EVALUATION OF STEAM ASSISTED GRAVITY DRAINAG PROCESS IN HEAVY OIL AND TAR SANDSRECOVERY IN IRAN

First A. Reza CheraghiKootiani*[1], Second B. HasanCheraghi Kootiani[2] and Third C. Mohammad Hossein Baghbanian[3]

[1]Department of Petroleum Engineering, Faculty of Petroleum and Renewable Energy Engineering, UniversitiTeknologi Malaysia, 81310 UTM, Johor Bahru, Malaysia
(Email: rchi1986@gmail.com)
[2]Free Zoon Arvand, Abadan, Iran
(Email: hchk_iran@yahoo.com)
[3]Faculty of Mechanical Engineering, Azad University of Dezfool, Khouzestan, Iran
(Email: m.h.baghbanian65@gmail.com)

Abstract
Oil sands must be mined or recovered in-situ. Deposits close to the surface are mined whileresources which are very deep require in-situ recovery. Steam Assisted Gravity Drainage process (SAGD) that is an in-situ recovery method that has been tested extensively in the heavy oil and bitumen reservoirs. Steam Assisted Gravity Drainage process uses one or more horizontal production well located near to the bottom of the reservoir with steam injection above from separate injection wells. This configuration will end in good production rates with good recovery and reasonably low SOR (steam-oil ratio).Use of steam assisted gravity drainage has been demonstrated to be a promising way of producing heavy oil and tar sands which are not recoverable in normal operation in fields. In the case of Iranian naturally fractured reservoirs, whatever has influenced the heavy oilproduction in other parts of the world can certainly help us for future productions and developments which can be achievedefficiently by use of horizontal and multilateral drilling techniques. However, weshould propose some modification of these methods (like SAGD) and initiate theprocess in a way that the vapor chamber in SAGD process or, combustion front, in thecase of combustion processes ,develops in matrix blocks instead of fractures, that deems to be appropriate for our naturally fractured reservoirs. This is merely a prospect for future works. This paper presents different aspects of SAGD operation together with its possible variations and numerous challenges.

Keywords: SAGD, oil sands, fracture reservoir, horizontal drilling.

1. Introduction

Interests in developing heavy oil industry are as old as the oil industry and generally date from the first discoveries in Canada around 1926. With those discoveries as well as the conventional crude oils the existence of some efficient techniques to produce these crudes (heavy oil, tar sands) was essential due to the lack of efficient technology as suitable strategies for heavy oil recovery and disappointing aspect of older technologies, the fact of developing new ways to achieved a good production of these reserves has been emerged. New methods in this area were developed in the middle 1970's. However practical or pilot test of these are underway. The importance of developing theories in laboratory or in pilot stage and optimizing the methods that are developed in practice in pilots or field test is another challenge which should meet the needs in industry of heavy oil for future. In this paper, the main effort is to document why SAGD process has been performed successfully in commercial scales. In this work Steam-Assisted Gravity Drainage concept is described and its relation to conventional steam flooding is investigated. In this way the main step is to understand the point that how gravity drainage theory works. In SAGD process one of the main points is the configuration of steam injection wells and the geometry of horizontal production well(s). These headlines together with the importance of prevention of water-oil emulsions formation within the reservoir well bore resistance and steam zone pressure in SAGD operations are discussed which the main focuses of this paper are.

2. Argumentation

2.1 Steam-Assisted Gravity Drainage Concept Description

In production of heavy crudes that uses a special form of steamflooding, movement ofoil to the production well is caused by gravity forces and has become known as Steam Assisted Gravity Drainage (SAGD). In this process the configuration of injection and production wells is such that the oil moves approximately parallel to the interface of a growing steam zone. This interface forms the boundary of a, steam-saturated zone known as the steam chamber [4]. The intention in developing the steam-assisted gravity drainage process was to devise a mean to give a more complete recovery than is possible in conventional steamflooding processes. In conventional steamflooding processes the oil is moved by pushing it with injected fluids. Here, in SAGD as the name implies the chief driving force to effect oil movement is the gravity force. One of the main issues considered in steam assisted gravity drainage is that the fingering problems are eliminated throughout the process. The differential fingering is usually caused due to the difference between the viscosity of the displacing fluid and the displaced fluid. In SAGD process, steam is injected above and close to a production well that is completed at the base of the reservoir. Steam rises and the condensate together with the warmed oil fall into a production well and oil with condensate would be removed continuously from the production well. An attraction of this concept is that, although the injection well and the production well can be very close, the mechanism will cause the steam chamber to expand gradually and eventually allow drainage from a very large area. In conventional steamflooding, the oil that is displaced from the steam chamber is cooled and is hard to push to the production well but in SAGD the oil remains heated as it flows around the steam chamber. The injector and producer do not have to span the drainage area and this is a novel change compared to the most of the enhanced oil recovery methods [1].

