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Comprehensive Evaluation of RDV® Technology for Enhanced Oil Recovery (EOR) and In-situ Upgrading of Extra-Heavy Crude in the Boscán Field, Venezuela

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Abstract: The chemical technology RDV® (Vasoactive Dynamic Reactor) demonstrated a highly effective dual mechanism for the treatment of extra-heavy crude oils, combining in-situ upgrading and EOR (enhanced oil recovery). Applied to the Boscán Field (API 9.6°), characterized by extreme viscosities (>25,000 cP), RDV® achieved a 74% reduction in viscosity (down to 6,500 cP), a 50% increase in API gravity (up to 14.4°), and an additional oil recovery of 12.2-15%, along with a 20% increase in effective oil permeability. The mechanism is based on protonation and carbocation formation, following the principles of Olah (Nobel Prize 1993) and quantum proton tunneling effects, inducing an irreversible molecular transformation via selective β-scission. Chromatographic analysis revealed a significant reduction in heavy fractions (C36+), confirming preferential molecular cracking. Core flooding tests validated the complete preservation of reservoir mineralogy (XRD (X-Ray Diffraction)) and intermediate wettability (stable Amott index), confirming the safety of field-scale application. The operational benefits, in comparative terms, include an approximate 40% reduction in steam-assisted pumping temperature—when steam is used—which decreases surface thermal demand and improves energy efficiency, as well as an approximate 60% reduction in diluent consumption, when diluent is required. These benefits, together with the ROI (return on investment), position RDV® as a disruptive, scalable, and environmentally sustainable solution for the transformation of extra-heavy crude oils.

Key words: EOR, extra-heavy crude, Boscán Field, RDV® technology, carbocations, in-situ upgrading, quantum tunneling, reservoir integrity.

1. Introduction

The Boscán Field, located in the Maracaibo Basin, Zulia State, Venezuela, about 40 km southwest of Maracaibo, is one of the most emblematic heavy oil reservoirs worldwide. With an average API gravity of 9.6° and viscosity exceeding 25,000 cP, its efficient exploitation requires advanced technologies that overcome the limitations of primary and secondary recovery.

Traditional chemical EOR (enhanced oil recovery) technologies, such as surfactants and polymers, face significant limitations in crudes of this type, including incompatibility with salinity, formation damage from emulsions or precipitation, and high operating costs [1]. Thermal methods such as steam injection present technical and environmental challenges in formations like Boscán.

The RDV® (Dynamic Vasoactive Reactor) chemical technology emerges as a paradigm-shifting alternative operating through a mechanism of protonation and carbocation generation, inducing irreversible molecular transformations in crude oil [2]. This approach builds on the principles established by George Olah (Nobel Prize in Chemistry, 1993) regarding carbocation stabilization and reactivity [3], later extended into petroleum engineering applications by Professor Davida Martucci in Venezuela.

This work synthesizes results from two independent studies conducted in Venezuela: (1) EOR core flood tests by the INPELUZ (Petroleum Research Institute at Universidad del Zulia), and (2) compositional analysis

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by Core Laboratories, providing conclusive evidence of RDV®'s dual mechanism: in-situ upgrading of crude and simultaneous enhancement of oil recovery, with particular emphasis on reservoir integrity preservation.

2. Experimental Methodology

The selection of INPELUZ and Core Laboratories for the experimental tests was based on their international accreditation and specific expertise in characterizing Venezuelan heavy crudes. This dual approach—combining reservoir evaluation (core flood tests) and advanced compositional analysis—provides comprehensive validation of the RDV® mechanism from complementary perspectives, ensuring reproducibility and technical soundness.

2.1 Materials and Initial Characterization

- Rock sample: Consolidated plug (1.5" diameter) from well BN-659, Boscán Field, prepared through cleaning with toluene and methanol in a cyclic distillation system to remove hydrocarbons and salts.
- Reservoir fluids: Crude from well BN-659 (API 9.6°, viscosity 25,000 cP) and synthetic formation water based on physicochemical analysis (salinity 3,513 ppm NaCl, pH 8.0, 3,513 ppm total ions).
- Chemical agent: RDV-01L®, characterized in Table 1.

2.2 Experimental Protocols

2.2.1 Core Tests (INPELUZ)

The tests were conducted under reservoir-representative conditions (confining pressure: 4,325 psi, ambient temperature), following a strict sequential protocol:

1. Initial characterization: Measurement of helium porosity (22.0%) and air permeability (349 md) under overburden pressure.
2. Saturation: 100% saturation with simulated formation water (3,513 ppm NaCl).
3. Establishment of Swi: Displacement with refined mineral oil (28.4 cP) until irreducible water saturation was reached (Swi = 17.4%).
4. Aging: Exposure to Boscan crude oil for 7 days to restore reservoir conditions.
5. Baseline: Measurement of effective oil permeability (K_o = 101 md) and residual oil saturation (Sro = 39.3%).

Table 1 Physicochemical characterization of RDV-01L® product.

Property	Value/description
Physical state and appearance	Liquid, light brown/beige, clear
Specific gravity	0.86 @ 25 °C (water = 1)
pH	6.24 @ 20 °C (100.0%)
Freezing/melting point	2.9 °C (37.2 °F)
Flash point	92 °C (198 °F)
Initial boiling point and boiling range	211-345.5 °C (412-654 °F)
Water solubility	Negligible, <1%
Evaporation rate	Slow, varies with conditions
Vapor density	>1 (air = 1)
Viscosity	9.7 cSt (mm^2/s) @ 23.9 °C (75 °F)
Flammability classification	Flammable liquid, Class 3
Lower explosive limit (LEL)	0.6%
Upper explosive limit (UEL)	6.5%
Auto-ignition temperature	485 °C (905 °F)
Density	7.18 lb/gal
Vapor pressure	<0.2 psia @ 20 °C (68 °F)
VOC content	100%
Odor threshold	1,300 ppm
Partition coefficient n-octanol/water	Not established
Decomposition temperature	>404 °C (>760 °F)

Table 2 Compositional transformation of Boscan crude by RDV® effect.

