GAS INJECTION IN CUSIANA & CUPIAGUA FIELDS

COLOMBIAN FOOTHILLS

by FABIAN A. TORRES

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12/08/16

Preliminary Note on Intellectual Authorship

This brief presentation about gas injection experience in some fields of Colombian Foothills evidence teamwork, participation and interaction of several professionals for over 20 years (1994 - 2016), actively involving:

Fluid Characterization:

1. Raul Osorio Gallego - PVT and Fluids Characterization, Ecopetrol
2. Sheng-Tai Lee* - PVT Expert, British Petroleum
3. Professor Curtis H. Whitson - Consultor, Norwegian University of Science and Technology
4. Professor Ali Danesh* - Consultor, Heriot-Watt University
5. Proffessor Abbas Firoozabadi - Consultor, Yale University - RERI
6. Wilson Barrios - Former PVT Lab Leader, ICP

Development Strategy and Operation:

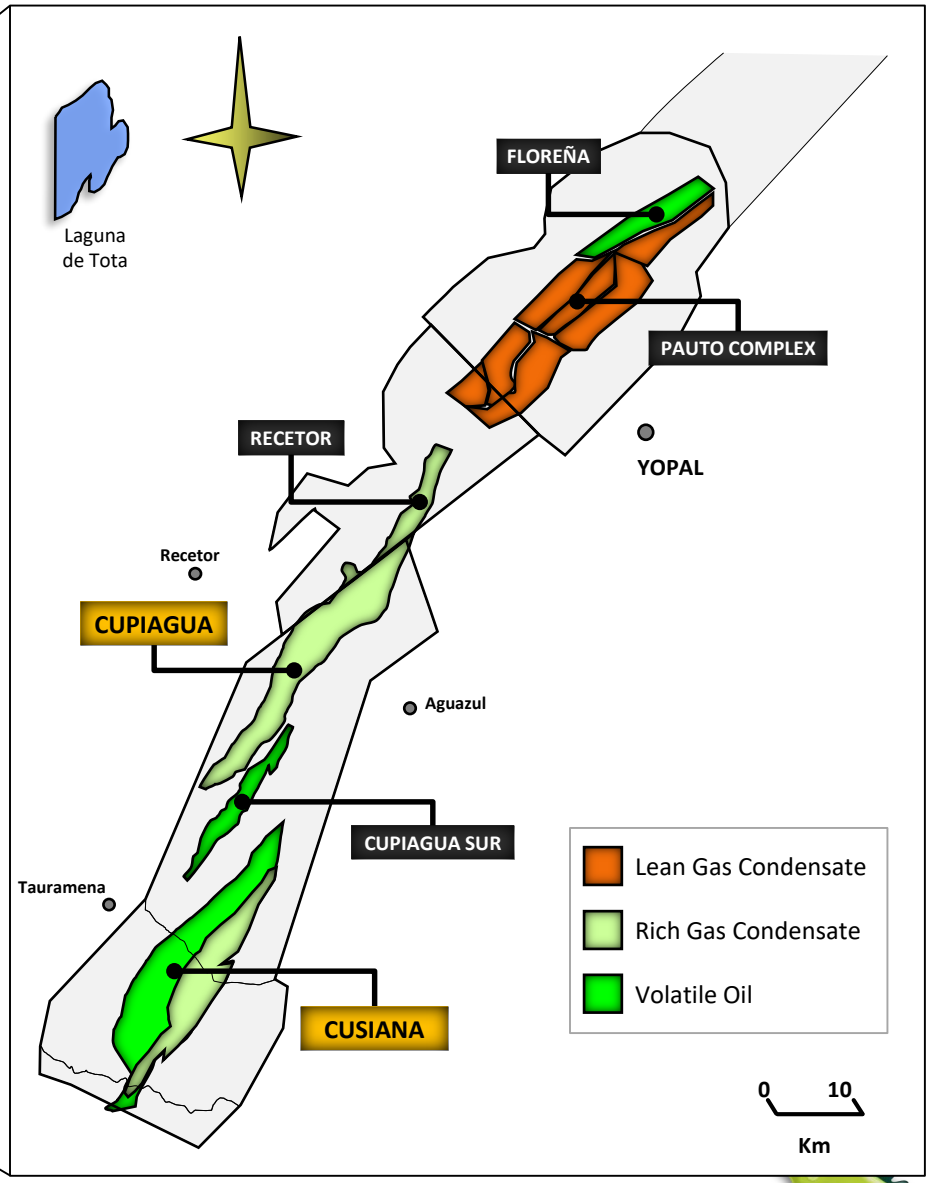
1. British Petroleum Company: BP Exploration Company Colombia - BP Energy Company Colombia
2. Equion Energía
3. Ecopetrol S.A

* R.I.P.

Outline

- ✓ General Information
- ✓ Data Acquired
- ✓ Wells, Lines & Gas Process Facilities
- ✓ Strategy
  - Gas Injection Optimization
  - Results
- ✓ Main Challenges - Lessons Learned

General Information - Location

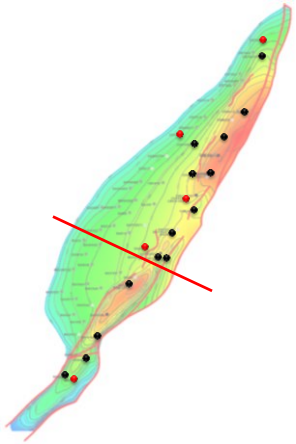


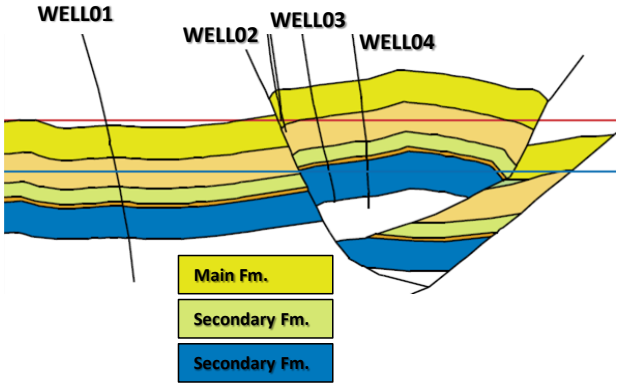
- Casanare, Colombia
- 175 Km northeast from Bogotá
- Foothills of Colombian Andes

General Information

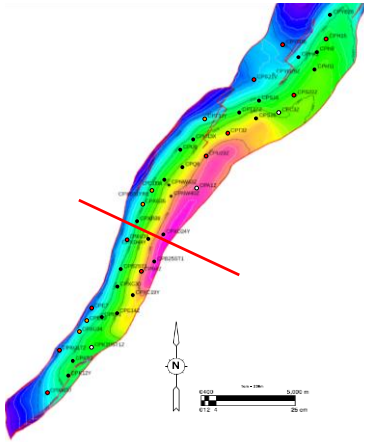
- ✓ Three naturally fractured sandstone reservoirs (main + 2 secondary layers)
- ✓ Asymmetric tight anticline NE-SW elongated
- ✓ Commingled production / injection
- ✓ Average depth = 12500 ft / 13000 ft (TVDss)
- ✓ Structurally complex reservoirs:
  - Thrust faulting
  - Imbricate inverse faults
  - Minor intra reservoir faults
- ✓ Fluid system: volatile oil + rich condensate gas cap / rich condensate gas
- ✓ Average initial reservoir pressure: 5900 psia @ 12950 ft TVDss / 6500 psia @ 12950 ft TVDss
- ✓ Reservoir temperature: 240 - 300 °F
- ✓ Reservoir permeability: 0.1 - 300 mD
- ✓ Reservoir porosity: 2 - 12 %
- ✓ **Early secondary recovery via lean gas miscible reinjection as main production mechanism**

