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Sustaining Gas Production in Low Perm Gas Reservoir: Case History from Mexico

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The rapid post-fracture production decline rate often observed in both oil and gas wells is considered to be associated with loss of fracture conductivity, often attributed to invasion of formation fines into the proppant pack, loss of fracture width due to proppant flowback, and fines derived from proppant crushing. However, recent studies have indicated that solid material generated from geochemical process in the fracture face known as proppant diagenesis, may have considerable impact on proppant conductivity.

Liquid resin systems (LRS), a specific type of hydrophobic material, have been used in the industry to prevent proppant flow back. The proppant is coated on the fly on location with a LRS. This technology has also proved to increase and sustain fracture conductivity over time. The production data presented in this paper comes from some low permeability gas fields located at the Burgos Basin in North Mexico which contains sand formations considered as a tight gas. The formation fractured is an intermediate/high temperature and high stress sandstone. The wells previously fractured in these fields had a historically rapid post-fracture production decline rate.

The wells successfully treated with LRS material show a significant production increase compared to non-treated offset wells due to a substantial change of the conductivity of the fracture. Based on laboratory experiments on proppant diagenesis and field results, it has been concluded that the proppant diagenesis protection treatment provided by the LRS significantly contributed to the production increase of the wells treated.

Introduction

Burgos Basin is located in northeastern Mexico along the southern border of the U.S. This gas basin covers more than 50,000 km2 (Fig. 1) and accounts for one third of the reserves of non associated gas in the country. The gas fields are located along well-defined bands that extend across the shared border between Mexico and the U.S. They are complex, sandy reservoirs, highly compartmentalized, and made up of a great number of small independent blocks characterized by very low permeability. Sustaining a high production level in this area requires a large number of wells to be drilled and hydraulically fractured.1.

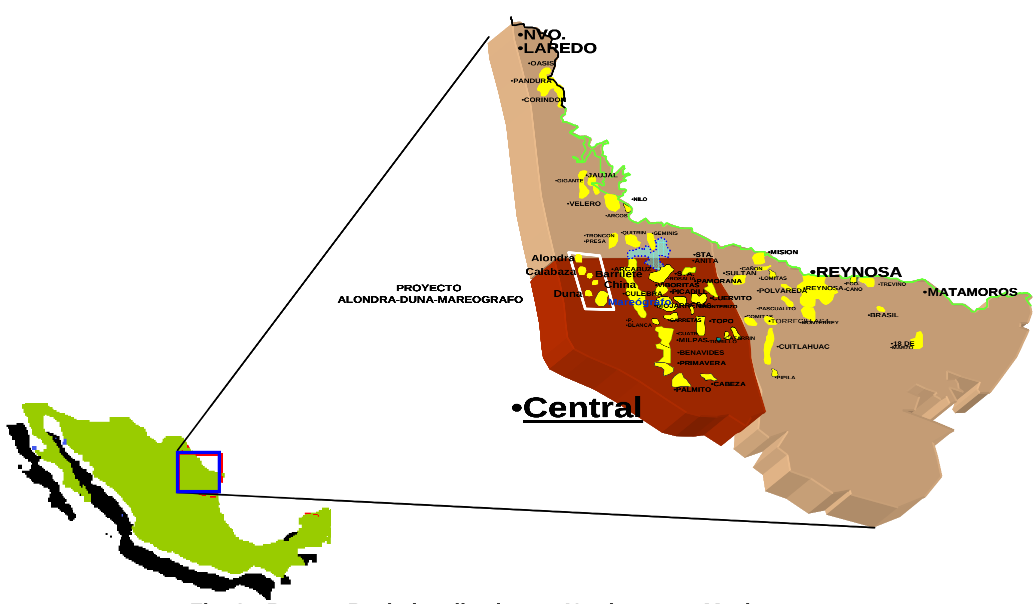

Fig. 1—Burgos Basin localization en Northeastern Mexico.

The stratigraphic column (Fig 2) includes sediments from the Paleocene trend with a thickness up to 30,000 ft. The producing trends include, from west to east, the Jurassic-Cretaceous, Paleocene-Eocene, Wilcox-Queen City, Jackson-Yegua, Oligocene Frio-Vicksburg, and Miocene trends The geological structure of the gas fields are complex and made up of numerous independent blocks with very low-permeability sandy reservoirs. The Burgos Basin produces from clastic Paleocene in the western portion of the basin to the Miocene in the east (Rivas et al. 2007).

