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MAT NO: 15/ENG07/026

COURSE: PTE 512 (ENHANCED OIL RECOVERY)

THERMAL OIL RECOVERY (STEAM STIMULATION)

The two key types of thermal EOR techniques are in situ combustion (ISC) and steam injection. Steam injection includes three basic categories: namely, cyclic steam stimulation (CSS; huff-and-puff), steam flooding (hot water flooding) and steam-assisted gravity drainage (SAGD). For the purpose of this paper, hot water flooding, CSS and SAGD will be discussed briefly.

STEAM ASSISTED GRAVITY DRAINAGE (SAGD)

Steam-assisted gravity drainage (SAGD; "Sag-D") is an enhanced oil recovery technology for producing heavy crude oil and bitumen. It is an advanced form of steam stimulation in which a pair of horizontal wells is drilled into the oil reservoir, one a few metres above the other. High pressure steam is continuously injected into the upper wellbore to heat the oil and reduce its viscosity, causing the heated oil to drain into the lower wellbore, where it is pumped out. Dr. Roger Butler, engineer at Imperial Oil from 1955 to 1982, invented the steam assisted gravity drainage (SAGD) process in the 1970s. Butler "developed the concept of using horizontal pairs of wells and injected steam to develop certain deposits of bitumen considered too deep for mining". In 1983 Butler became director of technical programs for the Alberta Oil Sands Technology and Research Authority (AOSTRA), a crown corporation created by Alberta Premier Lougheed to promote new technologies for oil sands and heavy crude oil production. AOSTRA quickly supported SAGD as a promising innovation in oil sands extraction technology.

Operation

In SAGD operations, pairs of stacked horizontal wells are drilled into the reservoir about 400 metres beneath the surface. The top well injects steam to heat the bitumen, which separates from the sand and collects with the produced water in the lower well, approximately five metres below. The bitumen is then pumped to the surface, where it is separated from the water. The water is treated and recycled into the system. The steam-oil ratio, or SOR, is an indicator of the efficiency of a SAGD operation. Generally, an SOR of less than 3 is considered to be an efficient operation. MEG achieved an SOR of 2.3 in 2017 at its Christina Lake project. Where implemented, the eMSAGP process has reduced the steam-oil ratio to an industry-leading range of 1.0 to 1.25. Lower rates equate to greater cost efficiency, as less steam-generating infrastructure is required. Low rates also mean greater energy efficiency, as less natural gas is used in the process.

Mechanism

There are two different phases are involved in SAGD processes (Saltuklaroglu, 2000).

Start-up phase

In this phase, steam is initially circulated in both wells until a caloric communication (startup phase) is established between them. This requires two strings of tubing in each well: one for injection and the other for production. If the production casing were not spacious enough to accommodate two tubing strings, an alternate process would be to inject or produce via the annular space; however, this is not advisable, since it may lead to a series of operational problems. When steam reaches breakthrough, circulation is stopped and steam is only injected to the upper well at constant pressure (just below fracture pressure, since fracturing the formation is not required to distribute steam).

In general, the start-up phase is slow and the oil production rates reached during this period are low, being directly proportional to the vertical spacing between the injecting and producing wells. It is believed that injecting a hydro-carboniferous additive (Naphta) together with steam may speed up this process.

Growing phase

From a theoretical point of view, this is the true beginning of the SAGD process: the steam chamber has reached the top of the formation and the productive well, registering the highest production rates. In this phase, it is essential to control temperatures of fluids produced, in order to prevent steam from flowing together with them; this mechanism is known as Steam Trap (Edmunds, 2000), and its function is to maintain temperatures at the well head a few degrees below steam's saturation temperature, making sure that the largest amount of injected steam remains inside the chamber.

PROCESS CHARACTERISTICS

It is important to know that:

− Pressure at steam chamber is constant.

− Steam and water condensed together with the gas in solution, plus thermal expansion, work to keep pressure around the producing well at optimal levels, avoiding any possible instability, such as coning and channeling.

− The steam chamber grows proportional to oil production; empty spaces in pores, as created by production, are filled with the steam injected to the field, thus allowing steam to fusion more immobile oil.

− Oil rate is not seriously impacted by steam injection rate.