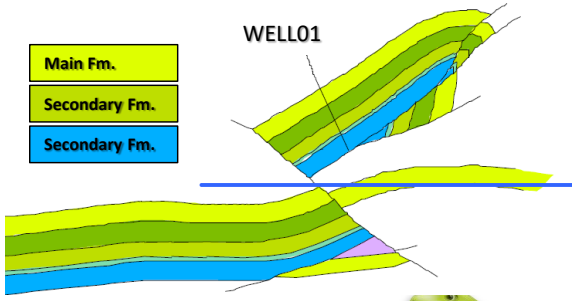
Cusiana Structure



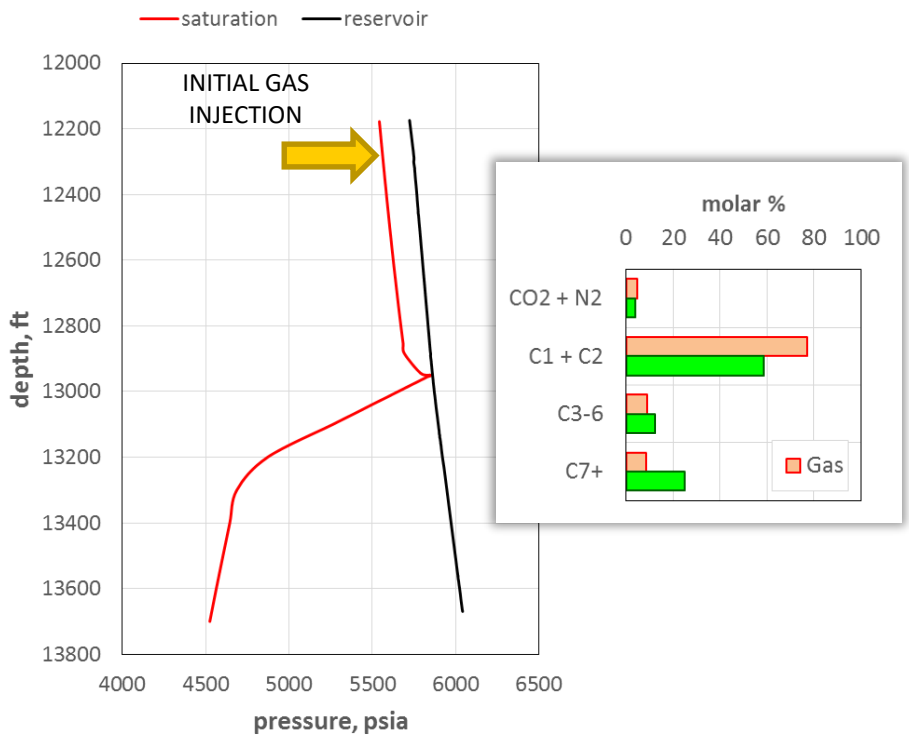


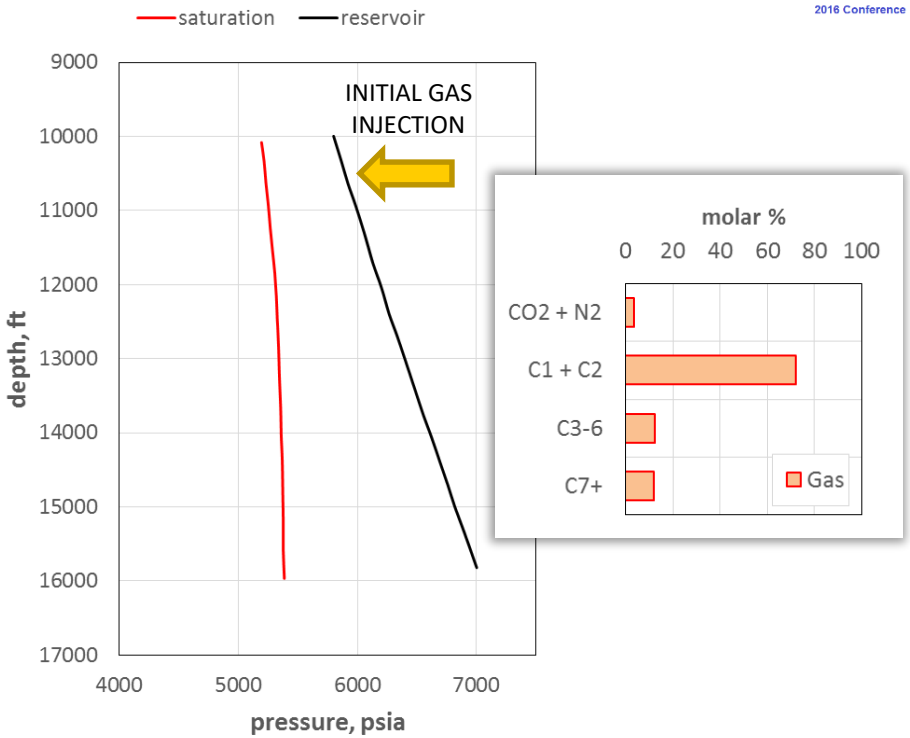
Cupiagua Structure





General Information - Fluid Systems





- ✓ Volatile oil + rich gas cap (170 - 200 STB/MMSCF)
- ✓ Relatively small near critical transition zone (≈ 100 ft)
- ✓ High compositional variation (150 - 700 stb/scf)
- ✓ Early crestal injection in main reservoir / late crestal injection in secondary reservoirs.
- ✓ 31 - 40 API, 0.4 - 0.5 cp @ reservoir conditions

- ✓ Very rich gas condensate (220 - 312 STB/MMSCF)
- ✓ Near critical fluid over 6000 ft. HC column
- ✓ Small compositional variation.
- ✓ Early crestal injection in main reservoir / late crestal injection in secondary reservoirs.
- ✓ 40 - 45 API, 0.2 - 0.5 cp @ reservoir conditions
- ✓ **Unique fluid system in the world!**

General Information - Fluid Systems

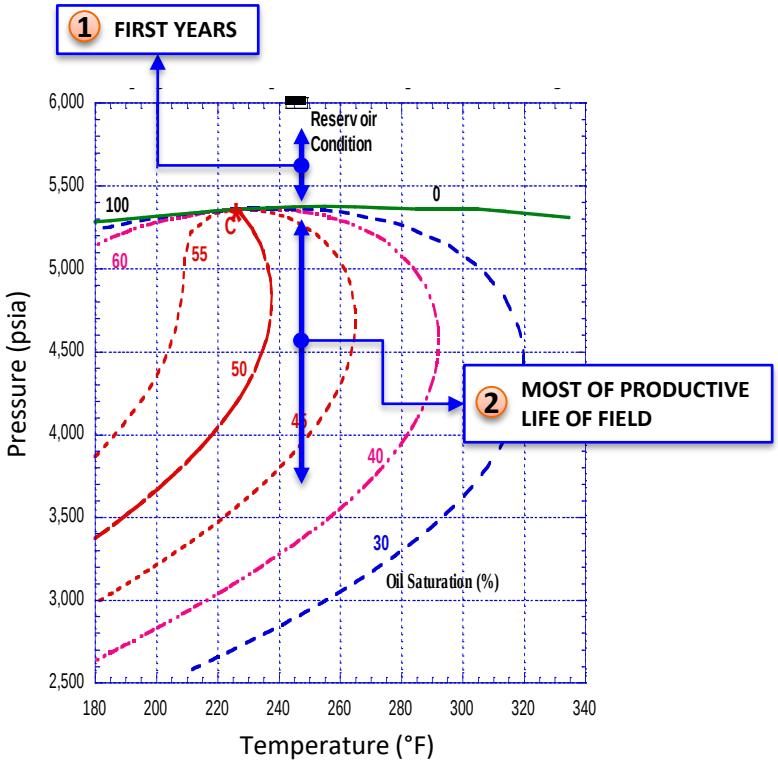
Maximum liquid recovery from gas cap and oil leg will be achievable through considerable gas reinjection and recycling. Process enhanced by:

CUSIANA

- ✓ Swelling due to gas solubility above MMP.
- ✓ High reservoir temperature and pressure will contribute to condensate revaporation below MMP.
- ✓ Partial pressure maintenance depending on areal gas injection distribution.