Parameter	Original crude	Crude + RDV®	Δ%	Method
API Gravity (°)	9.6	14.4	+50.0%	ASTM D287
Viscosity @ 25 °C (cP)	25,000	6,500	-74.0%	ASTM D445
Density (g/cc)	1.0018	0.9687	-3.3%	ASTM D4052
Molecular weight (g/mol)	490.0	398.0	-18.8%	Chromatography
Asphaltenes content (% wt)	18.0	12.5	-30.6%	ASTM D6560
C36+ fractions (% wt)	70.38	57.27	-18.6%	Chromatography

Table 3 Integral transformation of crude (in-situ upgrading).

Parameter	Original crude	Crude + 10% RDV®	Δ%	Significance
API gravity (°)	9.6	14.4	+50.0%	Transformation into commercial crude
Viscosity @ 25 °C (cP)	25,000	6,500	-74.0%	Flow assurance breakthrough
Molecular weight (g/mol)	490.0	398.0	-18.8%	Molecular fragmentation
Density (g/cm³)	1.0018	0.9687	-3.3%	Improved physical properties
Molecular distribution (% wt)				
Light fractions (C4-C15)	1.65%	8.54%	+417.6%	Generation of mobile components
Intermediate fractions (C16-C35)	27.97%	34.19%	+22.2%	Molecular reorganization
Heavy fractions (C36+)	70.38%	57.27%	-18.6%	Reduction of problematic components

6. RDV® injection: Exposure to RDV-01L® fluid for 8 hours under static conditions.

7. Post-treatment evaluation: Measurement of return permeability and wettability parameters by the Amott method.

2.2.2 Compositional Analysis (Core Laboratories)

1. Sample: Extra-heavy crude oil from well BN-695, Boscan Field: 9° API, Molecular weight: 490.0 g/mol, Density: 1.0018 g/cm³.

2. Treatment: Mixture with 10% v/v RDV-01L® under controlled agitation and time conditions.

3. Analysis: Gas chromatography with programmed temperature (40 °C to 300 °C over 55 minutes) using WCOT Fused Silica CP-Sil 5 CB capillary column and flame ionization detector.

2.3 Analytical Techniques

- Wettability: Amott method [4] modified for reservoir conditions, measuring spontaneous and forced imbibition for oil and water.
- Return permeability: ASTM D4525 [5] under 4,325 psi confining pressure.
- XRD (X-Ray Diffraction): Semi-quantitative mineralogy analysis pre- and post-treatment using diffractometer with copper tube (25 mA, 30 kV).
- Gas chromatography: Detailed analysis of molecular distribution C4-C36+ with quantification of molar, weight, and volume percentages.

3. Results

3.1 Molecular Transformation of Crude: In-situ Upgrading

Chromatographic analysis demonstrates a profound and irreversible molecular transformation of Boscan crude after treatment with RDV®. As shown in Table 2, a significant redistribution of fractions toward lighter components was observed.

To better understand the mechanisms behind these improvements, the molecular distribution analysis (Table 3) reveals a profound compositional transformation:

Fig. 1 dramatically illustrates the improvement in key crude properties (quantitative values in Table 3), showing the effective transformation achieved by RDV® (see Table 1). The chromatographic analysis (sample BN-695, CoreLab) corroborates this transformation, showing a clear shift toward lighter components.

