

Investigation of Hot Gas Injection in Gas Assisted Gravity Drainage Process in a Fractured Oil Reservoir

Arash Pourabdol Shahrekordi¹, Babak Moradi¹, Mahmood Reza Hojjati¹

Abstract: Applying gas assisted gravity drainage (GAGD) process in a fractured oil reservoir is led to create a gas invaded zone in the reservoir in which the gravity drainage mechanism caused to produce oil from the matrix blocks of this zone; but whereas gravity drainage mechanism is gradual and slow, so the oil production decreases from matrix blocks of this zone which is caused to reduce the oil production from the reservoir. To solve this problem, this research investigates hot gas injection in the GAGD process in a fractured oil reservoir. Results show that effects of hot gas injection in the GAGD process on the oil viscosity reduction within matrix blocks of the hot gas invaded zone and increasing in density difference causes to accelerate the gravity drainage mechanism and leads to create a new process entitled "Hot Gas Assisted Accelerate Gravity Drainage (HGAAGD)" which has 1.56% more oil recovery factor than GAGD process.

Key words: GAGD, Hot Gas Injection, Gravity Drainage, Fractured Reservoir, HGAAGD

1 Introduction

Water alternating gas injection (WAG) process, at first, introduced by Caudle and Dyes [1] to solve the problems of the continuous gas injection process such as: gas high mobility, gas viscous fingering and the overriding of gas; but this process had problems such as increasing water saturation in the reservoir which caused the reduction of reservoir permeability and consequently reduce oil production from the reservoir [2]. In addition to this problem, this process recovers 5-10% oil in-place which is low oil recovery [3]. It is due to the fact that gravity drainage takes place in the reservoir with high vertical permeability to horizontal permeability ratio, as a result, water and gas injected in the water alternating gas injection process move towards the bottom and the top of the reservoir respectively due to their density difference with oil in the reservoir that caused to take place the underriding and overriding phenomena there [4]. In this case, the high volume of oil doesn't produce and remain as residual in the reservoir; therefore researchers innovated the other process named "Gas Assisted Gravity Drainage (GAGD)" process to solve the problems of the water alternating gas injection process in which contrary to water alternating gas injection process, the gravity drainage between injected gas and oil in the reservoir is an advantage because it causes to produce more from oil in-place of the reservoir without increasing water saturation there [5, 6]. It should be mentioned that GAGD process, at first, has been applied for inclined reservoirs but nowadays it applies for fractured reservoirs by its perfect development.

Now, in this research, also, with increasing of injected gas temperature in the GAGD process, is tried to take it more applicable and developed it more for fractured reservoirs; as the oil production increases remarkably from fractured reservoirs.

2 Description of GAGD process in a fractured oil reservoir

GAGD [7] is a process in which used several vertical injector wells for gas injection and one horizontal producer well in bottom of the layer for oil production (Figure 1). In the beginning of gas injection in the GAGD process in a fractured oil reservoir, injected gas moves towards top of the reservoir and creates an artificial gas cap there due to the density difference between injected gas and oil in the reservoir. By continuous gas injection, this artificial gas cap grows and expands towards bottom and two sides of the reservoir which is caused to enter injected gas into fractures of the reservoir; due to the high permeability of fractures, their oil is produced quickly by more growing the artificial gas cap; but the oil of the matrix blocks due to the low permeability doesn't produce and remains there which is caused to create the gas invaded zone in the reservoir [8]. This zone is full of gas in the fractures and filled with oil in the matrix blocks and also in the gas invaded zone, gravity drainage mechanism affects to produce oil within the matrix blocks.

Corresponding Author, E-Mail: a.pourabdol@gmail.com (Arash Pourabdol Shahrekordi)

¹ Islamic Azad University, Fars Science and Research Branch, Department of Petroleum Engineering, Shiraz, Iran.

