Simulation of a New Well SAGD Configuration based on the example of an Oil Field in Kazakhstan

Alexandr Logvinenko
Satbayev University, Almaty, Kazakhstan
alex.kazntu@gmail.com (corresponding author)

Received: 3 September 2024 | Revised: 14 October 2024 | Accepted: 29 October 2024

 DOI: https://doi.org/10.48084/etasr.8894

ABSTRACT

Steam-Assisted Gravity Drainage (SAGD) method is recognized as one of the most effective methods for the recovery of heavy oil and natural bitumen. This technology has received several modifications throughout its history designed to improve it. One of the promising modifications is the Single Well-SAGD (SW-SAGD), which allows significantly reducing the CAPEX for drilling a well. However, this method has several disadvantages such as steam breakthrough into the production part and the uneven development of the steam chamber along the well. This article presents the concept of a Single-Well Cyclic SAGD (SWC-SAGD), which allows preventing the breakthrough of the injected steam into the production section and the uniform development of the steam chamber along the well. The comparison analysis of the developed modification of SWC-SAGD was carried out using the classical method of 3D hydrodynamic modeling of both options using the example of one of the fields of the Republic of Kazakhstan. The results of the work show the efficiency of the proposed technology in terms of field oil total production.

Keywords-SAGD; modeling; heavy oil; well configuration; well placement

I. INTRODUCTION

Until recently, traditional petroleum oil easily met the world demand. However, most light oil fields are currently in the final stages of exploitation. This has led to the consideration of alternative or underutilized energy sources, among which are heavy oil and natural bitumen, which are the most accessible in both short- and long-term runs. Heavy oil and natural bitumen reserves are twice the light oil reserves. The global demand for heavy oil and natural bitumen is 5.6 trillion barrels. Most of these reserves are in Venezuela and Canada [1, 2]. Heavy oil and natural bitumen reserves in the Republic of Kazakhstan equal to 42 billion barrels [3].

Among the main methods of producing heavy oil and natural bitumen, the SAGD method, a method of producing heavy oil by injecting high-temperature steam, stands out [4]. The main difference between this method and the traditional method of continuous steam injection [5] is the drilling of two horizontal wells located one above the other and the creation of a steam chamber, along the perimeter of which the heated oil has increased mobility (reduced dynamic viscosity), as a result of which such oil, setting in motion with water condensed from the steam, flows down under the action of gravity into the return production well (Figure 1). The upper well, designed for steam injection, creates steam chamber. As a result, as the mixture of oil and water flows down into the production well, space is freed for expansion of the steam chamber, the perimeter of the steam chamber increases, and a contact surface of steam with oil appears. This allows increasing the oil flow rate. Another reason behind the proposed method is the mechanism of the steam effect on oil itself – oil flows down only with great force, when in the method [6-9] the steam front displaces oil under pressure, so, great pressure is pumped into the steam, which allows oil to be moved forward, when in the SAGD method [4] there is significantly less pressure in the steam chamber, since the expansion of the steam chamber occurs due to the release of space from the flowing oil. Between two horizontal wells, there are boundaries between two phases: at the top – the gas phase, the current steam; Usually – a mixture of heated oil and hot condensed water. Such a barrier prevents steam from breaking through from the upper injection well into the production well. The SAGD method has the highest oil recovery factor of ~75%. SAGD has two important considerations: high capital costs due to the need to drill two long horizontal wells [10] and a limitation on the formation thickness of >30 m, since the two horizontal wells are located one above the other with a distance between them of about 5 m or more [11, 12]. According to the international analysis, when developing heavy oil in the Republic of Kazakhstan, it is most expedient to use SAGD technology and its analogue VAPEX (injection of vaporous solvent instead of steam). VAPEX is less studied, therefore, in most cases, the SAGD method is used [3].

There are many different modifications of the SAGD method [13-16]. However, there are no studies comparing all the modifications of SAGD. In view of this, it was decided at the initial stage to compare the modification developed in [17-18] with the conventional SAGD. Single-Well (SW)-SAGD, involves developing a reservoir using one horizontal well, which in turn has one obvious advantage: a significant reduction in CAPEX due to drilling only one well with production and injection sections instead of two wells as in the conventional SAGD option [19-21]. However, there are two obvious disadvantages:

- Due to the fact that the production and injection sections are in proximity, part of the injected steam, avoiding contact with oil, immediately breaks through to the production section, so steam that has not provided any useful action is produced. As a result, the steam-oil ratio increases. The steam-oil ratio is the main factor affecting OPEX in methods using steam injection;
- The development of the steam chamber occurs unevenly, spreading from the injection part to the productive part.

