Experimental Investigation of Cyclic Solvents Injection to Enhance the Production in Heavy Oil Reservoirs

Mohammed Mansour
e-mail: mamansour@su.edu.ly

Department of Petroleum Engineering, Faculty of Engineering, Sirte University

Abstract

Solvents injection for thin layered reservoirs that contains a very high viscous crude oil is an alternative way to improve the oil mobility, reducing its viscosity and increase the production. in this mechanism, the oil viscosity is reduced by dissolving the solvents and then becomes more capable to flow through the porous media, during the production period the production rate is also improved by gas expansion mechanism. However, during the production period the sample pressure is abruptly depleted due to the viscous fingering of solvents ahead of oil to outflow out of the sample. This study shows an experimental investigation of cold production of heavy oil by using the solvent as an enhancing technique to improve the recovery of heavy oil in thin reservoirs, experimental model has been designed to make several runs for injecting the solvents in cyclic process "huff & puff" to analyze the saturation of the sample and production conditions at the end of the runs. Unlike the vapor extraction process that is called VAPEX, where two horizontal wells (injector and producer) are designed to inject the gas by one well and produce by the other well, cyclic solvent injection is using only one well as solvent is initially injected for certain period of time, followed by soaking period then oil is produced from the same well for production period.

Keywords: *Solvents injection, Soaking Time, Sand Pack, Oil Recovery Factor*.

1. Introduction

Solvent based recovery methods are a potential alternative, capable of providing high recovery factors without high water requirements or potential for high temperature reactions [3]. The current tertiary recovery methods are being used currently to recover the heavy oil are function of the reservoir properties, like thickness, depth, porosity. The high viscosity of the oil prevents or minimizes its movement in the porous media, and as a result it makes it difficult to produce that amount of heavy oil with the primary or secondary recovery methods. Therefore, using the solvents as an agent to reduce the oil viscosity to improve its movement in the porous media could be a sufficient method in thin reservoirs. Since using thermal methods in thin formation are not economical due to the high amount of heat being lost to the over-burden and under-burden, that makes the percentage of water used to oil recovered sensitively high. Heavy oil has some properties that make it different than the conventional oil such as the high viscosity, ranges from

100 cp to 100,000 cp under reservoir conditions, with API less than 20 degree. Most of the heavy oil occurs in shallow layers less than 1000 m, and these layers have a very high permeability ranges from one darcy to several darcies. Another characteristic of these layers is the small thickness less than 10 meters.

2. Solvents as a Viscosity Reducing Agent

By injecting light hydrocarbons into the reservoir, the saturation pressure increases and the gas starts dissolving in the heavy oil and reduces the viscosity by molecular diffusion and convective dispersion which consequently change in the viscosity of heavy oil, the change of oil viscosity can be expressed in the following equation.

$$\ln(\mu_m) = x \ln(\mu_g) + (1 - x) \ln(\mu_o) \quad \ldots\ldots (1)$$

Where x is the mole fraction of the solvent, μ_o is the oil viscosity, μ_g is the solvent viscosity, and μ_m is the mixture viscosity. The solvent can be light hydrocarbon such as methane, ethane, propane or butane, ..etc.

3. The Cyclic Solvent Injection Process

For thin reservoirs, where the thickness of the formation is very low, in the range of 10 meters or less, using thermal recovery method is considered very inefficient where the injected steam propagate through the formation and causes leak in the energy. Moreover, applying continuous solvents injection could lead to a similar results, where the solvents escape through the formation due to many factors such the difference in the viscosity between the displacing and displaced fluids, which makes the displacing fluid's mobility faster than the displaced fluid, as well as the high continuous pumping pressure from the surface that increases the viscous fingering and outflow the gas away from the formation, However, cyclic solvent injection process consists of three stages, the first stage is the injection stage where the gas is being pumped from the surface with monitoring the conditions, the second stage where the injection stops and starts the soaking period, this allows the injected gas to be further distributed in the formation and dissolve with oil for certain period of time, at the third stage where the mobility of oil is improved, the well is opened for production to lift the oil to the surface by using artificial lift method and this continues as long as the production rate is economical. This cycle can be repeated several times for the same well to improve the production and increase the recovery factor.

