POSIBILIDADES Y RETOS PARA LA COMBUSTIÓN IN SITU EN COLOMBIA

Universidad Nacional de Colombia
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LÍDER DE ÁREA DE CONOCIMIENTO EOR, ICP
Outline

• In situ Combustion
• The Chichimene ISC Pilot
  • History
  • Current Status
• Laboratory Studies
• Nitrogen Conectivity Test
• Challenges and Future Activities
COMBUSTIÓN IN SITU
In-Situ Combustion

Inject Air or Oxygen

• Advantages:
  – Heat generated in-situ
  – No surface/wellbore heat losses
    • Fewer limitations on depth
  – Not dependent on latent heat
    • Fewer pressure constraints
  – Fuel used is residual OIP (usually 5 – 10% of OIIP is consumed)
  – Not dependent on water source
  – Applicable to thin reservoirs

• Disadvantages:
  – Difficult to control
  – Can result in well loss or damage
  – Produces combustion products
    • $N_2$, $NO_x$, if air is injected
    • $CO_2$
    • Various environmentally-unfriendly products
  – HSE risk if $O_2$ breaks through (auto-ignition risk if $O_2 > 9$ mole%)
  – HSE risk – air compression
  – Gas treatment of produced solution gas mixed with flue gases
“Classical” In Situ Combustion Process Schematic

Water

Air or O₂ containing gas

Burned Zone
Combustion Zone
Cracking/Vaporization Zone

Carbon Resid.

CO₂, N₂, C₀, H₂O

Steam Zone
Altered Saturation Zone
Native Reservoir
## Propiedades de Yacimiento – Principales Proyectos

<table>
<thead>
<tr>
<th>Campo, País</th>
<th>Formación</th>
<th>Buzamiento</th>
<th>Profundidad (ft)</th>
<th>Temperatura de yacimiento (°F)</th>
<th>Espesor neto (ft)</th>
<th>Porosidad (%)</th>
<th>Saturación de Agua irreducible (%)</th>
<th>Saturación de aceite al inicio CIS (%)</th>
<th>Permeabilidad (mD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suplacu de Barcau, Rumania Balol, India Santhal, India Bellevue, Lousiana, USA</td>
<td>S</td>
<td>5-8</td>
<td>115-720</td>
<td>65</td>
<td>20-89</td>
<td>32</td>
<td>15</td>
<td>&lt;85</td>
<td>5000-7000</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>4-7</td>
<td>3280</td>
<td>158</td>
<td>9-50</td>
<td>28</td>
<td>30</td>
<td>70</td>
<td>3000-6000</td>
</tr>
<tr>
<td></td>
<td>SS</td>
<td>3-5</td>
<td>3280</td>
<td>158</td>
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<td>28</td>
<td>30</td>
<td>70</td>
<td>3000-5000</td>
</tr>
<tr>
<td></td>
<td>SS</td>
<td>0-5</td>
<td>400</td>
<td>75</td>
<td>10-83</td>
<td>32</td>
<td>27</td>
<td>73</td>
<td>650</td>
</tr>
</tbody>
</table>

### Campo, País

<table>
<thead>
<tr>
<th>Campo, País</th>
<th>Viscosidad del crudo (cp)</th>
<th>Grave dad (ºAPI)</th>
<th>P inic/ P. inicio CIS (psi)</th>
<th>OOIP (MMbbl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suplacu de Barcau, Rumania</td>
<td>2000</td>
<td>16</td>
<td>140 / 80</td>
<td>310</td>
</tr>
<tr>
<td>Balol, India</td>
<td>100-450</td>
<td>16</td>
<td>1450 / 1450</td>
<td>128</td>
</tr>
<tr>
<td>Santhal, India</td>
<td>50-200</td>
<td>18</td>
<td>1450 / 1450</td>
<td>300</td>
</tr>
<tr>
<td>Bellevue, Lousiana, USA</td>
<td>676</td>
<td>19</td>
<td>/ 40</td>
<td>4.6 ;10.6</td>
</tr>
</tbody>
</table>