The objective of this study is to improve the SW-SAGD modification by preventing steam breakthrough and increasing the steam sweep efficiency. A comparison with the conventional SAGD will be conducted using simulations to evaluate the obtained modification. This approach (hydrodynamic modeling) is usually used to study underground and surface reservoirs [22, 23]

Prevention of steam breakthrough into the production section can be solved by introducing a non-perforated zone between the injection and production sections, simulating a water-oil barrier as in the traditional SAGD option. Increased steam coverage will be achieved due to cyclic (alternating, selective) operation of the injection and production sections. The stated goal of this study was achieved: a new single-well modification (SWC-SAGD) was developed, and a comparison analysis with the conventional SAGD option was made.

II. CONCEPT OF SWC-SAGD [17, 18]

The well, which is both an injection and a production well, is drilled to the productive formation of heavy oil. A horizontal well 1000 m long is drilled, which is divided into five sections of 200 m each. Each section is developed separately in two stages. It is worth noting that an option for the horizontal well is to have only one section, as considered in this study. The first stage involves dividing the section (the far section of the well) into 7 sub-sections (Figure 1). Two production and two injection sections are separated from each other by three sections with non-perforated and closed packers. Accordingly, the injection sections inject steam, creating a chamber around the perimeter of which the oil heats up (the viscosity decreases) and flows into the production sections. The non-perforated section is necessary to prevent the steam mixture from breaking through into the production section of the well. After the injection sections have been fully developed, i.e. the steam chamber has been maximally enlarged, the process moves to the second stage (Figure 2). The production and injection sections change places. The second stage is carried out according to the same principle as the first. This approach will allow the formation to be covered by the impact as fully as possible.

Steam injection and oil production will be performed simultaneously from the long (1000 m) well. When the maximum volume of the steam chamber is reached, the sections of the well producing oil will be switched to injection, and the sections injecting steam will be switched to production, which will allow the injection process to cover most of the formation. Between the production and injection sections there are non-perforated sections, the length of which will be selected based on sensitivity analysis. The purpose of such sections is to prevent the injection agent from breaking through to the production sections. For example, in the SW-SAGD method, due to the absence of such a section, the injected steam breaks through to the production section, bringing no benefit and increasing the steam-oil ratio. After a 200 m long section of the well has been fully developed, another section is developed using the same principle until the process covers the entire well. It should be noted that the sizes of all areas may vary.

III. MODEL DESCRIPTION. 3D HYDRODYNAMIC MODEL OF SAGD AND SWC-SAGD

The hydrodynamic model was created on the Eclipse 300 simulator. Half of the steam chamber of the SAGD and SWC-SAGD processes was simulated to reduce the calculation time. Since the steam chamber of these methods is uniformly distributed to the sides, symmetrically, it will be enough to build only one half. This approach does not affect the correctness of the results. Thus, the model is presented as a rectangular parallelepiped with the following number of cells: 70 along the OX axis, 12 along the OY axis and 30 along the OZ axis. The cell sizes along the OX axis are: 20×10 m, 5×20 m, 10×10 m, 5×20 m, 10×10 m, 5×20 m, 15×10 m. The model size along the OX axis is 850 m. The cell sizes along the OY axis are: 1×1 m, 5×7.5 m, 6×15 m. The model size along the OY axis is 128.5 m. The cell sizes along the OZ axis are: 23×1 m, 1×0.5 m, 1×1.5 m, 5×1 m. The model size along the OZ axis is 30 m. The reservoir and oil parameters are presented in Table I. The model dimensions were selected based on the capacity of the maximum size of the steam chamber, that is, the boundaries of the steam chamber should not extend beyond the reservoir model. The development period is 7300 days. [24]

TABLE I. PARAMETERS OF THE RESERVOIR AND OIL FIELD

Parameter	Value
Depth, m	300
Vertical and horizontal permeability, mD	124
Porosity, %	30.5
Reservoir pressure, MPa	3
Oil saturation, %	58
Water saturation, %	42
Oil dynamic viscosity, mPa×s	1378

Table II shows the parameters for steam injection into the formation. Under these conditions, the reagent reaches the bottomhole in a gaseous state.

