

Molecular Transformation and Sustainable Optimization of Bitumen in Alberta Oil Sands, Canada with RDV® Chemical Technology

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Abstract: RDV® (dynamic vasoactive reactor) chemical technology represents a disruptive innovation operating under both surface and downhole conditions, producing irreversible and in situ adaptable effects. It has demonstrated transformative capacity across crude oils of various API gravities, with notable impact on extra-heavy crudes and bitumens, through a mechanism based on targeted proton donation that induces selective protonation of polar structures, generating transient carbocations that catalyze molecular fragmentation. This work presents a comprehensive analysis of the effects of RDV-DMG001® treatment (currently named RDV-01L®) on bitumen samples from the Primrose field, Alberta, Canada, using capillary chromatography, SARA analysis, and rheological evaluation, complemented with comparative data on prior applications of RDV-01L® in extra-heavy crudes from Venezuela (Boscán and El Salto). Results for Primrose bitumen show an 85% reduction in viscosity (from 500,000 to 75,000 cP), an increase in API gravity from 8.5 to 15.0 (+76.4%), and molecular redistribution toward medium-chain hydrocarbons (C₁₃-C₁₆), with increases in molar and mass fractions up to 39.1% and 62.3%, respectively. SARA analysis confirmed fragmentation of asphaltenes (2.0% mass reduction) and a 5.8% increase in resins, improving colloidal stability and lowering precipitation risk. These changes align with RDV®'s mechanism of action based on carbocation generation. Notably, in field conditions—which are more dynamic and energetically favorable—RDV® treatment efficacy tends to exceed laboratory results, due to synergy among temperature, pressure, and fluid flow gradients which accelerate and enhance protonation and molecular fragmentation. Validated in contexts of advanced chemical transformation (Venezuela, Canada), the technology enables substantial improvements in fluidity, transport, processing, and recovery, with significant potential for annual cost savings in extraction and processing. This study positions RDV® as a disruptive, irreversible, and in situ adaptable chemical solution superior to conventional technologies such as surfactants, nanocatalysts, or aquathermolysis. RDV® is a quantum-impact chemical technology operating via molecular protonation reactions and controlled carbocation formation. The term “quantum” is used here as a conceptual analogy to describe the magnitude and specificity of the molecular reconfiguration induced by RDV®, without asserting direct experimental evidence of quantum reactivity.

Key words: RDV®, protonation, carbocations, bitumen, oil sands, SARA, chromatography, viscosity, extra-heavy crude, in situ upgrading.

1. Introduction

RDV® (dynamic vasoactive reactor) technology represents a disruptive chemical innovation capable of operating under both surface and downhole conditions, producing irreversible and in situ adaptable effects. It has demonstrated significant molecular reconfiguration across crude oils of varying API gravities, with

particularly strong impact on extra-heavy crudes and bitumens. The mechanism is based on targeted protonation, inducing selective activation of polar structures and generating transient carbocations that catalyze molecular fragmentation.

RDV-DMG001® (currently RDV-01L®) has been applied to bitumen samples from the Primrose field in Alberta, Canada, and evaluated through capillary

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Table 1 Physicochemical properties of bitumen in Alberta fields.

Field	Viscosity (cP at 20 °C)	API gravity (°API)	Asphaltenes (%)	Main formation
Primrose	>1,000,000	~8.5	>25	Clearwater
Jackfish	~500,000	~9.5	~20-22	McMurray
Kirby	~350,000	~10.5	~18-20	McMurray

chromatography, SARA fractionation, and rheological analysis. Comparative data from previous applications in Venezuelan extra-heavy crudes (Boscán and El Salto) are also included to validate the international transferability of the mechanism.

Field applications of RDV® consistently deliver measurable improvements in viscosity, API gravity, molecular distribution, and colloidal stability, confirmed under both controlled and in situ conditions. These outcomes not only offer operational advantages but also represent a scalable and sustainable alternative to conventional upgrading technologies.

While the term “quantum” is used to describe the magnitude and specificity of the molecular transformation induced by RDV®, it is employed here as a conceptual analogy rather than a claim of experimentally verified quantum reactivity.

Table 1 shows the physicochemical properties distinguishing bitumens from different fields in Alberta.

