The Impact of Hexane on the Dynamic Viscosity of Kazakhstans's Heavy Oil

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

Received: 9 September 2024 | Revised: 7 November 2024 | Accepted: 19 November 2024

 DOI: https://doi.org/10.48084/etasr.8958

ABSTRACT

The Republic of Kazakhstan has significant heavy oil and natural bitumen reserves. Some of these reserves contain highly viscous oil of more than 1000 mPa·s at shallow depths. The main recovery techniques are thermal methods, which use steam or hot water injections. One of the variants used to improve the thermal methods is the addition of a liquid or gaseous solvent. In this study, hexane was used as an additive solvent. The purpose of this study is to determine the effect of hexane on dead heavy oil in the Sarybulak field in the context of dynamic viscosity reduction. Mixtures of heavy oil and hexane in various proportions were prepared and studied. In addition, the dependence of the dynamic viscosity of heavy oil on the hexane content was evaluated.

Keywords-dynamic viscosity; heavy oil; hexane; solvent; thermal EOR

I. INTRODUCTION

Almost 90% of all reserves of high-viscosity oil are concentrated in Canada and Venezuela [1]. Approximately 220 oil and gas fields are in Kazakhstan, the largest part of which contains conventional hydrocarbons, which are extracted using standard technologies, including primary (considering the type of reservoir energy), secondary (flooding, gas injection to maintain reservoir pressure), tertiary, and other methods of increasing oil recovery (polymer flooding, thermal methods, etc.). However, in the Republic of Kazakhstan, 47 oil fields have been developed using only tertiary methods. These oils are characterized by very high dynamic viscosity and extremely low mobility. This leads to low oil production [2]. Without reducing the viscosity, such oils cannot be extracted from the surface. First, the oil must be either heated or brought to the liquid phase using a solvent. Hot water, steam, or gas is typically used to heat high-viscosity oil. Hydrocarbon gases and liquids are used for dissolution. The recovery of heavy oil is typically performed using thermal and non-thermal methods. The most effective thermal method is Steam-Assisted Gravity Drainage (SAGD), the efficiency of which can be enhanced by adding solvents to the steam [3].

In this study, hexane was used as a solvent additive for the primary injection reagent. Because of its high cost, hexane is widely used as a minor additive to injected steam (Es-SAGD technology) to reduce heat losses through the formation overburden. Hexane is also added to the injected low-hydrocarbon gas [4]. Laboratory and calculation studies [5, 6] have shown that when injecting a steam-hexane mixture with a hexane content of 1%, the oil flow rate increases by an average of two times. In [7], a high oil recovery value of 90.5% was obtained using a hexane additive. For comparison, using the SAGD technology, the oil recovery was only 73%. The most effective non-thermal method is the injection of aporized hydrocarbon solvents into heavy oil (VAPEX method) [8]. In this case, gas injection can be improved by adding a heavier solvent such as hexane.

The aim of this study was to determine the effect of hexane on dead heavy oil in the Sarybulak field in the context of dynamic viscosity reduction. Notably, a chemical additive was selected for each case owing to the unique composition of each oil. Therefore, this study is the first to explore the use of hexane as a solvent in different proportions for heavy oil from the Sarybulak field. The obtained results will enable further laboratory experiments and hydrodynamic modeling for steam or other gas injection with the addition of hexane, as well as the assessment of the technical and economic feasibility of these approaches.

II. METHODOLOGY

The research methodology consisted of the following stages.

- Measurement of the dynamic viscosity of dead oil at various temperatures (30 – 150 °C) and atmospheric pressure using a Stabinger viscometer. The dead heavy oil used in this experiment was sampled directly from the Sarybulak field (at the wellhead) and was transported to the measurement site.
- Determining the proportion of high viscosity oil and hexane as shown in Table I.
- Mixing procedure. The required amounts of oil and hexane, depending on the selected proportions, were measured by using graduated cylinders. The mixture was then thoroughly blended. A mechanical stirrer was used to

achieve a thorough mixing. The components must be fully combined, without phase separation.

- Measurement of the dynamic viscosity of a mixture of dead oil and liquid solvents in various proportions at a reservoir temperature of 40 °C and atmospheric pressure using a Stabinger viscometer. Viscosity measurements were performed four times for each sample and the arithmetic mean was estimated.