2.2 Steam Assisted Gravity Drainage versus Conventional Steam Flooding

Steamflooding tends to produce a stable displacement without steam fingering.Condensate that leaves the steam zone flows through the oil zone either as fingers or, in exceptional cases, by diffuse Buckley-Leveretttype flow. A major problem with conventional lateral steamflooding is the tendency for steam to override the oil zone and breakthrough at the production well. This effect can be reduced by completing the producer near to the base of the reservoir and by removing product at a controlled rate in order to allow gravity to keep the steam zone segregated. A considerable improvement can be achieved if the reservoir dips and if the steam is injected so that it flows down dip. Operation in this form has much in common with the steam-assisted gravity drainage. However, with conventional well the pressure gradients associated with radial flow to the production well make the maximum rate that is achievable without steam coning relatively low. In the steam-assisted gravity drainage process, horizontal wells are employed, and typical production rates of the order of 0.3 B/d per footof horizontal well (mostly in Alberta [1]) are indicated to be practicable without steam coning; withlong horizontal wells this provides an **economic** drainage rate. A major potential for the steam-assisted gravity drainage process lies in removing the drawback of conventional steamflooding that are created by the tendency of the steam to Override [1].

2.3 How Gravity Drainage Theory Works

According to the figure (1), when steam is injected near the bottom of the reservoir, it rises due to the lower density than the warmed oil and condensate but the condensate and heated oil which are heavier fall to the bottom. In addition it is possible to inject steam quite near to the bottom for displacing cold oil or higher up if the oil is mobile. It is also used for removing liquids as they drain to a lower location. When liquids are removed the vacant pores are filled with steam.

Completing a horizontal well at the bottom of the reservoir enables us to collect the heavier liquids. A steam chamber will be formed at the top of the horizontal producing well whereas steam is introduced continuously into the chamber and this is viable by placing another horizontal well as injection well above and near the horizontal producing well. This injection well can be a vertical well in some cases. There are some instances that the horizontal producing well is very long for which it is more effective to make avail of some vertical wells as injection wells. As the oil is removed, the steam chamber grows upwards and sideways and steam pressure is usually kept constant during the process. In the major mechanism of steam-assisted gravity drainage, steam does not push the oil but instead steam fills the volume originally occupied by oil now drained to the lower production well (Figure 2).

When pressure gradients are imposed upon the gravity drainage process, the recoverydecreases and the drainage rate increases. However, increasing the rate by lowering the production well pressure will leave additional liquid behind in the gas-saturated region. Although the dynamic hold-up of oil in the gas-saturated steam chamber is significant, it is relatively small, since the viscosity of the oil within the chamber is very low compared to the average viscosity of the oil draining below and around it. There are some practical cases with certain project life. For instance in a project life of 6 to 15 years, the average time that the chamber would drain might be 2000 days, and the corresponding residual oil saturation would be 0.1, the amount of oil which is left in the reservoir, or exactly speaking in the chamber [1].

According to Butler [1] the rate of upward growth of the vapor chamber is higher than sideways growth of the vapor chamber. Ultimately the upward growth is restricted by the top of the reservoir (Figure 2), and the sideward growth then becomes crucial. The steam chambers grow to the top of the reservoir and then spread sideways. After a period they form a single steam layer above the oil and continuous heating compels the oil to drain to the horizontal wells. As the figure (2) shows, this method allows almost complete coverage of the reservoir volume, representing a fantastic aspect of SAGD.

2.4 Steam-Injection Wells

There are two general arrangements of steam-injection wells that have been proposed to be used with horizontal production wells in steam-assisted gravity drainage:

1. Horizontal injection wells, with one well positioned above each producer.
2. Vertical steam-injection wells located directly above the producers.

