5. BITUMINOUS SANDS

BITUMINOUS SANDS AND VISCOUS CRUDE OILS

By Robert E. Covington

The bituminous sandstone deposits of the intermountain region contain hundreds of millions of barrels of liquid asphalt heretofore unproducible from an economic standpoint. New engineering techniques of viscosity reduction, in-situ thermal recovery, and the use of heavy machinery in strip-mining methods have caused an intensive industry-wide re-evaluation of this potential crude-oil reserve.

INTRODUCTION

Bituminous sandstones of the Rocky Mountain region contain large reserves of low gravity, highly viscous oil that can be recovered at costs equal to or less than the cost of finding and producing oil from conventional methods. Heavy crude oil is defined as "oil which cannot be produced through the normal reservoir mechanisms of gas expansion or water drive due to the low gravity and the high viscosity of the crude."

Today the American oil industry is in the process of a revolution of such magnitude that its implications are yet to be understood thoroughly. This is the "Quiet Revolution," which will double the proven oil reserves of the world within the next ten years, and will more than triple those reserves by the year 2060. The "Quiet Revolution" is the engineering application of thermal recovery to (1) low gravity, viscous crude oils heretofore unrecoverable by conventional and secondary recovery techniques and to (2) tremendous reserves of bituminous sandstones. This paper will show what thermal recovery is, how and when it can best be applied, and what its implication are to the oil industry and especially to the Rocky Mountain region. A brief discussion is given of two major areas of bituminous sandstone deposits in the State of Utah.

U.S. recoverable crude oil reserves at the beginning of 1963 stood at 31.4 billion barrels. This reserve figure is computed on the basis of a recovery of 29% of the original crude oil in place. If the recovery rate could be increased to 60%, then we could double the present reserve estimates. Many oil companies now believe that this will be possible through the use of thermal recovery methods, especially since more than one-third of these reserves exist in reservoirs at depths less than 3000 feet where porosities and permeabilities tend to be high.

THERMAL RECOVERY, A BRIEF DISCUSSION

Thermal recovery methods can be broken down into two categories: (1) fire flooding or in-situ combustion, and (2) steam-caustic injection systems. In the first system, the energy which is required for moving crude oil through the reservoir and into the production well bore, is created by injecting air into the reservoir and burning a portion of the oil. The process forms a slow-moving, narrow-burning zone, which advance...
from the air injection well to a production well, moving oil ahead of it. The second thermal recovery method was a logical outgrowth of the first. It involves the use of injected steam and chemicals to create the required energy needed to move the oil to the production well bore, and to decrease the viscosity to the point where the oil is sufficiently mobile to permit highly efficient recovery. This method is especially applicable to the secondary recovery of oil, and for the recovery of oil from the bituminous sandstones such as of the Canadian Athabasca area where it is being used.

The first known attempts to apply "in situ" combustion in the United States was in Oklahoma in 1952 by Magnolia and by Sinclair, both working independently. Since then, California has been the focal point for pilot plant and experimental work on "fire flooding." Tight security measures have been employed at all of these projects, except at the project of Mobil Oil Company in South Belridge, Kern County. Hence the success or failure of these experiments is relatively unknown.

With regard to South Belridge, Mobil stated that, after a year and a half of ignition, up to 30% of the oil in place had been recovered. The zone tested was a depleted oil sand at a depth of 700 feet in the upper portion of the Tulare formation, which contained an oil with a gravity of 13°. Some of the problems which arose were: (1) the disposal of toxic, explosive gases resulting from the operation; (2) the handling of high pressure air for injection; (3) the problems of high voltage electricity, if an electrical igniter were used; and (4) protection against well blowouts caused by high pressures induced by combustion. Other troubles were: (1) severe corrosion, due to elevated temperatures; (2) failure of steel pipe and regulating valves; and (3) difficulties associated with packer failure, due to "baking" effects.

The first application of "in situ" combustion were confined to oil located in sandstone reservoirs. Subsequent experiments showed that limestone reservoirs were equally adapted to this recovery technique. Data have revealed that the average bottom-hole temperatures in fire flooding probably average 1200° F.

