De-risking Caracara Sur Field cEOR implementation
From lab to field

June 2015
Outline:

0. Introduction
1. Surfactant Development
2. Laboratory work
3. Pre-pilot tests
4. Pilot design and execution
5. Next step. Field implementation
0. Introduction
The company

Cepsa is an integrated energy group that operates at every stage of the petroleum value chain.

- It boasts more than 80 years' presence in the market and over 11,000 employees

Presence in the world
CEPSA strengths in cEOR

Integrated company with a unique situation to face EOR projects:

• A strong petrochemical division with wide world presence and a leader position in LAB (Linear alkylbenzene) market

• An E&P division in continuous growth and a board of direction committed to continue with this growth

• A corporate research center with long experience on laboratory plants design and construction that support all the operational areas

• Research center has long experience in tracer analysis
CEPSA´s Integrated Approach to a cEOR Project

0. Introduction
Background to Caracara – Llanos Basin

- Operator CEPSA Colombia (70%), partner Ecopetrol (30%)
- End of license: April 2029
- Six main reservoirs with average depth 4000 ft TVDSS
- Oil: Gravity 18-22 API, Viscosity 6-14 cP
- Relatively hot reservoir temperature (86 C)
- Fresh water (2000 ppms TDS, < 10 ppm Ca2+)
Development Strategies for Caracara

Conventional (Horizontal) Infill Drilling
- Improve Sweep
- Increase rate
- Reduce Coning/Cusping
- Reduce wells

Near-Field Exploration
- Intra-field

Down-dip Appraisal
- Most reservoirs are thin and have ODT’s

Water Injection
- Some reservoirs are depleted (poor connection with aquifers)

EOR
- Improve macroscopic sweep (M>1)
- Reduce Sorw

<table>
<thead>
<tr>
<th>Volumes (MMbbl)</th>
<th>STOIIP</th>
<th>Cum Prod 01/01/2015</th>
<th>Current RF</th>
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<tbody>
<tr>
<td>Caracara Sur</td>
<td>106.7</td>
<td>29.9</td>
<td>28.0%</td>
</tr>
<tr>
<td>Toro Sentado/Rancho Quemado</td>
<td>30.7</td>
<td>5.6</td>
<td>18.3%</td>
</tr>
<tr>
<td>Elisita</td>
<td>33.9</td>
<td>12.5</td>
<td>36.8%</td>
</tr>
<tr>
<td>Peguita</td>
<td>67.8</td>
<td>12.9</td>
<td>19.1%</td>
</tr>
<tr>
<td>Peguita SW</td>
<td>12.2</td>
<td>2.8</td>
<td>22.8%</td>
</tr>
<tr>
<td>Unuma</td>
<td>2.5</td>
<td>0.3</td>
<td>10.0%</td>
</tr>
<tr>
<td>Total</td>
<td>253.8</td>
<td>64.0</td>
<td>25.2%</td>
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</table>
EOR Screening process

Screening of EOR Techniques:

a. **Thermal**
   - Steam: Too deep, viscosity too low
   - In-situ Combustion: Separation of produced gas, difficult to control

b. **Gas Injection**
   - Miscible Gas/CO₂/N₂: MMP’s too high, oil has too high viscosity
   - Immiscible Gas: Separation of produced gas, gas availability

c. **Chemical**
   - Polymer: Worth considering, but T at limit and aquifers could be too strong
   - Surfactant Polymer: Added advantage over polymer, facilities already there

Two screening studies on Caracara Sur (CCS) and Elisita:

- ASP ranked as the technology with highest potential and lowest risk
- Estimated incremental recovery between 15% and 25% (full field: 14 to 32 MMbbl). Assumed 20% as Base Case

Caracara Sur Preferred:

- Biggest field, high well density, existence of un-swept areas, economy of scale, higher reward
- Likely to target minimum 30% PV in 10 years life span (Phase 1)
 CCS cEOR Project: De-risking in Stages

- **Laboratory**
  - Optimize formulation (cost efficient, compatible with CCS water, thermally stable, stability surfactant-polymer mixture)
  - Core-flooding to prove enhanced sweep and Sor reduction, assess polymer shear and adsorption of chemicals.

