DOMESTIC TAR SANDS AND POTENTIAL RECOVERY METHODS — A REVIEW

By George B. Spencer, W. E. Eckard, and F. Sam Johnson

* * * * * * * * * * oral presentation

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DOMESTIC TAR SANDS AND POTENTIAL RECOVERY METHODS -- A REVIEW

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1/ George B. Spencer, 2/ W. E. Eckard, 3/ and F. Sam Johnson

5 ABSTRACT

The purpose of this paper is to review and evaluate present knowledge of United States tar sands including physical properties, occurrence, reserves, and recovery methods. Tar sands are oil-, bitumen-, asphalt-, tar-, or petroleum-impregnated rock from which little hydrocarbon material is recoverable by conventional crude oil production techniques. Tar sand oil has been produced by steam injection and underground combustion techniques and by mining methods. However, efficient application of nonmining recovery techniques is hindered because of difficulties in establishing and maintaining formation permeability.

Mining and processing methods being used in or proposed for Canadian commercial operations are also discussed.

INTRODUCTION

The production potential for tar sand oil from deposits located in the United States is poorly defined, and therefore neither industry nor government can make a conclusive judgment on economic production prospects at present (14). Since 1962, the Federal Bureau of Mines and Geological Survey and State and industry representatives have been actively interested in this national resource through participation in a joint Interstate Oil Compact Commission effort. The "Tar Sands" Subcommittee's work resulted in Bureau of Mines Monograph 12, a major contribution to

1/ Petroleum engineer. 2/ Project coordinator. 3/ Project leader. 4/ Underlined numbers in parentheses refer to items in the list of references at the end of this report.
knowledge of oil reserves available from tar sands (3). Early in 1969 the Bartlesville Petroleum Research Center of the Bureau of Mines, in cooperation with the subcommittee, began a detailed review of published literature on tar sand locations, characteristics, and recovery methods to update our technical knowledge. Because essentially no definitive data were found on physical properties or characteristics of domestic deposits, data from the Canadian Athabasca deposit are used to illustrate the apparent variable nature of these deposits. This report is a very condensed version of our results and includes the work of many investigators and companies. The final report, including numerous abstracts and references, is planned for early publication as a Bureau of Mines Monograph.

DEFINITION AND PHYSICAL PROPERTIES OF TAR SANDS

Tar sands are oil-, bitumen-, asphalt-, tar-, or petroleum-impregnated rock from which little hydrocarbon material is recoverable by conventional crude oil production techniques. Several rock types as well as petroleum materials are included in the term "tar sands." The rocks may vary from consolidated and unconsolidated sandstone to shale, dolomite, limestone, and conglomerate. The hydrocarbons range from those difficult to soften in boiling water to those which ooze slowly from an outcrop on a warm day.

This review shows that although few data are available on physical properties, they do vary widely. This variance occurs both in individual deposits and in those which are geographically separated. Table 1 illustrates the limits of physical property variations noted from several domestic deposits (2, 3, 4, 5, 6, and 17, pp. 551-571). Data from the Athabasca deposit in Canada, published by Carrigy (17, pp. 573-581) and others, illustrate the variation within a single deposit.

OCCURRENCE AND RESERVES

The 546 tar sand occurrences in 22 States which are listed in Monograph 12 are shown in figure 1. Forty-two counties in Kansas, Missouri, and Oklahoma contain 40 percent of the recognized tar sand deposits, though none of the larger individual deposits in the United States are located in those three States. They are located in Utah, California, 'New Mexico, and Kentucky. A paper describing several of these deposits was presented at the 7th World Petroleum Congress (17, pp. 551-571). Published data (11, 12, pp. 551-571) and unpublished data provided by Howard R. Ritzma, Utah Geological and Mineralogical Survey, were used to construct table 2, in which the largest reported domestic tar sand deposits are ranked by gross oil content.
### TABLE 1. -- Range of Physical Properties of Tar Sands