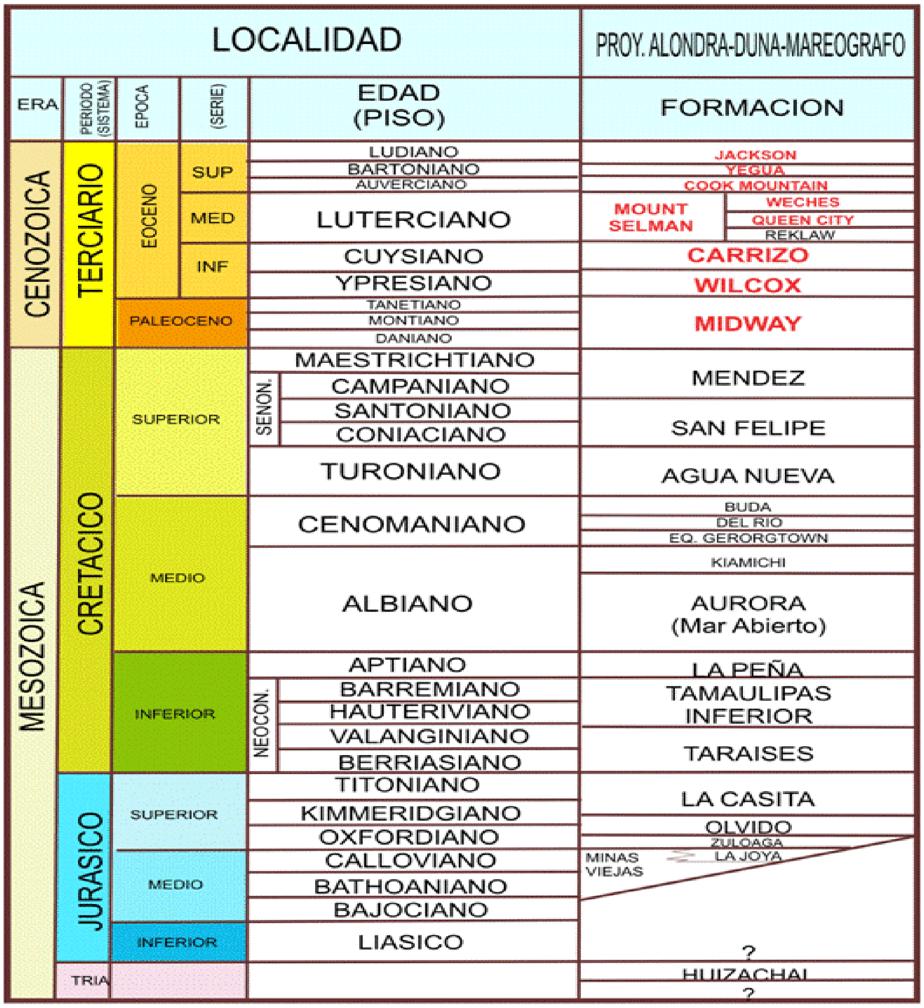

Fig. 2—Stratigraphic column in the Burgos Basin

The fields require a large number of wells to be drilled to make the field economically feasible (Soriano et al. 2007). Most of the wells are drilled to depths of 9,500 to 9,800 ft and often face challenges such as loss of circulation and high-pressure zones due to the geology complexity. The wells are completed and hydraulically fractured; the initial well productivity is high but declines quickly. This phenomenon seems to be associated with the loss of conductivity shortly after the well is fractured (Fig 3)

