Diluent Injection for Viscosity Reduction in Heavy Oil: Visoka Field Study

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Abstract: - Heavy crude oil production remains challenging mainly because of its high viscosity and complex non-Newtonian flow behaviour, which can reduce reservoir performance. Under these conditions, conventional recovery methods are often insufficient, necessitating enhanced oil recovery (EOR) techniques. This study focuses on the use of diluents, which reduce viscosity and improve production efficiency. Laboratory measurements under surface conditions indicate viscosity reductions of 50–99%, depending on diluent concentration and temperature. This paper examines diluent injection in the Visoka oilfield, Albania—a field with high-viscosity, non-Newtonian crude. The injection of light hydrocarbons alters the crude oil's rheological behaviour, allowing easier flow near the wellbore and during surface handling, while also contributing to reservoir pressure maintenance. Similar behaviour has been observed in other heavy oil fields. The results from the Visoka oilfield indicate higher recovery rates and improved well performance. Further investigation under reservoir conditions could help refine these strategies.

Key-Words: - heavy oil, diluent injection, enhanced oil recovery (EOR), non-Newtonian flow, viscosity reduction, Visoka oilfield.

Received: July 11, 2025. Revised: October 22, 2025. Accepted: November 13, 2025. Published: December 31, 2025.

1 Introduction

Heavy oil typically exhibits high viscosity, high density, and a relatively low proportion of volatile components compared to conventional light crude oil, [1], [2]. Its composition, rich in paraffins, waxes, resins, and asphaltenes, leads to high pour and melting points, [1], low hydrogen-to-carbon ratios, and elevated levels of sulphur, nitrogen, and heavy metals, [2]. These properties make extraction, production, transport, and refining more difficult.

A detailed understanding of heavy oil composition is important because it directly influences recovery, processing, and transport operations. High viscosity and melting points restrict fluid movement within the reservoir and limit fluid mobilisation. At the same time, the presence of resins, sulphur, and aromatic compounds, complicates upgrading and refining processes. In addition, high viscosity poses challenges for efficient flow in pipelines.

Consequently, viscosity stands out as one of the most critical barriers, increasing operational complexity and costs - particularly when coupled with high sulphur content and elevated resistance to flow, [1]. Furthermore, the high content of asphaltenes, sulphur, and heavy metals in such crudes makes both recovery operations and refining processes more demanding and expensive relative to lighter oils, [1], [3]. To assist in assessing and processing such crude oil, the SARA classification (Saturates, Aromatics, Resins and Asphaltenes) is commonly employed. The SARA distribution of Visoka crude oil, determined from field and laboratory analyses, is presented in Table 1.

Table 1. SARA analysis of Visoka crude oil (Romania, 2008)

Saturated Hydrocarbon (C_nH_{2n+2})	5.3
Aromatics (%)	47.9
Resins (%)	25.1
Asphaltenes (%)	21.7

Source: created by the authors.

Given its high viscosity, heavy oil requires property-reducing techniques to improve flow and extraction efficiency, [4]. Despite the large global reserves of heavy crude, recovery factors remain low, necessitating the use of enhanced oil recovery (EOR) strategies, [1], [5]. These techniques are generally divided into two main categories, [6], [7]:

- Thermal EOR techniques, such as Steam-Assisted Gravity Drainage (SAGD), Cyclic Steam Stimulation (CSS), and In-Situ Combustion (ISC), rely on increasing reservoir temperature to reduce viscosity and improve fluid mobility.
- In contrast, non-thermal methods, including physical, chemical, and biological approaches, [8], enhance recovery without heating by modifying fluid properties, reducing interfacial tension, or improving sweep efficiency.

Among these, thermal stimulation is the most common method to reduce viscosity and mitigate flow and transport issues. In addition, dilution—a specific non-thermal approach has also proven effective by injecting lighter hydrocarbons to reduce both viscosity and density, thereby facilitating pumping, enhancing oil-water separation, and improving overall oil quality, [9], [10]. This process typically involves injecting a low-viscosity hydrocarbon into the reservoir or wellbore, reducing the density of the produced oil from extremely heavy (~7.5–9° API) to lighter, marketable grades (e.g., ~32° API), [8]. Progressive Cavity Pumps (PCPs) are frequently used to lift the diluted crude to the surface. However, this method is often constrained by the availability and cost of suitable diluents, [11].

