Experimental Investigation of Natural Gas Huff-n-Puff on Organic Shale Samples

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Summary

Gas Huff-n-Puff (HnP) technique is implemented as an enhanced oil recovery technique in unconventional reservoirs since primary recovery is marginal due to rapid decline in production rate [1,2]. However, associated recovery mechanisms are still poorly understood [3]. Various injecting fluids such as methane, ethane, propane, and carbon dioxide have been used as potential candidates in the industry [4]. However, natural gas is the common choice of injecting gas due to its availability and incentives for reduction of venting and flaring of produced gas. Accordingly, we perform natural gas HnP tests using C_1 and C_1/C_2 on organic shale samples at reservoir conditions. Selected pressures are higher than minimum miscibility pressure to ensure miscibility condition between injected gas and oil. Our custom-designed visual cell enables us to visually observe the interactions of gas, oil, and shale during the whole cycle of HnP under elevated pressure and temperature conditions. Solution gas drive during depletion stage is observed as the dominant oil recovery mechanism. We observe that enrichment of injecting gas with C_2 results in faster and higher oil production compared to pure C_1. The ultimate oil recovery factor after one cycle of C_1 and C_1/C_2 HnP is 46.1 and 55.6 % of original oil in place, respectively.

Theory / Method / Workflow

We coat all the faces, except one face, of the oil-saturated core plug with a sealing material to study one-dimensional gas invasion through open-end face of the plug in the HnP experiments. The objective is to mimic the fracture-matrix interface at reservoir conditions. In the next step, we prepare the visual cell setup for the HnP tests. We typically perform a systematic leakage test using the same type of gas used in the main HnP test and under the same pressure and temperature conditions. When we do not observe any pressure drop during the leakage test, we proceed to the main HnP tests. Since the cell is already preheated to the temperature of interest in the leakage test, we can instantly put the oil-saturated core plug inside the visual cell. We vacuum the cell and all the connected lines for a very short period and then procced to three stages of the HnP experiment, i.e., injection, soaking, and depletion. We start injecting the preheated gas until reaching to a set pressure. Then, we isolate the visual cell by closing all the connected valves and monitor the pressure over the course of the soaking period. During this period, as gas leaks off into the oil-saturated plug, pressure of the cell decreases with respect to time, and when it is equilibrated, the soaking stage is ended. Finally, we start depleting the pressure of the cell using a backpressure regulator with a predefined rate of depletion. We record videos of the open-end face of the plug over the course of whole HnP test to visually observe the interactions between oil and gas. At the end, we remove the plug from cell and measure its weight to calculate oil recovery factor using mass balance.

Results, Observations, Conclusions

We conduct two HnP experiments with pure C_1 as injecting gas at pressure of 5,651 psig, and temperature of 106℃ in Test 1 and C_1/C_2 [70/30] at a pressure of 5,141 psig and temperature of 106℃ in Test 2. C_1/C_2 mixing ratio is based on molar ratio. In both tests, we observe that when gas is injected into the visual cell, oil at the surface of the rock dries out until the end of injection stage when the rock surface becomes almost dry.

The snapshots of the open-end face of the core plug shows that at early stages of soaking, oil swells due to gas diffusion and wets the dry surface of the core plug. Whereas at later stages, oil components vaporize into the gas phase and the surface starts drying until the end of soaking stage when the plug surface becomes completely dry. **Figure 1** shows the open-end face of the plug at different times during the soaking stage of Test 1.