4. The Effect of Solvent Composition on Cyclic Solvents Injection

The solvent composition and choosing the right concentration of the injected light hydrocarbon is indeed an effective factor on the cyclic solvents injection process, because it can change the solubility of light hydrocarbons in the heavy oil. Thermodynamically, the best time to inject light hydrocarbon in heavy oil reservoirs is near the dew point pressure (Das.S.K and Butler,1996) every component of the light hydrocarbon has a different dew point pressure. Methane, for instance, its dew point pressure is 1300 psi, while ethane is 600 psi, and another example is the propane which is 130 psi. choosing the composition of the solvents depends on the reservoir pressure. By opening the well on production and oil starts producing, the reservoir pressure starts declining, and in this case the amount of methane will not be completely dissolved in the oil due to the reduction in reservoir pressure less than the methane dissolving pressure, the injected methane will be produced separated to the surface which is uneconomical process. Mixing the methane with a percent of propane or butane, to increase the solvent concentration will give better results than injecting only methane.

5. The Effect of Soaking Time on Cyclic Solvents Injection

Adjusting the optimum soaking time for the cyclic solvents injection runs is very important and can effect on the dissolving gas in the heavy oil, because the gas needs enough time to be totally dissolved. This is better than producing the injected gas to the surface without being dissolved. Accordingly, the volatile solvents that is injected requires enough time for soaking to propagate into the oil and hence mix with oil. The effect of the sample condition during the soaking time, such as the sample pressure, temperature and solvent slug size determines the percentage of solvent that is mixed into the oil. Solvents slug composition is also an effective factor in determining the proper soaking time during the process.

6. The Effect of Viscous Fingering on The Cyclic Solvents Injection

Generally, the viscous fingering phenomena happens in the miscible displacement and also in the immiscible displacement, The reason behind that is the difference between the viscosity and mobility of the solvents and the viscous oil. Unlike the linear displacement where the injected gas (displacing fluid) is driving the crude oil (displaced fluid), in the experiment the solvent is injected and produced in a cyclic way (huff & puff), where the soaking time enables the solvent to be mixed and soluble in the crude oil. In the cyclic solvent injection process, after injection certain amount of solvent and leaving the sample soaking, a large part of the injected solvents is produced once the sample is put on the production. The effect of viscous fingering in this experiment has not been stated, however, from the experiment's result which shows that large amount of solvents produced that escaped from the sample either by channels or fingering.

7. Experimental Model

The schematic diagram of the experimental set up used for this test is shown in figure (1) It comprises of:

- A transparent sand pack model that has a dimensions of 101.3 X 3.17 X 4.9 cm. The upper cover was made by glass that allows direct visual observations of fluid movements and the gas bubbles. The sand pack has seven pressure ports, two fluid distribution, one ends to be used as an injections or production ends and a two-stem manifold valve at each end of the sand pack.
- A piston equipped transfer vessel used for oil injection into the sand pack.
- A positive displacement pump to hydraulically drive the piston of the transfer vessel.
- A piston equipped transfer vessel used for injection brine into the sand pack.
- An oil and gas collection vessel.
- Back pressure regulator.

A clean silica was used for preparing the sand pack, round sand grain with a density of 2.72 g/cc, and was washed before packing the core in order to remove the fines and any impurities.

