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Biotechnology Application to EOR in Talara Off-shore Oil Fields, Northwest Peru

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Abstract

Seven producer wells (oils between 32–36 ^{o}API) from Basal Salina fm. in Providencia and Lobitos areas of Z-2B Block (Talara basin, Northwest Peru) were selected to evaluate a biotechnology approach for Enhanced Oil Recovery.

The MEOR candidates are vertical and high-angle slanted wells. They produce from faulted reservoirs through intermittent gas lift methods under an off-shore operative environment. The oils are paraffinic and hence with positive bio-treatability.

The treated wells exhibited a typical MEOR response in two consecutive stages: 1) Clean-up effects by the removal of organic damage occurring in the near wellbore of the perforated interval, opening non-productive zones bearing oils with a more segregated, pseudoplastic behavior. The typical signature is a high pulse in oil rate but only lasting a short time. 2) Radial-Colonizing response, by generation of light-end solvents (biocracking on N-alkanes present in the oil) which cause a permanent rheological effects by the compositional alteration that occur at deeper colonization radius, in drainage zones with extremely low shear rate values (low fluid velocity).

The MEOR pilot stage in PG-U9 and PG-9 of Providencia and LO16-14 and LO16-24 of Lobitos fields resulted in ***3,086 M^3* (19,410 *bbls.*)** and ***2,211 M^3* (13,907*bbls.*) *of Incremental Oil*** respectively. MEOR Increments of **36.5%** in Providencia and **46.5%** in Lobitos were assumed as conservative (non optimized) MEOR performance indexes. Note: Due to operative reasons not directly related to MEOR, the complete inoculation program was concluded in only four of the original seven candidate wells.

The pilot project was considered profitable and economically feasible of further expansion.

Z-2B block possess 430 producers as excellent MEOR prospect and waterflooding schemes as potential targets for biotechnology (MEOR^2). [Ref. 7 to 14].

Biotechnology in the Oil Industry

Today the use of biotechnology in the Petroleum Industry is thought as a fully integrated process, that producing tangible benefits from the beginning of upstream operations, passing for the intermediate transportation segment and finally reaching the downstream sector, improving the complete added-value chain. Biotechnology methods are founded in the use of sophisticated enzyme biochemistry to accelerate redox reactions which involve different hydrocarbon compounds of ubiquitous presence in reservoired oils, transportation systems or refining facilities (sub-surface or surface installations). [Ref. 1, 2, 3, 5, 6]

General Reasoning Base

Following are basic principles guiding Biotechnological-Driven Processes to be combined with the conventional technological frame at subsurface drainage, upgrading and transportation (surface) stages .

1) If direct methods are selected, the physiology of the added biota associated with the biotechnological design need to be compatible with the thermodynamic status of reservoir fluids in order to couple at the current thermodynamic of oil extraction and post-processing scenarios.
2) If <u>indirect methods</u> are selected, the bioproducts generated like surfactants, solvents, polymers, etc. need to be of proven stability (time) at typical thermodynamic conditions of the target system.
3) The <u>active components (biota), passive substances and bioproducts</u> need to be non-pathogenic for humans, animals or plants with minimal environmental impact.
4) The consortial group/Enzimatic system under study need to have a long-term repeatable behavior in terms of EOR/upgrading functionality.
5) The timing of the biotechnology process must be in accordance with the available Residence Time of the fluids at subsurface and/or surface system geometries.
6) The bioprocess needs to be technically, operatively and economically feasible in the global Energy context.

Direct methods: The biota with MEOR functionality works at the same thermodynamic conditions that exist in the target system, **Indirect Methods:** The biota/Enzimatic system works at different thermodynamic environment, it produces bioproducts with desired upgrading functionality to impact target system. A biotechnological program is assisted with active (externally-added biota, indigenous biota, capsulated microorganisms) and passive products (chemicals and bio-products produced externally to the system or In-Situ like bio-surfactants, etc. [Ref. 4, 5]

MEOR in the Upstream sector: Application scope

Microbial Enhanced Oil Recovery (MEOR) technology in the upstream sector is based on the systematic inoculation of producers and/or injectors wells with specific microbial systems, biocatalyzers and nutrients. The "pulsing Program" pursues as primary goal to colonize the poral medium of the oil-bearing zones; the second objective is to control enzymatic reactions at water/oil interfaces in the productive formation, in order to modify oil mobility, by producing low molecular solvents and bio-surfactants. Sequential Rheological Lab Procedures in combination with Organic Geochemistry Methods monitor the stability and efficiency this sort of bioreactions (Biomarkers and serial GC-MS Chromatography, [Annex A, C in Ref. 7].

There are two main operational methodologies to achieve a controlled colonization in a target reservoir:

1) Treating producer well, by pumping downhole periodic microbial batches in order to reach the near wellbore poral space via tubing or annulus. This methodology is usually referred as MEOR[1] or simply MEOR. The microbial effect in treated wells can could be detected in two consecutive stages: A) Clean-up effects by removing organic damage occurring in the near wellbore of the perforated interval, opening non-productive zones bearing oils with a more segregated, heavy and pseudoplastic behavior. This effect produces a high peak in oil rate but only for a limited time. B) Permanent rheological effects by the compositional alteration occurring at deeper colonization radius, in drainage zones with extremely low shear rate values (Reynolds numbers below 5). This effect is the most important MEOR objective, as this improvement is sustainable for a long period if proper microbial inoculation schedule is continued. [Ref. 7 to 12]

2) Treating injector wells, introducing the microbial pulsing program via the injectors. In this case, the treatment uses the injected water as carrier to introduce microorganisms and passive substances into active streamtubes of flooded space for target layers. It is frequently termed as MEOR[2], because it is usually used in combination with the simultaneous treatments in injectors and producers descripted in point 1. Compared with the first approach, the main advantage of treating injection schemes results from a bigger size of colonized zones, with longer residence times with and the convergent role of multiple improving recovery mechanisms: 1) Rheology alteration of moveable oil in active streamtubes and its direct fractional flow dependence with oil/water mobility ratio. 2) Reduction of residual oil saturation (S_{or}) by In-Situ production of biosurfactant. 3) Improve conformance efficiency created by the colonizing biomass in active streamtubes that diverts fluids to unflooded zones. [Ref. 13, 14]

The project discussed in this paper belongs to the first mentioned category of biotechnological methods but the implicancies of positive results in this segment can be extended to injection schemes providing proper scaling and simulation procedures.

RA-CD Bioprocess - Biocracking of N-alkanes (free and bonded) - USA Patent 20020119557.

RA-CD Bio-cracking is based on a systematic (Mechanistic) way to alter N-alkane compositional profiles in oils. The use of Enzyme biochemistry permits to accelerate REDOX reactions involving linear hydrocarbons of ubiquitous presence in oils. Heavy paraffinic (free and bounded) compounds can be transformed in shorter ones by the enzymatic action of Repetitive cycles which are assisted with symbiotic microorganisms and specific nutrients, by Alternating aerobic/facultative hemicycles (C phase) with strictly anaerobic ones (D phase). The time-coordinated action of selected groups of microorganisms in oxidant and reductive environments permits a substantial shift in oil compositional profile. [Annexes, figures 30 to 33]

Such alteration in the linear saturate fraction improves oil properties like a lower Oil bulk viscosity concurrently with a higher API grade, reduced Oil-Water interfacial tension, changes in oil-rock interactions (wettability). The impact of such controlled enzymatic alteration in oil properties is forecast to have significative economical benefits in the Upstream, Transportation and even on Refining/oil Upgrading (Downstream sector), [Ref. 1 to 14]

Externally added microorganisms in RA-CD processes

Seven different microbial sub-communities of highly motile, synergetic and symbiotic microorganism consortia constitute the basic set of microbial products with biocracking functionality. A range of 15 to 25 strains usually integrates the blend structure to meet a specific application.

Indigenous Biota thriving in oil reservoir environments

Many studies [Ref. 26, 27] related with hot springs and hydrothermal vents describe harboring hyperthermophilic archaeas and bacteria with the highest growth known temperatures. It is reported the discovery of high concentrations of hyperthermophiles in the production fluids from four oil reservoirs about 3,000 meters below the bed of the North Sea and below the permafrost surface of the North Slope of Alaska. Presently, there is a complete line of Worldwide efforts in applied research pursuing to optimize the role of the indigenous thermophiles/extremophiles thriving at reservoir environment with the symbiotic and consortial interactions of externally added microorganisms.

Oil industry in Peru

It is of considerable importance to evaluate the macro- and microeconomy context in which an EOR project takes place. At pilot stages the local constraint dominates the course of actions, but in case of positive results, the expansion process is usually misconducted (in time and scale) when the macroeconomy scene is poorly assessed or forecast.

Context overview at the moment of MEOR start

Peru is currently a net importer of crude oil hence the importance to develop long-term cost effective EOR strategies. Peru had estimated proven crude oil reserves of 285 million barrels, as of January 2004, In 2003, Peru produced 95,000 barrels per day (bbl/d) of oil (including crude and NGLs), a decrease of 10.67% year-on-year, while consuming 163,000 bbl/d. Unable to meet oil demand with domestic resources, Peru is a net oil importer mainly from Ecuador and, to a lesser extent, from Nigeria, Colombia, Argentina, and Venezuela. Current oil activities are located in the northern jungle along the border of Ecuador (Loreto Department), along the northern coastal region (Piura Department), and in the central jungle region (Huánuco and Ucayali Departments). [Ref. 15, 16]

Project Discussion

MEOR in Talara Off-shore Oil Fields

Pilot Location

The project involves producers from two important fields of Talara Basin denominated Providencia and Lobitos respectively. Both pertain to Z-2B block (Figure 01).

The Talara Basin province is located on the continental shelf along the northern coast of Peru. La Brea–Amotape Mountains of the Coastal Range serve as its eastern limit, and the corresponding uplift constitutes the basin separation from the Lancones and Sechura Basins. The south boundary is the Trujillo Basin. The southeast boundary is east of the La Casita fault and the Paita High uplift, between the Talara and Sechura Basins; The west boundary of the province is materialized by the inferred location of the Nazca Plate subduction line of action under the South American Plate.

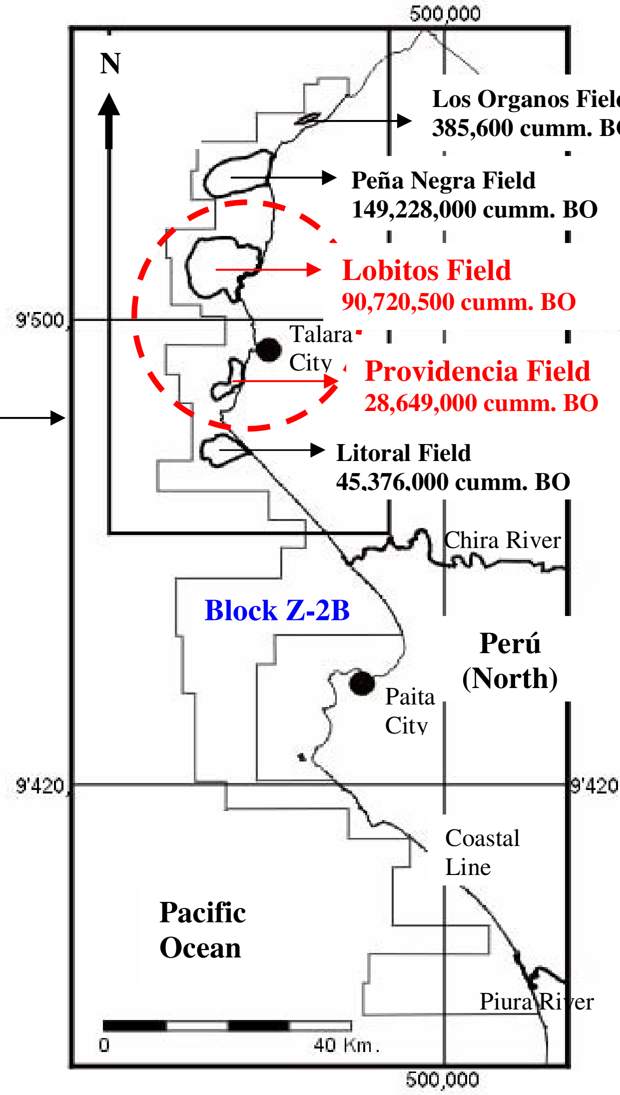

Figure 01: MEOR Project location of Lobitos and Providencia fields (Black contours circled in red). Both fields produce from Basal Salina formation under an off-shore operative Environment.

Talara basin constitutes an important objective to explore long-term use of biotechnology to enhance oil production and increase primary and secondary recovery factors, as can see below,

Table 01, Talara Basin as target of MEOR techniques

Importance of Talara Basin in Peruvian Oil Sector 2003		
Geographical scope	**Oil Production, BOPD**	**Participation, [%]**
Peru	104,058	100
Talara On/Shore	18,659	17.9
Talara Off/Shore	**10,147**	**10.0**
Jungle Field	74,982	72.1

Note: Further references can be found on, The Talara Basin Province of Northwestern Peru: Cretaceous-Tertiary Total Petroleum System, Debra Higley – U.S. Geological Survey Bulletin 2206-A, August 2004. [Ref. 15]

Objectives

The primary objective related with this work was to analize the feasibility of Biotechnological-driven methods to enhance oil recovery in reservoirs of Talara Basin (Z-2B block). Basal Salina formation was evaluated primarily as good target for MEOR by selecting two fields (Providencia and Lobitos) with important remaining oil reserves in the mentioned formation.

At January 2005, Block Z-2B has **77 platforms** operating in relative shallow waters of the Pacific ocean (50 to 380 feet) with **628 producers** (most of them high-angle slanted wells) producing **317,000 BO, 2,073,00 MSCF and 32,000 BW per month from five main fields** (Figure 01). There are 20 wells actuating as gas injectors (38,758 MSCF per Day). Other productive formations accounts in Z-2B block: Helico, Terebratula, Pariñas, Rio Bravo, Mogollon and the above mentioned Basal Salina. Figure 02 shows a typical sedimentary column, oil reservoirs (in red) and hyphotetical source rocks (S blocks). See also annexes with the N-S structural side view of Talara Basin and Basal Salina formation.

