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Sayed Mustafa Sayed
Introduction
Recovery Processes

1- Non-Thermal Processes
2- Thermal Process
   A- Cyclic Steam Stimulation
   B- Steam Flooding
   C- Steam-Assisted Gravity Drainage
   D- In-Situ Combustion
Heavy oil and tar sands are important hydrocarbon resources that play an important role in the oil supply of the world.

The heavy oil resources of the world over 10 trillion barrels, nearly three or four times the conventional oil in place in the world.
Canada and Venezuela account about **90 percent** of all known heavy-oil reserves, according to the Alberta Research Council, as reported by the Canadian Society of Exploration Geophysicists.
Most of the heavy oil deposits occur in:

- **Shallow depth:** (3000 ft or less)
- **High permeability:** (one to several darcies)
- **High porosity:** (around 30%)
- **Oil saturation:** (50-80 % pore volume)
- **Formation thickness:** (50 ft to several hundred feet)
Due to the different characteristics of heavy oils and tar sands, such as high viscosity and low gas solubility, conventional methods are rarely applicable.

Primary recovery is very low, averaging about 5 percent of the oil-in-place.

Alternative recovery processes include thermal and non-thermal methods.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Viscosity (cp at res. temp.)</th>
<th>Density at 15.6 C (Kg/m³)</th>
<th>API Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Crude</td>
<td>1000-100000</td>
<td>920-1000</td>
<td>22.3-10.1</td>
</tr>
<tr>
<td>Tar Sand Crude</td>
<td>&gt;100000</td>
<td>&gt;1000</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>
Thermal Methods

Thermal techniques aim to reduce oil viscosity in order to increase its mobility, through the application of heat.

- Cyclic steam stimulation
- Steam flooding
- In-situ combustion “Fire flooding”
Recovery Processes

Non-Thermal Methods

Non-thermal recovery techniques could be considered for moderately viscous oil “50-200 cp”, thin formation “less than 30 ft”, low permeability “less than 1 md” and depths greater than “3000 ft”.

Non-thermal methods aim to reduce the viscosity of oil, increase the viscosity of the displacing fluid, or reduce the interfacial tension.

1- Polymer flooding
2- Surfactant flooding
3- Caustic flooding
4- Water flooding
5- Emulsion flooding
“Cyclic steam stimulation”, “steam soak”, or “huff n’ puff” is the most widely used steam injection methods for heavy oil recovery; its popularity derives from low initial investment and quick return.

Cyclic steaming was discovered in 1957, when Shell Oil Company of Venezuela was testing a steam drive in the Mene Grande field, upon back flowing the injector, large volumes of oil were produced.
Steam is injected into a well at a high rate and high pressure for short time (10 days to one month).

Following the well may be shut in for a few days “soaking period” for heat distribution. After that, the well is allowed to flow for about 6-12 months.

** When production rate decrease to the minimum economic rate, the whole cycle is repeated.

** In some operations in California, more than 20 cycles have been conducted.

** The ultimate oil recovery by cyclic steaming could be in excess of 20% as reported by ESSO or could be much lower.
Long soak periods may be desirable in order to fully utilize the injected heat energy.
# Thermal Methods

## A- Cyclic Steam Stimulation

### Screening Criteria

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formation Thickness, “ft”</td>
<td>≥ 30</td>
</tr>
<tr>
<td>Depth, “ft”</td>
<td>&lt; 3000</td>
</tr>
<tr>
<td>Porosity, “%”</td>
<td>&gt; 30</td>
</tr>
<tr>
<td>Permeability, “md”</td>
<td>1000-2000</td>
</tr>
<tr>
<td>Oil Saturation, “bbl/acre-ft”</td>
<td>1200</td>
</tr>
<tr>
<td>API Gravity</td>
<td>&lt; 15</td>
</tr>
<tr>
<td>Oil Viscosity @ reservoir condition, “cp”</td>
<td>1000-4000</td>
</tr>
<tr>
<td>Temperature, “F”</td>
<td>250-450</td>
</tr>
<tr>
<td>Oil Recovery, “%”</td>
<td>6-15</td>
</tr>
</tbody>
</table>
The amount of oil recovered per cycle is a function of:

✓ The amount of steam injected
✓ The net sand thickness of the producing interval
✓ The surface injection pressure
✓ The rate at which energy is removed from the formation through production
✓ The number of preceding cycles
✓ Steam properties
✓ The state of the primary depletion
“Steam flooding”, “steam drive”, or “steam displacement” is an important heavy oil recovery method.

It has been shown to be effective in low viscosity oil formation.

The main effects present in steam flooding are the oil viscosity reduction and its thermal expansion.
Consider a five-spot pattern, consisting of a centre steam injector and four corner producer.

As steam is injected into the centre well, an expanding “steam zone” is formed.

The hot condensate leaving the steam zone creates a hot waterflood effect ahead of the steam zone.