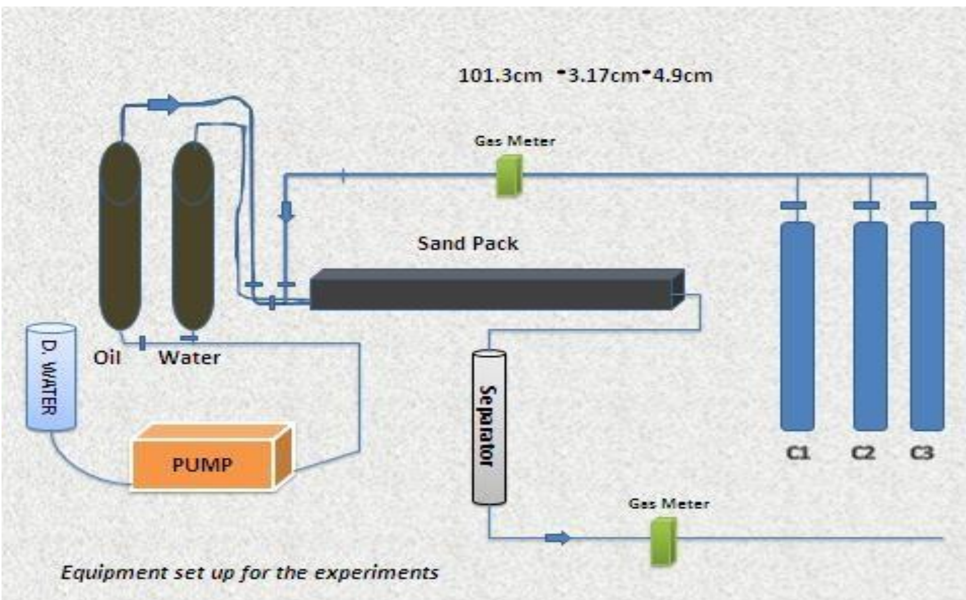


Figure1.The experimental model used for cyclic solvent injection

8.1 Preparing the Sand Pack

The sand pack had been cleaned very well by Varsol before the experiment started, to avoid any contamination or impurities from previous work that may affect the system. The sand pack was then carried out on a vibrating table that helps packing the sand grains correctly. A round grain of clean silica that has a density of 2.5 g/cc, and 130 to 150 mesh size was used. The sand was washed with a distilled water to remove fines prior the packing.

8.2 Sand Cleaning and Packing

A certain amount of sand was subjected to a washing by distilled water before packing it in the core holder. During the washing process, the sand in the vessel filled with water and was shaken to make the impurities and fines float by gravity segregation. Once all the fines were separated from the sand grains, the water dried from the sand. This process was needed in order to prevent any fines in the pores that may cause a reduction in the permeability of the porous medium.

8.3 Leak Test

In order to gain accurate results, the sand pack was tested to make sure that there is no leak. When the set up was ready and before starting any experiment, a compressed gas injected into the sand pack and then left for almost 24 hours. After that, the system pressure has not been changed which means that there is no leak in the model

8.4 Saturating the Sand Pack with Water

Once the sand pack completely filled with sand, the system was vacuumed by using a vacuum pump for about 7 hours in order to prevent air presence prior to saturating the pack with water. Right after, brine was flooded into the sand pack and measured later on in a separate vessel. That brine volume equals the volume of pores in the system, Pore Volume. The porosity also can be calculated using the porosity equation.

8.5 Sand Pack Properties

Table 1. Summarized the sand pack properties implemented in the tests.

Property	***Value & Unit***
Bulk volume	**1573.493 cc**
Pore volume	**503.517 cc**
Porosity	**0.32 %**
Water saturation	**0.19 %**
Oil saturation	**0.81 %**
Sand grain size	**1568.14 cc**
Oil viscosity	**4820 mPa.s at 15 C^0**
Oil density	**975 kg/m^3 at 15 C^0**
Solvent	**Ethane**
Temperature	**Room temperature**

