

# Hydrocarbon Solvent Injection Study for Heavy Oil Recovery in the Colombian Oil Sands\*

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## Abstract

There are huge, well-known resources of heavy oil, extra-heavy oil, and bitumen in Canada, Venezuela, Russia, USA, and many other countries, including Colombia. Historically, over the past 10 years, the Colombian Llanos basin has been the main source of oil and gas production in the country. Currently production from heavy oil sands in this basin are about 700 thousand barrels of crude oil; which represents over 70% of the country's production, and more than 500 million cubic feet of natural gas. Therefore, successful heavy oil technologies deployment in the Colombian Llanos Basin will represent a key factor for the Oil & Gas Industry to increase the recovery factor and the country's production in the nearest future.

Up to 80% of estimated heavy oil, reserves could be recovered by in-situ thermal operations. Sophisticated technologies have been required to economically develop complex and varying oil fields (Nasr and Ayodele, 2005). To achieve this goal efficient techniques using steam combined with appropriated hydrocarbon solvents resulting in a most cost-efficient recovery process. Equion Energia Limited is currently conducting a study to define a singular opportunity that can be developed in the east of Colombia, where reach gas reservoirs discovered near the big heavy oil accumulations can provide plenty of solvents (LPG) for enhanced recovery of heavy oil. Thus, a clear synergy between the heavy oil and the light hydrocarbon solvents resources becomes evident.

In most cases, viscosity reduction is the one common element of in-situ methods of heavy oil recovery with the exception of cold production. Currently, steam assisted gravity drainage (SAGD) and cyclic steam stimulation (CSS) are being used commercially in the field where the oil's viscosity is reduced by injecting steam. Thermal methods are energy intensive requiring vast volumes of water such that any improvement would be beneficial. Solvent extraction is one alternative requiring no water, the solvent is recoverable and reusable, and depending on the mode of operation, the heavy oil is upgraded in-situ. Vapour Extraction (VAPEX) and enhanced solvent extraction (N-Solv™) are two such methods. VAPEX and N-Solv reduce the bitumen's viscosity via mass transfer and a combination of mass and heat transfer, respectively. A light hydrocarbon solvent (instead of steam) is injected into an upper horizontal well where the solvent mixes with the heavy oil, reduces its viscosity and allows the oil to drain under gravity to a bottom production well.

This work presents numerical simulation studies; supported by laboratory experiments results, conducted in order to evaluate the technical feasibility of Equion's solvents coming from Cusiana's LPG Plant as vaporized hydrocarbon solvents for heavy oil extraction in the Colombian Oil Sands. A mechanistic model was built in CMG-STARs to understand the production behavior in heavy oil under a hydrocarbon solvent injection process, based on petrophysical and fluid properties typical from the Colombian Oil Sands. Cold productions, cyclic hydrocarbon solvent injection, solvent-aided CSS among others cases, were studied regarding the key variables in this kind of process: steam-injection rate, oil-production rate, oil-recovery factor, solvent-retention rate, fluid-saturation distribution, and temperature distribution.

### **Reference Cited**

Nasr, T.N., and O.R. Ayodele, 2005, Thermal Techniques for the Recovery of Heavy Oil and Bitumen: Society of Petroleum Engineers, doi:10.2118/97488-MS.

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Rodolfo J. Marin  
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December 2014

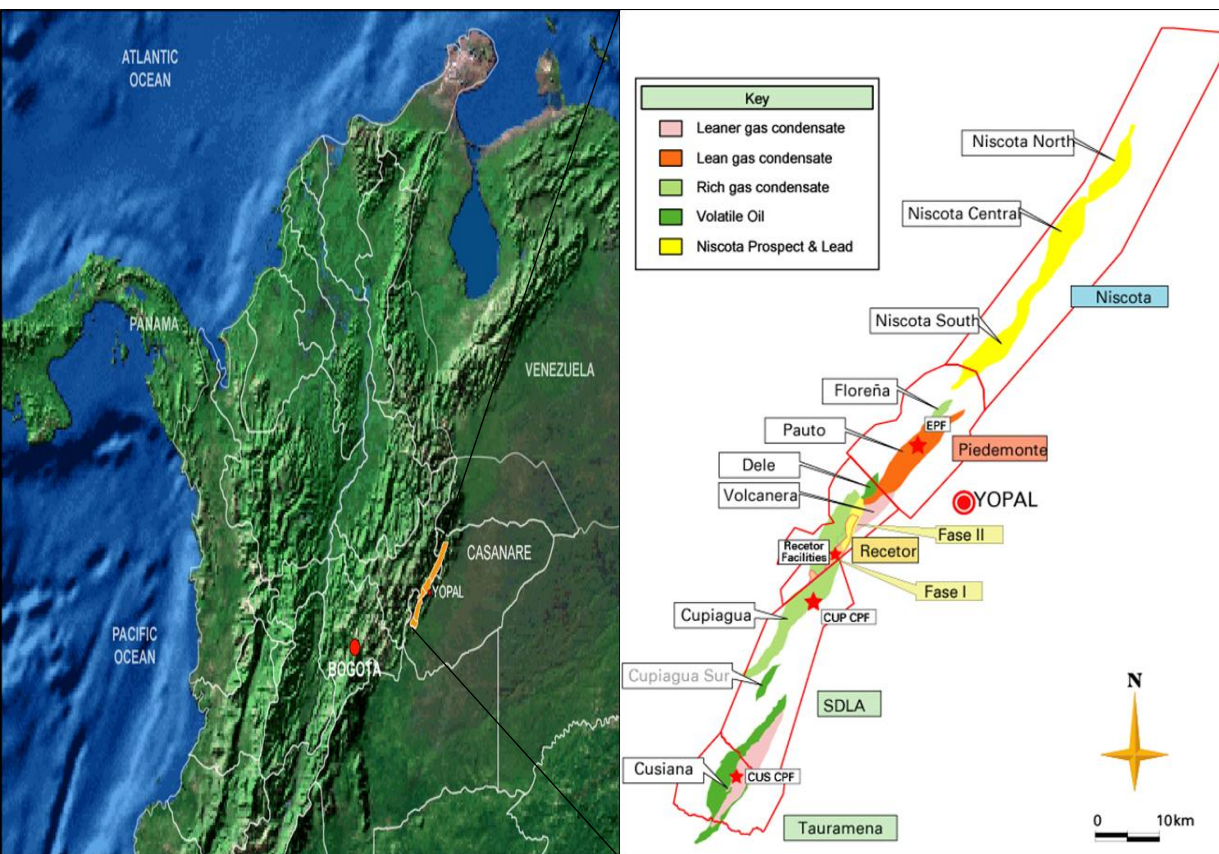
- Objectives
- Equion Energia Limited - Operations
- Colombia Oil Sands – Llanos Basin
- Oil Recovery Factor Evolution in Heavy Oil Fields
- Hydrocarbon Solvent Injection – VAPEX Process
- VAPEX Configurations
- Applicability of the Solvent Injection in the Llanos Basin
- Conclusions
- Questions



# Equion Energia Limited - Operations

## EQUION ENERGIA LIMITED

Equion is a former BP branch established in Colombia in 1986 (BP Exploration Company), whose shareholders from January 24, 2011 are Ecopetrol SA (51%) and Talisman Energy Inc. (49%). For over 27 years Equion has explored and exploited hydrocarbons in the Colombian Foothills, operating 5 partnership contracts: Niscota, Piedemonte, Recetor, Tauramena and Rio Chitamena.

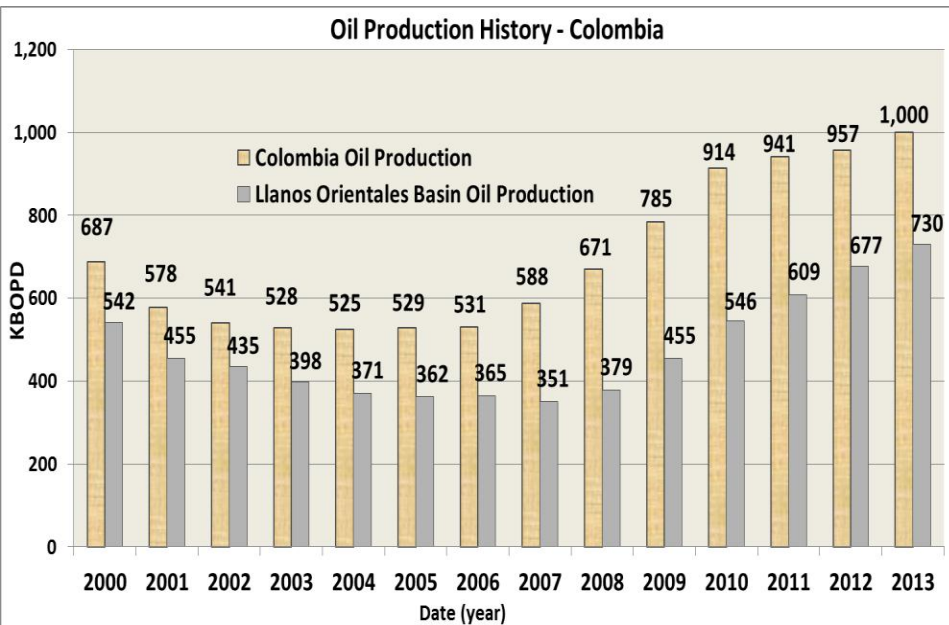


### EQUION Avg. Production:

- Oil: 40,000 bbl/day
- Gas: 850 MMscf/day
- **LPG: 7,500 bbl/day**
- **NGL: 2,200 bbl/day**

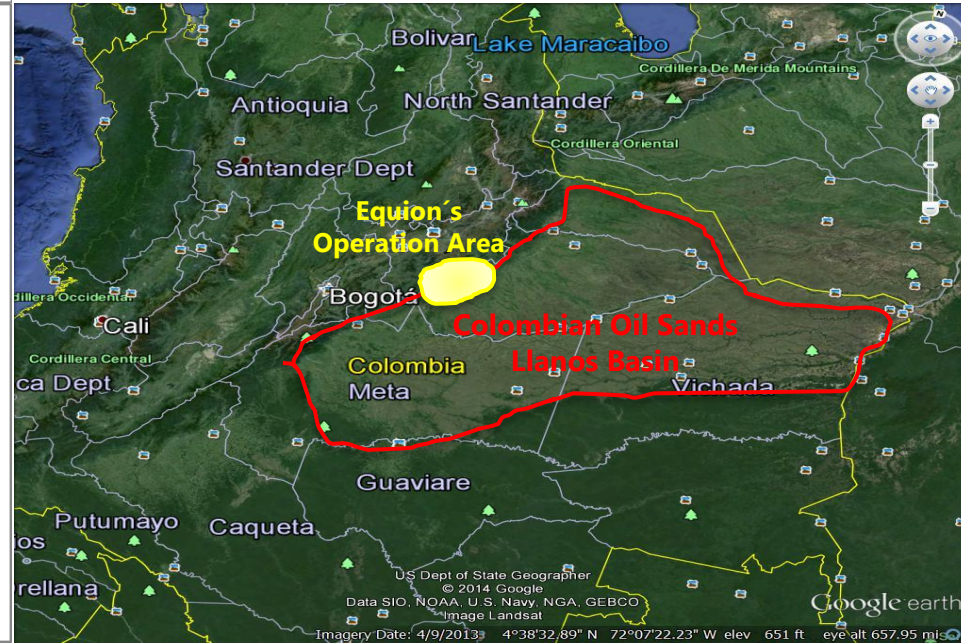
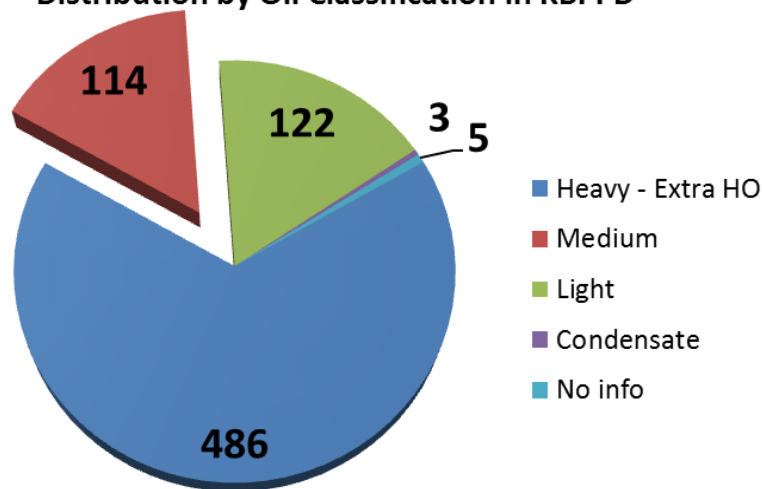
**Potential to increase liquid extraction up to 30,000 bbl/day in LPG and 8,000 bbl/day in NGL**

# Colombia Oil Production – Recent History



- 70% of oil production in the country comes from heavy oil fields which require solvents. Colombia is using this solvents mainly for transportation some for lifting but the big potential in **recovery** is currently undeveloped.
- Big source of solvents in the heavy oil exploitation area is achievable. Equion is progressing a liquid extraction project to supply **100 mmstb** LPG and NGL resources.
- Based on NGL and LPG owned resources availability, and experience with miscible recovery mechanisms, VAPEX and solvent technology to allow additional recovery in the heavy oil business is of interest for Equion.