TABLE I. PROPORTION OF DEAD OIL AND HEXANE

Proportions of the dead oil and hexane in mixture	
Dead oil	**Hexane**
1	1
2	1
3	1
4	1
5	1
6	1
7	1
8	1
9	1
10	1
11	1

The scientific results of this study are based on the dependence of the dynamic viscosity of the oil-solvent mixture on the concentration of hexane solvent.

III. RESULTS AND DISCUSSION

The VAPEX method assumes that high-viscosity oil displacement from the reservoir using chemical solvents does not involve oil displacement but its dissolution by mixing with a vapor and/or liquid solvent, and the resulting mixture with reduced viscosity flows into the lower production well [8].

Figure 1 shows the phase diagram of dead high-viscosity oil from the Sarybulak field. The green line marks the boundary between the single-phase (liquid) and two-phase (liquid-gas) regions. The red line also marks the boundary between the two-phase (liquid-gas) and single-phase (gas) regions. The oil sample will be in a single-phase (liquid) at reservoir conditions (reservoir pressure of 13.6 MPa, reservoir temperature of 40 °C), and it is necessary to increase the reservoir temperature to at least 650 °C while remaining in the low-pressure range (below 0.75 MPa) to convert such oil into the gas phase.

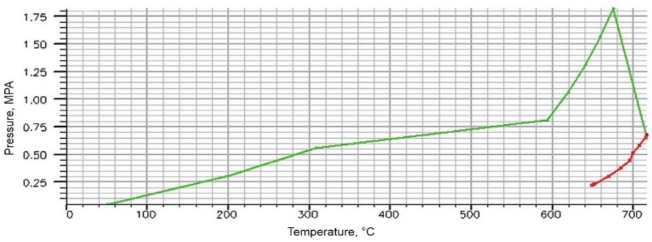

Fig. 1. Phase diagram of dead oil.

Figure 2 shows the phase diagram of high-viscosity reservoir oil from the Sarybulak field. The green line marks the boundary between the single-phase (liquid) and two-phase (liquid-gas) regions. The red line also marks the boundary between the two-phase (liquid-gas) and single-phase (gas) areas. Under reservoir conditions, this oil will also be in a single liquid phase, because for gas to begin to be released from the oil, it will be necessary to achieve a reduced pressure of 5 MPa at a reservoir temperature of 40 °C. Such conditions are most likely possible only in wells. In the single-phase gas phase, such oil is present at low pressures (below 1.75 MPa) and high temperatures (over 600 °C).

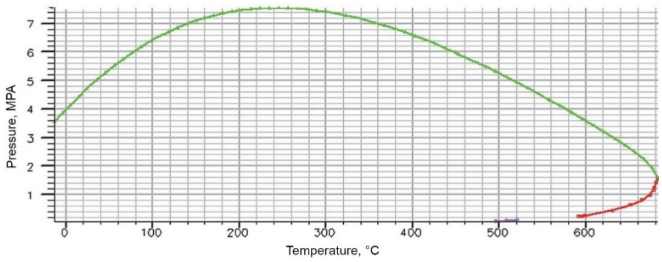

Fig. 2. Phase diagram of reservoir oil.

Figure 3 shows the viscosity measurements of the heavy oil extracted from the Sarybulak field. The studies were conducted using a Stabinger viscometer at atmospheric pressure. The range of studies was from 30 to 150 °C. As shown in Figure 3, the viscosity dropped sharply from 2247 to 9.3 mPa·s under these conditions, which in turn indicates a positive effect of the thermal methods on the oil in the Sarybulak field. From Figure 3, it can be concluded that there is no need to increase the temperature above 150 °C, because the viscosity will change insignificantly.

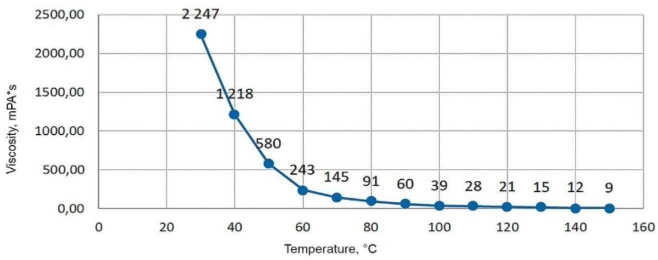

Fig. 3. Dependence of oil viscosity on temperature.