Traditional technologies for bitumen upgrading, such as steam injection (SAGD—steam assisted gravity drainage), the use of diluents, or thermal upgrading processes, are energy-, water-, and capital-intensive, and also have a high environmental impact. These limitations of conventional technologies provide few advantages in terms of sustainability and operating costs. In this context, chemical alternatives such as surfactants, emulsions, nanocatalysts, and aquathermolysis have been developed, with only partial results, limited by their reversibility, cost, or operational instability [1, 2, 5, 7, 9].

RDV® technology emerges as an innovative solution based on the irreversible molecular modification of bitumen through a mechanism of selective protonation. This process induces the formation of carbocations in polar structures (mainly

asphaltenes), promoting their fragmentation into lighter and more polar fractions, such as resins and aromatics, which favorably alters the rheology and colloidal stability of the system. RDV® technology integrates advanced principles of chemistry and quantum physics to induce selective protonation and the generation of transient carbocations in hydrocarbons. This quantum molecular approach sets RDV® apart from other conventional methods, by enabling specific catalytic reactions that permanently modify the structure of the crude and improve its flow and recoverability.

This work presents a rigorous technical-scientific evaluation of the impact of RDV® on bitumen from the Primrose field, Alberta, Canada, integrating data from capillary chromatography, SARA analysis, and rheological properties, and contextualizing the results with previous applications in Venezuelan heavy crudes (Boscan and El Salto). This enables validation of RDV®’s applicability in diverse geological and compositional contexts characterized by high resistance to flow and chemical complexity.

2. Scientific Basis: Mechanism of Action of RDV®

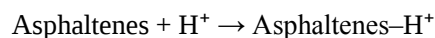
RDV® technology operates through the controlled release of protons (H^+), activated under reservoir conditions. These protons interact with nucleophilic centers in high molecular weight molecules, particularly in polycyclic aromatic and heteroatomic structures present in asphaltenes (C_{40}^+), inducing their selective protonation.

This reaction generates transient carbocations, which serve as reactive intermediates for C-C bond cleavage and structural reorganization [3, 4]. The fragmentation of condensed asphaltene structures produces smaller, more polar molecules—classified as resins—and

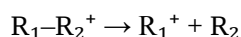
medium-length aliphatic chains (C_{13} - C_{16}), which improve the fluidity and rheological behavior of the system.

The mechanism can be summarized in three stages:

(1) Protonation:



(2) Beta-scission of the carbocation:



(3) Stabilization as resins or lighter hydrocarbons:

This process reduces the average molecular weight and modifies the resin-to-asphaltene ratio (R/A), a critical parameter for colloidal stability [5, 6]. An increase in resin content enhances the solvation of remaining asphaltenes, preventing aggregation and precipitation.

While the reaction mechanism is grounded in classical organic chemistry, its specificity and irreversibility allow for a conceptual interpretation through quantum chemical principles. Proton transfer and carbocation formation involve electronic reconfiguration and discrete energy states, which are explainable within quantum frameworks. This perspective distinguishes RDV® mechanistically from conventional upgrading methods, enabling targeted molecular transformation in highly polar and complex hydrocarbon systems.

3. Methodology

3.1 Samples and Treatment

Bitumen samples from the Primrose field in Alberta, Canada, were analyzed alongside samples treated with RDV-01L® at a 90:10 (v/v) ratio. This dosage was selected based on prior optimization studies to ensure sufficient proton availability for effective molecular transformation under static laboratory conditions, which differ from the dynamic and energetically favorable environment of downhole operations.

3.2 Analytical Procedures

The analyses were conducted by CoreLab Calgary using a Varian 3400 Star Capillary Chromatograph,

following ASTM standards:

- Capillary chromatography: Molecular distribution analysis (C_5 - C_{30}^+).
- SARA analysis: Fractionation by adsorption column (ASTM D-2007m).
- Rheological properties: Viscosity (cP), density (kg/m^3), API gravity.

3.3 Comparative Data Integration

Additional data were incorporated from previous RDV-01L® applications in Venezuela to validate the international transferability of the mechanism:

- Boscán Field: Chromatographic analysis of extra-heavy crude (API 14.4) treated with RDV® [7].
- El Salto Field, Orinoco Belt: Evaluation of RDV-01L® at 3% and 1% under laboratory and downhole conditions (1,200 psi, 168 °F), conducted by the Central University of Venezuela (UCV).

These tests reflect representative field conditions and confirm the adaptability of RDV® across diverse geological and compositional environments [11-14].