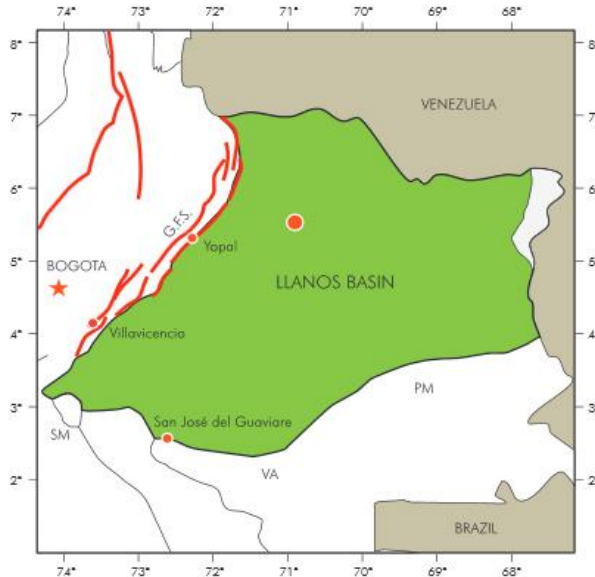
Llanos Orientales Basin Current Oil Production Distribution by Oil Classification in KBPPD



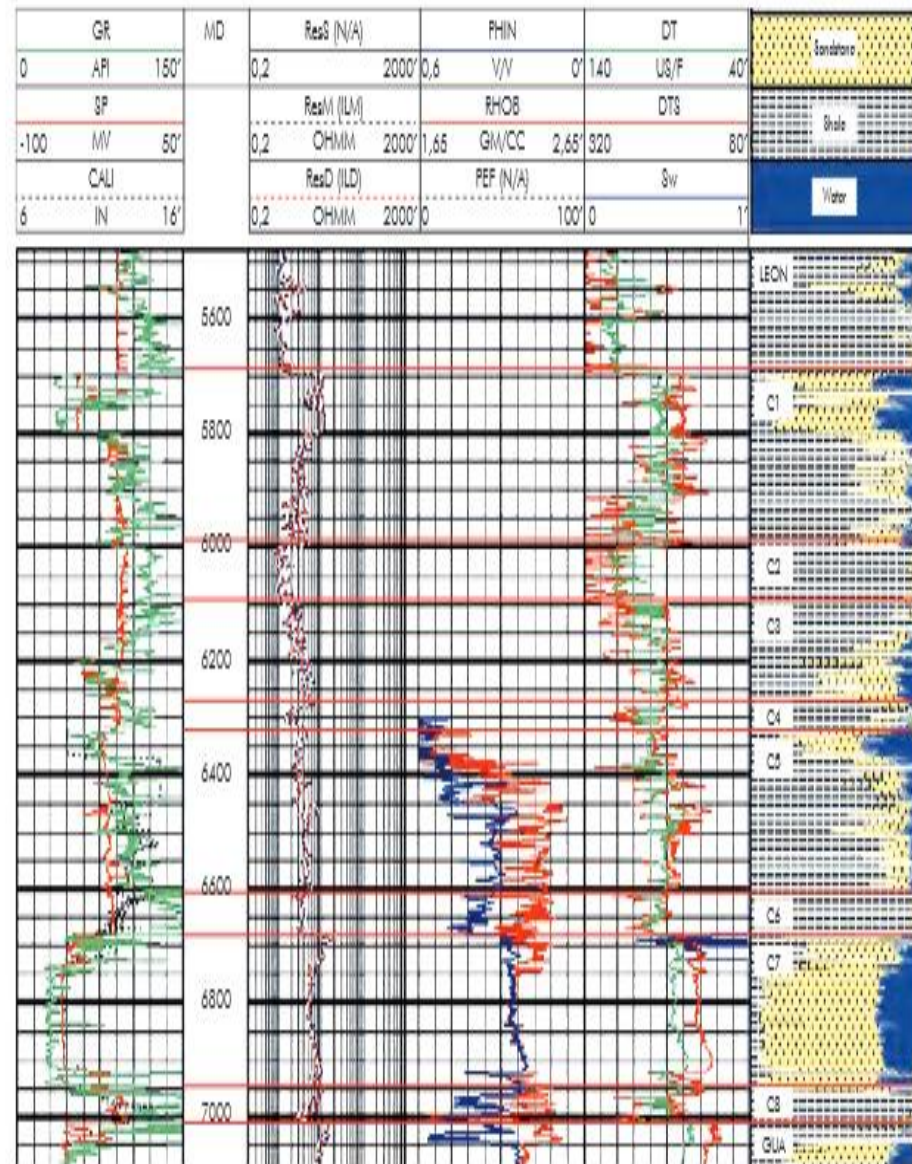
# Geological Aspects of Colombian Oil Sands



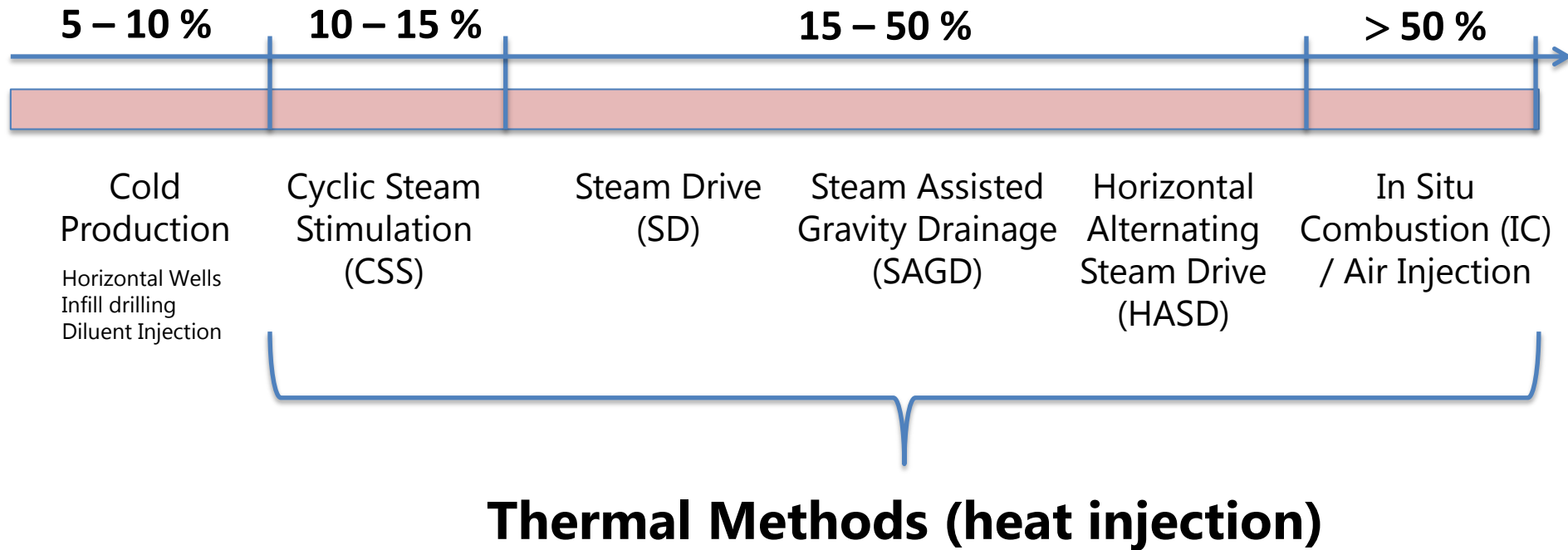
SM: La Macarena mountain range  
VA: Vaupés Arch  
PM: Precambrian metamorphic rocks  
GS: Guayana Shield



- The basin contains several heavy oil accumulations where production mainly comes from Oligocene Units (Carbonera Formation units C1 – C8).
- Carbonera Formation consists of sand layers (C1, C3, C5 and C7) and shale units (C2, C4, C6 and C8), which act as reservoirs and seals, respectively.
- The depositional environment varies from coastal plain, fluvial channel depositions to clay and silt surfaces flooding depositions. Reservoir thickness ranges from 5 – 50 meters.
- Under these geological settings, different patterns and well architecture have been adopted to develop the heavy oil resources (vertical, slant, horizontal wells).



# Oil Recovery Factor Evolution in Heavy Oil Developments



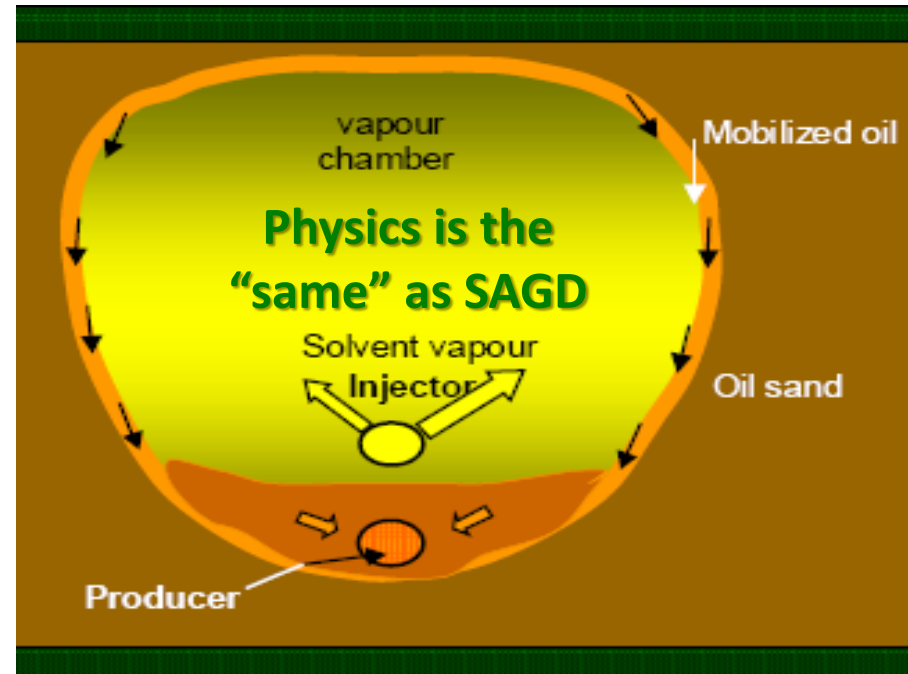
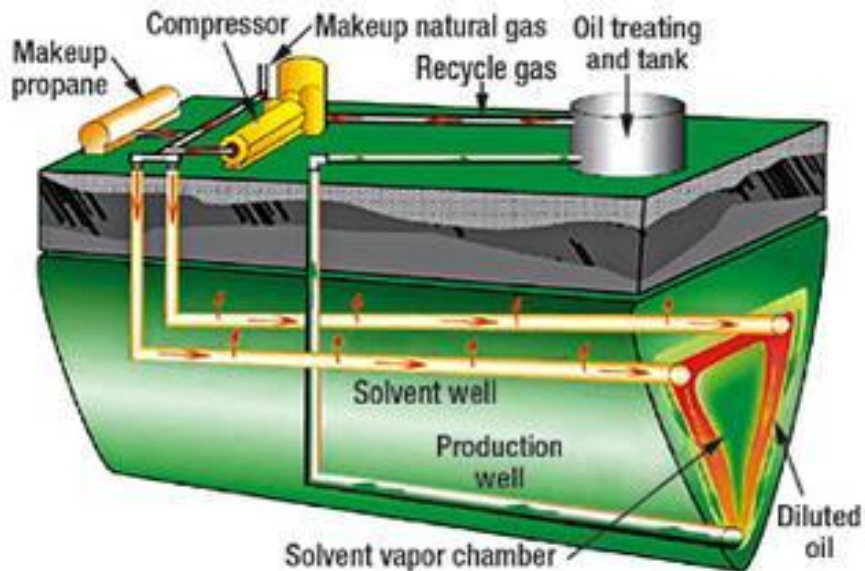
Alternative No-Thermal Method → **(Hydrocarbon Solvent Injection)**  
**VAPEX Process**

Field experiences in Canada  
USA  
Venezuela  
Iran  
China

# Hydrocarbon Solvent Injection Process, VAPEX Concept

**Vapour Extraction (VAPEX)** process was originally proposed by Roger Butler and Mokrys as an alternative EOR method to the Steam – Assisted Gravity Drainage (SAGD) process. The process involves the application of a pure hydrocarbon vapor or a vaporized hydrocarbon mixture as solvent to diffuse and dissolve in heavy oil to reduce its viscosity and make it mobile.

