Heavy Oil Recovery: Environmental Implications and Mitigation Measures

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Balancing oil and gas activities with environmental protection measures is necessary while producing heavy oil. This is because; heavy oil is produced by either chemical or thermal recovery methods which pose harmful effects on the environment. In order to ensure that the oil and gas industry sustainable, there must be elimination of all factors that degrade the environment. Since heavy oil must be produced to meet increasing energy demands, environmentally friendly measures should be used to ensure that there is low carbon emission, little or no chemical retention in the formation. This paper presents mitigation measures for eco-friendly heavy oil recovery; they include the use of renewable energy for heat/steam generation during thermal recovery in order to reduce emission of fuels and use of plant based non-toxic and degradable chemicals to avoid pollution of ground water and formation. These chemicals include polymers, alkali and surfactant during chemical flooding. This ensures the oil and gas industry keeps up with the sustainable development goals.

Keywords: SAGD- Steam assisted gravity drainage, ES-SAGD – Expanded solvent steam assisted gravity drainage

INTRODUCTION

According to Nwosi-Anele and Iledare, (2016), the oil and gas industry is said to be sustainable, if there is an elimination of all factors that constitute harm to the environment while exploiting the oil reserves. Oil and gas activities around the world is not just restricted to the conventional light and/medium crude oil recovery, it also includes recovery of unconventional heavy and extra heavy oil. Heavy and Extra heavy oil recovery involves complex recovery methods compared to conventional medium oil. The complex recovery used for heavy oil recovery involves use of chemicals and heat. According to US Geological Survey, Heavy oil is a complex hydrocarbon having API gravity between 10⁰API – 22⁰API, while extra heavy has API gravity below 10⁰API. World Energy council classifies heavy crude oil as crude oil with API gravity below 22⁰API and density above 920g/ml. The mode of recovery of heavy and extra heavy oil is complex because they require enhanced oil recovery methods, usually thermal and/or chemical recovery. Chemical flooding (polymer, surfactant) reduces interfacial tension between the oleic and aqueous phases and increases the viscosity of the displacing fluid resulting in favorable mobility and increased oil production. Thermal recovery methods involve the use of heat/steam generation to reduce the viscosity of the oil and increase its mobility. Chemical recovery processes involve the injection of various chemicals into the reservoirs. Alkali, surfactant and polymers have proven successful for heavy oil recovery (Obuebite et al, 2018) (Uzoho et al, 2015).

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Only little quantities of these chemicals are expected to be recovered with the produced oil. The interaction of the chemicals left in the subsurface geologic formations with connate fluids, brines, and rocks are not completely understood nor can it be positively stated that toxic substances or hazardous materials are not produced by the decomposition of such chemicals (Donaldson, 1989). Such toxic or hazardous substances may be confined to the reservoir, and no doubt transfer toxins to the environment, since the environment is part of the ecosystem (Ellis et al., 2017). This paper reveals that pollution could occur in the recovery of heavy and extra heavy oil because of the technologies used, the implications of the pollution and control and mitigation measures. It employs the use of environment management system techniques to aid the regulation of environmental best practices for the total efficiency of the oil and gas industry. This paper is necessary because it reveals how the recovery of heavy and extra heavy oil affect the environment and result in emission of hazardous materials into the environment.

LITERATURE REVIEW

Heavy and Extra heavy oil is formed by the cenozoic and mesozoic tectonic movement that damaged the paleo-reservoirs, causing conventional oil to migrate the shallow formations or earth surface. These migrated conventional oil experience micro degradation along with oxidation by free oxygen thereby forming heavy oil (Caineng et al., 2013). Heavy and Extra-heavy oil are characterized by high density, high viscosity, consisting of carbon, oxygen, hydrogen, nitrogen and sulphur where carbon and hydrogen are the dominant components. Metallic elements such as Nickel, Vanadium, Copper, and Iron occur in trace quantities.