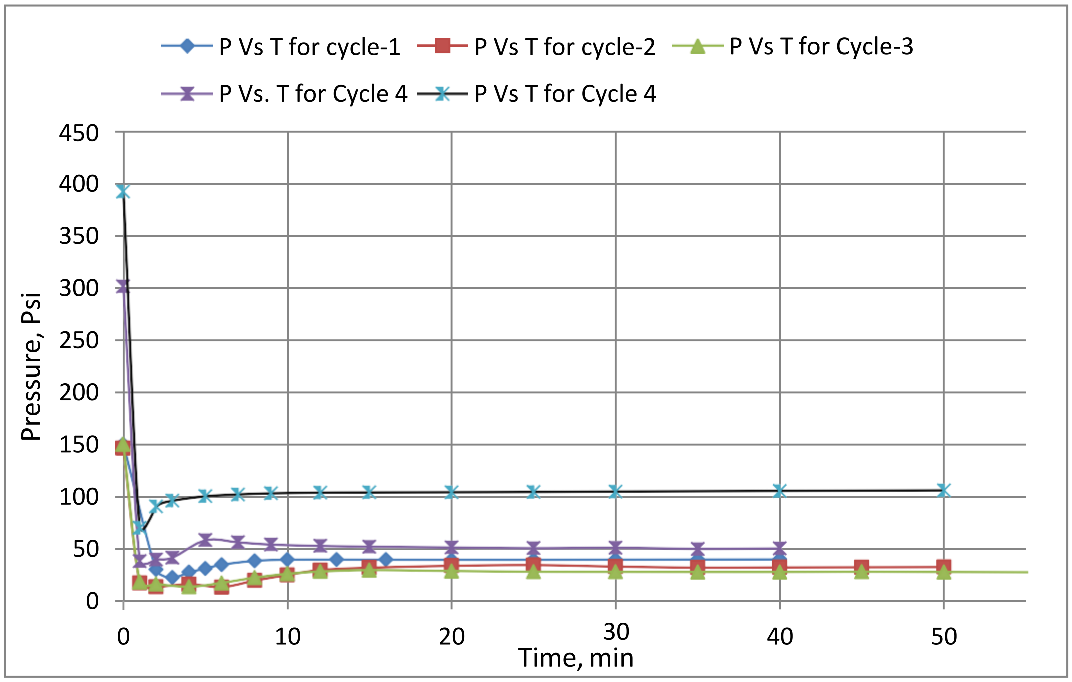
9. Experimental Procedure

Once the set-up is ready for run, the solvent is travel from the gas cylinder to the sample, passing through a digital gas flow meter to calculate the total volume of solvent injected in the sample until the end of injection period reached. At that moment, the injection valve was properly closed and the sample left a period of time for soaking which is 24 hours. During the soaking time, the oil viscosity was greatly affected by the dissolving and solubility of solvents and that is the main purpose of experiments. By the end of soaking period, the sample opened for production with the reading the reduction in sample pressure against time, and the flow of oil through the separator was recorded and collected, the solvents passing out of the separator was discharged out of the room. The procedure was repeated for every cycle during the experiments.

10. Results and Discussion

10.1 Sand Pack Pressure During Production Period

Chart (1) shows the relationship between the production time and production pressure, the sand pack pressure was monitored during the injection time, however, it has not been recorded, the variation in the sand pack pressure during the soaking time was not recorded as well, since the aim of this study was focused on the production results of heavy oil by solvent injection. This graph illustrate that at the beginning of production period in each cycle, the sample pressure drops sharply from the soaking pressure to around 30 psi in the first cycle, and similar values of production pressure after 2 to 3 minutes in the other cycles. In this early minutes of production, a large scale of the injected solvent discharged to the surface and hence did not advance effectively in the oil production by gas drive expansion or solution gas drive. The rapid reduction in the sample pressure should be controlled or regulated to allow more oil to be produced by gas drive or expansion mechanism.



Chat 1. Sand pack pressure during production period

10.2 Cumulative Oil Produced

In the cyclic solvent injection process, which contains injection period, soaking period and production period, the oil produced during each cycle is a function of all three periods, for instance, during the injection period, the amount of solvent slug injected and injection pressure contribute effectively in the distribution of solvent in the sample and dissolving the solvent in the oil, the more solvent dissolved in the oil leads to higher production rate. The soaking period as well, the pressurized solvent in the sample needs enough time to be dissolved in oil and to propagate in the oil to provide channels for the later solvent slug to be fingered and soluble in the oil. Finally, during the production period, the oil is produced and calculated in form of cubic centimeters to compute the amount of oil that is recovered, the amount of oil produced in each cycle is not constant, once the set-up is open for production, the pressure decreases abruptly to low values, the free solvent that has not been dissolved in the oil outflows initially from the sample causing the pressure to drops. Oil is produced by the mechanisms of expansion by solution gas drive during the outflows of solvents from the sample, part of the solvent that was dissolved in the oil improves the oil mobility by decreasing its viscosity.