This process offers the potential to reduce the oil sands' impact on the environment by increasing energy efficiency and producing fewer emissions.

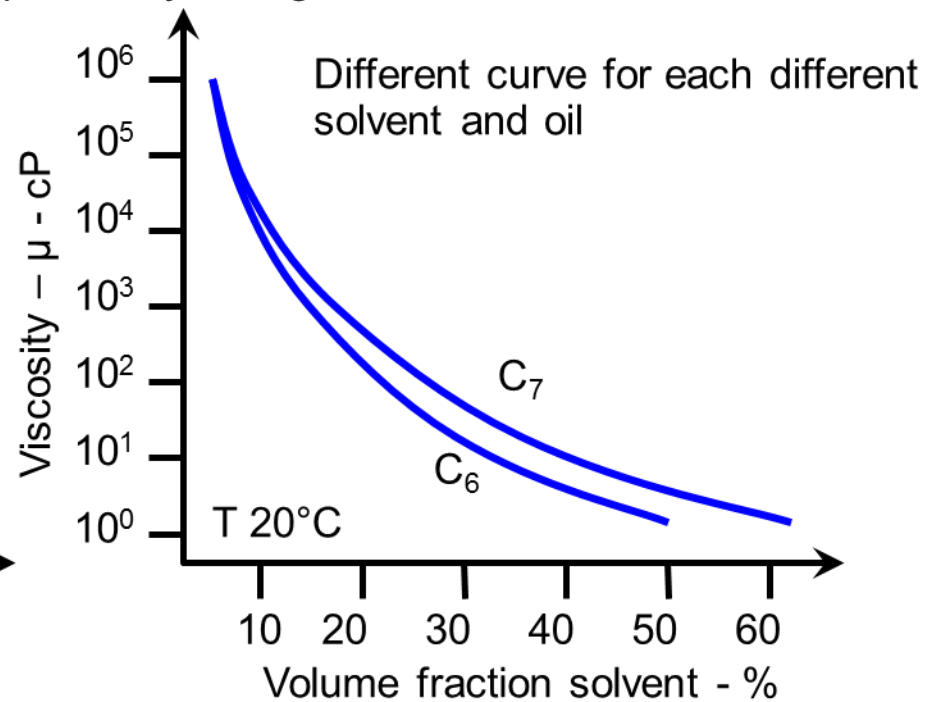
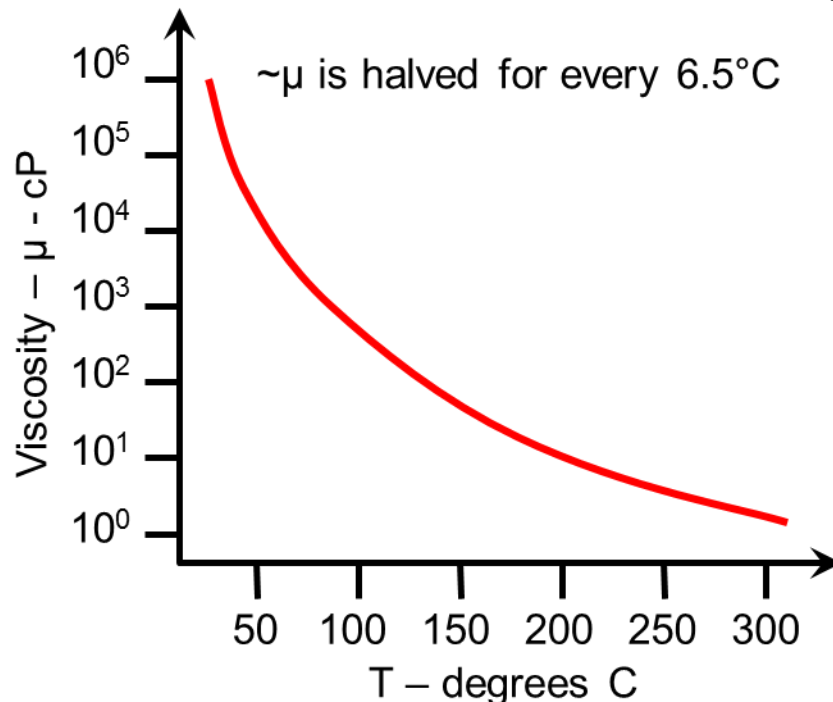


# Viscosity Reduction by Solvent Injection

- Different solvents reduce the viscosity by different amounts
- Also, different phase behavior (T, p)
- LPG is a raw product, fairly cheap
- Pure solvents are more expensive
- Naphtha for dilution methods

**Mass Transfer:**  
Diffusion – Dissolution –  
Dispersion – Convection

These curves are conceptual only, though realistic



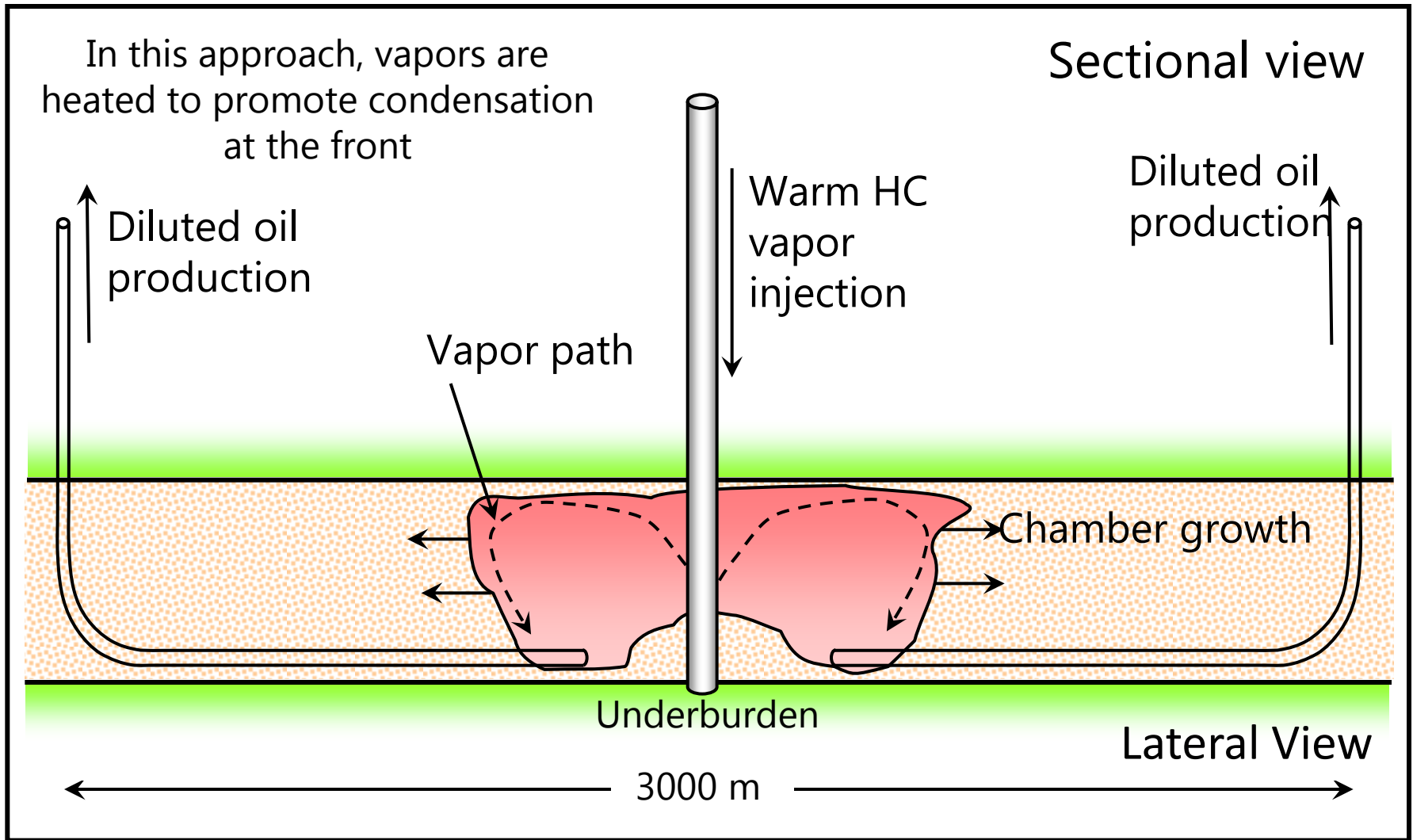
## VAPEX process comments

- Depending on p and T in situ, different condensable gas mix may be used (e.g.:  $C_2H_6$ - $C_4H_{10}$ )
- Main hydrocarbon solvents applied in the VAPEX process include ethane, propane and butane, commonly known as Liquefied Petroleum Gas (**LPG**)
- Inject from horizontal well toe, the upper well (1 or 2 well approaches), or verticals
- Miscible vaporized hydrocarbon solvent reduces the heavy oil viscosity
- VAPEX has potential in cases of bottom aquifer
- Can be combined with SAGD (Enhanced Solvent ES-SAGD)

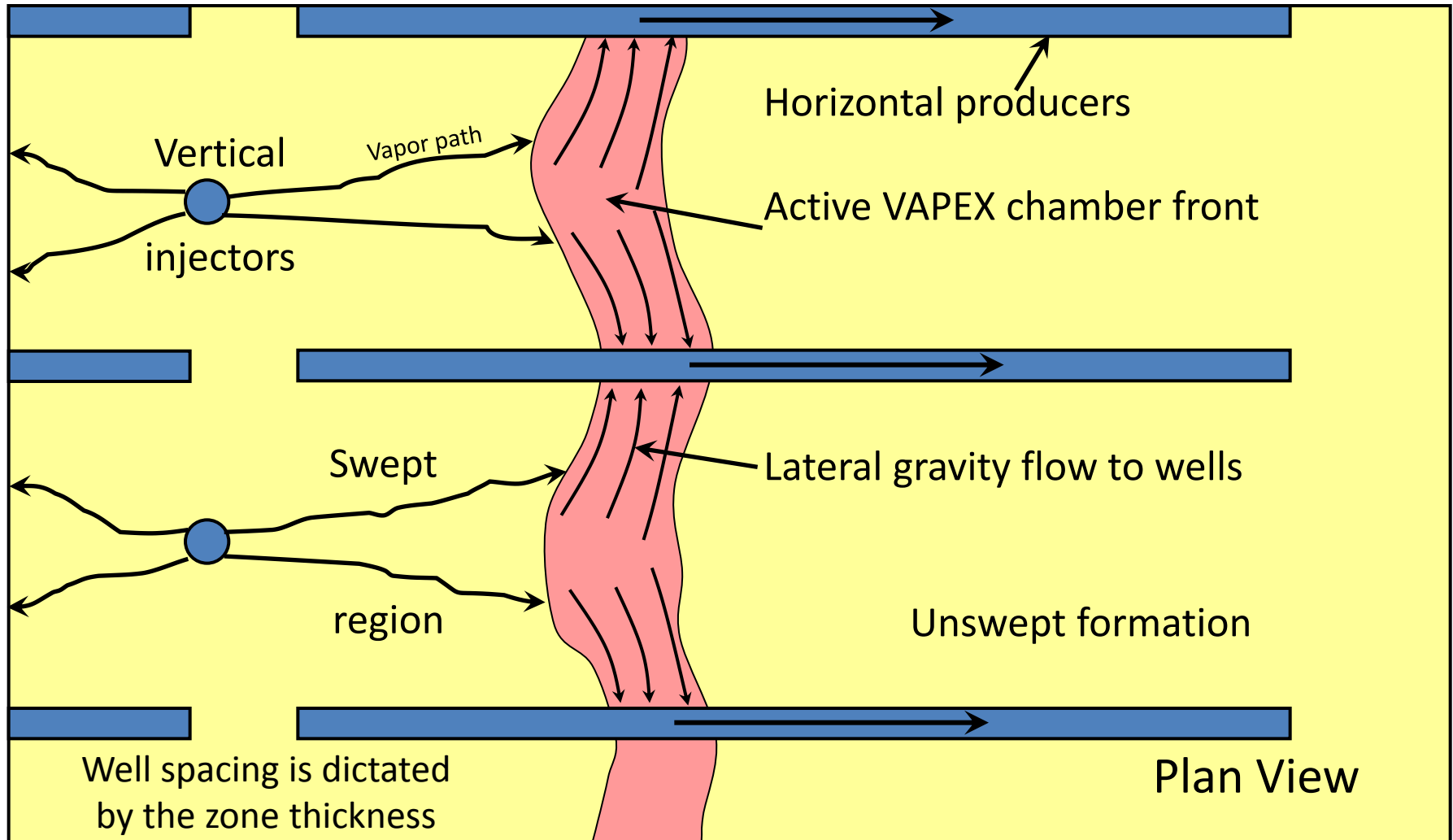
**The process was to be applied in reservoirs where the SAGD process is problematic. These reservoirs include:**

- Reservoirs thinner than the minimum for thermal processes
- Low-permeability carbonate reservoirs where the heat capacity per unit volume of contained oil is high
- Reservoirs underlain by aquifers and/or gas cap, where SAGD application leads to excessive heat losses to the under and overburden, aquifer, and/or gas cap.

