Crude oil prices effect on enhanced oil recovery projects

Vesna Karović Maričić

University of Belgrade-Faculty of mining and geology, Belgrade, Serbia, vesna.karovic@rgf.bg.ac.rs

Abstract— **Enhanced or tertiary oil recovery methods (EOR) contribute significantly in increasing oil recovery factor up to 60%. Additional oil recovery values depend on the type of the applied EOR method (thermal methods that include steam injection, in situ combustion; chemical methods such as polymer, alkaline or surfactant injection and injection of hydrocarbon, carbon dioxide or other gaseous fluids). Implementation of complex EOR methods involves high capital and operational costs, longer period of investment`s payback period and more risk and uncertainty in comparison to the use of conventional primary and secondary recovery methods of oil reservoirs.**

In general, oil prices have the largest impact on the EOR projects' economic viability.

Crude oil price decline since June 2014 had large impact at the world energy market, as well as at the application of oil exploitation methods and their commercial viability. In this paper are presented considerations of oil price impact on the oil production by EOR methods.

Keywords - oil production, enhanced oil recovery, crude oil price

I. Introduction

Tertiary recovery phase of an oil reservoir implies application of an enhanced oil recovery methods (EOR methods). These methods aim to mobilize the residual oil trapped in porous medium in existing producing oil fields. It is estimated that approximately 2/3 of the oil originally in place worldwide is still unrecoverable by conventional production methods, i.e. by natural depletion and waterflooding during primary and secondary oil recovery process [1, 2, 3]. EOR processes include application of: thermal methods (steam injection and in situ combustion), chemical methods (injection of polymers, alkaline or surfactants), injection of gases (hydrocarbon gases, carbon dioxide or other gaseous fluids in miscible or immiscible conditions) and other methods such as microbial, acoustic, electromagnetic that have for now small application.

Enhanced oil recovery techniques are not the new ones. They are developed and applied since 1970s with up and downs in number of EOR implemented projects that is directly related to the fluctuation of an oil price at the world market.

The most used EOR methods for decades were thermal ones i.e. steam injection, but lately the injection of CO_2 is becoming dominant method since it is considered also as an option for CO_2 geological storage and thus contributes to the CO_2 emission mitigation.

World oil production by application of EOR methods is at the about same level for years. It is about 3,5% of an overall world oil production [4,5]. So, the question that arise out of previous facts is: why EOR methods that contribute in increasing oil recovery factor up to 60% with production of million tones daily have relatively small application. The answer involves several reasons: implementation of EOR is complex process and it involves high capital and operational costs, longer period of investment payback period and more risk and uncertainty in comparison to the use of conventional primary and secondary recovery methods of oil reservoirs [6].

II. Application of EOR methods related to oil price

In general, oil prices have the largest impact on the EOR projects' economic viability. So, the most of the EOR projects were implemented in the 1980s, when a sudden rise in oil price has happened. Since 1986 when oil price decreased significantly, the number of implemented EOR projects had a moderate continuous declining trend with significant fall from 1994 when oil price was less than 20$/bbl [7]. Following increase in the EOR methods` use, primarily of implemented CO_2-EOR projects, was in the second half of the 1st decade in this century until 2014. From 2014 to date, the number of new EOR projects has significantly dropped; moreover, it has been practically ceased, since oil price decrease has been present in 2014-2018 period. Figure 1 shows the number of implemented EOR projects by applied methods in the world for 2004, 2010, 2012 and 2014 (last available data) [8, 9, 10].

Figure 2 presents the oil price trend during the 2000-2018 period [11]. The fluctuation of oil price is present in different extent. First largest oil price fall was in this century was in 2008 due to global economic crisis. After that, in June 2014 crude oil price has crashed from its peak of 115$ to the lowest price of 30$ in February 2016, and in 2018 has begun to slowly raise up.

By analyzing time relationship between number of implemented EOR projects and oil price, it could be noticed that is characterized with time delay. Reasons are that implementation of EOR projects is time lasting process that involves several phases: first phase of selecting an appropriate EOR method by multicriteria analysis, laboratory testing and numerical modeling; second phase of pilot test application and third phase of implementation at the whole field if pilot test results are positive. So, it takes 6-10 years for achieving additional production by EOR methods application [2, 6, 12].