− The maximum oil production rate usually occurs when the steam chamber reaches the top of the formation.

− First breakthrough occurs at the beginning of the horizontal section, forcing steam to heat the surrounding formation by thermal conduction, and make oil less viscous; this allows for injecting more steam, forcing it to drain the oil field, preferably at the heel of both wells.

− The main function of the Steam Trap control mechanism is to allow the formation of the steam chamber for preventing the production of live steam.

− In SAGD, the only mechanism for oil mechanism is gravitational drainage.

− The process is ineffective for vertical production wells, due to the relatively low flows that may be achieved under these conditions.

TYPES OF SAGD

In contrast with conventional thermal methods, SAGD processes evolve constantly: each pilot program and each lab test contribute new concepts and experiences that make this technique more efficient and allow it to diversify its application to different oil fields where thermal processes are required. This has led to the patenting of new types, in terms of:

− The way of drilling oil wells.

− The way of accessing the zone of interest.

− The number of wells to be used (only one well, one pair of wells, from two to eight wells).

− Combination of vertical and horizontal wells.

− Location of wells within the field.

− The way of injecting steam, among others.

The selection of the type of SAGD to be used will be strongly based on the field's description and characteristics and on an accurate financial assessment.

Shaft and Tunnel Access (SATAC)

Named after the way in which wells are drilled and entered into the interest formation. This type involves access to the field through mining (tunnels) and underground drilling (Edmunds, 2000). From the tunnel walls, horizontal wells are drilled through the layers that underlie the zone of interest, entering horizontally into the petroliferous sands (Figure 5). This type of SAGD is mainly applied to very shallow oil fields (less than 120 m) which contain oil sands and very viscous crude-oils (more than 5 000 000 Cp).

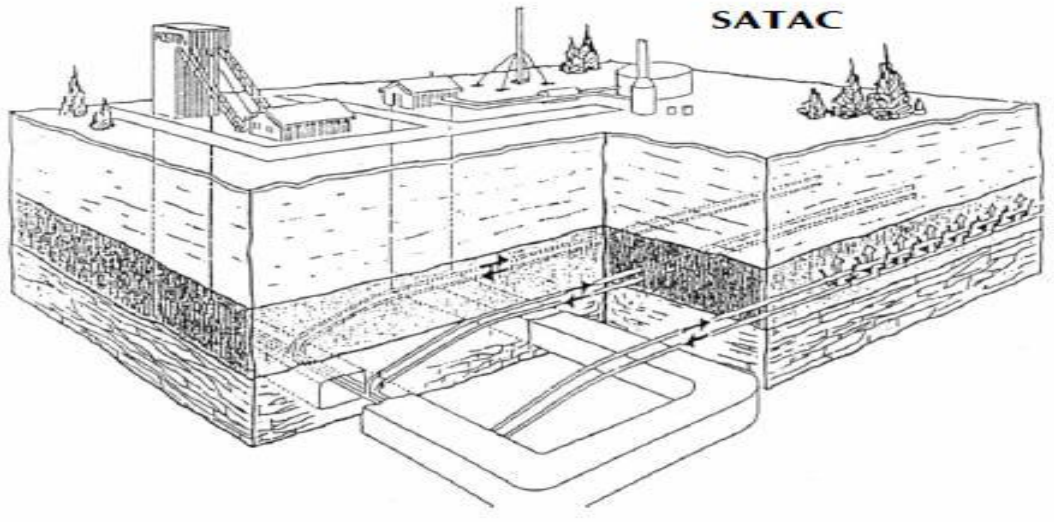


Figure 5. SATAC-type SAGD (Yee,1998)

Single Well SAGD (SW-SAGD)

In contrast with the SAC-SAGD, this type uses one single horizontal well through which it injects steam and produces oil simultaneously (Elliot, 1999; Singhal, 2000). Steam is injected at the end of the horizontal well (Toe) through an isolated concentric Coiled Tubing with numerous orifices; a portion of the injected steam and the condensed hot water returns through the annular to the well's vertical section (heel). The remaining steam, as well as in the double-SAGD, grows vertically, forming a chamber that expands toward the heel, heating the oil, lowering its viscosity and draining it down the well's annular by gravity, where it is pumped up to the surface through a second tubing string (Figure 7). This technique was specially developed to be applied in thin formations (30 ft) where it is not possible to place two horizontal wells and achieve optimal operation conditions. The SW-SAGD reduces start-up capital in half.

