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Simulation of Water and Gas Injection in an Oil Reservoir Intermittently

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Abstract In this paper, Simulation of water and gas injection was examined in an oil reservoir intermittently. Scenarios of water injection and gas injection were simulated separately and their results were compared with each other and with intermittent water and gas injection. CMG software was used in this article for reservoir simulation. Builder tool was used to make physical model and WinProp for making fluid model, and GMT simulator for making simulation of enhanced oil recovery processes. The results show that the coefficient of productivity and cumulative production is more than other scenarios of injection in the injection cycle of 4: 2. Investigations in the field of study show that the productivity coefficient will be more if the period of gas injection be higher than water. In WAG method if injection of gas to be done sooner than water (water phase as a secondary fluid be injected to the reservoir), production and efficiency increase compared to the state that injection of water earlier and as a first fluid be injected to the reservoir. Higher efficiency and production in IWAG method, compared to the other injection WAG methods show higher movement of sweep whether microscopic and macroscopic, and higher efficiency in this method compared to other methods of injection. Productivity coefficient and cumulative production of WAG method is higher compared to normal production methods, water and gas injection, therefore this method was introduced as an optimal enhanced oil recovery in the field of study.

Keywords Reservoir simulation, Intermittent injection of water and gas, Water injection, Gas injection, Enhanced oil recovery, CMG software

1. Introduction

In general, reservoir pressure is decreased by exploitation and production, leading to reduce the gas reservoir and decreased production. Regarding the role of oil and oil products on the world market and the world of economy, the adoption of appropriate contraptions and optimum enhanced oil recovery methods to improve efficiency and increase production have been a priority in oil-producing countries.

Intermittent water and gas injection was done for the first time in Alberta in 1957, and its successful results were reported. After that, and especially in the last two decades because of many advantages of this method compared to separate water and gas injection methods (such as the relative mobility control of revulsive and displacer phases, prevent premature fingering of gas in oil production wells, the capacity of producing remained oil from the non-swept regions in water injection and/or gas injection, creating a manageable and sustainable progressing front, The ability to use the operational methods of water and gas injection) was operated and executed in various fields such as the US, Canada, the North Sea, Russia, Turkey and Venezuela. During these years researchers study and investigate more aspects of WAG injection to understand the realities and changes in reservoir conditions during injection period.

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Tehrani and colleagues have conducted a set of programs of research and development with laboratory model simulation that can calculate three-phase capillary pressure and relative permeability functions. The results shown, oil production is controlled by film stream instead of piston movement during water flooding.

In cavity surfaces and during water injection, gas channels become narrow due to water film growth, and In cavity surfaces and during water injection, gas channels become narrow due to water film growth, and , gas bubbles are divided in the throat of many of cavities due to the interaction of capillary forces and the gas pressure oscillations. In this study, a significant portion of the oil was recovered after a small number of WAG injection cycles.

A test in a high pressure glass micro model was conducted to evaluate the effect of wettability alteration in 2001. The distribution of fluid flow was examined and fluid saturation in different stages was measured. The results showed that oil recovery in WAG injection in oil-like model and a model with mixed wettability provides have the most value.

Cobanoglu (2001) compared and evaluated the non-miscible gas injection and WAG methods in a field in Turkey with different scenarios of injection rate, cycle and the number of production and injection wells using Simulator Eclipse 100. His studies showed that the immiscible gas injection has a significant increase in returns field because of improper mobility. He proposed that the immiscible WAG injection has more returns and production compared to the immiscible gas injection.

Hustod and Klov (2002) examined the WAG injection and compared it with water and gas injection in layers with different permeability in North Sea's field. They stated that a fingering water and gas in layers with high permeability and lack of motion and inappropriate sweep process in layers with low permeability reduces the returns of injection in these methods. Their studies showed that intermittent injection of water and gas in the WAG method would prevent the movement of gas in layers with high permeability and the creation of the three-phase in the reservoir and the sustainability of front motion. Therefore this method has higher efficiency compared to gas and water injection methods.