Finally, as the condensate cools down to the formation temperature, it gives rise to a cold waterflood.
The steam drive process consists of a steam zone, a hot waterflood zone, and a cold waterflood in the remaining pattern volume.
# Thermal Methods

## B- Steam Flooding

### Screening Criteria

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formation Thickness, “ft”</td>
<td>≥ 30</td>
</tr>
<tr>
<td>Depth, “ft”</td>
<td>&lt; 3000</td>
</tr>
<tr>
<td>Porosity, “%”</td>
<td>&gt; 30</td>
</tr>
<tr>
<td>Permeability, “md”</td>
<td>4000</td>
</tr>
<tr>
<td>Oil Saturation, “bbl/acre-ft”</td>
<td>1200-1700</td>
</tr>
<tr>
<td>API Gravity</td>
<td>13-25</td>
</tr>
<tr>
<td>Oil Viscosity @ reservoir condition, “cp”</td>
<td>&lt; 1000</td>
</tr>
<tr>
<td>Temperature, “F”</td>
<td>250-450</td>
</tr>
<tr>
<td>Oil Recovery, “%”</td>
<td>20-40</td>
</tr>
</tbody>
</table>
Factors Affecting Performance

The amount of oil recovered is a function of:

✓ Pattern size
✓ Heat loss via the flood time
✓ Reservoir pressure “higher pressure would require high steam pressure”
✓ The amount of steam injected
✓ The net sand thickness of the producing interval
✓ Steam properties
✓ The state of the primary depletion
The steam-assisted gravity drainage process has application in the recovery of conventional heavy oil, it was originally for the recovery of bitumen.
The procedure is applied to multiple well pairs. The well pairs are drilled \textit{horizontal} and \textit{parallel} to each other.

The well pairs length is \textit{1 kilometer} and their vertical separation is \textit{5 meters}. 
The process begins by circulating steam in both wells so that the bitumen between the well pair is heated enough to flow to the lower production well.

The freed pore space is continually filled with steam forming a “steam chamber”.

Thermal Methods

C- Steam-Assisted Gravity Drainage “SAGD” Mechanism
The steam chamber heats and drain more and more bitumen until it has overtaken the oil-bearing pores between the well pair.

Steam circulation in the production well is then stopped and injected into the upper injection well only.

The steam chamber expands upwards from the injection well so, oil is heated and flows down the steam chamber via gravity.
Thermal Methods

C - Steam-Assisted Gravity Drainage “SAGD” Mechanism

The steam chamber expands upwards from the injection well so, oil is heated and flows down the steam chamber via gravity.
The amount of oil recovered is a function of:

✓ Injection pressure “steam is always injected below the fracture pressure of the rock mass”

✓ The vertical separation “affects the initial communication between the injection and production wells, this is necessary so that condensate from the steam can be removed and allow further steam to flow into the reservoir and continue heating”

✓ The amount of steam injected

✓ Steam properties

✓ The state of the primary depletion
### Thermal Methods

#### C- Steam-Assisted Gravity Drainage

**Screening Criteria**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Pay Thickness, “m”</td>
<td>15 - 20</td>
</tr>
<tr>
<td>Depth from Surface, “m”</td>
<td>125 - 175</td>
</tr>
<tr>
<td>Sand Porosity, “%”</td>
<td>35</td>
</tr>
<tr>
<td>Sand Permeability, “d”</td>
<td>5 - 12</td>
</tr>
<tr>
<td>Oil Saturation, “bbl/acre-ft”</td>
<td>1200-1700</td>
</tr>
<tr>
<td>API Gravity</td>
<td>8</td>
</tr>
<tr>
<td>Bitumen Viscosity @ 70 C, “cp”</td>
<td>$5 \times 10^6$</td>
</tr>
<tr>
<td>Oil Recovery, “%”</td>
<td>55</td>
</tr>
</tbody>
</table>
Thermal Methods

D- In-Situ Combustion

Mechanism

In situ combustion involves the creation of a fire front in the reservoir, and its subsequent propagation by air injection.

The burning front “combustion zone” thus created, would move in the formation and displace the fluids encountered ahead of it, into the producing wells.

A certain portion of the heat “30%” is transmitted to the overlying and the underlying formations.

A portion (about 10%) of the in-place oil is oxidized to generate heat by injecting air to oxidize the oil.
The injected air will be preheated by the hot sand, and will help recover some of the heat stored in the sand and transport it to downstream to the combustion front.

Due to the low heat capacity of air, the heat recovery rate is low and the heat contained in the hot sand will loss to the adjacent formation.

In order to increase the heat recovery, water can be injected with air, giving rise to the “wet combustion” process. Water has a heat capacity about 100 times that of air.
Thermal Methods

D- In-Situ Combustion

Mechanism
The fuel content of the rock-fluid system is the key factor in the in situ combustion process. Other factors include:

- Rock properties: permeability, porosity, mineral content
- Fluid properties: oil viscosity, specific gravity, and saturation
- Air injection rate
- Oxygen concentration
- Prevailing temperature and pressure

The fuel content range from 1.5 to 2.5 lb/cu. Ft.

The air-oil ratio is defined as the volume of air to be injected in order to displace one stock tank barrel of oil, expressed in scf/bbls.