It is well known that that the oil price depends on financial factors such as demand and supply, exchange rate of US dollar, inflation, status of global, regional or big countries` economy, as well as on the geopolitical factors and oil market speculations.

There are many different opinions on what of mentioned factors prevails in determining the oil price volatility at the world market, but the common one is that oil market recently became significantly more complex with many present uncertainties. For that reason, it is very difficult to make relevant long-term prediction of oil price trend.

Related to that issue, worldwide energy studies and reports use different scenario approach in analysis of future trends in oil production and demand. Thus, in the World Energy Outlook for 2014 (last available data) are considered three different scenarios by assumptions on deployment and future development of government energy and the environment policies: New Policies Scenario, Current Policies Scenario and the 450 Scenario. Central scenario in these projections is The New Policies Scenario that gives projection on the basis of adopted policies and regulations in 2014 on energy and environmental issues such as renewable energy, energy efficiency, programs and plans for carbon dioxide emission mitigation, etc. [13].

The New Policy Scenario of world oil production by 2040 estimated by International Energy Agency (EIA) is presented in Figure 3 [13]. According to that forecast, about 5 million barrels per day will be produced in 2040 by EOR methods, that indicates an increase of EOR share in future world oil production in comparison to today's 3 million.

Even with the low oil price, development of new technologies and techniques in the area of geophysics, drilling, reservoir and production engineering, as well as in reservoir modeling is improving cost efficiency and reducing risks in implementation of EOR projects. Importance in further developing EOR projects lies in the facts that the current production from most known oil fields has declining trend with large amounts of remaining oil reserves whose recovery could be increased and field production period extended only by application of these methods. EOR processes are less controversial compared to hydraulic fracking applied for production from unconventional resources (oil shale) and increase of their application is one of the main long-term strategies of major world oil companies such as: British Petroleum, Chevron Corporation, Cenovus Energy Inc., Canadian Natural Resources Limited, China National Petroleum Corporation, etc. [14].