TABLE II. PARAMETERS OF STEAM INJECTION

Parameter	Value
Temperature of steam injection, °C	300
Pressure of steam injection, MPa	3.24
Injection rate, m^3/day (cold water equivalent)	22.7

A. SAGD Variant

The preheating stage was not simulated, since the oil is quite mobile. The horizontal injection well is in the 19th cell, respectively, the drilling depth of such a well is at the 19 m mark relative to the reservoir thickness. The horizontal production well is in the 25th cell and the drilling depth of such a well is at the 25 m mark relative to the reservoir thickness. The vertical distance between the wells is 6 m. The length of the horizontal part is 750 m for both wells. However, the reservoir has dimensions of 850 m along the OX axis, therefore the well is in the center of the reservoir (50 m from the left edge and 50 m from the right). This is necessary to ensure that the steam impact does not go beyond the reservoir. This is the only way to objectively estimate the oil recovery factor and the reservoir coverage factor. The development period is 20 years.

B. SWC-SAGD Variant

1) Stage 1

The preheating stage was not modeled, since the oil is quite mobile. The horizontal well, combining injection, production and non-perforated sections, is in cell 25, respectively, the drilling depth of such a well is at 25 m relative to the formation thickness. Two injection sections are in the following cell ranges: 26–35 (length – 100 m, location – 300–400 m) and 56-65 (length – 100 m, location – 700–800 m). The distance between the injection sections is 300 m. The two production sections are in the following cell ranges: 11–20 (length – 100 m, location – 100–200 m) and 41–50 (length – 100 m, location – 500–600 m). The distance between the injection sections is 300 m. The length of the horizontal section is 750 m for both wells. Three non-perforated sections are located between the injection and production sections and are also 100 m each. The development period is 10 years.

2) Stage 2

Two injection sections are placed in 11–20 (length 100 m, location 100–200 m) and 41–50 (length 100 m, location 500–600 m). The distance between the injection sections is 300 m. Two production sections are placed in 26–35 (length 100 m, location 300–400 m) and 56–65 (length 100 m, location 700–800 m). The distance between production sections is 300 m. The length of the horizontal section is 750 m for both wells. Three non-perforated sections are located between the injection and production sections and are also 100 m each. Three non-perforated sections are located between the injection and production sections and are also 100 m each. The development period is 10 years.

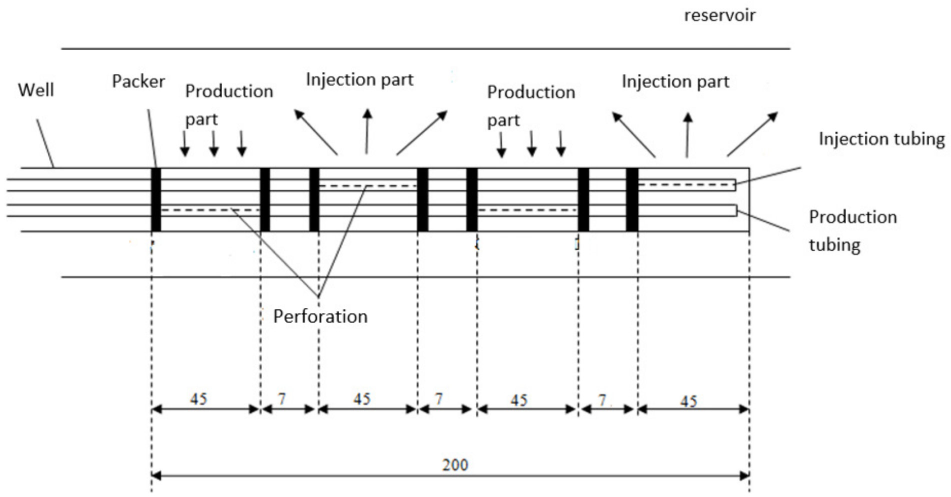

Fig. 1. First stage of the SWC-SAGD method.

