International Journal of Scientific Research and Engineering Development-– Volume 6 Issue 6, Nov- Dec 2023

Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Heavy Oil Production in Niger Delta: Core Flood Studies to Evaluate Efficiency of Oil Recovery by Combined Cyclic Steam Stimulation and Steam Flooding

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Abstract

Steam flooding and Cyclic Steam Stimulation (CSS) are thermally enhanced oil recovery methods that are effective with heavy crude oil and shallow reservoirs. Improved reservoir seepage, lower surface tension, and greater oil permeability result from the heating of the crude oil in the formation caused by the steam injection. Cyclic Steam Stimulation, as opposed to Steam Flooding, is a single-well operation in which oil production and steam injection both take place in the same well. The optimal steam injection temperature is investigated as well as the differences between Cyclic Steam Stimulation and Steam Flooding. Field studies have demonstrated that when a Cyclic Steam Stimulation scheme is changed to a Steam Flooding scheme, the recovery factor is at its highest. Thisstudy focuses on using Cyclic Steam Stimulation and Steam Flooding in combination to produce heavy oil from the Niger Delta, which has the potential to contribute 15% of Nigeria's total oil production. For effective heavy oil production in the Niger Delta, this study offers a thorough overview of thermally enhanced oil recovery methods.

Keywords: Heavy oil, Cyclic SteamStimulation, Steam flooding, Thermal-Enhanced Oil Recovery, Niger Delta.

1.0 Introduction

The increasing demand for oil due to the thriving global economy has led to the development of unconventional oil resources (heavy oil). Heavy oil has garnered worldwide attention following its abundant reserves and depletion of conventional oil resources. Enhanced oil recovery (EOR) techniques have been implemented and some are still being researched, to efficiently produce this type of crude.

Cyclic Steam Stimulation (CSS) and steam flooding are thermal-enhanced oil recovery techniquesthat work well with heavy crude oil and shallow reservoirs. The heating of the crude oil in the formation by injected steam (heat carrier) reduces its viscosity while increasing mobility [1,2]. This leads to improved reservoir seepage, lower surface tension, and increased oil permeability. Cyclic steam stimulation differs from Steam flooding by being a single-well operation as steam injection and oil production are done in the same well.

Various field cases have shown the recovery factor to be the highest when a CSS (steam soak) scheme is converted to a steam flooding (SF) scheme. A good case study is the Qi-40 Block in Laohe, China. Before SF, oil saturation was 0.57 and the recovery factor was 24%. A simulation study was conducted in 1997 to compare continuous steam soak, Water Flooding (WF), and Steam Flooding SF. The results for the Lian II are shown in Table 1[3].

Table 1: Simulated Results of Different Schemes [3]

Scheme	**Production Time (d)**	**Cum. Steam Injected (10^3 tons)**	**Cum. Oil Produced (10^3 tons)**	**Cum. Water Produced (10^3 tons)**	**Recovery Factor in Period (%)**	**OSR**	**Net Oil Produced (10^3 tons)**
Soak to end	1210	101.8	43.8	87	13.9	0.43	37
Soak to hot WF	2975	49.8	63.8	67.6	20.2		60
Soak to SF	1555	466.8	108.5	449	34.4	0.23	75

This study is focused on the application of a combined cyclic steam stimulation and steam flooding technique in the production of heavy oil from the Niger Delta.Heavy oils, when exploited, have the capability of contributing 15% of the total oil production in Nigeria [4]. A careful evaluation of the reservoir and fluid properties using the EOR screening criteria adapted from the works of Taber et al has confirmed the suitability of these techniques in the Niger Delta. The oil recovery data during the core flood experiments was collected and a comparative analysis was done to determine the optimum production strategy for this reservoir.

1.1 *Theory of* Cyclic Steam Stimulation

In 1959, the steam stimulation process was discovered by chance in the Mene Grande Tar Sands in Venezuela**.** During a steam injection trial, it was decided to relieve the pressure from the injection well by backflowing the well. When this was done, a very high oil production rate was observed. Since this discovery, many fields have been placed on steam stimulation [5].

