Recovery of Heavy Oil from Unconventional Source (Oil Sands) with Design Steam Injection System

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Abstract— *The use of steam ranging from 100°C to 280°C in extracting and producing oil from unconventional reservoir (oil sand) was investigated. Core samples were obtained from Edo state in Nigeria. An oil sand laboratory reservoir model was used to investigate technical feasibility of the injection of steam as an enhanced oil recovery agent for tight hydrocarbon reservoirs and the effect of temperature on the petrophysical properties such as porosity and permeability of oil sand reservoir. Steam was injected into the oil sand reservoir to recover bitumen at different temperatures ranging from 100°C to 280°C. Results showed that as the temperature of the steam increased, more hydrocarbon (bitumen) was recovered due to the reduction of its viscosity and oil-water interfacial tension. The core experiment indicates that the porosity and permeability of a tight formation such as that of oil sand at ambient temperature is 0.038 and 0.007MD respectively. An increase in reservoir temperature by the injection of steam altered the petrophysical properties (porosity and permeability) of the reservoir. Samples collected and analyzed after recovery showed a decrease in porosity and an increase in the permeability of the formation. Results indicate that the viscosity of bitumen decreased with an increasing temperature. Maximum recovery of bitumen was obtained at 280°C. The injection of steam at temperature of 300°C and above, would produce more bitumen at industrial scale and could be refined and upgraded to liquid fuels to supplement the drastic reduction of the conventional oil. The results obtained from this work showed good agreement with data from existing data.*

Keywords— Bitumen, Heavy oil, Oil sands, Permeability, Porosity, Steam, tight formation, Unconventional, viscosity.

I. INTRODUCTION

Oil sands are either loose sands or partially consolidated standstone containing a naturally occurring mixture of sand, clay and water, saturated with a dense and extremely viscous form of petroleum technically referred to as bitumen (or colloquially as tar due to its superficially similar appearance)(Ezra, 2011). crude bitumen is a thick, sticky form of crude oil, so heavy and viscous (thick) that will not flow unless heated or diluted with higher hydrocarbon such as light crude oil or natural gas condensate. At room temperature, it is much like cold molasses (Michael, 2009). The presence of water has long been considered to be an integral part of oil sands structure, although there is some conjuncture as to its extract nature. Early Cryo-transmission election microscopy (TEM) studies provided evidence that water in natural oil sands exists as water-in-oil (w/o) emulsion (Zajic et al, 1981). On the other hand, a model of oil sands with a layer of water (approximately 10mm thick) separating bitumen from the sand surface has been proposed(Takumura, 1982). It is also necessary that the oil composition may change during thermal production of bitumen with steam, for example a common observation is that the produced oil is lighter than the original, which is believed to be a consequence of in situ upgrading processes (Montgomery et al., 2014).

Natural bitumen is oil having a viscosity greater than 10,000 centipoises under reservoir conditions and an AP1 gravity of less than 10^0 API (Hoffman, 2009). The unconventional formations may be as porous as other sedimentary reservoir rocks, their extremely small pore sizes and lack of permeability make them relatively resistant to hydrocarbons flow. The lack of permeability means that the oil and gas typically remain in the source rock unless natural or artificial fractures occur.

Unconventional oil reservoirs are characterized by unfavorable properties of rock formation, in which are accumulated, as well as unfavorable parameters of reservoir fluids. Oil reservoirs of this type occur in many places on Earth, and are the vast majority, if it comes to the global resources of hydrocarbons. In most cases, subjects to the economically justified oil production is necessary to perform the stimulation treatment, like hydraulic fracturing or acidizing. (Beckwith, 2014).Unconventional reservoirs include reservoirs such as tight-gas sands, gas sands, gas and oil shales, coal bed methane, heavy oil and tar sands, and gas hydrate deposits. The existences of these resources worldwide have been known for decades, but it was difficult and economically enviable to extract them (Milagros et al, 2018). Unconventional hydrocarbon resources are becoming a significant component of world energy consumption (Jia et al 2012; Zou, 2013). The characteristics of the unconventional resources are as follows: the sources and the reservoir coexist; the porosity and the permeability are ultralow; nano-scale pore throats are widely distributed; there is no obvious trap boundary; buoyancy and hydro dynamics have only a minor effect (Sun and Jia 2011; Jang et al 2013). These reservoirs require assertive recovery solutions such as stimulation treatments or steam injection, innovative solutions that must overcome economic constraints in order to make recovery from these reservoirs. The selection of the right way to drill unconventional hydrocarbon resources is closely dependent on the individual properties of the reservoir rock (Beckwith, 2014). Due to the nature of this type of reservoir the drilling process should provide access to a maximum volume of reservoir due to low permeability and heterogeneity of the rock for unconventional reservoirs is explicable to vertical horizontal and multilateral wells (stopa et al, 2015).

