Indian Journal of Petroleum Engineering (IJPE)
ISSN: 2582-9297 (Online), Volume-3 Issue-2, November 2023

Reservoir Simulation of Cross CAGD (XCAGD) Thermal Enhanced Heavy Oil Recovery using Foam with Steam Injection

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***Abstract:** Among the most important thermal oil recovery enhancement methods, it is possible to point out In-Situ Combustion (ISC) and Steam Assisted Gravity Drainage (SAGD) processes. The "Combustion Assisted Gravity Drainage (CAGD) process" as an oil recovery enhancement method is a specific combination of two methods: 1-In-Situ Combustion process mostly in terms of the process mechanism and the combustion reactions and also the injected gas type. and 2-Steam Assisted Gravity Drainage process mostly in terms of well configuration. Cross CAGD (XCAGD) is akin to CAGD except that the horizontal injectors are placed perpendicular to the horizontal production wells. By combining both gravity drainage and lateral displacement, XCAGD is able to hasten recovery, diminish steam requirements and promote economic potential compared to CAGD. XCAGD is better suited for several near producers with several perpendicular injectors to achieve a better development. It should be noted that near above kick off point of the vertical injectors with the horizontal producers in XCAGD, slotted liner embedding is pivotal. In this paper, a reservoir simulation of Cross CAGD (XCAGD) thermal enhanced heavy oil recovery using Foam with Steam injection has been precisely scrutinized and studied then some good results have been obtained. These good results encompass more recovery factor of produced oil about %3-5 derived from FOIP curves.*

***Keywords:** Reservoir Simulation, Cross CAGD (XCAGD), Heavy oil, Foam with Steam injection.*

I. INTRODUCTION

Among the most important thermal oil recovery enhancement methods, it is possible to point out In Situ Combustion (ISC) and Steam Assisted Gravity Drainage (SAGD) processes. The "Combustion Assisted Gravity Drainage (CAGD) process" as an oil recovery enhancement method is a specific combination of two methods: 1-In Situ Combustion process, (mostly in terms of the process mechanism and the combustion reactions and also the injected gas type), 2-Steam Assisted Gravity Drainage process, (mostly in terms of well configuration).

Manuscript received on 25 November 2023 | Revised Manuscript received on 26 October 2023 | Manuscript Accepted on 15 November 2023 | Manuscript published on 30 November 2023.
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Combustion process is a displacement process that oxygen (air) is injected into the reservoir which reacts with the crude oil and forms a high-temperature combustion front which moves ahead through the reservoir. ISC method can be done in different forms based on the available circumstances. Two main types of oxidation reactions with high and low temperatures are done and each of them will be effective in the whole of the process. The SAGD process is done by means of a horizontal injection well above a horizontal production well that a high-temperature steam saturated zone is formed in the reservoir. The heat transfer from the injected steam to the reservoir rock and fluid (the original and cold oil) is in the form of conduction. The reservoir gravity force can cause the drainage of the heated oil with more mobility (the activated oil) accompanied with the produced condensed water (hot water) towards the reservoir bottom and the horizontal production well. SAGD has become suitable for Athabasca heavy oil. Once a steam chamber has been made it will be useful to move the injection and production wells farther apart, possibly both vertically and laterally, to improve steam trap control at higher production rates. XCAGD fundamentally is a struggle to move the points of injection and production farther apart at a strategic time to promote performance. The increased lateral distance between the injecting and producing parts of the wells improves the steam-trap control as steam vapor tends to override the denser liquid phase as injected fluids move laterally away from the injector. This allows rates to be increased while abstaining from live steam production. Of course, conceptually, there are at least two problems with this XCAGD concept. First, only the points near where the wells cross are effective in founding the initial steam chamber rather than the whole length of the wells. This confines the initial production and injection. This leaves XCAGD behind CAGD at the start. Second, the plugging operation needs additional cost and poses a serious practical challenge to operations, namely how to selectively plug hot wells operating within a steam chamber. [Rahnema H. and Mamora D.2010].

In 2008, J. Stalder studied about "Thermal Efficiency and Acceleration Benefits of Cross SAGD (XSAGD) , SPE-117244.