4. Results and Discussion

The comparative applications conducted in Venezuela reflect representative field conditions and confirm the adaptability of RDV® across diverse geological and compositional environments, supporting the experimental findings presented in Section 4 and reinforcing the mechanism's reproducibility and field relevance.

4.1 Changes in Molecular Distribution (Chromatography)

Table 2 shows that capillary chromatography revealed a significant redistribution toward medium-chain hydrocarbons (C_{13} - C_{16}), with increases in the molar and mass fractions of C_{13} - C_{16} hydrocarbons following treatment with RDV®.

Fig. 1 shows the comparative behavior of changes in the molecular distribution (chromatography) of the mass and molar fractions before and after treatment with RDV®.

Figs. 2 and 3 present the comparison between the molar and mass fractions of the bitumen system, highlighting their differential behavior in response to

RDV® treatment and their contribution to the consolidated molecular distribution shown in Table 2 and Fig. 1.

Table 2 RDV®-induced molecular redistribution: C₁₃–C₁₆ fractions.

Hydrocarbon	Δ Molar fraction (%)	Δ Mass fraction (%)
Tridecanes (C ₁₃)	+39.1	+59.0
Tetradecanes (C ₁₄)	+34.9	+62.3
Pentadecanes (C ₁₅)	+26.2	+51.7
Hexadecanes (C ₁₆)	+19.9	+44.2

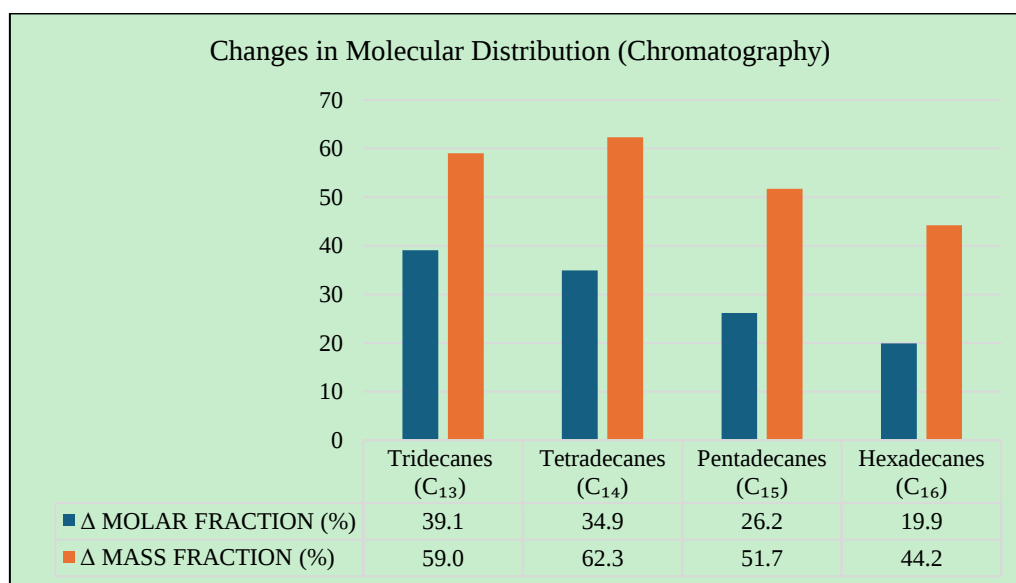


Fig. 1 Comparison of molecular distribution (C₁₃–C₁₆ fractions) before and after RDV® treatment, based on capillary chromatography.