2.5 Horizontal Injection Wells

In this arrangement a horizontal injection well is placed directly above each horizontalwell producer. The wells are drilled as injector-producer pairs, (Figure 3).In this application, the wells are very close together to allow inter-well reservoir heating and communication. Communication can be achieved initially by heating both wells and pressuring them cyclically. In this application, the steam chamber mustgrow upward, to the top of the reservoir. If the reservoir contains oil having an appreciable mobility, then it is possible to locate the injection well higher up in the reservoir. The limiting factor is that the mobility of the oil within the reservoir should be high enough to allow the steam chamber to advance downwards from the injector to the producer in a reasonable length of time. During this advance there is a displacement of cold oil and steam condensate to the production well, and, with adequate oil mobility, this communication period can be highly productive. The length of time required to achieve communication can be estimated approximately by calculating the breakthrough time. It can be reasoned that if the viscosity of the oil in the reservoir is low enough, then quite high vertical separations can be employed, particularly if the production well is preheated. A large separation is advantageous, since the pressure gradient resulting from the flow of steam assists the drainage of oil.

In some situations, there may be an advantage in employing two horizontal injection wells, with one located close to the producer to initiate steam chamber formation and a second located higher in the reservoir to be used as the steam chamber grows to it. When oil is displaced by downward steam flooding the volume that is displaced is somewhat less than would be calculated in theory because of the difference between the properties of the steam and the oil, because of the need for the condensate from the steam to flow with the oil, and because of the need to heat the reservoir.

2.6 Vertical Injectors

Vertical wells can also be used for steam injection above horizontal producers. Thereare several advantages to using vertical injection wells. They are cheaper and simpler to construct, and there is not the same need for drilling accuracy that would be required for horizontal wells. Also, it is possible to change the point of injection of the steam vertically as the project matures. In the initial stages it is desirable to have the steam injection close to the production well to facilitate communication. However, as the project continues, it becomes advantageous to raise the point of injection so that the motion of the steam through the chamber produces a favorable rather than an unfavorable pressure gradient. A major disadvantage of vertical injection wells is that each injector covers only a relatively limited length of the producer. For very long producers, it is necessary to employ more than one injector.

2.7 Well Bore Resistance

It is assumed that the pressure within the horizontal production well is constant, butthere is a need to consider this. An analysis of the effect of pressure drop along the horizontal well bore has been described by Butler (1989), [1] . He has considered three processes as occurring in series:

1. Gravity drainage around the steam chamber. The rate at which this occurs has been discussed previously.
2. Flow of oil from below the chamber to the production well. The resistance here is that due to the radial converging flow.
3. The pressure drop along the length of the well bore. The pressure gradient to achieve this, increase from zero at one end to a maximum at the outlet of the well.

According to Butler [1], the effect of the well bore pressure drop is to cause a slope in the bottom of the steam chamber along the well. This slope reflects the pressure difference along the well. In practical field situations the effect is relatively small unless the oil viscosity within the well is high because it is cold. If the well is cold then there is an advantage in heating it by circulating steam or otherwise. It is vital to consider the well bore pressure drop in three-dimensional scaled laboratory models having relatively long horizontal wells. A well scaled to have the same relativepressure gradient (measured as the slope of the bottom of the steam chamber) in the laboratory model should have a diameter larger than that which would come from simple geometric scaling.

2.8 SAGD Operations and Steam Zone Pressure

Today many of the researchers have focused on the issue of SAGD steam zonepressure and temperature. Their discussion usually is about the pressures around which an economic SAGD project can be performed without considerable damage to the economic aspects of SAGD operation in fields. Some of these researchers firmly believe that the operation should be done in order to reduce Steam-Oil Ratio (SOR).

According to Kisman [3], operation at reasonably low pressures provides savings not only due to reduced SOR, but due to the smaller production well liners and tubularthat may be used, and also it is necessary that low pressure SAGD remains to be confirmed in field tests. According to H.F.Thimm [2] Low pressure SAGD (LP-SAGD) is defined in such range of low pressures in which steam/gas lift can be performed and necessarily above pressures that oil rate is reduced and also in such range of low pressures to avoid some problems of required artificial lift. Hence three dominant factors that might influence the range of pressures for SAGD operation are oil production rate, SOR, and artificial lift. It is reasoned that a successful low pressure SAGD operation is a process at certain range of pressures in which oil production is economical and SOR is reasonably low. It is also implicated that at this range of pressure there should not be the prospect problems associated with the artificial lift.

