An Investigation of Oil Viscosity and Depletion Rate Effect on Heavy Oil Recovery by Primary Production and CO_2 Huff and Puff Process

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Summary

In this work primary depletion by sulution gas drive followed by enhanced heavy oil recovery by CO_2 cyclic injection was conducted on laboratory scale sand packs. Three experiments were done on the same sand pack by using different oil or depletion rate. Experiments #1 and #2 used different oil, but same depletion rate. Experiment #3 used different depletion rate, but same oil as experiment #2. Effects of viscosity and depletion rate on recovery factor were studied.

Results from the three experiments indicate that the less viscous oil and the higher depletion rate gives higher recovery factor for primary prodution. Not so much oil recovery difference by CO_2 process were observed from experiments #1 and #2. However, greater difference (~50%) was observed for oil recovery by CO_2 process from experiments #2 and #3.

The tentative conclusion drawn from this study is that oil viscosity on heavy oil recovery shows a stronger effect in primary production. Depletion rate effect on heavy oil recovery is more significant in the CO_2 process. The higher recovery factor of 17.6% by CO_2 process for experiment #3 suggests that the CO_2 huff and puff process shows more promise for enhancing heavy oil recovery if the proper depletion rate is applied.

Introduction

The increasing oil and gas consumption in the world leads us to increase recovery from the bulk of the heavy oil resources remained in the reservoirs after primary recovery by conventional technologies. Carbon dioxide injection is thought of as a very promising enhanced oil recovery technique for thin light and medium light oil reservoirs where thermal recovery methods are unsuitable (Thomas, 2007). This process can recover over 30% OOIP incremental oil than that recovered by initial waterflooding for moderately viscous oils (Farouq Ali et al., 1987).

The CO_2 huff and puff process shows considerable promise as a secondary or tertiary method to recover incremental oil (Haskin and Alston, 1989; Palmer et al., 1986; Simpson, 1988). However, all these studies were done on conventional oils or moderately viscous oils. We used a CO_2 huff and puff process for recovering very viscous oil (~18000-30000mPas) in this study.

Enhanced heavy oil recovery by CO_2 cyclic injection was studied on a sand pack core with diameter of 38mm and length of 228mm. The core was saturated by live oil and a primary depletion experiment was conducted. Then the core was undergone a huff and puff process twice with CO_2 being the injection fluid. Recovery rates during primary depletion and by CO_2 cyclic injection were obtained.

Method

The model used for this experiment consists of a copper sleeve with a 38mm ID and 228mm length, packed with sand (average particle diameter: 0.6mm). After cleaning and drying the core, porosity by means of gas expansion and permeability measurements to nitrogen and brine were performed.

After measurement of porosity and permeability to brine, the core was saturated with live oil. Compressibility of the system was also tested. After compressibility tests, the core was undergone primary production by solution gas drive. After primary production, CO_2 huff and puff process were conducted on the core. The core was pressured up to around 7000kPa by CO_2. Then both core inlet and outlet were closed and the core was allowed to stabilize. When the core was stabilized the outlet was opened and prodution started. Data were collected until production stopped.

Results and Discussions

Altogether, three experiments using same core were conducted for this study. The only difference between experiments #1 and #2 is oil viscosity. The dead live oil viscosity used for experiments #1 and #2 are 18100mPas and 28646mPas, respectively. The difference between experiments #2 and #3 is the depletion rate with 0.347kPa/s and 0.116kPa/s, respectively.

The core has porosity of around 36.5% and absolute permeability of 10.5 Darcy. The porosity and permeability results from the three experiments are quite consistent, suggesting the core has been cleaned very well and other results from these three experiments are comparable. The system compressibility is very small, around 0.000027-0.000086psi^{-1}.

All production data for both primary and CO_2 huff and puff process for the three experiments are shown in Table 1. It can be seen that for experiments #1 and #2, oil recovery in primary production shows great difference (52.9% for the experiment #1 and 36.2% for the experiment #2). Oil recovery from the CO_2 process shows only 0.5% difference between tests. This suggests the oil viscosity has more effect on primary production. Gas recovery both in primary production and CO_2 depletion does not show great difference. However, for experiments #2 and #3, not only oil recovery shows great difference, but also gas recovery also shows great difference. In primary production experiment #3 gives 27.5% OOIP recovery, which is much lower than that from experiments #1 and #2. Most significant difference for experiment #3 from the other two experiments is another 17.6% OOIP oil was recovered by the CO_2 process. The higher CO_2 production may be the direct effect of depletion rate, but we can not exclude the possibility that this may be due to more oil left after primary production. The higher oil recovery for experiment #3 may suggest that oil recovery by the CO_2 process is more controlled by proper depletion rate. This is only a tentative conclusion from the three performed experiments. More experiments using different experimental parameters are currently performed to further confirm this conclusion.

Figures 1, 2 and 3 show production profiles for the three experiments, respectively. Only data during the early days of production are shown in this paper.