Since 1959, recently acquired data from the original pilot plant work on fire flooding have given a tremendous boost to the thermal recovery method which involves the use of steam injection into the reservoir, together with chemicals. Steam flooding was attempted in the Vernon County area along the Kansas-Missouri border in the early 1950's by the Carter Oil Company. Here the famed Bartlesville sands lap over the Bourbon Arch. The sands contain an inert oil which has no associated gas and has a gravity of 18° to 20°. Sand permeabilities are from a few milidarcies to as high as two darcies, and porosities are from 18 to 25%. Oil content ranges between 600 barrels per acre foot to as high as 1500 barrels per acre foot. The sand thickness measures from 15 to 40 feet. Carter abandoned the project in the late 50's, and Shell Oil moved in and began leasing. To date Shell Oil is credited with approximately one million acres, and is conducting both steam and fire-flooding, pilot-plant experiments. Other companies in this area are Continental, Marathon, Mobil, Tenneco, Texaco, and Sinclair.
Operation "Plumbob" was conducted in 1958 by the Atomic Energy Commission with a 1.7 kiloton atomic bomb at a depth of 900 feet below the top of a mesa in Nevada. Some of the purposes of the test were: (1) to determine what temperatures were generated; (2) what chemical reaction occurred; and (3) at what rate the heat was dissipated and in what manner.

From the thermal-energy standpoint, the test was disappointing, for the heat was dissipated rapidly as a result of the vaporization of formation waters.

It has been estimated recently that there are between 30 to 40 steam-drive projects underway in the United States. Current leasing of low-gravity oil-sands at relatively shallow depth by major producers has infused a new vigor into the oil industry, and interest in thermal recovery methods.

THE MECHANICS OF THERMAL RECOVERY

Since it is energy that causes oil to move through porous rock into the well bore, the addition of new energy will displace more oil. Steam-flooding adds energy from the heat content of injected fluids, as well as mechanical energy from the reservoir pressure increase from injection. Steam at 300° F. has 1179 British Thermal Units per pound, or four times as much energy as water at that temperature. The steam gives up heat, cools, and condenses into water which is pushed farther into the reservoir. The viscosity of thick, heavy crudes decreases dramatically with an increase in temperature. Further, as the crude is heated, its volume decreases, thus adding mechanical energy to the reservoir. Also, steam distillation takes place, for the steam tends to vaporize substantial quantities of a heavy crude in conformance with the vapor pressure of each constituent in the oil. Then too, the gas-drive displacement effect of the steam is important. Some of the unexpected reservoir pressure increases are attributable to changes in the mobility ratio due to the intimate mixing of steam, oil, and water.

Steam-injection methods can be classified into four, basic, heat-application techniques, two of which can be classified as true thermal-recovery methods. These four methods are: (1) the straight-forward-drive technique; (2) the modified-forward-drive; (3) the steam-soak method (often called the "huff and puff" technique); and (4) the packer technique. In the straight-forward-drive technique, steam is injected into injection wells, and the fluid recovered at a center bore. The modified-forward-drive technique is similar to the first, but fracturing techniques are utilized to establish communication between the injection and the production wells. In the steam-soak method, steam is applied for several days, and then the well is shut in for an established period of time. The well is then allowed to flow back or is pumped, and the process is repeated intermittently. The packer technique utilizes a packer set high in the saturated section; steam is injected above the packer, and oil is produced through the tubing below the packer.

Any steam-injection system demands the availability of large amounts of fresh water. If the water source must be treated, this often poses a problem of the costs of such treatment. Fuel costs for steam generation run from 25c to 35c per 1000# of steam. If a 5-spot-well injection-recovery system takes 100 tons per day of steam, fuel costs may vary from
$50.00 to $70.00 per day.

EVALUATION OF A THERMAL RECOVERY PROJECT

In evaluating a steam prospect, careful attention should be paid to both engineering and geologic data. Laboratory tests should be conducted to determine oil displacements in cores. Viscosity measurements must be run to determine the effect of steam on the crude. Core analysis should be run and field production and reservoir engineering data, if available, should be evaluated. Recovery efficiencies should be recorded. Ideally, it is desirable to evaluate many variations of both spacing and well injection patterns. A complete economic study should be made, including a study of present wells, new wells, the existence of old holes which may not have been plugged properly upon abandonment, water supply and treatment, fuel supply for steam generation (lease crude, natural gas, coal), depth to the objective oil zone, reservoir temperature, nature of the crude, cost of surface handling equipment, and markets. Steam-injection or fire-flooding is especially adaptable to the production of crude oil from reservoirs with little or no reservoir energy, such as abandoned oil fields, bituminous sand reservoirs, or where problems or high viscosity, combined with relatively low reservoir temperatures make the production of this type of crude uneconomic. The effective use of these methods, like anything else worthwhile, requires good engineering practices and good management.

There are other methods of producing viscous or waxy oils where some reservoir energy is present, including the use of electric or gas bottom-hole or mid-bore heaters, the use of hot water circulating heaters, and hot oil circulating systems (Kobe pump system). Each of these has been employed with varying degrees of success. Another method which offers some promise for the production of viscous crudes is the use of the carbon-dioxide-condensing, gas-drive process. Exhaust engine gases or carbon dioxide is injected directly into the reservoir from large, "thermos type," CO2 trucks. This is an effective viscosity-reduction technique.