<table>
<thead>
<tr>
<th>Property</th>
<th>United States</th>
<th>Athabasca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity, percent</td>
<td>26 - 39</td>
<td>17 - 46</td>
</tr>
<tr>
<td>Permeability, air, md</td>
<td>10 - 3,800</td>
<td>0 - 600</td>
</tr>
<tr>
<td>Saturation, percent pore volume</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td>13 - 33</td>
<td>40 98</td>
</tr>
<tr>
<td>Water</td>
<td>23 - 82</td>
<td>1 39</td>
</tr>
<tr>
<td>Saturation, oil, weight percent</td>
<td>4 - 22</td>
<td>0 18</td>
</tr>
<tr>
<td>Viscosity, centipoise @ formation temp</td>
<td>1.8 X 10&lt;sup&gt;3&lt;/sup&gt; - 500 X 10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>3 X 10&lt;sup&gt;6&lt;/sup&gt; - 600 X 10&lt;sup&gt;6&lt;/sup&gt;</td>
</tr>
<tr>
<td>Gravity, degree API</td>
<td>3.7 - 15.0</td>
<td>6 - 10</td>
</tr>
<tr>
<td>Sulfur, percent</td>
<td>0.5 - 4.2</td>
<td>3.7 - 5.0</td>
</tr>
</tbody>
</table>

### TABLE 2. -- Major Tar Sand Deposits in the United States

<table>
<thead>
<tr>
<th>Name of Deposit</th>
<th>Gross Oil, Million Barrels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tar Sand Triangle, Utah-*</td>
<td>3,500 - 5,000</td>
</tr>
<tr>
<td>Elaterite Basin</td>
<td></td>
</tr>
<tr>
<td>Teapot Rock</td>
<td></td>
</tr>
<tr>
<td>Tar Cliff</td>
<td></td>
</tr>
<tr>
<td>Hatch Canyon</td>
<td></td>
</tr>
<tr>
<td>Fault Point</td>
<td></td>
</tr>
<tr>
<td>The Cove</td>
<td></td>
</tr>
<tr>
<td>P. R. Spring, Utah</td>
<td>3,700</td>
</tr>
<tr>
<td>Sunnyside, Utah</td>
<td>2,000 - 3,000</td>
</tr>
<tr>
<td>Circle Cliffs, Utah</td>
<td>1,000 - 1,300</td>
</tr>
<tr>
<td>Asphalt Ridge, Utah</td>
<td>1,000 - 1,200</td>
</tr>
<tr>
<td>Dragon-Asphalt Wash, Utah</td>
<td>100 - 500</td>
</tr>
<tr>
<td>Raven Ridge, Utah</td>
<td>100 - 500</td>
</tr>
<tr>
<td>Edna, Calif.</td>
<td>165</td>
</tr>
<tr>
<td>Whiterocks, Utah</td>
<td>65 - 125</td>
</tr>
<tr>
<td>Argyle Canyon, Utah</td>
<td>10 100</td>
</tr>
<tr>
<td>Capita Wells, Utah</td>
<td>10 100</td>
</tr>
<tr>
<td>Deep Creek Nose, Utah</td>
<td>10 100</td>
</tr>
<tr>
<td>Myton Bench, Utah</td>
<td>10 100</td>
</tr>
<tr>
<td>Santa Rose, N. Mex.</td>
<td>57</td>
</tr>
<tr>
<td>Sisquoc, Calif.</td>
<td>50</td>
</tr>
<tr>
<td>Asphalt, Ky.</td>
<td>48</td>
</tr>
<tr>
<td>Davis-Dismal Creek, Ky.</td>
<td>22</td>
</tr>
<tr>
<td>Santa Cruz, Calif.</td>
<td>20</td>
</tr>
<tr>
<td>Kyrock, Ky.</td>
<td>18</td>
</tr>
</tbody>
</table>

// Believed a major deposit composed of the listed smaller deposits,
The reserve and resource status of domestic tar sand deposits would be clarified by a comprehensive geological evaluation program as recommended by the "Tar Sands" Subcommittee. The Utah Geological and Mineralogical Survey is making such a study (11). The variability of reserve estimates can be judged from their study. In 1964 an apparent reserve of 87 million bbl of oil was listed for the P. R. Spring deposit in Utah. A later field study (j>) showed apparent reserves of 3,700 million bbl of oil.

