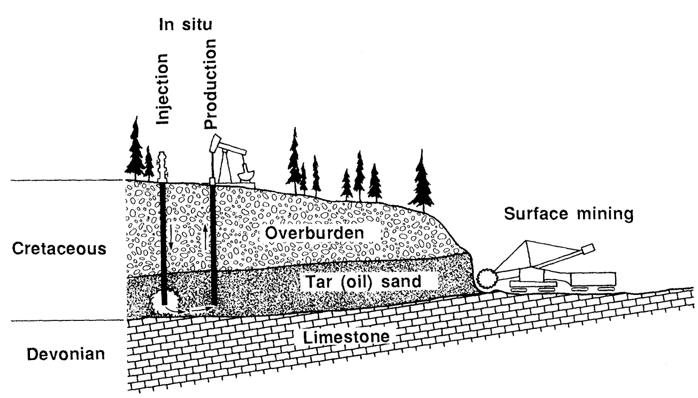

Fig. 2. In Alberta the bitumen extraction technique depends on the depth of burial. The near-surface oil sands are mined, whereas in the deeper deposits the sands are left in situ and the bitumen is heated and extracted through wells.

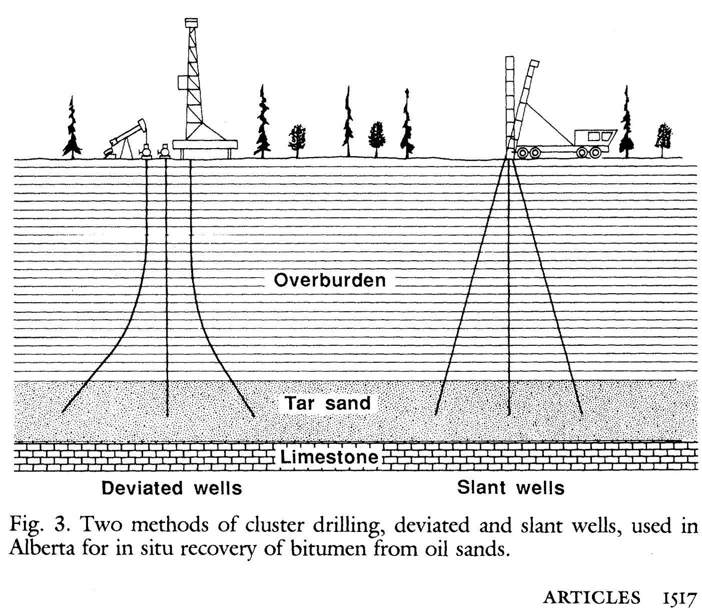

Fig. 3. Two methods of cluster drilling, deviated and slant wells, used in Alberta for in situ recovery of bitumen from oil sands.

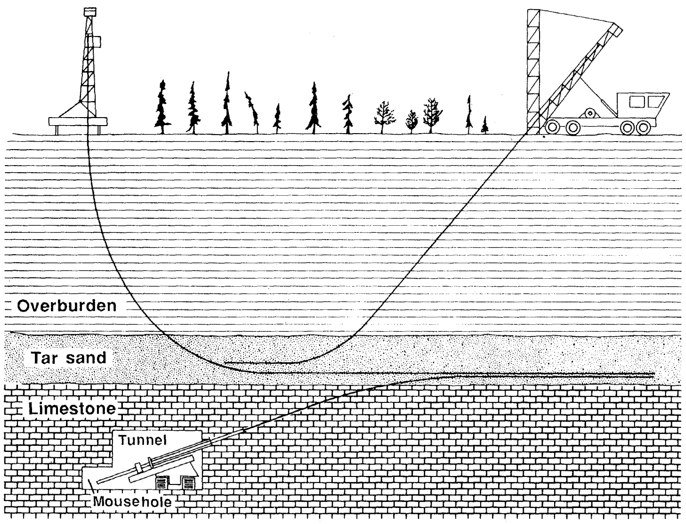

Fig. 4. Three methods of emplacing horizontal wells in oil sand for in situ recovery of bitumen.

deviated to the horizontal (Fig. 4). These wells will be used to inject steam and extract bitumen. The processes being tested are based on heating the bitumen with steam and removing the liquid product as it drains toward the bottom of the reservoir. It is expected that the first heating experiments at the underground test facility will be completed in 1989. If they are successful, a larger gravity drainage pilot system will be installed, and operations will begin in 1990. By that time, the price of oil is expected to be high enough to sustain a commercial operation.

In the Cold Lake deposit the steam stimulation process (known as "huff and puff") is being supported by a regular pattern of wells drilled vertically from a single platform and deviated to their final bottom hole locations in the reservoir (Fig. 3). Also at Cold Lake, Esso has installed and operated two experimental horizontal steam wells from the surface by deviating to the horizontal (*4, 14, 15*) (Fig. 4). In the Athabasca deposit, Texaco has drilled and operated a three horizontal well experimental pilot from the surface (*16*) by using a slant hole rig to achieve the horizontal attitude at a depth of only 150 m (Fig. 4).

To complement the horizontal drilling procedures mentioned above, new down hole logging tools will have to be perfected. In addition, accurate and efficient directional control techniques must be developed, and methods to cut cores, prevent pipe sticking, and insert liners in horizontal holes need to be proven (*17*).

Synthetic Crude Oil Conversion

Paralleling the progress in bitumen recovery technology in Canada, new facilities for upgrading the high boiling point fractions or "bottom of the barrel" have been installed in a number of refineries throughout the world. Since this same technology can be used to upgrade very heavy crude oil and bitumen to so-called synthetic crude oil, there is less of a barrier to the introduction of these feedstocks into the refinery and marketing system than was the case 10 years ago. This situation should allow the market to absorb fairly large quantities of heavy oils and bitumen in the future if they are needed quickly.

Upgrading problems common to both surface and in situ extraction in commercial coking technologies are the low conversion rate of bitumen to upgraded synthetic crude oil that can be transported by pipeline, and the difficulties associated with using upgrader residues in an environmentally acceptable manner. Attempts to resolve both these problems are being undertaken in several emerging upgrading technologies that involve the addition of hydrogen to the native bitumen. By reacting hydrogen with whole bitumen at high temperatures and pressures, the yield of synthetic oil can be increased to more than 100% by volume. Although this result is desirable and cost-effective, these new high-conversion technologies have not been demonstrated on a scale that would reduce the risk of commercial use to an acceptable level.

An in-depth survey by AOSTRA, with the cooperation of the oil companies, identified several emerging proprietary technologies for hydrogen addition that could improve the liquid yield from Alberta bitumen. During the next few years, AOSTRA plans to demonstrate the performance of these new methods on Alberta bitumen and heavy oil feedstocks in existing pilot plants.

Future Developments

At this time the commercial development of the Canadian oil sands faces an uncertain future. If the price of oil remains below production costs for an extended period of time, it will be difficult to sustain the current commercial production without some assistance from the provincial and federal governments to save jobs and protect investments already made. Adequate technology to produce the synthetic crude from oil sands in large quantities is now available. The resource is large and widespread, and the only question is when it will be needed. In the meantime, several improvements to the current in situ and surface-mining technology are being made and will be pursued in Alberta, regardless of the current price of oil. For example, the increase in synthetic oil reserves that could be gained by lowering the bitumen losses in mining and extraction and increasing conversion rates would greatly benefit the Canadian oil sands mining industry. Even without extending the current mining limits (less than 50 m of overburden), the amount of synthetic crude oil recoverable from the surface-minable oil sands of Alberta alone would be increased immediately from 26×10^9 barrels to more than 30×10^9 barrels from such improvements.

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