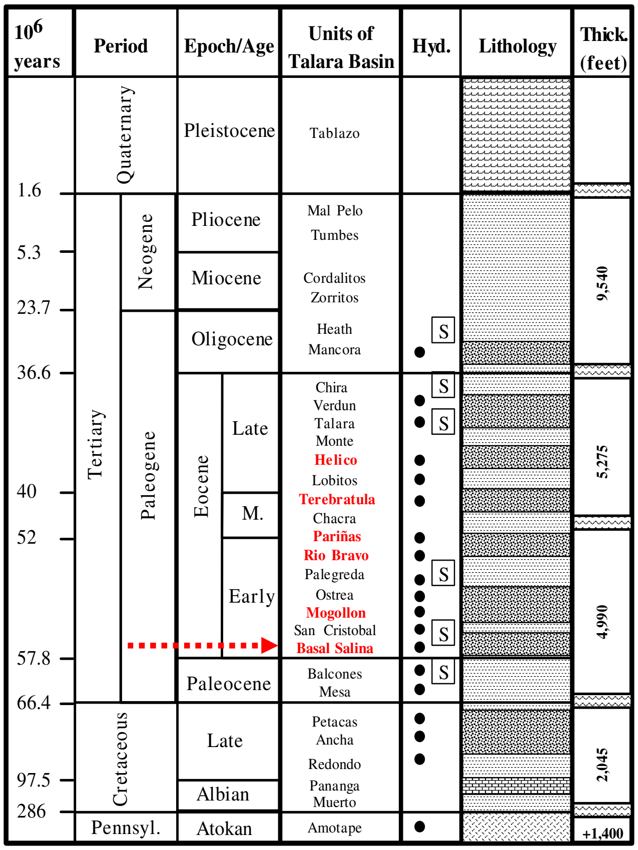

Figure 02: Simplified stratigraphic column in Talara Basin, with main productive formations of interest in Z-2B block. Basal Salina fm. is indicated by the arrow. See Annex with N-S side view.

Providencia and Lobitos Fields: Main characteristics

Table 02: General profile of Providencia Field

Providencia Field: General Information		
Subject	**Unit**	**Avg. value**
Date of discovery	-	1960
Drilled wells	-	106
Active producers	-	67
OOIP	Std MMBls	286.2
Oil Production	BOPD	869
Co-produced water	BWPD	96
Average Water Cut	%	10
Cumm. Oil (July 2004)	MMBls	28.5

Table 03: General profile of Lobitos Field

Lobitos Field: General Information		
Subject	**Unit**	**Avg. value**
Date of discovery	-	1960
Drilled wells	-	412
Active producers	-	215
OOIP	Std MMBls	1392.8
Oil Production	BOPD	3,156
Co-produced water	BWPD	480
Average Water Cut	%	13.2
Cumm. Oil (July 2004)	MMBls	90.3

Basal Salina

The economical importance of the **Basal Salina** reservoir in the **Talara Basin** (Northwest Peruvian area) is supported by the **51.6 MMBO** cumulated up to December 2004, which represents the **16 %** of the total oil produced in the off-shore Peru.

Reservoirs characterization

The Basal Salina sediments represent the Lower Eocene section, and the sedimentary environment is marine, forming turbidities sequence flowing from SE towards NW under marine conditions. Based on data obtained from wells drilled in the Talara Basin, all producer formations act as isolated reservoirs because the hydrocarbons are trapped on individual normal faulted blocks. [Annexes, Ref. 15]

Lithostratigraphy characteristics

There are not recorded outcropping of this formation. However, based on ditch cuttings, electrical logs, conventional and side wall cores can be infered that this formation is formed by alternations of thicker and thinner beds of milky-white quartz and gray to dark gray quartzite sandstone, medium to coarse grained gradding to conglomerate, poorly sorted, interbedded with dark steel- gray, claystone. Sedimentary environment is marine, forming turbidite sequence flowing from SE towards NW under marine conditions. The vertical gross thickness ranges from 500 to 1150 feet. According to palynological analysis from the shale beds, the microflora is characteristic of Zone VI. [Ref. 15]

Structural features

Many investigators (Zuñiga and Rivero, 1998, Montagna 1999, Bianchi 2002) describe the complex structural aspects in Talara Basin Province affecting oil and gas reservoirs. Normal faulting occurs as low-angle gravitational slide faults and large vertical transcurrent ones. The structural features of off-shore portion of the basin, include extensive growth faulting with associated rollover-type folding, seismic and subsurface data indicates an intensification of faulting toward eastern (onshore) regions of the northern basins, decreasing in a seaward direction.

Oils in Talara Basin and Geochemical parameters

Geochemical data is scarce and in some sense controversial showing a multiplicity of hypothetical hydrocarbon Source Rocks (from Cretaceous Albian Muerto Limestone and Marine shales of the Campanian Redondo formation, passing by Cretaceous Redondo Fm. including Cretaceous Muerto and Oligocene Heath, shales of Eocene age in San Cristobal formation, to Lower Paleocene Palegreda neritic marine shales are also believed to have adecuate TOC values (> 1% as Total Organic Carbon) to be potential source rock. The special structural features of Talara Basin influencing its productive formations (Figure 02) suggest a great diversity of migration routes and time dependent events to the final traps (Basal Salina reservoirs are part of this context), producing significative potential alterations in the compositional profile of reservoired oils. The extension of natural biodegradation has a logical detrimental impact in MEOR efficiency, therefore and despite that oils in Basal Salina show no-signs of natural biodegradation, any extrapolation of the results of this work to other oil accumulation in Talara Basin requires the evaluation of specific geochemical fingerprints [Ref. 21, 22].

Traps and seals

Based on data obtained from wells drilled in the Lobitos offshore field, it is inferred that all productive formations actuate as isolated reservoirs because the basic architecture is a system of faulted blocks where the hydrocarbons are trapped. Interbedded and overlaying marine shales constitutes the primary reservoir seals.

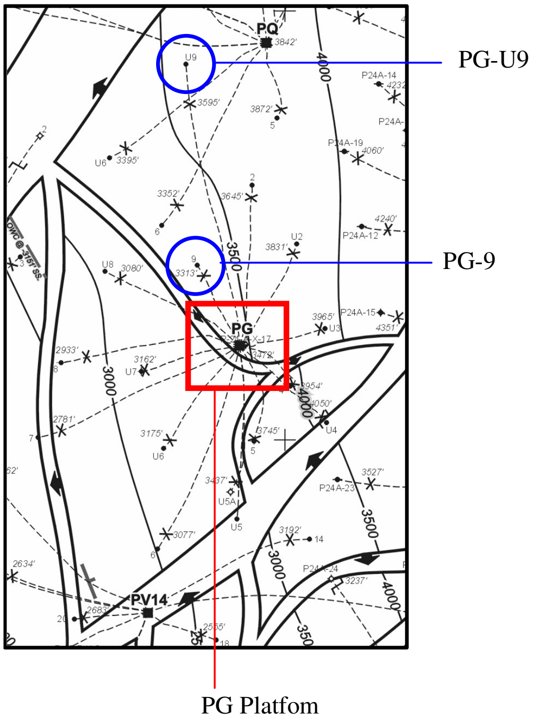

Figure 03: PG platform and cluster of slanted wells in overlap with corresponding block under exploitation in Providencia Field. PG-9 and PG-U9 producers are objectives of MEOR program.

Drainage Mechanisms

The production response of the reservoirs indicates a combination of **gas solution and gravity segregation** driven-mechanisms, and will depend of the sand quality, net oil pay, extension, structural position, porosity, water saturation, permeability and reservoir pressure.

Reservoir parameters

Below main parameters are compiled for a quick review.

Table 04: Basal Salina Reservoir in Providencia field

Basal Salina : General Information Providencia field		
Subject	**Unit**	**Value**
Top depth (a.s.l.)	feet	3,300
Average pay thickness	feet	70
Productive area	Acres	4,143
OOIP	Std MMBls	89.7
Reservoir Temperature	°F	113
Initial/Actual Pressure	Psia	1,800/220
Saturation Pressure	Psia	1,670
Average porosity	%	15
Average permeability (Cores)	mDarcy	17
Specific Gravity	°API	39
Initial Oil Viscosity (113 °F)	cp	0.689

Reservoirs are low in permeability, with large net sand thicknesses. A severe depletion is observed in both fields.

Table 05: Basal Salina Reservoir in Lobitos field

Basal Salina : General Information Lobitos field		
Subject	**Unit**	**Value**
Top depth (a.s.l.)	feet	7,000
Average pay thickness	feet	70
Productive area	Acres	2,327
OOIP	Std MMBls	108.9
Reservoir Temperature	°F	130
Initial/Actual Pressure	Psia	4,600/850
Saturation Pressure	Psia	3,580
Average porosity	%	9.6
Average permeability (BHP)	mDarcy	4.85
Specific Gravity	°API	33.6
Initial Oil Viscosity (130 °F)	cp	0.92

Production profile, Basal Salina fm. participation.

Providencia offshore field up to April 2004 cumulated **29 MMBO**, with **85%** of produced oil becoming from **Basal Salina** fm.The Lobitos offshore field up to April 2004 had cumulated **90 MMBO**, where the most prolific reservoirs are the **Pariñas**, **Rio Bravo** and **Basal Salina** with **35%**, **30%** and **20%** of this production respectively.

General parameters of produced fluids

It is remarkable the °API range and oil viscosities at BHT's

Table 06: Fluids parameters in Basal Salina (Providencia)

Basal Salina fm Fluid Properties – Providencia field		
Subject	**Unit**	**Value**
Specific Gravity	°API	39
Actual Oil Viscosity (113 °F)	cp	6.5
Oil Volume Factor (@ Initial Pressure	Dim.	1.275
Typical cloud point	°F	-8 to 7
Gas-Oil ratio	Scf/bbl	2,300
Water salinity (TDS) at 70 °F	ppm	14,500
Water salinity (Cl-) at 70 °F	ppm	8,200
Water Viscosity (113 °F)	cp	1.1
Density (113 °F)	gr/cc	1.01

Table 07: Fluids parameters in Basal Salina (Lobitos)

Basal Salina fm Fluid Properties – Lobitos field		
Subject	**Unit**	**Value**
Specific Gravity	°API	33.6
Actual Oil Viscosity (130 °F)	cp	13.5
Oil Volume Factor (@ Initial Pressure	Dim.	1.351
Typical cloud point	°F	-14 to 4
Gas-Oil ratio	Scf/bbl	4,200
Water salinity (TDS) at 70 °F	Ppm	19,000
Water salinity (Cl-) at 70 °F	ppm	11,200
Water Viscosity (130 °F)	cp	1.1
Density (130 °F)	gr/cc	1.015

Biotreatability of produced fluids

The first task to device a MEOR program is to evaluate oil bio-treatability, in simple words this means how good is the oil as carbon substrate to derive nourishment for the microbial community. Details about the lab methodology and testing protocols can be consulted on reference papers [Ref. 7 to 14]

Products structure

Seven oil samples from three main formations were analized by computed rheometry to determine the best combination of microbial products (segment of different microorganisms with specific rheological impact according with hydrocarbon type and chain length). Below is a graph illustrating the rheological impact on inoculate portions according with different microbial cultures (EOR-BAC serie).

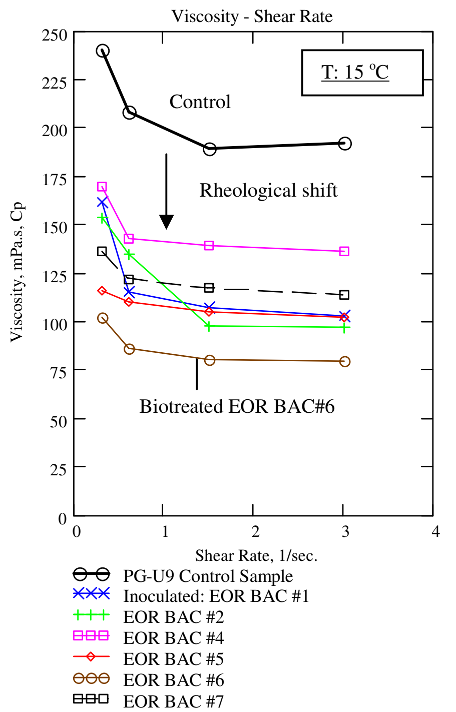

Figure 04: Microbial subgroups response in Basal Salina oils

The rheology profile of tested oils using seven different microbial products determined that a good combination for Basal Salina oils could be EOR-BAC#1 (20%), EOR-BAC#2 (10%), EOR-BAC#5 (20%) and EOR-BAC#6 (50%).

Time-derived considerations

To evaluate the time-dependency of bio-reactions which take place in the oil, an experimental design using a specific pool of microbial inoculants (usually having the participation determined above) was continuously cultured. The lab-scale module uses 500 ml. twin bioreactors to explore reology impact with extend of biorreaction (biocracking severity is time dependant). To extend these results to the well completion-Reservoir geometry the scaling was accomplished by parametric simulations. The central idea is to calculate flow patterns of incoming fluids production through perforated interval, to measure available resident time, dilutive effects on passive substances and migration rates on active ones (colonizing biota). The final results are translated in terms of initial and successive shut-in times, displacing volumes, etc. as operative parameters during a treatment job (pulsing program).

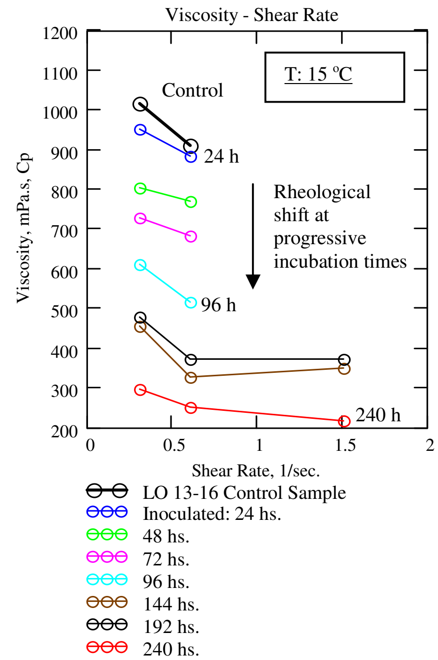

Figure 05: Influence of Incubation time on oil treatability

According with reservoir parameters of Basal Salina fm. (Kabs. Porosity, saturations), completion characteristics (net pay intervals, shots density) and operative constraints (BLT or conventional Gas lift), a compromise was assumed to fix the initial and successive shut-in periods in 48 and 24 hours respectively.

Thermodynamic conditions of target reservoirs

Basal Salina fm. registrates 113 (45) and 130 (55) °F (°C) as SBHT respectively, therefore it is necessary to measure the reological shift at those conditions in order to model the impact in productivity indexes for different colonizing radii.