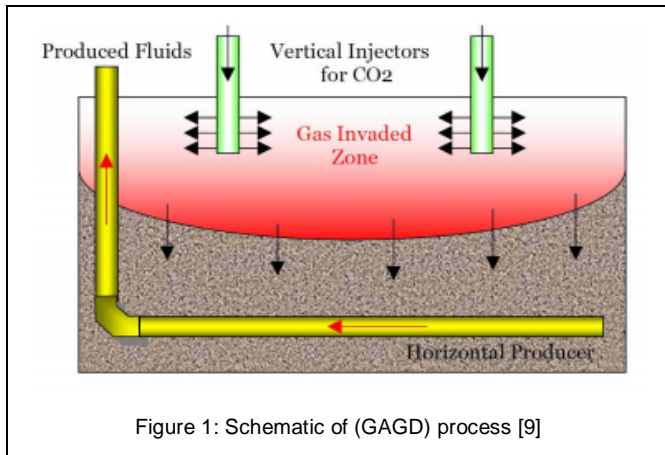


Figure 1: Schematic of (GAGD) process [9]

3 Investigation of effects of hot gas injection in the GAGD process in a fractured oil reservoir

As mentioned above, in the gas invaded zone created by GAGD process in a fractured oil reservoir, oil produces from the matrix blocks which is affected by gravity drainage mechanism; whereas, this mechanism is gradual and slow, the oil production from the matrix blocks of the gas invaded zone becomes a few. Therefore, to solve this problem, the hot gas injection can be used than ordinary gas in the GAGD process. Hot gas injection in the GAGD process in a fractured oil reservoir effects on 3 factors as below:

3.1 Creating the artificial hot gas cap quickly in the reservoir

Gas volume has a direct proportion to temperature, therefore by increasing injected gas temperature in the GAGD process, this gas occupies more volume in the reservoir, which is caused to create the artificial hot gas cap sooner and begins to expand therefore the oil produces sooner from the reservoir.

3.2 Reducing oil viscosity in the matrix blocks of the hot gas invaded zone

Hot gas injection in the GAGD process in a fractured oil reservoir, creates a hot gas invaded zone in which the matrix blocks are surrounded by hot gas. In such conditions, by heat transferring from hot gas within fractures to matrix blocks, the oil within matrix blocks is heated and reduced its viscosity. Thus, the oil mobility in the matrix blocks is increased and led to accelerate the gravity drainage mechanism in matrix blocks of the hot gas invaded zone and is led to produce more amount of oil from matrix blocks of this zone.

3.3 Increasing density difference in the hot gas invaded zone

Gas density has an inverse proportion to temperature; therefore, by increasing injected gas temperature in the GAGD process, injected gas density is reduced which is led to increase the density difference in the hot gas invaded zone. therefore, the high volume of injected hot gas penetrates to matrix blocks from fractures of this zone and causes to accelerate the gravity drainage mechanism in the matrix blocks of the hot gas invaded zone and results to produce more amount of oil from matrix blocks of this zone.

Hence with respect to effects of hot gas injection in the GAGD process in a fractured oil reservoir on the oil viscosity reduction in the matrix blocks of hot gas invaded zone and on density difference increase in this zone, the gravity drainage mechanism accelerates in the hot gas invaded zone. Therefore, it can be said that the hot gas injection in the GAGD process in a fractured oil reservoir is caused to create a new process under title "Hot Gas Assisted Accelerate Gravity Drainage (HGAAGD)" process.

4 Reservoir description and methodology

The oil reservoir study in this research is an undersaturated fractured carbonate medium oil reservoir.

In this research, for comparing the performance of two GAGD and HGAAGD processes to each other, the reservoir model provides separately in the both of black oil simulators, which are shown its properties in table1.