According to historical field records, the use of diluents for heavy oil production in Albania dates from 1962. The Visoka carbonate reservoir served as an early testing ground for this approach. The introduction of a diluent helped maintain oil mobility and extend well productivity by reducing crude oil viscosity.

The crude oil produced from the Visoka oilfield is classified as a heavy, asphaltic type, [12], with the following physico-chemical characteristics:

- Density: 0.9816–1.0218 g/cm^3
- Viscosity: up to 210,000 cP at 20 °C, decreasing significantly under shear
- Boiling range: 72–112 °C
- Acidity: 0.23–0.67 mg KOH/g
- Sulphur content: high, ranging between 4.7–6.8%
- Resin-to-asphaltene ratio: 1.04, indicating a resinous nature

These physico-chemical characteristics are further supported by detailed compositional laboratory analyses of Visoka crude oil, as summarised in Table 2.

Table 2. Compositional analysis of Visoka crude oil

Resins (%)	16-22
Asphaltenes (%)	14.8-25.5
Oils (%)	35
H_2S (%)	2.5-6
CO_2 (%)	2.5-4.5
Coke (%)	56
Light Fractions (%)	25

Source: created by the authors.

The flow behaviour of Visoka oil corresponds to a pseudoplastic-dilatant fluid, meaning that its viscosity is not constant but varies in response to the flow regime due to the presence of asphaltic micelles. Based on laboratory analyses the Visoka crude is classified as extra heavy oil, with a specific gravity of approximately 1.013 g/cm^3 and viscoplastic properties, indicating non-Newtonian flow characteristics, [13].

One important consequence is that challenges in production arise during oil filtration from the reservoir rock to the wellbore, further complicated by multiphase flow dynamics in a highly water-flooded reservoir. Currently, conventional cold production methods are in their final stage due to the upward progression of the oil-water contact.

While the use of progressive cavity pumps (PCPs), combined with enhanced downhole and surface equipment, can support production in certain wells, it does not resolve transportation issues or the oil-water separation required during decantation to meet commercial quality standards.

Injection of a diluent into this high-viscosity oil has become essential, not only to improve the emulsion's physical properties and facilitate gravity-driven flow during early well activation, but also to enhance the pumping efficiency of SxN piston-type downhole pumps. Additionally, diluent injection reduces crude oil density, enabling more effective water separation during decantation.

To ensure efficient separation during decantation, in addition to applying demulsifiers and raising the temperature to 90 °C, diluent injection is necessary. This reduces oil density from 1.013 g/cm^3 to approximately 0.982–0.984 g/cm^3. Based on this analysis, the use of diluent in the Visoka field is indispensable for improving recovery and preparing the crude for market delivery.

To enhance clarity and highlight the novelty of this work, this study integrates laboratory viscosity measurements with field operational applications, bridging experimental evidence with practical implementation, to assess the effectiveness of diluent injection in the Visoka field, providing practical guidance for surface treatment, well interventions, and future EOR optimisation.

2 Methodology

The data analysed in this study originate from laboratory analyses conducted by Terraoil Swiss on samples from the Visoka oilfield. Measurements were systematically performed at varying temperatures and diluent concentrations, and the results were graphically presented for multiple wells, confirming the effectiveness of diluent injection in enhancing flow properties and mobility of ultra-viscous crude oils.

All measurements were conducted under laboratory surface conditions, using degassed crude oil samples at atmospheric pressure. The applied temperature range (10–80 °C) was selected to represent typical surface handling, treatment, and decantation conditions rather than in-situ reservoir pressure-temperature conditions. Consequently, the measured viscosity values are representative of surface processing behaviour and may differ from absolute in-reservoir values.