As the demand of finished produce of hydrocarbon increases and the abundance of unconventional oil reservoir, this work will explore recovery of heavy oil (bitumen) from unconventional source (oil sand) with designed steam injection system which will be refined to liquid fuels for our consumption.

II. MATERIALS AND METHOD

2.1 Experimental Setup

An unconventional (oil sand) reservoir was modeled to recover bitumen using steam (at different temperature) injection. The schematic showing the design of the recovery system is presented in figure 1.

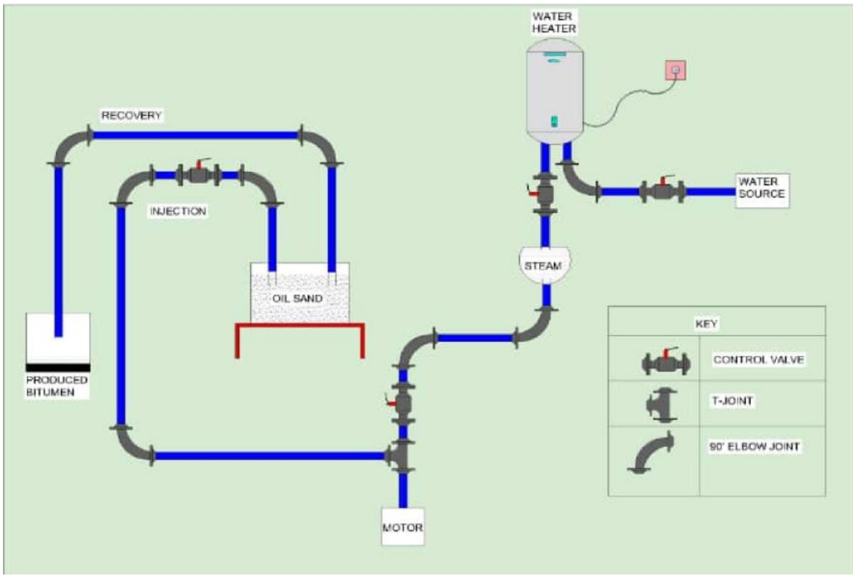

FIGURE 1: Schematic Diagram of Experimental Set Up

2.2 Materials

The following materials were used for the experiment: Core samples, steam, an oil sand reservoir model, bitumen (1940g), crucible, weighing balance, tong, spatula, core holder, cement, soil water, meter rule, measuring cylinder, stop watch, thermometer, darcy flow line, beaker.

2.3 Experimental Procedure

1940g of bitumen (001P) was buried in the reservoir at a depth of 1.8ft.

60 litres volume of water was pumped into the water heater through the water source and heated for 100^{0}C.

The valves connecting the reactor (steam) and motor were opened and the steam pumped into the reservoir at a pump pressure of 0.5hp continuously while the reservoir gets heated up, melting the bitumen (turning it into a pumpable slurry) and pushing it out through the producer pump. The reservoir was evacuated and filled again with oil sands and another 1940g of bitumen at same depth and the process repeated for the temperature of 100^{0}C, 115^{0}C, 130^{0}C, 145^{0}C, 160^{0}C, 175^{0}C, 190^{0}C, 205^{0}C, 220^{0}C, 235^{0}C, 250^{0}C, 265^{0}C, and 280^{0}C respectively and the recovery (production) made were: 45.385g, 63.08g, 80.07g, 98.04g, 116.1g, 133.8g, 151.5g, 169.2g, 186.9g, 1,904g, 1,923g and 1,939g respectively, there was no liberation of bitumen at 60^{o}C therefore, no recovery (production) was made.