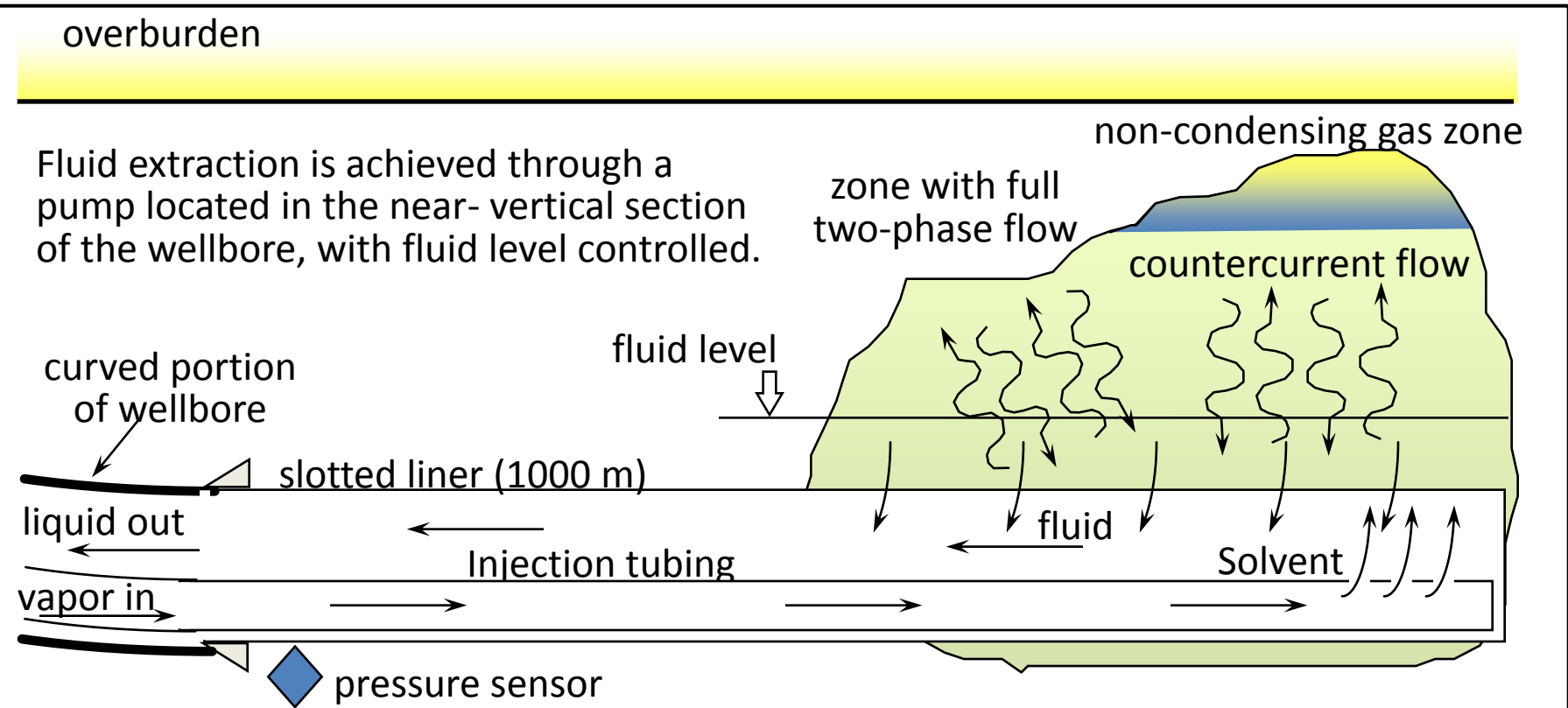
# VAPEX Configurations



# VAPEX Configurations



## Single-Well VAPEX

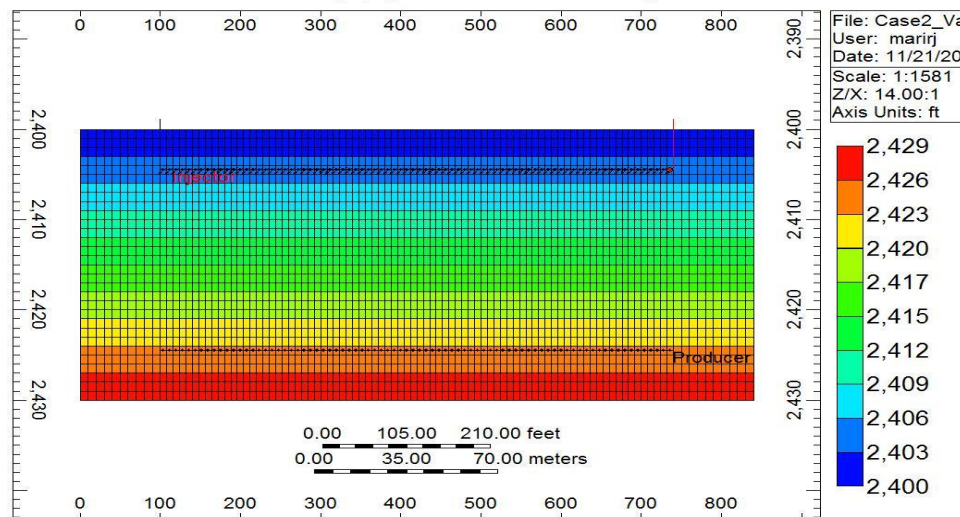


The vapor phase can be steam, steam plus non-miscible (N<sub>2</sub>) or miscible (C<sub>3</sub>H<sub>8</sub>) gases, a single gas, or a mixture of gases formulated to best lead to spreading and drainage.



# Applicability of the Solvent Injection Process in the Llanos Basin

Grid Top (ft) 2015-01-01 J layer: 25



- Considering the physics involved in the process to study a very refined model was built. Grid block size was set at 8 ft. by 8 ft. in X and Y directions and 1 ft. in Z.
- These are the characteristics of the grid:
  - Cartesian grid containing blocks of 8 ft. x 8 ft. in X and Y direction
  - Block vertical thickness of 1 ft.
  - Total number of blocks 150,000
  - Length in X direction is 960 ft.
  - Length in Y direction is 560 ft.
  - Four components model (C1, C3, C4 and C7+)

Reservoir Properties (Llanos Basin Data)	
Initial reservoir temperature, °F	160
Initial reservoir pressure at injection well depth, psi	1300
Permeability (kh), mD	3000
kv/kh	0.8
Porosity, %	30
Oil saturation, %	87
Reservoir thickness, ft	30
Well spacing, m	200
Fluid Properties	
Initial solution-gas/oil ratio for live oil, scf/stb	50
Light component C1, mole fraction	0.2
Heavy component C7+, mole fraction	0.8
Viscosity at 160 °F, cp	630
Viscosity at steam-injection temperature (cp, T)	5.7 (500 °F)
K-values for the solvent (Cusiana LPG)	Calculated by Winprop
Operating Parameters	
Injection pressure, psi	1200
Steam quality	0.7
Saturation temperature, °F	500
Max live steam production, bbl/day	10
Steam injection volume, bbl	18900
Thermal Properties	
Rock heat capacity, BTU/ft <sup>3</sup> .°F	35
Rock thermal conductivity, BTU/ft.day.°F	106
Oil thermal conductivity, BTU/ft.day.°F	15
Water thermal conductivity, BTU/ft.day.°F	24
Gas thermal conductivity, BTU/ft.day.°F	5
Over/underburden volumetric heat capacity, BTU/ft <sup>3</sup> .°F	35
Over/underburden thermal conductivity, BTU/ft.day.°F	24
Rock/Fluid Parameters	
Sorw	0.39
Swc	0.13
Sorg	0.12
Sgc	0.05
Krwro	0.41
Krocw	0.95
Krogc	0.95
Krg(Sorg)	0.5
Three-phase relative permeability model	Stone's Model 2

**Dead Oil Characterization**

**Live Oil Characterization**

**HC Solvent Characterization**

**Live Oil + HC Solvent Characterization**

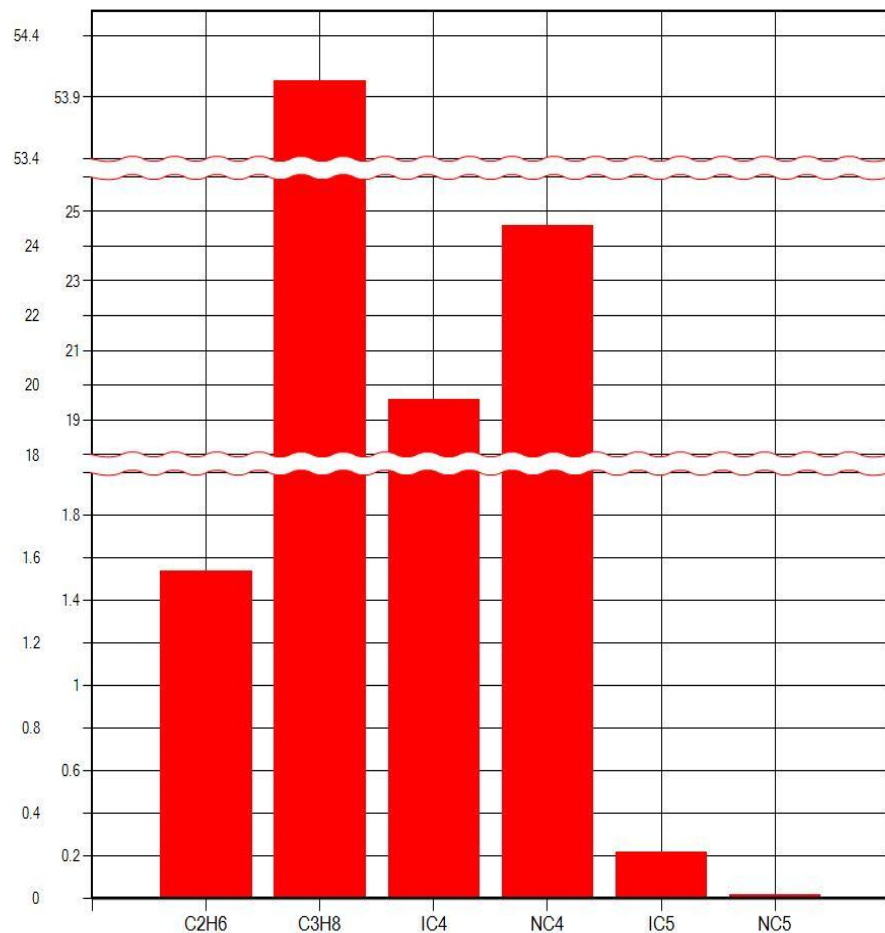
# Set of Laboratory Tests

FLUID	PARAMETER	CONDITION
Dead Oil	Density	Standard Conditions
	Composition	Specific Gravity and Molecular Weight
	Viscosity	Set of Temperatures
Live Oil	Chromatography	Gas Compositions
	Density	Live Oil @ Standard Conditions
	Saturation Pressure	Reservoir Temperature
Solvent	Chromatography	Composition and Max. Molar Fraction
	Density	Standard Conditions
	Saturation Pressure	P injection @ Reservoir Temperature (Kte)
Oil + Solvent	Saturation Pressure	Pb Mixture (S + O) @ Reservoir Temperature
	Swelling	Max Swelling @ Px , Tx
	Viscosity	Set of Temperatures