RECOVERY METHODS

In Situ Methods

The definition of tar sands indicates that they cannot be produced by ordinary crude oil production methods. The tar sand oil cannot be simply pushed to the production well by the injection of water as in waterflooding. Three elements must be present for any process to affect a large areal extent of the deposit: (1) establishment of communication between wells, (2) reduction of tar sand oil viscosity in the formation, and (3) maintenance of the flow path once established.

As Doscher (L7, pp. 625-632) explains, although the Athabasca tar sand has a high specific permeability, oil saturation is generally low and is the nonwetting phase. However, because of the very high oil viscosity at reservoir temperature, essentially no flow occurs even when pressure gradients are imposed which might fracture the formation. Even though the average water saturation may be high, the formation has a low relative permeability to water because the water is the wetting phase and because of the rock lithology. Doscher concludes that even though the wetting phase saturation possesses low viscosity it does not provide a permeable path for injected fluids.

Although natural fractures may exist in some tar sands, improved fluid injectivity can be created by hydraulically fracturing the formation. However, the fracture is more likely to be created in a vertical plane than a horizontal plane and would not necessarily result in a connection between wells. Techniques for initiating horizontal fractures include notches or perforations through a casing string or packers in an open hole.

The highly viscous nature of tar sand oil as found in place makes lowering of the viscosity necessary so that the bitumen will flow into and through fracture paths. Some viscosity reduction methods suggested have been the use of solvents such as LPG or kerosine or the dissolving of natural gas or CO2 in the tar sand oil. However, the most easily applied method for viscosity reduction is through heat because it causes
a rapid lowering of viscosity in obtainable temperature ranges and is conducted through the formation without fluid movement. Bott (4) gives an example of this viscosity reduction. The 5° API Vaca tar sand in California has a viscosity of 38,000 cp at 140° F, 1,050 cp at 210° F, and 57 cp at 325° F.

Many tar sands are incompetent; that is, they tend to slump or cave into any voids created when the tar sand oil becomes mobile because the sand grains are not cemented to one another. Thus, when a fracture is created and heat is applied to the formation through the fracture, the incompetent formation will slump into the fracture and reduce the permeability, even when the fracture contains a conventional propping agent. Slumping can sometimes be prevented by maintaining sufficient pressure in the fracture and by regulating the fluid composition and flow rate (15).

Over 200 patents and articles were reviewed pertaining to in situ recovery methods. From this review six basic recovery methods were found which are listed in the order of their significance. Many of the patents reviewed embody features from several of these basic methods and contain many variations.

Cyclic Steam Injection

Cyclic steam injection ("huff and puff") is a recovery process in which steam is injected into the reservoir for a few days to several months; this may be followed by a short soak period, or the well may immediately be put back on production (12, pp. 471-476). The same well is used for injection and production. Production above the pre-stimulation rate may continue for as much as a year; then the cycle is repeated. In susceptible crude oil reservoirs, production rate increases to as much as 100 times the pre-treatment rate have been noted immediately after stimulation, though the average increase is from 10 to 30 times.

Experience has shown that best results are obtained in thick reservoirs (more than 50 ft) at shallow depth (less than 3,000 ft) and with oil viscosity of 1,500 to 11,000 centipoise. High permeability is desirable though not necessary. High oil saturation, at least above 1,000 bbl of oil per acre-ft of formation, is also necessary (6).

Cyclic steam injection has been economically successful in California tar sands. Some 2 million bbl of oil have been recovered by steam injection from the 2,000-ft-deep, 100-ft-thick upper tar sand of the Huntington Beach Field in California, which originally contained 1,800 bbl per acre-ft of 13° API (/). Although this process is an effective recovery method, its overall recovery is low because only the tar immediately around the wellbore is affected(4).
Steam Drive

This method involves continuously injecting steam into at least one injection well and producing from at least one other well. Upon entering the formation the heat lowers the viscosity of the oil, while the flow of the steam and hot water drives oil ahead of it into the producing well (12, pp. 465-466).

The use of steam drive in tar sands is subject to most of the limitations that are applicable to cyclic steam injection. Although steam drive should affect more of the reservoir than the cyclic method, heat loss in thin formations may limit its applicability as noted by Ali (12) and Ramey (17, pp. 471-476) in their comprehensive review papers.

Pilot projects using steam drive methods have recovered oil from tar sands in California (1) and in Canada (17, pp. 625-632).