The main advantage of manipulating SAGD at low pressure is that at reasonably low pressure as discussed there is no need to sulfur recovery. Acid gases, carbon dioxide and hydrogen sulphide, are produced in SAGD projects. Hydrogen sulphide is produced completely from bitumen; Carbon dioxide originates from the bitumen and sand. It is firmly believed that inorganic carbonates such as calcite and dolomite will not decompose thermally at SAGD conditions; but thermal decomposition of other minerals in the sand will ease carbon dioxide production. It is noted that production of the acid gases, on a basis of bitumen produced, is low and another thing is that hydrogen sulphide production is negligible below some certain temperatures. Hence it may be possible to avoid sulphur recovery altogether where low pressure SAGD is practical. But it would be worth mentioning that the determination of the optimum SAGD pressure is delicate because of the effects of steam pressure on solubility of gases in water, which is the main removal mechanism for gases from the steam zone. Low pressure SAGD therefore requires to be proved in the field [2]. In the case of NFR as in Iranian reservoirs, because most of the rocks are carbonates and dolomites, and will not thermally decompose, so the prospect of carbon dioxide formation is eliminated partially and process might be more consistent to the environment [8].

There are many applications where lower pressures are required because of thief zones or to improve the SOR. Low pressure SAGD may be required because of the presence of thief zones. Potential thief zones for SAGD operations are common features of the Athabasca oil sand deposit (in Canada). The upper gas and water sands are generally under-pressured at virgin conditions, and gas production operations are further lowering the pressure. When SAGD steam chambers achieve hydraulic communication with associated thief zones, the pressure in the steam chamber must be reduced to close to that in the overlying thief zone. This will require new methods of artificial lift to meet difficult SAGD requirements. The fluids to be lifted from horizontal wells are hot, high volume, and prone to steam/gas flashing. When the fluids reach the lift system, they are close to or at saturated steam temperature and will readily flash to steam. Hence it is it is very important to develop the required artificial lift systems in advance and define the lift requirements for low-pressure SAGD [3].

If artificial lift is used in SAGD operations, the requirements that must be met by theartificial lift system are high production rates and high temperature fluids and problems with flashing of hot water to steam in bottom-hole pumps due to the fact that the fluids reaching the pump are at or close to saturated steam conditions. Addressing the steam flashing problem in fluids reaching a lift system requires an introduction to the steam-trap method used to control the operation of SAGD production wells. With steam-trap control, the production rate is controlled so as to keep the temperature of the fluids in the production liner a certain number of degrees (called the subcool value) below the temperature which the fluids would have if they were at saturated steam conditions at the pressure in the production liner (usually taken to be at the inlet to the production tubing). It is important for a SAGD lift system to be able to lift at high enough rates to achieve low subcool values, and it has been established that fluids arriving at the intake to a lift system in a SAGD project are expected to be close to or at saturated steam conditions.

According to Kisman [3] steam/gas lift is the SAGD lift system of choice where possible. However, fluid slugging, and adverse properties such as high viscosity ratios, may limit the range of conditions in which it can provide sufficient lift for vigorous steam trap control. Some current SAGD applications of steam/gas lift may not be providing low subcool values and hence may not be providing optimum recovery performance. Electrical submersible pumps and E-Lift are considered as two choices for SAGD artificial lift. However, a proven lift system has not yet been demonstrated in field [8].

2.9 Steam and Gas Push (SAGP)

SAGP, which is a variation of the SAGD process, involves addition of a small amount of non-condensable gas such as natural gas or flue gas to the injected steam. The process presents opportunities for reducing steam requirements and thus improved energy efficiencies for SAGD [8].

2.10 Formation of Water-Oil Emulsions within the Reservoir in SAGD Operation

The formation of water-in-oil emulsions is very common in thermal recovery operations. According to Butler [1] the main cause of emulsion formation within the reservoir during recovery processes which involves steam is the condensation of steam on cooler bitumen surfaces. The tendency of bitumen to spread on water surfaces causes small droplets of water which are created by the condensation of steam to become buried within the bulk of the bitumen. For small water droplets to form it is necessary for the steam to be supersaturated (i.e. the partial pressure of the water vapor needs to be somewhat above the vapor pressure of liquid water at the temperature of the condensate). It is this super saturation which provides the driving force for the emulsification. The degree of super saturation which can be achieved depends upon how easy it is for water to condense elsewhere. In particular if the reservoir rock is water-wet then there is considerable water available with a flat surface on which steam can condense without droplet formation. From this reasoning it would be expected that emulsion formation would be greatest in circumstances where steam can contact cooler bitumen surfaces without contacting relatively flat water surfaces.