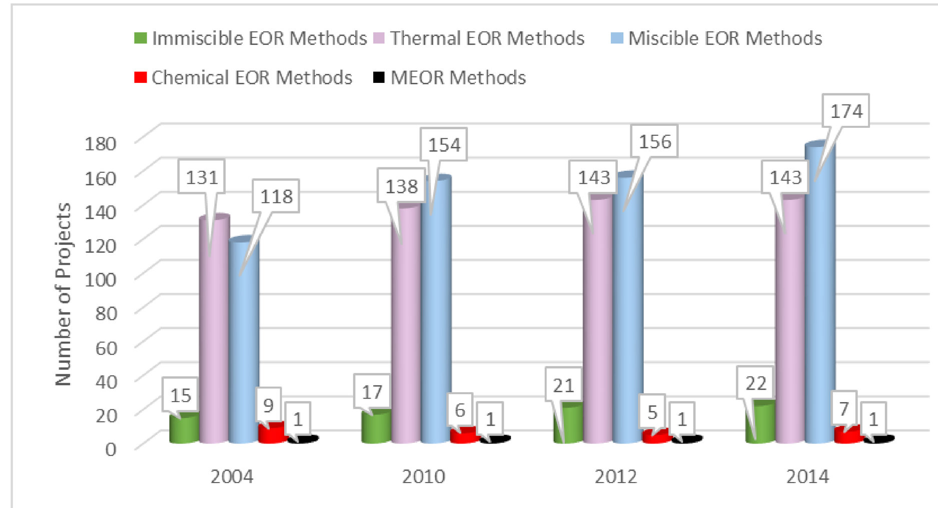

Figure 1. Number of implemented EOR projects by applied methods

Figure 2. Crude oil price trend during the 2000-2018 period

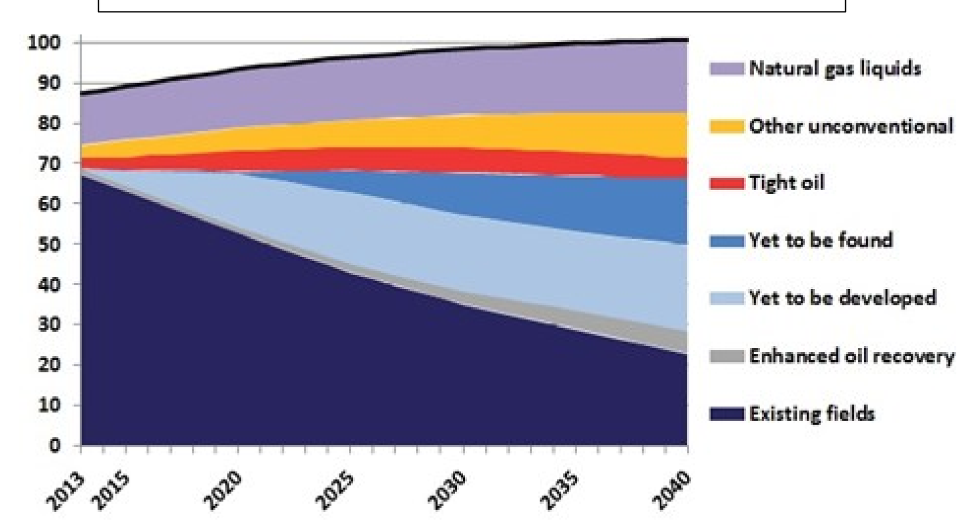

Figure 3. New Policies Scenario- Crude oil world production by 2040 (10^6 bbl/day)

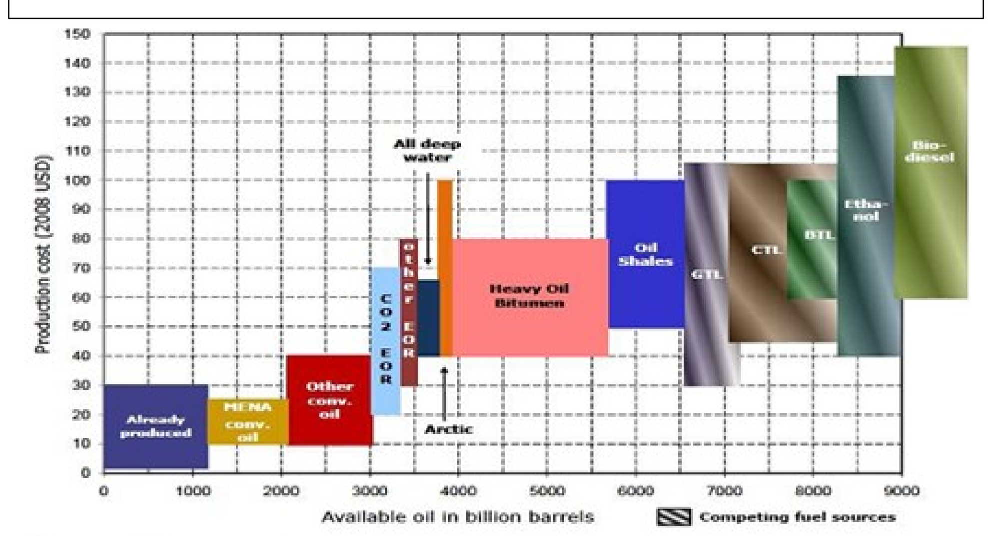

Figure 4. Production costs of oil resources

III. The brief description of EOR projects` economics

Application of EOR technique involves high capital and operational expenditures, delayed revenue with high sensitivity to discount rates since more time is needed for production increase in comparison to conventional production methods. Capital and operational costs of EOR methods can be classified as process independent and process dependent costs [15]. Process independent costs are same as the costs of oil production in primary and secondary recovery phase such as: well drilling, well completion, workover costs, process maintenance costs, accompanying operational costs, surface equipment and infrastructure. Process dependent costs are related to the specifics of applied EOR methods and primarily involve: cost of injected fluids, costs of injection wells and costs of injection plants. The cost of injected fluid (chemicals, CO_2, hydrocarbon gases, nitrogen, etc.,) has a largest impact besides oil price on project economic viability. OPEX are the highest costs and account for 60 to 80% of the overall project costs depending on the type of applied EOR method [16]. The analysis of crude oil price, capital and operational costs of EOR projects application, where cost of injected fluid has a highest share, points out that the minimum oil price for commercially viable project is about 60-80 US $/barrel [17]. The production costs of CO_2 and other EOR methods related to the costs of other oil resources is given in Figure 4 [18].