# HC Solvent and Heavy Oil Composition

## Cusiana LPG

Composition

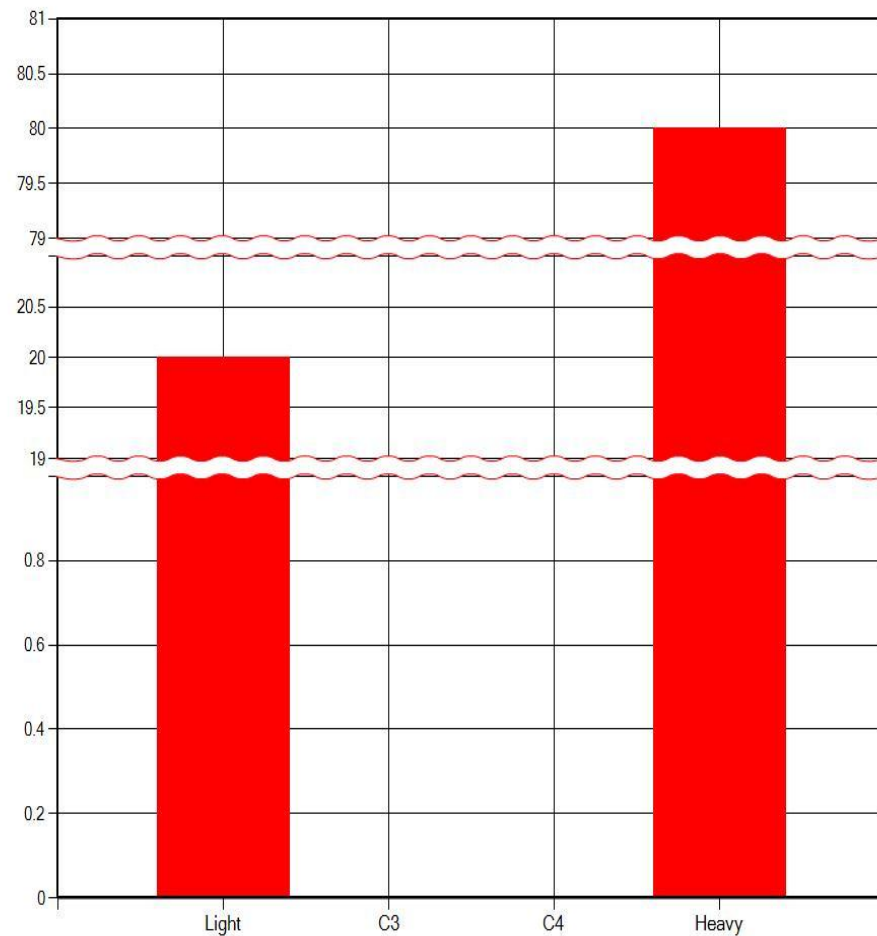


Legend

■ Primary

## Llanos basin Heavy Oil

Composition

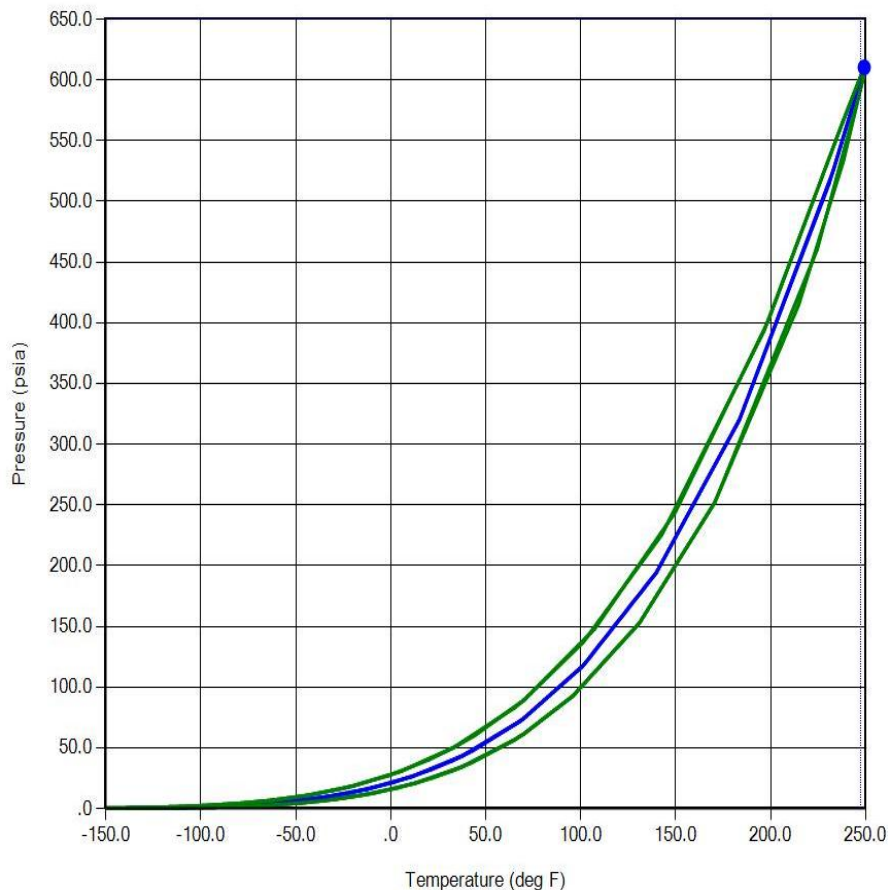


Legend

■ Primary

# Two-Phase Envelope. P-T Diagram

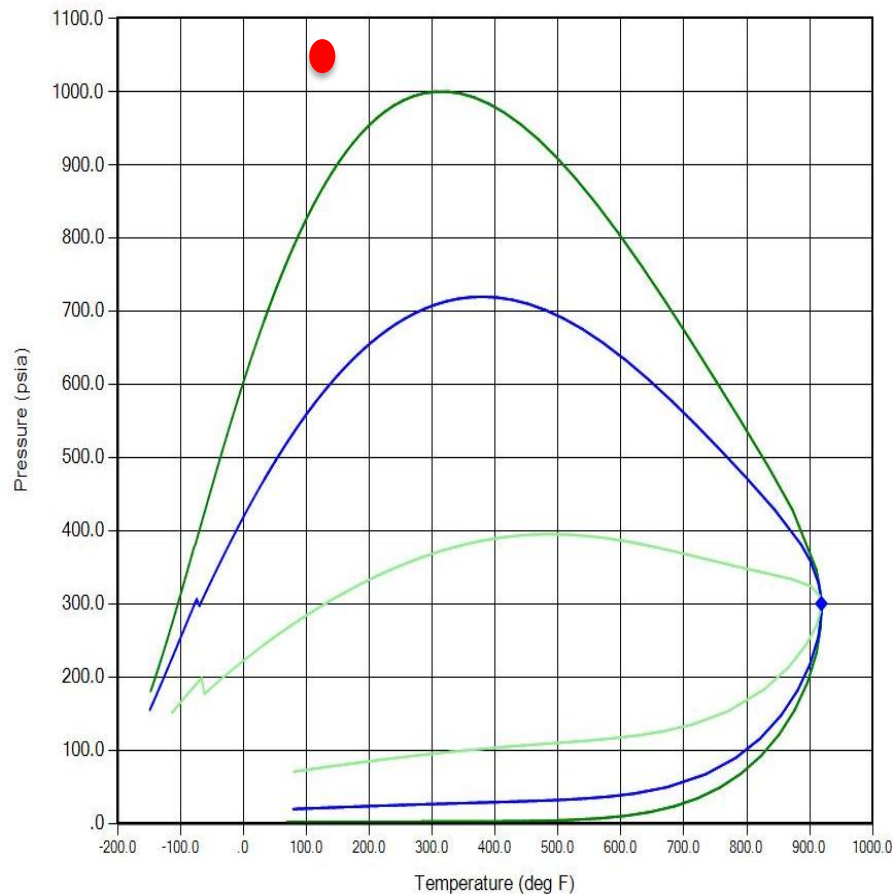
## Cusiana LPG



**Legend**

- 2-Phase boundary
- 50.000 mole %
- 2-Phase boundary(3)
- Critical

## Llanos basin Heavy Oil



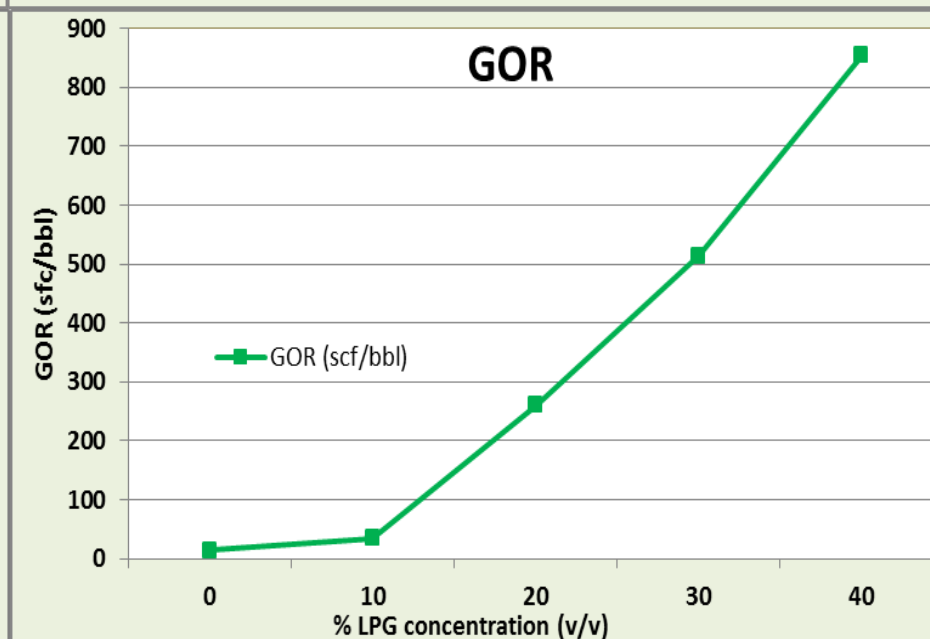
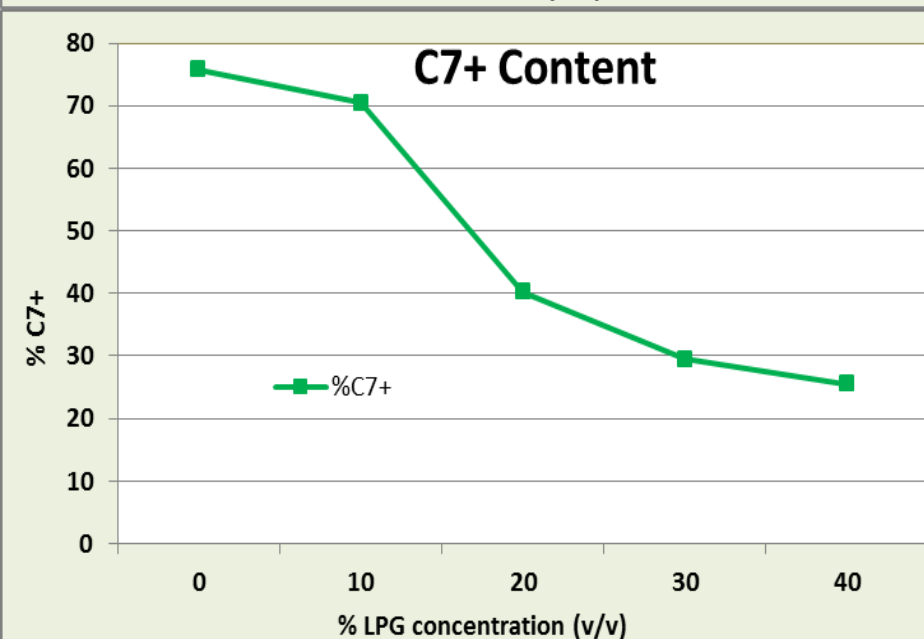
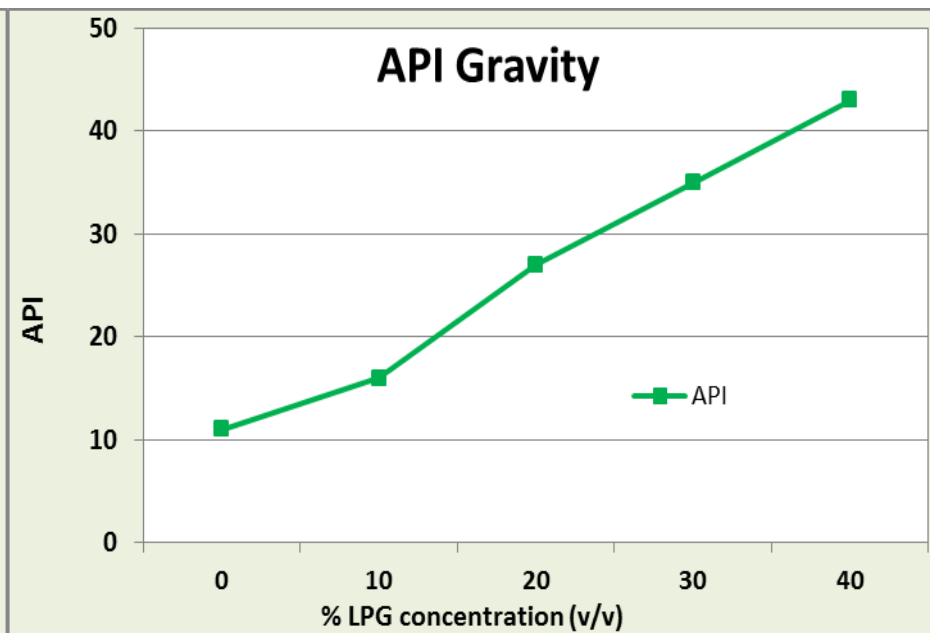
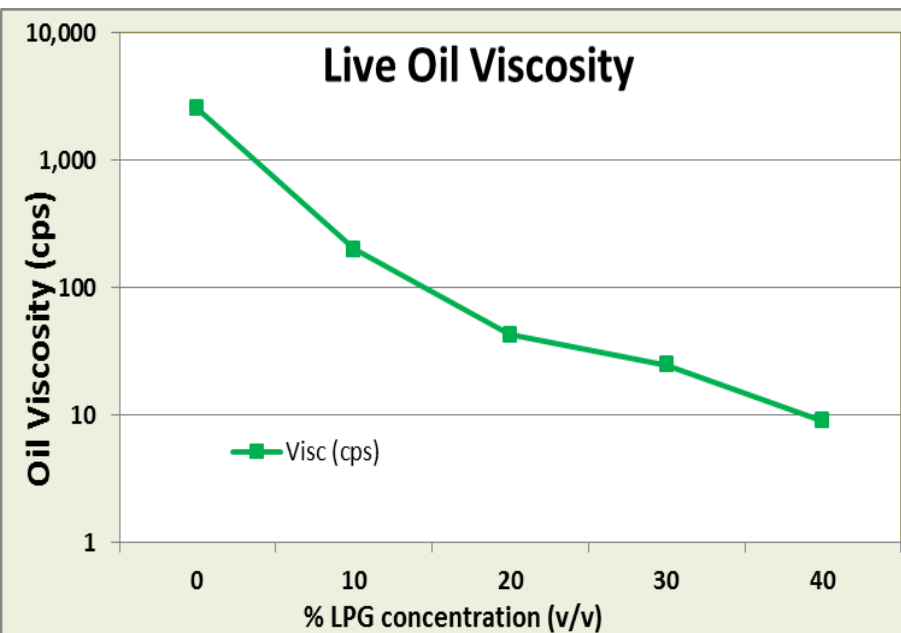
**Legend**