2.11 Naturally Fractured Reservoirs and Future Heavy Oil Recovery in Iran

Investigations show that in Iran, heavy oil reserves are estimated to be about 20 billion barrels, if specific gravity less than 20 ◦API is taken as the heavy oil. Vast deposits have settled in Kuh-e-Mond (most of the deposits). In addition to Kuh-e- Mond, in Zagheh, Ferdos, Paydar, Bushehr and Ramshir reservoirs, there is considerable deposits of heavy oil which are not very important compared to the Kuh-e-Mond reserves.

Up to this day, about seven shallow wells have been drilled (depth< 1500 m) in Kuhe- Mond, but pressure was not high enough (about 1000-1200 psi) to produce oil from wells. The specific gravity of heavy oil in Kuh-e-Mond varies between 6-8 ◦API and reaches to 15 ◦API in some points. If all reserves considered being 100 billion barrels in Iran, 20 percent of this, is related to the heavy oil reserves. Due to this fact it seems necessary to find some efficient ways to produce from these vast reserves. Our main purpose is not to produce this oil now, but identify appropriate IOR methods for future developments in heavy oil. Nobody knows whether these modern drilling methods as in SAGD (horizontal or multilateral) are suitable for our future production or not. Also, one day it may be necessary to build special refineries for heavy oil or use of in-situ upgrading (as in Toe-to-Heel Air Injection (THAI) or Hydrocarbon Injection or Vapor Extraction Method or solvent-variant of SAGD (VAPEX)) instead of steam injection by using multilateral or horizontal wells. It goes without saying that, we should start producing from our heavy oil reserves as soon as possible, regarding the fact that heavy oil production from these reservoirs is intensively influenced by time.

From technological point of view for Iranian naturally fractured reservoirs, because combustion front may impinge through the fractures and can burn part of the recoverable oil in fractures, it is suggested to develop some methods in a manner that, combustion front (or in the case of the SAGD application, vapor chamber) displacement and propagation starts and takes place in matrix blocks not in fractured network, initially [5-7].

Today in Iran some studies are underway in laboratory scale on heavy oil production methods such as solvent injection using both horizontal injector and producer (VAPEX) that can be done alternatively with dual-lateral wells. Some studies are also underway on in-situ combustion and steam injection using horizontal wells in steam assisted gravity drainage form (SAGD) or conventional form, in a hope to make applicable these methods or at least one of them for the future field production in practice.