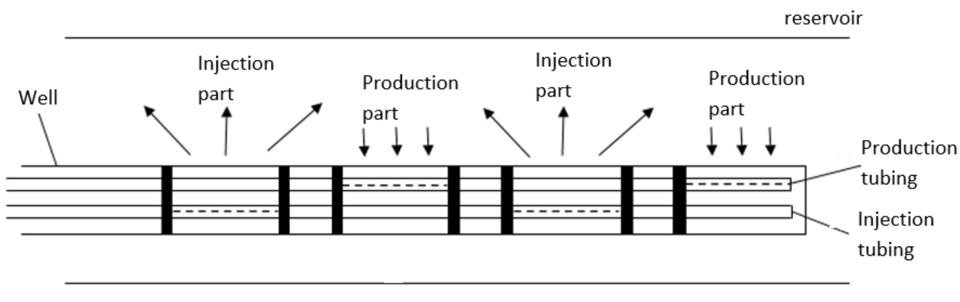

Fig. 2. Second stage of the SWC-SAGD method.

IV. RESULTS AND DISCUSSION

Figure 3 shows a comparison of the steam chambers of the SAGD and SWC-SAGD methods on the gas saturation scale. It can be seen that half of the steam chamber was modeled. We can see that the steam chamber increases closer to the formation roof, since steam is a gas, and it tends to rise. The steam chamber begins to develop as follows: at the beginning of the injection, the steam chamber grows vertically upward, then, reaching the roof, it begins to expand to the sides. The size of the steam chamber is 83.5 m (SAGD), i.e. the width of the full steam chamber is 167 m. In SWC-SAGD, the size of the steam chamber is 98.5 m, i.e. the width of the full steam chamber is 197 m. Based on this, the required distance between SAGD wells should be 167 m, while for SWC-SAGD it would be 197 m. It is quite possible that the steam chamber will increase in size if the development time is increased over 7300 days. For this purpose, it is recommended to conduct additional numerical modeling of the SAGD and SWC-SAGD process, providing for an increase in the development duration. Also, when using the innovative modification of SWC-SAGD, it is possible to identify non-perforated areas. In general, the new modification has a greater reservoir coverage with reagent than the conventional version. It should be noted that in thermal methods, a greater reservoir coverage by area can lead to increased heat losses through the collector roof.

Figure 4(a) shows the development of the steam chamber for the SWC-SAGD method by years. From left to right, there are 5 layers (top view) as of the 1st, 5th, 10th, 15th and 20th year of development. A slight unevenness in the development of the steam chamber may occur due to insufficient disclosure of the potential of the 1st and 2nd stages of development, which is 10 years. It is necessary to conduct a sensitivity analysis to the duration of each stage and their relationship to each other.

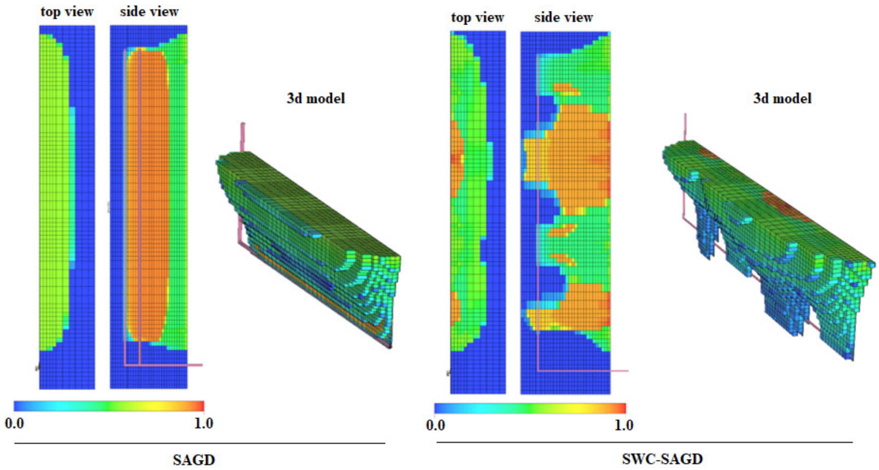

Fig. 3. Comparison of steam chambers of SAGD and SWC-SAGD methods (scale – gas saturation).

