

# New Improved Oil Recovery from Heavy and Semi-Heavy Oil Reservoirs by Implementing Immiscible Heated WAG Injection

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**Abstract:** Only next to thermal processes used to produce heavy oil, gas injection is the second most common enhanced oil recovery process. To increase the extent of effects of the gas on the heavy and semi-heavy oils in the reservoir by gas injection, the gas is generally injected intermittently with water. This mode of injection is called Water-Alternating-Gas (WAG) method. In recent years, there has been an increasing interest in WAG process both miscible and immiscible.

In this paper, an experimental study of immiscible Heated WAG (Heated Water-Alternating-Heated Gas) injection into a sand pack is presented for the first time. This new method is a combination of WAG and thermal process and can be used to produce heavy and semi-heavy oils from hydrocarbon reservoirs. Oil recovery efficiency resulting from Heated WAG injection was significant in comparison with unheated WAG injection. The original reservoir fluid was dead oil, and core flooding experiments were performed on it using carbon dioxide as the injection gas. In this experimental study, the sand pack was initially saturated with dead oil and irreducible formation water. A number of WAG and Heated WAG cycles with low and constant rate and, below the minimum miscibility pressure for this system were injected into sand pack alternatively.

Results of laboratory tests showed that oil recovery efficiency resulting from the immiscible Heated WAG injection is about 15% more than that of unheated WAG injection. These results also indicate that using heated water and heated CO<sub>2</sub> instead of unheated water and CO<sub>2</sub> can lead to interfacial tension reduction, oil swelling and viscosity reduction. Therefore, immiscible heated WAG injection can be used as an effective and feasible enhanced oil recovery method in heavy and semi-heavy oil reservoirs with significant improved results.

**Key words:** Water-Alternating-Gas, Immiscible Injection, Heavy Oil, Enhanced Oil Recovery, Core Flooding, Sand Pack

## 1 INTRODUCTION

THERE are three methods for improving oil production from the hydrocarbon reservoirs:

- Improvements in the primary methods of production such as drilling infilling wells.
- Secondary methods of enhanced production such as immiscible injection methods including water or gas injection or water alternating gas injection.
- Enhanced oil recovery methods such as thermal, chemical and miscible injection methods.

During recent years, great effort has been directed towards investigating different methods of enhanced oil recovery from the hydrocarbon reservoirs. One of these methods is Water-Alternating-Gas (WAG) injection. In this process which is formed by combination of the two older and traditional methods of alternative injection of water and gas. Certain volumes of water and gas are alternatively injected into the reservoir [1]. The main aim of water alternating gas injection is increase in the recovered oil volume in the hydrocarbon reservoirs. It needs to be mentioned that this method has the required potential for improving microscopic displacement efficiency and can improve mobility potential, increased swapped area and increased microscopic displacement too [2, 3, 4]. This study shows, in normal injection of water or gas, at least 50 % of oil remains in the reservoir and can not be produced, whereas in WAG injection possibility of efficiency increases up to 90 % [5]. This can express importance of WAG injection

use in hydrocarbon reservoirs. As indicated earlier use of thermal recovery method is one of the most important methods for enhanced oil recovery. This has a more effective role in increase of hydrocarbon fluids recovery in heavy and semi heavy oil reservoirs. Therefore combining WAG injection and thermal methods can result in an increase in final oil production from these reservoirs.

In this laboratory experiment in addition to immiscible WAG injection method which is considered as an effective method in enhanced oil recovery in hydrocarbon reservoirs, method i.e. immiscible heated water alternating heated carbone dioxide gas (immiscible heated WAG) injection is employed too. In this new process aim of injecting heated fluids is effecting heavy and semi heavy fluids. Further below process and its results will be investigated.