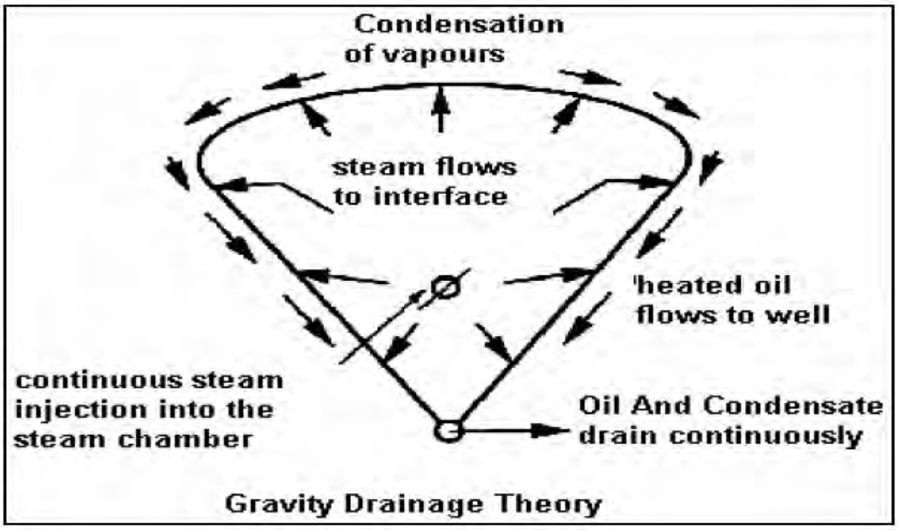

Figure1. Steam-Assisted Gravity Drainage Process

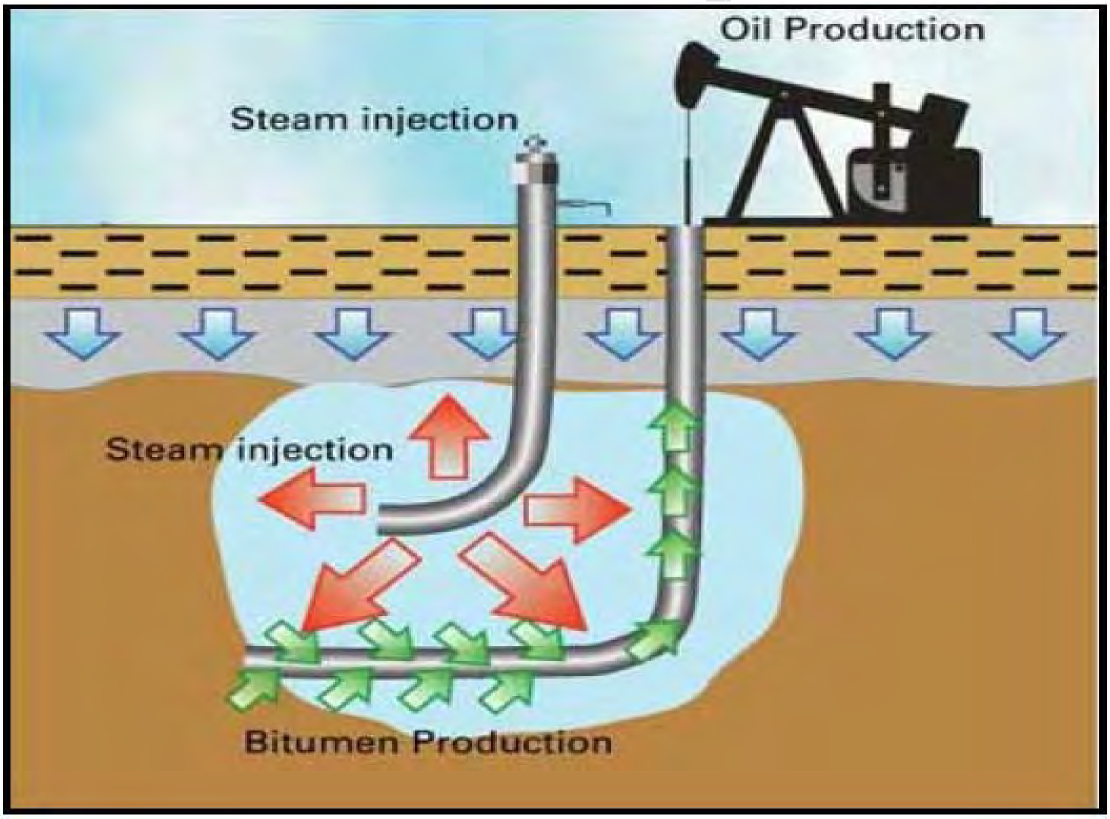

Figure2. Schematic Diagram of Steam Assisted Gravity Drainage and Steam Chamber Growth.

