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Integrated modelling and thermodynamic optimisation of heavy oil recovery as a pathway to Ukraine's energy independence

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Abstract – The development of domestic heavy oil resources represents a strategically important direction for strengthening Ukraine's energy independence and reducing dependence on imported hydrocarbons. This study develops an integrated modelling and methodological framework for the optimisation of heavy oil recovery from deep reservoirs of the Dnieper-Donets Basin. The proposed approach combines PVT analysis, thermodynamic simulation, material-balance evaluation, well-performance modelling and reservoir–well coupling within an integrated asset modelling workflow. The methodology is intended to evaluate the applicability and operating conditions of Enhanced Oil Recovery (EOR) methods under the high pressure, temperature and fluid-viscosity conditions characteristic of deep heavy oil reservoirs. Particular attention is given to the interaction between reservoir-fluid properties, wellbore hydraulics and artificial-lift performance. The framework enables technically feasible development scenarios to be compared before field implementation, thereby reducing uncertainty associated with EOR selection and operating conditions. The expected result is a more systematic basis for increasing recovery from complex Ukrainian resources and converting technically challenging heavy oil accumulations into an additional component of the country's domestic hydrocarbon production and energy potential.

Keywords: heavy oil; Dnieper-Donets Basin; integrated asset modelling; Enhanced Oil Recovery; thermodynamic simulation; energy independence.

INTRODUCTION. Ukraine's energy security is closely connected with the ability to develop its own hydrocarbon resources and increase the efficiency of domestic oil and gas production. In this context, unconventional and technically difficult reserves represent not only an additional resource base but also an opportunity to strengthen the resilience of the national energy system. Heavy oil accumulations are particularly important because their development is constrained by high viscosity, complex pressure–temperature behaviour, unfavourable mobility and substantial hydraulic losses during production.

The Dnieper-Donets Basin is one of the principal hydrocarbon-bearing regions of Ukraine and contains reservoirs with significant geological and technological complexity. Deep heavy oil resources within the basin are therefore a relevant object for advanced modelling and Enhanced Oil Recovery (EOR) research. Their development requires an integrated assessment because reservoir performance cannot be adequately represented by considering fluid properties, reservoir depletion and well performance separately.

Modern petroleum engineering provides a range of numerical and analytical tools for such integrated evaluation. Petroleum Engineering software suites, including PVTP, PROSPER and MBAL, enable PVT behaviour, well inflow/outflow performance and reservoir material balance to be evaluated within a consistent engineering workflow. Coupling these approaches with thermodynamic simulation creates a methodological basis for identifying technically and energetically feasible heavy oil recovery strategies.

Objective of the research. The objective of the research is to develop an integrated modelling and methodological framework for optimising heavy oil recovery from deep Ukrainian reservoirs, with particular emphasis on the Dnieper-Donets Basin. The framework is intended to establish relationships between reservoir-fluid properties, pressure and temperature conditions, wellbore hydraulics, artificial-lift operation and EOR performance.

The principal research hypothesis is that optimisation of deep heavy oil production should be performed as an integrated reservoir–well–surface problem rather than through independent optimisation of individual components. Such an approach makes it possible to identify operating constraints that may remain invisible when reservoir and production-system models are analysed separately.

Research methods. The proposed workflow begins with the characterisation of reservoir fluids and PVT properties. Pressure–volume–temperature relationships are evaluated to determine the behaviour of the heavy oil under reservoir and production conditions. Particular attention is given to viscosity variation with pressure and temperature because viscosity directly affects mobility and therefore the pressure losses required to deliver reservoir fluids to the surface.

The second stage involves thermodynamic and reservoir evaluation. Reservoir pressure, temperature, fluid properties and production characteristics are incorporated into a material-balance and reservoir-performance assessment. MBAL-type calculations can be used to establish the relationship between reservoir depletion, fluid withdrawal and cumulative production.

The third stage couples reservoir behaviour with well performance. PROSPER-type well modelling enables inflow and outflow relationships to be evaluated together with artificial-lift requirements. This is especially important for deep heavy oil reservoirs because substantial frictional and hydrostatic pressure losses may restrict production even when sufficient reservoir energy remains available.

The integrated workflow can therefore be represented as:

PVT characterisation → thermodynamic evaluation → reservoir modelling → well-performance modelling → EOR scenario simulation → production optimisation.

Within this framework, EOR scenarios can be assessed by varying the principal operating parameters and evaluating their influence on pressure distribution, fluid mobility, well deliverability and recovery. Depending on the geological and thermodynamic characteristics of a particular reservoir, candidate approaches may include thermal stimulation, pressure-maintenance mechanisms or other mobility-enhancement techniques.

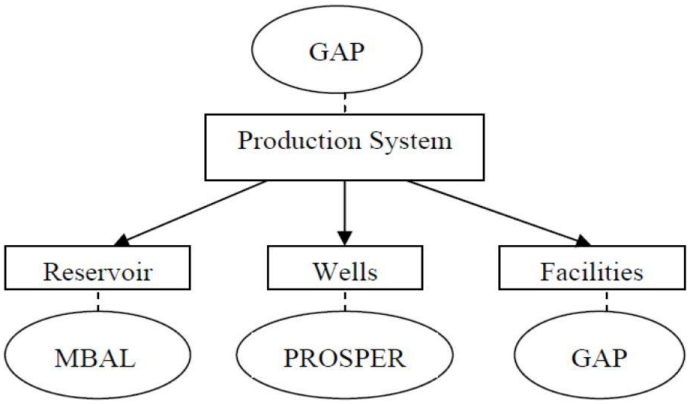

Figure 1: Integrated production modelling architecture for reservoir, well and surface-system optimisation.