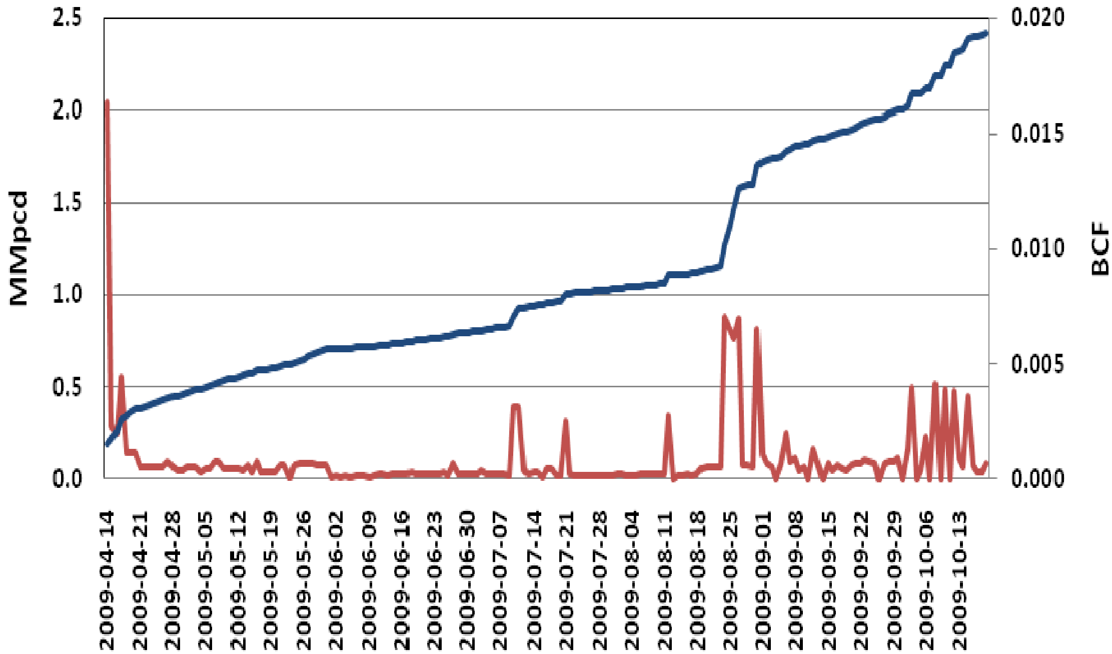

Fig. 3—A typical production vs time behavior of wells with rapid decline.

Factors Affecting Fracture Conductivity

Since its early application, it has been observed that wells stimulated by hydraulic fracturing have shown a similar pattern in the production curve; they show an initial productivity increase followed by a rapid production decline. This effect has already been a matter of investigation and several hypotheses have been developed in an attempt to explain the cause of the problem.

The loss in proppant conductivity has normally been associated with the damage of the proppant pack caused by solid material effects. The impact of this effect is given by the type of damage, as follows.

Fines migration**:** Significantly reduces the permeability of the pack because small particles (normally smaller than 325 mesh or 44 microns) occupy the porous space**.**

Proppant flowback**:** Causes loss in fracture width and therefore loss in conductivity.

Proppant crushing**:** The debris resulting from the pressure and mechanical load cycling occupies space in the porosity, resulting in decreased permeability.

Proppant embedment and spalling**:** Extrusion of formation material into the proppant pack fills in *the porous media.*

Proppant diagenesis**:** Recent research on proppant conductivity has found that geochemical reactions occur at the proppant/fracture interface and result in proppant degradation and mineral recrystallization in the pore spaces. This effect seems to have the greatest impact on long-term fracture conductivity reduction, especially on high-pressure/high-temperature wells.

Proppant Diagenesis

Weaver et al. (2005) and Weaver et al. (2006) have presented the results of a series of tests that simulated a hydraulically fractured formation at downhole conditions. The proppant pack was placed between formation rock wafers and closed in with 2% KCl water-based fluid for several days (140 hr) at 250°F. The cell containing the proppant pack/formation was maintained under confined compressive stress (10,000 psi) during the entire test. The results indicated that new crystalline and amorphous materials were formed in the volume surrounding the proppant grains (right picture of the Figs. 4). Note that the formation of debris surrounding the proppant grains does not appear to be derived from the proppant. This material appears throughout the proppant pack.

Hydrophobic Materials

Surface modification agents (SMA) and LRS are two types of hydrophobic materials commonly used in fracturing operations for different applications. In 2003, Lehman et al. reported that the use of SMA to coat proppant in hydraulic fractures increased the conductivity of proppant because of its capacity to prevent close packing of the proppant. Later studies indicated that it also provided excellent results as a fines-migration control agent. The SMA is a non hardening tacky resin film that locks the fines in place to prevent fines migration into the proppant pack.
Field studies presented by Weaver et al. (2005) have indicated that long-term results in gas wells treated with SMA coated proppant showed a drastic improvement in well productivity. The wells not treated with SMA produced fines and had a relatively high formation stress and intermediate bottomhole temperature. The results indicated that the use of a SMA controlled the invasion of fines material into the proppant pack as well as prevented the proppant diagenesis process that would potentially have affected well productivity when compared with the untreated wells.