A. Thermal methods

Thermal methods have the greatest application of all EOR methods, primarily method of steam injection with share of about 60%. They are applied for increasing recovery of heavy oil reservoirs, extra heavy oil reservoirs and oil sands. Their main mechanism for producing additional oil is reduction of oil viscosity.

Depending on the way of generating heat in the oil reservoir, thermal methods are classified into: steam injection (cyclic and continuous injection-steam flooding) and in-situ combustion.

In the first group of methods, the conversion of water into the steam is carried out in surface steam generators, and after that stem is injected by injection well into the productive reservoir layer. In situ combustion, heat is produced in the reservoir due to combustion of certain part of oil in the productive layer. Oil combustion occurs by its spontaneous or induced ignition in the presence of injected air or air/water mixture. In Figures 5 and 6 are presented schemes of steam flooding and in situ combustion with zones that are formed in layer during these processes [19, 20].

Thermal methods are the least expensive EOR methods where highest share in operational costs are energy costs for steam generation. Cyclic steam injection involves three operating cycles: steam injection period, period of well shut-in and period of reproduction. This process is characterized by greater increase in oil production, lower capital costs, and lower operating pressures compared to the continuous steam injection. It produces 20-40% of additional oil recovery, with the ratio of injected steam and produced oil of 3-5, which means that for production of $1m^3$ of oil it is required to inject 3-5 m^3 of steam [21, 22]. The steam oil ratio (SOR) is parameter that shows efficiency and cost-effectiveness of oil production during steam injection. Approximately one third of the additional produced oil is used to generate needed amount of steam [23]. So, it is considered that the steam injection project is cost-effective at SOR values up to 8 [24].

Steam flooding can increase oil recovery up to 60%, while recently most used „Steam assisted gravity drainage" technique of steam injection for heavy oil production from oil sands, primarily in Canada and Venezuela, can achieve recovery up to 80% [5, 16].

In situ combustion applied projects have shown significant contribution to the increase of heavy oil recovery, but they are not applied so much in comparison to the steam injection. Main reasons are high risk of project failure mainly due to difficulties of process control and monitoring.

B. Chemical methods

Chemical methods include injection of polymers, alkaline or surfactants added to water for increasing production of light and medium residual oil in mature and waterflooded fields. Additional oil production mechanisms are: increase of oil microscopic displacement by reduction of interphase tension between oil and reservoir rock or wettability alternation and improving macroscopic oil displacement by controlling oil /injected fluid mobility ratio. The most applied chemical EOR process is polymer flooding (Figure 7) [25]. Chemical EOR is receiving lately more attention primarily due to increasing cost effectiveness and improving performance such as: development of stable surfactants at high temperatures, less expensive surfactants of low concentration which effectively reduce the value of interphase tension, and due to increasing use of combined chemicals such as alkaline-surfactant-polymer (ASP) [6].

For chemical processes, OPEX depend on type and quantity of injected chemicals where polymers are less expensive comparing to alkaline or surfactants, on type and capacity of surface chemical injection and treating facilities and additional costs if drilling of new injection wells is needed after waterflooding.

C. Gas injection methods

Gas injection methods involve injection of hydrocarbon gases, carbon dioxide, nitrogen and flue gases in light oil reservoirs for producing residual oil by lowering oil viscosity in miscible conditions, increase or maintain reservoir pressure, oil swelling, vaporization of oil and reduction of interfacial tension. The most applied are CO_2 injection processes that differ by the used CO_2 injection technique. The most successful one is the „water alternate gas"(WAG) method that involves the injection of slugs of water alternately with certain amount of CO_2 (Figure 8) [26].