Reservoir conditions in the Visoka field, derived from historical reservoir measurements, are summarised below:

- Crude oil density: 0.963 g/cm^3
- Oil viscosity: 600–1,200 cP
- Oil formation volume factor: 1.065–1.077
- Gas saturation pressure: 90 atm
- Gas solubility in oil: 0.3 m^3/m^3·atm
- Gas formation volume factor: 27 Nm^3/m^3
- Associated gas: mainly methane (60–80%) with a relative specific gravity of 0.7

These in-situ properties provide the necessary context for interpreting laboratory viscosity reduction results and for evaluating the effectiveness of diluent injection under field conditions.

The selected diluent concentrations (0%, 16.8%, 18%, 25%) were defined based on operational experience, preliminary laboratory testing, and practical requirements related to viscosity reduction and oil-water separation. The diluent used was a light hydrocarbon solvent intended to modify the crude oil's flow behaviour during surface processing. Lower concentrations correspond to untreated or marginally treated crude oil, whereas higher concentrations represent operationally feasible upper limits constrained by economic and handling considerations.

In addition to laboratory testing, this technology has been systematically applied in the field across several operational stages. Its application covers well utilization, crude oil lifting by piston mechanisms, decantation processes, and preparation of the final product before injection, with the primary objective of improving crude mobility.

The practical applications of diluents in the field cover multiple operations. They support well operations, particularly in cases of tubing obstruction caused by paraffin deposition, thereby restoring flow and stabilising production rates. Diluents also facilitate major well interventions, including capital workovers, and have been used to reactivate shut-in wells to restore production potential. During open-hole drilling, they reduce viscosity and enhance emulsion-breaking efficiency, which facilitates subsequent oil-water separation. At the surface facilities, diluents are integrated into oil–water separation systems to reduce emulsions and optimize crude conditioning. In parallel, their application is complemented by geophysical logging, specialised instrumentation, and the injection of auxiliary substances such as gas oil or cement.

The combined use of diluents and gas oil also dissolves asphaltene deposits, enhancing near-wellbore permeability and facilitating oil inflow. Furthermore, their systematic application has been incorporated into preventive maintenance programs and commissioning of new horizontal wells to ensure operational continuity and enhanced recovery.

Statistical analysis was applied selectively depending on data availability. For well G‑86, viscosity changes were quantified and expressed as percentage reductions relative to the 0% diluent baseline at corresponding temperatures common to both baseline and treated samples (20, 40, 60 °C). For well G-605, viscosity variations were analysed as a function of increasing diluent concentration (0–20%) at a fixed temperature (35 °C), and percentage changes were used to illustrate the relative trend. For well G‑154, numerical trend analysis was adopted due to the limited number of measurements and the use of a single diluent concentration (16.8%).

By integrating laboratory analyses with operational measurements from the wells, this methodology provides a robust framework for assessing the impact of diluent technologies on the production of ultra-viscous crude oils in the Visoka field.

3 Results and Discussion

The results for wells G-86, G-154, and G-605 are presented in Table 3, Table 4, Table 5, Table 6, Table 7, and Table 8. The corresponding trends are also illustrated in Figure 1, Figure 2, Figure 3, Figure 4, and Figure 5, allowing both numerical comparison and visual interpretation.

Table 3. Oil analysis for the well G-86 with 0% diluent

Temperature (°C)	Viscosity (cP)	Viscosity (log)
10	296,483.1	5.4719
20	116,144.8	5.0649
30	51,888	4.7151
40	16,856	4.2267
50	6,313	3.8002
60	2,620	3.4183
70	1,220	3.0864

Source: created by the authors.

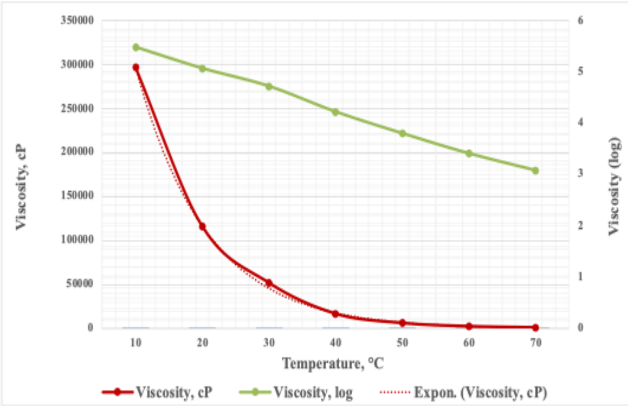

Fig. 1: Viscosity of oil as a function of temperature, for the well G-86 with 0% diluent (Note: A logarithmic scale is used for viscosity to improve graphical clarity)
Source: created by the authors.