- 1.0000 volume %
- 10.000 volume %
- 30.000 volume %
- Critical

Key parameters in equilibrium constants calculation:  
Critical Temp, Critical Pressure, and Compositions

 Reservoir Conditions

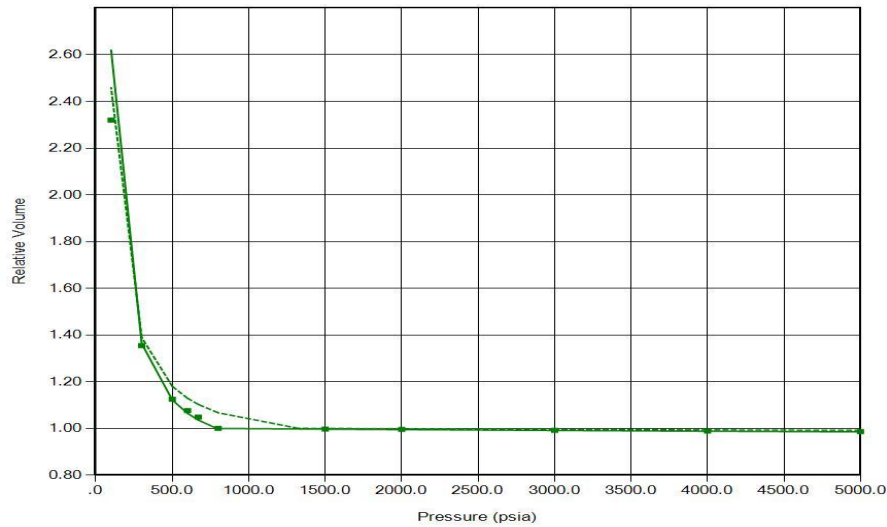
# Laboratory Experiments Results



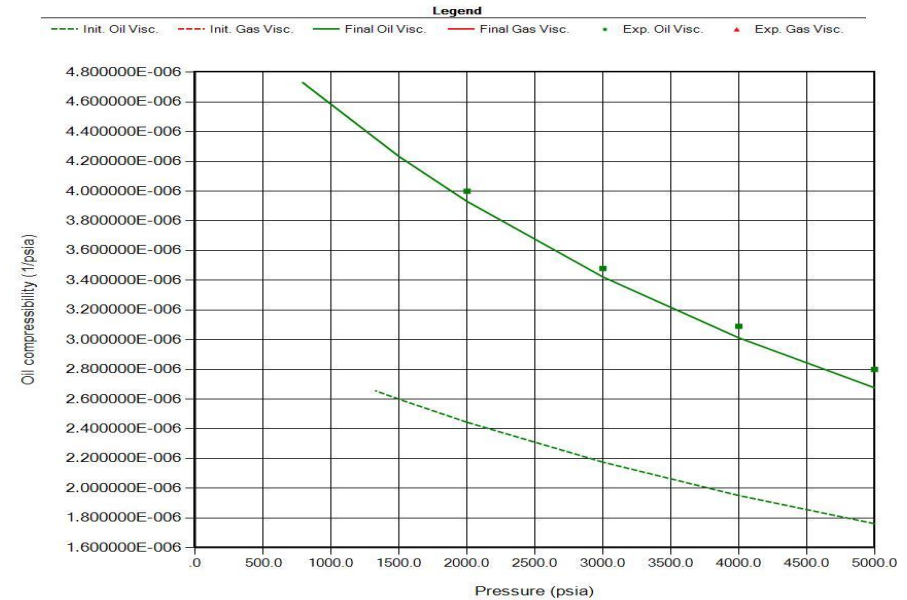
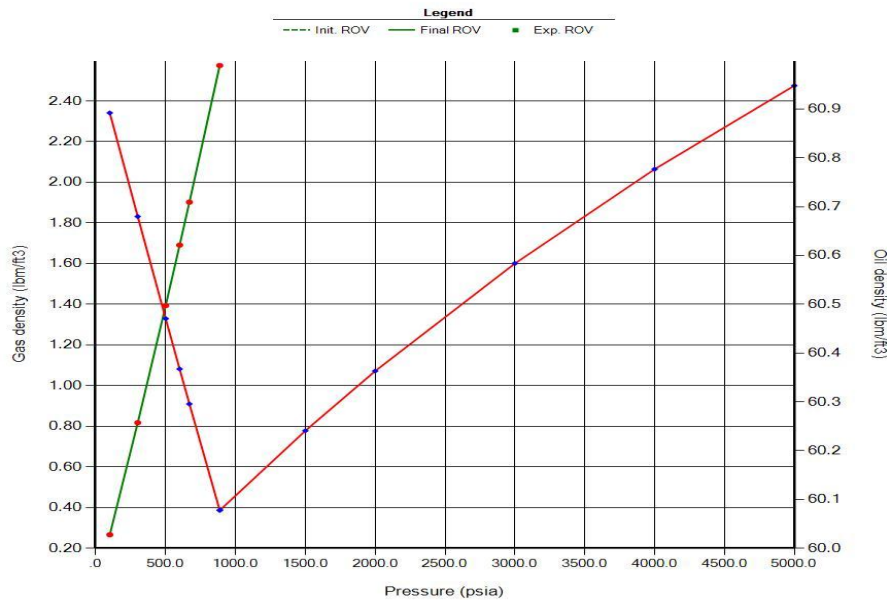
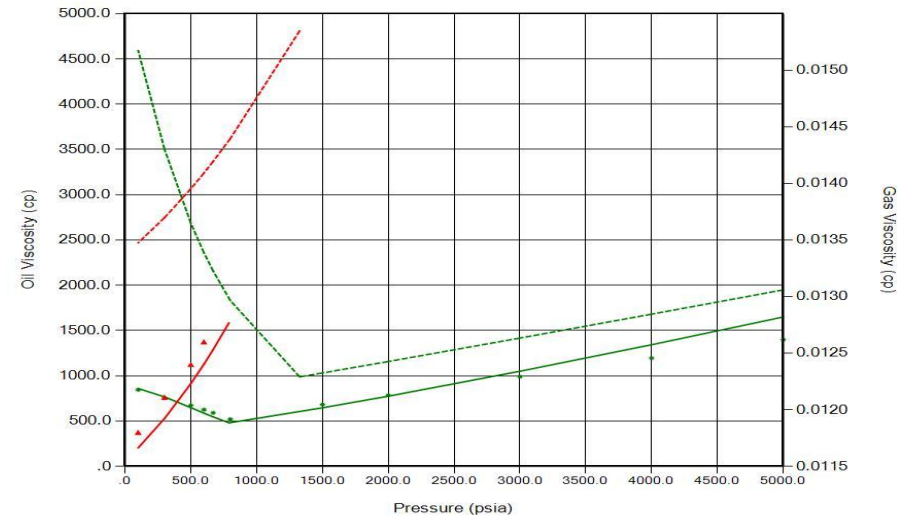


# CCE Lab Test. Experimental Matching

CCE to match the live oil viscosity : CCE Calc. - Summary Plot:



CCE to match the live oil viscosity : CCE Calc. - Summary Plot:

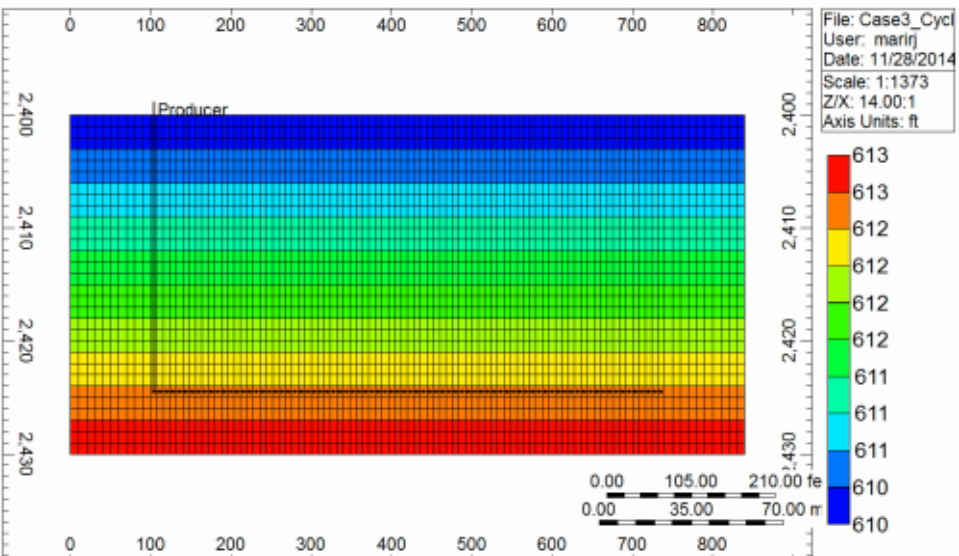


## **Cases Studied**

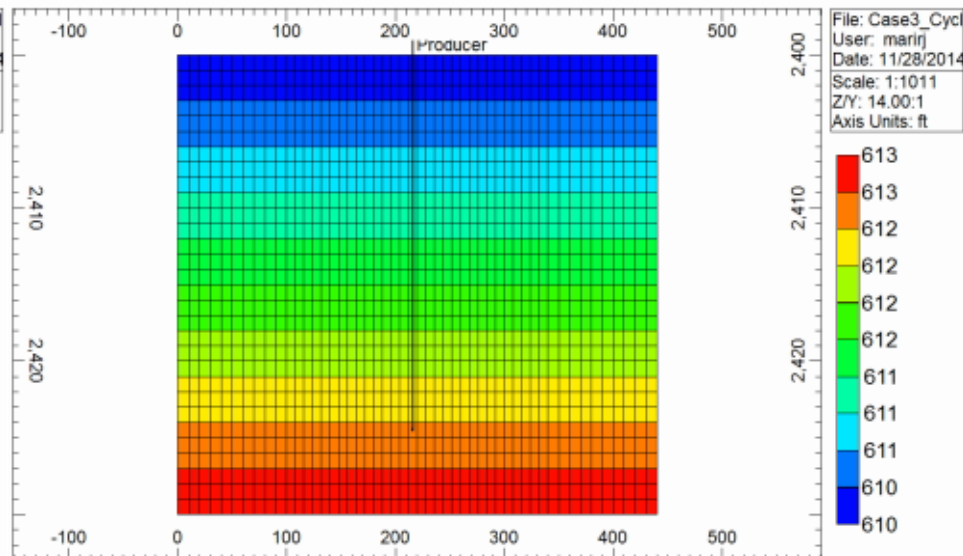
1. Cold production (Base Case). Neither solvent nor steam is injected.
2. Cyclic hydrocarbon solvent injection. A volume of Cusiana LPG is injected per cyclic at the producer well in a huff-puff scheme.
3. Cyclic steam stimulation (CSS). steam is injected per cyclic at the producer well in a huff-puff scheme.
4. Solvent-aided CSS process (steam + 15 % v/v of Cusiana LPG). Solvent proportion obtained at atmospheric conditions.
5. Cusiana LPG is continuously injected at the injector well in a VAPEX scheme.
6. 100 TMV of steam are continuously injected at the injector well in a SAGD scheme.
7. Solvent-aided SAGD process (steam + 15 % v/v of Cusiana LPG). Solvent proportion obtained at atmospheric conditions.