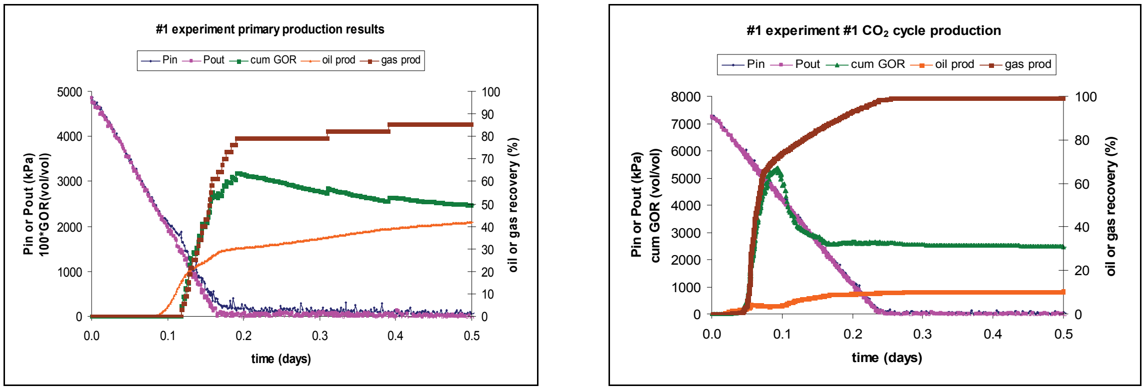

Figure 1: Experiment #1 production profile during primary production (left) and CO2 process (right).

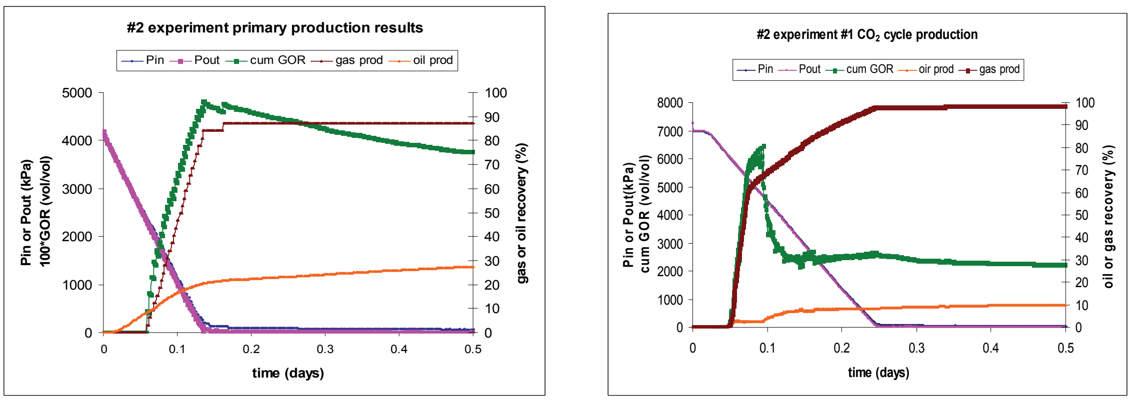

Figure 2: Experiment #2 production profile during primary production (left) and CO2 process (right).

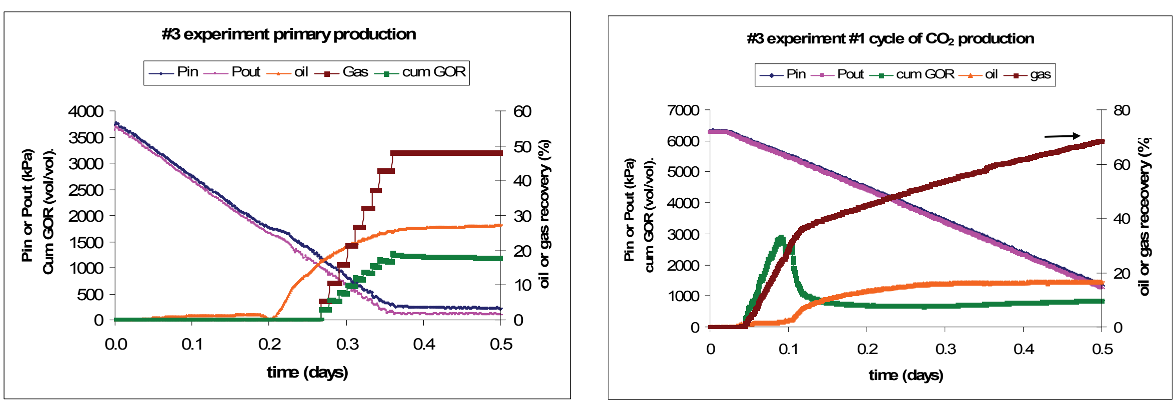

Figure 3: Experiment #3 production profile during primary production (left) and CO2 process (right).

Process	Parameters	Experiment #1	Experiment #2	Experiment #3
	GOR(vol/vol)	12.3	11.8	11.8
	Connate water (%)	6.5	7.0	5.5
Primary depletion	Oil recovery rate (%)	52.9	36.2	27.5
	Gas recovery (%)	94.2	93.0	58.0
CO_2 Process	Oil recovery rate (%)	10.9	11.4	17.6
	Gas recovery (%)	99.4	99.1	77.8

Table 1: Summary of primary production and CO2 huff and puff process production

Conclusions

- Preliminary experiments of CO2 huff and puff following primary production in sand packs are presented.
- The effect of oil viscosity and depletion rate on heavy oil recovery were analysed. The lower oil viscosity shows higher oil recovery in primary production, but not great difference in oil recovery for the CO2 process. The lower depletion rate gets higher oil recovery for the CO2 process. This may be due to depletion rate, but it may also be due to higher oil saturation after primary production.
- Gas recovery also shows great difference for different deplationr rate. The lower gas recovery was observed for the lower depletion rate.
- The effect of oil viscosity on heavy oil recovery is stronger in primary production.
- The effect of depletion rate on heavy oil recovery is more significant in the CO2 process.
- The recovery factor with the CO2 huff and puff process was increased by 10.9%, 11.4% and 17.6% for the three experiments, respectively. This suggests the potential of CO2 as a method for enhancing heavy oil recovery.

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