New technologies of enhanced oil recovery

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Nové technológie zvýšenia ťažby ropy

It is known from the literature that up to 27 % of oil in oilfields can be produced using primary and hydration methods. The efficiency of production can be increased by employing more advanced methods, i.e. EOR. *The Polish Oil and Gas Company iwork with Polish oilfields, where currently primary methods are applied, but the Polish experiences with* EOR *date back to the years 1932-1987. In view of high oil prices, reconsidering* EOR *as a production method is economically justifiable. Therefore, it is purposeful to implement new pilot technologies, aimed at implementing new technologies, understanding accompanying phenomena, and calibrating of simulation models, including economical models for an optimal control of the oilfield exploitation. World's new exploitation methods worked out in the last few years and suggestions for their implementation in Polish conditions are presented in the paper.*

Key words*. EOR, SAGD, Vapex, LTO, multilateral wells*

Introduction

It is known from the literature that up to 27 % of oil in oilfields can be produced using primary and hydration methods. The efficiency of production can be increased by employing more advanced methods, i.e. *EOR* (*Enhanced Oil Recovery*). However, owing to high costs, these methods have not been commonly applied or developed. This problem can be encountered especially by The Polish Oil and Gas Company in its work with Polish oilfields, where currently primary methods are applied. This signifies that the Polish „depleted" fields still contain considerable quantities of oil to be recovered.

The Polish experiences with *EOR* date back to the years 1932-1987 and encompass:

- Gas injection – 13 projects (5 positive, 8 negative);
- Gas injection – 3 projects (all positive);
- Microbiological methods – 8 projects (2 positive);
- Gas and water injection – 2 projects (all positive).

In view of high oil prices, reconsidering *EOR* as a production method is economically justifiable. Therefore, it is purposeful to implement new pilot technologies, aiming at implementing new technologies, understanding of accompanying phenomena, and calibration of simulation models, including economical models for an optimal control of the oilfield exploitation. The world's new exploitation methods worked out in the last few years and suggestions for their implementation in Polish conditions are presented in the paper.

Traditionally, *EOR* methods can be divided into 4 major groups:

- Thermal methods (mainly steam injection and combustion within the reservoir);
- Chemical methods (polymers, surfactants);
- Gas injection methods (natural gas, CO_2, nitrogen);
- Other (e.g. microbiological methods).

New technologies of enhanced recovery

New EOR methods

SAGD – Steam Assisted Gravity Drainage

SAGD is a thermal method used for enhancing the heavy oil or bitumen recovery. Similar to other conventional thermal methods, it reduces the oil viscosity through an increased temperature. During *SAGD,* two parallel horizontal wells are used, 500 to 1000 m long. They are drilled one above the other, usually at a small distance of 5 to 10 m (Fig. 1). The lower well is localized near the bottom of the deposit.

Steam is injected to the upper well, from where it penetrates the space, gradually forming a "steam room" above the well. The steam precipitates in the room, giving off the heat to the reservoir. Heated oil and condensed steam gravitationally flow down towards the lower production well, where the fluids

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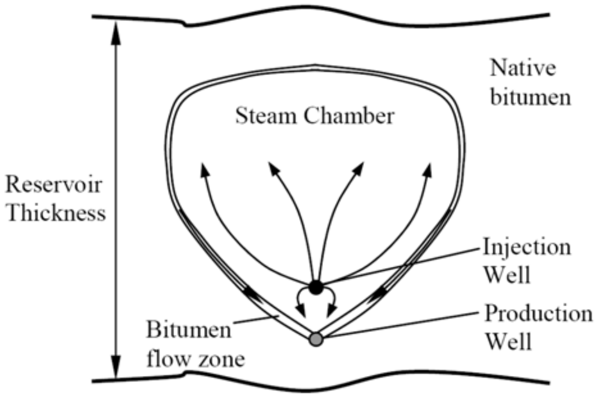

are recovered. The "steam room" zone expands in all directions during the process. For optimizing the *SAGD* process it is required that the whole length of the lower part of the room is located immediately above the production wells, and the steam produced from this part of the room is minimal.