Insterfjord (2002) also examined the injection of 10 years WAGO in the field Gulfaks. Studies show that oil production in this field during the injection is approximately more than normal production in amount of MMSTB 2. He stated that WAG injection in this field increases returns and displacement efficiency and reduces the percentage of produced water.

Shi et al. (2008) using obtained field results studied and examined 20 years period of WAG injection in the north of Alaska's Kuparuk field. They stated that although the gas injection was selected and performed as the method of enhanced oil recovery in this field, but because of premature fingering gas and increased GOR, WAG injection was suggested and was used to solve this problem. So that during injection, oil production rose to the MMSTB 120. Fatemi (2011) examined the effect of wettability on the WAG process. The results showed that in the recovery water injection when the rock has mixed wettability is more than when the rock is hydrophilic.

Jiang et al. examined the ratio of WAG injection process that following results were obtained: Jiang et al (2012) examined the injection of the WAG gave the following results were obtained: calculating optimum WAG ratio and use it had been one of the important parameter of designing which has a major effect on the operating and economic conditions of the project. Predicting and study of gas injection as pure suggest that the WAG ratio can be increase after the increase of optimal amount of gas production (GOR).

Decrease of WAG ratio increases mobility ratio control and creates fixed gas production profile. Optimum WAG ratio is influenced by the type of rock wettability. High WAG ratio in the oil returns process in hydrophilic reservoirs has the greatest impact and reduces the amount of remaining oil.

Ghaderi (2012) in his research obtained following results: water masses injection is essential for reducing the effect of fingering. It is noteworthy point that the carbon dioxide because of its very low viscosity, fingering phenomenon occurs quickly when using this gas. For this reason, the amount of injected water must be higher than high carbon dioxide so that the phenomenon occur later. It is more important for fractured reservoirs. But low viscosity of carbon dioxide can help the process in normal reservoirs and very low permeability reservoirs.

Signal and Nadion of intermittent water and gas injection were examined by conducting a test in Dulang field. The study showed that intermittent immiscible injection of water and gas is potential and has an acceptable option for injection into reservoirs. The laboratorial studies and simulation on performance of WAG immiscible injection using high content of Carbon oxide increased the amount of in-situ original oil recovery about 5 to 7 percentage.

Another advantage of the WAG was shown by Sheldon and Champion by the effect of the injected gas be trapped in formation. Change the mobility of our fluid reservoir leads us to improve swipe returns of flood. In this study, intermittent immiscible water and gas injection was performed using the produced gases. Simulation studies showed enhanced oil recovery by as much as 2 to 9% of the original oil in-situ using WAG process.

Also other reports were published about WAG rejection by Trnerr in Seeligsou field, Qual et al. in Stephansen, Siri in Viking field, Skauge and Aarre in Snorer field, and Quaraini et al. in West sak field that the results showed the successfulness of this method compared to other conventional methods of enhanced recovery.

In recent decade about 40% of gas injection projects throughout the world such as Canada, Russia, Turkey, and Norway have conducted such a WAG injection and 80% of these projects have also reported successful.

In present research simulation of gas and water injection was examined intermittently in an oil reservoir.

The main purpose of the study is to simulate intermittent gas and water injection in an oil reservoir and to evaluate its effect on enhanced oil recovery. This paper offers several parameters of optimization of injection and the optimal amount.

Also the scenarios of water injection and gas injection were simulated separately and their conclusions were compared with each other and with the intermittent injection water and gas method. In this article CMG software is used to build models and to simulate different mentioned processes of enhanced recovery.

2. Intermittent Water and Gas Injection Method

In the design of enhanced recovery oil in WAG method, water and gas are injected into an oil reservoir in define cycle time and intermittently, in this method increased returns is because of increased contact surface of injected fluid(water and gas) with non-swept regions (regions that have not affected by water and gas).

The injected gas in this method occupies cavities with high oil saturation and thus causes the movement of the oil in the non-swept sections of reservoir. And then with water injection, oil remaining trapped around rocks of reservoir moves and decreases the amount of oil saturation and increases the returns of production.

In addition, water injection after gas would prevent saturation percentage and gas relative mobility, control and reduction of mobility ratio and the creation of sustainable mobility front in the reservoir, this front prevents from creation of premature gas fingering phenomenon (accumulation gas liquids in the mouth of the well) produced in wells.