CUPIAGUA

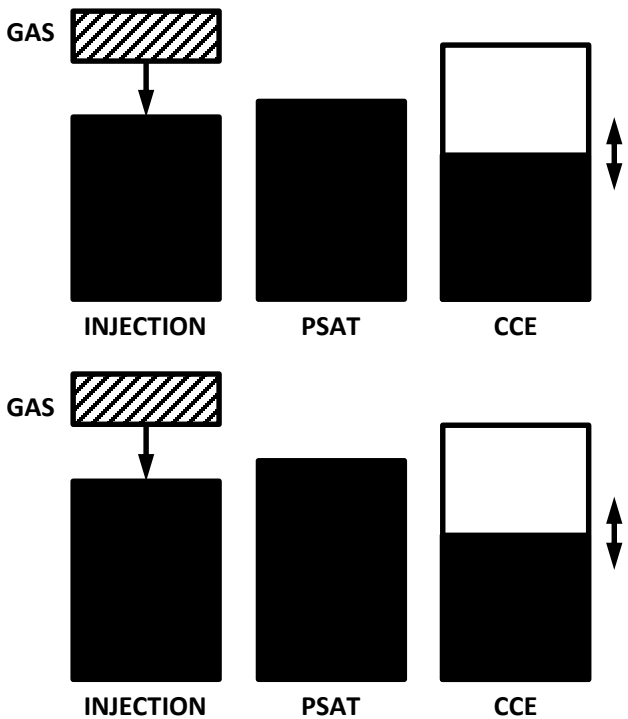
- ✓ First contact miscibility above Psat. 1
- ✓ Below Psat, high reservoir temperature and pressure will contribute to condensate revaporation in contact with reinjected gas through multiple contacts. 2
- ✓ Partial pressure maintenance depending on areal gas injection distribution.



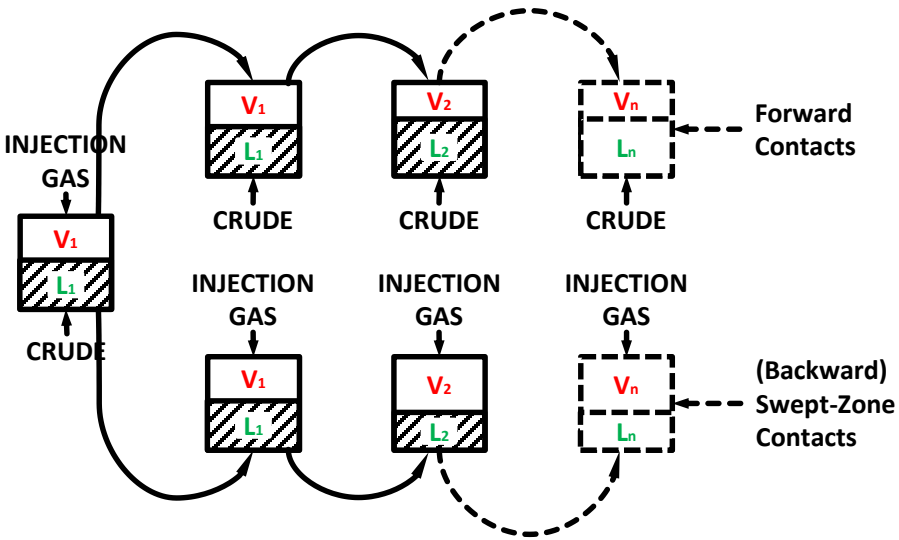
Data Acquired - Key PVT Testing

Main miscibility processes driven by gas/liquid mass transfer trough swelling (above MMP) and revaporation (below MMP)

SWELLING TEST*



MULTIPLE CONTACT TEST* (forward/backward)

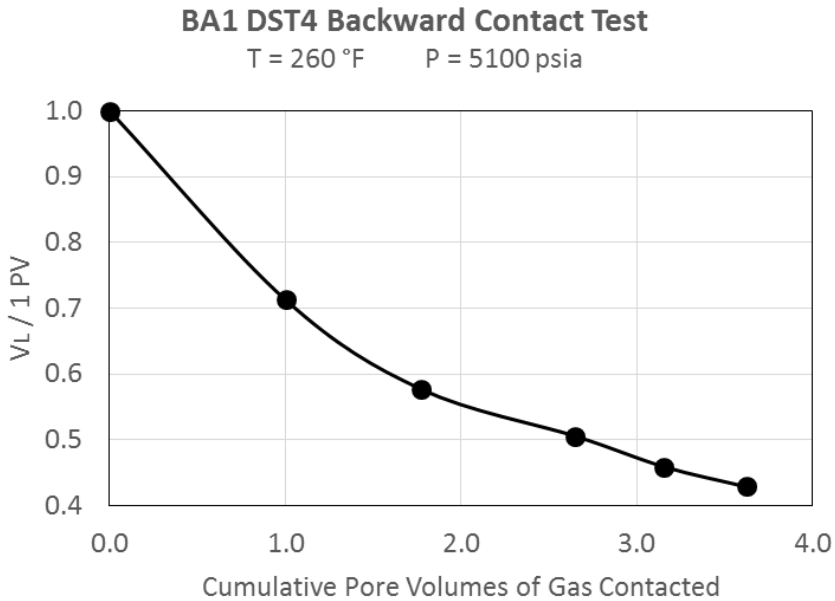


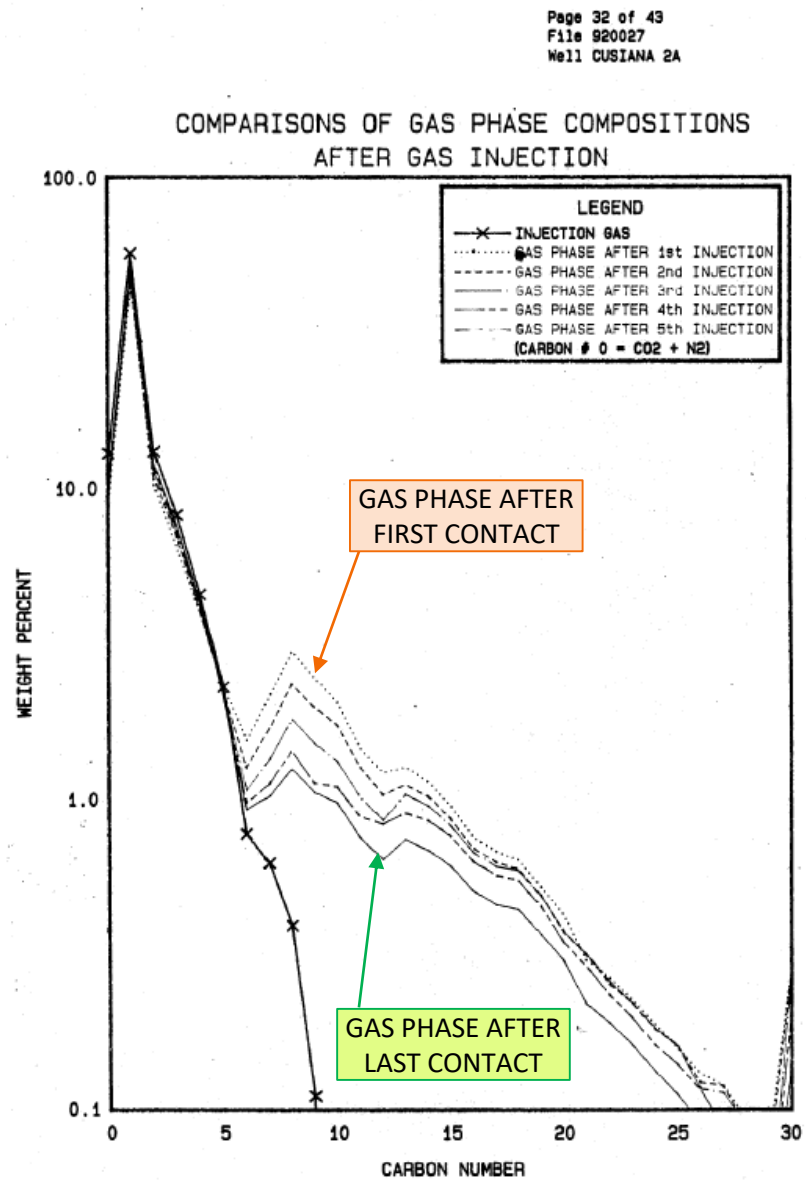
Some adaptations needed to better understand related processes (e.g. adapted backward multiple contact test for oil revaporation, Vogel and Yarborough - 1980).