Steam stimulation involves three stages, which are namely: injection of steam, soaking period, and production of oil [6]. The steam stimulation process, also known as the steam huff and puff, steam soak, or cyclic steam injection (CSS), begins with the injection of 5000–15,000 bbl of high-quality steam [5]. This can take days or weeks to complete. The well is then shut in, and the steam is allowed to soak the area around the injection well. This soak period is fairly short, usually ranging from 1 to 5 days. The injection well is then placed on production. The length of the production period is dictated by the oil production rate and can last from several months to a year or more. The cycle is repeated as many times as is economically feasible. Oil production will decrease with each new cycle [7]. In CSS, the steam injection and production are operated in a single well [8].According to the National Petroleum Council, 2007, typical recovery factors for CSS are 20% to 40% OOIP with steam/oil ratios of 3 to 5.

1.2 Steam Flooding Process

The steam injection process involves a continuous steam injection into an oil-bearing, porous medium. This results in the formation of an almost constant-temperature, slow-advancing steam zone around which the viscosity of the oil is drastically reduced, thereby increasing oil mobility. This highly mobilized oil within the steam zone is subjected to a vaporizing gas drive, as a result of which the initial oil saturation is reduced to as low as 10% [6]. However, because it is a pattern-driven process, its performance is ultimately determined by the size of the pattern and the geology [9,10]. A numerical study conducted on steam injection in heavy oil revealed that it improves oil recovery up to 60% during a fixed period and that only 30% of OOIP can be recovered by the hot water injection method [11].

Several mechanisms have been identified that are responsible for the production of oil from a steam drive. These include thermal expansion of the crude oil, viscosity reduction of the crude oil, changes in surface forces as the reservoir temperature increases, and steam distillation of the lighter portions of the crude oil [5]. Another important mechanism is the increased reservoir pressure (energy) owing to steam injection. Steam applications have been limited to shallow reservoirs because, as the steam is injected, it loses heat energy in the well bore. If the well is very deep, all the steam will be converted to liquid water.