## 2 EQUIPMENT DESCRIPTIONS

General description of the equipment used in immiscible WAG injection and immiscible heated WAG injection used in this project include:

- **Core holder:** Core holder is made of anticorrosion stainless steel of 4.2 cm diameter and 35 cm height.
- **Pump:** It consists of a standing glass tube of water and a U shaped tube. At the base of the column a valve and at its top a three way manifold have been placed. One of the three routes is used for carbon dioxide injection, another for filling the tube with water and the third is used for injection of the water.

- **Heating system and air bath chamber:** All of the system is placed in an air bath, which has the ability of controlling the temperature between ambient to 350 °C.
- **Pipes and Valves:** Valves are anticorrosion and resistant against H<sub>2</sub>S and CO<sub>2</sub> effects. The pipes were made of copper and plastic with inner diameter of 2mm. For heated fluids copper pipes were used.
- **Heater:** For heating the injected fluids a heater was placed on route. Over this heater, a vessel containing a high boiling point material was placed. Also two 2 meter spiral shaped copper pipes for heating the water and Carbon dioxide were placed in it.
- **Separator and produced fluids measurement system:** Separator was constructed from a steel pipe with an opening at the top for entering fluids and two openings for leaving it. An outlet at the top for gas and another at the bottom for draining the liquids were constructed. Figure 1 shows the injection system schematics for this experiment.

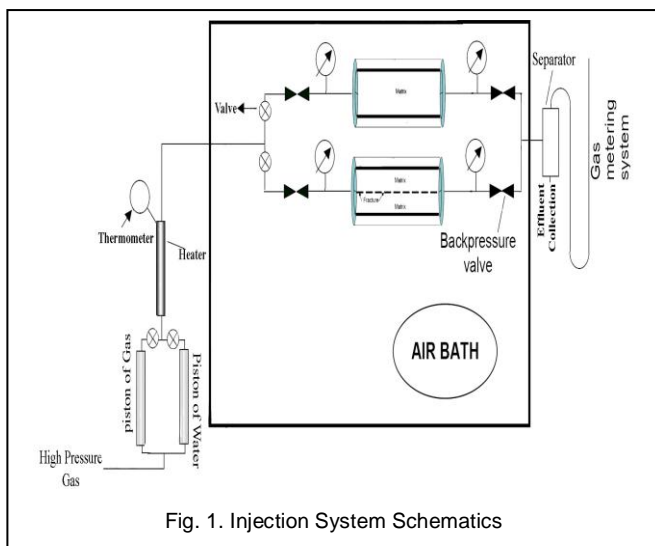


Fig. 1. Injection System Schematics

### 3 TEST STUDIES

#### 3.1 Method of Experiment

In this experiment, carbon dioxide was used as the immiscible injection gas and dead Oil was used as the displacing fluid. Conventional sand pack used in this experiment was implemented as below. Inside the core holder, 80-100-140-170 mesh quartz sand with equal ratios and with suitable moisture at high pressure was compacted. The aim was to obtain a homogeneous model with suitable permeability. Figure 2. Also for preventing silicon leaving the core holder, the entrance and exist of the apparatus were covered by mesh size 100 and glass fiber. Details of the conventional sand pack are indicated in table 1. Also dead oil in this experiment had 0.93 specific density and °API of 20.

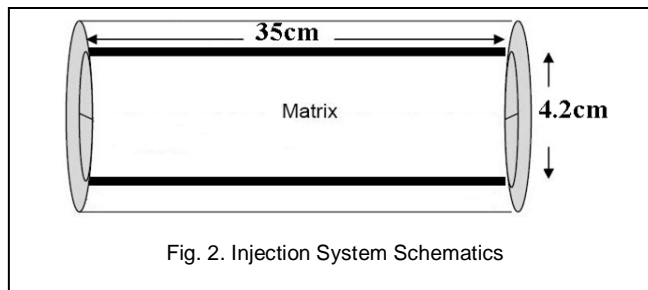


Fig. 2. Injection System Schematics

#### 3.2 Sand Pack Preparations

- First the conventional sand pack was wash by Toluene.
- After cleaning the Sand Pack, it was placed in the air bath at 120 °C to be completely dried by carbon dioxide gas.
- Since the tests are carried out under irreducible water saturation, first the sand pack must be saturated with water and then with oil [9]. Therefore for sand pack saturation with water, the lower core holder valve is kept open so water can enter it from the bottom and to water saturate it to 100 %. Then oil is injected into core holder through its top valve. In this stage, initial level of saturation of the oil in sand pack was 84.94 %, and irreducible water saturation was 15.06 %.
- Permeability was measured accurately [9].
- Core holder and sand pack in it were places horizontally inside the air bath chamber.