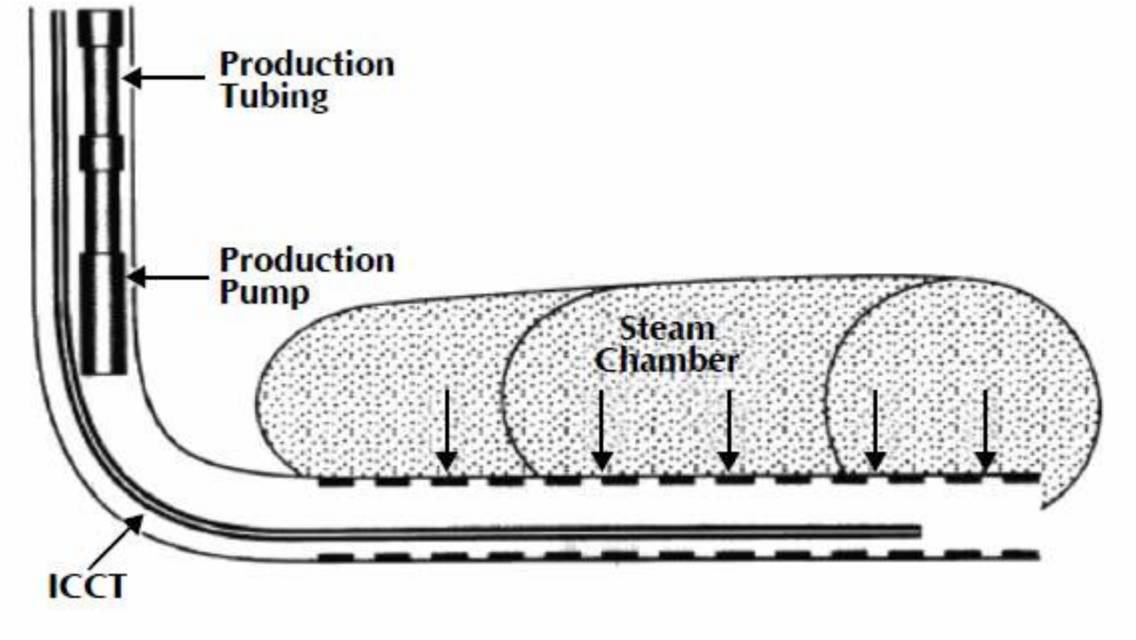


Figure 7. Single well SAGD

Multi-drain SAGD

Named after the multiple number wells involved (from 3 to 9). Out of the aforementioned configurations, this is the most recent and it is now being successfully applied at Joslyn Creek (Canada). Under this technique, several horizontal wells (from 2 to 8) are drilled and connected to a vertical central well. In contrast with the previous techniques, the horizontal wells are used to inject steam, and production is collected by the vertical well. Multi-drain SAGD is recommended for thin formations with good areal continuity.

This technique has the potential to significantly reduce costs, since less horizontal wells need to be drilled to drain the oil field completely.

Fast- SAGD

The Fast-SAGD principle (Polikar, 2000) is intended to produce the same amount with half the wells and 30% less steam, by implementing the conventional SAGD, plus Cyclic Steam Injection. This technique uses a horizontal auxiliary well located at the same depth of the horizontal production well, but at a certain distance from it.

The operation principle is the following: once the SAGD is set, a balancing well starts to operate, to which steam is injected at a pressure higher and greater in amount than that of the two other SAGD wells, in order to promote earlier communications between the steam chambers.

This process has been tested only at lab level and has been refined through simulation. Given its positive results, a pilot testing is soon to be started at Cold Lake, Canada.