# Numerical Simulation Study – Cyclic HC

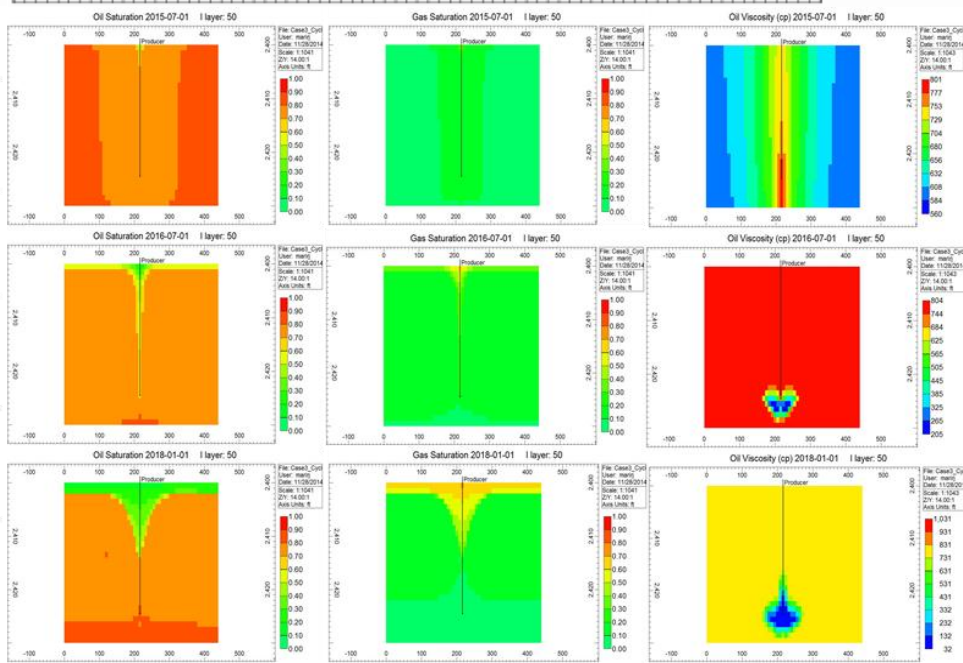
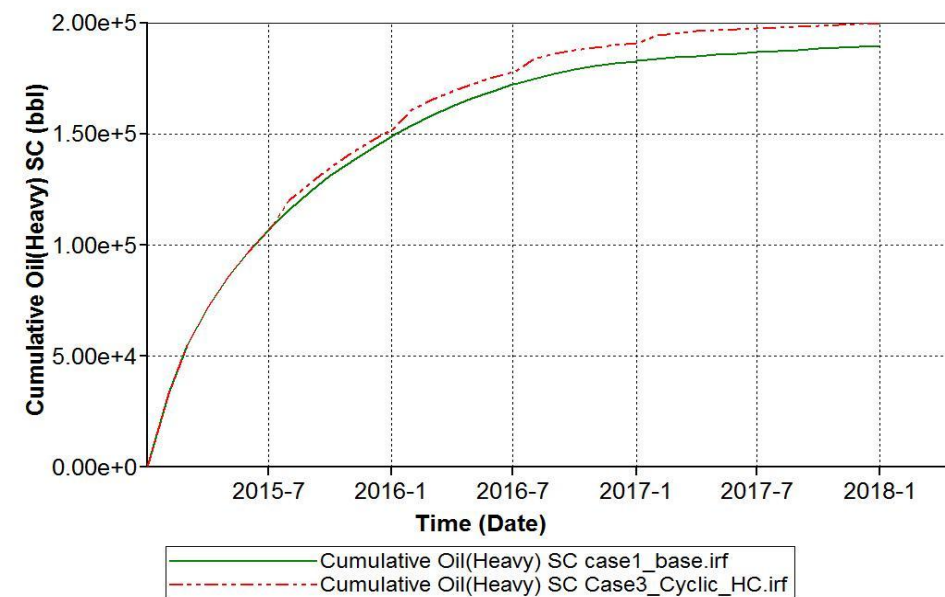
Oil Viscosity (cp) 2015-01-01 J layer: 25



Oil Viscosity (cp) 2015-01-01 I layer: 50

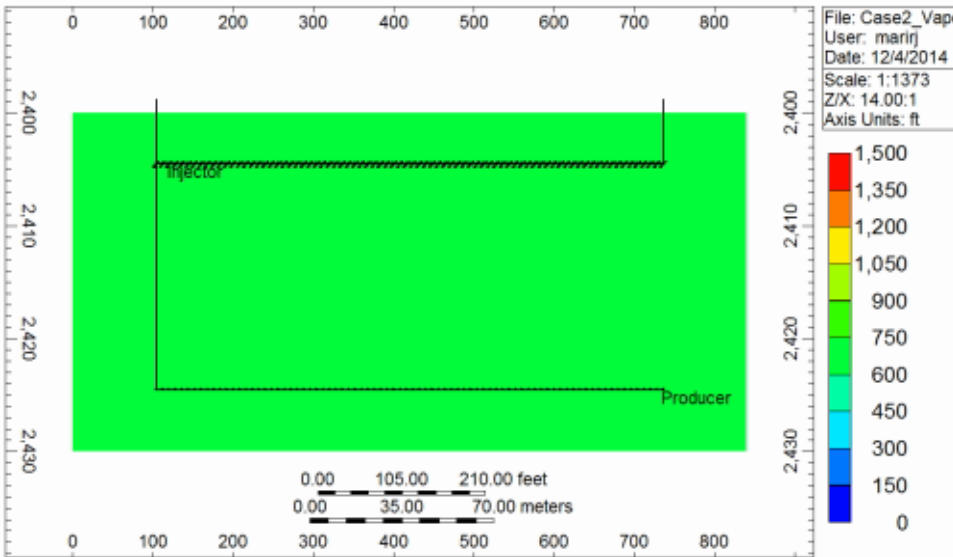


Producer case1\_base.irf

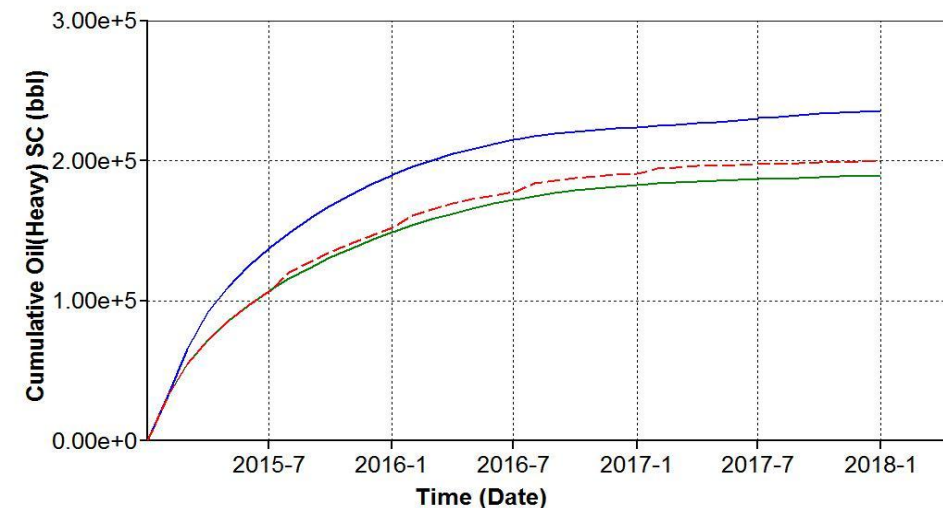


# Numerical Simulation Study – VAPEX Case

Oil Viscosity (cp) 2015-01-01 J layer: 25

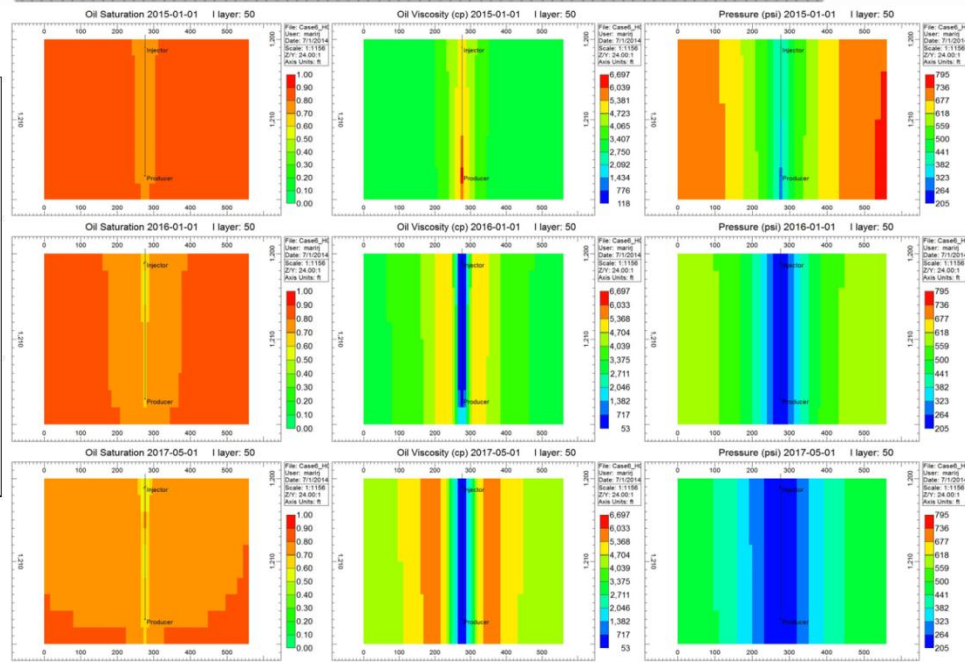
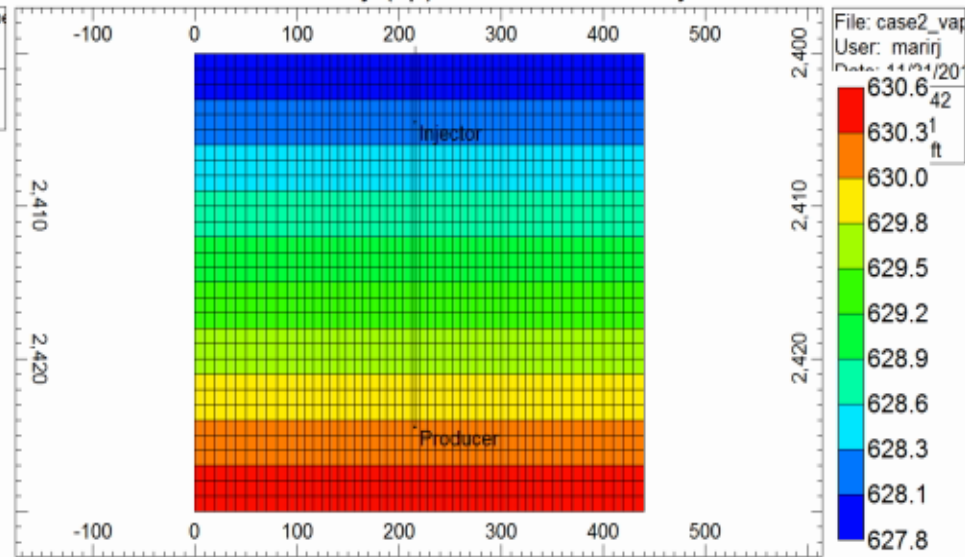


Producer case1\_base.irf



- Cumulative Oil(Heavy) SC case1\_base.irf
- Cumulative Oil(Heavy) SC Case2\_Vapex.irf
- - Cumulative Oil(Heavy) SC Case3\_Cyclic\_HC.irf

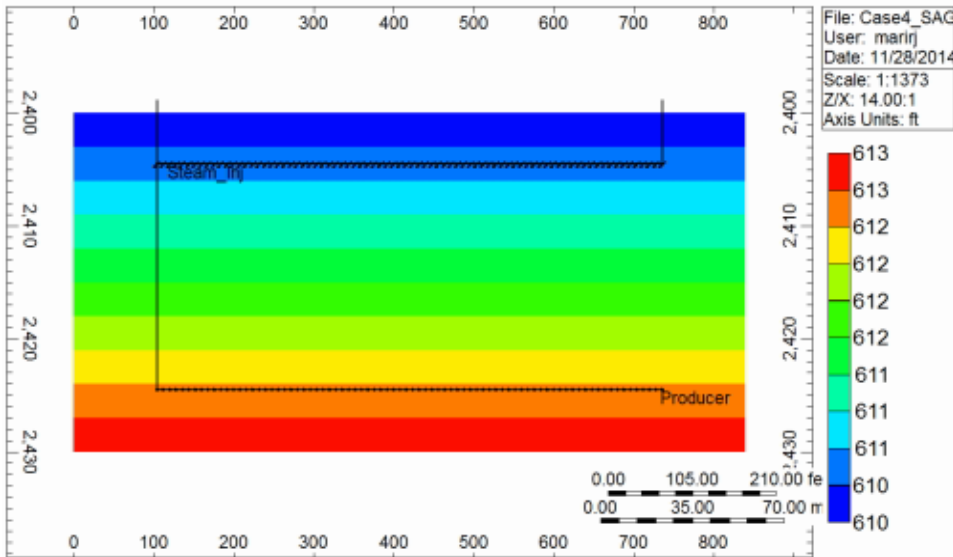
Oil Viscosity (cp) 2015-01-01 I layer: 50