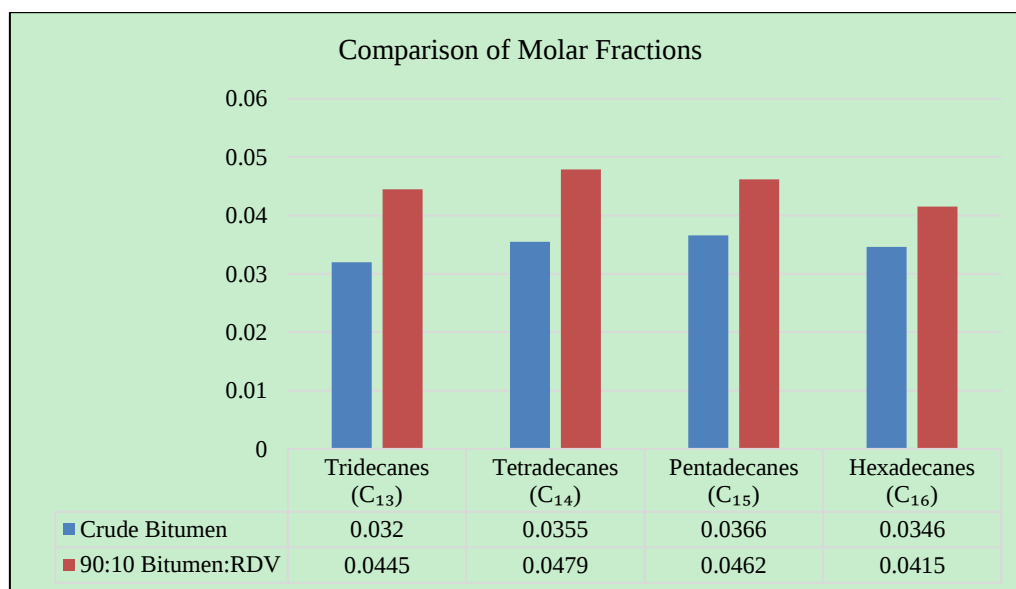


Fig. 2 Comparison of molar fractions in crude and RDV®-treated bitumen.

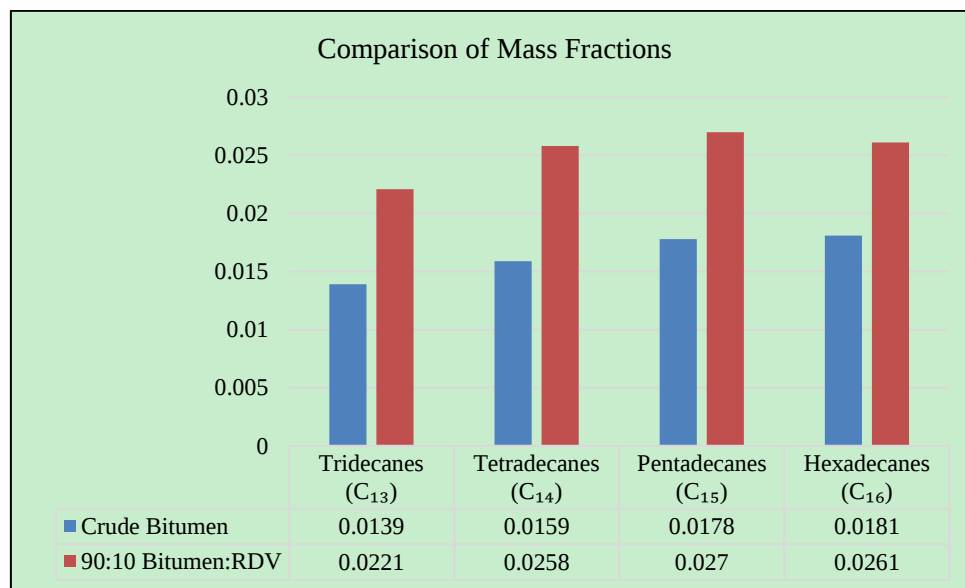


Fig. 3 Comparison of mass fractions in crude and RDV®-treated bitumen.

This pattern indicates a preferential fragmentation of long chains (C_{20}^+) toward medium fractions, consistent with a beta-scission mechanism of carbocations. The greater transformation into shorter chains suggests increased mobility and reactivity of the formed intermediates, which reduces the average molecular weight and weakens the intermolecular interactions responsible for high viscosity.

This redistribution confirms the selective cleavage of long-chain hydrocarbons (C_{20}^+), consistent with RDV®'s carbocation-driven beta-scission mechanism, resulting in enhanced flowability and reduced intermolecular cohesion.

This behavior is consistent with previous results obtained from applying RDV-01L® in the Boscán field (Venezuela), where RDV® treatment also induced an increase in C_{10} - C_{15} fractions, accompanied by a reduction in C_{30}^+ components, confirming the transferability of the mechanism in diverse geological and compositional contexts characterized by high flow resistance and chemical complexity.

4.2 Colloidal-Molecular Transformation (SARA Analysis)

Table 3 shows that SARA analysis confirmed a profound transformation of the molecular matrix of the

bitumen, which can be observed by comparing the SARA composition of Alberta bitumen before and after RDV® treatment.