- **Single Well Tracer Tests (SWTT’s) & Injection Tests**
  - Assess injectivity of water, SP and ASP at well scale
  - Evaluate the capability of the formulation to reduce and mobilize the residual oil saturation at well scale and reservoir conditions
  - Assess potential emulsion issues during back-flow tests

- **Pilot:**
  - Prove the technical success of the CEOR process as a whole
  - Calibrate breakthrough, incrementals in full field level
  - Acquire data for deployment at field scale (chemical interaction with reservoir fluids and rock, injection and production behavior & profiles)

- **Increase Geological Knowledge**
  - After a successful pilot, drill downdip appraisal wells to minimize geological risk
  - If successful, pre-produce wells for 1 year before conversion to injectors

- **Full Field Deployment**
  - Define the technical-economical viability of the CEOR application at field scale
  - Design and implement the CEOR development of the field in phases
1. Surfactant development
CEPSA petrochemicals

- CEPSA Química is world leader in LAB production with factories in
  - Spain
  - Canada
  - Brazil

- State-of-the-art manufacturing route of LAB
  - Detal® technology co-licensed by UOP and CEPSA
  - R&D Center works on process engineering, development of catalysts at its pilot plant facilities

- State-of-the-art surfactants evaluation laboratory integrated in corporate research center.
Surfactant development steps

- Characterization of precursor (existing CEPSA stream)
- Sulfonation and neutralization
- Study of the influence of process conditions on product performance
- Handling studies
- Production and supply chain optimization
2. Laboratory work
2. Laboratory work

Laboratory work flow

- Most of the work carried out by CEPSA staff in CEPSA Research Centre facilities
- Four different laboratories involved:
  1. Fluid and solid analysis lab for oil, brines, rocks and chemicals analysis and characterization
  2. Surfactants lab for developing EOR surfactants and formulations
  3. Core-flooding lab for testing EOR formulations
  4. Tracers analysis lab for analyzing effluent fluids
- Strong interaction between R&D and business units
2. Laboratory work

Polymer selection work flow

Polymer screening → Polymer qualification → Surfactant formulation → SP Coreflooding

- **Polymer screening**
  - Polymer selection

- **Polymer qualification**
  - Polymer data set

- **Surfactant formulation**
  - Surfactant selection.
  - Formulation assessment

- **SP Coreflooding**
  - Formulation behavior in coreflood
  - % Recovery Increase

- **Candidate polymers**
  - PRE-Screening
  - Field data: Temperature, Pore size, Salinity

- **Surfactant Workflow**
  - Field data: Temperature, Salinity

**EOR POLYMER WORKFLOW**

- V Plots
- Filtrability
- Thermal stability
- Coreflood test (at 100% water saturation and Sor)
  - Rf
  - RRF
  - Adsorption and IPV

**SPE-174653-MS**

An Innovative Approach to Make HPAM an Effective Solution to Optimize the Low Salinity ASP Application in Caracara Sur Field, Colombia - Field Case
Surfactants from CEPSA Química and other manufactures

Addition of co-surfactants for ultra low IFT adjustment and compatibility

Robustness tests:
- Surfactant/Polymer compatibility. Stability of the formulation.
- Static adsorption studies

2. Laboratory work
Surfactant formulation work flow

Polymer screening
- Polymer selection

Polymer qualification
- Polymer data set

Surfactant formulation
- Surfactant selection. Formulation assessment

SP Coreflooding
- Formulation behavior in coreflood
  % Recovery Increase

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2. Laboratory work

Core flood experiments

- Initial experiments performed on outcrop cores
- Final experiments performed on real field cores
- Cores cleaned by solvent injection, re-saturated and aged to restore initial state
- Waterflooding:
  - Oil production profile, SorW
- SP/ASP Flooding:
  - Incremental oil recovery profile
  - DP profiles
  - Chemicals production profile

Polymer screening

Polymer qualification

Surfactant formulation

SP Coreflooding

Formulation behavior in coreflood

% Recovery Increase
3. Pre-pilot tests
3. Pre-pilot test

Single well ASP field test

**SWTT#1 to measure** $S_{orw}$  
**ASP CEOR Process sequence injection**  
**SWTT#2 to measure** $S_{orASP}$

Single Well ASP field test with following objectives:

- Confirm formulation injectivity
- Validate formulation behavior of Sor reduction in real field conditions
- Test out and develop QC/QA procedures to be used during pilot
- Obtain real samples for de-emulsification sub-project
- Accelerate learning curve related to chemical EOR logistics
3. Pre-pilot test

Single well ASP field test

SWTT#1 to measure $S_{orw}$

ASP sequence injection

SWTT#2 to measure $S_{orASP}$

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3. Pre-pilot test

Single well ASP field test test achievements

- **SWTTs measured residual oil saturation to water in CCS C17 well**
  - C17 – C7 A5 sequence: 20% +/- 2%

- **ASP formulation successfully tested in CCS C17 well**
  - 10% PV Polymer preflush/33% PV ASP/33% Polymer Drive/10% Viscosity tapering
  - Good injectivity
  - ASP CEOR performance proved at well scale
  - Oil mobilization measured
  - Increase in oil cut from 0% to 4% measured during 5 days before close the well

- **SWTTs to measured residual oil saturation to ASP in CCS C17 well was successfully conducted**
  - C17 – C7 A sequence: 8.5% +/- 2.0%
  - Around 11.5% incremental recovery from Sor reduction