2.0 Materials and Methodology

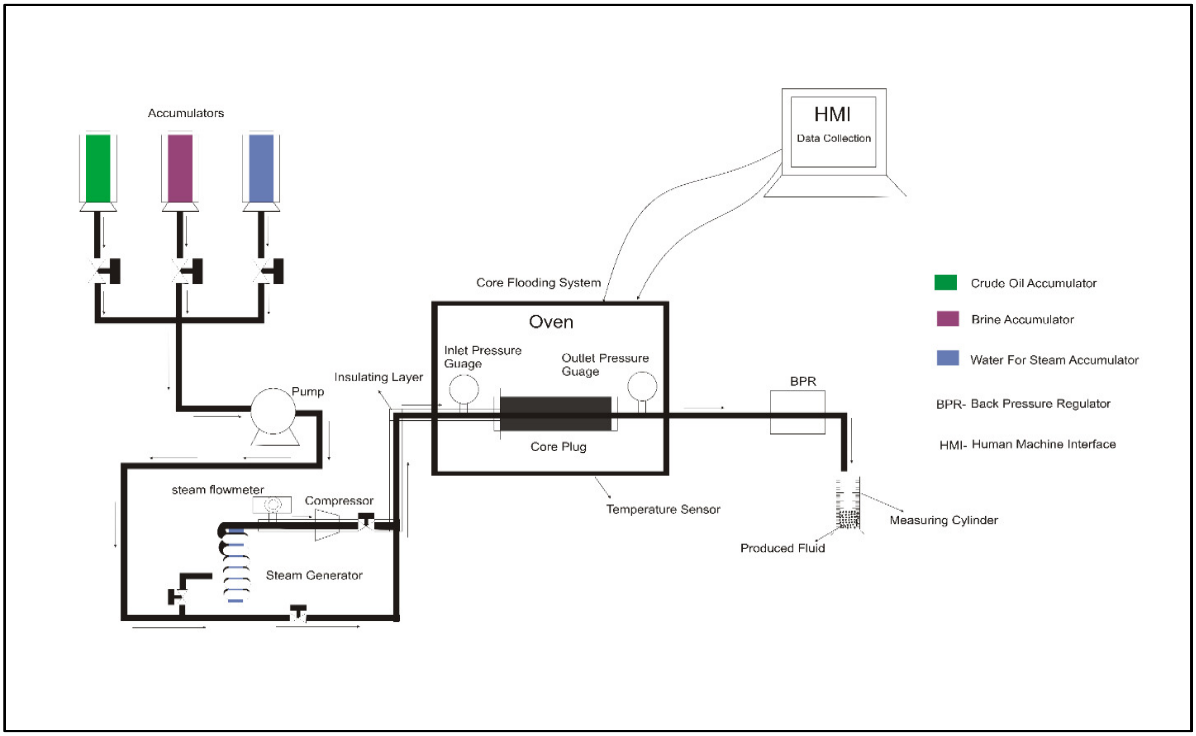

Fig 1: Schematic of core flooding set up for the experiments.

2.1 *Materials*

a. Core Material

Reservoir core sampleswith the designationB1 and B2 were used. These core samples were obtained from the sandstone facies of the Agbada and Akata formations of the Niger Delta. The porosity of the cores was calculated using the saturator and a 30,000ppm saline brine. When formulating the cores, the utmost concern was that they are highly representative of the Niger Delta in its porosity and mineralogy.

Table 2: Dimensions and Properties of the Core Sample

Core ID	Length (cm)	Diameter (cm)	Porosity (%)	Permeability (mD)
B1	5.9	3.65	20.6	2500
B2	5.7	3.7	21.2	2900

b. Fluids

Brine solutions used were prepared in the laboratory by dissolving 30g soft ions salt (NaCl) in water obtaining a density of 1.031g/cm^3.

c. Crude Oil

The crude oil sample used to saturate the core was obtained from a local exploration company following a Non-Disclosure Agreement. Table 3 states the properties of the crude oil at room temperature.

Table 3: Calculated Properties of the Crude Oil Sample

Oil Sample	Density (g/cm^3)	Viscosity (cp)	Temperature (^{o}C)	API (^{o})	Specific gravity
Crude B	0.946	264.97	28	18.14	0.95

2.2 *Methodology*

a. Core Preparation

Sand grains were washed with toluene and packed (compressed) into an aluminum cylindrical plug. The plug samples were dried in the conventional oven at a temperature of 100^{o}C. After drying, the dimensions, porosity, and permeability of the cores were measured or calculated. The core was put in a saturator filled with brine and allowed two days at 2000psi. The saturation-weight method was applied to measure porosity.

b. Oil Displacement

The saturated core was inserted in black rubber tubing, held in place by the end stems of the core loop and tightly sealed with its lids. Using a gas cylinder, pressure is inserted into the core loop to 1500psi, representative of the reservoir overburden pressure. Oil migration into the core was done using an accumulator composed of a diaphragm made of Teflon material. One end of the accumulator was filled with heavy oil and linked to the core loop, while the other end was attached to a flowrate pump that pumped water into it, forcing the diaphragm and at the same time pushing the oil into the core. At the recovery end, a measuring cylinder was used to collect the displaced water from the core. The displaced water in the cylinder is measured and assumed to be equal to the volume of oil in the core which is taken to be the Original Oil in Place (OIIP). This is based on the mechanism of fluiddisplacement.

c. Combined Cyclic Steam Stimulation and Steam Flooding Test

A core holder apparatus (core loop) was used in the flooding experiments. The core was placed in the core loop with a confining pressure of 1500psi mimicking that present in the subsurface reservoir. Varying steam temperature conditions of 100^{o}C and 120^{o}C, varying soak times of 5mins and 10mins, and an average flooding rate of 0.13cm^3/s were used in all the floods. The pressure drop across the core was carefully monitored in all the experiments and measured with a differential pressure gauge. Two floods were performed for each core at a particular steam temperature. The first flood and second floodswere done after 5 minutes and 10 minutes of steam soaking respectively. The produced oil was collected using a measuring cylinder and the oil recovery was determined as the percentage of original oil in place (percentage of OOIP). Table 4 shows the experimental layout of core displacement experiments.