Fig. 4 presents a graphical comparison of the percentage variation of the SARA fractions, allowing visualization of the changes in the colloidal structure and molecular distribution of the bitumen system due to the effect of RDV®.

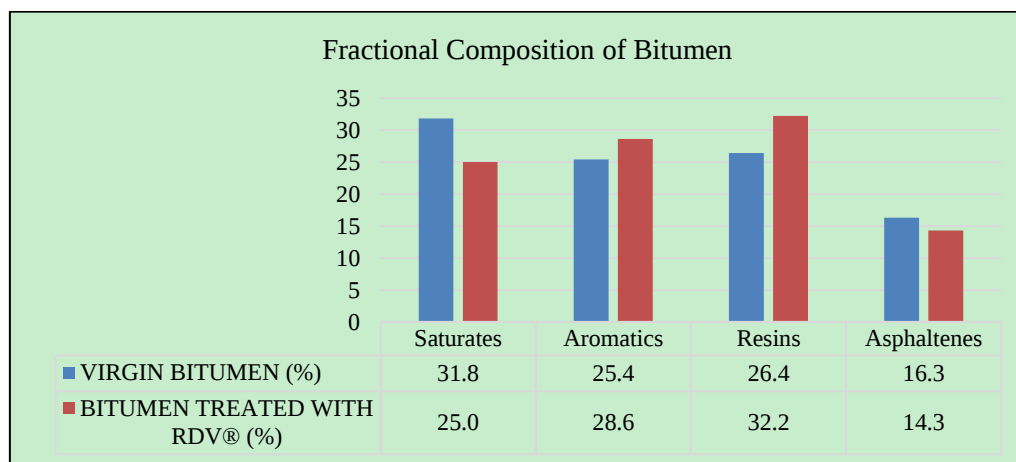
These changes are highly favorable:

- The relative increase of 22% in resins (from 26.4% to 32.2%) improves colloidal stability by surrounding and solvating the remaining asphaltenes through specific interactions between resin molecules and the polar structures of the bitumen.
- The reduction in asphaltenes decreases the tendency to form gels, sediments, and blockages in equipment.
- The slight increase in aromatics favors the solubilization of heavy fractions.

This behavior is identical to that observed in the extra-heavy crude from the El Salto field (Venezuela), where treatment with RDV-01L® at 3% generated an increase in resins and a reduction in asphaltenes, accompanied by a 44% reduction in viscosity at 40 °C and a 5 API unit increase after 14 days, demonstrating the progressive and cumulative action of RDV-01L®.

Table 3 SARA composition before and after RDV® treatment.

Fraction	Virgin bitumen (%)	RDV®-treated bitumen (%)	Δ (%)
Saturates	31.8	25.0	-6.8
Aromatics	25.4	28.6	+3.2
Resins	26.4	32.2	+5.8
Asphaltenes	16.3	14.3	-2.0

**Fig. 4 Percentage variation of SARA fractions in bitumen before and after RDV® treatment, showing improvements in colloidal stability.****Table 4 Physical and rheological properties of bitumen before and after RDV® treatment.**

Property	Virgin bitumen	RDV®-treated bitumen	Δ (%)
Viscosity (cP)	500,000	75,000	-85
API Gravity	8.5	15.0	+6.5
Density (kg/m ³)	1,011	966	-4.4

These changes reflect a shift in the colloidal equilibrium, where increased resin content enhances asphaltene stabilization, reducing the risk of precipitation and operational fouling.

4.3 Rheological Changes and Physical Properties

Table 4 describes how the rheological impact of the treatment is transformative by showing the changes in physical properties of the bitumen before and after treatment with RDV-01L®.

The 85% reduction in viscosity and increase in API gravity achieved position the RDV®-treated bitumen directly within the range suitable for pipeline transport and conventional refining, representing significant operational and environmental savings.

The rheological shift induced by RDV® enables direct pipeline transport and conventional refining,

eliminating the need for diluents and reducing operational complexity.

These results are comparable to those obtained in the El Salto field of the Orinoco Petroleum Belt, where treatment with RDV-01L® under downhole conditions (1,200 psi, 168 °F) immediately reduced viscosity by 43%, demonstrating that this chemical technology is effective even under extreme pressure and temperature conditions.