- **Production fluids interaction**
  - Production fluids successfully treated with the current production treatment
  - No emulsion issues were observed in the production fluid samples
  - It is expected minimum impact in OPEX associated to production fluids
4. Pilot selection, design and execution
Pilot design

Why to do a pilot:

- Pilot is needed to calibrate reservoir models to assess feasibility of Full Field implementation
- To learn how to implement a cost effective process
  - to measure increased rates, decreased BSW
  - to assess the increased sweep
  - to estimate the reduced Sor
- Learn operational matters
- Build experience

Where to do the pilot:

- Minimize Costs
  - Drill a single injector, use existing producer wells
  - Get results within 1-1.5 years → Limit Well Spacing
  - Minimize work-overs
  - Avoid building another drilling pad, use available slots
- Perform a pilot test using selective injection and production (multi-zone), avoid C7-M (bottom water!)
- Select a pattern with equal offtake wells

How to do the pilot:

- All wells involved in the pilot completed in the same way
- Stable conditions during the pilot time
Pilot design

Mobility control: mobility of displacing fluid > mobility of displaced fluid => mobility ratio < 1

<table>
<thead>
<tr>
<th>Water</th>
<th>Polymer Drive</th>
<th>ASP</th>
<th>Front: Polymer Slug</th>
<th>Back: +oil bank</th>
<th>Water + Oil Bank</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_w$</td>
<td>$\lambda_p$</td>
<td>$\lambda_{ASP}$</td>
<td>$\lambda_{ASP}$</td>
<td>$\lambda_p + \lambda_o$</td>
<td>$\lambda_w + \lambda_o$</td>
</tr>
</tbody>
</table>

- Requires polymer drive tapering
- Similar mobilities by design
- ASP mobility to match oil + polymer bank minimum mobility
- Polymer mobility to match water + oil minimum mobility

direction of slugs designing
Pilot design. Injection plant

Injection plant basis of design:
1. Injection rate: (injectivity test confirmed during SWTT-ASP)
2. Injection pressure, not exceeding fracture pressure
3. Integrated mixing and injection facility
Pilot success criteria and uncertainties

Pilot Success Criteria:

• The main aim of a pilot is to evaluate the effectiveness of the technology application. The objective of the Pilot is to learn how to implement a cost effective Chemical EOR process by calibration of the pilot simulation model.

• The pilot has been designed for success, which is defined as:
  • To see a reaction relatively soon (within one year)
  • To have noticeable oil increases
  • To see changes in at least 2 of the 3 producer wells

Uncertainties expected to be resolved from pilot information:

• Long term ASP stability flowing in the formation
  • Chemical losses
  • Chromatography effects
  • Polymer degradation

• Macroscopic residual oil saturation

• Impact of facies distribution and relative permeabilities

• Long term injectivity

• Volumetric sweep efficiency

• Commingled injection experience. Selective breakthrough information
4. Pilot selection, design and execution

Production wells monitoring plan

1. Production rates and BSW
   - Production tests

2. Pressures
   - Wells to be produced at constant Q

3. Fluids chemistry
   - Production water chemistry
   - Injected chemicals production
   - IWTT tracers analysis
   - Production fluid emulsions

Injection well monitoring plan

1. WHIP to be maintained below fracture pressure

2. ILTs will be run at different times during the project.
   - Early injection
   - ASP injection
   - End of project
4. Pilot selection, design and execution

QA/QC lab during pilot operations

1. Raw materials
   - Purity of surfactants
     - Active matter by two-phase titration (colorimetric end-point)
     - Viscosity of bulk surfactants
     - pH
   - Polymer quality
     - Viscosity plots
     - Filterability

2. Injection Solutions
   - Alkali-polymer solutions
     - Viscosity
     - Filtration ratio
     - pH
   - Alkali-surfactant-polymer solutions
     - Interfacial tension against crude oil
     - Viscosity
     - Filtration ratio
     - pH
5. Next step. Field implementation
cEOR project following steps

- Pilot cEOR history matching
- Full field calibration with pilot and lab results
- Identify viability of Phase 1 cEOR development in CCS
- Minimize geological risk by drilling appraisal wells
- Well planning & optimization
- Produce incremental forecasts for Phase 1 EOR
- Detailed costing of Phase 1
- Detailed Economic Evaluations
5. Next step. Field implementation

Field Implementation. Phase I definition

- Pool C was defined as target for cEOR Phase I application based on the following criteria:
  - OOIP and current recovery factor
  - Estimated remaining oil at cEOR injection initiation (2018) and expected remaining oil at End of License (2029)
  - Selection of two main reservoirs (C7-A and C7-2) to be developed commingled
  - Well density and current pilot present
  - Production facilities

- Eight subsurface cEOR development scenarios were defined and evaluation is ongoing

- Preliminary Results indicate ~20% incremental RF of the cEOR development

- Some wells included in the Phase I development are part of the actual field development and will be used for geological de-risking
Thank you
Merci beaucoup
Gracias