THERMAL RECOVERY COSTS

The cost of production of oil from the bituminous sandstones will determine the extent and the time of development of these large reserves of oil. Initial investment will be in exploration work, especially in geologic and topographic mapping and in core drilling and core analysis. The second phase of investment costs will be in the establishment of pilot plant construction and operation. Cost analysis must then be employed to determine the economic merits of further large scale production. There is presently, in the Rocky Mountain area, a relatively strong demand for asphalt and asphalt products. The upswing and demand for petrochemicals could mean the development of this product for a raw feeder stock for this mushrooming industry. Therefore, market research and analysis will be the final deciding factor in determining what sands will be produced, and where, when, and in what manner. The fourth and final phase will be the actual commencement of large scale production.
There are two areas in Utah which have bituminous sandstones which are of economic significance with respect to thermal-recovery methods of oil production. The most important area is within the Uinta Basin, in Uintah, Duchesne, and Carbon Counties in northeastern Utah. The second area is the Green River Desert in central Utah in Sevier, Wayne, and Garfield Counties. In the Uintah Basin, the most important deposit lies in the Sunnyside area, Carbon County. Next in order of importance are the asphaltic sandstones of the Asphalt Ridge area, the Whiterocks Canyon area, the Peor Springs area, the Chapita Wells area, and the Dragon - Asphalt Wash area, all in Uintah County, Utah. Other deposits of lesser importance are the Deep Creek area, North Tabiona area, Lake Fork-Yellowstone River area, South Myton Bench area, Indian Canyon area, and the Raven Ridge Area. Three deposits in the Uinta Basin and one deposit in the Green River Desert will be discussed.

1. Bituminous Sandstones of the Sunnyside Area

The Sunnyside deposits are located in Townships 13 and 14 South, Ranges 13 and 14 East, Carbon County, Utah. They can be reached from U. S. 6-50, 7 miles northeast of the coal mining town of Sunnyside, Utah. The Denver and Rio Grande Railroad has a spur into the town. The tar sand is exposed throughout a stratigraphic interval of 1000 feet, and occurs in the Eocene Wasatch and lower Green River formations. The outcrop is along a northeast to north trending escarpment which is the topographic expression of the south flank of the Uinta Basin, with the formations dipping north to northeast from 3 to 10 degrees. Estimates of measured and indicated reserves range from 475,000,000 to 500,000,000 barrels. If recovery rates are as high as 70% of total reserves, the recoverable oil should approach 300,000,000 barrels. The Sunnyside reserves are adequate for large scale strip mining, in part. Over one-half of the total reserves contain at least 9% bitumen by weight. With reference to reservoir data, the bituminous sandstones range from 25 to 30% by volume. Permeability ranges from 150 to 650 millidarcies. Little or no water is present interstitially. The bitumen has a low sulphur content but a high percentage of aromatic hydrocarbons and resins, and would thus make good feed stock for motor oils, lubricants, petroleum coke and petrochemicals. The major drawback to the area, from the point of view of thermal recovery, is the lack of a large source of fresh water for steam injection. Within the past year, the deposits have been core drilled by the Shell Oil Company and the Atlantic Refining Company.

2. Bituminous Sandstones of the Asphalt Ridge Area

The bituminous sandstones of the Asphalt Ridge area lie 3 to 4 miles west of the town of Vernal, Utah on U.S. Highway 40, approximately 180 miles east of Salt Lake City, Utah and 330 miles west of Denver, Colorado, in the northeastern part of the state and in the northeastern portion of the Uinta Basin. The deposit is exposed along a series of northwest - southeast trending ridges and hogbacks. The area extent is approximately 11 miles in length and is several miles in width. Proven reserves are 475,000,000 cubic yards of material containing 250,000,000 barrels of oil.
Probable reserves are approximately 500,000,000 barrels, with additional reserves indicated in a downdip, basinward direction.

The bitumen is in the Cretaceous Asphalt Ridge and Rim Rock sandstones of the Mesaverde formation and in the unconformably overlying Eocene Duchesne River formation. The richest impregnation lies along the close to unconformities. The oil has an A.P.I., gravity of 10° and is extremely low in sulphur content. The Cretaceous sands which are saturated are not as indurated as those of the Sunnyside area. In the County Pit area, for example, after the "hardpar" on top of the Rim Rock sand is removed by blasting and ripping, the bulk of the sandstone can be mined with a dozer and ripper.