Table 4: Experimental layout of core displacement experiment

Temp (^oC)	OIIP (mL)	Cycle	Soak Time (mins)	Permeability, k_o(D)	Oil Recovered (mL)	Recovery Factor (%)
100	4	First	5	510.3	2	50
		Second	10	241.8	0.5	25
120	3	First	5	546.8	2	67
		Second	10	241.8	0.2	20

In this experiment, a locally fabricated steam generator comprising a boiler and a fire furnace was used to generate steam. The boiler was filled with 4 liters of water and heated in the furnace tilla defined temperature before the core loop injection valve was opened. With the recovery end of the core loop closed, steam was allowed to flow into the core for 3 minutes. The injection valve was then shut off and the core was left to soak for the specified soak time for each cycle. After soaking, the recovery end of the loop was opened to allow flow into the measuring cylinder. When flow ceased, steam from the boiler was used to flood the core to recover the residual oil. The measuring cylinder was submerged in a water bath which will act as a condenser to reduce fluid loss through evaporation.

3.0 Results and Discussion

3.1 *Results*

This study investigated the combined cyclic steam stimulation and steam flooding for heavy oil production. The core sample was first flooded with steam and all flow lines closed allowing the steam to soak for a specified soak period then the production line was opened while steam flooding was resumed.Steam injection at 120^{o}C and 100^{o}C resulted in 87% and 75% total oil recovery of the OIIP respectively. Figure 2 shows a chart comparing the recovery factor at different temperatures.

It is expedient that an economic analysis is carried out to determine if revenue to be generated from extra recovery at 120^{o}C is worth the cost of energy required to inject steam at that temperature. Figure 3 is a scatter plot showing the correlation between the recovery factor and soak time.

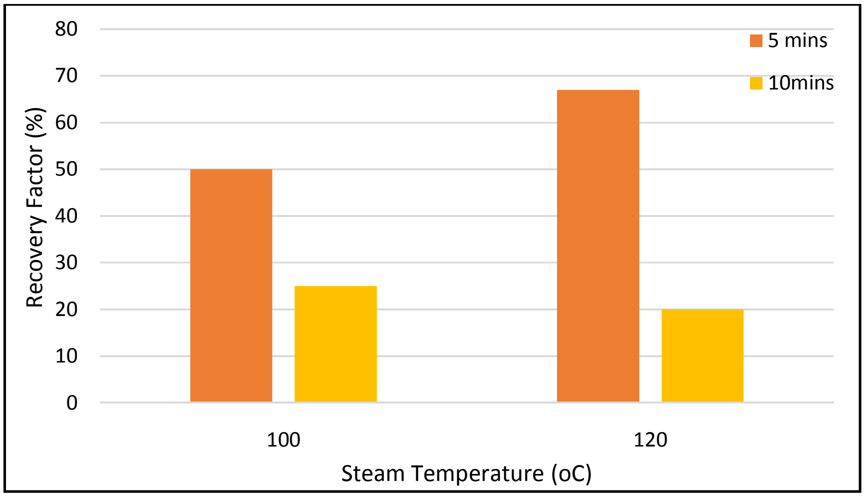

Fig 2: Recovery Factor at different temperatures.