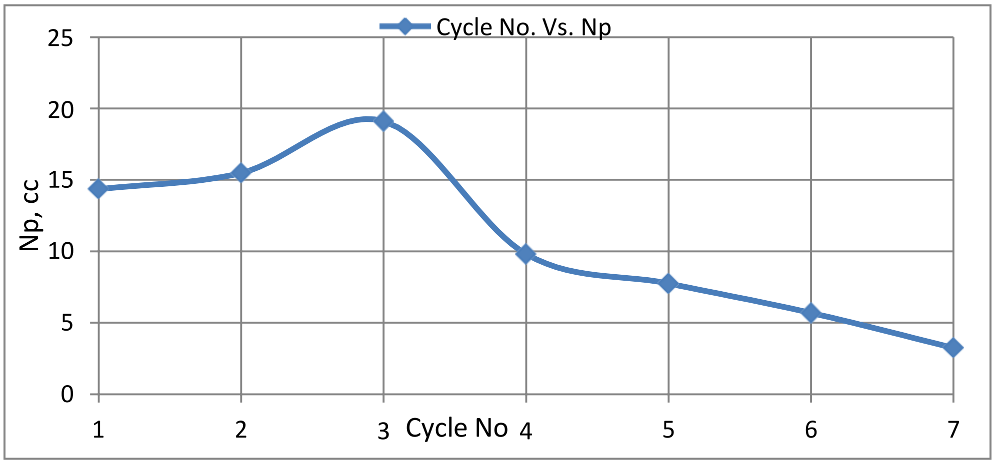


Chart 2. cumulative oil produced during the experiments

10.3 Oil Recovery Factor

The experimental results show that the recovery of oil during the cyclic solvents injections reach its highest rate during the first and second cycles of production in sequence, this is due to sample conditions at the first cycle where the sample is fully saturated with oil and the distribution of oil in the sample lowers the phenomena of viscous fingering. As we notice in chart(3), it shows the percentage of oil recovered in the first and second cycles is almost equivalent to the rest of the cycles. Additionally, the injected solvents propagate in the sand pack and resolves in the oil by utilizing the mechanisms of lowering the oil viscosity and increase its mobility. In regards to the oil recovery factory, it has been calculated for the total cycles as a cumulative factor, in other words, not a function of each cycle separately. The results shows that the amount of oil produced in the cycles not equal, and more oil has been produced during the first two cycles. Similarly, the slug size of solvent that was injected in each cycle is not equal. One of the reasons behind the high production in the first cycles is, due to the high pressure at the beginning of injection, more solvent was dissolved and mixed in the oil, this has formed an effective solution gas impact. Consequently, the oil viscosity was decreased and the mobility changed to allow the oil to move freely through the porous media.

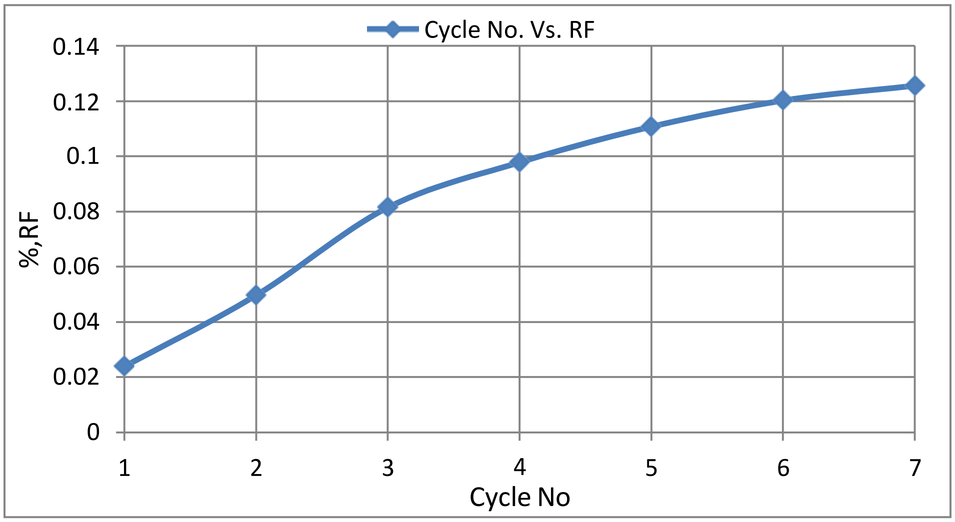


Chart 3. Oil recovery factor (cumulative)

10.4 Oil Saturation Profile

The oil saturation in the sample was determined by calculating the amount of oil that was primary injected into the sample which is the initial oil saturation Soi, which is equal to the brine size produced during the sample preparation. Once the sample is put on production the saturation of oil, consequently, started to decrease. What is noticeable is that the value of oil saturation reduction in the first two cycles, (from 0.81 to 0.74) is greater than the rest of the cycles.