Table 1: Properties of Reservoir Model

Properties	Value	Unit	Properties	Value	Unit
Number of grid blocks in I direction	10		Permeability in K direction (Matrix)	10	md
Number of grid blocks in J direction	7		Permeability in I & J directions (Fracture)	395.9	md
Number of grid blocks in K direction	2		Permeability in K direction (Fracture)	395.9	md
Reservoir length	5000	ft	Reservoir temperature	122	°F
Reservoir width	3500	ft	Initial reservoir pressure	2500	Psia
Reservoir thickness	542	ft	Bubble point pressure API	1500	Psia
Reservoir has no gas cap and aquifer			Original oil in place	24.1388	
Porosity (Matrix)	0.1392		Original oil in place	130E+06	STB
Porosity (Fracture)	0.039585		Rock thermal conductivity	24	Btu/ft.day.°F
Permeability in I & J directions (Matrix)	100	md	Bottom hole pressure (BHP) for producer well	4000	Psia

Then the wells including two vertical injector wells and one horizontal producer well are entered into the reservoir model. Figures 2 and 3 respectively show the two-dimensional view (I-K) and three-dimensional view of the reservoir model and its drilled wells.

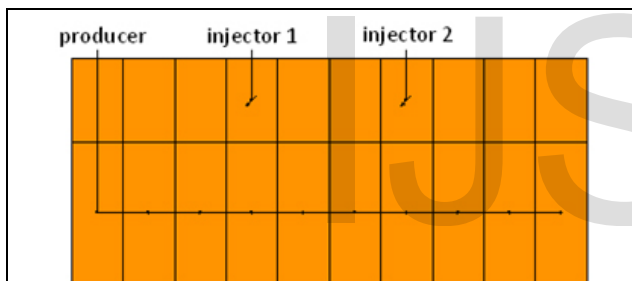


Figure 2: Two-Dimensional View (I-K) of Reservoir Model and Its Drilled Wells

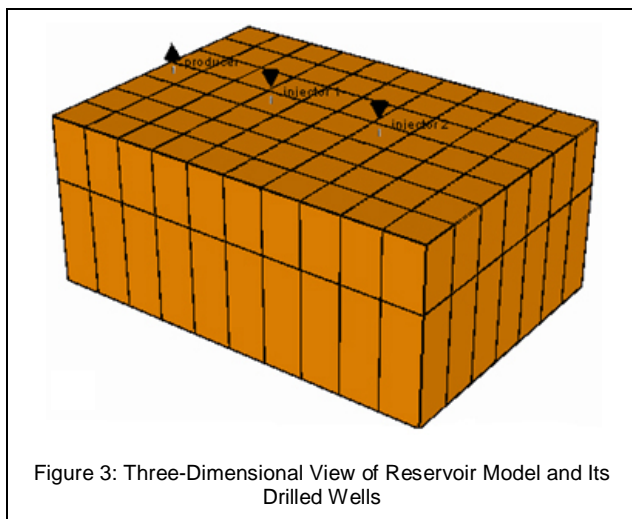


Figure 3: Three-Dimensional View of Reservoir Model and Its Drilled Wells

Now, GAGD and HGAAGD processes are simulated by IMEX and STARS simulators as in this simulation, from each of two injector wells, inject CO₂ gas with constant rate 15 MMScf/day in both GAGD and HGAAGD processes, with a difference that ordinary CO₂ gas injects in the GAGD process but hot CO₂ gas with (284°F) injects in the HGAAGD process; also in this simulation, the injection duration of the ordinary CO₂ gas and hot CO₂ gas is 7 years from 2013/09/12 to 2020/09/12 in the GAGD and HGAAGD processes respectively.

5 Results and Discussion

Since, the hot injected CO₂ gas in the HGAAGD process occupies more volume in the reservoir than ordinary CO₂ gas in the GAGD process, therefore the artificial hot gas cap in the HGAAGD process is created and begins to expand in the reservoir 31 days sooner than the artificial gas cap in the GAGD process. Thus the oil produces from the reservoir 31 days sooner in the HGAAGD process than the oil production in the GAGD process (beginning of the figure 4). Also in the HGAAGD process, because the heat arises from hot injected CO₂ gas causes to oil viscosity reduction within matrix blocks of the hot gas invaded zone and increases the density difference in this zone, Hence, gravity drainage mechanism is accelerated and result in more oil production from matrix blocks of the hot gas invaded zone which is caused to be significant increase of the oil production rate and cumulative oil production from the reservoir in the HGAAGD process than the GAGD process (figures 4 and 5).