Generally remaining oil saturation percentage resulted in enhanced oil recovery method by the WAG injection is less than conventional methods of water and gas injection, therefore, there is an appropriate capacity to increase the efficiency of macroscopic and microscopic movement in the country's oil reservoir with this method.

In this method, gas molecules are forced into vicinity and contact with oil and increase oil droplets volume, on the other hand the displacement of oil by injected water if there are gas bubbles in the oil droplets, the amount of remaining oil in the reservoir which is not recoverable with present methods reduces in amount of gas bubbles volume, and thus intermittent injected water and gas reduces remained saturation and increases the returns of the oil reservoir.

2.1. Principles and Method of WAG

In this method water and gas masses intermittently are injected into the reservoir. In this process that made by the combination of the two traditional and old methods of water injection, certain volumes of mass water and gas are injected into the reservoir successively. Intermittent water and gas injection processes generally by improve of returns in the macroscopic displacement simultaneously increase production.

In intermittent water and gas injection, the injected gas occupies cavities with high oil saturation level and moves the oil of the non-swept sections of reservoir. In continue, with water injection, the enclosed remaining oil around the reservoir rocks moves and leading to more reduction in saturation of the remaining oil and enhances oil recovery.

Water injection after gas injection also cause prevention of gas saturation percentage and gas relative mobility, control and reduction of mobility ratio and creation of sustainable mobility front in reservoir, thus will prevent the occurrence of rapid breakthrough in the productive well. The main objective of the operation of intermittent water and gas injection is to increase the amount of recoverable oil from a hydrocarbon reservoir.

It should be noted that this method has the potential to enhance microscopic displacement returns and can increase the level of oil recovery through improving mobility, increasing the level of swept surface, and increase the microscopic displacement returns.

In this regard, studies show that in regular injection by water and/or gas, at least 50 percent of the oil remains in the reservoir and cannot be produced while there is a possibility of increasing sweep efficiency of up to 9o% percent in intermittent water and gas injection. This can be reflect well the performance efficiency level of intermittent water and gas injection in the hydrocarbon reservoirs. In this article of WAG injection important parameters such as injection ratio, injection cycle, the injected slug volume, injection rate, type of injected gas, injection method, miscible or immiscible gas injection and pattern injection, injected water, etc. in laboratorial and field conditions or using simulators must be studied and investigated exactly.

The estimation and calculate of amount and optimum conditions for above parameters with regard to geological and petrophysical characteristics of reservoir is necessary for reducing operating costs and increasing final returns and production. Also the cost of preparing water, gas and transport to the location is the most important issues of the project. Gas availability and cost of preparing solvent is also important for the injection process.

Because of the gas availability or low cost is one of the important factors of reducing costs in enhanced oil recovery process. In addition, the cost of new injection wells drilling, sampling, maintenance and reparation of wells and the costs of the study and investigation of optimal processes of miscible and immiscible injection are also to be considered.

In the absence of knowledge of the conditions of reservoirs layers, design and performance of the injection project may be not only successful, but also by creating fingering and water move downward and/or upward gas cause the loss of reservoir, so that some reports indicate the formation of asphalting and hydrate, reducing infectivity, corrosion, oil accumulation and the creation of mineral hydrates in WAG injection project.

3. Simulation of Alternate Injection of Gas and Water

In this paper, using the CMG software has been dealt to simulate the alternate injection and of gas and water process in Ilam-Sarvak formation in Mond Mountain and optimization of various parameters in this enhanced oil recovery scenario. Enhanced oil recovery scenario for gas injection and water injection also has been done on this reservoir and the results obtained from three methods have been compared with each other.

3.1. Describes the Simulated Model of Study

Simulated model under the study is an example of Ilam-Sarvak formation in Mond Mountain and properties and characteristics of the rock, fluid and rock and fluid of the model is close to the real reservoir. Static reservoir model has length of 1,000 feet, width of 1,000 feet and thickness of 90 has been divided to 20, 20 and 15 grade in the X, Y and Z directions. In Figure 1 is visible the schematics of three-dimensional model of the reservoir.