Expected oil recovery for this method is 50-75 % of resources.

Fig. 1. Scheme of SAGD process (Gates I.D., Kenny J., 2005)

Vapex (Vapor extraction)

Vapex is a heavy oil and the bitumen recovery, employing the gaseous hydrocarbon solvent injection, leading to a considerable decrease of the oil and bituments viscosity. This method becomes more and more frequently applied in oil industry. *Vapex* process brings about positive results even for thin beds, or highly water-saturated beds, with a bed-cap, with unfavourable thermal conditions, where thermal methods are unprofitable. This method requires two horizontal wells drilled one under the other; the injection well is above the production well. A scheme of the process is visualized in Fig. 2.

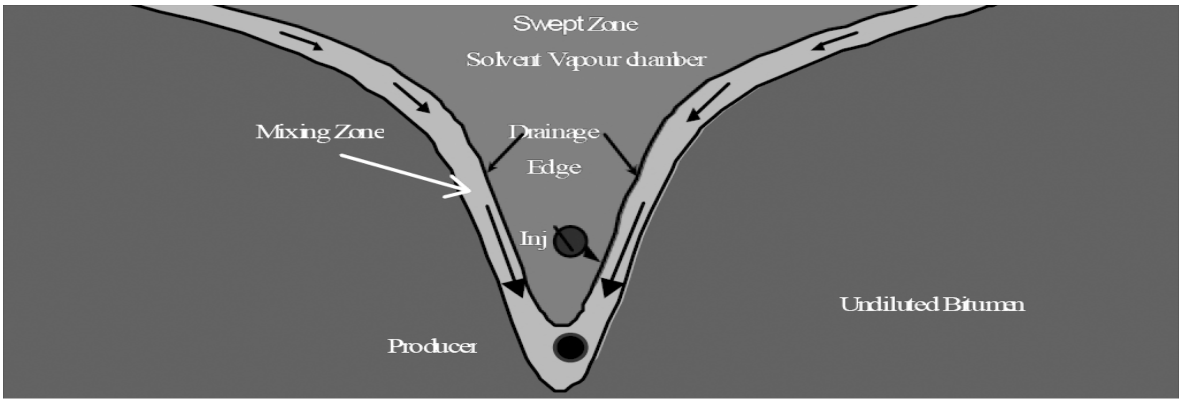

Fig. 2. Cross-section illustration of the Vapex process (Khelifa T., Brij B., 2003)

Diluted oil is mobile enough to enable a gravity flow towards the production well disposed near the bottom of the reservoir, and from where it is pumped out to the surface. The pore space around the injection well, from which the oil was depleted, fills up with a gaseous solvent forming a „steam room". The mobile oil flows only along a thin layer adjacent to the room. As the solving and flow processes go on, the room expands. When it reaches the top of the reservoir, it will expand sideways, reaching the V shape presented in Fig. 2. Then the oil-gas contact will decline and the oil production decreases. This process will be continued, it is still profitable. In a typical *Vapex* process the injected gaseous solvent is a mixture of propane and/or butane. However, owing to the high cost of these gases, per an oil barrel, the economic profits are lower. Therefore, to reduce the production costs, CO_2 is proposed as the main solvent component. Besides, CO_2 is more environmentally friendly.

LTO – Low Temperature Oxidation

LTO is a light oil enhancement recovery technique. It employs the oxidation processes taking place in low temperature conditions between the injected air and oil. In the course of these reactions, all oxygen injected with the air is absorbed, thus protecting against its penetration to the production well (and providing safety of the process itself). During the *LTO* process, the reaction takes place spontaneously and independently of the oxygen pressure. "The combustion" gases are produced" (N_2 – ca. 85 % and CO_2 – ca. 15 %). They cause the oil movement in the reservoir. Thus, the main objective of this process is generating nitrogen and carbon dioxide, which provide an energy for the production. The *LTO* process is presented in Fig. 3.