Since the two Cretaceous sands which are saturated are fairly uniform in saturation, water content, thickness, porosity, permeability, and in areal extent, the thermal recovery techniques can be employed with a high degree of success. With reference to the saturation in the beds of the Duchesne River formation, problems will arise when employing steam or fire flooding, due to the highly erratic depositional pattern of the individual beds, lower porosities and permeabilities, high silt content and a clay matrix.

An ample supply of excellent quality water is available for both mining and for steam flooding operations in the Asphalt Ridge area. The water should require little or no treatment. Electricity is also available; so is natural gas. A crude oil pipeline lies 14 miles to the south. Adequate housing and supply facilities are available at Vernal. The bitumen content within the Cretaceous sands ranges from a few gallons to as high as 53 gallons per cubic yard, and probably averages 38 gallons per cubic yard. Porosities range from a low of 6 to as high as 38%, and average about 34%. Water saturations range from 1 to as high as 20 gallons per cubic yard of material, and average 3 gallons per cubic yard. Sand which averages 30 gallons of bitumen per cubic yard or less will probably produce 6 gallons of water per cubic yard. The sands are noticeably free from sulphur, averaging about 0.09 per cent. The sand grains are water wet, a factor which makes efficient extraction possible.

During 1954 and 1955, detailed mapping, core drilling, core analysis and engineering studies were made of certain patented and unpatented mining claims in the Asphalt Ridge area by the author for the Knickerbocker Investment Company and for the Barnes Engineering Company of New York City and Los Angeles, California, respectively. Various mining methods and methods of extraction were explored. These properties were later turned to Sohio Petroleum Company, and additional detailed work was done on them, including the first "in situ" fire flood in the state. The fire flood was done within the Asphalt Ridge sandstone member of the Mesaverde formation. The results are not available but it is believed that they were extremely encouraging.

Detailed mapping and sampling were also done in the area by the Shell Oil Company, the Husky Oil Company, and lately, by the State of Utah (the state is applying for a part of this acreage as "in lieu" lands from the
federal government). The Shell Oil Company is core drilling in the Asphalt Ridge area, and other companies have exploration work planned here. Uintah County is still mining asphalt at the County Pit tract for local use. The product is so rich that it is mixed with dry sand, hauled by dump truck, and rolled cold on roads and driveways. The material makes an excellent surfacing material, because the bitumen is extremely tenaceous and holds together well in hot weather. It is also very resistant to wear. Some of the streets in Denver, Colorado, were patched with the material several years ago; today the patches stand up as "bumps" while the original surfacing material made with crude oil has weathered away.

3. The Bituminous Sands of the Whiterocks Area

The bituminous sandstones of the Whiterocks area are located in Township 2 North Ranges 1 East and 1 West, Uintah Special Meridian, about 20 miles northwest of Vernal, along the mountain front on the south flank of the Uinta Mountains in northeastern Utah. The property can be reached by paved road from Vernal to Lapoint, from Lapoint to Tridell, and from Tridell to the Uintah & Ouray Indian Reservation, and thence north along Whiterocks River on the benchlands to the mouth of Whiterocks Canyon, crossing the reservation boundary a mile south of the outcrop.

The bitumen fills the pore spaces and coats the sand grains of the Jurassic Navajo sandstone. This formation strikes northeast - southwest and dips 60 degrees to the southeast; it has a total thickness in the area of approximately 1000 feet; and the tar saturation within the tilted formation extends to a depth of approximately 550 feet. The proven reserves of this deposit, based upon core drilling, are 125,000,000 barrels of oil in place, with possible additional reserves of another 120,000,000 barrels to the northeast and to the southwest of the Whiterocks Canyon area. Federal oil and gas leases on both sides of the fee lands (which lie in the center of the deposit) are held by the Shell Oil Company. This company has just completed exploratory core drilling on the extreme northern edge of the prospect.

The Navajo sandstone is a clean, fine-to-medium grain sand with porosities ranging from 26 to 39%. Permeabilities range from 10 to 127 millidarcies. Water saturation in the bituminous zones ranges from 34 to 82%, and averages 44%. Oil saturation ranges from 13 to 33%. The base of the zone of bitumen saturation within the sand body drops 375 feet in elevation from the east side of Whiterocks River to the southwest, along the strike. It also drops 1000 feet per mile in a southeast direction, perpendicular to the strike of the beds. Several tar seeps, or "brea," occur on the west side of the Whiterocks River. They are related to fracturing within the Navajo. With regard to the bitumen saturation within the Navajo sand body, there is no increase or decrease of any significance from the surface downward to the bitumen-water contact. Further, although the Tertiary Green River formation has been proposed as a source for the bitumen in the eolian "sand dune" Navajo formation, there is no saturation along the unconformity between the Navajo and the overlying Duchesne River formation, along which the bitumen or oil would have had to migrate from the downdip, basinward-lying Green River beds. There were no significant
shows of oil or dead oil staining or bituminous sandstones encountered within the Green River formation in the No. 2 Whiterocks well drilled by the Carter Oil Company in Section 6 of Township 1 North, Range 1 East, U.S.M.