Enhanced Steam Assisted Gravity Drainage (ESAGD)

As indicated in its name, this is an enhanced SAGD; in contrast with the SAGD types referred to above, this one does not imply drilling of additional wells or alteration of wells configuration, although it is necessary to have at least a pattern with two pairs of wells. A small pressure difference is applied between adjacent steam chambers that have been previously set under SAGD operations. This pressure differential results in the addition of a steam-thrusting component to enhance the SAGD efficiency. The pressure differential may be achieved by lowering the injecting pressure in one of the pairs, causing the steam to flow from the high-pressure chamber to the low-pressure chamber (Figure 6).

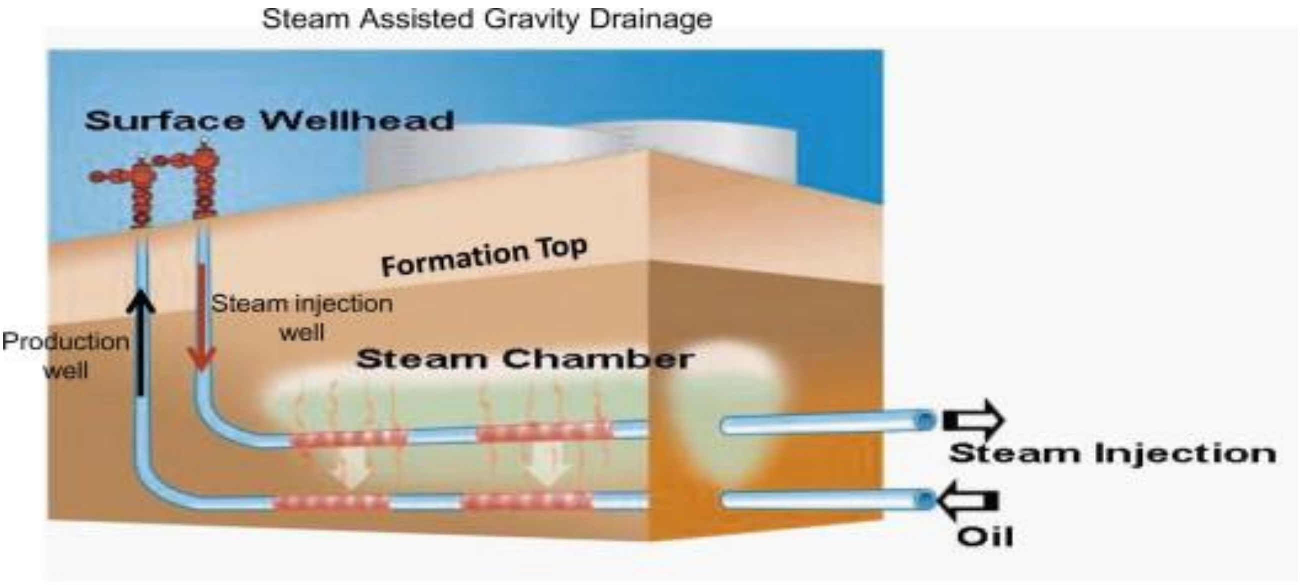


Figure 6-12. Schematic illustration of the SAGD concept

ADVANTAGES OF THE SAGD

Numerous advantages derive from using SAGD in the recovery of heavy crude oils and oil sands, as compared to conventional thermal methods. SAGD offers a series of technical, financial and environmental advantages that have made the heavy crude-oil industry more attractive and profitable.

Techniques

For the use of horizontal wells versus vertical wells:

− The drainage area is increased, allowing to reaching reserves that could not be drained in some other way.

− Better disposition and efficiency to manage thin oil formations of great lateral continuity, with gas layers, or aquifer bottom.

− Ability to carry out orthogonal fluid injection and production, resulting in greater flooding, better sweep efficiency, reduction of the steam canalization processes, reduction in number of wells required in oil-field development, better recovery rate in lesser times, minimization of blind spots, etc.

− Override elimination (Guanghul, 1995)

− Less pressure drop per length unit, which reduces water coning possibilities, minimizes damage to the well's "skin". Facilitates transportation of fluids to the surface.

As for the operation process:

− Lower injection pressure, which helps to preserve the oil field's integrity

− Greater crude-oil mobility. Once the oil contacts steam, this remains hot until drained to the production well. This is not probable in conventional steam injections, where displaced oil tends to cool on its way to production.