TABLE 1  
UNITS FOR MAGENTIC PROPERTIES

Material	Quartz Sand
Core Height	35 (cm)
Core Diameter	4.2 (cm)
Bulk Volume	484.904 (Cm <sup>3</sup> )
Pore Volume	135.773 (Cm <sup>3</sup> )
Permeability	0.4 (Darcy)
Porosity	20%

### 4 COREFLOODING EXPERIMENTS

Experiments were carried out on a conventional sand pack and in the following order.

#### Scenario one: Immiscible Water Alternating Carbon Dioxide Gas Injection.

After sand pack preparations, the oil saturated sand pack at presence of irreducible water for immiscible WAG injection was placed horizontally in the air bath system. For a uniform-

ly heated apparatus, temperature was set at 100 °C and sand pack was heated for one hour. Volume of each slug was equal to 5 % of the pore volume. Ratio of injected water and gas volume was set as one. First the carbon dioxide and then water slugs were injected. Alternative Injection of water and gas was continued until no oil was observed in sand pack outlet. During injection operation, injection flow rate was 0.5 cm<sup>3</sup>/min. After each injection stage amount of oil recovery was measured.

**Scenario two: Immiscible Heated Water Alternating Heated Carbon Dioxide Gas Injection**

Immiscible WAG injection under normal conditions was carried out and oil removed to the point where there was no oil output by this process, i.e. the process reached its final output. Then immiscible heated water alternating heated carbon dioxide gas injection began and the on route heater was turned on. After the water and carbon dioxide were heated to 120 °C, injection operation under identical conditions -apart from heating- as the previous scenario was carried out. After a few minutes injection, further oil recovery started. Immiscible heated WAG injection operation was continued until no oil was found in the sand pack outlet. After each injection stage amount of oil recovery was measured.

**5 RESULTS AND DISCUSSION**

As mentioned earlier, aim of this laboratory experiment was comparison between the two mentioned enhancement oil recovery methods i.e. immiscible WAG injection and immiscible heated WAG injection. Below effects of these methods together with their figures are presented.

**Immiscible Water Alternating Carbon Dioxide Gas Injection**

While water and carbon dioxide were injected alternatively into the conventional sand pack according to figure 3, final oil recovery factor in this sand pack was observed to be equal to 61% of pore volume. So that after this reading, oil production stopped completely and no further oil production was observed.

**Immiscible Heated Water Alternating Heated Carbon Dioxide Gas Injection**

After immiscible WAG injection under normal conditions and when no oil was observed, immiscible heated water alternating heated carbon dioxide gas injection began. Therefore if injected heated water into the sand pack is carrier out, it can be observed that further oil recovery will begin again. In this way the oil recovery factor will increase to around 15 % of the pore volume. Figure 4 shows amount of oil recovery from conventional sand pack after immiscible heated Water Alternating heated carbon dioxide gas injection.