During the drilling operations, a system of two vertical wells (injection and production) is made at a distance of a few hundred meters from each other. In the oxidation zone, the oxygen is entirely absorbed from the injected air (oxygen concentration in the reservoir decreases gradually with the distance from the injection well). Depending on the reactivity of oil, it may oxide quicker or slower, but always at a relatively low temperature of 100–250 °C. During the reaction with oxygen, only a small part of oil is absorbed. The remaining oil moves under the influence of the produced gases.

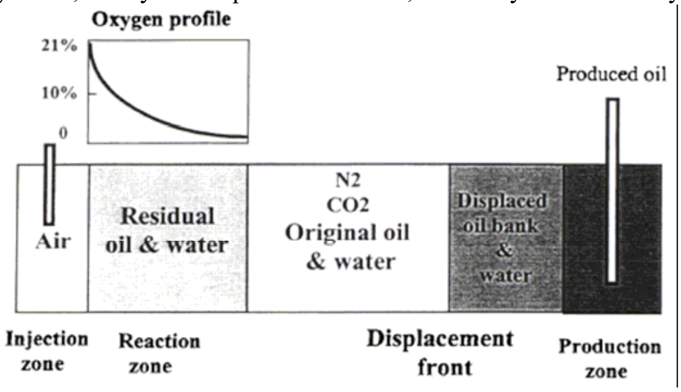

Fig. 3. Scheme of "Air Injection LTO" (Greaves. M, Ren S.R., 1999)

Complex-geometry wells (multilateral wells)

The first multilateral well (9 off-sections) was made in USSR in 1953. Later a few more such wells were drilled, but in the mid 1980s further attempts were abandoned. Owing to the development of drilling technologies in the early 1990s an increasing interest in multilateral wells has been observed. At present, the multilateral systems are used all over the world for new wells and reconstructions of the already existing ones [www.taml.net]. Multilateral systems offer more economic and technological optimization possibilities than their conventional counterparts. The potential profits from the use of multilateral wells frequently can be divided into two categories. The first category gives a possibility to increase reserves and/or accelerate the production from specific wells. The other one creates possibilities of decreasing costs spent on the exploitation project realization. Among the economic advantages of the multilateral wells use are, e.g.:

- ***Reduction of costs*** – the multilateral well technology considerably reduced capital costs as a considerable amount of money spent on developing operations is covered when drilling the main well. For instance, a two-lateral well may increase the production by 100 % at a 50 % increase of costs.
- ***Increased reserves*** – the multilateral wells may enable a production from recoverable reserves by an access to the isolated, remote parts of the reservoir. This technology turns out to be also profitable for small deposits, where other recovery technologies are economically inefficient.
- ***Accelerated recover*** – this factor is especially important in the case of high oil prices of high operating costs. A proper system of laterals enables an enhanced draining of the reservoir and a faster recovery.
- ***Heavy oil recovery*** – *SAGD* is a multilateral technology of heavy oil recovery, lying in drilling two horizontal off-sections. The upper section is used for the steam injection and the lower one for the oil recovery.

A new generation of multilateral systems focuses on a minimized risk of their application [Oberkircher J., 2000]. Statistically, in the years 1998-2002, for 477 applications 18 were failed (3.8 %). For marine applications, the failure ratio was 11.6 %. In the years 2001-2002, 208 multilateral wells only 4 were failed (1.9 %) which proves the development of the technology and the decrease of the risk factor.

Fig. 4. Exemplary application of SAGD (Cavender T. W., 2004)

The multilateral well construction is still considered to be risky. Despite their potential multilateral systems are still accepted with a caution. It should be remembered that a multilateral well may substitute a number of conventional wells. Trying to assess the ability for the Polish conditions, the authors numerically modelled near-wellbore zones for one of the Carpathian gas fields. The maximal rates from one 4-section well presented in Fig.5 were: for the reservoir pressure 30 [bar] – 15 nm^3/s (1.3 mln nm^3/day), the reservoir pressure 40 [bar] – 23.15 nm^3/s (2 mln nm^3/day). Such a well sufficies for an UGS of active capacity equal to100 mln nm^3.