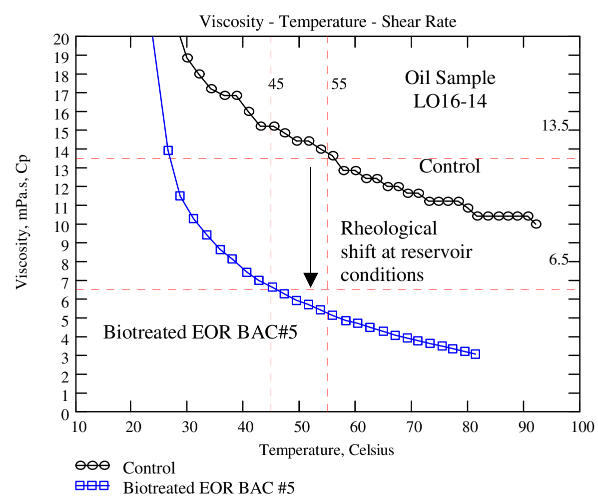

Figure 06: Viscosity- Temperature curves for control and biotreated oils. It is observed a significative viscosity shift at reservoir temperatures.

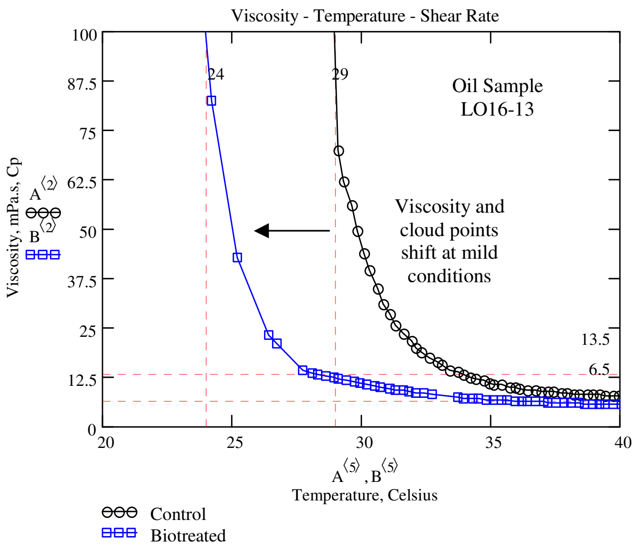

Figure 07: 5 °C Shift in cloud points on biotreated oil samples

The curves in Figures 06 illustrate this concept for LO16-14 oil sample at typical reservoir conditions (Basal Salina fm.) Figure 07 explains the same at lower temperatures for LO16-13 oil sample at typical reservoir conditions (Mogollon fm.) at the subsurface-surface temperature ranges found in Providencia and Lobitos producers. In sake of brevity the rheological tests conducted on the rest of oil samples to test biotreatability are summarized using the NI, DV and EOR indexes methodology (Table below). [Ref. 10, 11, 12]

Table 08: Summary of Biotreatability Indexes in oils from productive formations of Z-2B block (Talara Basin)

Sample Id.	Formation	NI	DV	EOR
PG-U9	Basal Salina	2.15	0.58	2.38
LO16-14	Basal Salina	2.96	0.42	1.71
LO13-16	Basal Salina	3.67	0.44	1.80
PG-1	Basal Salina	6.17	0.52	2.08
LO16-13	Mogollon	2.36	0.71	3.50
PN10-17	Mogollon	1.14	0.44	1.77
VV-5	Rio Bravo	5.85	0.66	2.93
Limits for a Positive test		**> 1.10**	**> 0.10**	**>1.15**

Compositional profile of Basal Salina and Mogollon oils

MEOR methodologies based on biocracking technology require substantial amounts of N-alkanes in the whole oil to be effective. Interactions with other hydrocarbons families are also important. SARA analysis conducted by a third party analist [Ref. 35] is given below.

Table 09: SARA analysis

Sample Id.	Well		Formation
CO-812	**LO16–16**		**B. Salina/Mogollón**
Saturates	**Aromatics**	**Resins**	**Asphaltenes**
61.0	27.8	10.7	0.5
CO-815	**PVX8–12**		**B. Salina/Pariñas**
Saturates	**Aromatics**	**Resins**	**Asphaltenes**
65.9	24.7	8.8	0.6

Considering the saturate Hydrocarbon portion, all tested oils exhibited a similar profile of N-alkanes, covering the same range of carbon chain lengths (C_1 to C_{33}, even to C_{44})

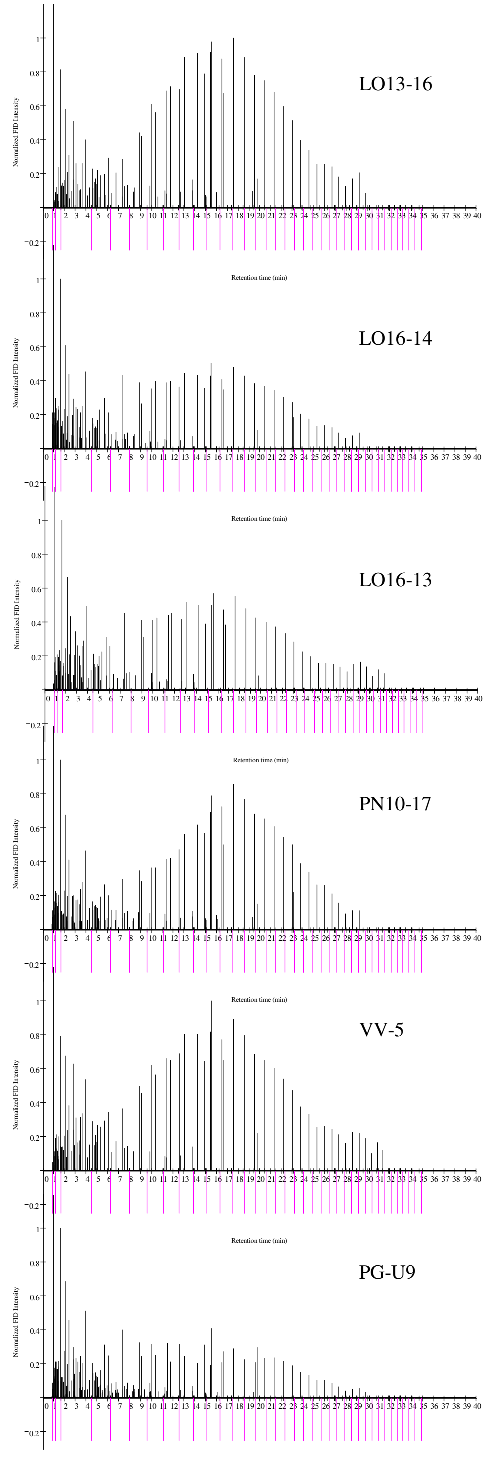

Figure 08: GC profiles of several oils in Z-2B block, showing unimodal and similar N-alkanes profiles

The oils are monomodal in N-Alkanes distributions and not evidencing any signs of significant natural biodegradation.

Normally crude oils contain boths resins/resinoids and asphaltenic compounds. The first actuates as amphiphilic compounds to maintain asphaltenes in solution. The high resins/asphaltenes ratio turns unlikely asphaltene precipitation at reservoir typical condition found in Basal Salina fm., however a more detailed study taking into account different thermodynamics scenarios and species could be necessary to interpret more deeply wellbore damage mechanisms by organic/inorganic co- precipitates.

Tabla 10: Compositional Ratios in Talara oils (B.Salina, Mogollon fms.)

Sample Id.	Hydroc. to non-Hydroc. ratio	Saturates to Aromatics ratio	Resins to Asphaltenes ratio
CO-812	7.9	2.2	21.4
CO-815	9.6	2.7	14.7

Phase behaviour of oils with high content of N-alkanes can explain subsurface obturation and progressive wellbore damage. A simplified analysis considering the melting points for these hydrocarbons and BHT's at Basal salina fm. in Lobitos and Providencia areas, indicates that n-C22 (Docosane) and higher N-alkanes exist as solid particles in a fluidic matrix of lighter compounds (gas/liquid state). Complex rheology exhibited in mixtures of multiple molecular species with part of the components as liquids and part as solid particulates exhibits pseudoplastic, non-newtonian behaviour. Flow patterns (typically below Reynolds of 5 at near wellbore) in producers with large perforated intervals, are suited in a cascade effect according with viscosity-shear rate dependency, causing that production ceases completely in some regions (low flow, high apparent viscosities), with the corresponding increase in others (higher flow rates, app. viscosity turns lower). As the well declines this situation is aggravated with the net effect of progressive reduction in vertical efficience of pay intervals.

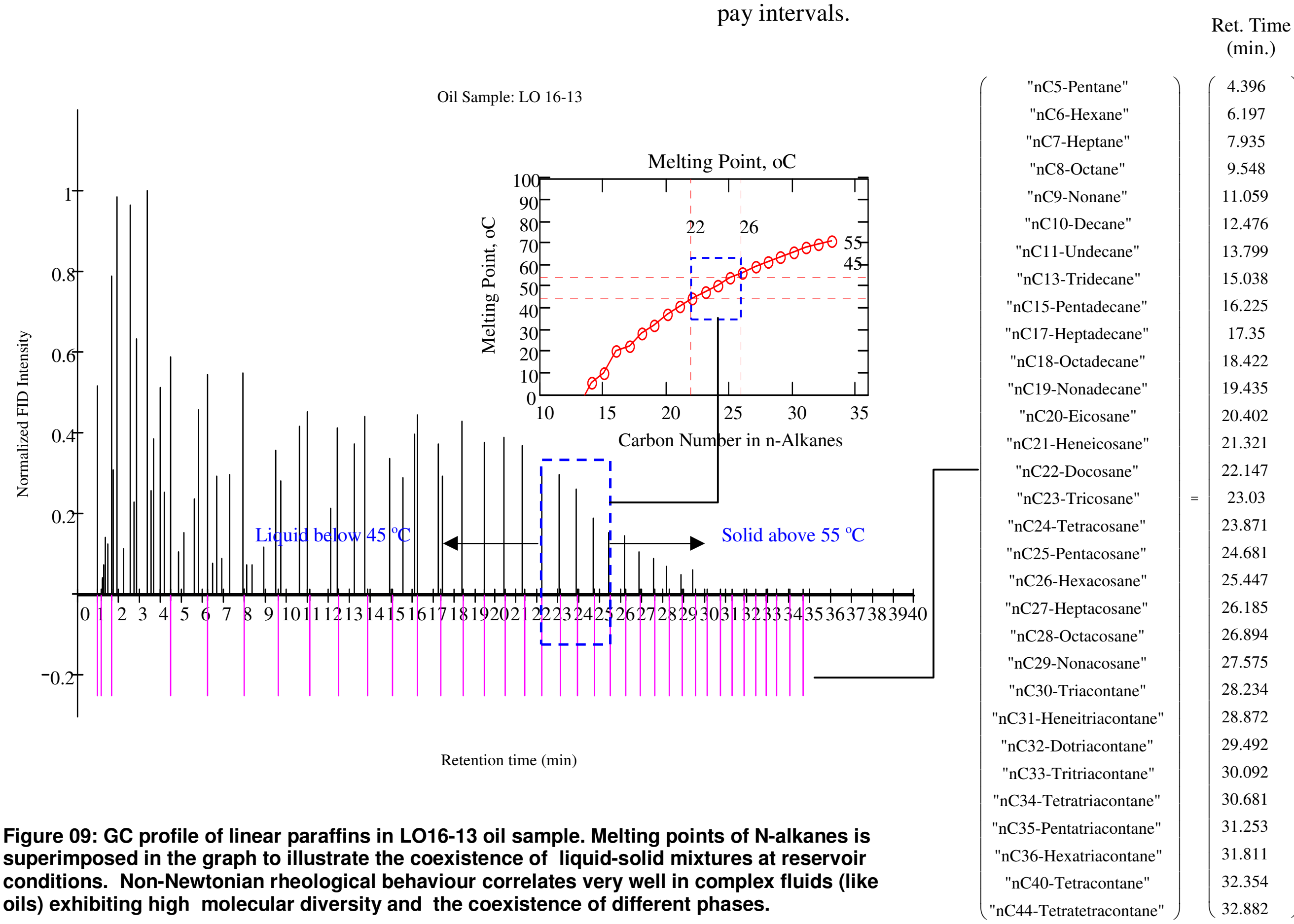

Figure 09: GC profile of linear paraffins in LO16-13 oil sample. Melting points of N-alkanes is superimposed in the graph to illustrate the coexistence of liquid-solid mixtures at reservoir conditions. Non-Newtonian rheological behaviour correlates very well in complex fluids (like oils) exhibiting high molecular diversity and the coexistence of different phases.

Poral network characteristic and solids interact to reduce absolute permeability by incipient precipitates in tight regions creating an excess of flow in neighbouring regions, the shear rate consequently increases causing a further reduction in apparent viscosities. The combined mechanism terminates at some equilibrium point with a net reduction in overall productivities for the open interval. MEOR methods based on Biocracking mechanisms correct the problem in virtue of the molecular conversion of heavy end in lighter ones. The compositional alteration turns more homogeneous the oil by reducing the range of molecular sizes (carbon chain lengths) , this causes the oil to behave as more Newtonian even at low shear rates. See annex for BSI (Biocracking Severity Index) calculation in PG-09 case. [Ref. 13, 14, 20]

Bio-Applicability

There is a number of factors affecting MEOR design and corresponding field implementation. A second stage of feasibility screening tasks pursue to determine the way that positive oil biotreatabilities at lab scale can be extrapolated to downhole geometries. Multiphase flow of non-newtonian fluids converging to the wellbore, poral space characteristics, type of completion and extractive system, usually contributes as main constrains to define MEOR applicability and the corresponding operative microbial "pulsing" program.

Reservoir characteristics

Basal Salina fm. has an intrinsic low permeability matrix which can cause lower microbial migration rates and limitates the radial colonization. The high proportion of saturates in reservoir oils turns it as an excellent substrate for biocracking but the fact that reservoir isotherm cross the melting point curve for these compounds, can cause a restricted fluid uptake during inoculations. [Ref. 3 to 6]

Completion methodology

Target blocks in Providencia and Lobitos fields are produced by a completion architecture based on clusters (in a number of 10 to 25) of high-angle slanted wells operated from shallow waters marine platforms (Figure 25 to 29). The Basal Salina low-permeability feature is partially solved by slanted wells with large perforated intervals using variable shoot-densities followed by various types of stimulation strategies (Oil-base fracturing using selective techniques, matrix acidizing, solvent batches) according to petrophysis of each zone.