Heavy oil has been found to be a good alternative to light/medium crude oil in this era of increasing energy demand and reducing light and medium crude oil reserve base. Countries like Canada, Venezuela, Trinidad and Tobago heavy oil recovery have begun to yield millions of barrels and meeting their countries energy demand. Recovery methods that have been applied with great success are:

Chemical Recovery Methods
- Polymer flooding
- Alkali-surfactant and polymer flooding

Thermal Recovery Methods
- Steam assisted gravity drainage
- Expanded steam assisted gravity drainage.
- Steam flooding/injection
- Cyclic steam stimulation
- In situ combustion
- Toe to heel air injection

CHEMICAL RECOVERY METHODS

Polymer Flooding

Many heavy-oil reservoirs in Canada are relatively small, thin and are not good candidates for expensive thermal recovery methods. This has made Polymer, Alkali and Surfactant flooding relevant for thin and small reservoirs. Polymer flooding involves the injection of high viscous polymer fluids into the reservoir to act on the thick oil layers. Polymers act as the displacing fluid, effectively displacing (pushes out) the oil thereby increasing the sweep efficiency due to its high viscosity resulting in improved oil recovery. This method has been applied in Nigeria by Mogbo, (2011) in a reservoir located in the Niger Delta with a gas cap and little water aquifer. It was found that there was incremental oil production of 7% but a lot of polymers were lost in the subsurface formation which is hazardous to the environment.

Alkali-Surfactant-Polymer Flooding (ASP)

This method involves the injection of alkali -surfactant into the reservoir to obtain an ultra-low interfacial tension and enhance oil recovery. In Enhanced oil recovery, Surfactants are primarily used to reduce the tension between the fluids at the interface. Alkalis (high pH chemicals) form natural surfactant upon reaction with the napthenic acid in the crude oil. They are less expensive than the synthetic surfactant and reduces the absorption of synthetic surfactant. In Nigeria, Awioroko et al., (2014) applied alkali-surfactant and polymer flooding for heavy oil recovery. Alkali used was sodium hydroxide, surfactant was Tween (polysorbate), and polymer used was Gum Arabic and salt. The Gum Arabic used as polymer is a local plant found in the wild rain forest in Nigeria and other parts of Africa. An incremental recovery of 57% was observed with ASP in Nigeria. The advantage of this method is that a local plant is used and such polymer even though lost in the formation may not be of any harm to the environment and the ecosystem.

THERMAL RECOVERY METHODS

Steam Assisted Gravity Drainage (SAGD)

This is an advanced method of heavy oil production. It utilizes steam as an agent to conduct heat through thermal conduction and convention while being produced through a gravity drainage. According to Delamaide, (2015) SAGD can be applied in three different ways:
- Two horizontal wells are drilled near the reservoir bottom with one on top of another. The upper well is an injector while the bottom well is a producer.
- A horizontal well is drilled alongside two or more vertical wells. The horizontal well is drilled at the bottom of the reservoir with the vertical wells above it. The vertical well serves as the injectors while the horizontal well is the producer.
The third way is to use only one horizontal well with a steam string running into it to introduce steam into the reservoir. This method is more economical than the other two; it enhances Gas oil ratio and oil production rates.

SAGD has been found to be uneconomical in certain formation especially in North America (Amirian et al, 2018). Hence SAGD can be said to be not economical and environmentally friendly, because steam generation results in increasing carbon emission into the environment and is also costly. Thermal methods may by environmentally friendly if carbon emission via steam generation is eliminated. Steam generation can be done using solar power. This can be applied to all the thermal methods.

**Figure 1: Steam assisted gravity drainage**
(source: oilfield team)

**Expanded Steam Assisted Gravity Drainage (ES-SAGD)**

This method is similar to SAGD, but it involves the combination of steam with solvent injected via the injection well to aid production of oil. The solvent injected could be either an alkali, surfactant or a polymer (this reduces the interfacial tension between oil and water, capillary pressure and alter wettability). It has shown improved heavy oil recovery rates. Encana Corporation of Canada has tried ES-SAGD pilot scheme at its Senlac thermal project in 2002 for heavy oil (Nasr, 2005). Solvent-assisted SAGD can lead to lower steam usage and energy intensity than that of SAGD. This has several implications. First, less steam use means less energy consumption which in turn implies less fuel gas emissions to the atmosphere. Second, less steam use means less water handling, production and treatment. Third, produced solvent can be separated and re-injected into the oil sand formation, i.e., it can be recycled. The injected steam keeps the region near the well bore hot, making the solvent to remain in the vapor phase which in turn promotes its transport (Gates, 2010). The major disadvantage of this method is the retention of the solvent in the shallow reservoir which is likely to cause pollution of ground water.