In the case of reservoirs with fracture permeability, the multilateral wells would create possibilities of linking a number of fractions and a considerable increase of porosity and fracture permeability. Parts of reservoir which were not subject of exploitation would be opened and reserves could be increased.

A number of possibilities of making a realistic computer simulation of multilateral wells exist at the Faculty of Drilling, Oil and Gas, AGH-UST. Then, they can be implemented in a simulation model of a reservoir in the *ECLIPSE* system.

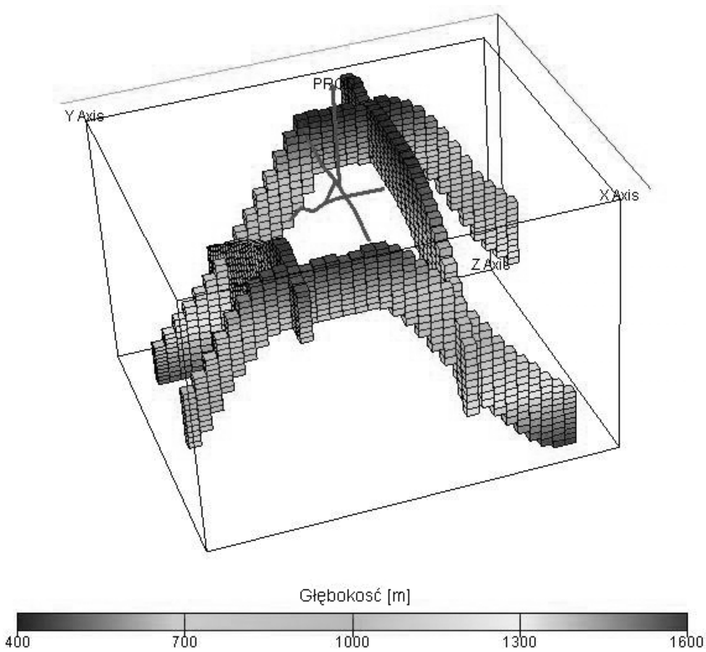

Fig. 5. Simulation model of a near-wellbore zone of the 4-section well

Geological sequestration of CO2 in oil fields

In the framework of own research program at the Faculty of Drilling, Oil and Gas the authors made a few computer simulations of the CO_2 injection to oil fields with the economic analysis of the investment [Stopa J., et al., 2005]. The results of these simulations and analyses indicate that the project is profitable at the oil price over 60 USD/barrel. In the present conditions of high oil prices and an increasing urge to reduce CO_2 emissions, such an investment may turn out very attractive. One may risk saying that geological sequestration may become a new type of activity of oil companies in the future. If the geological sequestration of carbon dioxide coming from large stationary sources is necessary, the basic problem will lie in finding funds for such operations. The most expensive element of sequestration is CO_2 separation and recuperation from combustion gases. It follows from the literature, that the cost of CO_2 separation may range from 20 to even 70 USD for tonne, the cost of transport and injection is much lower from 5 to 15 USD per tonne of CO_2. It may be an interesting option for large-scale emittents to undertake a co-operation with oil sector, which offers a respective knowledge and experience in the underground gas storage technologies. Such a co-operation may assume various forms, e.g. sales of CO_2 to a gas company to be used for the enhanced recovery of oil or natural gas, or joint projects.

Resume

The development of such new *EOR* technologies as *VAPEX* or *LTO* and the increasing pressure on reducing anthropogenic CO_2 creates favourable conditions for anincreased interest in the *EOR* methods accompanied by the CO_2 sequestration also in Poland. The spectacular development of multilateral well technology, significantly increasing recovery rates and enabling the management of small reservoirs, is of special interest. One of the newest *EOR* methods, i.e. the *SAGD* is a process described in this paper. This technology links the *EOR* method with the multilateral well technology and is applicable for gravity production reservoirs.

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