Table 11: Stimulation methods in Basal Salina reservoirs

Well Id.	Completion Date	Productive Interval (ft)	Stimulation Job
PG-1	07/1968 09/1998	3,369 -3,620 3,369-3,403	Oil frac, 260 sacks, (20/40 sand)
PG-2	04/1969	4,185-4,545	Fracturing, Acids, Massive Solvents
PG-9	03/1969	3,593-3,794	Oil frac, 270 sacks, (10/20 sand)
PG-U9	01/1969	5,414-5,684	Fracturing, Acids, Massive Solvents
LO16-14	04/1995	9,460-9,664	80 bbls Microb.
LO16-24	04/1998	9,986-10,086	60 bbls. 10% HCl
LO13-16	11/1987	9,040-9,050	Hot oil

Based on swabbing test results the bottom layers with higher water cuts are isolated, maintaining as productive the upper ones. MEOR design, which is dynamic in nature, takes in consideration all of these factors [Ref. 23, 24, 25]

Extractive system

85% of the artificial lifting system in Z-2B is based on intermitent GL using conventional and BLT (Bottom Lateral Taking) string system (70%).

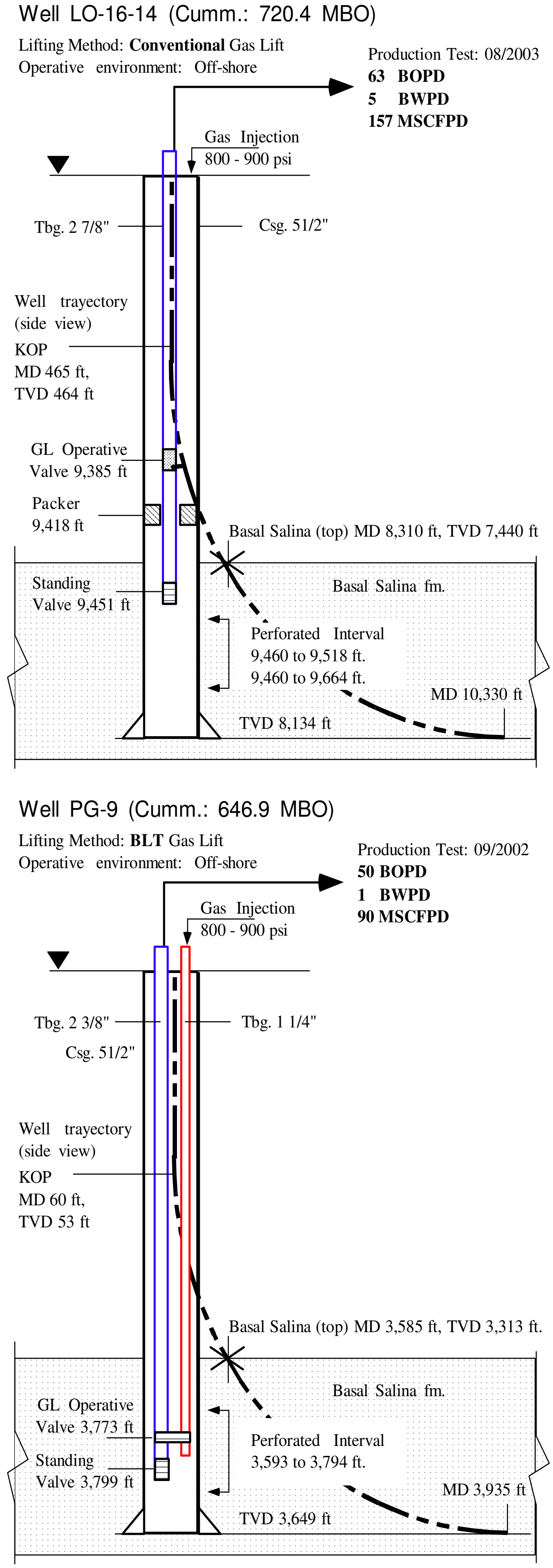

Figure 10: Conventional (LO-16-14) and BLT (PG-U9) GL systems.

There are few cases of hydraulic installations, with minor cases of producers under natural flowing.
The produced gas in Z-2B block (115,057 MSCFD, Jan. 2005) is captured and compressed to assist GL installations (41% or 48,181 MSCFD) with a range of 10 to 25 independent wellhead injection points per platform. The excedent gas (66,876 MSCFD) is re-inyected for pressure maintainance in 20 injectors (34% or 38,758 MSCFD) and the rest (25%, 28,118 MSCFD) is used as fuel gas, vented or commercialized. The recycled gas has a Gr. Sp. of 0.6843 with 85.9% of C_1 and is relatively rich in C_2-C_6 fraction (14.4%). The compressed gas reaches the GL injection points rounding **850 to 900 psia.** with temperatures of **180 to 220 ^oF (82.2 to 104 ^oC).** A typical intermittent GL cycle has an "on" period of 6 minutes followed by an "off" segment of 60 minutes, but it can vary on an ample range. There is a limitation in the number of simultaneous wells that can be simultaneously assisted with pressurized gas in the on part of the cycle, therefore GL operation need to be in close supervision to optimize gas resources according with production objectives.

Parafin deposits problems and SH_2

The high parafinic characteristic of Z-2B Block oils causes severe deposits on surface production facilities and subsurface production string. The problem is afforded by a systematic program based on a mix of paraffin inhibitors (32 55-gallons drums are consumed per month in the entire area). As illustrative example (LO16-14 well) accounted a cost of $ 2,850 U$D per month for paraffin removal (chemicals, 11%, Scrapping, 12% and 77% as deferred production). Periodic cutting/scrapping procedures occurred every 17 days, 800 to 2600 feet of mean scrapped length per job, and taking in average 4 hours as well shut-in time. Sometimes, complemented with hot gas injection to melt the crystallized recipitates. The mentioned problem was concomitant with incipient biogenic SH_2 corrosion (mainly in Peña Negra and during waterflooding experiences)

Operative program

MEOR is highly dependant of mentioned operative context, completion geometry and extractive systems. The inoculation methodology and treatment schedule was discussed and adapted with the agreement of field supervisors, production managers, reservoir engineers and microbiologists.

Inoculation methodology (well treatment job)

The main objective of a MEOR treatment program (also called a "pulsing" program) is to permit an active penetration of bacterial pool to contribute with a quick and deep colonization, reducing to a minimal shut-in periods(latency). These aspects have a direct influence on MEOR response, lowering microbial flow-back optimizing the efficience of microbial formulation and pulse size.
MEOR field implementation requires different procedures for wells using BLT in opposition with Conventional GL. Well PG-9 (BLT) was treated by gravity-driven batchs using the annulus and LO16-14 required squeezing techniques via production string (2 7/8 O.D. inches tubing).
Figure 10, [Ref. 11]

For Conventional GL systems (like in LO16-14), the inoculation procedure needs to be performed thru the **tubing line**, because the packer interrupt the annulus. The standing valve (SV) installed at tubing end need to be "fished" using wireline procedures to permit the inoculation into the reservoir. Despite that this methodology can exert a controllable and positive (not just by gravity) displacement of microbial blend into the formation, sometimes there is an intrinsic risk to be part of additional fishing/repairment/pulling problems during SV capture. No matter what procedure is in use, the general principle behind a sequence of MEOR treatments is to generate stable bioreaction regions as bigger as possible and preserved during the all productive life of the well with minimum interference or downfall in production (deferred oil). When sound enginnering is applied, a well conducted MEOR Program, creates stable split the drainage volume of the near reservoir in two concentric zones with the inner altering the reological behaviour for in-transit fluids coupled with outer ones with native properties. [see annex B in Ref. 10].

Project Monitoring

MEOR response is related with the productivity Index (P.I.) of the treated well (Eq. 01), so it is expected a measurable change in inflow performance for a given drop of pressure (usually calculated by subtracting the Bottom Hole Flowing Pressure from current Static Reservoir Pressure).

$$MEOR_{(T_i)} = \frac{\dfrac{Qmeor_{(t_i)}}{Pe - Pwfmeor_{(t_i)}}}{\dfrac{Qo_{(t_i)}}{Pe - Pwf_{(t_i)}}} \quad \text{..................Eq. 01}$$

where:

$Qo_{(t_i)}$	Declined oil production (convtentional), [BOPD]
$Qmeor_{(t_i)}$	Enhanced oil production [BOPD]
$Pwf_{(t_i)}$, $Pwfmeor_{(t_i)}$	Dynamics pressures, [psi]
Pe	Static reservoir pressure, [psi]

This concept is of general application for any EOR method or stimulation technique influencing parameters of the fluid-rock complex. MEOR response can be measured as a **rate improvement**, combined **with an increase in botton hole flowing levels (pressures)**.
By far the most important surveillance activity during a MEOR program is to collect confident (low noise), dense and accurate production data in coordination with the appropiate sampling frequency and catching protocols. In order that MEOR response in P.I. can be entirely expressed as oil rates increments it is imperative to verify the constancy of bottonmhole flowing pressure during pre- and post-MEOR stages. It is also necessary to exert a close supervision on GL efficience for treated producers.

MEOR "pulsing" Design

The basic data to calculate treatment volumes of microbial concentrates and shut-in times is the fluid production information for selected wells with the geometrical description of subsurface equipment (downhole hardware). Fluid-Rock parameters joined with the thermodynamic variables serves as input to simulate microbial migration rates and corresponding biocracking severity indexes. The final result is a set of J-shaped Curve-Types summarizing the MEOR performance in the Qoil, Qwater vs. time dominium.

Table 11: MEOR candidates, parameters used for treatment design

Well Id.	Interval Basal Salina fm. (ft)	Net pay interval (net perforated sand , ft)	BOPD @ MEOR start	BWPD @ MEOR start	MSCFPD @ MEOR start	BHSP (psi)	Cumm. Oil @ MEOR start (MBO)	GAS Lift System
PG-1	3,519-3,620 3,369-3,403	55 17	16	0	39	180	490.3	BLT
PG-2	4,185-4,545	143	28	0	87	200	495.8	BLT
PG-9	3,593-3,794	40	50	1	90	150	646.9	BLT
PG-U9	5,414-5,684	134	51	13	72	220	1045.7	BLT
LO16-14	9,460-9,664	90	63	5	157	850	720.4	Conv.
LO16-24	9,986-10,086	50	27	1	135	480	152.5	Conv..
LO13-16	9,040-9,050	10	31	0	-	750	1771.8	Flowing/GL

As was pointed before, the operative context conspirates with a perfect match between MEOR original program and the effectively implemented in the field. Table below summarizes the executed MEOR program, pointing discrepancies.

Table 12: Treatment effectively done (PG-1, PG-2 and LO-13-16 received 3, 3 and 1 treatment respectively)

Well Id.	Treatment Frequency (days)	Microbial blend (gals)	EOR#1 (gals) 10^6 CFU/ml	EOR#2 (gals) 10^6 CFU/ml	EOR#5 (gals) 10^6 CFU/ml	EOR#6 (gals) 10^6 CFU/ml	EOR-DRY (Pounds)	Shut-in time (hours)	Displacing Batch (bbls)
PG-9	Initial	70	15	10	15	30	20	48	60 KCL 2%
	54	70	15	10	15	30	20	24	60 KCL 2%
6 pulses	57	70	15	10	15	30	20	24	60 KCL 2%
	62	70	15	10	15	30	20	24	10 KCL 2%
	197	70	15	10	15	30	20	24	10 Sea water
	63	140	30	20	30	60	40	24	10 Sea water
PG-U9	Initial	70	15	10	15	30	19	48	50 KCL 2%
	29	70	15	10	15	30	19	24	60 KCL 2%
	41	70	15	10	15	30	19	24	60 KCL 2%
7 pulses	76	70	15	10	15	30	19	24	60 KCL 2%
	42	70	15	10	15	30	19	24	10 KCL 2%
	175	70	15	10	15	30	19	24	10 Sea water
	31	70	15	10	15	30	19	24	10 Sea water
LO16-14	Initial	45	10	5	10	20	13	48	13 KCL 2%
	30	27.5	5	2.5	5	15	8	24	13 KCL 2%
	93	27.5	5	2.5	5	15	8	24	13 KCL 2%
7 pulses	44	27.5	5	2.5	5	15	8	24	13 KCL 2%
	150	27.5	5	2.5	5	15	8	24	13 KCL 2%
	81	27.5	5	2.5	5	15	8	24	10 KCL 2%
	39	50	10	0	10	30	10	24	13 KCL 2%
LO16-24	Initial	45	10	5	10	20	13	48	10 KCL 2%
	35	27.5	5	2.5	5	15	8	24	10 KCL 2%
	29	27.5	5	2.5	5	15	8	24	10 KCL 2%
6 pulses	28	27.5	5	2.5	5	15	8	24	10 KCL 2%
	115	85	15	10	15	45	24	24	13 KCL 2%
	34	82.5	15	7.5	15	45	24	24	13 KCL 2%
Total	28 pulses	**1507.5**	310	187.5	310	700	**421** all mixed in 60 bbls (blending water)		
Product participation structure		100 %	21%	12%	21%	46%	0.28 Pounds per microbial gallon		

Note: Discrepancies are mainly in treatment periodicity (in red) or displacing water, and constitutes a matter of optimization.

Project results

The analysis of MEOR response will be restricted to PG-U9, PG-9 (Providencia) and LO16-14, LO16-24 (Lobitos). Despite that initially PG-1 and PG-2 integrated the group of MEOR candidates, only three treatments were performed on these wells, in the same way the well LO16-13 received just the initial treatment and due to operative reasons not related with MEOR, was discontinuated.

MEOR performance at Lobitos Field

Well LO16-14: Technical discussion is centered on Pre-meor and Post-MEOR production series, with corrections in pwf´s derived from GL optimization stages (see Figures below). MEOR performance is considered very satisfactory with two clear radial colonization stages preceded by strong clean-ups. The excessive lagging between treatments 4 and 5 caused a retractive behaviour in colonizing radious (estimated in 20 meters by curve-type analysis, see the tilted "J" shape curve between 3 to 5 points). Considering two different declines and data corrections according with DPwf detected in Pre- and Post-MEOR series (Figures 12, 13), a 73% of increase in cumulative oil was considered conservative as MEOR response for this producer. The "pulsing" of microbial laden fluids proceeded by tubing string at low injection rates (below 1-2 BPM).