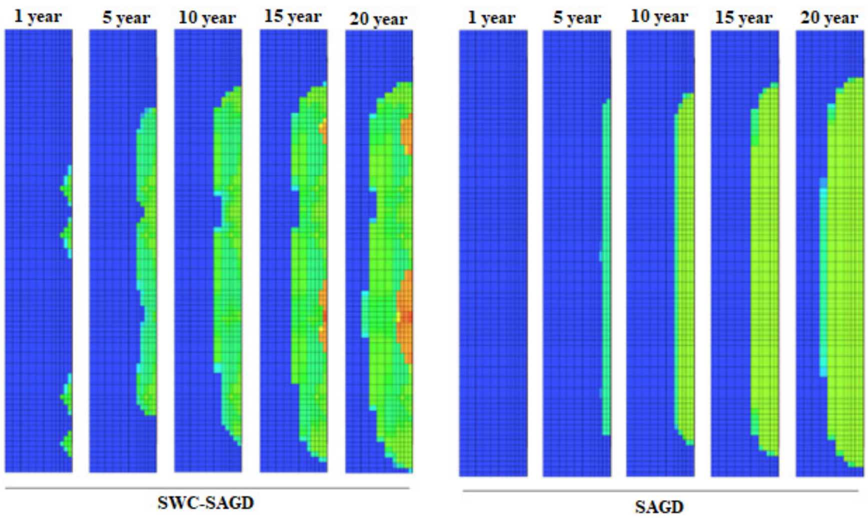

Fig. 4. Comparison of the distribution of the steam chamber against time.

Figure 4(b) illustrates the process of steam chamber development for the classic SAGD variant. As for the new modification, 5 formations are located from left to right (top view) as of the 1st, 5th, 10th, 15th and 20th year of development. It is noteworthy that in the 1st year of development, the injected steam does not reach the formation roof. The reason for this is the longtime of heating the interwell space, where the distance is 6 m. In this case, the preheating stage was not modeled. At the same time, given the distribution of the steam chamber as of the 1st year of development (Figure 4), it can be concluded that the preheating stage for the SAGD method will have a longer duration than for the new SWC-SAGD modification. For this, it is necessary to conduct a separate study on modeling the preheating stage for both methods. This study does not set such a task.

Figure 5 shows the graphs of cumulative oil production. In general, for the entire period of oil development, the following quantities were produced: SAGD - 220571.19 m^3, SWC-SAGD - 234904.15 m^3. Accordingly, the difference between the cumulative oil production is 14332.96 m^3 or 6.5%. The SWC-SAGD hydrodynamic model is distinguished by a more detailed elaboration in places where injection sections are located.

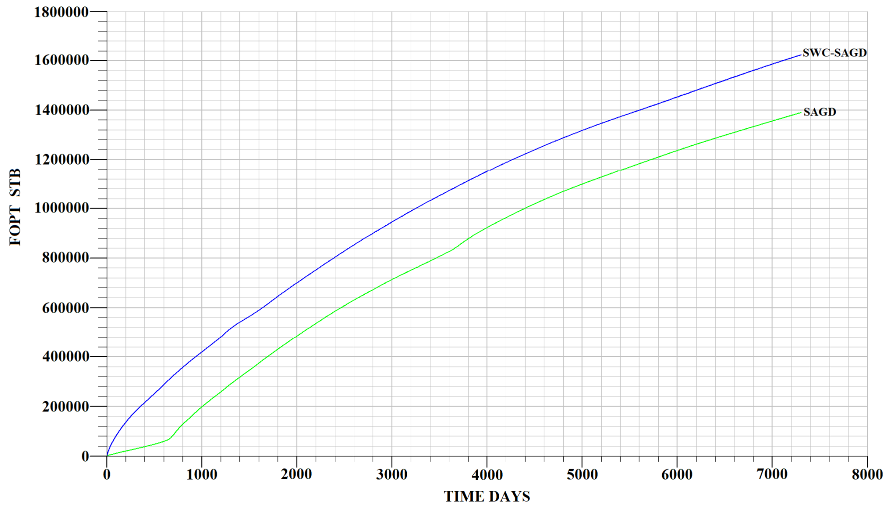

Fig. 5. Cumulative oil production comparison.