* From: Phase Behavior - C. Whitson, M. Brulé

Data Acquired - Key PVT Testing

Multiple Contact Test in Cusiana



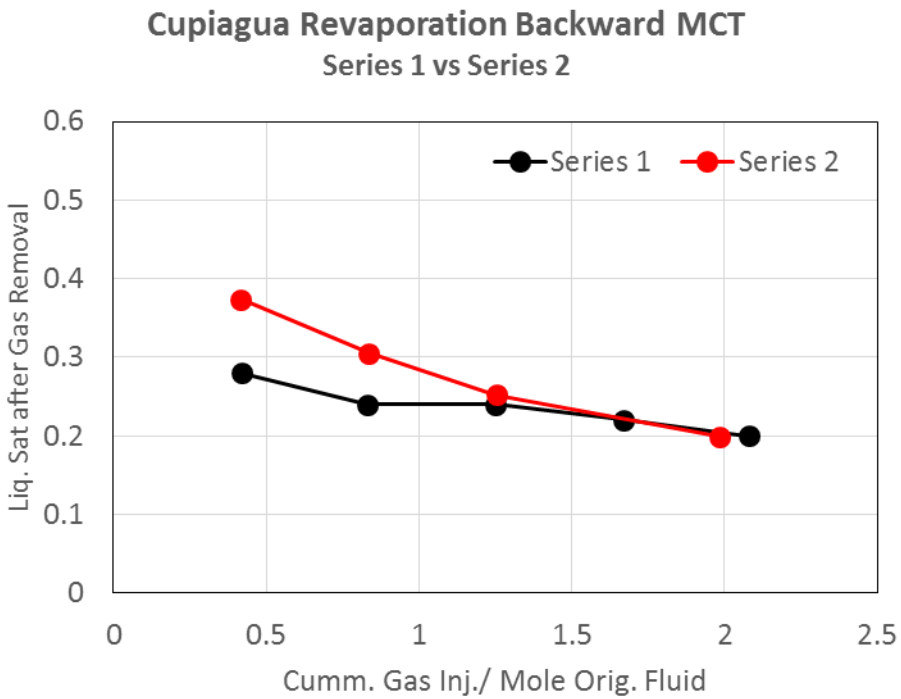


- ✓ Backward test better describes involved phenomena.
- ✓ MCT shows high efficiency at initial contacts.
- ✓ Process efficiency (≈60%) must be adjusted by sweep and areal efficiency to get maximum theoretical incremental volumes.

Cusiana backward MCT results

Data Acquired - Key PVT Testing

Multiple Contact Test in Cupiagua

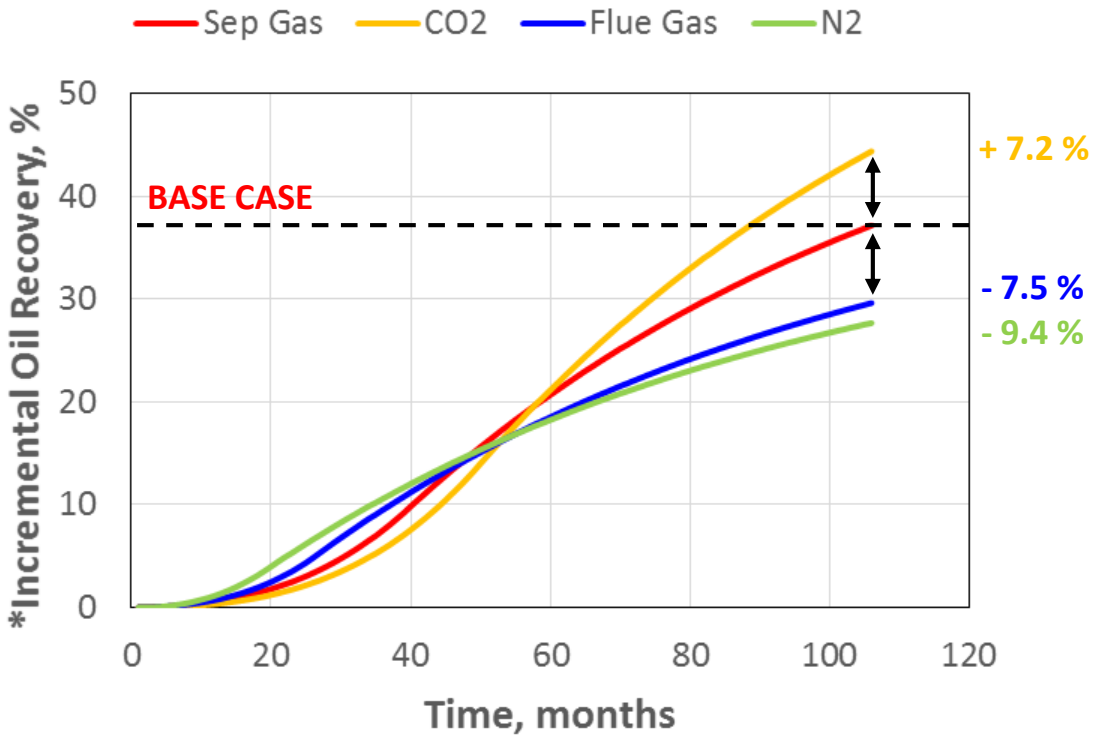


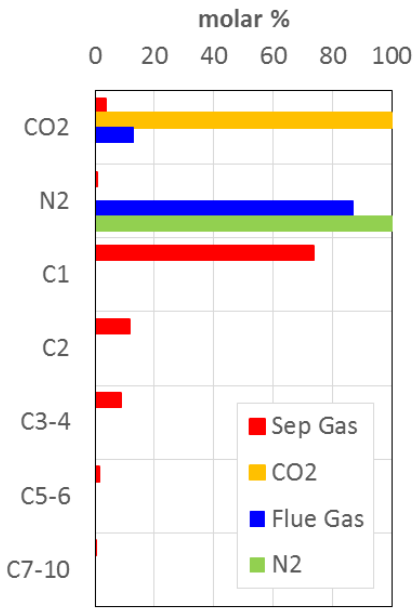
	Gas Injection Step	Pressure	Cumm. Gas Inj./ Mole Orig. Fluid	Liq. Sat after Gas Removal
Series 1	0	6000		
	1	5400	0.42	0.28
	2	4920	0.83	0.24
	3	4580	1.25	0.24
	4	4300	1.67	0.22
	5	4150	2.08	0.2
Series 2	0	4750		0.4838
	1	4750	0.417	0.374
	2	4750	0.835	0.305
	3	4750	1.252	0.252
	4	4750	1.9827	0.199

✓ Two different test configurations in order to completely understand revaporation phenomena:

- Series 1: pressure depletion + constant volume (not common).
- Series 2: constant pressure + constant volume.