In Situ Combustion

This process, which is also called "fire flooding," consists of igniting oil in the formation adjacent to the wellbore and driving the combustion front through the reservoir rock toward the producing wells by injection of air and/or combustion gases (12, pp. 373-413). The two basic in situ combustion processes are forward combustion, in which the front moves from the injection well toward the producing wells, and reverse combustion, in which the front moves from the producing well toward the injection wells; that is, in the opposite direction to that of the injected air. In forward combustion air is usually first injected into the injection wells and produced from the producing wells to insure that the formation has permeability to air. The oil in the formation is then ignited, using an electrical resistance heater or gas burner.

In the early 1950's, investigators began to study methods of adding water to the forward combustion process. The historical patents and articles are listed by Parrish and Craig (10). Their laboratory study shows that after forward combustion has been initiated water can be injected with an air to water ratio of 1,000-2,600 SCF/bbl. Immediately ahead of the narrow combustion zone, a broad steam zone is developed, the leading edge traveling at velocities 20 to 100 percent higher than the combustion zone. The major benefits are that there is a 3-fold reduction in the air required to produce a barrel of crude oil, less oil is burned as fuel, and the steam zone formed contains significant (4-21 percent pore volume) amounts of producible oil.
Muskeg Oil Co., a Pan American Oil Co. subsidiary, proposes to use this method in a significant development program in the 1,000-ft-deep Athabasca tar sand. Their technique involves hydraulic fracturing the formation. Air is then injected and the tar is ignited. After a combustion zone is established, air and water are injected. Air injection is regulated so that only the heat necessary for water vaporization and reservoir heat losses is generated. Using this process, Muskeg Oil Co. proposes an initial program to recover some 8,000 bbl per day of tar sand oil by 1970 (I., 16).

Solvent Extraction

Doscher (17, pp. 625-632) has described the problems associated with applying solvent (miscible fluids) and emulsifying fluids in viscous crude reservoirs as gravity overlay and viscous fingering. Furthermore, the only solvents of much use in dissolving the complex hydrocarbons comprising the Athabasca tar are the relatively expensive naphthenic and aromatic substances. A possible solution would be a system which, after emulsifying considerable tar, possesses a viscosity just slightly greater than that of the oil-free fluid. Two aqueous emulsifying fluid systems have been developed for use in the Athabasca tar sands, (1) an alkaline surfactant solution and (2) a dilute sodium hydroxide solution. Field testing of these two solutions showed the contacted portion of the reservoir was completely depleted of oil. However, the contacted portion of the reservoir was very limited because the nonpermeable bulk of the reservoir was not penetrated.

Solvent stimulation of low gravity oil fields has been reviewed by Jeffries-Harris and Coppel (8). Their evaluation showed viscosity reduction by solvent injection was not generally economical when compared with steam stimulation. A general discussion of the miscible fluid displacement has been published by Smith (2, pp. 314-372).

Hot Water and Hot Gas Injection

The hot fluid drives, steam, hot water, and hot gas injection, all have the same character. The fluid serves as a carrier for both thermal and mechanical energy. Hot water drive is more efficient than hot gas injection, but less efficient than steam. The main reason for this is the heat-carrying capacity of the fluids involved. Steam heated to 350°F could carry up to 1,192 Btu/pound, hot water 322 Btu/pound, but hot gas only about 100 Btu/pound. However, hot water and hot gas injection have been used to recover tar sand oil in combination with other listed recovery methods.
Nuclear Applications

Doscher (17, pp. 625-632) indicates that the rich Athabasca tar sand is less than 50 to 100 ft in thickness; thus, much of the fracturing and heat energy from a nuclear explosion would be expended in altering low or barren deposits. The sand is soft, unconsolidated, sticky, and deformable, and the fractures caused by a nuclear explosion would close as previously discussed. Also heat energy from a nuclear detonation is not economically competitive with, for example, steam injection.