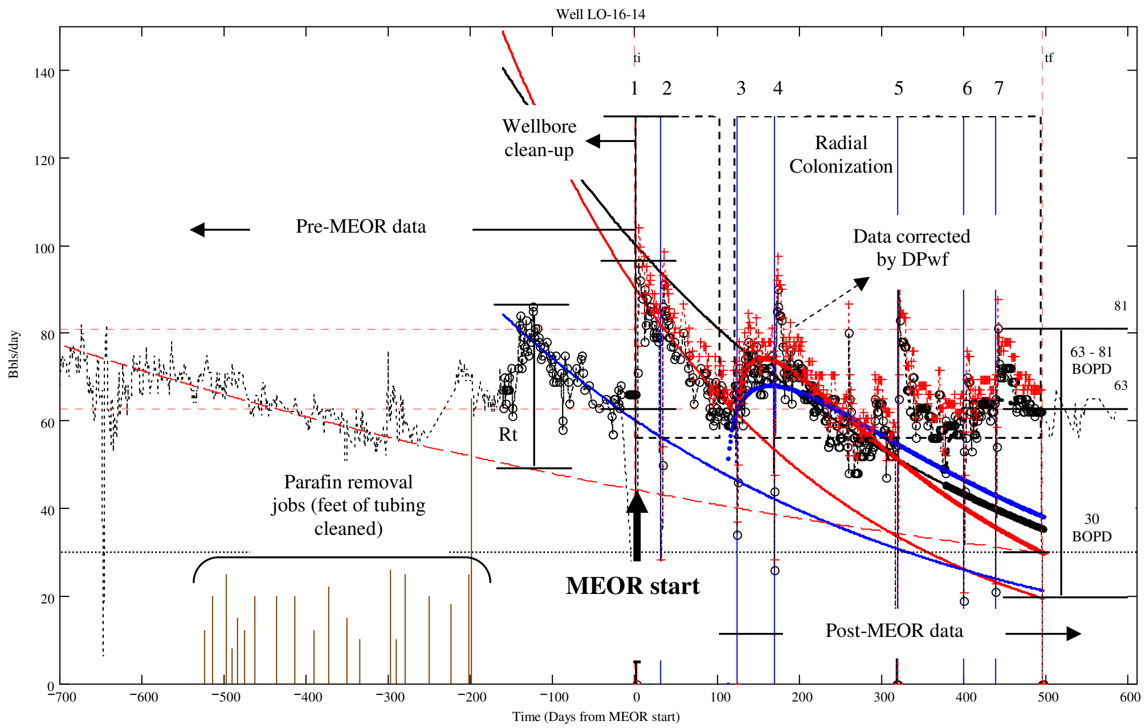

Figure 11: Pre-and Post-MEOR data series for LO16-14, indicating typical behaviour, decline models and curve type analysis

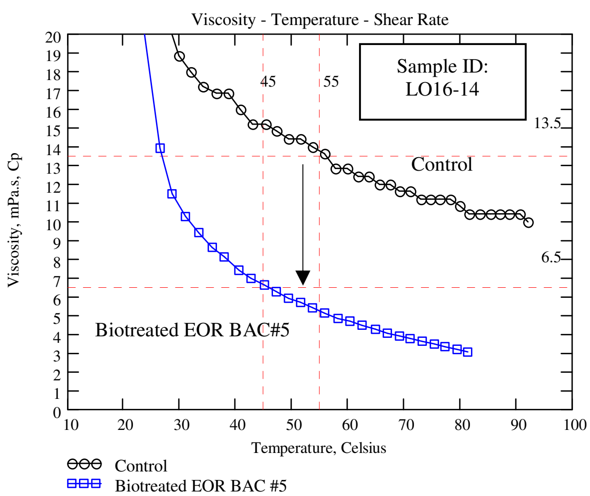

Figure 12: Viscosity shift measured at reservoir temperature Accounted a reductive factor of 2.

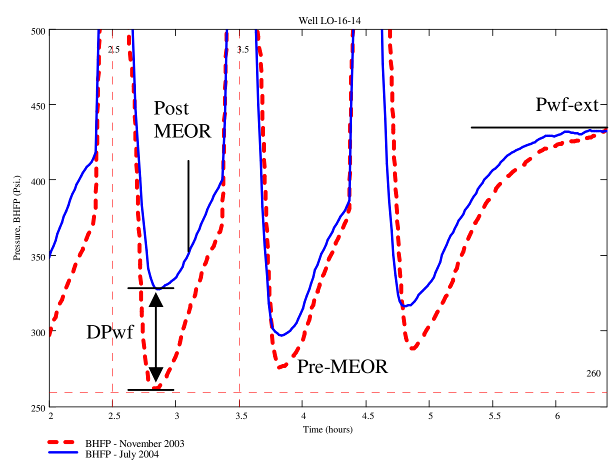

Figure 13: Pre- and Post-MEOR bottom hole dynamic pressures measured during a routinary GL session shows increasing levels not directly translated in rate improvement.

Projet results (Cont.)

Well LO-16-24: MEOR performance is considered near to marginal, despite that a clear wellbore clean-up is observed, with abrupt obturation (after treatment 2) downstream the perforated interval (along subsurface extractive installation). A weak radial incursion (<10 meters) after treatment number 4 indicates a retarded effect in microbial migration, probably by the concurrent factors of intrinsic low permeability in the near to wellbore with strong heavy paraffinic deposits. Low incursion radius during the inoculation job and/or a relatively short shut-in period can explain this abnormal behavior (shut-in times need to be raised from 24 to 36 hours). A 10% of increase in cumulative oil was considered as the average MEOR response for this producer, an additional 11% is explained by differences in Bottom hole flowing pressure before and after MEOR (see Figures below). The "pulsing" of microbial laden fluids proceeded by tubing at low-rate injection regime (1-2 BPM).

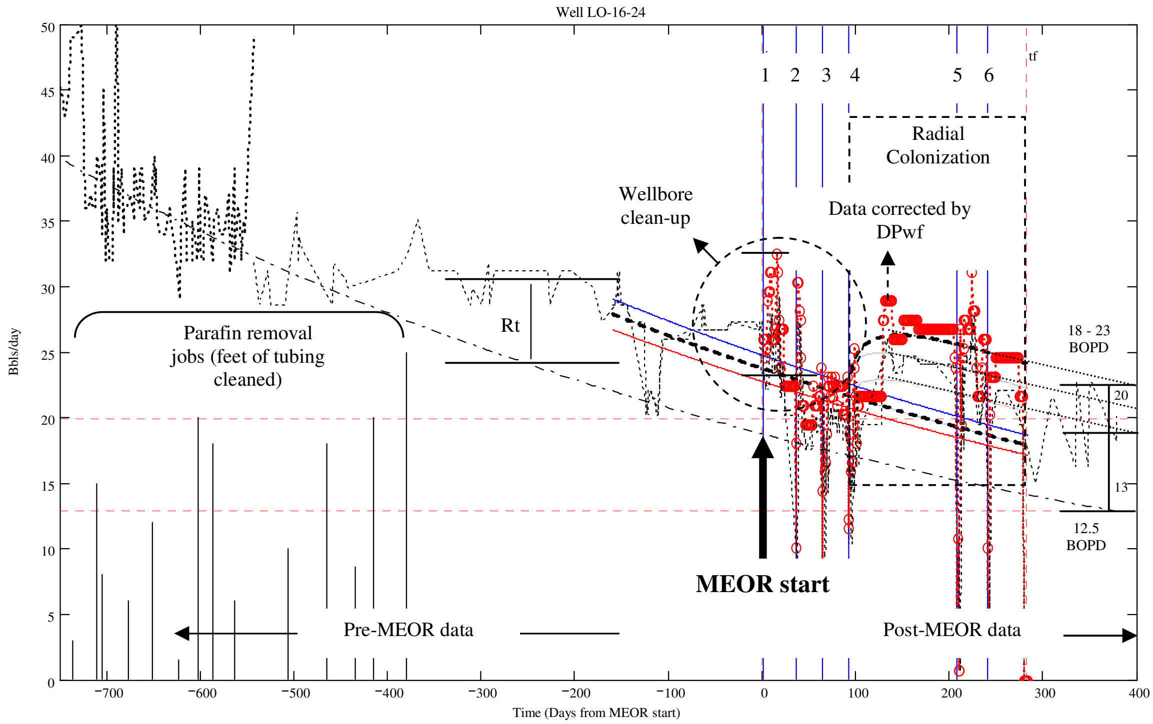

Figure 14: Pre-and Post-MEOR data series for LO16-24, indicating marginal behaviour, and small radial incursions. Decline models and curve type analysis

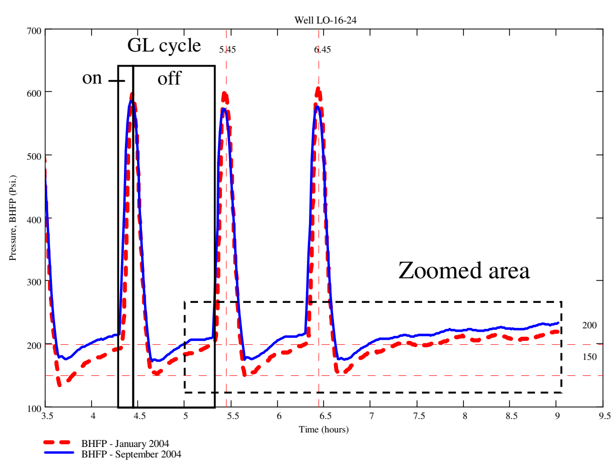

Figure 15: GL data series of pressure vs. time registered via downhole EMR

The graph permitted to infere that part of MEOR performance is accounted by an increase in dynamic levels. It was necessary to perform periodic evaluations and adjustments in GL cycles to translate excess in dynamic levels to corresponding higher production rates.

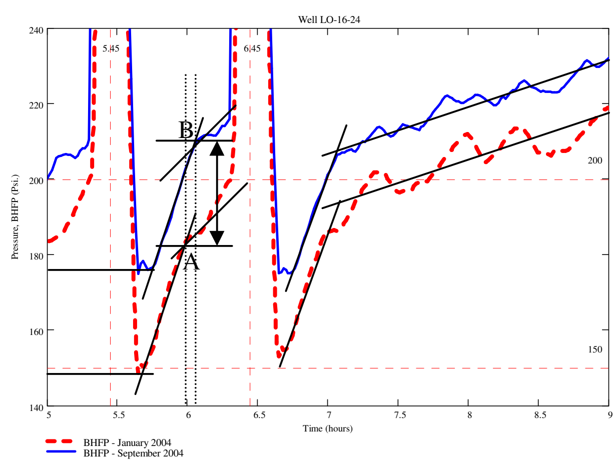

Figure 16: Zoom showing differences in Pwf pre and post-MEOR (points A and B respectively).

It is also observed the need of shortening the off interval in GL cycle (break segments after A, B points) After MEOR serie is considered more stable when is compared with conventional (Pre-MEOR data).

Project results

MEOR Performance at Providencia Field

Well PG-9: MEOR performance is considered very positive and a classic MEOR behaviour with a first clean-up stage (1, 2 and third treatments) followed by weak radial bioreaction developments (after 4). Excessive lagging between inoculation jobs caused some retraction in colonizing rate that was solved with treatments 5, 6. The MEOR performance is not exhibiting new clean-up peacks with a definite radial colonization signature (estimated in 15 meters by curve type analysis, see the tilted "J" shape curve after inoculations 5, 6). Considering declining history, a 29% of increase in cumulative oil was considered as mean MEOR response for this producer. Pre-MEOR and Post-MEOR production series were not corrected by differences in pwf´s derived from GL optimization stages. This case has a remarkable compositional signature (BSI: +372, 62% of viscosity reduction, Figures 30 to 33). [Ref. 10, 13, 14, 20]

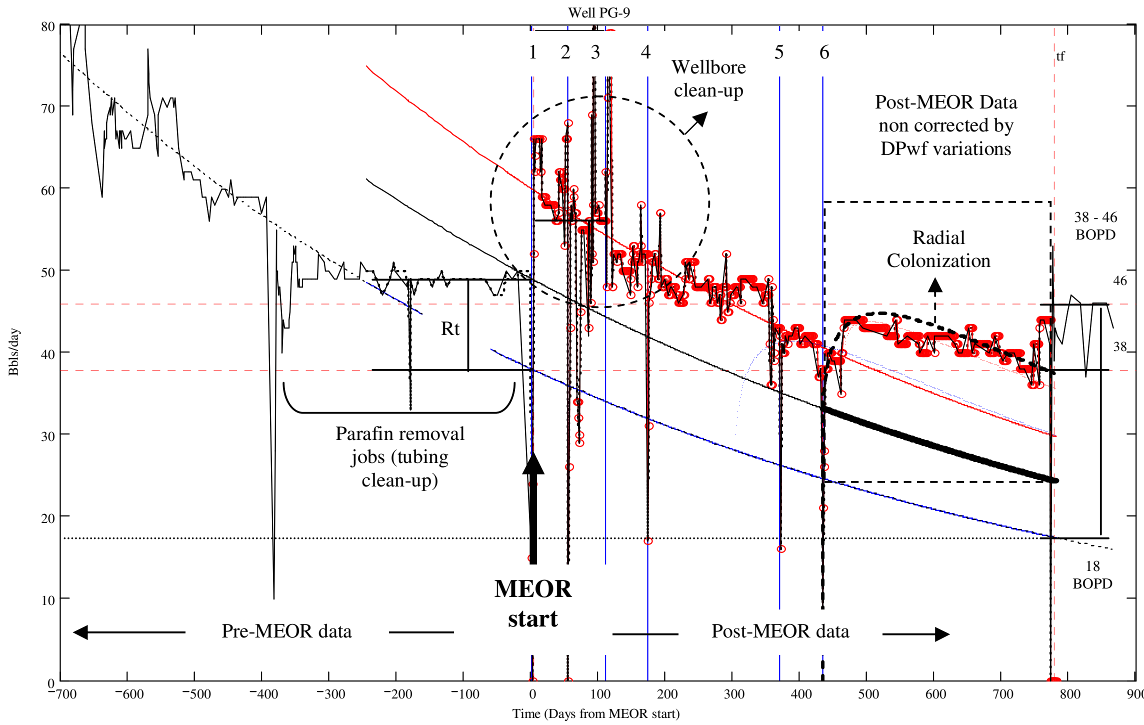

Figure 17: Pre-and Post-MEOR data series for PG-9, differentiating wellbore clean-up pulses from stable radial colonizing stage. Decline models and curve type analysis. Rt symbol is used to denotes tubing flow resistances.