Injected Gas

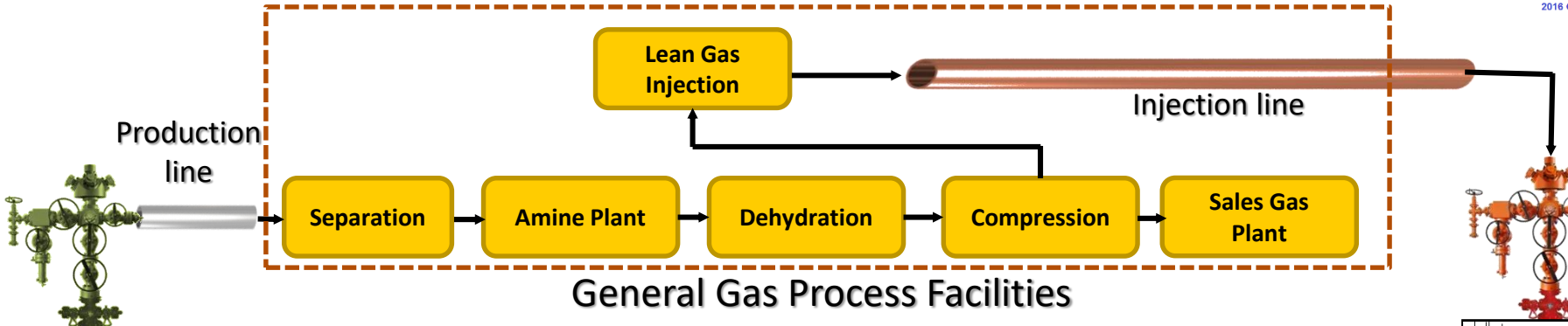




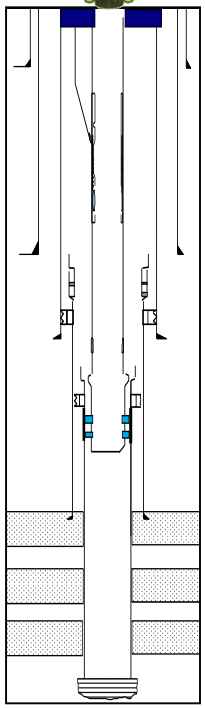
- ✓ Injected gas corresponds to dehydrated separator gas
- ✓ Other gases used for sensitivity purposes
- ✓ No N2 or CO2 available for economically feasible EOR application

*Results from compositional numerical simulation model

Wells, Lines & Gas Process Facilities



General Gas Process Facilities



Typical Producer Well Schematic

- ✓ Due to commingled production and injection, completions must be designed for easy GSO/WSO, PLT/ILT etc.
- ✓ Easily converted depending on pad facilities availability.
- ✓ Maximum flexibility pipes to optimize gas injection strategy.
- ✓ Modular design will allow special adaptability to production/injection evolution and availability. Optimization function:

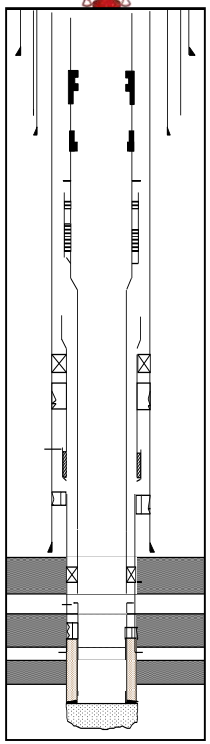
STAGE I

Production – Injection = Flare & Consumption

STAGE II

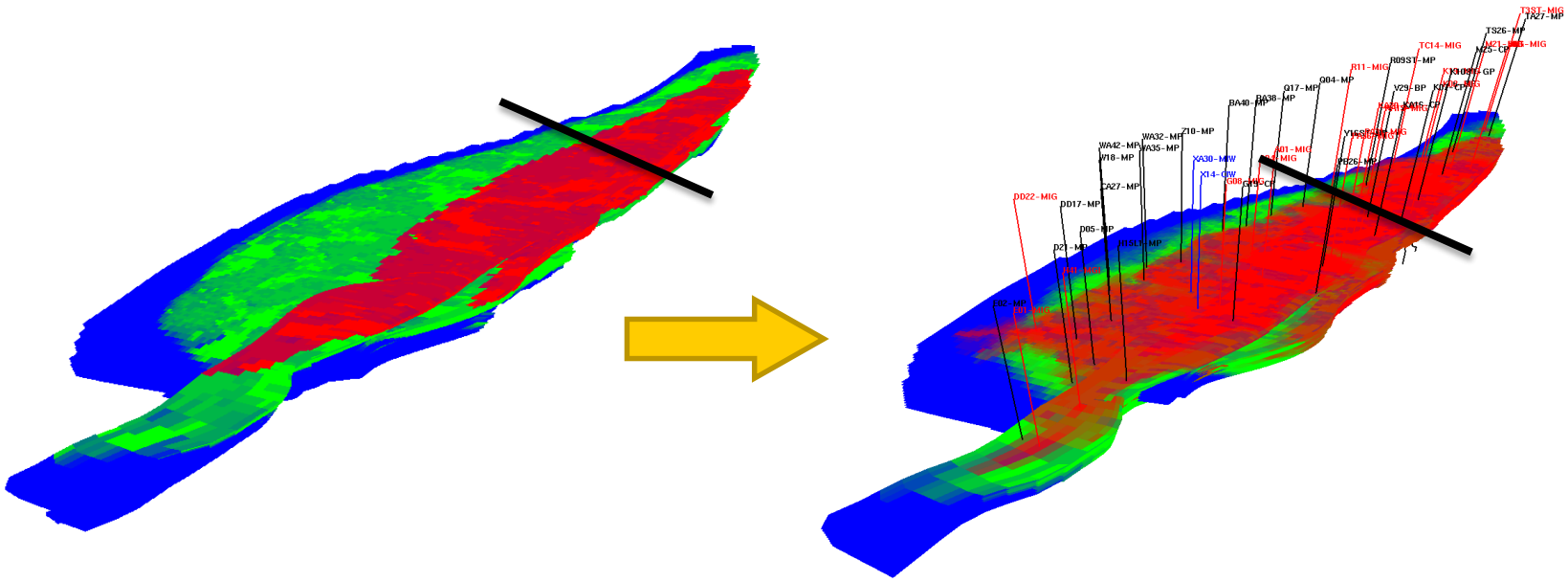
Production – Injection = Flare & Consumption + LPG/NGL + Gas Sales

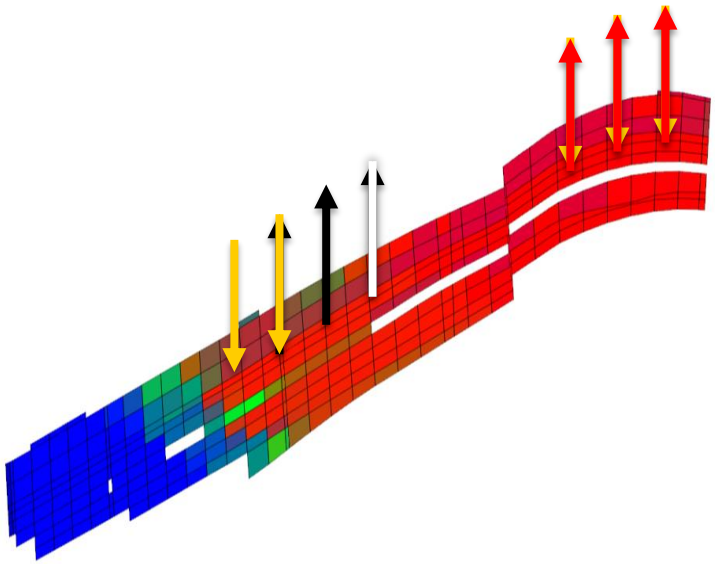
- ✓ **KEY POINT:** The overall architecture was designed taking into account long-term vision to guarantee the change of strategy: STAGE I ➔ STAGE II, avoiding extremely expensive future modifications.