Recent growing interest in CO_2-EOR method lies in the facts that this method represents one of the main new technological solutions for CO_2 emission mitigation by storing certain amount of used CO_2 in deep geological formations[27]. About 30-40% percent of injected CO_2 is recycled while the rest of injected CO_2 is stored in reservoir [28].

Major investments in CO_2 injection project represents purchase of CO_2 and costs of facilities for separating CO_2 from produced oil and compression for reinjection into the reservoir. The cost of CO_2 depends on the type of source type, source location related to the oil reservoir, and on availability of pipeline infrastructure. In the USA, which is the greatest oil producer by CO_2 injection (6% of its total oil production in last two decades) 20% of used CO_2 is anthropogenic in origin i.e., from industrial sources, such as natural gas processing plants, hydrocarbon conversion facilities [29]. CO_2 costs that include purchase price and recycle costs are estimated as 25% to 50% of the total cost per barrel of oil produced. Specifics of CO_2 injection projects in USA it is that their number has continuous increasing trend with significant additional production independently of oil price volatility. That is explained by their relatively lower costs due to presence of many natural cheap CO_2 sources and pipelines for CO_2 transportation to the oil field.

IV. Conclusion

The potential of EOR method application for oil recovery increase has been recognized for many years, but their use is still disproportionate to the contribution, i.e. significant additional production, due to an unstable economic factors-oil prices and a more complex process of oil reservoir recovery by using these methods in comparison to the production by conventional methods. Since oil prices have the largest impact on the EOR projects' economic viability it is obvious that in the period of high oil price, the most of EOR processes have been developed and applied, and contrary, in the period of low oil price the number of new EOR processes has decreased. The certain exceptions are CO_2 injection projects. Oil price drop is slowing down investments in EOR production for the reason that these projects require high operational costs where largest share has a cost of injected fluid. On the other side, it should be considered that EOR projects brings additional oil production in period of 6-10 years, so in the period of low price their development should not be ceased, but put on delay. Importance in further developing EOR projects lies in the facts that the current production from most known oil fields has declining trend with large amounts of remaining oil reserves whose recovery could be increased and field production period extended only by application of these methods.

Development of the new EOR oil production techniques, as well as further development of seismics, reservoir simulation models, application of horizontal, multilateral wells and hydraulic fracturing methods will enable more cost effective implementation of the EOR methods in the future period.

Acknowledgment

This article is the result of the project financed by the Ministry of Education and Science of Republic of Serbia (Project No. 33001). We thank the ministry for the support.