Table 4. Oil analysis for the well G-86 with 18% diluent

Temperature (°C)	Viscosity (cP)	Density (g/cm^3)
20	3,019.159	0.982
40	581.223	0.9689
60	170.952	0.9552
80	66.695	0.9412

Source: created by the authors.

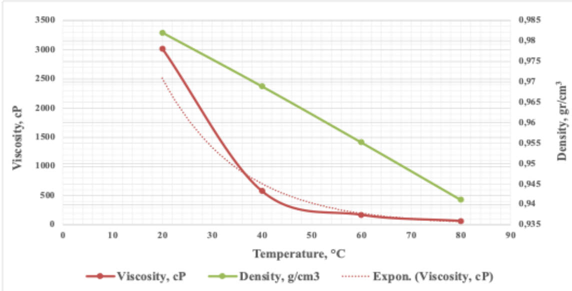

Fig. 2: Viscosity of oil as a function of temperature, for the well G-86 with 18% diluent
Source: created by the authors.

Table 5. Oil analysis for the well G-86 with 25% diluent

Temperature (°C)	Viscosity (cP)	Density (g/cm^3)
20	282.160	0.9526
40	85.351	0.9404
60	34.183	0.9281
80	16.056	0.9141

Source: created by the authors.

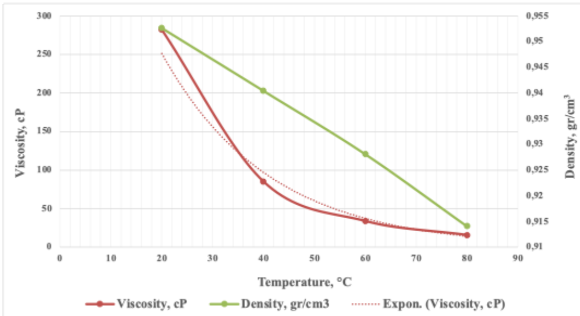

Fig. 3: Viscosity of oil as a function of temperature, for the well G-86 with 25% diluent
Source: created by the authors.

Table 6. Viscosity reduction for well G-86 at varying temperatures for 18% and 25% diluent concentrations

Temperature (°C)	20	40	60
Viscosity with 0% Diluent (cP)	116,144.8	16,856	2,620
Viscosity with 18% Diluent (cP)	3,019.159	581.223	170.952
Viscosity with 25% Diluent (cP)	282.160	85.351	34.183
Viscosity Reduction with 18% Diluent (%)	97.4	96.6	93.5
Viscosity Reduction with 25% Diluent (%)	99.8	99.5	98.7

Source: created by the authors.

Table 7. Oil analysis and viscosity reduction for well G-154 with 16.8% diluent (relative to 20 °C)

Temperature (°C)	Viscosity (cP)	Viscosity (log)	Viscosity Reduction from 20 °C (%)
20	38,800	4.5988	0.0
30	17,340	4.2390	55.3
40	5,634	3.7508	85.5
50	2,109	3.3241	94.6
60	876	2.9425	97.7
70	408	2.6106	98.9

Source: created by the authors.

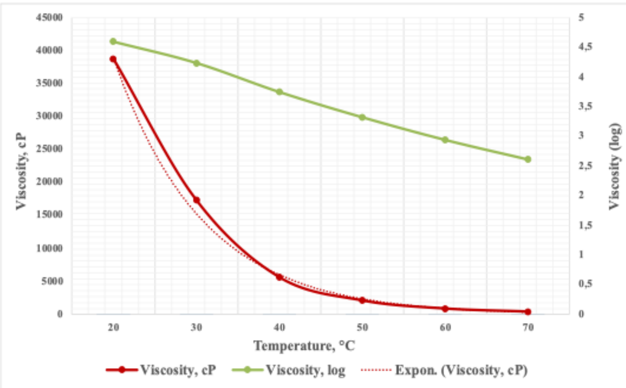

Fig. 4: Viscosity of oil as a function of temperature, for the well G-154 with 16.8% diluent (Note: A logarithmic scale is used for viscosity to improve graphical clarity)
Source: created by the authors.