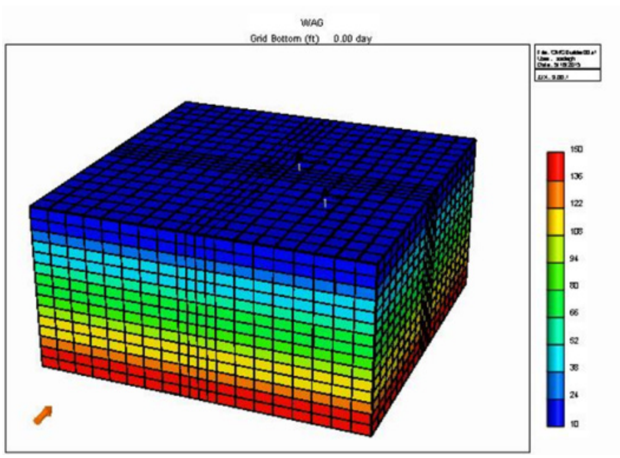

Figure 1. Three-dimensional shape of simulated model

This model has been 6000 grades that grids have been selected in dimensions of 15 x 20 x 20. In this model have been considered a production well and two injection well. Two injection wells have been considered on each other and have been completed in similar coordinates been used to intermittently for water and gas injection. The following table shows the manufacturer components of oil. In Table 1 are seen the general properties of the under study reservoir.

Table 1. General properties of under study reservoir

Initial pressure	Psi 1225
Pressure of reservoir	Psi 927
Reservoir temperature	F 139.3
Porosity	0.23
Permeability	0.17
Reservoir rock	Sandstone
Compressibility of reservoir rock	4.67 e-06 1 / psi

Reservoir has Initial pressure of Psi 1225 and Initial temperature of 139.3 ° F. Reservoir has a type of Rocktype. In this article CMG software was used for reservoir simulation. from the manufacturer tool was used to build physical model and WinProp tools was used for build of the fluid model and from simulation of GEM was used to simulate the enhanced oil recovery processes.

4. Results

4.1. Primary Model of WAG

In Figure 2 you can see daily and cumulative of oil production in the primary model. In this model, amount of oil recovery from the reservoir is 48.04%.

In Figure 3 has been shown the cumulative oil production of primary model. Our aim in this section is optimization of above operating parameters above to achieving the maximum amount of oil recovery by using the gravity drainage method with the help of steam. Initially for the parameters specify a reasonable interval and in that range we choose several points for review to comparing the level of oil production.

We find amount of optimal operational parameters by examining the results for all tested values in each section, and according to operational parameters presented above and found optimal values for each section, to achieve optimum point to investigate the other parameters. Ultimately all parameters achieve to their optimal level in order to maximum oil production in a specified time interval.

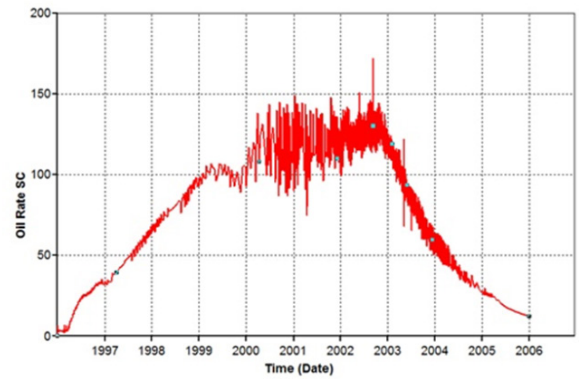

Figure 2. Daily oil production of the primary model

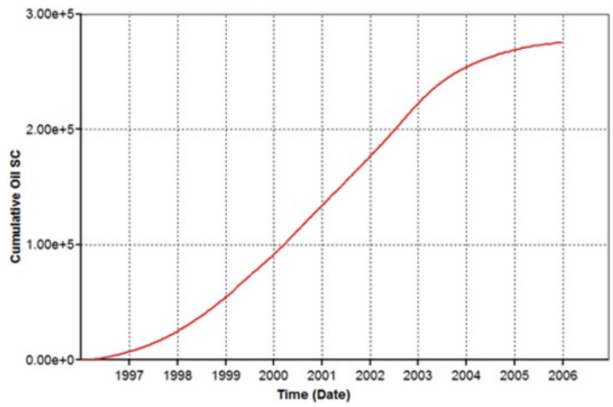

Figure 3. Oil cumulative production of the primary model

4.2. Injection Cycle

In this way, gas and water are injected in alternate courses and cycles into the reservoir. Therefore, determining the period of water and gas injection are the most important issues and challenges of this approach. As the choice of optimum injection cycle not only increases the efficiency and production, but also will be reduces the volume of water required and also the cost of injection.