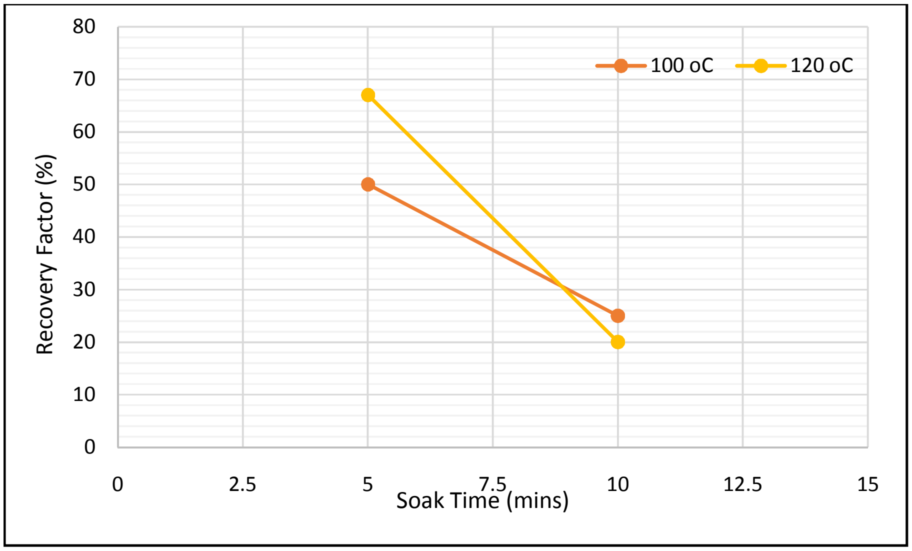

Fig 3: Correlation between recovery factor and soak time

From Figure 3, a sharp decline is observed when steam is continuously injected at 120°C. This shows that the benefit of injecting steam at 120°C is only reaped at the first cycle. After the first cycle, further injection at that temperature is cost-intensive and yields lower. An optimum strategy for producing this reservoir would be to inject steam at a higher temperature at first cycle and subsequently lower its injection temperature.

3.2 *Discussion*

A close and critical evaluation of the results has led to the following deductions:

1. Impressive reservoir response at first cycle, hence, the oil recovered is greater than that of the second cycle. This could be attributed to thorough well clean-up and improvement of permeability. It could also be a result of heat loss due to the extended soak time of the second cycle. A better comparison would have been made if the soak time for both cycles were equal. Howbeit, the above statement is valid as

other literary works have it that oil recovered after the first cycle of steam soak is always higher than predicted.

2. Also, the permeability of oil in the first cycle is greater than that of the second cycle. This follows the permeability-saturation curve which establishes that in a two-phase system, the permeability of oil decreases when water saturation increases.

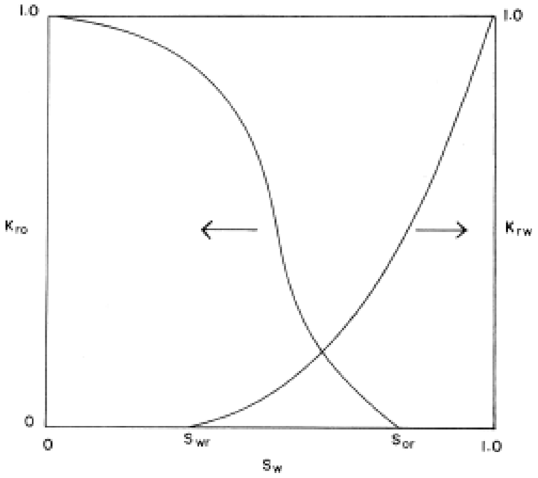

Fig 4: Typical water–oil relative permeability curves for a porous [5].

4.0 Conclusion

Heavy oil recovery has been one of the industry's primary concerns, necessitating efficient methods of ensuring its recovery. Many strategies have been used to overcome this problem, including thermal flooding, chemical flooding, gas injection, and, most recently, advancements in biotechnological technologies. Steam injection is the most efficient enhanced oil recovery method used in the thermal EOR process.

A combined cyclic steam stimulation and steam flooding experiment was performed in the laboratory on the obtained heavy oil sample as well as core samples collected from the Niger Delta. The crude oil sample was subjected to experimental examination, and parameters such as API gravity, viscosity, temperature, density, and specific gravity were acquired. Also, for the core samples, the necessary dimensional properties and petrophysical properties such as porosity, and permeability were determined. The laboratory experiment with steam injection was then carried out and oil recovery data was gathered.

5.0 Recommendation

Certain parameters, such as steam quality and other steam-related studies, were not taken into account in the laboratory experiment. As a result, future studies should intend to take these characteristics or parameters into account for efficient analysis.

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