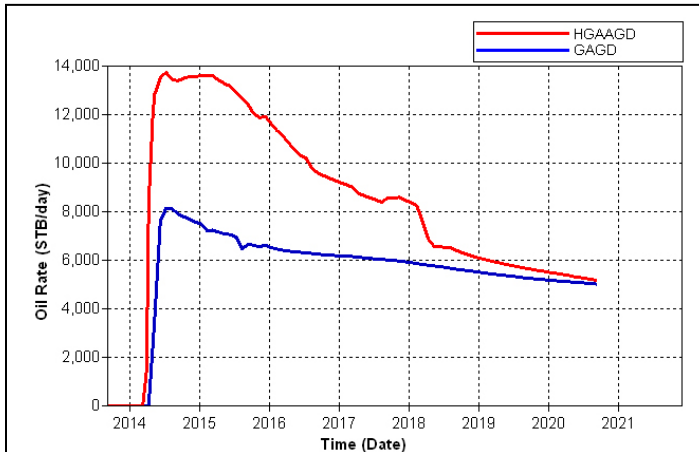


Figure 4: Oil Production Rate from Reservoir versus Time for GAGD and HGAAGD Processes

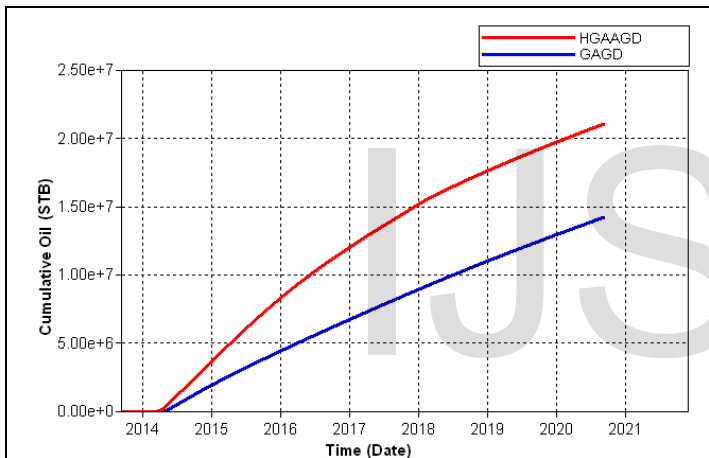


Figure 5: Cumulative Oil Production from Reservoir versus Time for GAGD and HGAAGD Processes

As shown in the figure 6, gas-oil ratio (GOR) in the HGAAGD process is reduced significantly than the GAGD process due to the 2 factors as below:

1. Because density of the hot injected CO_2 gas is low, therefore the density difference increases in the hot gas invaded zone; Hence the high volume of the hot injected CO_2 gas penetrates into matrix blocks from hot gas invaded zone fractures which is caused the reduction of the hot injected CO_2 gas rate which are moved from fractures towards the producer well and is resulted in GOR reduction.

2. Whereas gravity drainage mechanism is accelerated in the HGAAGD process and more amount of oil produce from matrix blocks of the hot gas invaded zone therefore, the oil production is increased from the reservoir and is resulted in GOR reduction.