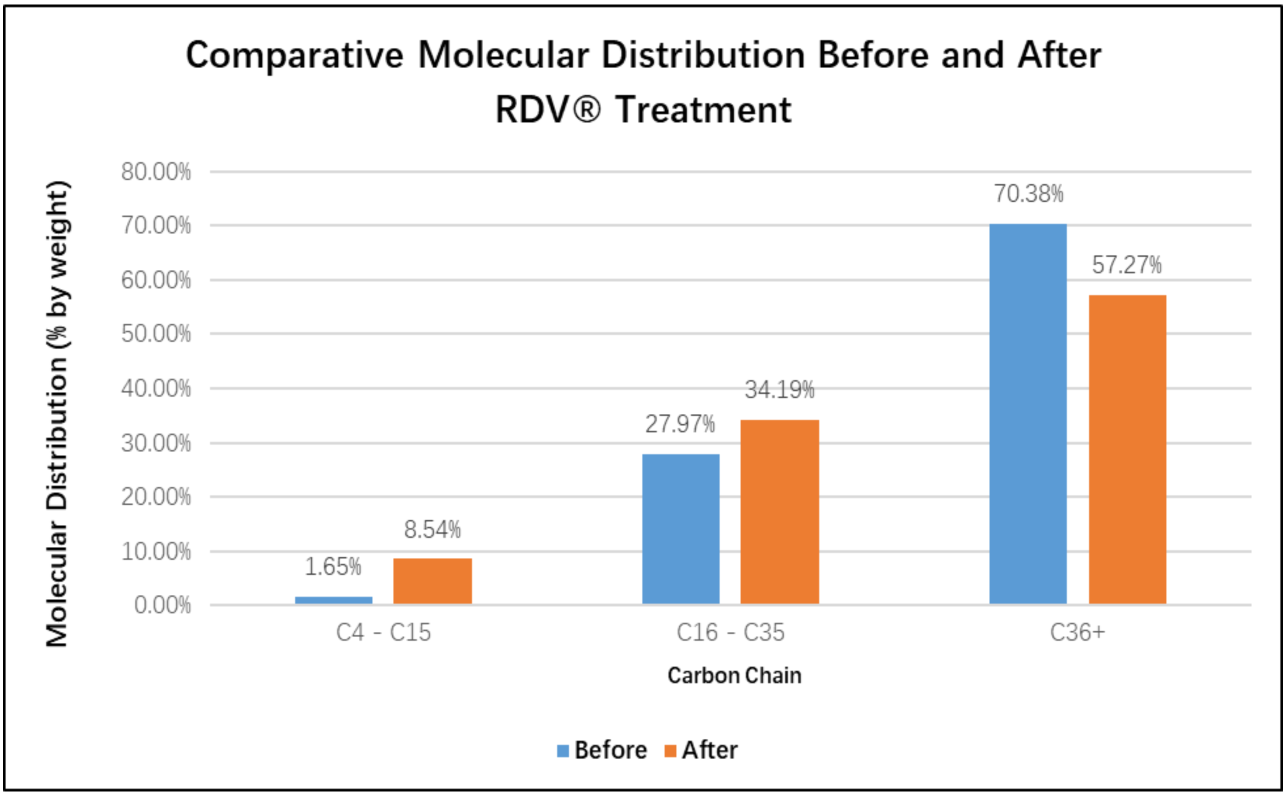
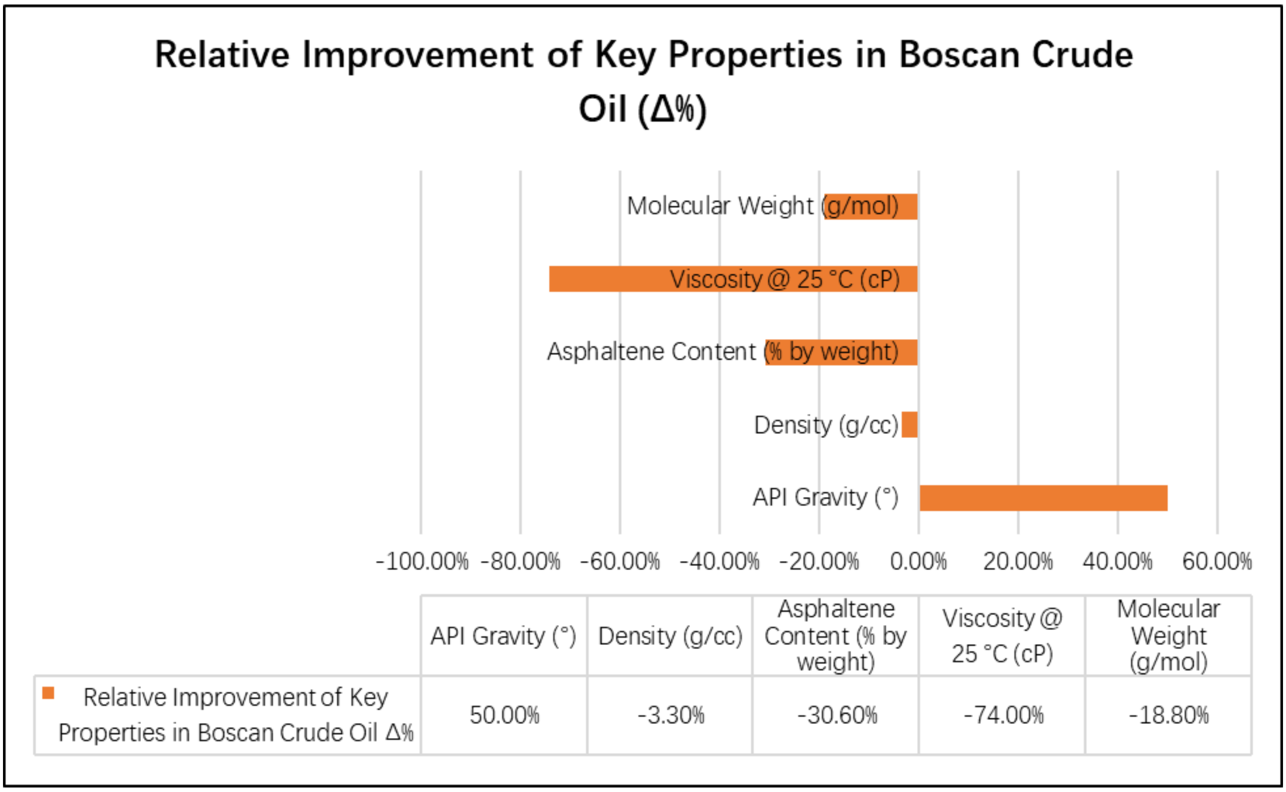


Fig. 1 Comparative molecular distribution pre- and post-RDV® treatment.

Bar chart showing distribution in three fractions: C4-C15, C16-C35, C36+.



	API Gravity (°)	Density (g/cc)	Asphaltene Content (% by weight)	Viscosity @ 25 °C (cP)	Molecular Weight (g/mol)
🟧 Relative Improvement of Key Properties in Boscan Crude Oil Δ%	50.00%	-3.30%	-30.60%	-74.00%	-18.80%

Fig. 2 Relative improvement of key properties of Boscan crude.

3.2 Mechanism of Selective Fragmentation and Fraction Analysis

The RDV® mechanism represents a significant advancement over conventional upgrading methods. Unlike thermal cracking, which indiscriminately breaks bonds, RDV® operates through catalytic selective fragmentation, where protons (H^+) preferentially attack weaker C-C bonds at specific positions of long molecular chains, via a sequential process that includes (see Fig. 7):

1. Protonation: Hydrocarbon molecules are protonated by H^+ from the acidic medium.
2. Carbocation formation: Generation of planar and stable carbocationic intermediates.
3. Preferential β-scission: Selective cleavage of C-C bonds at the beta position to the carbocation.
4. Immediate saturation: Hydrogen transfer from the protonating medium.
5. Stabilization: Production of stable linear paraffins and new carbocations.