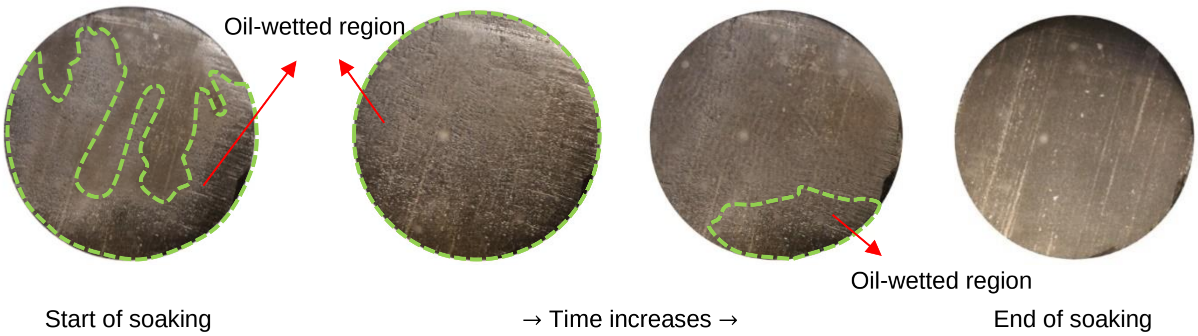
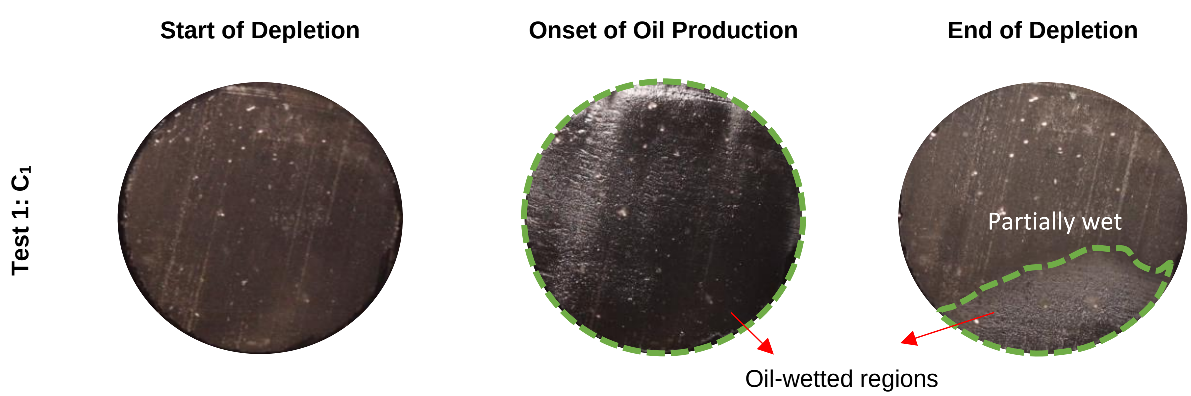


Figure 1. Open-end face of the core plug during the soaking stage of Test 1. Green dashed curves show the oil-wetted regions of the rock surface

At the beginning of depletion, the surface of the plug is completely dry due to the vaporization process over the soaking period. As pressure decreases, the dissolved gas evolves out of the oil and expands due to pressure reduction. Subsequently, gas moves toward the open-end face of the plug and drags the oil with itself. This phenomenon makes the surface of the plug wet by produced oil. This mechanism is known as solution gas drive which is clearly observed in our experiments. **Figure 2** shows that onset of oil production from the open-end face occurs at 4,000 psi in Test 1. When no more gas evolves out of the core, the plug surface starts drying and eventually it becomes dry. This observation shows that the oil production during the depletion stage is more significant than that during the soaking and injection stages. We observe similar phenomenon for Test 2.



P = 4,500 psi **P = 4,000 psi** **P = 60 psig**

Figure 2. Open-end face of the core plug at different pressures during the depletion stage of the HnP tests. Green dashed curves show the oil-covered sections of the rock surface

After the depletion stage, we measure the weight of the core plug, and estimate the ultimate oil recovery factor, RF, using mass balance. We observe that after one cycle of natural gas HnP, the ultimate oil RF is 46.1 % and 55.6 % for Test 1 and Test 2, respectively. Approximately 10 % higher oil RF in Test 2 is remarkable considering that the initial set pressure of Test 2 is 510 psig lower than that of Test 1.

Novel/Additive Information

The results improve the understating of natural gas HnP in organic shale reservoirs. It provides reasonable values of recovery factor for both lab- and field-scale applications. We recommend operational field-scale parameters like soaking duration, depletion rate, and injection pressure for maximum oil recovery by application of this technique. The tests are conducted at elevated pressure and temperature conditions of 5600 psi and 106℃, respectively which results in miscibility between injected gas and oil.

References

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