Structural conditions suggest a deeper, Paleozoic (Weber) source. Overburden on fee land in Whiterocks Canyon ranges from 10 to 40 feet, and, on the benches southwest and northeast of the river, ranges from 600 to 1000 feet or more. The oil has an A.P.I., gravity of 12 degrees and is low in sulphur. In summation, the relative uniformity of bitumen saturation of the Navajo sandstone of the Whiterocks area make this prospect extremely attractive from the standpoint of either strip mining or thermal recovery. Due to the thickness of the Navajo sandstone and the depth of saturation, this deposit has the unique distinction of having perhaps the greatest recoverable reserves of oil of any bituminous sandstone on the North American continent. Recoverable reserves approach 132,000 barrel per acre, while the Athabasca tar sand deposits have recoverable reserves of 90,000 barrels per acre, although, of course, the areal extent of the latter is many times greater than those of the Whiterocks deposit.

4. Bituminous Sands of the Green River Desert, Utah

An active lease play has recently developed in the Green River Desert area of central Utah, principally in Sevier, Wayne and Garfield Counties. Two of the most active leasing areas within this province are the French Seep and the Nequoia Arch plays. The total area includes Townships 24 and 31 South, Ranges 12 and 17 East. Shell drilled stratigraphic core tests early this year to the west of this play on the San Rafael Swell but recently dropped this particular acreage. Shell now has leased southwest of the Swell toward the Green River. Other companies, holding acreage on this play involving bituminous sand within the Coconino formation at depths ranging from 1700 to 2600 feet, are Pure, Union, Amax, Sinclair, Richfield, Forest, and Sun. Daniel Meyer and John Osmond also hold acreage in this area.

An example of the type of deposit under consideration for steam injection in this area is a play centered around the old Standard Oil Company of California No. 1 Moonshine Wash well in Section 32, township 25 South, Range 15 East. This hole was cored in the Coconino sand; it recovered over 200 feet of bitumen or dead oil saturation at a depth ranging from 2000 feet to 2200 feet. Core analysis showed the permeabilities to average 50 millidarcies, and porosity to average 15%. Oil saturation within the zone averaged 44%, while water saturations averaged 12%. The following list gives an idea of the saturations and areal extent of the future thermal recovery potential of this area from the Coconino sandstone:
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<tr>
<th>Well Name &amp; Number</th>
<th>Location</th>
<th>Saturation (ft)</th>
<th>Depth</th>
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<tr>
<td>Superior</td>
<td>Sec. 2 T 24 S R 13 E</td>
<td>100</td>
<td>2200</td>
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<tr>
<td>Garter</td>
<td>Sec. 21 T 24 S R 14 E</td>
<td>45</td>
<td>2295</td>
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<td>2000</td>
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<td>Sec. 14 T 28 S R 14 E</td>
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With regard to water supply, ample water can probably be obtained from the Green River, which lies east of the area under discussion, although it is possible that the water may have to be treated.

**LEGAL PROBLEMS INVOLVED IN THERMAL RECOVERY**

There is a legal conflict between the holders of oil and gas leases on federal lands and the owners of federal bituminous sandstone leases. In the Sunnyside area, in the fall of 1963, the Bureau of Land Management held competitive bidding on federal lands. Bidding prices were depressed since the notice was so short that few companies were given sufficient time to examine and evaluate the leases which were put up for bid. Further oil companies, holding oil and gas leases under the lands put up for bituminous sandstone lease-bid, claimed, perhaps with some justification, that their leases entitled them to produce the oil from the bituminous sands, if they could do it through secondary recovery techniques (i.e. thermal recovery). With regard to the State of Utah, the oil and gas leases issued specifically excludes any solid hydrocarbon which it is necessary to remove through the use of heat, and further stipulates that the lease only refers to oil in its native liquid state, gas, and drip gas. Before any commercial development can take place on bituminous sands under federal lands, it will be necessary that the legal problems involved be clarified.

**CONCLUSION**

The future is tremendous for the thermal recovery of hydrocarbons from formerly "depleted" reservoirs, from the vast reserves of bituminous sands throughout the United States, and from reservoirs with low energy...
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