This mechanism explains the efficient conversion of heavy hydrocarbons into lighter fractions without generating residual olefins (as illustrated in Fig. 7).

3.2.1. System Stability and Absence of Residual Olefins

A critical aspect that differentiates the RDV® mechanism from conventional acid-cracking processes is the complete absence of residual olefins in the final product. This is evidenced by chromatographic analyses that show no peaks corresponding to unsaturated compounds. The explanation lies in the system's dynamic equilibrium:

- Excess of protons: The medium maintains a high proton density that favors immediate hydrogenation.
- Intramolecular hydrogen transfer: The crude oil molecules themselves act as hydrogen donors.
- Kinetic control: Transient olefins have extremely short lifetimes (< milliseconds).
- Thermodynamic stability: The system converges toward saturated linear paraffins, which are more energetically stable.

Experimental evidence confirms this stability: no gum formation, sediment, or deterioration is observed in oxidative stability tests.

The detailed analysis of the heavy fractions (Tables 3 and 4) reveals the transformation pattern:

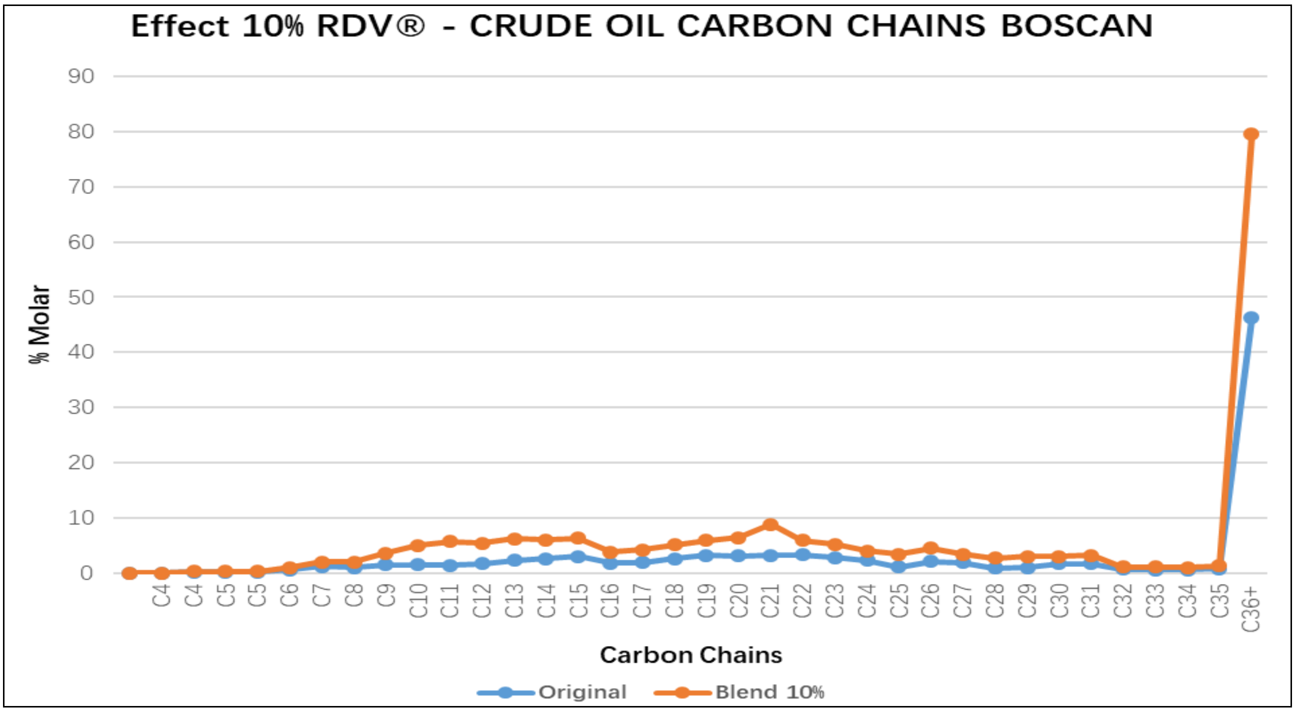


Fig. 3 Molecular distribution curve by carbon chain (C4 to C36+).

Line graph showing molar/weight percentage for each individual carbon.

Table 4 Transformation of heavy fractions of Boscán crude.

Fraction	Original API	API with RDV®	ΔAPI	Original MW	MW with RDV®	ΔMW
C7+	9.5	14.3	+4.8°	494.6	400.4	-19.1%
C11+	8.9	13.4	+4.5°	514.9	422.8	-17.9%
C15+	7.9	11.3	+3.4°	546.2	474.4	-13.1%
C20+	6.1	9.0	+2.9°	598.1	522.7	-12.6%
C30+	1.7	2.2	+0.5°	711.1	655.4	-7.8%
C36+	0.1	0.2	+0.1°	745.2	685.7	-7.9%