Benefits of LRS

LRS are hydrophobic materials that create a dielectric film around the proppant grain when applied as a coating material. The LRS have effectively been used in the industry as a proppant-flowback control agent and have proven to provide excellent results in both controlling proppant flowback and increasing cycle-pressure tolerance. The hardened LRS increases the unconfined consolidation strength (UCS) of the proppant pack as reported in lab test analyses (Nguyen et al. 1998). This additional strength allows the fracture to tolerate higher fluid velocities (production rates) without losing the proppant.
Furthermore, long-term results have indicated that wells treated with LRS have changed the conventional production decline contour characterized by initial high production rates followed by a rapid loss of production, which suggested proppant diagenesis damage.
The LRS is a hardening material that requires temperature to activate; it is applied to the proppant on-the-fly at the location during the fracturing operation. Similar to the SMA, the LRS increases the proppant-pack conductivity while preventing proppant diagenesis (left picture of the Fig 4)

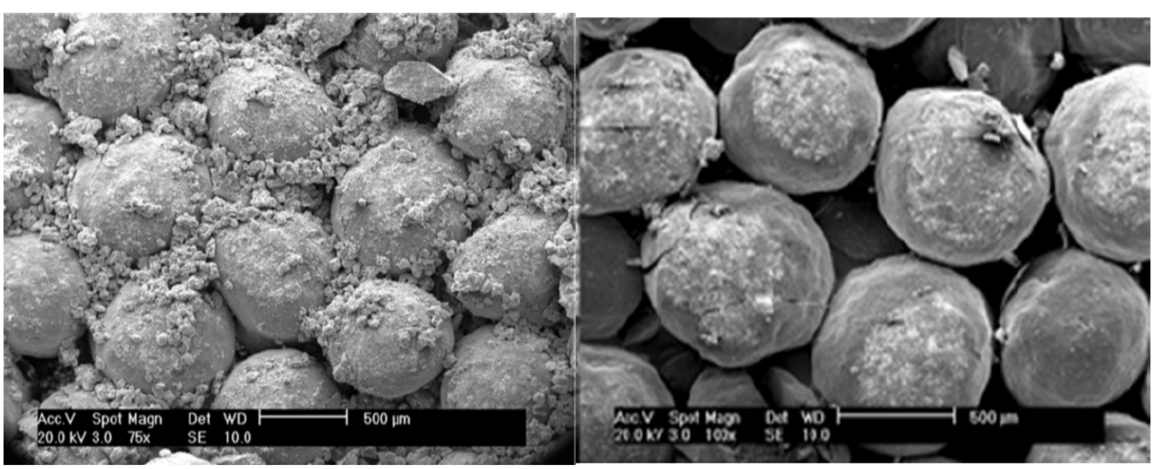

Fig. 3—(Left) Micrograph of a 20/40-mesh 2-lb/ft2 ceramic proppant after exposure to 10,000 psi closure stress at 250°F for 140 hr in 2% KCl solution under static flow condition. (Right) Same proppant exposed to same conditions but coated with a hydrophobic agent (Weaver et al. 2006).

Area of Application

This paper shows results from two tight gas fields located in the Burgos Basin, all the wells were hydraulic fractured and LRS was added to the proppant in some of the wells.The production results were compared with equivalent offset wells. Field results indicated that significant long-term well productivity is achieved when proper engineering practices are used to prevent harmful downhole chemical reactions, especially in reservoirs with severe stress and temperature conditions.(Al-Ghurairi et all, 2006), (Schubart et all at 2002).

The area of study is kwon as Alondra-Duna-Mareógrafo (ADM) and is located in the west central portion of the Burgos Basin, inside the Paleocen trend, covering a surface of 1600 km^2.
These reservoirs are composed of sections of sandstones from Midway formation belonging to the Early Paleocen age, the sandstones are forming stratigraphic traps in the form of lobes which were originated by gravitational flows of sediments under a regimen of stratigraphic compensation as a result of the continuous processes of tilting and subsidence of the carbonated platform on which they were deposited. The seal of this formation is formed by sequences of interdigitated shales from the Midway trend.