### Resultados de los Principales Proyectos

<table>
<thead>
<tr>
<th>Campo, País</th>
<th>Fecha (inicio de operación)</th>
<th>Presión inyección (psi)</th>
<th>N de pozos inyectores</th>
<th>N de pozos productores</th>
<th>Producción diaria con ISC (Bbl/día)</th>
<th>Corte de agua (%)</th>
<th>Utilización de O₂ (%)</th>
<th>Relación aire/crudo (scf/bbl)</th>
<th>Recobro esperado de crudo (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suplacu de Barcau, Rumania</td>
<td>1971</td>
<td>150-200</td>
<td>111+</td>
<td>736+</td>
<td>9000++</td>
<td>82</td>
<td>95</td>
<td>14000</td>
<td>52</td>
</tr>
<tr>
<td>Balol, India</td>
<td>1997</td>
<td>1300-1600</td>
<td>30</td>
<td>75</td>
<td>4400</td>
<td>60</td>
<td>&gt;95</td>
<td>5600</td>
<td>38</td>
</tr>
<tr>
<td>Santhal, India</td>
<td>1997</td>
<td>1200-1500</td>
<td>30</td>
<td>105</td>
<td>4000</td>
<td>60</td>
<td>&gt;95</td>
<td>5600</td>
<td>36</td>
</tr>
<tr>
<td>Bellevue, Lousiana, USA</td>
<td>1970</td>
<td>60</td>
<td>15</td>
<td>90</td>
<td>300</td>
<td>90</td>
<td>80</td>
<td>15000</td>
<td>60</td>
</tr>
</tbody>
</table>

+ 24 de los pozos fueron estimulados bajo inyección cíclica de vapor (CSS)

Suplacu de Barcau. Position of the combustion front as of July 1st, 2004

- Initial water/oil contact
- Burnt out area
- Injection wells (111)
- Major Fault
Patterns bad line drive good

Suplacu de Barcau, Rumania
Suplacu: Essential Results/Problems

Results

- Ultimate oil recovery: >50%
- AOR in the range of 6,000 to 18,000 scf/bbl (1,000 – 3,000 sm³/m³), increasing in time
- At the low inj. pressure, even the AOR of 18,000 scf/bbl is economical
- Water cut increased slowly, up to 82%

Operational Aspects

- Burning out of some producers
- Hot well workover challenges; special killing drilling mud needed
- Dehydration/desalting coupled with a stripping unit for processing of crude oil
- Leakage to the surface of some combustion gases/air
## Balol and Santhal - Reservoir Properties

<table>
<thead>
<tr>
<th>Field</th>
<th>Depth</th>
<th>Gross pay</th>
<th>Oil viscosity</th>
<th>Permeability</th>
<th>Res. Pressure Initial / @ start of ISC (psi)</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suplacu de Barcau</td>
<td>115-720</td>
<td>27-290</td>
<td>2,000</td>
<td>5,000-7,000</td>
<td>140/80</td>
<td></td>
</tr>
<tr>
<td>Balol</td>
<td>3280</td>
<td>10-95</td>
<td>100-450</td>
<td>3,000-8,000</td>
<td>1450/1450</td>
<td>Very strong edge water drive</td>
</tr>
<tr>
<td>Santhal</td>
<td>3280</td>
<td>16-195</td>
<td>50—200</td>
<td>3,000-5,000</td>
<td>1450/1450</td>
<td></td>
</tr>
<tr>
<td>Bellevue</td>
<td>400</td>
<td>70/30</td>
<td>676</td>
<td>650</td>
<td>/40</td>
<td></td>
</tr>
</tbody>
</table>

* Coal and carbonaceous material is present in the formation; sulphur content: 0.14
Desempeño del Campo Balol

Fuente: SHARAD H, BHUSHAN M, SIDHARTHA S. “In situ Combustion: opportunities and Anxieties” SPE 126241
Balol & Santhal: Results/Problems

Results
- Ultimate oil recovery: >36%
- AOR 5,600 scf/bbl (1,000 sm³/m³)
- High inj. pressure: 1,500 psi (10.3 MPa)
- Average water cut: reduced from 70%-90% to 5-20%, due to ISC application (in some cases)
- Spontaneous ignition used for ISC initiation

Operational Aspects
- Hot well workover challenges;
- Some H₂S is present in combustion gases, which are flared in tall flare stacks with outside make-up gases
- Challenges of operating separately two layers in the same stack
HPAI: Reported field applications

- **Medicine Pole Hills Unit (MPHU)**
  Secondary HPAI
  Air injection started in 1987
- **Buffalo Red River Unit (BRRU)**
  Secondary HPAI
  Operations started in 1979
- **Horse Creek Field**
  Secondary Air Injection started in 1996
  Some published results

Others:
- **West Hackberry Field** - Louisiana
  Tertiary Pilot in 1996
- **Handil Field** - Indonesia
  Recent HPAI Pilot (2001)
- **Barrancas Field** - Argentina (2005)
HPAI = High Pressure Air Injection in Williston Basin