Table 8. Oil analysis and viscosity reduction at 35 °C for well G-605

Diluent (%)	Oil Viscosity (cP)	Oil Density (g/cm^3)	Viscosity Reduction (%)
0	59,323.5	1.02	0.0
6	17,721.3	1.0095	70.1
8	9,294	1.006	84.3
10	7,045.8	1.0025	88.1
12	4,170.2	0.999	92.9
14	2,620.7	0.995	95.6
16	2,244.3	0.992	96.2
18	1,892.4	0.988	96.8
20	1,389.4	0.985	97.7

Source: created by the authors.

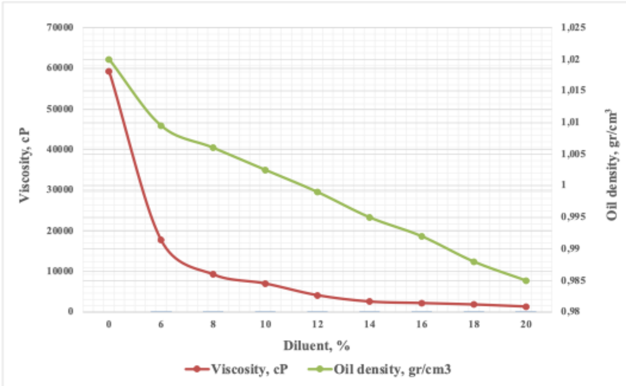

Fig. 5: Variation of oil viscosity and density as a function of diluent percentage for well G-605 at 35 °C (diluent density 0.845 g/cm^3)
Source: created by the authors.

The data in Figure 1, Figure 2, Figure 3, Figure 4, and Figure 5 show an inverse relationship between temperature and oil viscosity: as temperature increases, viscosity decreases. At the same time, increasing the diluent concentration leads to a further reduction in viscosity. When higher diluent percentages are combined with elevated temperatures, the decrease becomes more pronounced, and a slight reduction in oil density is also observed.

Table 6, Table 7, and Table 8 quantify these changes and demonstrate a progressive decrease in viscosity with increasing diluent concentration, confirming the effectiveness of diluent injection in surface treatment operations.

For well G- 86, as shown in Table 6, the percentage decrease in viscosity was calculated relative to the 0% diluent baseline. Although viscosity decreases in absolute terms with temperature, the percentage reduction shows a slight decline, from 97.4% at 20 °C to 93.5% at 60 °C. This behaviour is mainly related to the complex composition of the crude oil, particularly the presence of asphaltenes and resins, which interact with the diluent in a non-linear manner. At higher temperatures, partial destabilisation of asphaltene structures and changes in pseudoplastic flow behaviour reduce the relative contribution of the diluent, while temperature effects become more dominant. Minor variations in laboratory measurements may occur, but they do not affect the overall trend. This well-specific trend demonstrates that both temperature and crude composition must be considered when evaluating diluent performance.

For well G- 154, the limited dataset prevents statistical testing; however, numerical analysis clearly supports the trend of viscosity reduction. The effect of temperature on the viscosity of well G- 154 (with 16.8% diluent) is summarised in Table 7. The percentage reduction column indicates the decline in viscosity relative to the reference temperature of 20 °C. Since no 0% diluent data is available for this well, the observed effect reflects the effect of temperature at a fixed diluent concentration of 16.8%. The influence of temperature is also evident in the viscosity reduction, which increases from 55.3% at 30 °C to 98.9% at 70 °C, as shown in Figure 4.

For well G‑605, viscosity measurements at 35 °C show a clear decreasing trend with increasing diluent percentage (Figure 5). The calculated viscosity reduction varies from 0% (without diluent) to 97.7% at 20% diluent (see Table 8). These results can be used to select suitable diluent concentrations during field operations.