Typical Gas Injector Schematic

Strategy





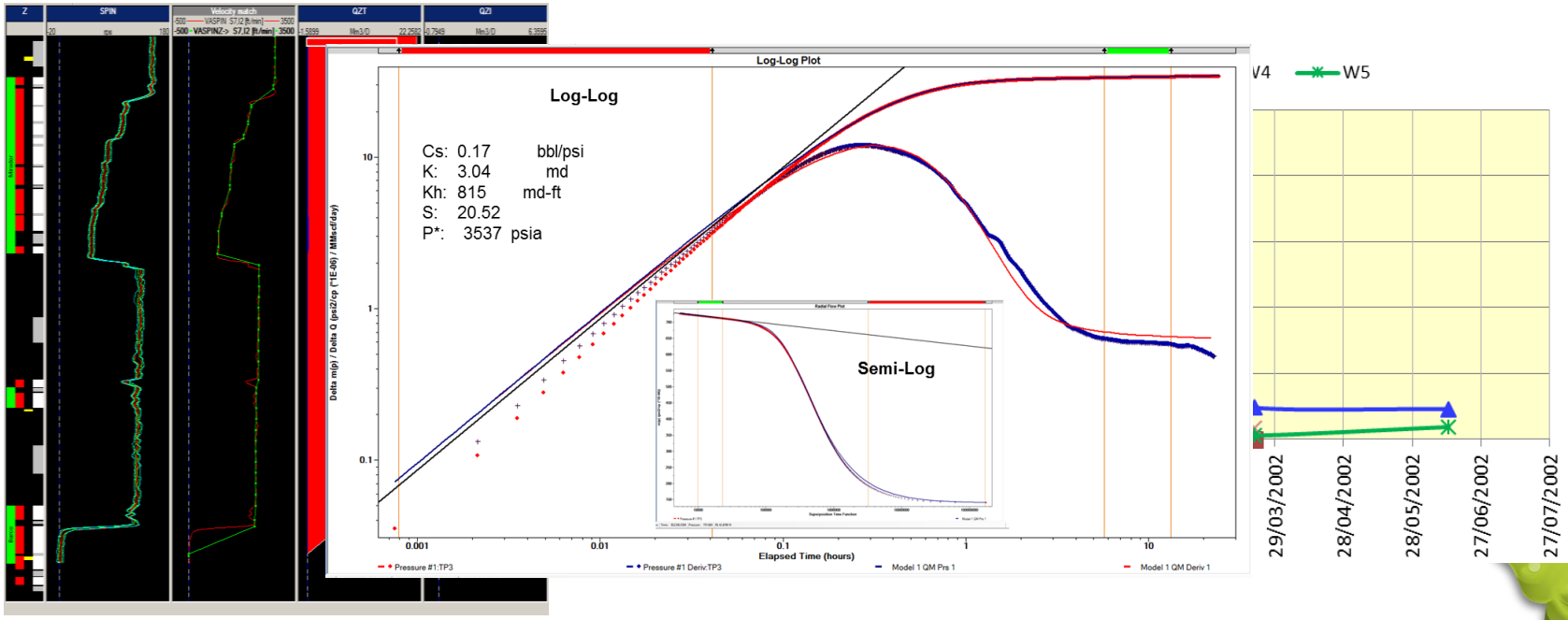
1. Crestal reinjection for gas cap expansion + flank / middle flank oil production.

2. Flank reinjection + middle flank recycling wells closed.

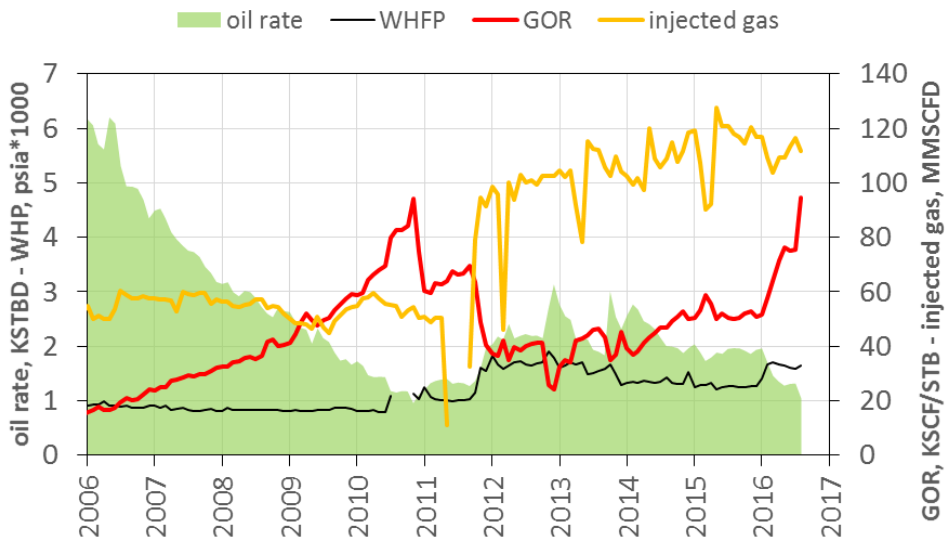
3. Flank producer wells converted to injectors + Middle flank producer wells reactivation + gas cap blowdown.

Gas Injection Optimization - Surveillance Data

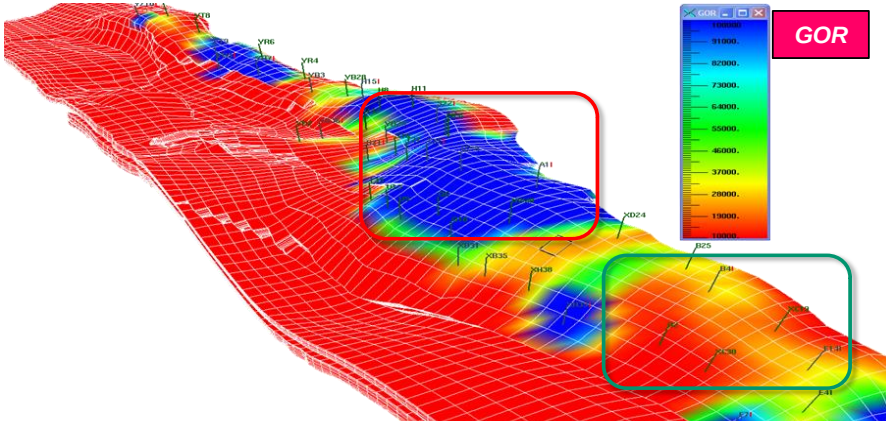
SURVEILLANCE ALTERNATIVE	DIAGNOSED ISSUES	SUBSEQUENT ACTIVITY
WT Real Time WHT / WHP / inj rates	Gas recycling	GSO / Foams
	Lifting problems	CTGL / AutoGL / WSO
PLT / ILT Tracers	Crossflow	WSO / partial isolation
	Unefficient gas injection conformance	Foams / sand plugs / DH choke
	Injectivity problems	Hydraculic fracturing / Gas dispersible CHS / TTRD
	Compartmentalization	Numerical and analytical model updating History match tuning
	Flow barriers	
	Low / High transmissibility zones	
PBU / PFO / Static	Skin damage	Hydraculic fracturing / Gas dispersible CHS / TTRD
	Injectivity problems	

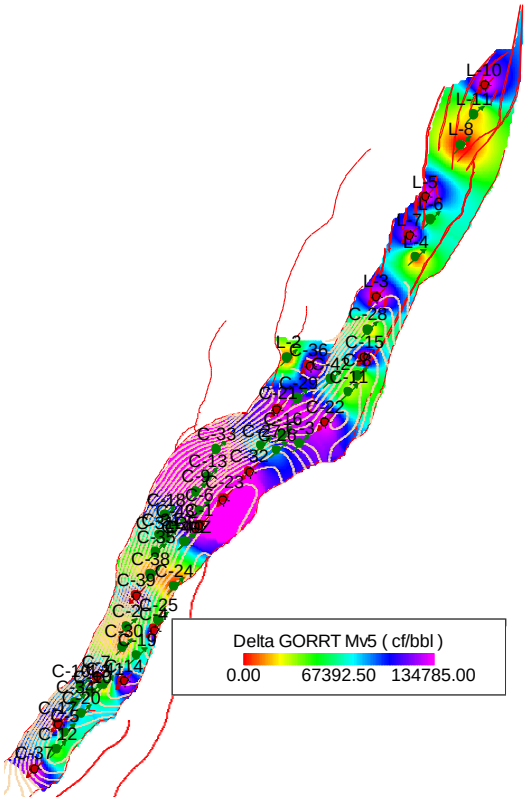


Gas Injection Optimization - Analysis & Diagnosis



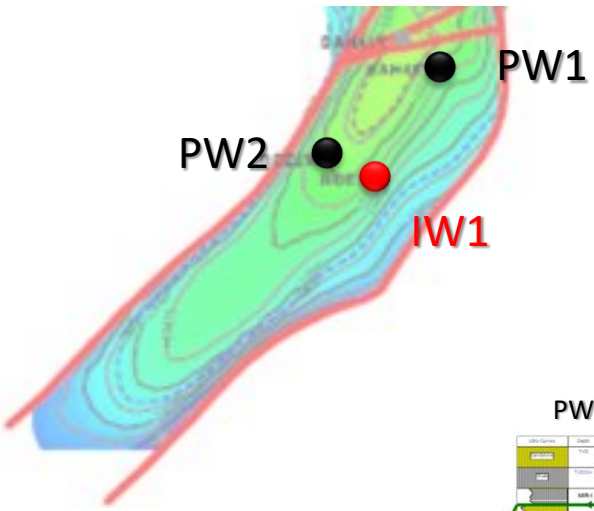
- ✓ Recycling pattern identification
- ✓ Real GOR vs depletion GOR (or yield)
- ✓ GOR as process tracer