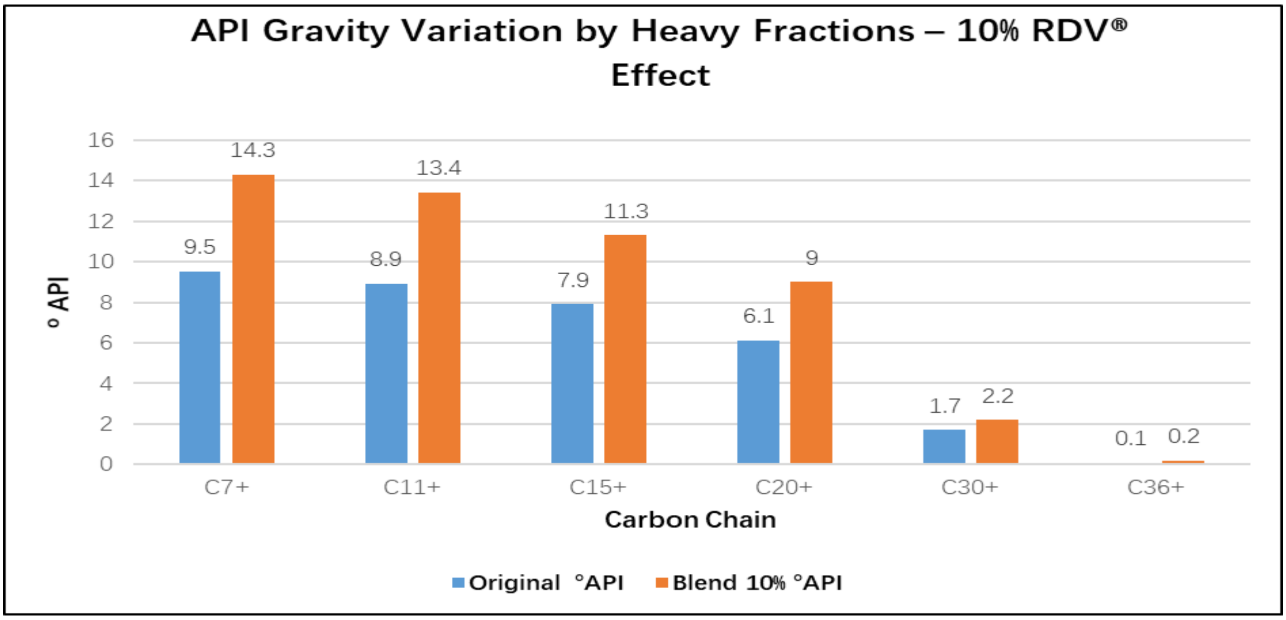


Fig. 4 Variation of API gravity by heavy fractions.
Bar chart showing API increase for each fraction (C7+, C11+, etc.)

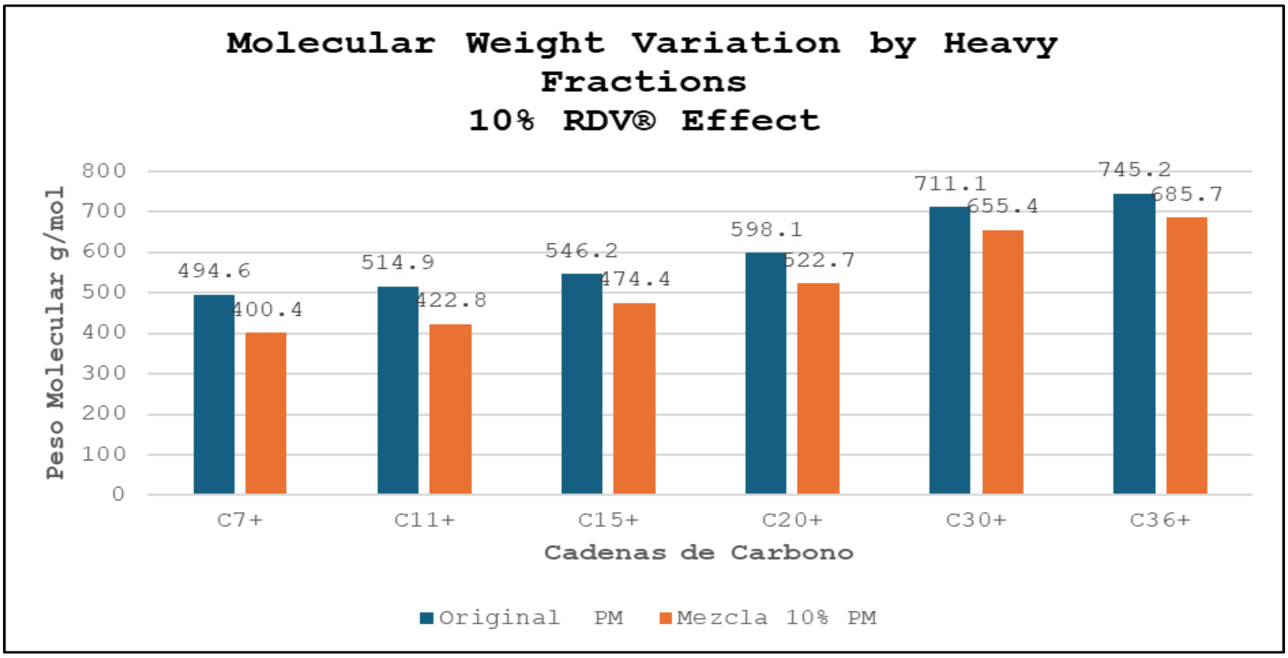


Fig. 5 Molecular weight variation by heavy fractions.
Bar chart showing molecular weight reduction for each fraction.