Figure 4 shows the dependence of the temperature on the saturated pressure. Steam was prepared according to the steam tables. This graph provides crucial information about the phase behavior of water under various pressure and temperature conditions. The saturation line serves as a boundary between the liquid and steam phases. The area above the saturation line corresponds to the liquid phase. The area below the saturation line corresponds to the steam phase. The temperature will be 335 °C at a formation pressure of 13.6 MPa and the water will be in the steam phase. This means that the injected steam can only be obtained at temperatures above 335 °C. In this regard, generating steam of this quality is expensive. Therefore, replacing the steam injection technology with the VAPEX method is a logical choice.

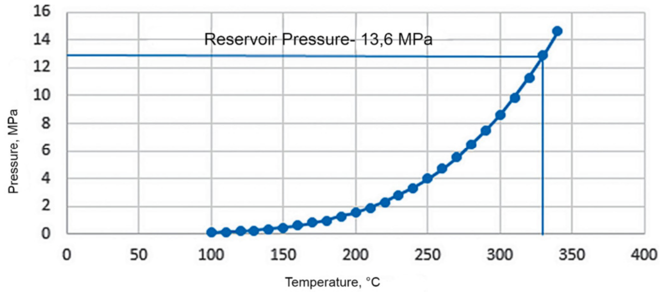

Fig. 4. Dependence of temperature on saturated vapor pressure.

Figure 5 describes conditions for conducting an experiment to determine the viscosity of dead oil at 0.1 MPa.

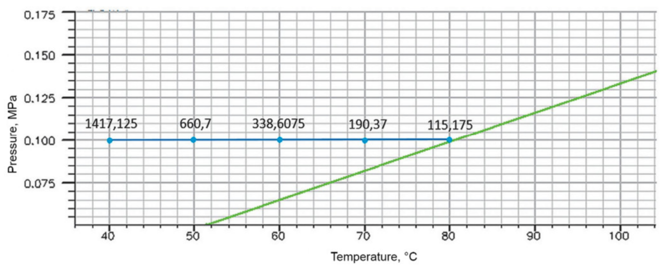

Fig. 5. Dynamic viscosity of dead oil depending on temperature at atmospheric pressure.

Figure 6 shows the results of measuring the dynamic viscosity of the mixture of dead oil and hexane based on the hexane concentration. Hexane is the best solvent according to the results of many studies [6, 9]. At proportions of 1:1 oil to hexane, the viscosity of oil drops from 2247 to 0.4 mPa·s at a temperature of 40 °C, i.e it decreases by 5600 times. When the proportion of hexane was reduced to the lowest value of 10:1, the viscosity drops to 236.1 mPa·s, which is almost 10 times lower than that of oil. The viscosity of hexane is 0.253 mPa·s at 40 °C. The dynamic viscosity is not an additive property. Thus, the most accurate way to estimate viscosity is through experimentation.

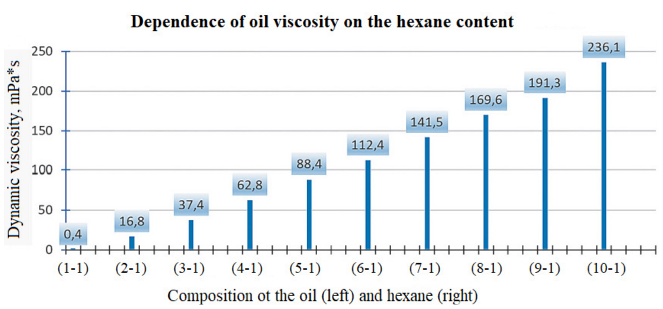

Fig. 6. Graph of the dynamic viscosity of a mixture of dead oil and hexane with varying hexane content.