In 2007, He also had studied about "Cross-SAGD (XSAGD) - An Accelerated Bitumen Recovery Alternative", SPE-97647.

In this paper, the XCAGD has some more advantages related to XSAGD and other thermal heavy oil recovery enhancement methods and can be beneficial for oil industry.

II. MATERIALS AND METHODS

Drainage (CAGD) process" as an oil recovery enhancement method is a specific combination of two methods: 1-In-Situ Combustion process (mostly in terms of the process mechanism and the combustion reactions and also the injected gas type) and 2-Steam Assisted Gravity Drainage process (mostly in terms of well configuration). In Cross CAGD (XCAGD) the injection wells are perpendicular to the producers that minimize bitumen viscosity allowing the maximum rate of gravity drainage and production. Usually, the injector is placed about 5 m above the producer. It should be noted that near above kick off point of the vertical injectors with the horizontal producers in XCAGD, slotted liner embedding is essential.

III. RESULTS AND DISCUSSION

In Cross CAGD (XCAGD) the injection wells are perpendicular to the producers that minimize bitumen viscosity allowing the maximum rate of gravity drainage and production. Usually, the injector is placed about 5m above the producer. This close spacing of the wells has a distinct advantage during the early portion of the process of founding the steam chamber. However, this close spacing shows a challenge to avoid short-circuiting of the steam from the injector directly into the producer later on. This challenge can be due to hot channels between the wells. Abundant drawdown can draw live steam into the producer risking sand control failure and poor heat management. Now, a reservoir simulation of XCAGD thermal enhanced heavy oil recovery using Foam with Steam injection should be clarified. The usage of foam injection with steam may be able to increase the steam viscosity and diminish the steam mobility. It means that in each section of the top of horizontal production wells, the steam effectiveness to heat that section of cold heavy oil of the reservoir would be increased. So, more oil would drain by gravity force and fractures downwards into the production wells and the recovery factor of oil in terms of science and economy would be improved. In CAGD process, there are some reactions between the reservoir heavy oil and the injected oxygen with SAGD wells configuration and steam chamber upward movement. In XCAGD the case is the same but the injectors are perpendicular to the horizontal producers. In XCAGD process, sub-cool control should be paid attention too much to harness and dwindle the heat loss to overburden. Sub-cool control means to prevent the steam bypass to overburden and as a result heat loss and not heating the cold heavy oil of the pay zone. The heat transfer from the steam and vapored water injected from the injection wells is in the form of conduction. Of course, the form of XCAGD process heat transfer could be in the form of convection to some little extent too. Here are the most important simulation results for XCAGD process:

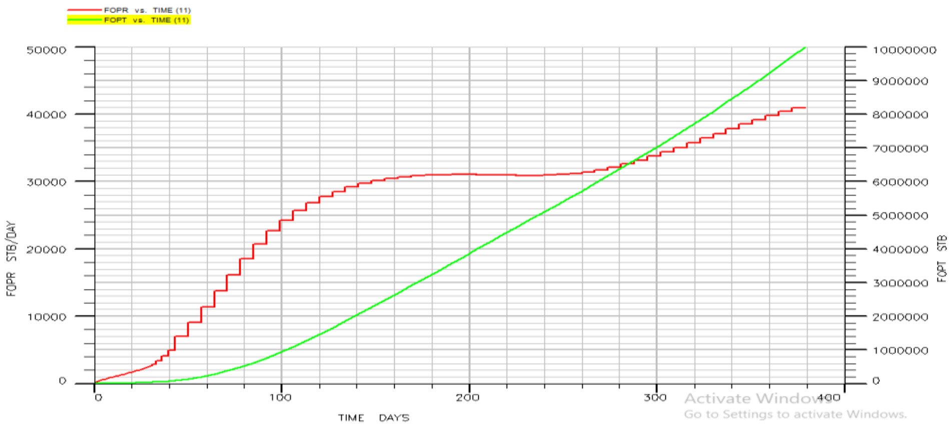

Figure: 1. (XCAGD) FOPR-Time/FOPT-Time

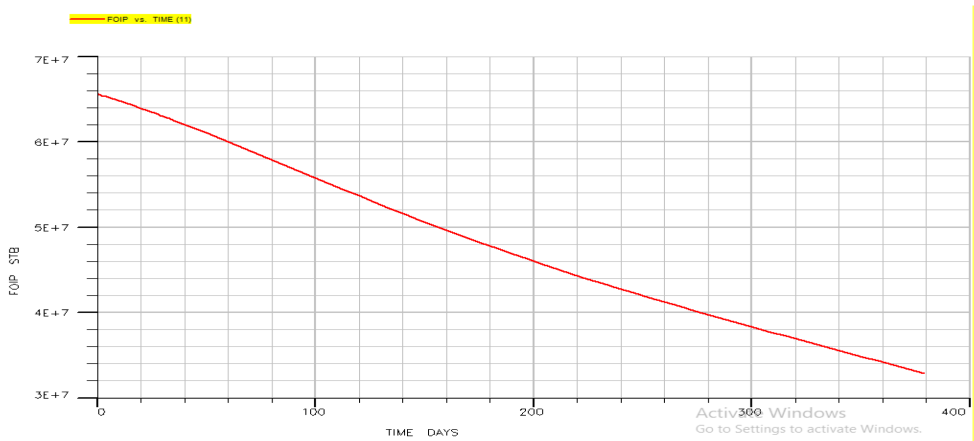

Figure: 2. (XCAGD) FOIP-Time

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DOI:10.54105/ijpe.B1914.113223
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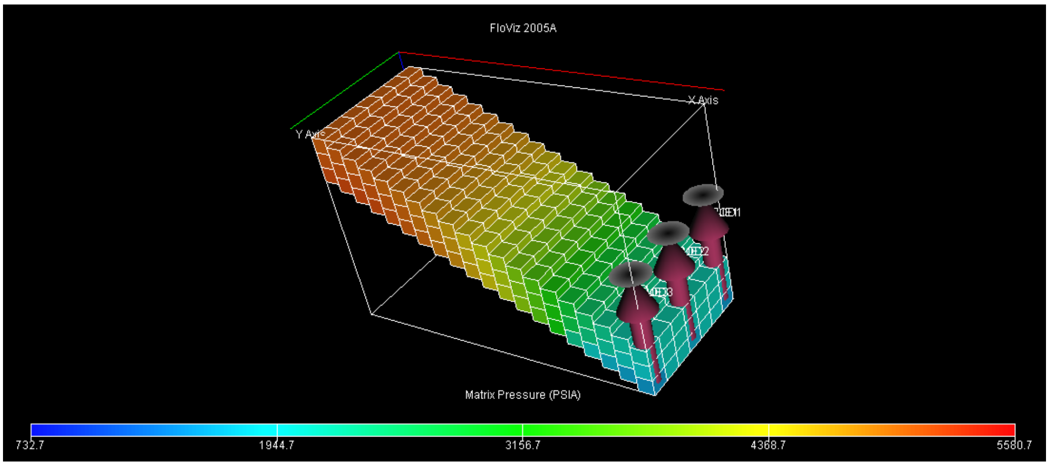

Figure: 3. XCAGD Process Matrix Pressure (psi)