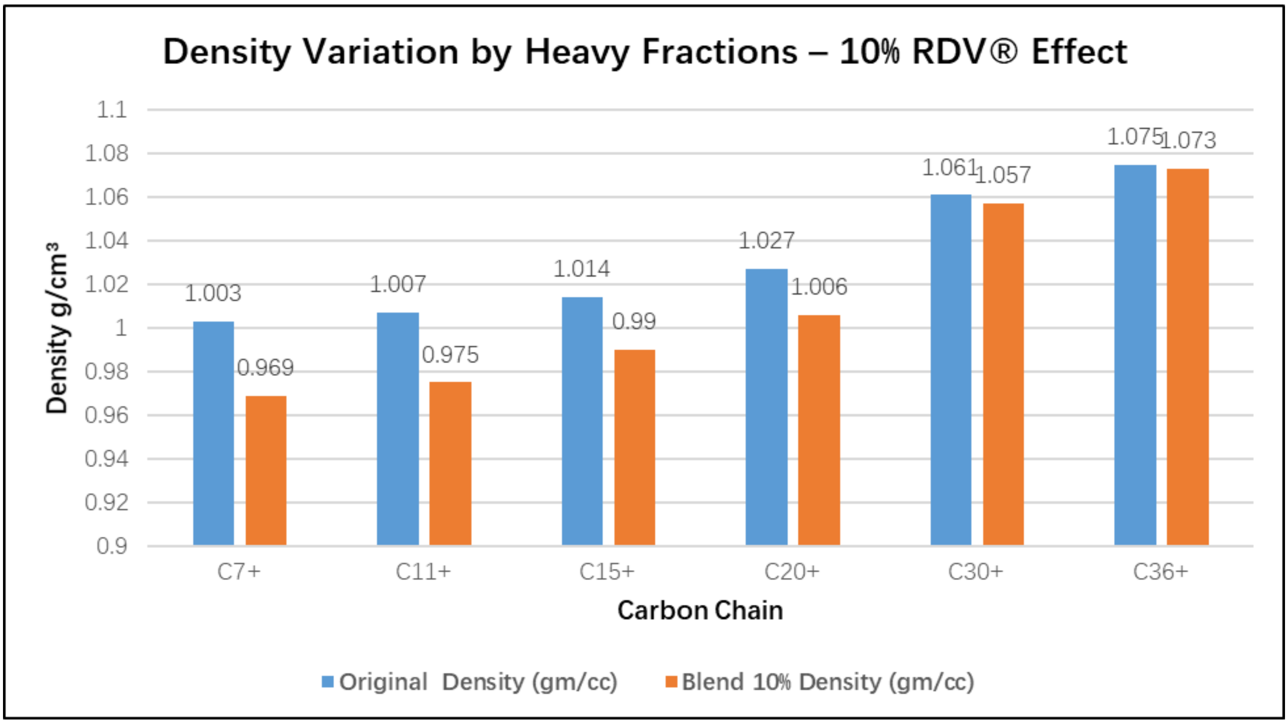


Fig. 6 Density variation by heavy fractions.

Bar chart showing density reduction for each fraction.

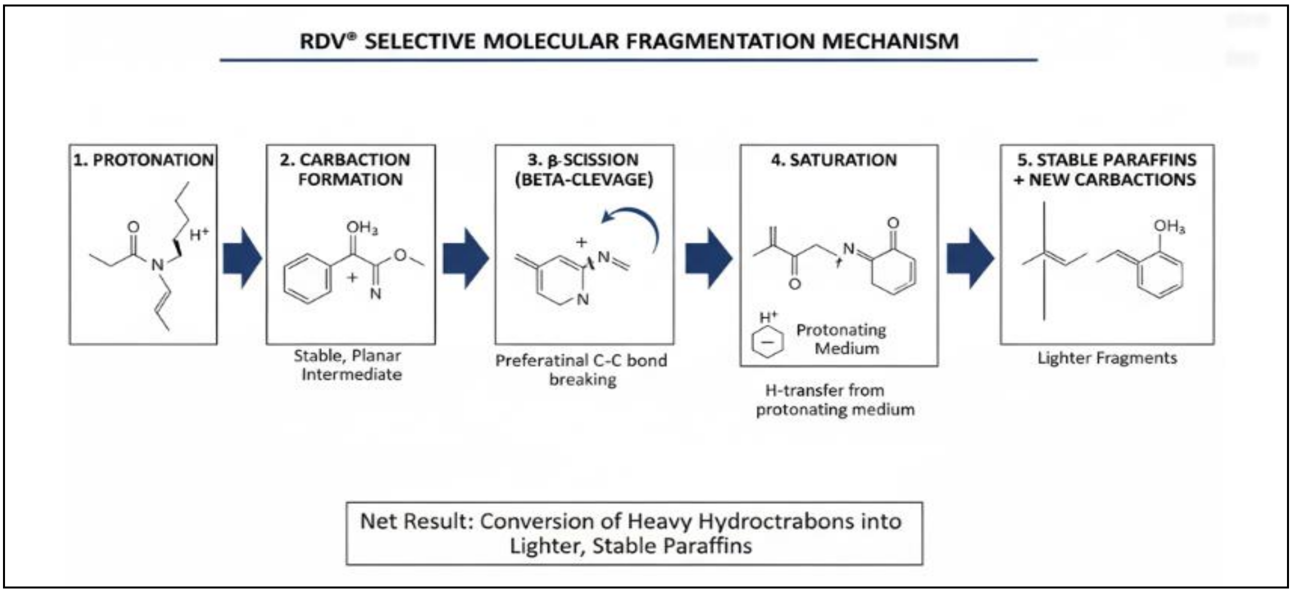


Fig. 7 RDV® selective molecular fragmentation mechanism.

A schematic diagram illustrating the sequential process of:

(A) Protonation of heavy hydrocarbons by H^+, (B) Formation of planar carbocation intermediates, (C) Preferential β-scission of C-C bonds, (D) Immediate saturation by hydrogen transfer, (E) Generation of stable paraffins and new carbocations. Result: Efficient conversion of heavy fractions (C36+) into lighter, more stable components.

3.3 Scientific Foundations: Olah Carbocations and Quantum Effects

The RDV® mechanism finds its theoretical foundation in the pioneering work of George Olah (Nobel Prize in Chemistry, 1993), who demonstrated the stabilization of carbocations in superacid media [3]. Olah established that carbocations, far from being mere transitory intermediates, can exist as stable species under suitable conditions, facilitating molecular rearrangement reactions.