IV. CONCLUSIONS

Hexane has a high dissolving capacity and can be easily mixed with oils. A small amount of hexane in the injected reagent can significantly reduce the dynamic viscosity of the oil from the Sarybulak field, thereby increasing the mobility of the formation fluid. This indicates its effectiveness as a low-concentration additive for the primary injection reagent. At reservoir pressure and temperature, hexane is in the liquid phase. In the case of hot water injection, hexane is also present in the liquid phase. The temperature of hot water should not exceed 100 °C. At 150 °C, the viscosity of the dead oil decreased to 9 mPa·s. To inject steam at reservoir pressure, it is necessary to achieve a temperature at the bottomhole of 335-340 ºC, which is economically unprofitable, while the main cost of steam methods is steam generation. In this case, the addition of hexane significantly reduces the steam-oil ratio, which leads to a significant reduction in steam generation costs, as well as an increase in total oil production owing to an additional mechanism for reducing the dynamic viscosity of the reservoir fluid. When different gases (not VAPEX) are injected as the primary displacing agent at the reservoir temperature, hexane remains in the liquid phase. The injected gases will primarily displace oil from the upper part of the reservoir, whereas hexane, owing to its higher density, mixes and gradually displaces oil from the central part of the reservoir, moving downward. This can lead to an increase in the vertical sweep efficiency. When hexane is used as an additive in the VAPEX method, gravitational segregation also occurs, resulting in enhanced vertical sweep efficiency. Overall, the effect of hexane on oil is consistent with the results obtained in previously published studies. However, the degree of viscosity reduction in the oil-hexane mixture depends on the compositional characteristics of the oil. Based on the obtained results, it is recommended to test the injection of various reagents (different gases, steam, hot water) with a small concentration of hexane into a bulk model of reservoir, as well as to conduct hydrodynamic modeling to assess the effectiveness of these approaches from both technical and economic perspectives.

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] EIA, U.S. Energy Information Administration, *Country Analysis Brief: Canada*. Washington, DC: U.S. Department of Energy.

[2] N. Mamulaishvili, G. Partskhaladze, G. Chavleshvili, T. Khitarishvili, and N. Salimova, "A Technological Nanofluid for Washing Off Oil Deposits and Increasing Oil Recovery," *Engineering, Technology & Applied Science Research*, vol. 13, no. 4, pp. 11058–11063, Aug. 2023, https://doi.org/10.48084/etasr.5904.

[3] 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.

[4] W. Li, "Improved Steam Assisted Gravity Drainage (SAGD) Performance with Solvent as Steam Additive," PhD Thesis, Texas A&M University, 2011.

[5] T. N. Nasr, G. Beaulieu, H. Golbeck, and G. Heck, "Novel Expanding Solvent-SAGD Process 'ES-SAGD,'" *Journal of Canadian Petroleum Technology*, vol. 42, no. 01, Jan. 2003, Art. no. PETSOC-03-01-TN, https://doi.org/10.2118/03-01-TN.

[6] M. E. McCormack, "Design of Steam-Hexane Injection Wells For Gravity Drainage Systems," *Journal of Canadian Petroleum*

Technology, vol. 48, no. 01, Jan. 2009, Art. no. PETSOC-09-01-22, https://doi.org/10.2118/09-01-22.

[7] Y. Souraki, M. Ashrafi, A. J. Ghahfarokhi, and O. Torsaeter, "Application of Solvent Alternating SAGD Process to Improve SAGD Performance in Athabasca Bitumen Reservoir," presented at the SPE Western Regional & AAPG Pacific Section Meeting 2013 Joint Technical Conference, Monterey, California, USA, Apr. 2013, Art. no. SPE-165327-MS, https://doi.org/10.2118/165327-MS.

[8] R. M. Butler and I. J. Mokrys, "A New Process (VAPEX) For Recovering Heavy Oils Using Hot Water And Hydrocarbon Vapour," *Journal of Canadian Petroleum Technology*, vol. 30, no. 01, Jan. 1991, Art. no. PETSOC-91-01-09, https://doi.org/10.2118/91-01-09.

[9] M. H. Mohebati, B. B. Maini, and T. G. Harding, "Experimental Investigation of the Effect of Hexane on SAGD Performance at Different Operating Pressures," presented at the SPE Heavy Oil Conference, Calgary, Alberta, Canada, Jun. 2012, Art. no. SPE-158498-MS, https://doi.org/10.2118/158498-MS.