Parameters such as availability cost of providing and determining the type of injected gas and the type of reservoir is also affective in determining cycle and duration of infusion. In this section at same injection period (6 months) for 10 years, were studied and simulated five cycles of 1: 5, 2: 4, 3.: 3., 4: 2, and 5: 1 (in Cycle is injected 2: 4, two months gas and four months of water).

As can be seen, oil production rate at during the ten years is more than rest of scenarios for 3: 3 and 4: 2 cycles, (Figure 4 and 5). Here, what is remarkable is that we reach to the maximum recovery rate of 52.11% for 4: 2 cycles, after 10 years. In general, studies in under study field show that efficiency of and production coefficient is more while the period of gas injection is greater than water. Ultimately 4: 2 cycles is selected as the optimum cycle.

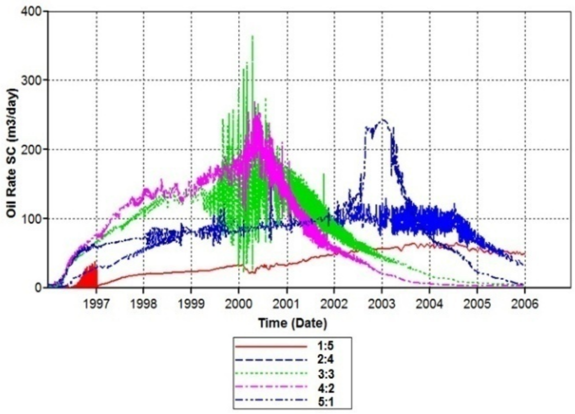

Figure 4. Daily oil production at different injection cycles

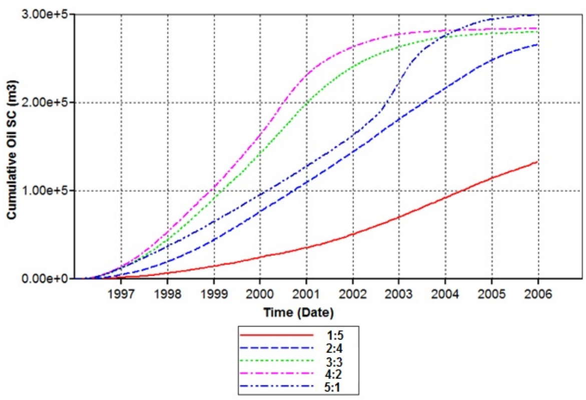

Figure 5. Cumulative oil production at various injection cycles

4.3. Injection Type

Depending on the hydrophilic or oil-wet reservoir rock, horizontal and vertical permeability and petrophysical conditions and reservoir layering in the periodic injection, water can be injected into the reservoir before the gas and in contrary, gas before the water. injection type of WAG project must be designed and selected so that the initial phase of injection is not only causes accumulation of oil but also causes the displacement and reducing of residual oil saturation, and to alter the conditions of reservoir in such way that second phase injection causes improving the process of reservoir oil displacement.

In this section two types of WAG injection were designed so that in first type of gas injection sooner than water and in the second type of water injection water be done sooner than gas. As shown in the figure, production rate is higher if the gas injection to be done sooner than water (Figure 6). The reason of this is hydrophilic of reservoir rock and become blocked of oil because of water injection as the first phase (in the second method).