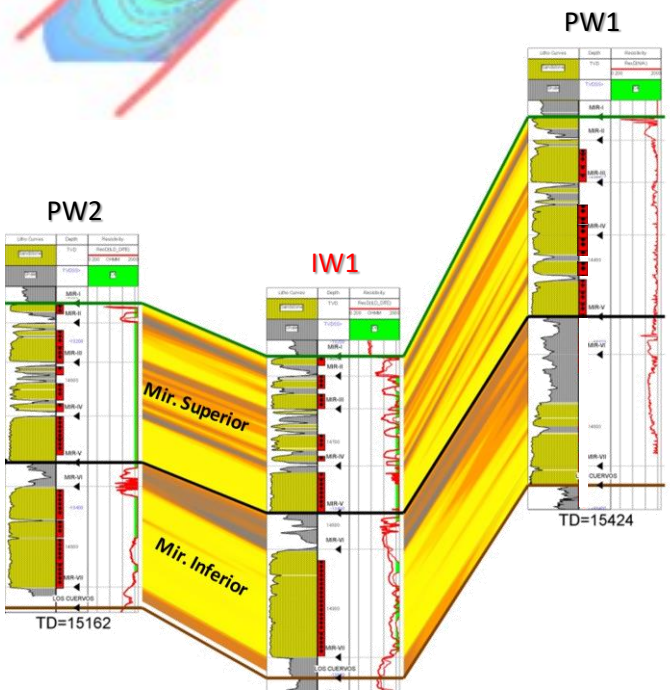


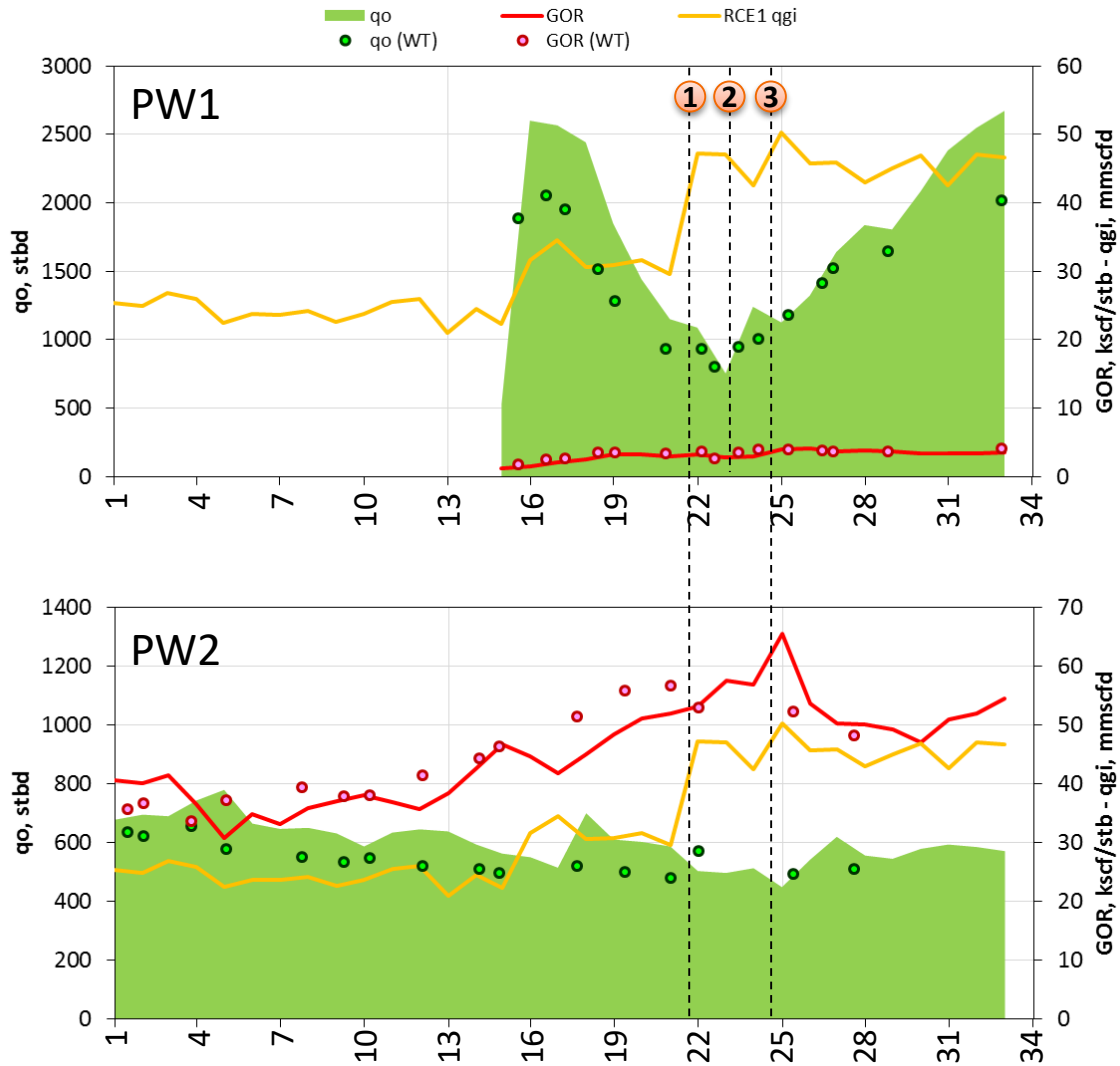


Gas Injection Optimization

1. 50 mmscfd
2. Asphaltene dissolution at reservoir level
3. Partial GSO







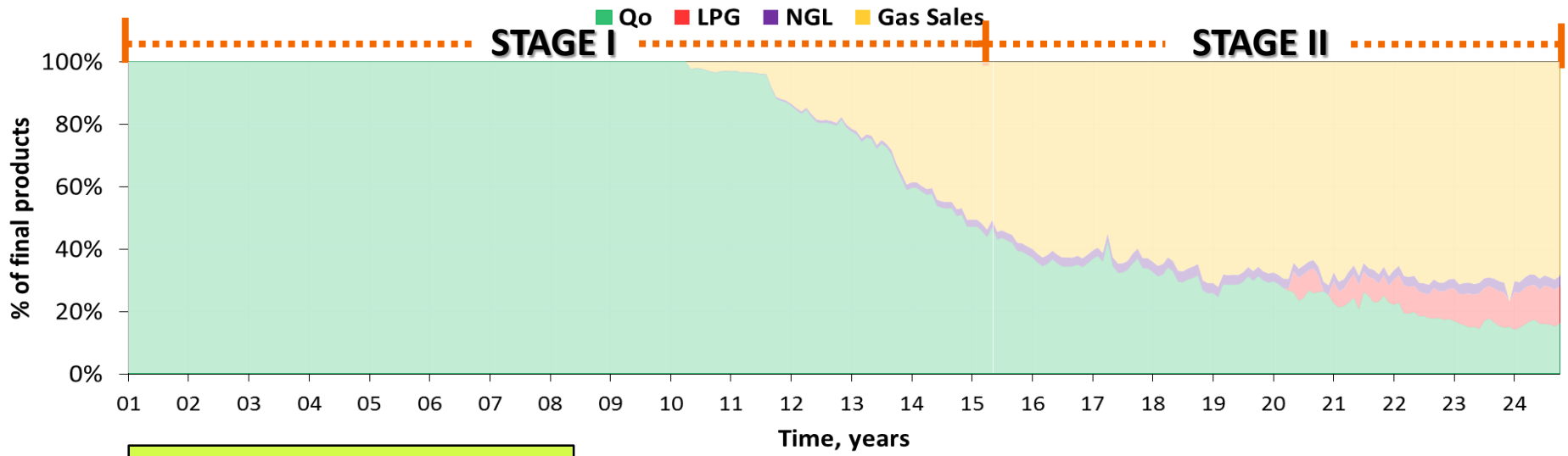
✓ *Asphaltene + recycling + conformance = inefficiency.*