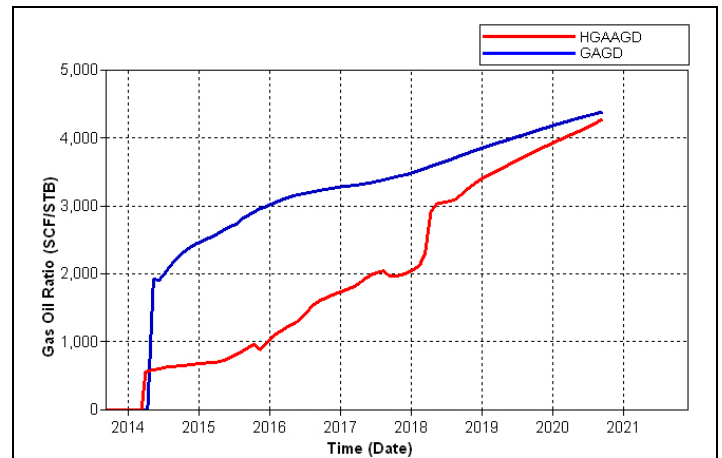


Figure 6: Gas-Oil Ratio (GOR) versus Time for GAGD and HGAAGD Processes

As it is shown in table 2 which is provided according to figure7, HGAAGD process has 1.56% more oil recovery factor than the GAGD process due to the more oil production from the reservoir in the HGAAGD process than the GAGD process.

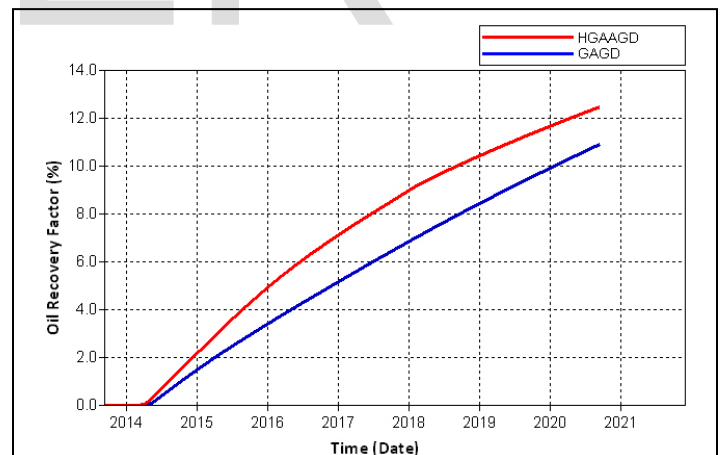


Figure 7: Oil Recovery Factor versus Time for GAGD and HGAAGD Processes

Table 2: The Comparison of Oil Recovery Factor in the GAGD and HGAAGD Processes

Process	Injection rate for each of two injector wells (MMScf/day)	Simulation time (year)	Oil recovery factor (%)
GAGD	15	7	10.90
HGAAGD	15	7	12.46

6 Conclusions

1. Hot gas injection in GAGD process in a fractured oil reservoir causes the oil viscosity reduction in the matrix blocks of the hot gas invaded zone and increases the density difference in this zone and accelerates the gravity drainage mechanism and result in creating a new process under title "Hot Gas Assisted Accelerate Gravity Drainage (HGAAGD)" process.

2. Whereas gravity drainage mechanism is accelerated in the hot gas invaded zone in the HGAAGD process therefore, the oil production from matrix blocks increases and consequently increases the oil production from the reservoir; thus, the HGAAGD process has more oil production rate, cumulative oil production and oil recovery factor than GAGD process.

3. Because the oil production from the reservoir in the HGAAGD process is more than GAGD process and also the gas production from the reservoir in the HGAAGD process is less than GAGD process, therefore the gas-oil ratio (GOR) in the HGAAGD process becomes less than GAGD process.

4. Whereas the oil production from a fractured medium oil reservoir in the HGAAGD process is more than GAGD process hence, applying HGAAGD process is more suitable than GAGD process in the fractured medium oil reservoirs.

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Corresponding Author, E-Mail: a.pourabdol@gmail.com (Arash Pourabdol Shahrekordi)

¹ Islamic Azad University, Fars Science and Research Branch, Department of Petroleum Engineering, Shiraz, Iran.