Mining Methods

Great Canadian Oil Sands Method

Four basic approaches have been proposed for tar sand mining: the use of large bucket-wheel excavators, motorized scrapers, drag lines, and shovel excavators as reviewed by Otto (17, pp. 605-614). The first method is being used by Great Canadian Oil Sands, Ltd. (GCOS), a Sun Oil Co. subsidiary, in its commercial development in the Athabasca tar sands. The overburden, averaging 53 ft thick, is first removed by conventional earth-moving equipment. The exposed tar sand, averaging 130 ft thick, is mined by bucket-wheel excavators which transfer the material to a system of conveyor belts. The raw material is carried to an extraction plant where the bitumen is separated in a two-stage process. The bitumen is then upgraded to synthetic crude oil by coking and hydro-refining. McClements (9) explains that other necessary operations include (1) disposal of sand tailings, (2) hydrogen production, (3) sulfur recovery, (4) steam and power generation, and (5) water treating.

The GCOS mine is one of the largest open pit mining operations in North America. The giant bucket-wheel excavators are 210 ft long and 12 stories high, weigh 1,700 tons, and cost $4.6 million which is a small portion of the estimated $240 million initial project cost. About 97,500 tons of material is mined in an average calendar day to provide a production of 45,000 bbl of synthetic crude oil. Thus some 3.3 tons of tar sand and overburden are processed per produced bbl of oil; about 2.2 tons of tar sand are required per bbl, and the amount of sand to be disposed of per bbl may range from 1.5 to 4.0 tons depending on the bitumen content of the tar sand.
Syncrude Canada, Ltd., Method

The motorized scraper system will be used in the planned 80,000-bbl-per-day operation by Syncrude Canada, Ltd., an operating consortium set up to operate the plant for Imperial (30%), Cities Service (30%), Atlantic Richfield (30%), and Royalite (10%). In this operation, the tar sand is discharged into drive-over dump belt loading stations from which conveyors carry material to the extraction plant. Scrapers also move the overburden which is used for dikes built across the mined out pit. These dikes will create cells into which solid and liquid effluent from the extraction plant will be dumped.

PROCESSING

Hot Water Method

In the GCOS system the mined sand is conveyed to conditioning drums where it is mixed with hot water and steam to form an aerated pulp (j). At 180° F the pulp is conveyed to separation tanks, where the sand sinks to the bottom and the bitumen rises to the top. The bitumen is skimmed off as a froth and is centrifuged to remove water and minerals. Naphtha is used to dilute the bitumen. Then the naphtha is distilled off and the bitumen is sent to a coking unit. When the molten coke cools it is cut with water jets, crushed, and used as plant fuel. Gaseous products are collected and fractionated into naphtha, kerosine, and gas oil, which are mixed to form the synthetic crude oil.

Other Proposed Methods

Syncrude Canada, Ltd., in discussing its proposed process, favors hydro-visbreaking (13). Under certain conditions other approaches such as thermal-visbreaking or fluid coking might offer an advantage. Basically the first two methods consist of subjecting the bitumen to high temperature and high pressure with or without hydrogen. The product stream from either of the three processes is separated and processed into naphtha, light gas oil, and heavy gas oil which is blended into synthetic crude oil.
DISCUSSION

This review indicates that few detailed data are available concerning location, characteristics, and reserves of domestic tar sand oil. State, Federal, and other interested conservation agencies should undertake a program to further define this potential resource.

Tar sands in the United States are found in two broad classifications which dictate their mode of recovery:

(1) Outcropping or near-surface deposits. The GCOS project is an example of a commercial venture for strip mining these deposits with subsequent processing to obtain a synthetic crude oil.

(2) Buried deposits. When fluid injectivity is obtained these deposits may be exploited by cyclic steam stimulation. When saturation decreases or communication between wells can be established, steam drive or in situ combustion or some variation of these methods may be applied.

CONCLUSIONS

1. More detailed information is needed on the extent and nature of domestic tar sand oil reserves.

2. Tar sand oil is presently being produced by both mining and in situ recovery methods.

3. The nature of the tar sand deposit determines the recovery method to be applied.

4. The most difficult problem presently hindering further development of in situ recovery methods for tar sands is the establishment and maintenance of communication between injection and producing wells.
REFERENCES


Ritzma, Howard R. (compiler), Map No. 25, Preliminary Location Map, Oil-Impregnated Rock Deposits of Utah. Utah Geol. and Mineralogical Survey, April 1968.


AFTER BUREAU OF MINES
MONOGRAPH 12