III. RESULTS

3.1 Recovery at Different Temperatures

The result of the heavy oil recovered at different temperature is presented in figure 2.

The trend of the result in figure 2 shows the gradual liberation of bitumen as temperature of the steam injected was increased from 110°C to 230°C. With further increase in the temperature of the steam injected, there was a rapid corresponding increase in the (recovery) of bitumen from the sand grains. Maximum recovery was made between 230°C to 280°C. This recovery efficiency is found to be associated with minimum in oil-water intertacial tension and reduction in viscosity. Increasing the temperature of steam injected into the oil sand reservoir showed significant improvement in the recovery of bitumen oil sand rock surfaces by reducing the oil-water interfacial tension and also the viscosity of bitumen. There appeared to be a linear correlation between oil bitumen recovery rate and viscosity ratio.

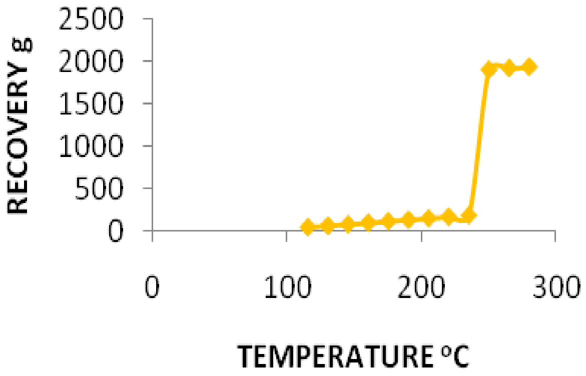

FIGURE 2: Heavy Hydrocarbon (Bitumen) Recovery from Oil sands with Steam Injection

3.2 Effect of Temperature on Viscosity and Recovery

The recovery of heavy oil as a function of temperature and viscosity is presented in figure 3. The result shows a continuous decrease of the viscosity of bitumen with increase in temperature, hence an increase in recovery as bitumen easily flows through the recovery pipe. One major hindrance in the mobility (recovery) of bitumen from deep formation is its high viscosity. The viscosity of bitumen is about one million CP (10^3 pars) at reservoir conditions. The asphatene molecule in unconventional oil (bitumen) has a high concentration of heavy polar molecules. These molecules interact strongly with the host rock oil to make the flow extremely difficult. One of the effective ways of liberating (producing) bitumen from sand grains is to reduce its intermolecular interactions by increasing the temperature to lower its viscosity.

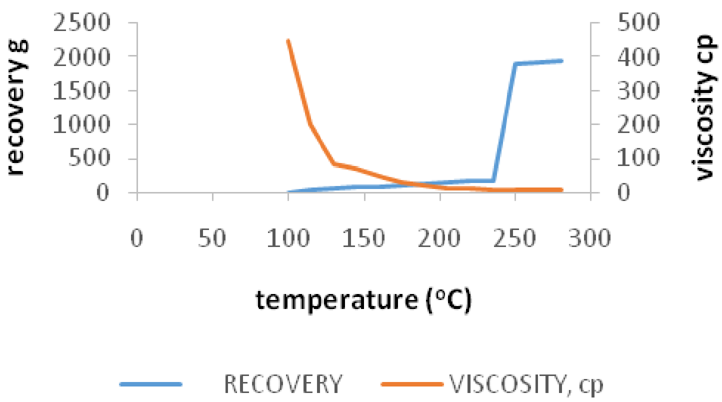

FIGURE 3: Effect of Temperature on Viscosity and Recovery

3.3 Temperature effect on porosity and recovery

The result of the influence of temperature on porosity and recovery is presented in figure 4.

From the plot, an increase in temperature gives a corresponding increase in the permeability of the formation and a decrease in its porosity.