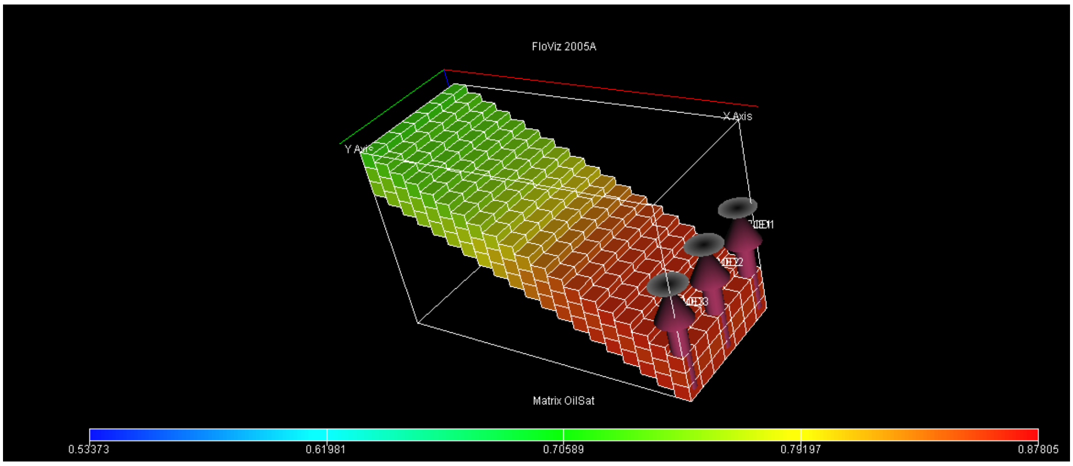

Figure: 4. XCAGD Process Matrix Oil Saturation

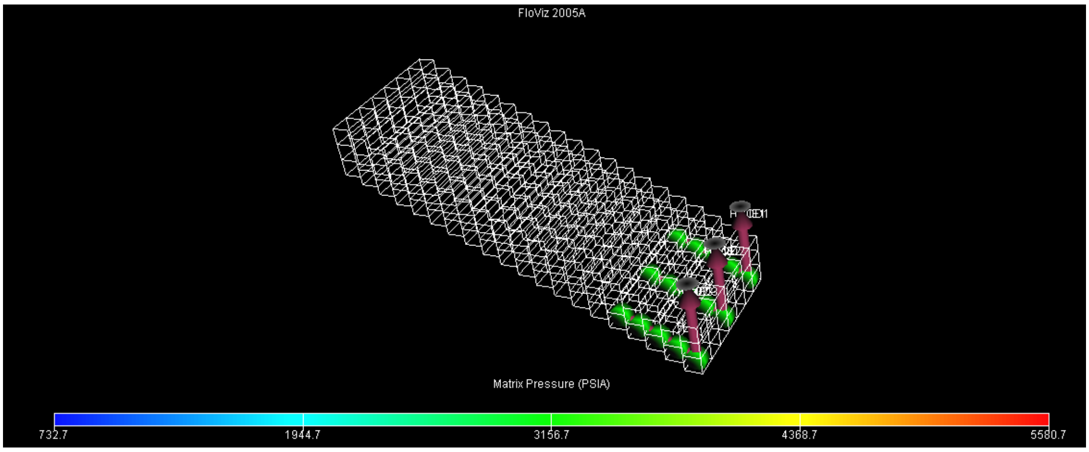

Figure: 5. XCAGD Process Wells Configuration

As a result and shown in figure 2 and 6 (Recovery factor of oil= $R_f = \frac{FIP_1 - FIP_2}{FIP_1}$), the oil recovery factor of the simulation of the XCAGD process can be calculated from FOIP-Time graph.