V. CONCLUSION

This work intends to solve some problems of the SAGD and SW-SAGD methods, such as the high cost of CAPEX for well drilling, the prevention of breakthrough of the injected steam into production sections, by developing a new modification of SWC-SAGD aiming to increase the reservoir sweep efficiency. As a result of the conducted study, the new SWC-SAGD modification was developed, and a comparison of SAGD and SWC-SAGD was carried out using hydrodynamic modeling. It was shown that SWC-SAGD can be considered for application in heavy oil and natural bitumen fields as an alternative to the conventional SAGD, since it is more efficient from a technical point of view. Some of the key points of the current paper are:

- A new modified SWC-SAGD method was developed and proposed, which includes alternating injection and production sections separated by non-perforated sections. This modification prevents the penetration of the injected steam into the production sections and, using a cyclic development system, provides a more uniform impact on the formation.
- The hydrodynamic modeling of the SAGD and SWC-SAGD methods was carried out over a development period of 7.300 days showing the effectiveness of the new modification.
- The width of the SWC-SAGD steam chamber is 30 m greater than that of the classic version.
- The cumulative oil production is: SAGD – 1389587.5 STB, SWC-SAGD – 1623320.5 STB.

The study of the SWC-SAGD method should be continued in future studies. The following issues should be considered:

- Range of oil dynamic viscosity.
- Range of reservoir thickness.
- Determination of optimal relationships between production, injection, and non-perforated sections.
- Feasibility study for the use of SWC-SAGD.

ACKNOWLEDGMENT

This research was funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan, grant number AP14972678.

REFERENCES

[1] P. J. Briggs, P. R. Baron, R. J. Fulleylove, and M. S. Wright, "Development of Heavy-Oil Reservoirs," *Journal of Petroleum Technology*, vol. 40, no. 2, pp. 206–214, Feb. 1988, https://doi.org/10.2118/15748-PA.

[2] R. F. Meyer, E. D. Attanasi, and P. A. Freeman, "Heavy oil and natural bitumen resources in geological basins of the world," U.S. Geological Survey, Reston, VA, USA, 2007–1084, 2007, https://doi.org/10.3133/ofr20071084.

[3] Y. Tileuberdi, Z. A. Mansurov, Y. K. Ongarbayev, and B. K. Tuleutaev, "Structural Study and Upgrading of Kazakhstan Oil Sands," *Eurasian Chemico-Technological Journal*, vol. 17, pp. 173-179, 2015.

[4] R. M. Butler, G. S. Mcnab, and H. Y. Lo, "Theoretical studies on the gravity drainage of heavy oil during in-situ steam heating," *The*

Canadian Journal of Chemical Engineering, vol. 59, no. 4, pp. 455–460, 1981, https://doi.org/10.1002/cjce.5450590407.

[5] G. R. Scott, "Comparison of CSS and SAGD Performance in the Clearwater Formation at Cold Lake," in *PE International Thermal Operations and Heavy Oil Symposium and International Horizontal Well Technology Conference*, Calgary, AB, Canada, Nov. 2002, pp. 1–12, https://doi.org/10.2118/79020-MS.

[6] K. Sasaki, S. Akibayashi, N. Yazawa, Q. Doan, and S. M. Farouq Ali, "Numerical and experimental modelling of the steam assisted gravity drainage (SAGD) process," *Journal of Canadian Petroleum Technology*, vol. 40, no. 1, pp. 44–50, Jan. 2001.

[7] L. Pujol and T. C. Boberg, "Scaling Accuracy of Laboratory Steam Flooding Models," in *SPE California Regional Meeting*, Bakersfield, CA, USA, Nov. 1972, pp. 1–7, https://doi.org/10.2118/4191-MS.

[8] B. T. Willman, V. V. Valleroy, G. W. Runberg, A. J. Cornelius, and L. W. Powers, "Laboratory Studies of Oil Recovery by Steam Injection," *Journal of Petroleum Technology*, vol. 13, no. 7, pp. 681–690, Jul. 1961, https://doi.org/10.2118/1537-G-PA.

[9] J. V. Howard, "Status Of Thermal Recovery," in *SPE Permian Basin Oil Recovery Conference*, Midland, TX, USA, Dec. 1965, pp. 5–10, https://doi.org/10.2118/1142-MS.

[10] K. A. Lawal, "How Economic is Steam-Assisted Gravity Drainage for the In-situ Development of the Nigerian Bitumen Deposit?," in *Nigeria Annual International Conference and Exhibition*, Lagos, Nigeria, Aug. 2012, pp. 1–9, https://doi.org/10.2118/162949-MS.