All viscosity measurements were conducted under laboratory surface conditions at atmospheric pressure and temperatures representative of surface processing (10–80 °C). Consequently, actual viscosity under reservoir pressure-temperature conditions may differ. This limitation should be considered when interpreting the effectiveness of diluent injection for in-situ operations.

Despite these positive effects, improper application has led to adverse subsurface effects, as shown in laboratory experiments. Increased viscosity raised axial rod loads, reducing both well and surface equipment efficiency. Furthermore, degassing may create challenges, and separators must be carefully managed to avoid emulsion formation. Ensuring proper preparation and compatibility of the diluent is essential for efficient processing.

Therefore, in the operational context of Visoka, diluent injection remains essential for both production and commercialisation. It continues to serve as the primary technological enabler for ensuring flow in both naturally flowing and artificial lift wells. For example, the use of low-speed piston pumps ($S \times N \leq 1.5$) has resulted in production increases of 12-14%, whereas high-flow systems ($S \times N \geq 3$) require 16–18% diluent by volume. Operational interruptions, temperature drops, and abrupt viscosity changes necessitate compensating for losses, typically by restoring up to 10% of the injected diluent.

The viscosity reduction trends observed in this study are consistent with findings reported in international literature on solvent-assisted heavy oil treatment. For example, [14], reported significant viscosity decreases in heavy crude blends when organic solvents, such as toluene and dimethyl ketone, were applied at concentrations up to 15% by volume, with further reductions observed at higher temperatures. Operational experience from other heavy oil fields, particularly in Canada and Venezuela, indicates that light hydrocarbon diluents such as condensate or naphtha are commonly used to lower viscosity. Typical concentrations range from 0–20% for heavy crude oils and may reach up to 50% for bitumen, [15]. These findings are consistent with the results from the Visoka field and confirm that viscosity reduction depends on crude composition, temperature, and the type of diluent used.

These comparisons confirm the practical applicability of diluent injection in the Visoka field. The trends observed can guide surface treatment operations:

- Optimising diluent concentration for effective viscosity reduction;
- Maintaining an appropriate diluent ratio to enhance oil-water separation during decantation and facilitate surface handling;
- Supporting near-wellbore operations such as pumping and well interventions.

If the diluent concentration is too low, viscosity may increase again, requiring additional thermal treatment. Therefore, careful management is essential to ensure both technical performance and economic efficiency.

4 Conclusion

According to the results, diluent injection in the Visoka oilfield proves to be an effective method for addressing the main challenges of heavy oil production. By reducing viscosity and enhancing flow behaviour, it improves reservoir deliverability and well performance, while also supporting reservoir pressure maintenance. Given the specific geological and rheological characteristics of the field, this approach proves to be a scalable and field-adapted solution.

Laboratory and field data consistently demonstrate that increasing both temperature and diluent concentration leads to notable viscosity reduction. These observations offer practical guidance for optimising surface operations, including diluent selection, oil-water separation, and well interventions.

From an operational perspective, efficient processing depends on the combined use of diluent injection, chemical additives to aid oil-water separation, and controlled heating. Together, these measures ensure that the produced oil meets the required conditions for transport and commercial use.

In summary, diluent injection remains a key technique in the Visoka oilfield, ensuring efficient production and enhancing the quality of the extracted crude oil. This methodology has been systematically applied across production, transportation, separation, and final commercialisation, with viscosity reduction as a primary objective, providing valuable guidance for future operational optimisation.

Future work should focus on:

- Optimising diluent selection and injection protocols to maximise cost-effectiveness and technical performance.
- Conducting economic feasibility studies to ensure operational benefits outweigh expenses.
- Performing measurements under reservoir pressure-temperature conditions to validate in-situ effectiveness.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

Ortenca Gropa and Erison Karamani contributed to the study's conception, structure, and conducted the literature review related to diluent injection in heavy oil recovery.
Ortenca Gropa contributed to data gathering and analysis specific to the Visoka oil field and assisted in revising the manuscript.
Both authors contributed to the discussion of the results and approved the final version of the manuscript.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.