In regards to sand production, it can be said that when comparing SAGD processes against conventional thermal recovery methods, SAGD minimizes this issue, since it:

− Dos not require formation fracturing to achieve steam distribution; therefore, steam injecting pressures can be low.

− Since this is no steam thrust process, low fluid speeds can be managed inside the well's skin.

− Thermal efforts on the well skin are minimized by reducing heating and cooling cycles.

− From an instrumental point of view, the use of stainless-steel covered, grooved liners in both wells provide an efficient control on sand production

Process limitations. Possible loss of injected steam due to poor process control which can lead to low oil recovery rate. SAGD oil production is considered uneconomical in pay zones with thickness.

Disadvantages and limitations

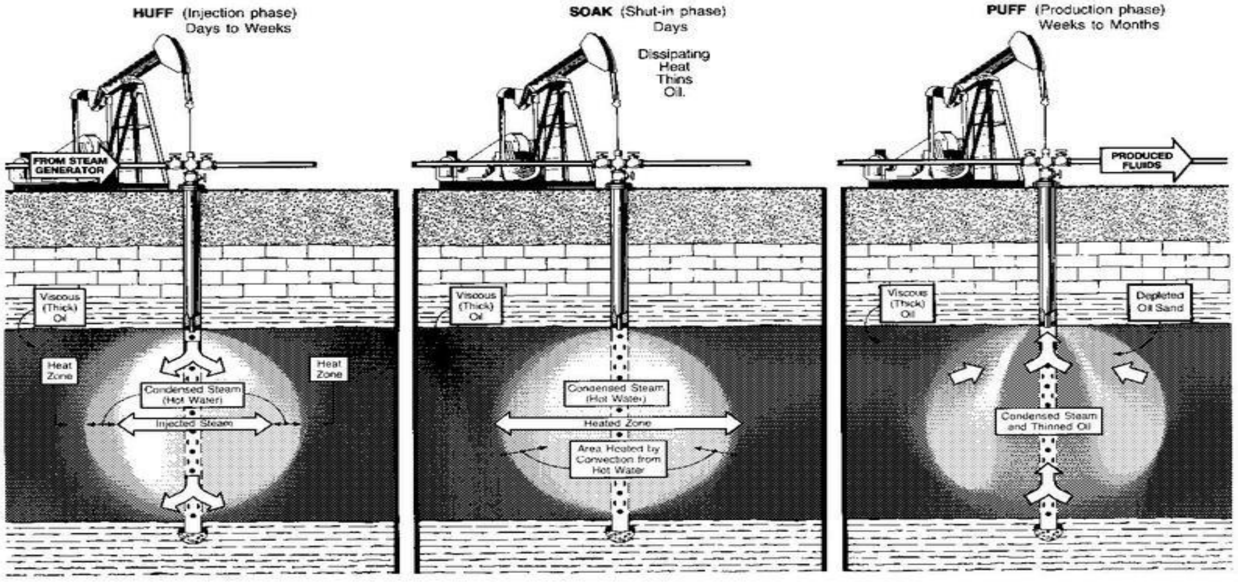
The biggest limitation of SAGD processes is its handling of high steam quantities, particularly for thin and low-quality oil fields, where heat losses due to overburden are larger. Likewise, handling of these steam requirements needs an enormous source of fresh water, an issue that may sometimes become an obstacle. Additionally, as in most steam injection process methods, efforts are limited by oil-well depths, as imposed by steam's critical pressure.

CYCLIC STEAM STIMULATION (CSS)

This method, also known as the Huff and Puff method, consists of 3 stages: injection, soaking, and production. Steam is first injected into a well for a certain amount of time to heat the oil in the surrounding reservoir to a recover approximately 20% of the Original Oil in Place (OOIP), compared to steam assisted gravity drainage, which has been reported to recover over 50% of OOIP. It is quite common for wells to be produced in the cyclic steam manner for a few cycles before being put on a steam flooding regime with other wells.