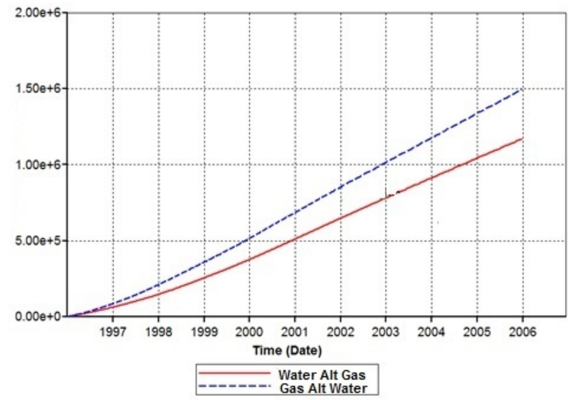

Figure 6. Cumulative oil production depending on the type of injection

4.4. Injection Method

Christensen (1998) divided the water and gas alternate injection to miscible, immiscible, continuous and continuous selective methods. Among the above methods the miscible injection 79% and immiscible 18% of the total operational project assigned and are considered as the most used methods.

- Immiscible WAG injection

In this way, gas slugs with water are injected as immiscible and alternately into the reservoir. This type of injection is performed with the aim of increasing the sustainability of movement front and increasing the level of injected fluid contacts with not swept sections of reservoir to conventional water and gas injection.

This method is used in reservoir that because of existing severe heterogeneity or being angular, cause the instability of front of injection. In this study gas with discharge of Mscf / day 18000 and water with discharge of STB / day 10800 with injection cycle of 4: 2 and with injection ratio of 1: 1 for 10 years is injected into the reservoir.

- Continuous injection of WAG

A method in which water and gas is injected continuously into the reservoir at the same time is called the water and gas injection. Water and gas injection is done in two ways. In the first method water and gas are combined at the surface and as single phase is injected into the reservoir.

This method is called WAG continuous injection. In the second method, by dual completing in vertical injection well, at the same time water and gas are injected respectively top and bottom of hydrocarbon layer and is proposed as a WAG continuous selective injection. In this method density difference between the injected fluids, causes water movement downward and gas movement upward and consequently creating the thrust mechanism and increasing productivity displacement process.

Thus, displacement is conducted in two ways (macroscopic and microscopic) and causes the increasing in production. Therefore final return and production in this method is much higher than other methods of injection. Continuous injection of water and gas has been operationalized in several field in Canada and the Siri field in the North Sea, and reports indicate being successful of injection and increase in efficiency and production in these fields.

- Comparison of different methods of WAG injection

In this section have been compared various methods of injection for selecting the optimum method. In shape has been shown the productivity coefficient and cumulative oil production in mentioned methods. As is clear in figures, immiscible injection method has the best performance among the various scenarios.

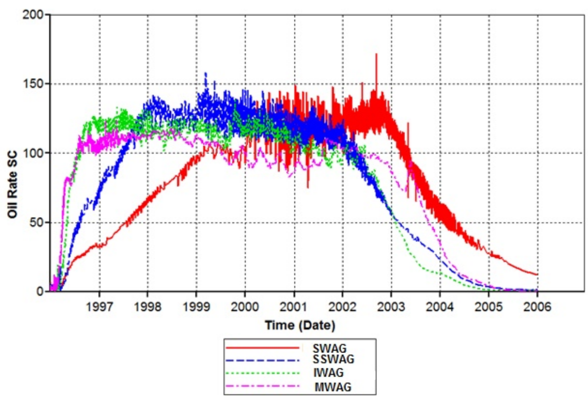

Figure 7. Daily oil production in different scenarios of WAG

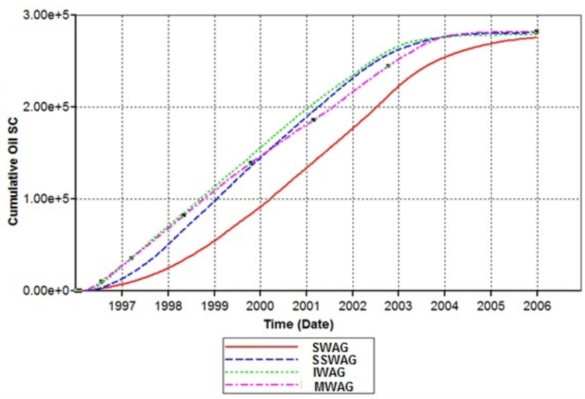

Figure 8. Cumulative oil production in different scenarios of WAG

4.5. Comparing the Methods of Water and Gas Alternate Injection and Single Injection Water and Gas

Because of WAG injection incudes injection methods of water and gas, comparing this method with water and gas injection is necessary for finding suitable method of enhanced oil recovery and increase of production efficiency. For correct and principled comparison between the above methods in addition to WAG injection method, different water and gas injection methods were designed and studied.