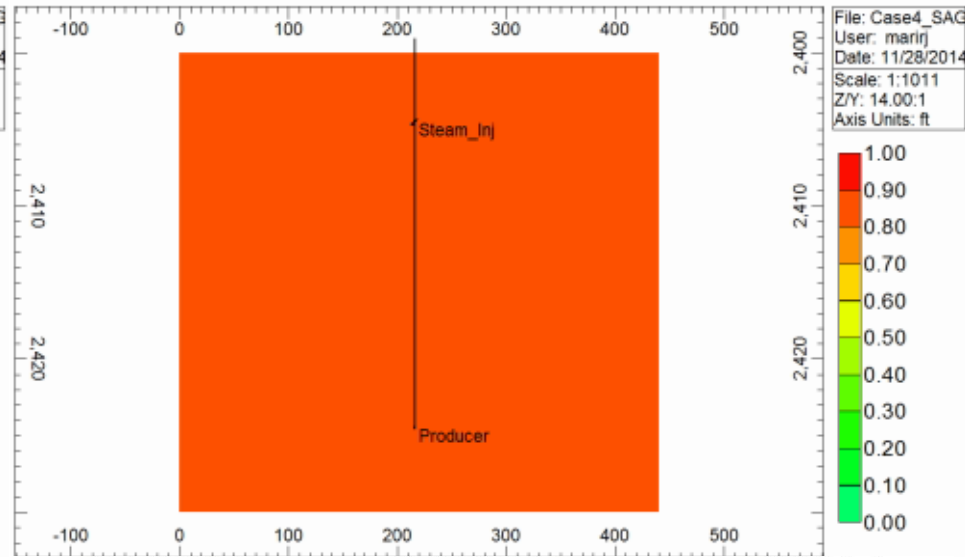


# SAGD vs. Solvent-Aided SAGD Case

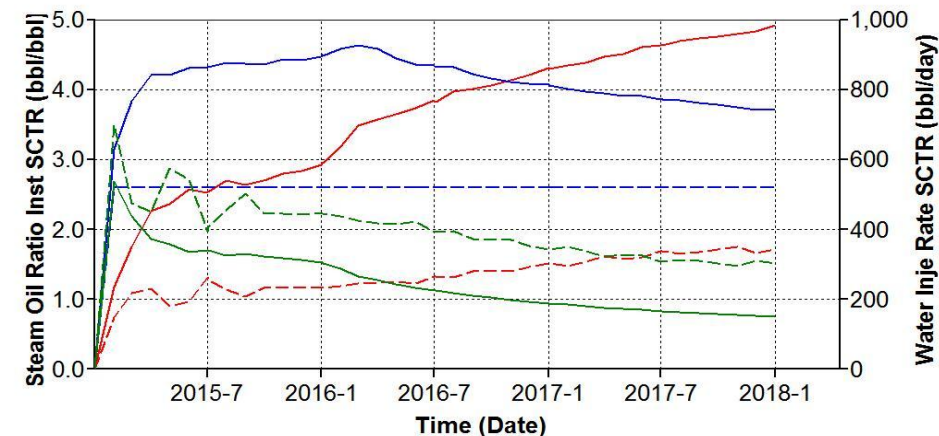
Oil Viscosity (cp) 2015-01-01 J layer: 25



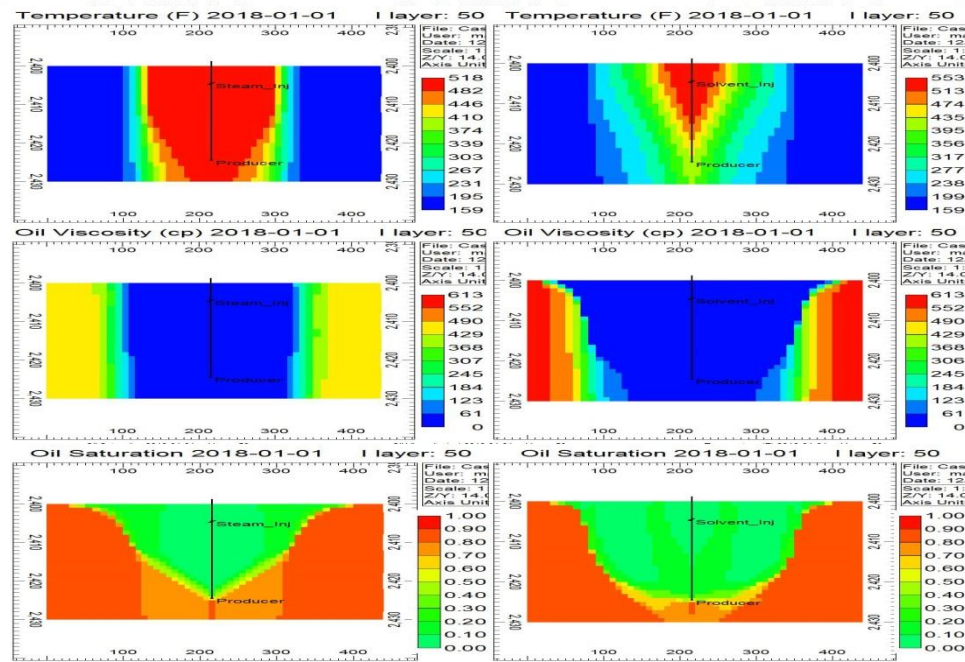
Oil Saturation 2015-01-01 I layer: 50



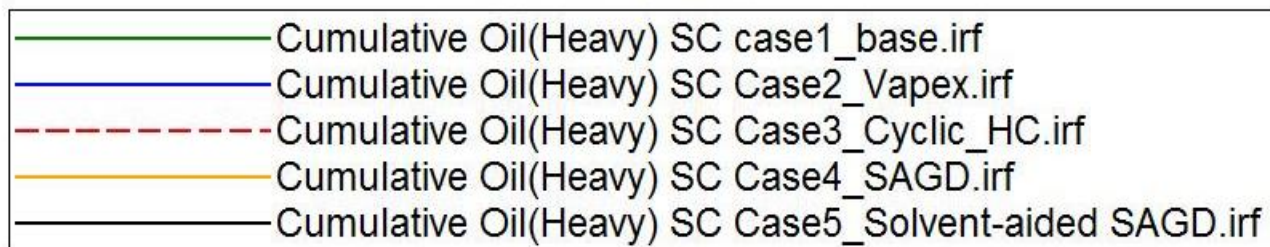
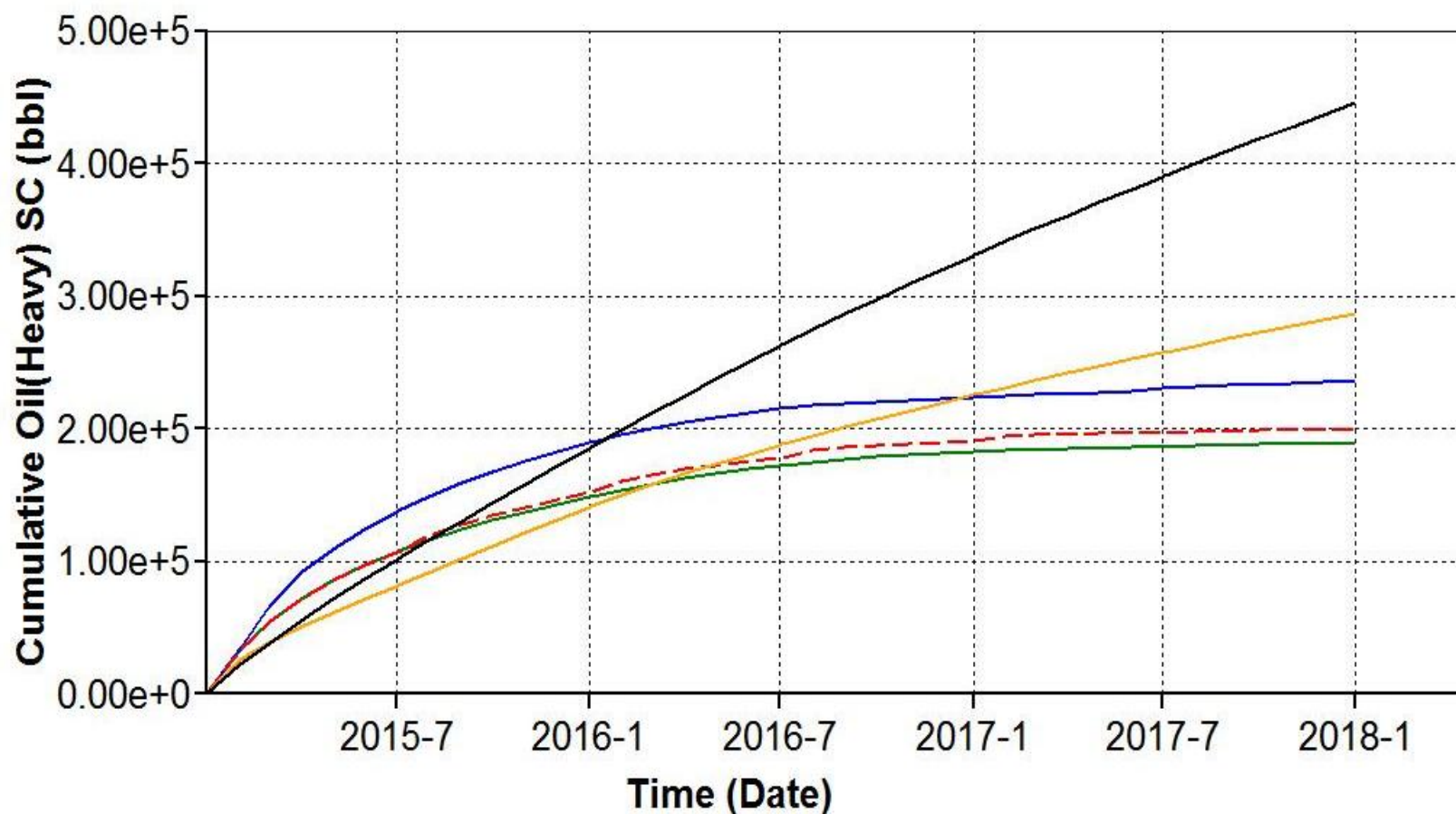
Entire Field Case4\_SAGD.irf



- Steam Oil Ratio Inst SCTR Case4\_SAGD.irf
- - - Steam Oil Ratio Inst SCTR Case5\_Solvent-aided SAGD.irf
- Water Inje Rate SCTR Case4\_SAGD.irf
- - - Water Inje Rate SCTR Case5\_Solvent-aided SAGD.irf
- Oil Prod Rate SCTR Case4\_SAGD.irf
- - - Oil Prod Rate SCTR Case5\_Solvent-aided SAGD.irf



# Summary of Results



# Conclusions and Recommendations

- Heavy oil viscosity is reduced more than 10 times (one magnitude order) by adding 10% of LPG (ratio 90:10 v/v). For higher blend ratio (70:30, 60:40 v/v) the viscosity reduction is much lower compare to 90:10 and 80:20 blend ratio.
- API gravity increases with the addition of LPG. The resultant blend is upgraded crude. Molar fraction of heaviest components C7+ is reduced considerably by the LPG, resulting in heavy oil with better physical properties (API and viscosity).
- Lab experiments results demonstrated that the Cusiana LPG is an excellent hydrocarbon solvent to be used in heavy oil extraction. A major portion of the solvent is dissolved in the in-situ oil and produced, which aids heavy oil transport in the wellbore and surface pipelines.
- Cusiana LPG can be an effective solvent for the Colombian Oil Sands. The optimum Cusiana LPG concentration is around 10 to 20 v/v%; higher amounts lead to small incremental oil recovery due to limited solubility at the operating conditions of this study.
- Simulation studies indicate that Cusiana LPG solvent (with v/v% < 20%) has the potential to enhance the oil recovery and thermal efficiency of CSS and SAGD processes. This hydrocarbon additive creates a high-oil-phase-mobility zone which accelerates the oil production in the CSS and SAGD processes. Addition of the Cusiana LPG solvent at 15% by volume in the heavy oil reduces the energy intensity of the CSS and SAGD process by almost 40% or higher.

# QUESTIONS ?