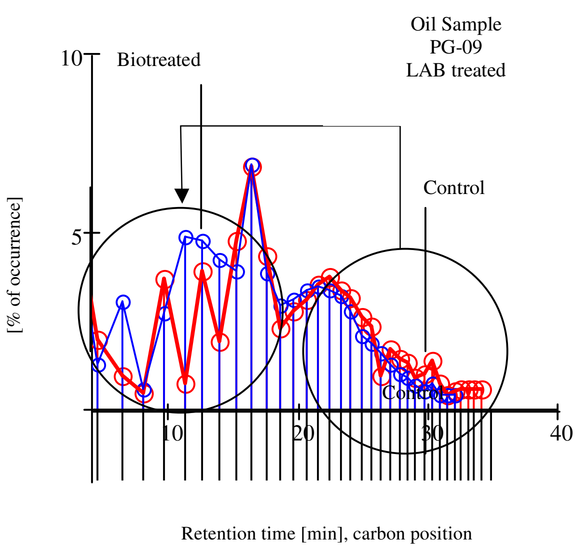

Figure 18: GC signature on N-Alkanes control and biotreated series at lab conditions (biotreatability tests), The biocracking of heavy ends produces lighter components.

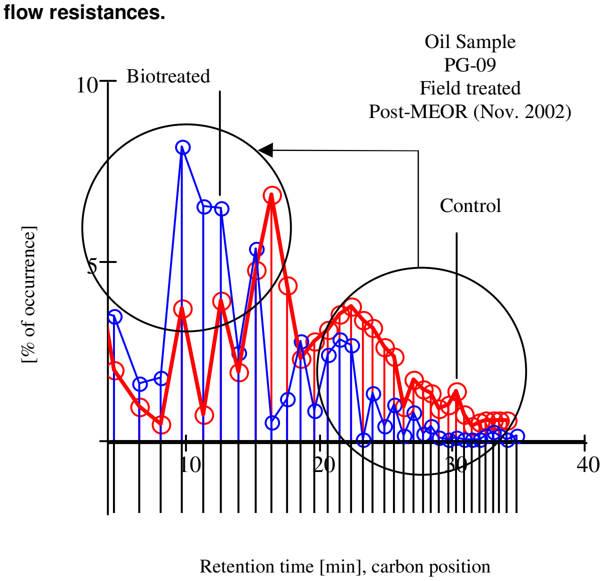

Figure 19: The same GC analysis conducted on after MEOR (Nov. 2002) field samples reveal an impressive shift to low molecular N-alkanes. Biocracking Severity Index is proportional to GC shift.

<u>Well PG-U9:</u> Oil and Water Pre-MEOR and Post-MEOR production series were used to analize mobility alterations caused by biocracking reaction at the poral space. MEOR performance is considered very satisfactory with two clear radial colonization stages. Clean-up peacks are only weakly observed after the initial and 2nd treatment followed with two concatenated deeper radial incursions in coincidence with 3 to 5, and 6, 7 inoculation jobs Two set of tilted "J" shape curves permitted to estimate the microbial migration radii in 15 and 30 meters respectively. 44 % of increase in cumulative oil was considered conservative as MEOR response for this producer. After 800 days of post-MEOR history, PG-U9 produces in a range of 33-40 BOPD, compared with just 22 BOPD as inferred from decline prediction.

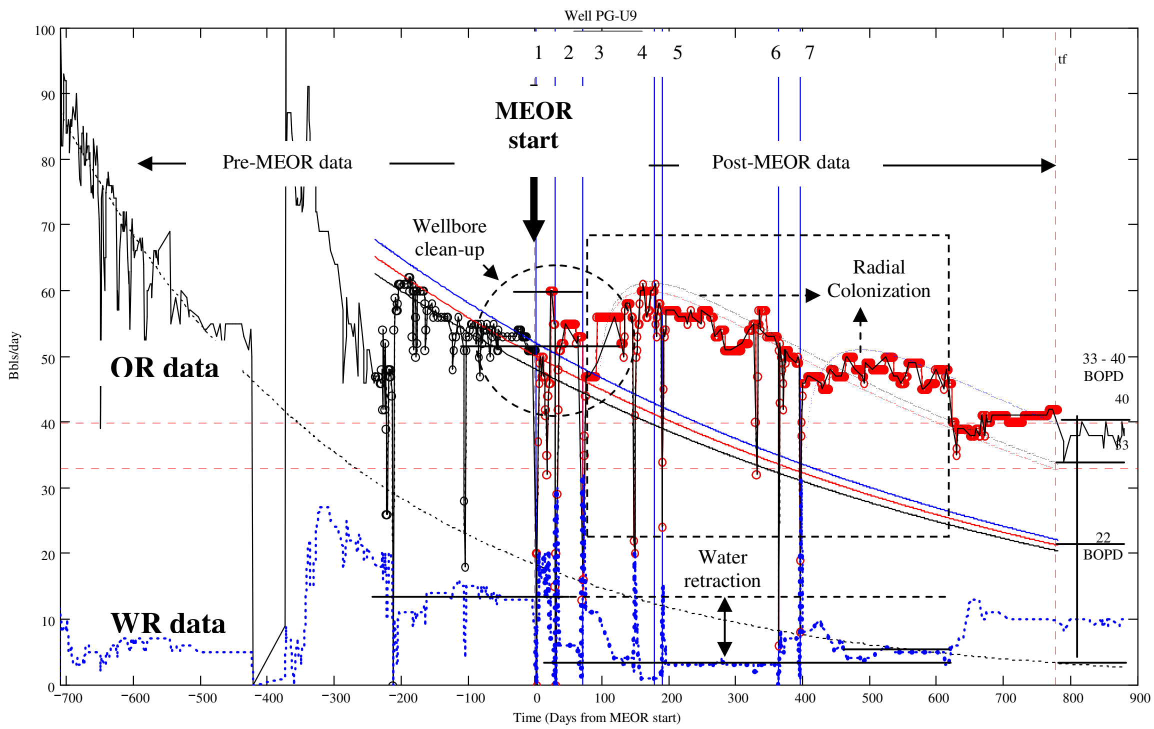

Figure 20: Pre-and Post-MEOR data series for PG-U9, differentiating wellbore clean-up pulses from stable radial colonizing stage. Decline models and curve type analysis. Water retraction rounded 9%.

Water retraction behaviour in PG-U9

Wells selected to integrate MEOR program in Providencia and Lobitos fields produce oils with very low rates of co-produced water (see Tables 02, 03, MEOR design section) In some degree the exception is the PG-U9 producer (13 BWPD, 51 BOPD) that produces oil with a fairly 20% of water. This well has a net pay of 134 feet (also the highest in MEOR candidates group). MEOR response for this well was double-validated by considering oil increase in simultaneous analysis with water retraction. The reduction in oil viscosity (see aside Figure 21) influences the relative oil/water mobility in addition with the activation of idle zones (non productive sub-intervals) producing a distinctive signature in water production as is observed in PG-U9 post-MEOR production series. New stable water cut rounding 4% was achieved during radial colonization (mainly during the more of 400 days of compared evaluation) compared with the previous 13% exhibited in pre-MEOR WR data. Wells like PG-U9, with large net pay intervals and parafinic oils which have part of paraffin profiles falling below melting points at reservoir temperatures (Figure 09, compositional section) show this typical behavior. **MEOR in PG-U9 resulted in 44% as oil rate improvement and 9% of water retraction.** [Ref. 10]

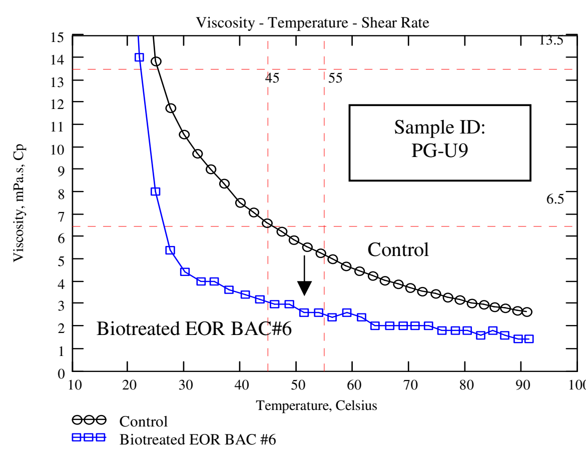

Figure 21: Reological testing on control and inoculated samples demonstrated the high biotratability of PG-U9 oils. Control values of 5.5 mPa.s (cp) compared with 2.5 mPa.s mean values on inoculated samples. The increase in compositional homogeneity (change in roundness) in biotreated oils turn them less pseudoplastic (more Newtonian) at low shear rates of typical occurrence especially in reservoir drained from long perforated intervals.

Economical analysis

Incremental Oil

The first step to quatify the MEOR economical impact is to determine the incremental oil by comparing Pre-MEOR decline curves (baselines) with post-MEOR production series As was pointed before on the well-by-well analysis section, two consecutive stages appeared in post-MEOR production series: wellbore clean-up and radial colonization., being the first a short-term pulse and the second a long lasting effect if proper treatments are synchronized with the particular flow back behaviour and biorreaction dynamics for each treated well.

The analysis is divided by field despite that Basal Salina appears as the unique MEOR target formation. This criterium pursues to remark operative differences in GL installations and depth of net pay intervals with MEOR response.

Tabla 13: Providencia Field: PG-9 and PG-U9 (BLT system)

Well Id.	Base oil BO	Incremental Oil (MEOR) BO	% of Increase over baselines
PG-9	27,462	7,934	29
PG-U9	26,181	11,476	44
Total	**53,643**	**19,410**	**Avg: 36.5**

Tabla 14: Lobitos Field: LO16-24 and LO16-14 (Conv. GL)

Well Id.	Base oil BO	Incremental Oil (MEOR) BO	% of Increase over baselines
LO16-14	18,489	13,562	73
LO16-24	5,854	345	10
Total	**53,643**	**13,907**	**Avg: 41.5**

Cost of the Biotech program

Direct cost involves two main segments: 1) Microbial products and complements, and 2) Operative support intended with the inoculation program.

Table 15: Microbial products (EOR-BAC's) and complements (EOR-Dry's)

Well Id.	Microbial products Gallons	Complements Pounds	Direct Cost U$S FOB-HOU
PG-9	490 (6 treat.)	140	15,915
PG-U9	490 (7 treat.)	133	15,854
Total PG	**980**	**273**	**31,769**
LO16-14	233 (7 treat.)	63	7,536
LO16-24	295 (6 treat.)	85	9,587
Total LO16	**528**	**148**	**17,123**
Grand T	**1,508**	**421**	**48,892**

Operative segment implies the multimodal transportation from on-shore warehouses (trucking) to PG and LO16 platforms (by boat to off-shore locations), and corresponding blending&pumping tasks to displace the treatment downhole. The average cost per operative segment resulted 3,600 U$S per treatment. No significative investment was necessary to implement the MEOR pilot in Z-2B block.

Adding both segments it is possible to evaluate several easy-to-capt indexes of MEOR economic efficiense by first dividing the total Direct Cost (D.C., U$S) with the corresponding Incremental Oil (I.O., Barrels). The term Incremental Oil is used in the sense of computed oil above baselines during a substantial post-MEOR period, and it is not subject of speculation about what portion is due to accelerate oil production or really true-added reserves (ultimate reserves by extending the economic life of the wells from the conventional end point).

Tabla 16: MEOR, Economical profile

Well Id.	Incremental Oil per used Gallon	Cost per Incremental Oil	Profitability Index (*)
Unit	**BO/gal**	**U$S/Barrel**	**US/US**
PG-9	16.2	2.00	17.5
PG-U9	23.4	1.38	25.3
Avg. PG	**19.8**	**1.69**	**21.4**
LO16-14	58.2	0.55	63.6
LO16-24	1.2	27.78	1.25
Avg. LO16	**29.7**	**14.16**	**32.4**
Grand avg.	**24.7**	**7.92**	**26.9**

Note: Reference Oil price assumed in **35 U$S/Bbl**. (*) quotient between incremental oil valuated at price of reference, and MEOR direct cost.

MEOR Prospects in Z-2B block, course of future actions

In view of MEOR results obtained in Basal Salina fm. (Lobitos and Providencia fields) and considering the similarities in rheological and compositional parameters of oils produced from others active formations, an extrapolation exercise of pilot results was deviced for the rest of active fields in Z-2B block. The course of action is tackling first by the evaluacion of potential producers as candidates for a MEOR program following a similar scheme like in the pilot project. Secondly, and due to operative constraints, wells were grouped according with 1) BLT or conventional Gas Lift system and 2) Commingled production from several reservoirs in opposition with single-formation reservoirs. Third, a brief analysis is devoted to the waterflooding experience in Z-2B Block with the objective to test preliminary MEOR2 feasibility (by treating injection schemes and not just producers like in present pilot).

MEOR Prospects in producers

As pointed before, there are 6 main formations (Helico, Terebratula, Pariñas, Rio Bravo, Mogollón, Basal Salina) in Z-2B block (Talara Basin), with 75% of fields located off-shore. At January 2005, Block Z-2B accounts 628 producers producing 317,000 BO, 2,073,00 MSCF and 32,000 BW per month from five main fields. Assuming that just wells under GL BLT can be operatively treated by MEOR, a total of **430 candidate wells** emerge as potential, following table summarizes the potencial MEOR prospects in Z-2B block:

Table 17: MEOR, Potential prospects in producers of Z-2B Block

Talara Basin (Z-2B Block) Field Denomination, (Cumm Oil, BO at Dec. 2004)	Active Producers sorted by type of GL installation and productive reservoirs.	
	Producers from a Unique Formation	Producers from Multiple Formations (commingled Production)
Peña Negra (149,228,000)		
BLT Gas Lift	85	94
Conventional GL	38	5
Lobitos (90,720,500)		
BLT Gas Lift	78	57
Conventional GL	47	6
Providencia (off-shore, 28,649,000)		
BLT Gas Lift	16	16
Conventional GL	11	1
Z-2B (on-shore)		
BLT GL	12	4
Conventional GL	4	0
Litoral (45,376,000)		
BLT GL	57	11
Conventional GL	4	0
Totals in Z-2B Block		
BLT GL	248	182
Conventional GL	104	12

MEOR prospects in waterflooding schemes

There is another category of biotechnology-driven applications that are of increasing interest in areas with active waterfloodings schemes. The group is called MEOR[2] techniques to distinghish it from simple MEOR or MEOR[1] oriented with just producers [Ref. 13, 14]

Waterflooding history in Z2-B block

A first waterfllooding scheme in Z-2B Block was started in Providencia I field, Basal Salina fm. on 1969 by injecting water initially through on-shore wells located close to the water leg and later on the watered out ones. On 1982 the project was reformulated and PQ-U7 producer was dressed as injector. Due to casing leakeage was furtherly changed by PQ-U9 on mid June of 1985. Nominal rates and injecting pressures were maintained below 3000 BWPD and 2,400 Psia respectively below fracturing gradients. The injecting pattern was non-regular and having a direct influence in four producers (PQ-5, PQ-1, PG-2, PG-U9). The project was considered satisfactory with slight response mainly in PQ-1 and PQ-5. The performance can be summarized as follow

Table 18, Waterflooding in Providencia I, Basal Salina fm.