Proposed mechanism:

- Selective protonation: The protons from RDV® (pH~4) are preferentially adsorbed at nucleophilic sites of the long hydrocarbon chains.
- Carbocation formation: Generation of planar carbocation intermediates, stabilized by inductive and hyperconjugation effects.
- Preferential β-scission: Selective cleavage of C-C bonds in the beta position to the carbocation, generating transient olefins that are immediately saturated via hydrogen transfer from the protonating medium, producing stable linear paraffins and new carbocations.
- Molecular rearrangement: Hydride-shift and methyl-shift reactions that redistribute the molecular structure.

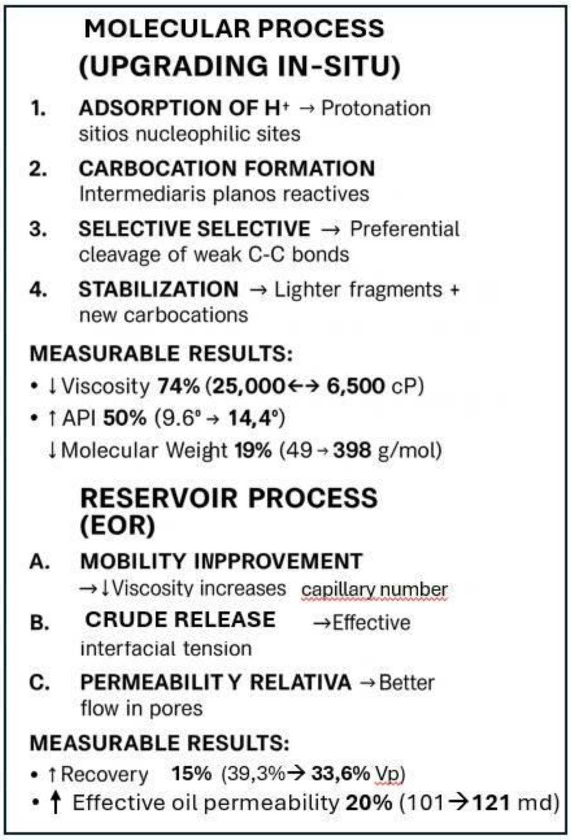
From a quantum mechanical perspective, the protons donated by RDV® exhibit quantum tunneling properties that explain their selectivity [6]. Unlike conventional acids where proton transfer follows classical barrier-crossing pathways, the protons in RDV® can access specific nucleophilic sites through tunneling effects, particularly at the weaker C-C bonds of long paraffinic chains.

3.4 Impact on Enhanced Oil Recovery (EOR)

Core flooding tests demonstrate significant improvements in flow and recovery parameters, as summarized in Table 5.

The 20% increase in effective oil permeability is primarily attributed to the reduction in crude oil viscosity, which improves mobility within the rock according to the modified Darcy equation. The decrease in Sro (residual oil saturation) from 39.3% to 33.6% indicates greater displacement efficiency, translating to a 12.2% increase in oil recovered with a 15% increase in in-situ oil displacement efficiency.

The absence of damage from olefin polymerization—common in other acid cracking methods—validates the safety of the RDV® process. Unlike traditional acid catalysts that generate stable olefins, the RDV® system ensures their immediate saturation, preventing stability and deposition issues that would compromise the operation.



MOLECULAR PROCESS
(UPGRADING IN-SITU)

1. **ADSORPTION OF H+** → Protonation sitios nucleophilic sites
2. **CARBOCATION FORMATION** Intermediaris planos reactives
3. **SELECTIVE SELECTIVE** → Preferential cleavage of weak C-C bonds
4. **STABILIZATION** → Lighter fragments + new carbocations

MEASURABLE RESULTS:

- ↓Viscosity **74% (25,000↔ 6,500** cP)
- ↑API **50%** (9.6° → **14,4°**)
- ↓Molecular Weight **19%** (49 → **398** g/mol)

RESERVOIR PROCESS
(EOR)

A. **MOBILITY INPPROVEMENT** →↓Viscosity increases capillary number
B. **CRUDE RELEASE** →Effective interfacial tension
C. **PERMEABILIT Y RELATIVA** →Better flow in pores

MEASURABLE RESULTS:

- ↑Recovery **15%** (39,3%→ **33,6%** Vp)
- ↑ Effective oil permeability **20%** (101→**121** md)

Fig. 8 RDV® dual mechanism of action: In-situ upgrading + EOR.

Integrated flow diagram showing molecular and reservoir processes.

Table 5 Core test results—RDV® effect on flow properties.

Parameter	Pre-RDV®	Post-RDV®	Δ%	Interpretation
Effective oil permeability, Ko (md)	101	121	+20.0%	Improved flow capacity
Residual oil saturation, Sro (% Vp)	39.3	33.6	-15%	Greater displacement efficiency
Oil recovered (% Vp)	43.3	48.6	+12.2%	Increase in recovery
Oil wetting index (Amott)	0.072	0.011	-84.7%	Maintains favorable condition
Water wetting index (Amott)	0.084	0.022	-73.8%	System stability
Porosity (%)	22.0	22.0	0.0%	Integrity preserved

Table 6 Mineralogy analysis by XRD pre and post-RDV® treatment.

Mineral	Pre-treatment (%)	Post-treatment (%)	Δ%	Interpretation
Quartz (SiO2)	93.57	84.85	-9.3%	Variation within analytical margin
Kaolinite (Al2 Si2 O5 (OH)4)	3.02	5.70	+88.7%	Clay reorientation, not alteration
Montmorillonite (AlSi2 O6 (OH)2)	1.41	3.55	+151.8%	Natural dispersion, not chemical damage
Plagioclase (NaAlSi3 O8)	1.00	1.20	+20.0%	Mineralogical stability
Illite	0.00	1.00	+100.0%	Detection due to better dispersion
Muscovite	0.00	2.70	+100.0%	Detection due to better dispersion
Chlorite	1.00	1.00	0.0%	Complete stability
Total clays	4.43%	9.25%	+108.8%	Physical dispersion, not chemical reactivity

Table 7 Comparison of mechanisms: RDV® vs. conventional technologies.