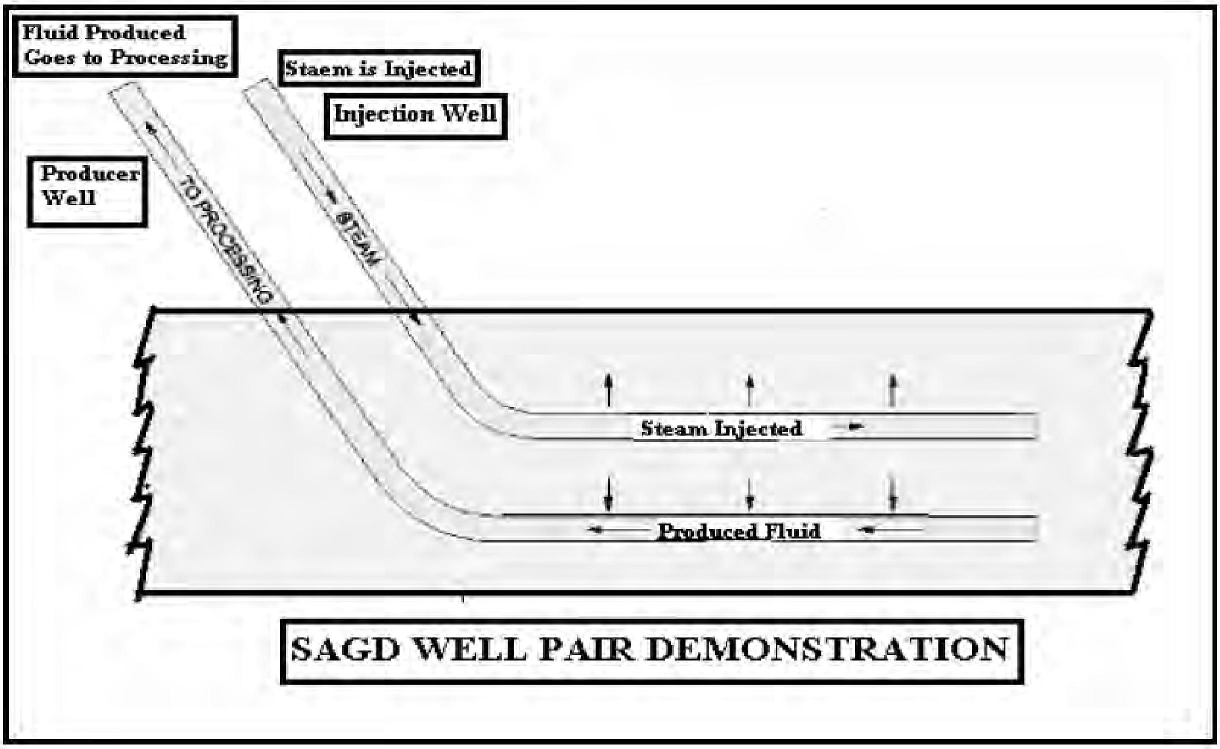

Figure3. Simplified Demonstration of SAGD Well Pairs [8].

3. Conclusions

1. Steam Assisted Gravity Drainage process uses of one or more horizontalproduction well located near to the bottom of the reservoir with steam injection above from separate injection wells. Thanks to the invention of Roger Butler, father of SAGD, this configuration will end in good production rates with good recovery and reasonably low SOR.
2. The process is somehow similar to conventional steam flooding but, because of the use of horizontal wells, much higher rates per production well can be obtained because contact with the reservoir is improved due to the presence of horizontal wells.
3. As opposed to conventional steamflooding in SAGD operation it is possible to operate at satisfactory rates without steam-coning. Hence better recovery can be obtained.
4. The process can be used for the production of bitumen or conventional heavy oils.
5. It is also possible to reduce steam requirements by adding small amount of non-condensable gas in a mood called SAGP to improve energy efficiencies for SAGD.
6. Two arrangements of steam-injection wells are used with horizontal production wells in steam-assisted gravity drainage. In horizontal arrangement wells are drilled as injector-producer pairs. In this application, the wells are very close together to allow inter-well reservoir heating and communication. In vertical configuration it is possible to change the point of injection of the steam vertically.
7. Water-Oil emulsions formation is very common in SAGD field operations. In water-wet reservoirs it is possible to avoid emulsion formation because of the presence of flat water

layers to prevent droplet formations. In the presence of flat water layers steam condenses easily without droplet formations which cause emulsion formation.

8. Low-Pressure SAGD reduces effectively SOR and ultimately improves theoperating costs of field operations.

9. Achieving very low mixed sub-cool values is a possibility to enhance drastically the performance of a well pair with much better economics and recovery factor in SAGD operations.

10. For the Iranian heavy oil reservoirs researchers are working on VAPEX, SAGD and in-situ combustion to modify one or more of these methods for naturally fractured reservoirs to recover heavy oil (mostly deposited in Kuh-e-Mond).

11. For Iranian heavy oil reservoirs it sounds that the combustion front should be developed in matrix blocks instead of fracture network.

12. Use of Horizontal and multilateral wells for recovery in Iranian heavy oil reservoirs is not fully obvious now, but their application from other parts of the world should be modified for Iranian heavy oil reservoirs.

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