- Tight limestone / dolomitic limestone
- Net Pay 10-18 ft
- Porosity 15-20%
- Sw around 50%
- Permeability 10 mD
- Reservoir pressure 3600 psi

Why Air injection?
- Water injectivity low (low perm, low water rel.perm) – needs high well density
- Air is cheap
- HPAI = flue gas drive (thermal contribution to RF is <25%)
- RF 18% on 160-320 Acre spacing
<table>
<thead>
<tr>
<th></th>
<th>Medicine Pole Hills</th>
<th>Buffalo Red River</th>
<th>Horse Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formación</td>
<td>Red river</td>
<td>Red river</td>
<td>Red river</td>
</tr>
<tr>
<td>Zona productora</td>
<td>B y C</td>
<td>B</td>
<td>D</td>
</tr>
<tr>
<td>Profundidad</td>
<td>9500</td>
<td>8450</td>
<td>9125</td>
</tr>
<tr>
<td>Porosidad Promedio</td>
<td>B 19%, C 15%</td>
<td>20%</td>
<td>16%</td>
</tr>
<tr>
<td>Permeabilidad Promedio</td>
<td>B y C 5 md</td>
<td>10 md</td>
<td>10 y 20 md</td>
</tr>
<tr>
<td>Net pay promedio</td>
<td>18</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>GOR SCF/STB</td>
<td>525</td>
<td>120</td>
<td>205</td>
</tr>
<tr>
<td>Saturación de agua promedio</td>
<td>B 37%, C 48%</td>
<td>45%</td>
<td>35%</td>
</tr>
<tr>
<td>Temperatura de yacimiento °F</td>
<td>230</td>
<td>215</td>
<td>220</td>
</tr>
<tr>
<td>Presión inicial de yacimiento psi</td>
<td>4120</td>
<td>3600</td>
<td>4000</td>
</tr>
<tr>
<td>Gravedad API</td>
<td>39</td>
<td>30</td>
<td>32</td>
</tr>
<tr>
<td>OOIP</td>
<td>40,000,000</td>
<td>37,000,000</td>
<td>45,740,260</td>
</tr>
<tr>
<td>Factor de recobro primario %</td>
<td>15</td>
<td>5.95</td>
<td>9.92</td>
</tr>
<tr>
<td>Factor de recobro incremental %</td>
<td>14.25</td>
<td>15.67</td>
<td>16.62</td>
</tr>
<tr>
<td>Factor de recobro total %</td>
<td>29.25</td>
<td>21.62</td>
<td>26.53</td>
</tr>
</tbody>
</table>

Fuente: paper spe 38359
Field Case: HPAI vs Waterflood

SPE 99454: Air Injection and Waterflood Performance Comparison of Two Adjacent Units in Buffalo Field: Technical Analysis

V.K. Kumar, D. Gutiérrez, G. Moore, S. Mehta
PILOTO DE INYECCIÓN DE AIRE EN CHICHIMENE
Why In situ Combustion in Colombia?

70% of the heavy oil reserves in Colombia are located at a depth > 6000 ft.

PRODUCTION FORECAST - EXPANSIONS

CHICHIMENE

- POTENCIAL 2040
- ALCANCE 2021

- Potential 356 MBLS
- 89 MBLS
- 267 MBLS

CASTILLA

- POTENCIAL 2040
- ALCANCE 2021

- Potential 316 MBLS
- 52 MBLS
- 264 MBLS

RUBIALES

- POTENCIAL 2040
- ALCANCE 2021

- Potential 554 MBLS
- 127 MBLS
- 427 MBLS

CAÑO SUR

- POTENCIAL 2040
- ALCANCE 2021

- Potential 49 MBLS
- 30 MBLS
- 19 MBLS
Chichimene Field

Discovery: 1969, Chevron
Start of Operations: 1985
Back to Ecopetrol: August, 2000
Current Production: 80,000 bpd
Steep Pressure Decline
Primary UER≈ 9%
Allied with world-class strategic partners, Ecopetrol has acquired skills and capacities for ISC physical and numerical modeling for extra-heavy oil reservoirs.
Eco-GSAI® Pilot Design (Gravity-Stabilized Air Injection)

- **Producer**
- **Injectors**
- **Cooling water circulation, annular return**
- **Cooling tubing 1 ¼”**
- **Casing 9 5/8”**
- **Injection Tubing 2 7/8”,**
- **High-Temperature Packer**
- **Liner 7”**
- **7900’-7930’**
- **7960 FT**
- **7945’-7955’**
- **8100 FT**