4.4 Synergistic Mechanism and Technological Transferability

The effectiveness of RDV-01L® in Alberta bitumens was conceived considering prior successes in Venezuela:

- In Boscán extra-heavy crude, chromatographic analysis showed a redistribution toward lighter

fractions with a reduction in heavy components (C_{30}^+).

- In El Salto extra-heavy crude, RDV-01L® demonstrated activity both at surface and downhole conditions, with cumulative (residual) effects over time.

RDV® acts on shared molecular features of extra-heavy crudes—characterized by high polarity, elevated asphaltene content, and structurally unfavorable resin-to-asphaltene ratios—making its protonation-based mechanism universally applicable to chemically complex systems.

In all analyzed cases, RDV® treatment shows irreversible transformation of the bitumen molecular matrix, permanently reconfiguring its rheological behavior and production efficiency. It is noteworthy that under field conditions—which are more dynamic and energetically favorable—RDV® efficacy tends to increase due to synergies among temperature, pressure, and flow, outperforming laboratory results.

The mechanism of action of RDV® is grounded in quantum chemical principles. Proton transfer and controlled carbocation formation are molecular phenomena explainable by quantum physics, where electronic configuration and discrete energy states modulate chemical reactivity. This quantum nature allows RDV® to act with high molecular specificity, generating irreversible changes that optimize crude rheology and production efficiency.

4.5 Industrial, Economic, and Environmental Impact

The implementation of RDV® technology in oil sands extraction centers not only transforms bitumen properties but can also redefine the economic and environmental model of exploitation. By acting directly on the crude's molecular matrix, RDV® chemical technology eliminates or significantly reduces dependence on energy-, water-, and diluent-intensive processes, which represent the main components of OpEx (operating costs) in SAGD-, steam injection-, or diluent-, transport-based projects. Unlike treatments such as surfactants, nanocatalysts, or diluents, the change induced by RDV® is irreversible and persists under variable reservoir conditions.

Table 5 presents an estimate of the potential percentage impact in cost and resource reductions associated with conventional operations, based on technical results from the RDV® treatment applied to Alberta bitumen, which can be extrapolated to other extra-heavy crude reservoirs (Venezuela, Russia, etc.).

4.5.1 Global Projection and Scalability

These percentage reductions can be extrapolated to various production environments of extra-heavy crudes or bitumen, such as:

- Orinoco Petroleum Belt (Venezuela): where the crude shares similar characteristics (API < 10, high viscosity, high asphaltene content). Previous applications

Table 5 Estimated technical impact of RDV® treatment on operational costs.

Category	Potential reduction (%)	Technical basis
Pipeline transport cost	60%-70%	Elimination of diluents (dilbit - diluted bitumen), which can represent up to 30% of the barrel value. RDV® allows crude flow without mixing with condensates.
Use of diluents	90%-100%	RDV® treatment reduces viscosity by 85%, eliminating the need to blend with naphtha or condensates to meet transport specifications.
Energy consumption (steam generation)	40%-50%	By eliminating steam injection (SAGD), natural gas consumption for heat generation, the main energy cost, is avoided.
Water consumption	40%-60%	Thermal processes like SAGD require large volumes of treated water; RDV® operates without the need for aqueous injection.
CO ₂ emissions (Scope 1 and 2)	25%-30%	The reduction in gas usage for steam generation and secondary processing directly translates into lower direct and indirect emissions.
Upgrading and refining costs	15%-20%	Increase in API gravity (from 8.5 to 15.0) and reduction in asphaltenes decrease processing severity, reducing fouling and extending catalyst life.
Maintenance and pipeline cleaning costs	50%-60%	Improved colloidal stability (increase in resins, reduction in asphaltenes) prevents deposit, gel, and stable emulsion formation.
Primary recovery rate	15%-25%	In situ upgrading improves crude mobility, enabling increased extraction with lower pumping pressure or without thermal stimulation.

Table 6 Technology comparison: RDV® vs. conventional methods.

Technology	Potential cost reduction (%)	Limitations
RDV®	40-70 (per component)	Permanent, irreversible effect
Surfactants	10-20	Reversible, sensitive to salinity and temperature
Nanocatalysts	15-25	Costly, dispersibility issues, aggregation risk
Aquathermolysis	20-30	Needs steam injection, high energy consumption
Steam injection (SAGD)	-	High energy and water intensity, high emission

of RDV® in El Salto demonstrated a 44% reduction in viscosity and a 5 API unit increase after 14 days.