References

[L. W. Lake and M.P. Walsh, „Enhanced oil recovery (EOR)", Technical report, Department of Petroleum and Geosystems Engineering, University of Texas at Austin, Austin, TX, 2008.
[P. Bonder (2010). EOR-the time is now: Its contribution of world energy supply, Society of petroleum engineers. Available at: https://www.spe.org/dl/?redirected_from=/dl/%202010.php
[American petroleum institute, Oil production statistics. Available at: https://www.api.org/
[S. Kokal, and A. Al Kaabi, „Enhanced oil recovery: chalanges and opportunities. World Petroleum Council: Official Publication.Global energy solution, 2010, pp.64-69
[E. Manirique, C. Thomas, R. Ravikiran et al., "EOR: Current Status and Opportunities," SPE paper 130113, presented at the IOR Symposium, Tulsa, OK, 2010, April 26-28.
[V. Karovic Maricic, D. Danilovic, and B. Lekovic, „Factors influencing successful implementation of enhanced oil recovery projects" , Undergroung mining engineering, 25, 2014, pp 41-50.
[J.J. Taber, F.D.Martin and R.S Seright, „EOR screening criteria revisited-part 2: Application nd impact of oil prices", SPERE, August 1997, pp.199-205.
[G. Moritis, "2010 Worldwide EOR Survey," OGJ, vol.108, No. 14, 2010, pp. 42–44.
[L., Koottungal, "2012 Worldwide EOR Survey," OGJ, vol. 110, No. 4, 2012, pp. 57–69
[L., Koottungal, "2014 Worldwide EOR Survey," OGJ, , vol. 112, No. 5, 2014, pp.79–91
[Infomine. (2018). Crude Oil Prices and Crude Oil Price Charts. Available at http://www.infomine.com/investment/metal-prices/crude-oil/
[Schlumberger. (2014).Seizing the EOR opportunity. Available at: http://www.slb.com
[International Energy Agency (2017). World Energy Outlook 2014. Available at: https://www.iea.org/publications/freepublications/publication/WEO2014.pdf
[Visiongain (2014).The 25 Leading Companies in Enhanced Oil Recovery (EOR). Available at: https://www.visiongain.com
[National Petroleum Council (1984). Enhanced oil recovery. Available at: https://www.npc.org/reports/rd1984-Enhanced_Oil_Recovery.pdf
[V. Alvarado, and E.Manrique, "Enhanced oil recovery: An update review", Energies, 2010, 3(9), pp. 1529-1575
[International Energy Agency. (2016). Data and publications. Available at: https://webstore.iea.org/world-energy-investmentI
[International Energy Agency (2010). Resources to Reserve – Production Cost Curve, Available at: www.iea.org.
[M. James, R. Wing, and Wood Group ESP Inc. (2018). Steam Flooding, Available at: http://www.upstreampumping.com/article/production/high-temperature-electric-submersible-pumps-effective-oil-sands-production
[A. Turta. (2018). In-Situ Combustion. Available at: http://www.insitucombustion.ca/
[I. Sandrea, and R Sandrea, „Global oil reserves—1: Recovery factors leave vast target for EOR technologies," Oil and Gas Journal 105(41), 2007, pp. 44-47
[National Petroleum Council, „Heavy oil, extra-heavy oil and bitumen unconventional oil", NPC Global Oil and Gas Study, 2007.
[A. Satter, and G. Thakur, „Integrated petroleum reservoir management", PennWell books, Tulsa, 1994.
[C.Chu, „State-of-the-Art Review of Steamflood Field Projects", J. Pet Technol 37 (10), 1985, pp. 1887-1902.
[N. El-Hoshoudy, M.Y. Elkady, and S. A. Mahmoud, "Hydrophobic Polymers Flooding", Chapter In book: Application and Characterization of Surfactants, 2017, DOI: 10.5772/ intechopen.69645
[ARI. and Melzer Consulting, „Optimization of CO2 storage in CO2 enhanced oil recovery projects", Department of Energy and Climate Change, 2010.
[L. Tomić, V. Karović Maričić, D. Danilović and M. Crnogorac, „Criteria for CO2 storage in geological formations" , Undergroung mining engineering 32 (2018), pp 61-74
[S.Holloway, et al., „Carbon dioxide transport, injection and geological storage", IPCC Guidelines for National Greenhouse Gas Inventories, vol.2, Energy. 5.2., 2006.
[V. Kuuskraa et al, „ CO2 Utilization from "Next Generation" CO2 Enhanced Oil Recovery Technology", Energy Procedia 37 ,2013, pp. 6854 – 6866