Flooded Volume (563 acres, 94 ft)	Acres-ft	52,922
OOIP (Sor: 36%, Kabs.: 14.2 mD)	MBO	26,901
Injectors/producers	Dimm.	1/5
Water injected to Oil produced	WIB/OStB	9.6
Recovery Factor	**%**	**6.25**

Several waterflooding projects (Table 19) were deviced after the mentioned experience in Providencia I, covering the rest of Z-2B fields (6 in Peña Negra, 4 in Lobitos, and one in Litoral). The results varied from good response in the higher range of fm. permeabilities (14 to 54 mDarcies) to poor in cases with very tight formations (values below 1 mDarcy). Premature break-through and excessive injection pressures caused project discontinuation. The resulted performance ranges from 0 to 7.7 % of OOIP. The water injected was sea water conditioned in terms of TSS and TDS control but never additivated to improve injectivity or to improve a major efficience in recovery mechanisms (water conformance).

Table 19, Waterflooding Projects in Z-2B Block

Field Waterflooding Project	Reservoir	OOIP (MBO)	Water Injected (MBW)	Recovery Factor (RF, %)
Peña Negra				
Z-AA	Cabo Blanco	28,600	15,091	4.2
BB-DD	Mogollón	98,000	17,594	1.3
FF-YY-PN6	P. Negra	15,740	7,857	1.3
Z-KK	P. Negra	39,000	991	-
R-FF	P. Negra	18,000	2,867	2.4
AA-TT	Mogollón	91,377	1,193	-
Lobitos				
HOT-I	Pariñas	21,000	12,912	6.3
HOT-II	Pariñas	20,300	9,642	6.1
HOT-III	Pariñas	14,000	7,092	3.9
MM-VV	Rio Bravo	105,000	22,961	0.7
Providencia				
Providencia I	B. Salina	26,901	26,040	7.7
Litoral				
D-E	Pariñas	40,000	9,300	-
Block Z-2B				
Summary Block Z-2B		517,918	129,489	0 – 7.7

Note: Injection of nitrate is a proven method to stimulate NRB at expense of SRB, mitigates H_2S souring. Nitrite is by-product itself inhibitory to SRB growth by differences in REDOX potential.

Waterflooding Pilot project in Parcela area

To date, an incipient new project is sustained from on-shore locations is a matter of study to inject water into upper Basal Salina fm.(net thickness of 101 ft.) and involving a floodable area of 92 acres. The well L1-14 was dressed as injector with a nominal rate of 1200 to 1500 BWPD. The expected secondary recovery oil is 190 MBO. Parcelas area has currently affected 7 producers to this project. The analysis group for biotechnology application in Z-2B block, considers that the use of MEOR[2] could be a potential option to increase recovery efficiencies in the waterflooding pilot of Parcela area, however a more profound lab evaluation, complemented with reservoir simulations need to be done. It is also necessary to collect field data to define the conventional response to be used as contrast for biotechnological assisted stages. [Ref. 13,14, 31, 32].

Biosafety issues

MEOR bacteria used in Providencia and Lobitos fields are of natural occurrence non-pathogenic strains and not genetically manipulated. During the pilot and even more during scaling operations, special care need to be taken to meet local and foreign regulation in regard to environmental and health topics. Toxicity tests on animals and plants were done by the Institute of Microbiology (Academia Sinica) and by the Institute of Atom Energy Utilization, Chinese Academy of Agriculture Science, both in the Peoples Republic of China. Selected animals and plants were Kunming mice (200 individuals, weighting 18-20 grams., half-male, half-female) and Cucumber (Jinyan #5 strain) and rice (Yuefu strain) seeds respectively. Special essay protocols and method of exposure using microbial products number #1, #4, #5 and #6 were applied to germinated plants, seeds and animals under test.

All results demonstrate no adverse affects for plants or animals. The microbial product caused no abnormalities in plants (rice and cucumber) and mice. No abnormality or disease occurred on different crops by different ways of treatment. No abnormality occurred of heart, liver, spleen, lung, kidney or intestine of test mice.

Logistic considerations

Microbial products were supplied in aqueous phase as living bacteria accompanied by inorganic nutrients (salts containing N, P, K, etc.), in sealed (under sterile condition) plastic drums of five gallons capacity. Each recipient was conveniently labeled with type of product, quality check marks and make-up tracking information. A total quatity of 2,240 gallons of four different microbial concentrates and 650 pounds of complementary nutrients were in a multimodal transit from Minessota plant in USA and Venezuela base (optional delivery point) to Talara storage area at MEOR start date (August 2002).

Conclusions

1- The MEOR pilot stage in wells PG-U9 and PG-9 of Providencia and LO16-14 and LO16-24 of Lobitos fields resulted in ***3,086 M³ (19,410 bbls.)*** and ***2,211 M³ (13,907bbls.) of Incremental Oil*** respectively. MEOR Increments of **36.5%** in Providencia and **46.5%** in Lobitos were assumed as conservative MEOR performance indexes, and subject to further optimization under current operative frame.
2- MEOR resulted profitable at pilot stages. Considering the pool of PG-U9, PG-9 and LO16-14 wells, the Cost per Incremental Barrel (CIB) averages ***1.3 $/barrel***. Including the marginal case of LO16-24 the overall average CIB increase to 7.92 $/Barrel.
3- The risk of marginal cases (like LO16-24) resulted **1:4** (one marginal case from a pool of four biotreated wells) This concept constitutes part of the “learning curve” drawback associated with any EOR development and justify to proceed with pilot stages prior to define expanded scales in new MEOR prospects.
4- There is a considerable potencial scope to scale MEOR in **430 existing producers** of Z-2B Block, under cost-effective (Inoculation by annulus) and favourable operative and monitoring conditions (having GL-BLT installations). Due to rheological and compositional (N-Alkane profile) similarities in oils tested from different reservoirs (Basal Salina, Mogollón, Rio Bravo), MEOR is equally feasible to both single or commingled production.
5- MEOR^2 techniques could be feasible to assist waterflooding schemes in the relatively high permeability range of Z-2B reservoirs.

Course of Actions

1- To continue in-course MEOR optimization stage in Talara Field
2- To complete the Biotreatability Data Base and Geochemical characterization studies for all oils being produced in Z-2B block (corresponding to reservoirs in Helico, Terebratula, Pariñas, Rio Bravo, Mogollon and Basal Salina fms).
3- To evaluate best rate of expansion for Lobitos/Providencia reservoirs to maximize economic return.
4- To evaluate new treatment procedures in producers equipped with BLT GL installations to optimize operative cost.
5- To perfect project-monitoring context to validate fractional flow improvements in producers under microbial treatment.
6- To initiate MEOR^2 feasibility studies in waterflooding schemes.

SI metric Conversion Factors

acre-foot	*x 1.233 489 E+03*	*= m^3*
barrel	*x 1.589 873 E-01*	*= m^3*
md	*x 9.869 233 E-04*	*= μm^2*
ml	*x 1.0 E-06*	*= m^3*
psi	*x 6.894 757 E+00*	*= kPa*
U.S.Gal	*x 3.785 412 E+00*	*= L*
°F	*(°F -32)*5/9 E-01*	*= °C*

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Nomenclature

$MEOR_{(t_i)}$ = *productivity index ratio, MEOR performance index, dimensionless*
pwf = *dynamic pressure before MEOR, [psi]*
pwfmeor = *dynamic pressure after MEOR, [psi]*
Pe = *static reservoir pressure, [psi]*
$Qmeor_{(t_i)}$ = *oil rate after MEOR,* $[m^3]$
$Qo_{(t_i)}$ = *oil rate before MEOR,* $[m^3]$

Subscripts

control = *original sample condition (pre MEOR)*
e = *natural logarithms base, 2.7172...*
h = *horizontal.*
i = *data point, spatial reference*
m = *microbial enhanced*
o = *original*
t = *time*

Annex A: Complementary Figures

Figure 22: Project location in the World context (Perú North)

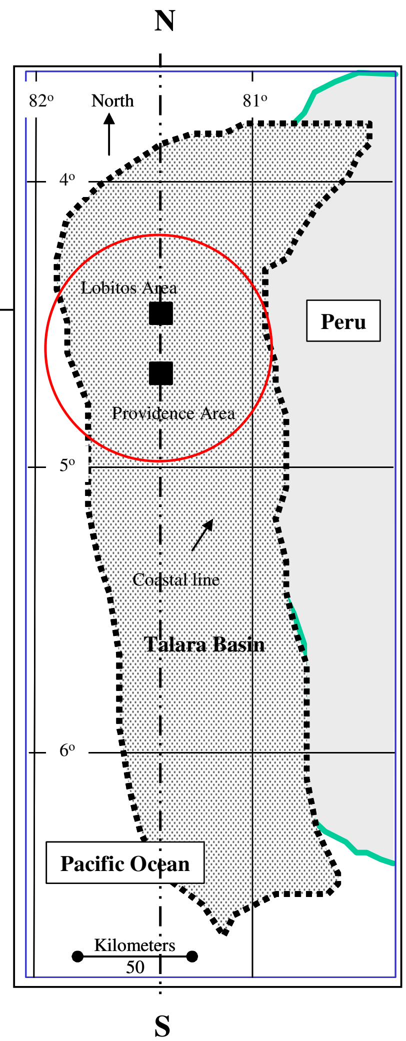


Figure 23: Talara Basin and location of target Fields

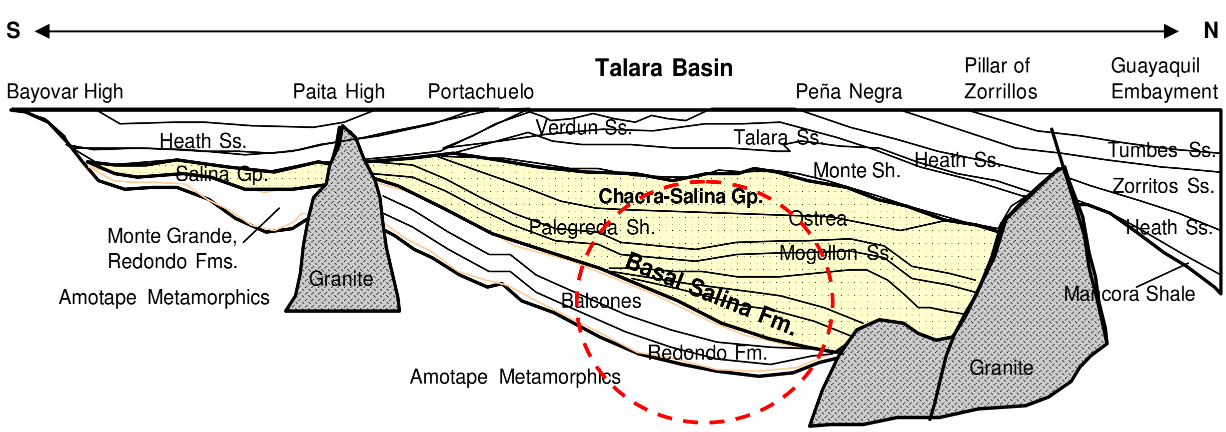
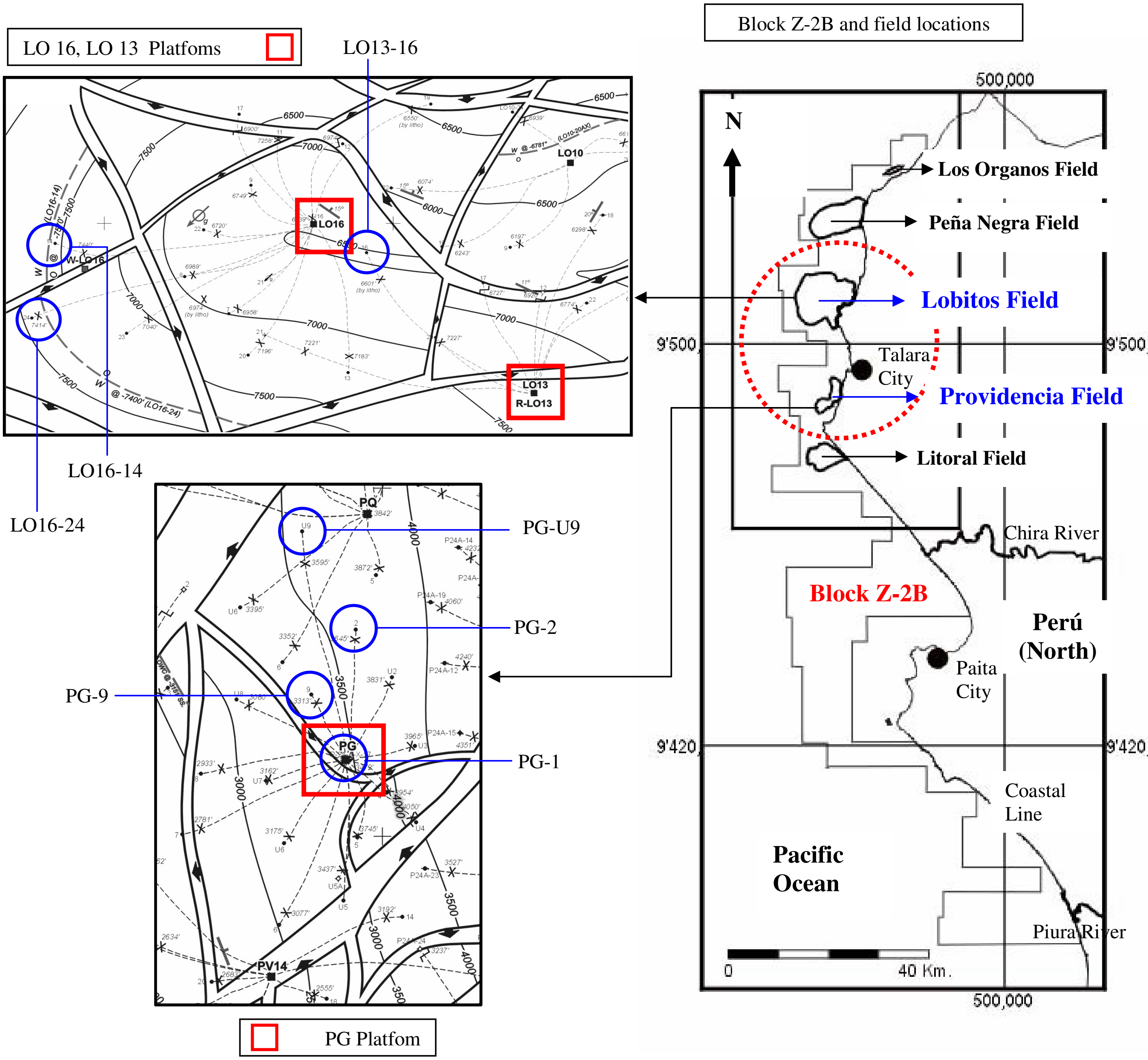


Figure 24: Simplified structural cut showing relative position of Basal Salina fm. (market by red-dotted circle)



Well Id.	Interval Basal Salina fm. (ft)	Net pay interval (net perforated sand , ft)	BOPD @ MEOR start	BWPD @ MEOR start	MSCFPD @ MEOR start	BHSP (psi)	Cumm. Oil @ MEOR start (MBO)	GAS Lift System
PG-1	3,519-3,620 3,369-3,403	55 17	16	0	39	180	490.3	Interm. BLT
PG-2	4,185-4,545	143	28	0	87	200	495.8	Interm. BLT
PG-9	**3,593-3,794**	**40**	**50**	**1**	**90**	**150**	**646.9**	**Interm. BLT**
PG-U9	**5,414-5,684**	**134**	**51**	**13**	**72**	**220**	**1045.7**	**Interm. BLT**
LO16-14	**9,460-9,664**	**90**	**63**	**5**	**157**	**850**	**720.4**	**Conventional**
LO16-24	**9,986-10,086**	**50**	**27**	**1**	**135**	**480**	**152.5**	**Conventional**
LO13-16	9,040-9,050	10	31	0	-	750	1771.8	Flowing/GL

Figure 25: Summary and Plant view of objective blocks and and platforms in Providencia and Lobitos field. Data of wells affected to MEOR.