The mechanism proceeds through cycles of steam injection, soak, and oil production. First, steam is injected into a well at a temperature of 300 to 340° Celsius for a period of weeks to months. Next, the well is allowed to sit for days to weeks to allow heat to soak into the formation. Finally, the hot oil is pumped out of the well for a period of weeks or months. Once the production rate falls off, the well is put through another cycle of injection, soak and production. This process is repeated until the cost of injecting steam becomes higher than the money made from producing oil. The CSS method has the advantage that recovery factors are around 20 to 25% and the disadvantage that the cost to inject steam is high.

Canadian Natural Resources use "employs cyclic steam or "huff and puff" technology to develop bitumen resources. This technology requires one well bore and the production consists of the injection and production phases. First steam is "injected for several weeks, mobilizing cold bitumen". Then the flow "on the injection well is reversed producing oil through the same injection well bore. The injection and production phases together comprise one cycle. "Steam is re-injected to begin a new cycle when oil production rates fall below a critical threshold due to the cooling of the reservoir. Artificial lift method of production may be used at this stage. After a few cycles, it may not be economical to produce by the huff and puff method. Steam flooding is then considered for further oil recovery if other conditions are favorable. It has been observed that recovery from huff and puff can be achieved up to 30% and from steam flooding recovery can be up to 50%”.



CYCLIC STEAM STIMULATION

Steam, injected into a well in a heavy-oil reservoir introduces heat that, coupled with alternate "soak" periods, thins the oil allowing it to be produced through the same well. This process may be repeated until production falls below a profitable level.

Schematic portrays one well during the 3 phases of this process. Flow pattern is stylized for clarity.

COMPARISON BETWEEN SAGD AND CSS

STEAM-ASSISTED GRAVITY DRAINAGE (SAGD)

1. A dual-pair of horizontal wells are drilled approximately 5 meters apart, one above the other. Well depth can vary anywhere from 150 to 450 meters. Each well can be up to 1,000 meters long.
2. High pressure steam is injected into the top well, or the **injection** well. The hot steam heats the surrounding bitumen.
3. As the bitumen warms up, it liquefies and begins to gravity flow to the lower well, or the **producing** well.
4. The bitumen and condensed steam emulsion contained in the lower well are pumped to the surface and sent to a processing plant, where the bitumen and water are separated.
5. The recovered water is treated and recycled back into the process. The bitumen is typically diluted with condensate and sold to market.

CYCLIC STEAM STIMULATION (CSS)

1. A single well is drilled into the oil sands deposit.
2. High pressure steam is injected into the reservoir to heat the bitumen and reduce its viscosity. This steam continues to be injected for several weeks in order to fully saturate the reservoir.
3. The bitumen is then allowed to soak for several days or weeks in the hot pressurized reservoir.
4. As the reservoir cools, this provides the driving force to bring the oil up to the surface. The flow is then reversed so that the bitumen/water emulsion can be pumped up to the surface. This production phase can last for several weeks.
5. At the processing plant, water is removed from the bitumen, treated and recycled back into the process. The bitumen is typically diluted with condensate, and sold directly to market.

SAGD is a continuous process, allowing for much higher production rates than CSS and improved bitumen recovery, near 60% in most cases. This technological breakthrough has enabled a major increase in bitumen production from the oil sands, with minimal land disturbance.

HOT WATER FLOODING

Hot Water Flooding, also known as hot water injection is a technique of increasing crude oil production from a producing well by injecting hot water into the reservoir. The hot water is injected through an injection well which is drilled parallel to the primary producing well. The heat from the hot water acts as a way of reducing the viscosity of crude oil, making it to flow toward the producing well with ease. Hot water flooding is generally used to extract crude oil which has an API degree of less than 20.

It is method of thermal recovery in which hot water is injected into a reservoir through specially distributed injection wells. Hot waterflooding reduces the viscosity of the crude oil, allowing it to move more easily toward production wells. Hot waterflooding, also known as hot water injection, is typically less effective than a steam-injection process because water has lower heat content than steam. Nevertheless, it is preferable under certain conditions such as formation sensitivity to fresh water.