**Steam Flooding/Injection**

Dry steam is injected into the reservoir through the injection well to supply energy and heat the oil layers reducing the oil viscosity, making thick oil layers mobile to flow into the production well. This method is effective in heavy oil reservoirs with bottom aquifer and large gas cap.

**Figure 2: Steam injection**
(source: oilfield team)

**Cyclic Steam Stimulation**

Steam is injected into a drilled well in the formation; the well is shut for six (6) days to allow the steam to soak for a few days. The steam soaks the formation, mobilizing the oil and building up reservoir pressure. After six (6) days, the oil is produced from the same well.

**Figure 3: Cyclic Steam injection**
(source: oilfield team)
In-situ Combustion

This method is one of the earliest methods used in heavy oil recovery. It was patented in the United States in the year 1920. It is sometimes referred to as fire flooding. Air/oxygen is introduced into the reservoir; the well ignites the oil in the reservoir and starts a fire. Heat is generated as a result of oil oxidation, increasing the temperature. The heat generated by burning the heavy hydrocarbons in place produces hydrocarbon cracking, vaporization of light hydrocarbons and reservoir water in addition to the deposition of heavier hydrocarbons known as coke. As the fire moves, the burning front pushes ahead a mixture of hot combustion gases, steam and hot water, which in turn reduces oil viscosity and displaces oil toward production wells.

Toe to Heel Air Injection (THAI)

Toe to heel air injection (THAI) process is a new enhanced oil recovery process used in the recovery of heavy oil formulated by Petro bank Energy and Resources limited of Canada. It is a thermal recovery method that integrates advanced reservoir technology and horizontal well concepts for heavy oil recovery. It burns the heavy coke fraction of the reservoir to produce heat required to increase the temperature of the oil-bearing formation, this reduces the viscosity of the oil, making it mobile (Fatemi et al, 2011). THAI is similar to in-situ combustion in operation but the injector well is a vertical well, while the producer well is a horizontal well, more of the mobile oil penetrates the producer well because it is a horizontal well as seen in Figure 4. Recovery efficiency is high with toe-to heel air injection compared to in-situ combustion.

Table 1: Environmental implication of heavy oil recovery

<table>
<thead>
<tr>
<th>S/N</th>
<th>RECOVERY METHOD</th>
<th>ENVIRONMENTAL IMPLICATION</th>
<th>MITIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Polymer Flooding</td>
<td>Polymer retention in the formation causing ground water pollution and pollution of ecosystem resulting from water cycle processes.</td>
<td>Use of environmentally friendly natural polymers sourced from plants or trees e.g. Gum Arabic</td>
</tr>
<tr>
<td>2.</td>
<td>Alkali-Surfactant-Polymer Flooding</td>
<td>Alkali-Surfactant-Polymer retention in the formation causing ground water pollution and produced water pollution.</td>
<td>Use of locally sourced/ environmentally friendly alkali-surfactant. Typically sourced from plants and trees. e.g. Lecithin</td>
</tr>
<tr>
<td>3.</td>
<td>Steam Assisted Gravity Drainage</td>
<td>Carbon emission resulting from fuel used to generate steam.</td>
<td>Use of renewable energy (wind, solar, hydro) as source of steam generation</td>
</tr>
<tr>
<td>4.</td>
<td>Expanded Steam Assisted Gravity Drainage</td>
<td>Carbon emission resulting from fuel used to generate steam and retention of injected solvent</td>
<td>Use of renewable energy (wind, solar, hydro) as source of steam generation and use of eco-friendly solvent.</td>
</tr>
<tr>
<td>5.</td>
<td>Cyclic steam stimulation, Steam Injection, In-situ combustion and Toe to heel air injection</td>
<td>Carbon emission resulting from fuel used to generate steam.</td>
<td>Use of renewable energy (wind, solar, hydro) as source of steam generation</td>
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</table>

CONCLUSION

Heavy oil recovery methods are mainly thermal and/ or chemical method, only a few reservoirs are successfully recovered using artificial lifts systems. The use of synthetic chemicals and harmful solvent to enhance oil recovery is a threat to the environment and the climate. To mitigate this challenge, use of environmentally friendly chemicals (green fluids) that are mostly plant based and the generation of heat/ steam using renewable energy sources (wind, solar, hydro) is a way to ensure that a balance of Energy - Economy- Environment is attained complying with Sustainable Development Goals.
REFERENCES


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