Parameter	RDV® technology	Polymers	Surfactants	Thermal methods
Mechanism	Protonation→Carbocations →β-scission	↑ Water viscosity	↓ Interfacial tension	↓ Viscosity via heat
Type of effect	Irreversible (chemical)	Temporary (physical)	Temporary (physical)	Temporary (thermal)
API impact	+50% (9.6°→14.4°)	No change	No change	No change
Viscosity reduction	-74%	Indirect	Indirect	-30% to -60%
Formation compatibility	100% preserved	Risk of adsorption damage	Emulsions, wettability change	Thermal alteration
Energy efficiency	Leverages reservoir energy	Medium	Medium	Very low

Table 8 Comparative advantages of RDV® in extra-heavy crude oils.

Feature	RDV®	Conventional technologies	Practical impact
Transformation speed	Exponential with ↑T and P	Linear or limited	ROI 6-12 months
Product stability	Saturated linear paraffins	Emulsions/separation	Stabilized crude
Applicability	Universal (8°-45° API)	Limited by API gravity	Wide operating range
Environmental footprint	Minimal	Medium to high	Sustainable

3.5 Reservoir Compatibility: Integrity Preservation

A critical finding is the complete preservation of the reservoir rock properties. XRD (X-Ray Diffraction) analysis (Table 6) showed no significant changes in mineralogy after the RDV® treatment.

The stability of the wettability indices (Amott) confirms that RDV® does not alter the formation's wetting conditions, maintaining the optimal intermediate condition for EOR processes. The absence of chemical reaction with the formation minerals validates the treatment's compatibility and safety.

4. Discussion

The experimental results obtained allow for a comprehensive analysis that integrates scientific validation with practical operational and economic implications.

4.1 Validation of the RDV® Mechanism of Action

The RDV® protonation-carbocation mechanism represents a fundamentally different paradigm, operating at a molecular level versus conventional macroscopic approaches. Experimental evidence confirms the irreversible transformation through compositional redistribution (C36+ ↓18.6%, C4-C15 ↑417.6%).

4.2 Reservoir Compatibility and Integrity Preservation

The mineralogical compatibility evidenced by XRD is complemented by the stability of the permeability after prolonged exposure to the treatment, demonstrating the absence of clay migration or pore plugging. The preservation of 100% of the reservoir integrity, confirmed by both mineralogical analysis and wettability tests, constitutes a crucial finding for field-scale applicability.

Table 9 Quantified operational benefits.

Operational parameter	Before RDV®	After RDV®	Improvement	Economic impact
Pumping temperature	60 °C -80 °C	35 °C -45 °C	-40%	40%-60% energy savings
Diluent requirement	30%-40%	10%-15%	-60%	Reduced logistics costs
Shear stress	High	Low	-70%	Increased equipment lifespan
Pumping pressure	High	Medium	-35%	Lower energy consumption

Table 10 Comparative economic analysis.

Indicator	RDV® technology	Conventional methods	RDV® advantage
Estimated ROI	6-12 months	18-36 months	300% faster
Initial CAPEX	Low	Medium-high	-50% vs. thermal
Annual OPEX	40%-60% reduction	Maintenance or increase	Substantial savings
Crude valorization	+20%-25% (↑ API)	No quality improvement	Additional revenue

4.3 Operational Implications and Performance Benefits

4.4 Economic Impact and Commercial Viability

From an economic perspective, the 30%-40% reduction in diluent requirements and the decrease in pumping temperature represent substantial savings. Conservative estimates indicate that RDV® implementation could reduce operating costs by 40%-60% for fields with characteristics similar to Boscán.

4.5 Sustainability and Future Perspectives

- The preservation of reservoir integrity ensures the long-term sustainability of operations.
- Reduction of the carbon footprint by decreasing energy requirements for heating and pumping.
- Potential for application in other extra-heavy crude oils with similar characteristics.

5. Conclusions

1. Proven upgrading efficiency: RDV® demonstrated exceptional capacity to transform extra-heavy crude, increasing API gravity by 50% (from 9.6° to 14.4°) and reducing viscosity by 74% (from 25,000 to 6,500 cP) through selective molecular fragmentation.

2. Validation of the mechanism of action: Results support the protonation/carbocation mechanism, based on Olah's principles, where RDV® protons induce preferential selective β-scission in long hydrocarbon chains, confirming that its action is fundamentally different from conventional surfactant-based mechanisms.

3. Significant EOR enhancement: Core flooding tests confirmed a 12.2% to 15% increase in oil recovery and a 20% improvement in effective permeability, validating RDV®'s dual impact on upgrading and recovery.

4. Total reservoir safety and compatibility: 100% preservation of reservoir integrity was confirmed by mineralogical analysis (XRD), with no alteration in wettability, porosity, or clay migration—demonstrating long-term operational sustainability.

5. Economic viability and scalability potential: The identified operational and economic benefits justify immediate implementation. Given its robustness, safety, and promising results, pilot projects are recommended in the Boscán Field and similar reservoirs, demonstrating proven scalability and economic feasibility.

6. Sustainability and commercial viability: The approximate 40% reduction in steam-assisted pumping temperature and 60% reduction in diluent use—when these methods are applied to this type of crude—optimize energy efficiency and operating costs, positioning RDV® as a disruptive, scalable, and environmentally sustainable solution for the transformation of extra-heavy crude oils, with direct applicability demonstrated in the Boscán Field.

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