Strategy

The development of the fields has been carried out in two stages:

Development focused on early secondary oil recovery

Development focused on gas recovery



Drilling campaign +
Crestal lean-gas injection

Crestal lean-gas injection optimization + gas sales start-up

Lean-gas injection at flank and mid-flank + Gas inj at secondary Fm

Higher Gas sales + LPG/NGL generation

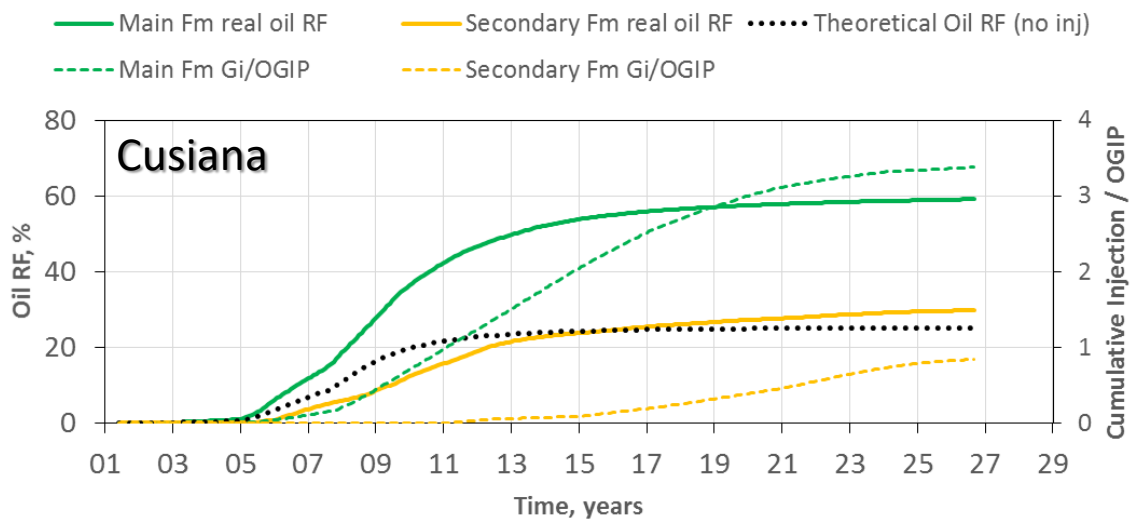
Blowdown

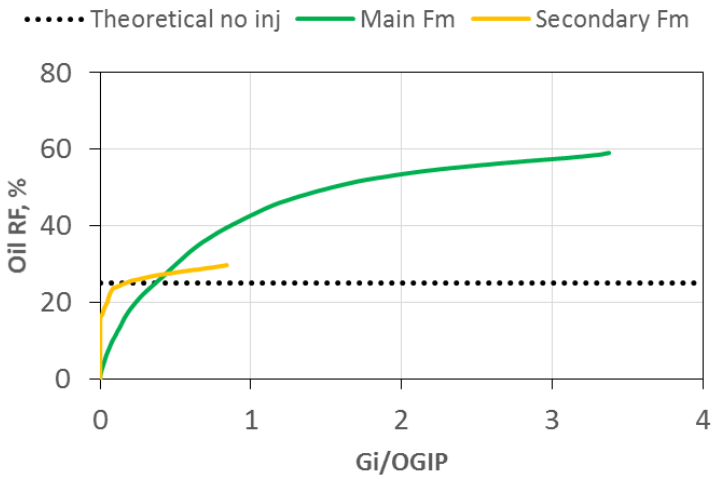
Fluid Expansion

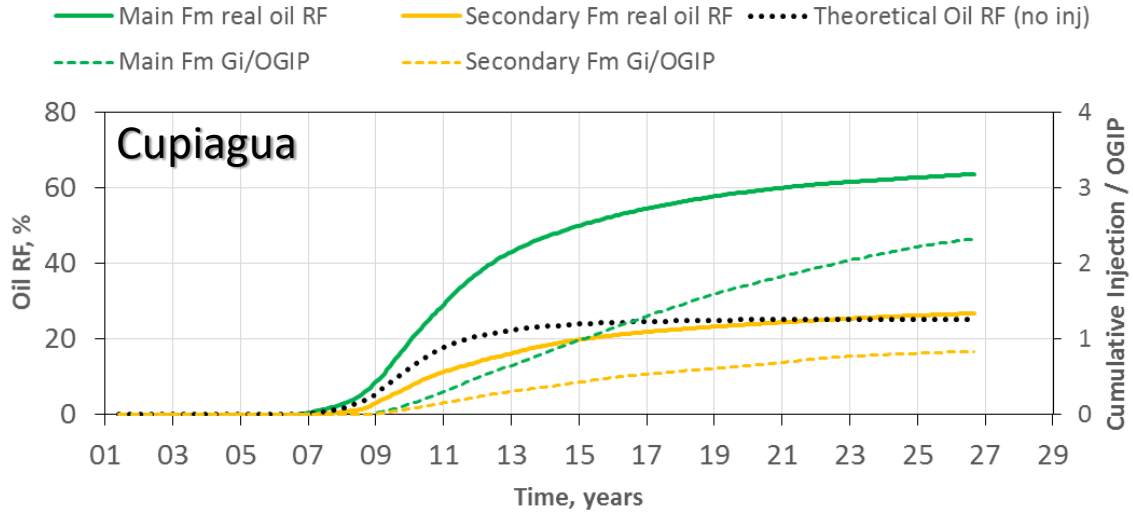
Multiple Contact Revaporation

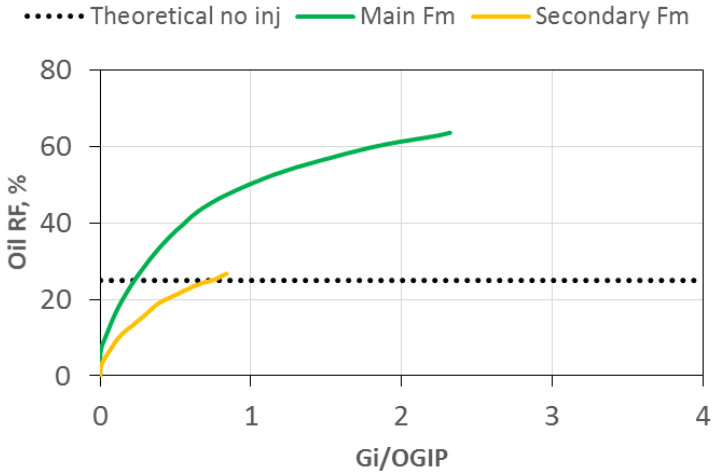
Miscible Lean Gas Reinjection

Strategy Results









Main Challenges - Lessons Learned (Stage I)

- ✓ For Cusiana and Cupiagua fields, fluid system detailed understanding and their response to miscible gas reinjection implies understanding of over 70 % of total process, hence the importance of a correct PVT test design and EoS calibration.

- ✓ A good process understanding, associated efficiencies, heterogeneities and reservoirs dimension, makes it possible to identify areas in which optimal recovery can be reached. Prioritization strategies if required.

- ✓ A rigorous monitoring strategy based on identifying deviations from theoretical behavior allows for optimization measures even at early stages.

- ✓ A complete field development plan containing detailed strategies for each production stage will lead to optimal wells, flow lines and processing facilities design focused on cover most of the assets life. This way, investments can be efficiently apply reducing mid or late term additional CAPEX utilization.

ecopetrol

ENERGÍA PARA EL FUTURO