- Heavy oil fields in Russia (e.g., Tigris): with high-density, low-flow crudes where the use of diluents and steam is common.

- Other Alberta fields (Kearl, Athabasca): where SAGD and dilution costs are structural.

RDV® technology acts as a catalyst for cumulative and irreversible efficiency gains, functioning as an efficiency multiplier compatible with existing infrastructure and requiring no additional CAPEX (Capital Expenditures) compared to conventional processes.

RDV® delivers cumulative and irreversible improvements in crude properties, enabling cost reductions of 40%-70% across key operational components, while aligning with decarbonization and sustainability goals.

Table 6 presents the competitive advantages compared to other technologies currently in use.

4.5.2 Summary of the Potential Impact on Oil Sands Extraction Operations

RDV® technology not only improves the crude but also transforms the economic equation of its production. By achieving reductions of 40% to 70% in the main cost components, it positions oil sands projects as more competitive, sustainable, and resilient against price volatility and environmental regulations. This advantage is transferable to any region with heavy crudes, marking a turning point in the exploitation of unconventional resources.

Unlike reversible technologies such as surfactants or thermal methods, the improvement obtained with RDV® is irreversible and residual: the molecular change persists even after variations in operating conditions, sustainably increasing production

efficiency and the commercial value of the treated crude. This characteristic positions RDV® as a disruptive solution for operations that require long-term stability and performance.

4.6 Integrated Summary of Results and Technological Implications

The results confirm that RDV® induces a profound and irreversible transformation of the bitumen molecular matrix, validated through chromatography, SARA analysis, and rheological evaluation. The consistent increase in medium-chain hydrocarbons (C₁₃-C₁₆), reduction in asphaltenes, and rise in resins collectively enhance flowability, colloidal stability, and transport compatibility.

The mechanism's transferability across fields in Canada and Venezuela demonstrates its universal applicability to high-polarity, chemically complex systems. RDV® acts not on crude type, but on shared molecular structures—enabling targeted protonation and carbocation-driven fragmentation.

Operationally, RDV® enables pipeline transport without diluents, reduces energy and water consumption, and lowers CO₂ emissions, with estimated cost reductions of 40%-70% across key components. Unlike reversible technologies, RDV® produces permanent molecular reconfiguration, positioning it as a superior solution for sustainable upgrading of extra-heavy crudes and oil sands.

5. Conclusions

- RDV® (dynamic vasoactive reactor) technology irreversibly transforms the molecular matrix of Alberta bitumen through a mechanism of selective protonation and carbocation formation, inducing asphaltene

fragmentation and generating resins and medium-chain hydrocarbons (C_{13} - C_{16}), as evidenced by chromatographic and SARA analyses.

- The treatment achieves an 85% reduction in viscosity (from 500,000 to 75,000 cP) and an increase of 6.5 API units (from 8.5 to 15.0), converting the extra-heavy bitumen into a medium-density crude, processable without diluents, with improved fluidity and compatibility with conventional infrastructure.

- An increase of 5.8% in the resin fraction and a reduction of 2.0% in asphaltenes were observed, significantly enhancing colloidal stability, reducing sedimentation tendency, and minimizing the risk of scaling in transport and processing equipment.

- The results are consistent with previous applications in heavy crudes from Venezuela (Boscán and El Salto), where similar patterns of molecular redistribution and rheological improvement were observed, demonstrating the transferability of the mechanism of action in highly chemically transformed, low-saturate systems.

- RDV® represents a disruptive, irreversible, and in situ adaptable chemical solution with significant economic and environmental benefits: 60%-70% reduction in operating costs, elimination of 90%-100% of diluent use, 40%-50% energy savings, and 25%-30% reduction in CO₂ emissions, all without requiring additional capital investment.

- The quantum basis of the RDV® (dynamic vasoactive reactor) mechanism provides unique advantages, including irreversibility and molecular specificity, guaranteeing permanent changes in crude structure. This positions RDV® as a disruptive and superior technology compared to conventional methods, with significant impact on production efficiency and

sustainability in the exploitation of oil sands and extra-heavy crudes globally.

- These benefits position RDV® as a key technology in the energy transition of heavy crudes, aligned with sustainability, operational efficiency, and decarbonization goals, and applicable at global scale to oil sands reservoirs, extra-heavy crudes, and high-polarity systems.

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