*Image credits: [University of Calgary](https://www.ucalgary.ca), [IFP](https://www.ifp.com), [BELGRAVE OIL AND GAS CORP](https://www.belgraveoil.com), [XYTEL](https://www.xytel.com), [STANFORD UNIVERSITY](https://www.stanford.edu), [UNIVERSIDAD NACIONAL DE COLOMBIA](https://www.uninews.unal.edu.co), [Universidad Industrial de Santander](https://www.uis.edu.co)*
Pilot Design

2nd line wells

3rd line wells (flanks)
Pilot Premises

Able to prove the technology concept for deep, extra-heavy oil reservoirs

Evaluation time of 2 years is sufficient

Ultimate RF of 35% OIIP is possible
Project Timeline

**Before 2011:** Screening, preliminary lab tests, kinetics model, ISC world survey, People assignment (40+ professionals)

**2012-2014:** Construction of own ISC laboratory and equipment, Pilot detailed design

**2015-2017:** Construction of field facilities, Detailed lab tests, Connectivity test, Ignition
Reactivity Studies: Core vs. Outcrop

Particle size distribution

Bulk Composition

Clay Composition

Core

Outcrop

Reactivity Studies: Core vs. Outcrop

• The outcrop samples compositionally resemble the reservoir rock
• Their reactivities are also comparable
• This means using the outcrop rock for RTO and combustion test studies is feasible
• It results in significant cost savings
• Enables experimental studies to evaluate the effect of reservoir and operating parameters on reactivity and combustion performance
Experimental Studies at the ISC lab

Effects on Reactivity and Combustion Performance

- Asphaltenes
- Water saturation
- Air injection rate
- Rock minerals
- Chemicals for assisted ignition

- RTO Reactor
- Isothermal Cell
- Combustion Tube
Ignition Study

(Ignition Evaluation of In-Situ Combustion Process of Chichimene Field, H. Bottia, M. Aguillón, H. Lizcano, C. Delgadillo, C. Gadelle, ThEOR 2016, Kazan, Russia)

- Ignition delay ≈ 2 days
- Ignition distance ≈ 2 m
High Resolution Radial Model (Ignition)

Results:

- 2 d
- 4.5 d
- 8 d
- 29 d
High Resolution Radial Model (Ignition)

Results:

2 d

8 d

29 d
Experimental Study: Emulsions

Produced oxidized crude oil in a continuous flow reactor (Patent pending)

Create synthetic emulsions.
They are comparable with analogue field produced emulsions

Proactively studying alternatives for effective treatment: Chemical, dilution, thermal, combined.
Nitrogen Connectivity Test

- Objectives:
  - Test if any preferential direction for gas flow exists
  - Dimension the residence time of the combustion gases in the pilot area
  - Test the response of the artificial lift system to increased GOR
  - Update the simulation model
ES pumps had a hard time with high GORs. The wells were eventually shut in.

$N_2$ broke through between days 8-10 at the 1st line wells.

Injection continued for almost 30 days. $N_2$ was measured in almost all of the 2nd line wells and some 3rd line wells.
How are we for ISC?

Challenges:

Oxygen Production
High reactivity at reservoir T
Transit time (8 d) longer than ignition delay (2 d)

Emulsions
Proactively preparing a response for treatment

Artificial Lift
Fewer options at 8,000 ft deep, extra-heavy oil, high GOR
Optimizing ESP design for expected rates and GORs.
Next Steps

- Deploy the artificial lift solution
- Predict the ignition performance based on the updated simulation model
- Make slight adjustments to treatment facilities to allow for flexible emulsion treatment
- Adjust the monitoring plan for ignition and steady air injection
- Continue with the experimental efforts to support the operation before any deviation
Challenges and Future Activities

• Predictive modeling of ISC at field scale (Stanford)
• Nano-catalysts for promoting ignition
• Finishing “base lines” and measuring deviations
• Operate the pilot with minimal disturbance
• Extrapolate the pilot findings to the field scale
• Deal with hot well operations (expansion)
• Cost reduction (lower-grade metallurgy, fluid treatment, compressor reliability)
• Environmental (Emissions, flue gas use, water quality)
Acknowledgments

• The laboratory, operations and reservoir Chichimene ISC team, both at the Colombian Petroleum Institute and other areas of Ecopetrol

• Our team of partners and consultants throughout the stages of the project: Alex Turta, Claude Gadelle, Louis Castanier, Olivier Clause, John Belgrave, Antony Kovscek, Margot Gerritsen, Marco Thiele, Gordon Moore, Raj Mehta, ONGC
ENERGÍA PARA EL FUTURO