Results and novelty. The principal scientific and methodological result is the development of an integrated framework that connects reservoir-fluid thermodynamics with well and production-system behaviour. This is particularly relevant to deep heavy oil reservoirs, where apparently favourable reservoir conditions may not translate into economically or technically feasible well production.

The framework provides several advantages for EOR screening. First, PVT and thermodynamic analysis establishes the physical limits within which a recovery technology can operate. Second, reservoir modelling identifies the expected pressure response and depletion behaviour. Third, well modelling determines whether the resulting reservoir conditions can be translated into stable surface production. Consequently, an EOR scenario is not evaluated solely according to its theoretical increase in displacement efficiency but according to its compatibility with the complete production system.

An important feature of the methodology is the possibility of evaluating sensitivity to key parameters before field-scale implementation. For example, changes in fluid viscosity, reservoir pressure, temperature or artificial-lift operating conditions can be propagated through the modelling chain. This allows critical bottlenecks to be identified and reduces the risk of selecting an EOR method that is theoretically effective but operationally unsuitable.

For Ukraine, this methodological capability has strategic significance. Deep heavy oil resources require greater technological input than conventional reservoirs, and investment decisions therefore depend strongly on the reliability of pre-development forecasts. Integrated modelling can reduce uncertainty by establishing a quantitative connection between geological assumptions, fluid behaviour, well deliverability and expected recovery.

The novelty of the proposed approach lies in treating heavy oil recovery optimisation as an integrated thermodynamic and production-system problem. Rather than selecting an EOR technology independently from well and reservoir constraints, the methodology provides a common modelling environment in which these factors can be evaluated simultaneously.

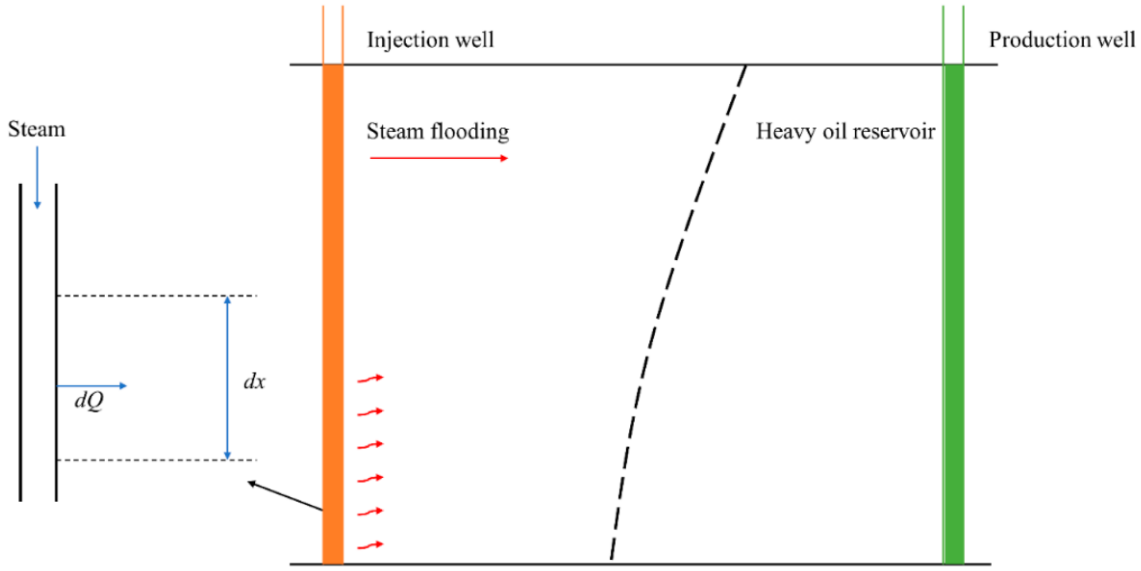

Figure 2: Schematic representation of thermal EOR in a heavy-oil reservoir.

The practical outcome is a methodological basis for ranking technically feasible development scenarios according to their predicted production response and operating constraints. Such pre-field evaluation can support the transition from geological resource potential to technically justified development projects.

SUMMARY. The development of deep heavy oil resources in the Dnieper-Donets Basin can contribute to the expansion of Ukraine's domestic hydrocarbon resource base and, consequently, to strengthening national energy independence. However, the high viscosity, depth and complex pressure–temperature conditions of these reservoirs require an integrated engineering approach.

The proposed methodology combines PVT analysis, thermodynamic simulation, reservoir material-balance evaluation and well-performance modelling within an integrated asset modelling workflow. The coupling of reservoir and well models makes it possible to identify technological constraints and assess EOR scenarios under realistic production conditions.

The methodological framework therefore provides a basis for reducing uncertainty before field implementation, improving the selection of EOR strategies and increasing the probability of technically successful development of complex Ukrainian heavy oil resources. Its further application to representative reservoirs of the Dnieper-Donets Basin can support quantitative optimisation of recovery factors and contribute to the development of Ukraine's domestic energy potential.

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