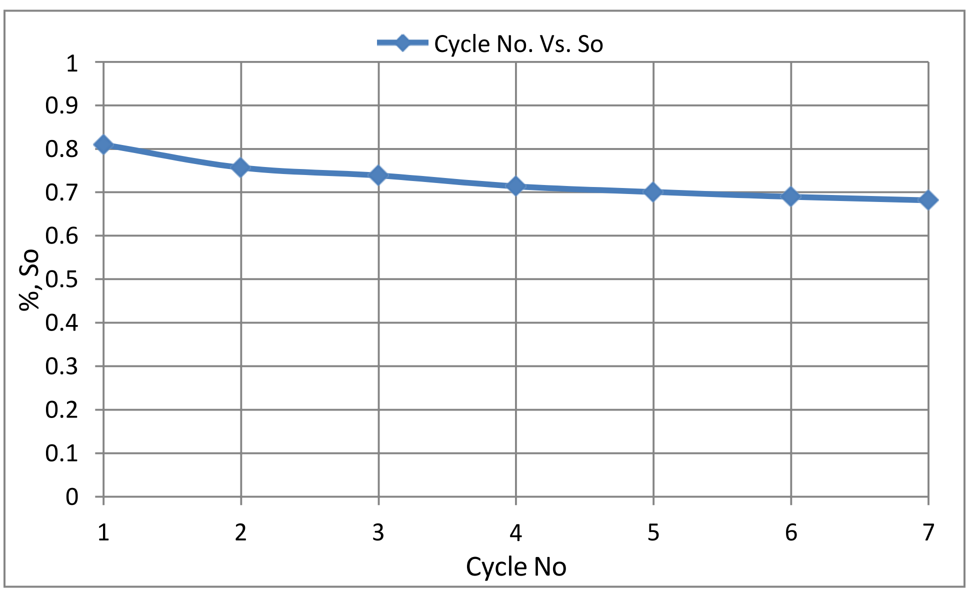


Chart 4. Oil saturation profile

11. Conclusion

- The experimental results for the cyclic solvents injection as a tertiary recovery method shows that this technique can improves the oil production in thin formation and increases the recovery factor.
- This experimental work shows a great understanding of the cyclic solvents injection process, although the reservoir conditions are different that the experiment condition, the impact of solvent on the heavy oil recovery have brought good results during the cyclic runs.
- The chemical reactions between the injected solvents and oil throughout the experiments, the molecular diffusion and convective dispersion, as well as the interfacial tension, all these parameters were not counted in this study, the attention mainly focused on the results of production conditions by using cyclic solvents injection.
- During the production period in the cyclic solvent injection, the quick gas release from the sample is one of the weakness of the process, this might slow down the production rate and cause the process inefficient.
- The rapid reduction in the sample pressure should be controlled or regulated to allow more oil to be produced by gas drive or expansion mechanism.
- Using a surfactant or foamy agent in the cyclic solvent injection "huff & puff", could contribute positively to regulate the movement of solvents during the production stage, and to overcome the outflow of gas early in the production.

References

[1] D. Cuthiell*, G. Kissel, C. Jackson, T. Frauenfeld, D. Fisher, K. Rispler. "Viscous Fingering Effects in Solvent Displacement of Heavy Oil" journal of Canadian petroleum technology, volume 45, No.7, July 2006.

[2] G.B. Lim, R.P. Krv, B.C. Harker, and K.N. Jha. "Three-dimensional Scaled Physical Modelling of Solvent Vapour Extraction of Cold Lake Bitumen". " journal of Canadian petroleum technology, April 1996, volume 35, No.4

[3] J. Ivory, J. Chang, R. Coates, and K. Forshner " Investigation of cyclic solvent injection process for heavy oil recovery" " journal of Canadian petroleum technology, septmber 2010, volume 49, No. 9

[4] J. QI, M. Polikar, "Optimal Solvent and Well Geometry for Production of Heavy Oil by Cyclic Solvent Injection" Canadian international petroleum conference, 2005-194

[5] Mingzhe Dong, Sam Huang, and Kelth Hutchence, "Methane pressure cycling process with horizontal wells for thin heavy oil reservoirs" SPE Reservoirs evaluation and engineering, April 2006.

[6] Juhua Li, Tao Jiang, LinPeng Xiao, Mingqiang Yang, Jian Zhao. "field study of enhancing oil recovery by gas cycling injection in Ultra deep heavy oil reservoirs" SPE 115877, society of petroleum engineers, 20-22 October 2008.

[7] M. Feali and R. Kharrat " feasibility study of cyclic VAPEX process for low permeable carbonate systems" SPE 3-5 December 2008.

[8] NG.B. Lim, P.R. Kry, B.C. Harker , K.N. Jha "Cyclic Stimulation of Cold Lake Oil Sand With Supercritical Ethane". SPE 30298. 19-21 June 1995.
[9] Shehbaz Shoaib, and B. Todd Hoffman " CO2 Flooding the Elm Coulee Field" SPE 123176. 14-16 April 2009.
[10] Butler, R.M., Mokrys, LJ. 1993A, "Recovery of Heavy Oils using vaporized hydrocarbon Slovent: Further development of the VAPEX Process. J. Can. Petro-Tech. 32(6):56-62.
[11] Frauenfeld, T.J.W., Lillico, D.A 1996. "Solvent Assisted method for mobilizing Viscous Heavy Oil". United States Patent No. 5899274.
[12] Upreti, S.R. Lohi, A., Kapadia, R.A., EHaj, R. 2007. Vapor Extraction of Heavy Oil and Bitumen. Energy Fuel. 21(3): 1562-1574.