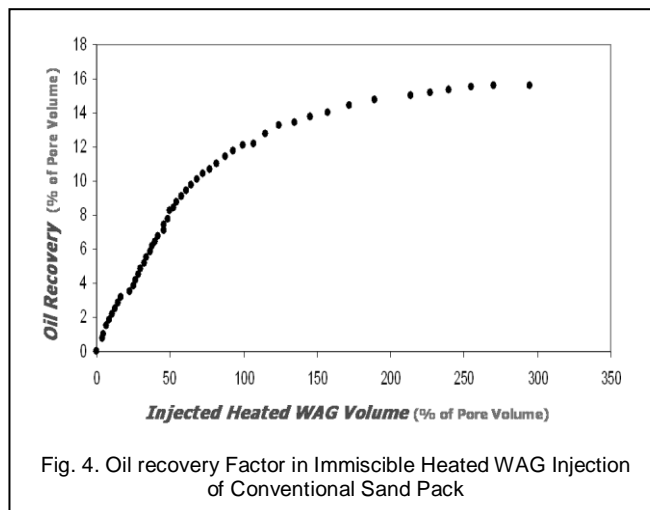


Fig. 4. Oil recovery Factor in Immiscible Heated WAG Injection of Conventional Sand Pack

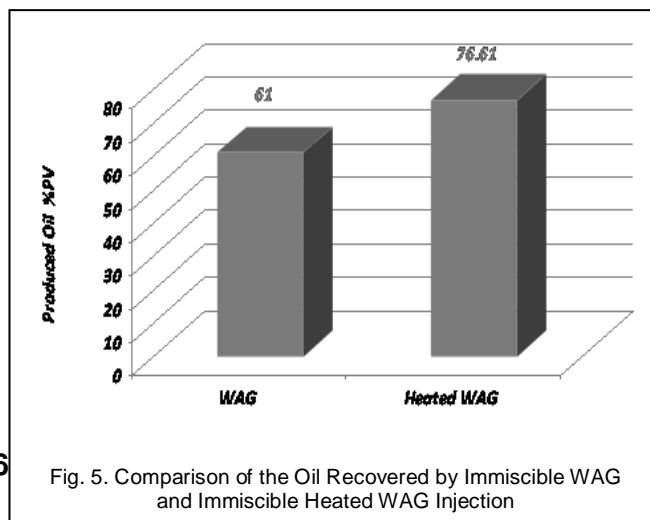
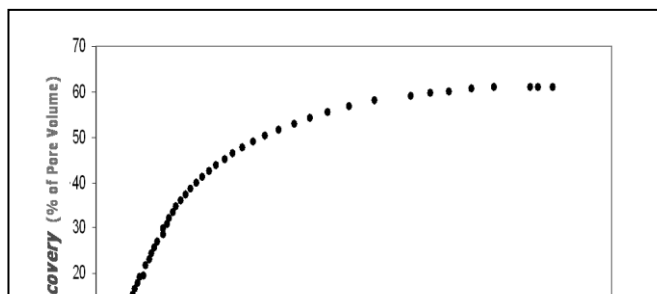


Fig. 5. Comparison of the Oil Recovered by Immiscible WAG and Immiscible Heated WAG Injection

- According to figure 5 it can be observed that the recovered oil by immiscible heated Water Alternating heated carbon dioxide gas injection method comparing with immiscible water alternating carbon dioxide gas injection method is higher.
- Use of alternative heated water and heated carbon dioxide gas injection method increases the volume of the swapped oil by water after gas injection. The reason being when the gas is injected into the reservoir, the existing free gases in the porous media cause the



relative permeability of water phase in three phase regions to be less than the relative permeability of water in the regions where there is only oil and water. As a result water from the two phase region enters the three phase region and removes a greater volume of oil.

- In this method we observe the phenomena of reduction in percentage of the remaining oil in the reservoir due to the three phase effects. It can be said in water wet reservoir rocks, trapped gas during imbibitions operation causes the oil phase to move in lower saturation percentages and an effective reduction in residual oil saturation to occur.
- The heated carbon dioxide gas, because its mobility, enters areas which are not accessible during ordinary injection.
- One of the problems encountered in use of carbon dioxide especially when heated is its corrosive nature. Of course this will not be encountered in laboratories testing, but while using it on industrial scale this factor also must be taken into consideration.
- Alternative heated water and heated carbon dioxide gas injection in the conventional reservoirs bearing heavy and semi heavy oils can be used as a suitable method of enhanced oil recovery.

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