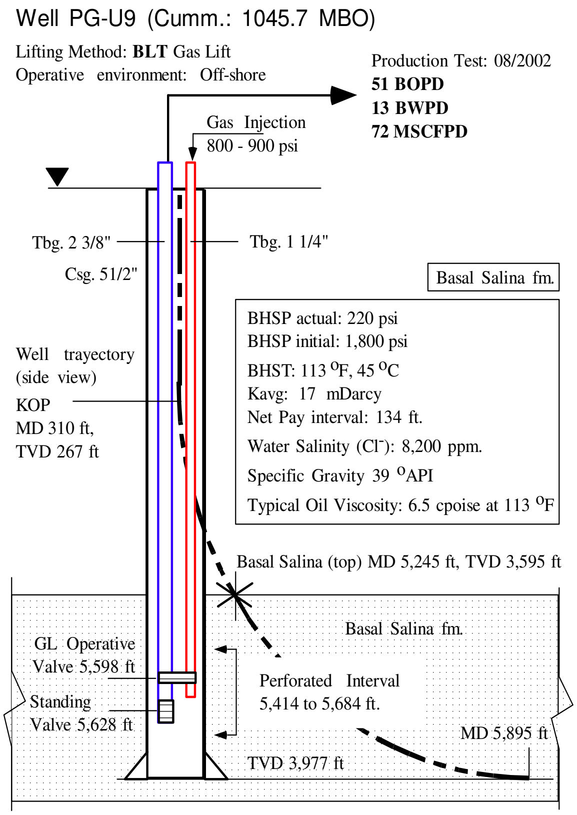


Figure 26: Completion and reservoir data for PG-U9

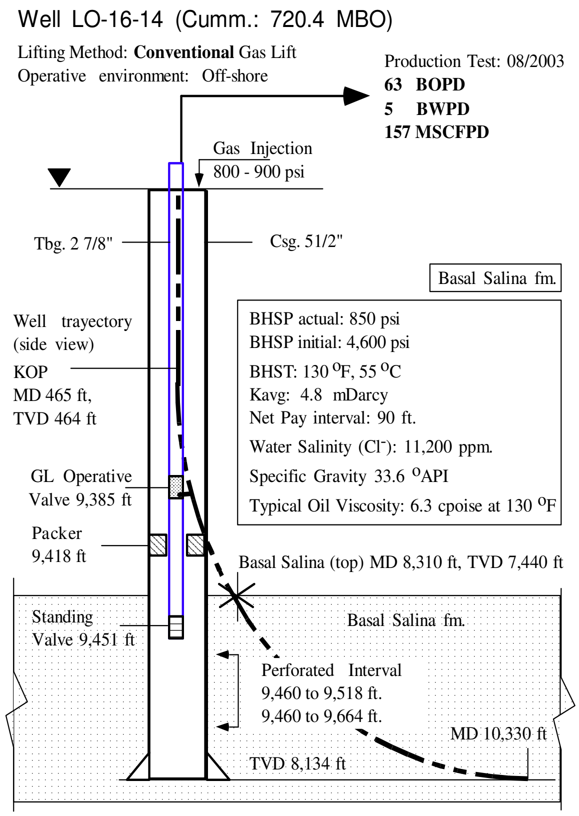


Figure 27: Completion and reservoir data for LO16-14

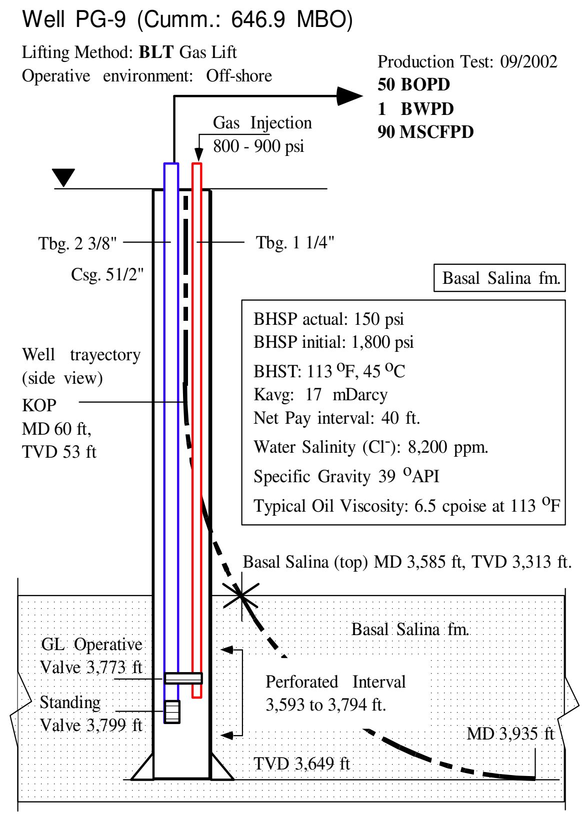


Figure 28: Completion and reservoir data for PG-9

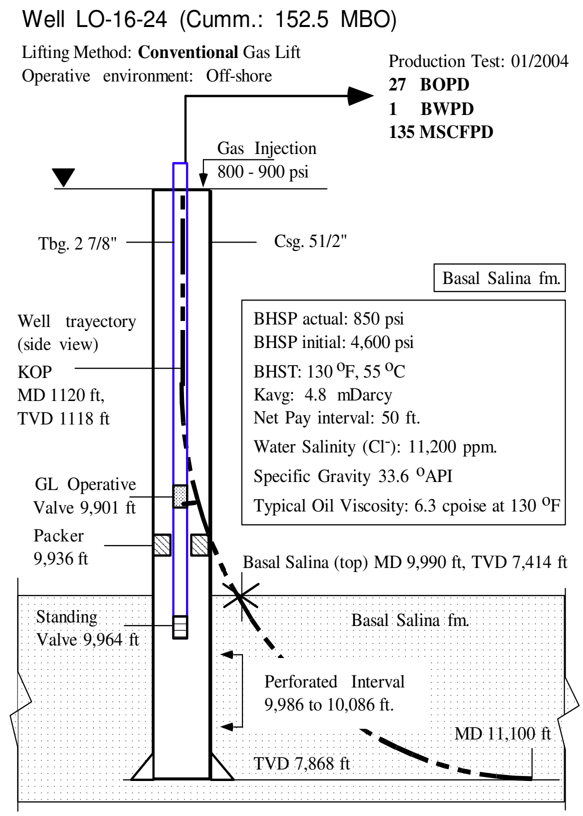


Figure 29: Completion and reservoir data for LO16-24

Biocracking Severity Index (BSI)

BSI was developed as a quantitative index to correlate the magnitude of compositional and rheology changes operated during a bio-cracking process. BSI calculation is based on compared GC chromatographic series of control and inoculated oil samples. [Ref. 11]. Due to the fact that shift in composition caused by Enzymatic Cracking (Biocracking) in oils is qualitatively similar to parent thermal process, the correlation among composition changes and rheology alteration can be analyzed using this methodology. Eq. 2 and 3 and figures 10 and 11 summarize these concepts using PG-9 analysis as example:

$$BSI = 0.5 \times \left(\left[\sum_{nCi}^{nCf} |mass\_gain| \right] + \left[\sum_{nCi}^{nCf} |mass\_loss| \right] \right)_{PRE-MEOR\_GC}^{POST-MEOR\_GC}$$

…………………………………………………………….....Eq. 2

$$\mu_{POST-MEOR} = \mu_{PRE-MEOR} \times 10^{-OGP \times BSI}$$

…………………………………………………………….....Eq. 3

Where: μ denotes Viscosity (mPa.s) at a predetermined temperature (T° test: 17 °C in this case) and defined shear rates (1/s) for Pre- and Post-MEOR samples. The ***mass gain*** and ***mass loss*** is calculated from the normalized intensity (dimensionless mass contribution) changes in mass gained or lost over the complete range of n-Alkanes explored (*nCi* to *nCf* carbon number). This calculation is performed on Pre- and Post-MEOR GC data series and is a quantitative measure of the compositional shift. **OGP** is denominated ***Oil Group Parameter*** and remain constant for any sample pertaining to the same oil family (OGP: -0.18+/-0.05 for Basal Salina oils). The compositional alterations observed in PG-9 oil samples are first originated during lab biotreatability screening (Figure 32) and then during early post-MEOR field samples (October 10, 2002; Figure 33) as consequence of assisted-microbial processes. Control sample is based on original pre-MEOR evaluation stage (October 2001). BSI value: + 372 (early post-MEOR stages), Viscosity reduction (Fig. 31): 62% (8 S^{-1}, 17°C). nCi to nCf carbon number: nC5 (N-pentane) to nC44 (N-tetratetracontane) Retention times window covers the range of N-alkanes found in Basal Salina oils.

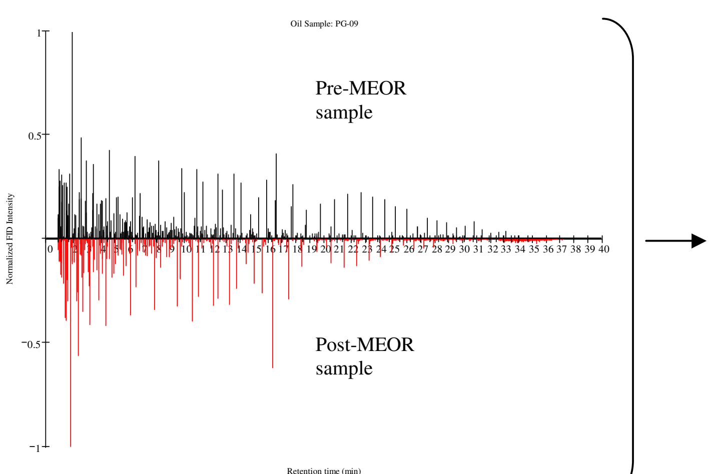


Figure 30: GC source data in PG-9 (Field treated)

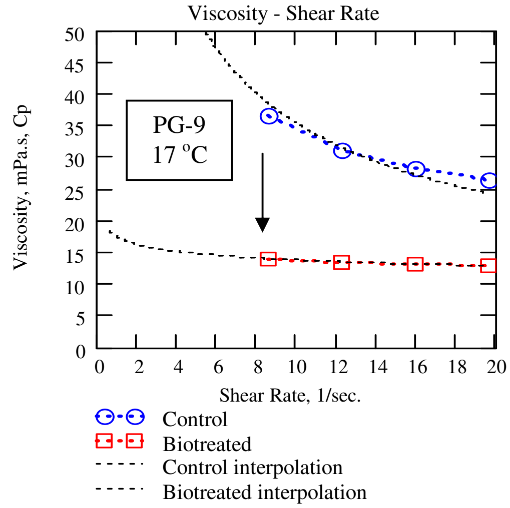


Figure 31: Viscosity shift in PG-9 (used in OGP calibration)

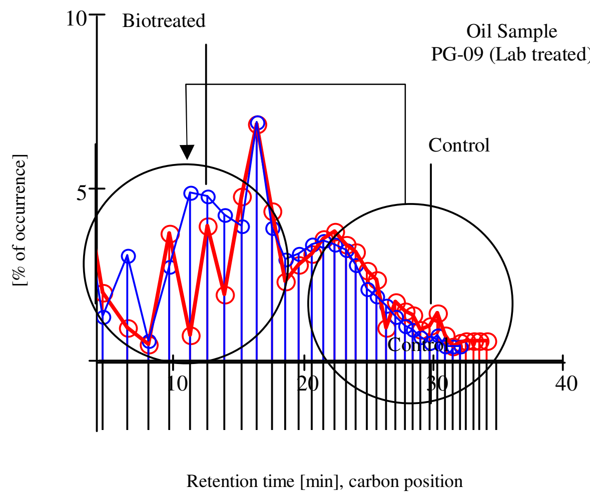


Figure 32: GC shift in PG-9 (lab treated)

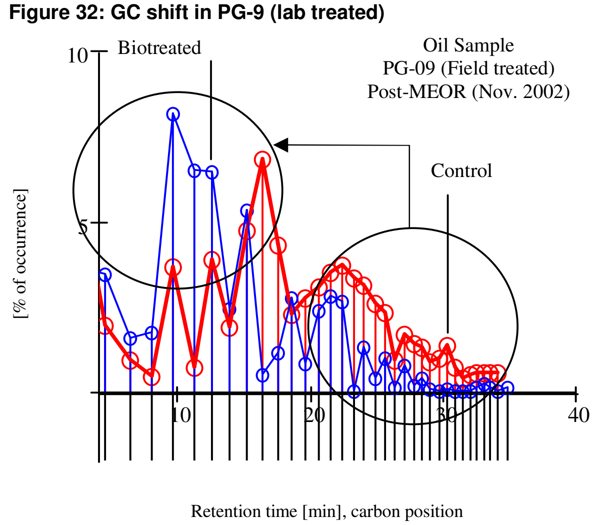


Figure 33: GC shift in PG-9 (Field treated), BSI value: + 372 (early post-MEOR stages).