[11] Z. Zargar and S. M. Farouq Ali, "Analytical Treatment of Steam-Assisted Gravity Drainage: Old and New," *SPE Journal*, vol. 23, no. 1, pp. 117–127, Jun. 2017, https://doi.org/10.2118/180748-PA.

[12] S. Yang and D. Yang, "Development of a heat-penetration criterion to characterize steam chamber growth and propagation dynamics during a steam-assisted gravity drainage (SAGD) process," *Applied Thermal Engineering*, vol. 238, Feb. 2024, Art. no. 121855, https://doi.org/10.1016/j.applthermaleng.2023.121855.

[13] M. Tavallali, B. Maini, T. Harding, and B. Busahmin, "Assessment of SAGD Well Configuration Optimization in Lloydminster Heavy Oil Reserve," in *SPE/EAGE European Unconventional Resources Conference and Exhibition*, Vienna, Austria, Mar. 2012, pp. 1–6, https://doi.org/10.2118/153128-MS.

[14] M. Mojarab, T. G. Harding, and B. B. Maini, "Improving the SAGD Performance by Introducing a New Well Configuration," *Journal of Canadian Petroleum Technology*, vol. 50, no. 4, pp. 9–18, Mar. 2011, https://doi.org/10.2118/146626-PA.

[15] M. R. Tamer and I. D. Gates, "Impact of Different SAGD Well Configurations (Dover SAGD Phase B Case Study)," *Journal of Canadian Petroleum Technology*, vol. 51, no. 1, pp. 32–45, Jan. 2012, https://doi.org/10.2118/155502-PA.

[16] R. A. Pratama and T. Babadagli, "What did we learn from steam assisted gravity drainage (SAGD) applications in three decades, and what is next?," *Geoenergy Science and Engineering*, vol. 232, Jan. 2024, Art. no. 212449, https://doi.org/10.1016/j.geoen.2023.212449.

[17] Patent 35457 RK, "Cyclic Method of Single Well Steam-Assisted Gravity Drainage", 2022 (in Russian).

[18] International application for PCT patent PCT/KZ2020/000025 "Cyclic Method of Single Well Steam-Assisted Gravity Drainage (SWC-SAGD)", 2022.

[19] K. T. Elliott and A. R. Kovscek, "Simulation of Early-Time Response of Single-Well Steam Assisted Gravity Drainage (SW-SAGD)," in *SPE Western Regional Meeting*, Anchorage, Alaska, Dec. 1999, pp. 1–12, https://doi.org/10.2118/54618-MS.

[20] G. Cui, T. Liu, J. Xie, G. Rong, and L. Yang, "A review of SAGD technology development and its possible application potential on thin-layer super-heavy oil reservoirs," *Geoscience Frontiers*, vol. 13, no. 4, Jul. 2022, Art. no. 101382, https://doi.org/10.1016/j.gsf.2022.101382.

[21] G. Hocking, T. Cavender, and J. Person, "Single-Well SAGD: Overcoming Permeable Lean Zones and Barriers," in *Canadian Unconventional Resources Conference*, Calgary, AB, Canada, Nov. 2011, pp. 1–2, https://doi.org/10.2118/148832-MS.

[22] R. Sabeti, S. Jamali, and H. H. Jamali, "Simulation of Thermal Stratification and Salinity Using the Ce-Qual-W2 Model (Case Study: Mamloo Dam)," *Engineering, Technology & Applied Science Research*, vol. 7, no. 3, pp. 1664–1669, Jun. 2017, https://doi.org/10.48084/etasr.1062.

[23] I. Ehibor *et al.*, "Numerical Simulation of Heavy Oil Recovery for a Niger-Delta Reservoir," in *SPE Nigeria Annual International Conference and Exhibition*, Lagos, Nigeria, Aug. 2024, pp. 1–5, https://doi.org/10.2118/221801-MS.

[24] D. A. R. da Silva, T. V. D. Junior, and J. L. M. Barillas, "Energy lost study for the steam and solvent assisted gravity drainage process, using reservoirs with Brazilian northeast characteristics," *Research, Society and Development*, vol. 13, no. 2, Feb. 2024, Art. no. e8813245051, https://doi.org/10.33448/rsd-v13i2.45051.