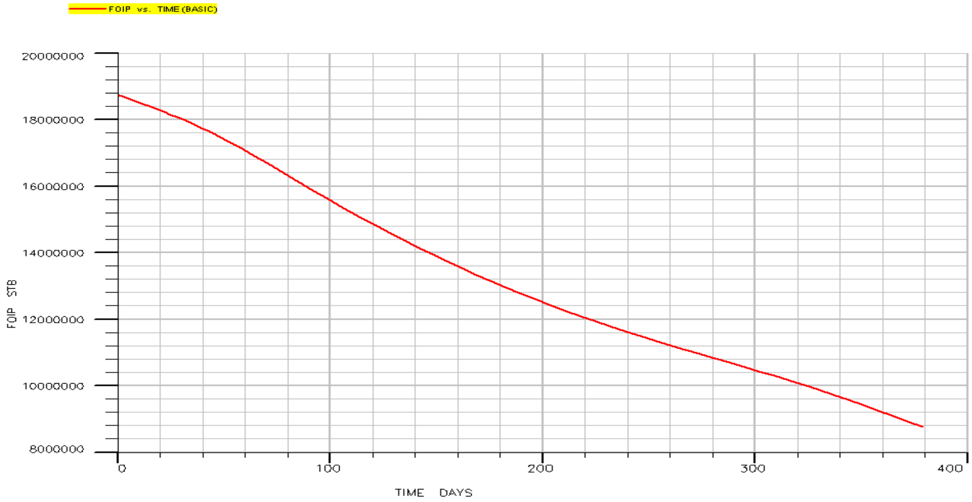

Figure: 6. (CAGD process) FOIP-Time

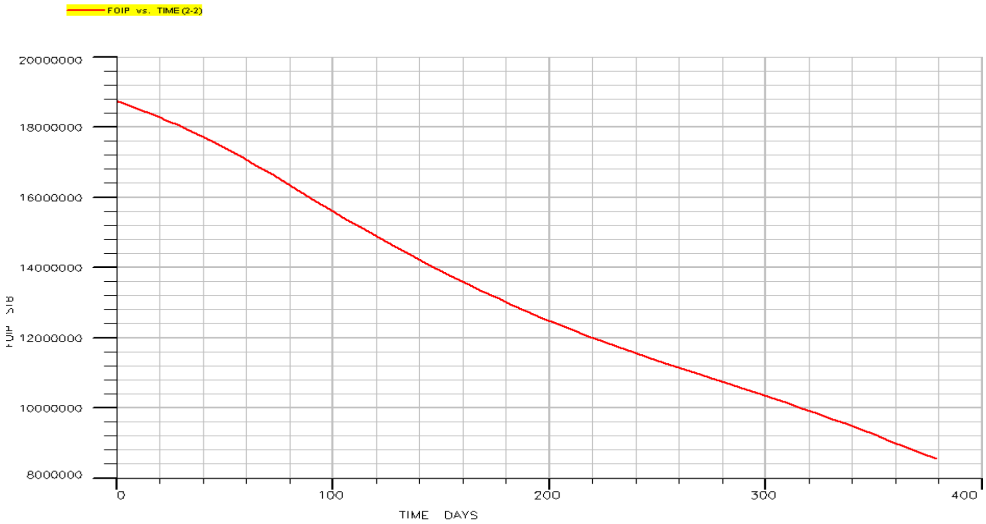

Figure: 7. XCAGD process FOIP-Time (foam assisted)

As the simulation for the XCAGD process shows in figure 7, the oil recovery factor can be increased about 5% by means of foam accompanied with the injected water into the reservoir.

IV. CONCLUSIONS

1. The “Combustion Assisted Gravity Drainage (CAGD) process” as an oil recovery enhancement method is a specific combination of two methods: 1-In-Situ Combustion process mostly in terms of the process mechanism and the combustion reactions and also the injected gas type. 2-Steam Assisted Gravity Drainage process mostly in terms of well configuration. Cross CAGD (XCAGD) is akin to CAGD except that the horizontal injectors are placed perpendicular to the horizontal production wells.
2. It should be noted that near above kick off point of the vertical injectors with the horizontal producers in XCAGD, slotted liner embedding is pivotal.
3. In this paper, a reservoir simulation of Cross CAGD (XCAGD) thermal enhanced heavy oil recovery using Foam with Steam injection has been precisely scrutinized and studied then some good results have been obtained.
4. XCAGD is better suited for several near producers with several perpendicular injectors to achieve a better development.
5. The usage of foam injection with steam may be able to increase the steam viscosity and diminish the steam mobility. It means that in each section of the top of horizontal production wells, the steam effectiveness to heat that section of cold heavy oil of the reservoir would be increased. So more oil would drain by gravity force and fractures downwards into the production wells and the recovery factor of oil in terms of science and economy would be improved.
6. In XCAGD process, sub-cool control should be paid attention too much to harness and dwindle the heat loss to overburden. Sub-cool control means to prevent the steam bypass to overburden and as a result heat loss and not heating the cold heavy oil of the pay zone. The heat transfer from the steam and vapored water injected from the injection wells is in the form of conduction. Of course, the form of XCAGD process heat transfer could be in the form of convection to some little extent too.
7. As the simulation for the XCAGD process has shown, the oil recovery factor can be increased about 5% by means of foam accompanied with the injected water into the reservoir.

Retrieval Number: 100.1/ijpe.B1914113223
DOI:10.54105/ijpe.B1914.113223
Journal Website: www.ijpe.latticescipub.com

Published By:
Lattice Science Publication (LSP)

DECLARATION STATEMENT

Funding/ Grants/ Financial Support	No. I didn't receive any funding.
Conflicts of Interest/ Competing Interests	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	All authors having equal contribution for this article.

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