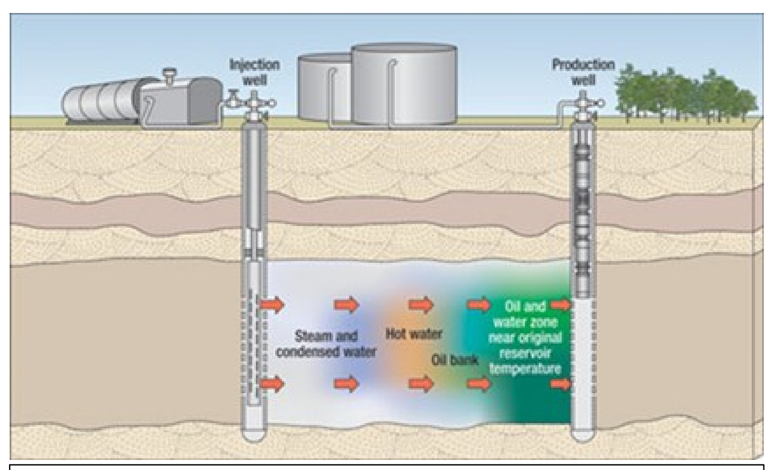

Figure 5. Steam flooding process

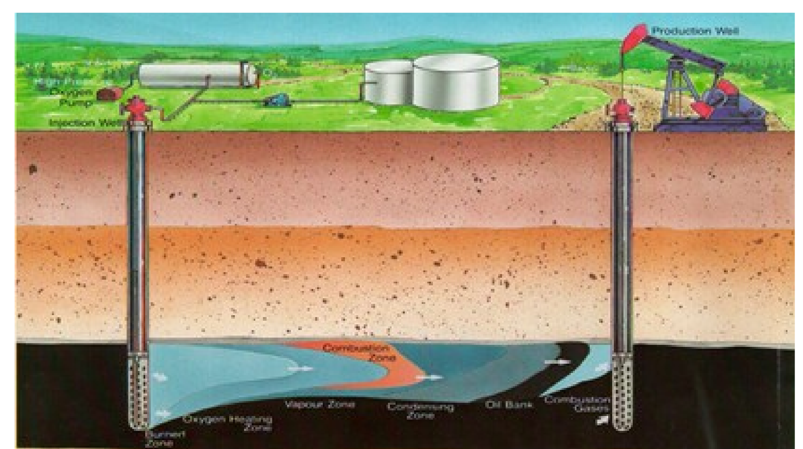

Figure 6. In situ combustion process

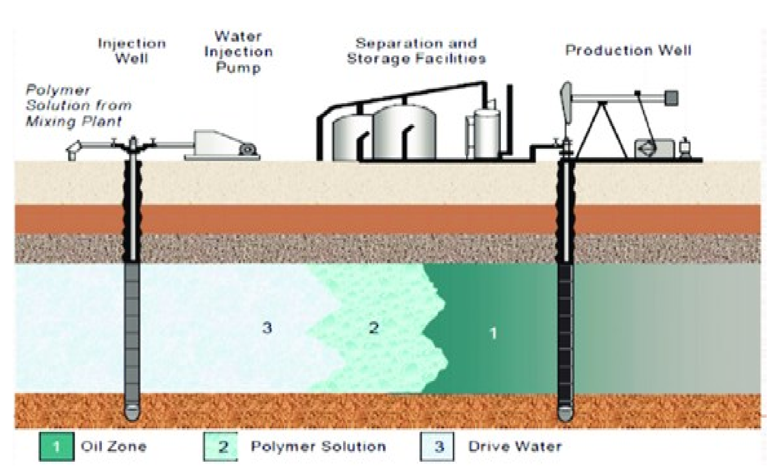

Figure 7. Polymer flooding

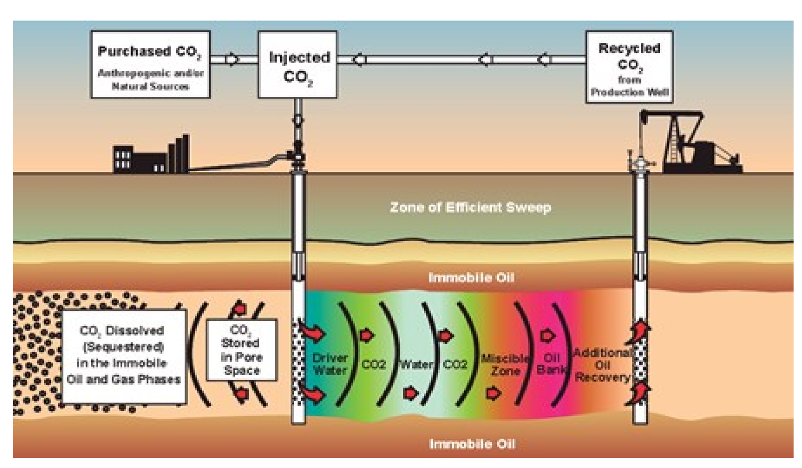

Figure 8. CO_2 injection"water alternate gas" method