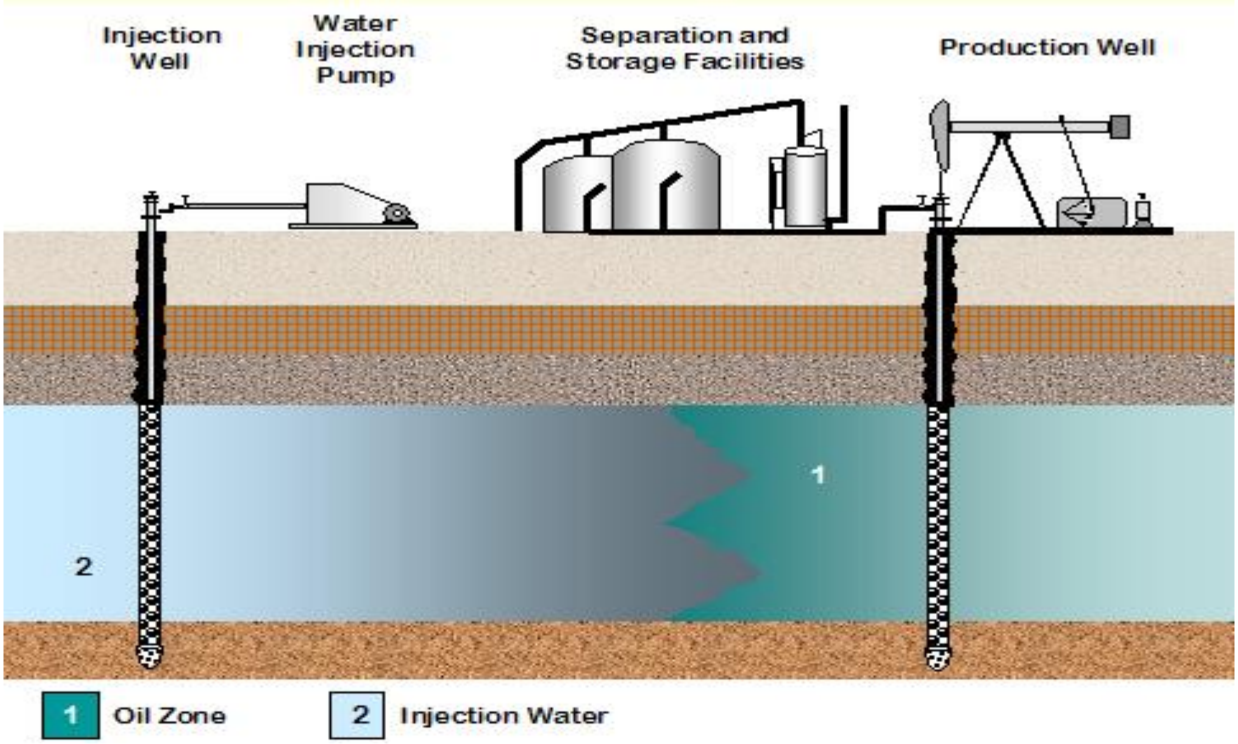
Hot water flooding is considered as one of the techniques of increasing crude oil production under Enhanced Oil Recovery Technique (EOR) and thermal recovery. It is less effective than steam injection process, due to the fact that hot water has a lower heat content as compared to steam.

Over time the pressure in an oil reservoir slowly and steadily decreases and as a result the production rate decreases. This is one of the techniques used by E&P organizations to enhance the production of heavy to medium category crude oil from a reservoir. To use this technique, an injection well is drilled parallel to the primary producing well through which hot water is injected forcefully into the reservoir in the direction of the producing well.

The benefits of injecting water into the reservoir are:

1. It supports the reservoir pressure, also known as voidage replacement.
2. As oil is lighter than water hence it floats on top of the water. Also, the heat content of the water reduces the viscosity of heavy crude oil, making it not to stick on the edges of the reservoir and move quickly toward the producing well. Thus, water helps in displacing oil from its location in the reservoir and pushes it toward the producing well.

With this technique, oil recovery factor can be increased and well production rate can be maintained for a longer period.



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4. *Solvents in situ: the Hybrid Car of the Oil Sands (Report). Canadian Association of Petroleum Producers (CAPP). 2009. Archived from the original on 2012-04-29. Oil sands operators are exploring the use solvents with steam-assisted gravity drainage (SAGD) to help loosen and extract bitumen. Laricina Energy CEO Glen Schmidt likens the technology to a hybrid car.*