Then to perform comparison between the above methods, was chosen a scenario of each method which had the highest production. Therefore comparison was done between optimum scenario of each method that has higher production and marginal returns. In Figure 9 and 10 were compared the daily production in enhanced oil recovery methods. As can be seen in this figure, WAG injection has more production than other methods.

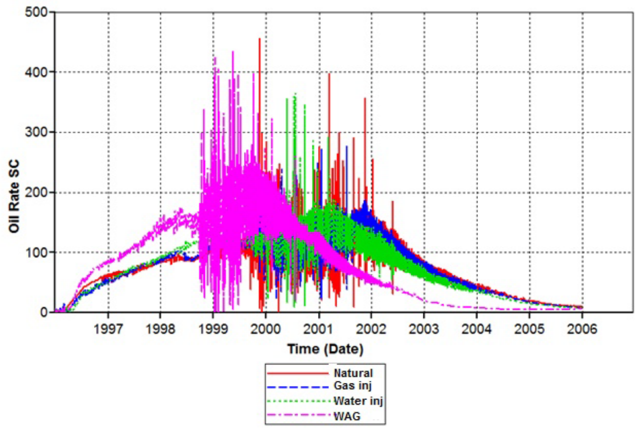

Figure 9. Daily oil production in natural discharge scenarios, water injection, gas and WAG injection

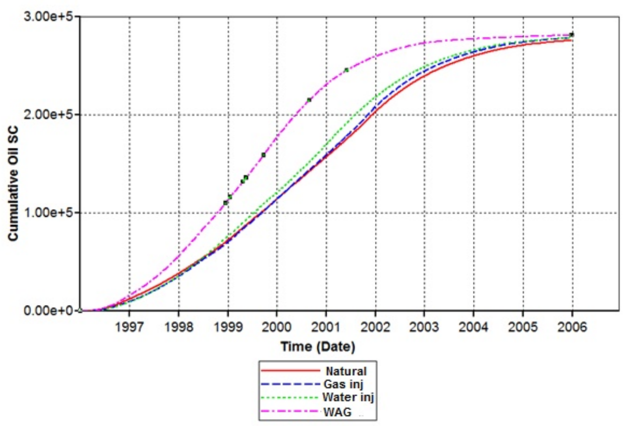

Figure 10. Cumulative oil production in scenarios of natural discharge, water injection, gas and WAG injection

5. Conclusions

In this paper, simulation of water and gas injection was checked in an oil reservoir intermittently. Water injection and gas injection scenarios also were simulated separately and their results were compared with each other and by alternate injection water and gas.

In this paper, the CMS software was used to build models and simulation of various mentioned enhanced oil recovery processes. According to the results obtained from the simulation of different methods of water and gas alternate injection and separately water and gas injection in the formation of Ilam-Sarvak, can be noted to the following points:

- Productivity coefficient and cumulative production in injection cycle of 4: 2 is more than other injection scenarios. The results in field study show that coefficient of water productivity will be increased if the period of gas injection is more than water.
- In WAG method efficiency and production is more If the gas injection be done sooner than water (water phase as a secondary fluid to be injected into the reservoir), than when that water injection fluid to be injection into the reservoir sooner and as primary.
- In the field of study because of the hydrophilic of reservoir rock, water injection has higher recovery factor than gas injection.
- higher productivity and production in IWAG method, compared to other methods of WAG injection indicate being higher sweep displacement in both microscopic and macroscopic and being more efficient of this method compared to other methods of injection.
- The productivity factor and cumulative production WAG method is more than methods of natural production, water and gas injection, so this method was introduced as optimum enhanced oil recovery method in the under study field.

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