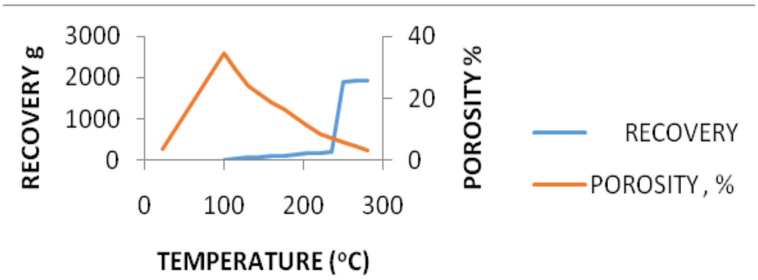

FIGURE 4: Effect of Temperature on Porosity and Recovery

3.4 Temperature Effect on Permeability and Recovery

The relationship between the recovery and permeability with temperature is shown in Figure 5.

Permeability is high at higher temperature which corresponds to the recovery.

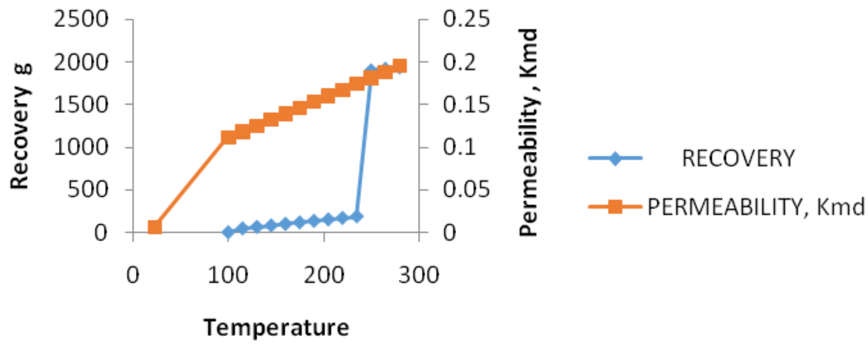

FIGURE 5: Effect of Temperature on Permeability and Recovery

3.5 Relationship between Petrophysical Properties, Viscosity and Temperature

Figure 6 presents the relationship between all the parameters studied at different temperature and the recovery of heavy oil.

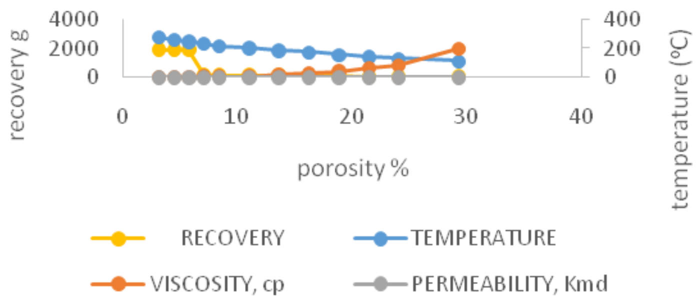

FIGURE 6: Effect of Temperature on Petrophysical Properties and Recovery

IV. CONCLUSION

A technical feasibility of heavy hydrocarbon bitumen recovery in an oil sands reservoir is evaluated on the laboratory scale and from an unconventional reservoir model. The following conclusions were drawn based on preliminary findings.

- The unconventional (oil sands) reservoir (sample from Edo state) is a tight formation with porosity of 0.038 and a permeability of 0.007MD.

  The recovery of heavy hydrocarbon (bitumen) with the injection of steam remains challenged by factors such as low permeability and low porosity; however experimental results do indicate that the injection of steam is enhanced oil recovery method based upon encouraging increase in bitumen production obtained in the laboratory.

- The increase in the production of bitumen is dependent on an increase in temperature. As the temperature of the steam injected into the reservoir increase, recovery also increases.
- The softening and melting points temperature of bitumen are 110^0C and 116^0C respectively. The higher the temperature, the more bitumen softens, melts and turns into a pumpable slurry as the viscosity reduces.
- Oil recovery method based upon encouraging increase in bitumen production obtained in the laboratory.
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