Main details of this reservoir are**:**

Type of trap: Estratigrahic
Depth Range: 2000 - 2900 m.
Net pay Range: 3 - 40 m.
Porosity: 12 - 23 %
Water Saturation: 30 - 70%
Permeability: 0.01 - 1.80 mD
Reservoir Pressure: 3000 - 7000 psi
Flow Rates: 0.2 - 9.3 MMSCFD
Type of Reservoir: Tight Gas

Cases Histories

Case 1

Well 106 is located in the ADM area mentioned before. Wells located in this field are producing from the Midway Trend. This formation has low permeability, and drainage is therefore controlled by stimulation, propped fracture length and fracture conductivity. Permeability ranges from 0.1 to 1.8 mD in some areas. Bottomhole static temperatures are around 274°F and reservoir pressure is approximately 6,500 psi. Formation stress ranges from 7,500 to 8,500 psi.
Immediately after the well was perforated it was put on production, initial gas rates were measured on 3.0 MMSCFD by a choke size of 10/64".The first plan after this production was evaluated, was to put the well on production straight to the gas station and not further stimulation treatment considered.
A well test was finally run in order to evaluate the potential of the well. and also to evaluate the drawdown pressure in the face formation(Fig 4)
Interpretation of the build up curve showed a low value of the permeability however a remaining drop pressure of almost 1,700 psi was observed in the analysis of productivity realized. With this data obtained, a hydraulic fracture was considered in order to eliminate the drop pressure and gain additional production. Experience gained in some well of the area where LRS were used led to consider this option with the target of maintain production versus time.

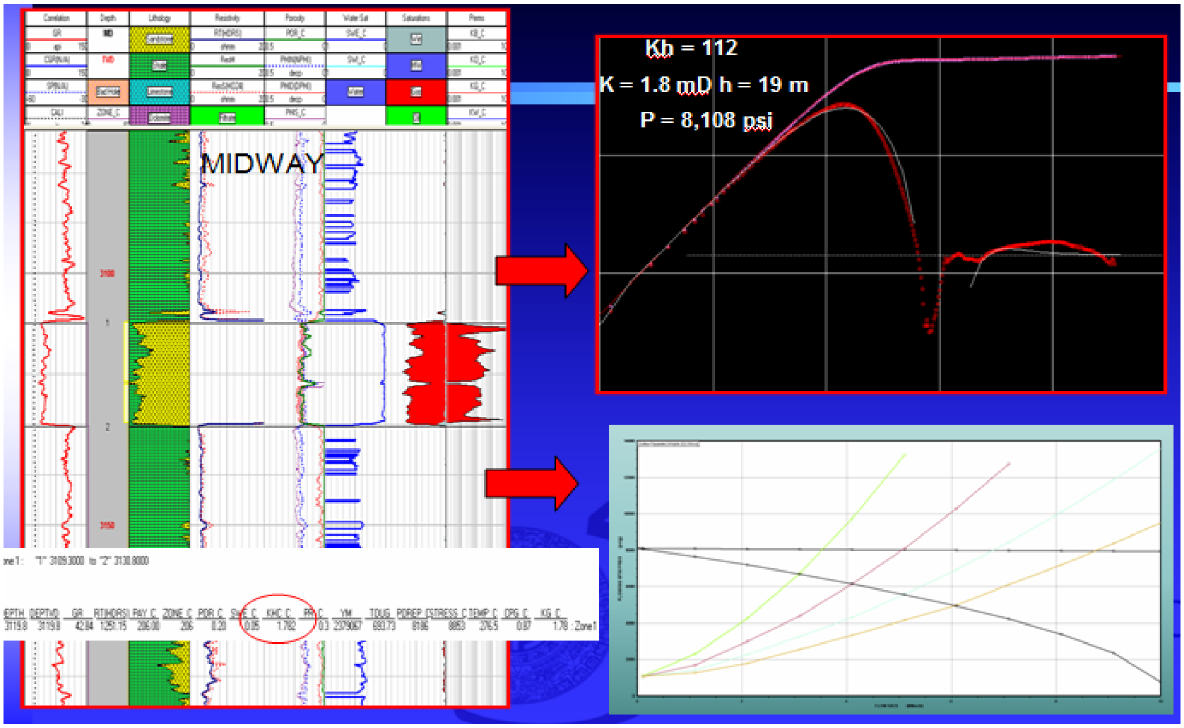

Fig. 4— Synthetic potential log from wells in Case 1 calibrated using pressure buildup tests.

The well was fractured with 95,000 lbs of 16/20 size of Intermediate strength ceramic (ISC) proppant with LRS. Gas rates obtained after the treatment were used again to generate the post frac inflow performance relationship curve (IPR) Fig 5. Something to highlight is the significant portion of drawdown pressure removed, this is visualized by looking to the flat shape of the IPR curve

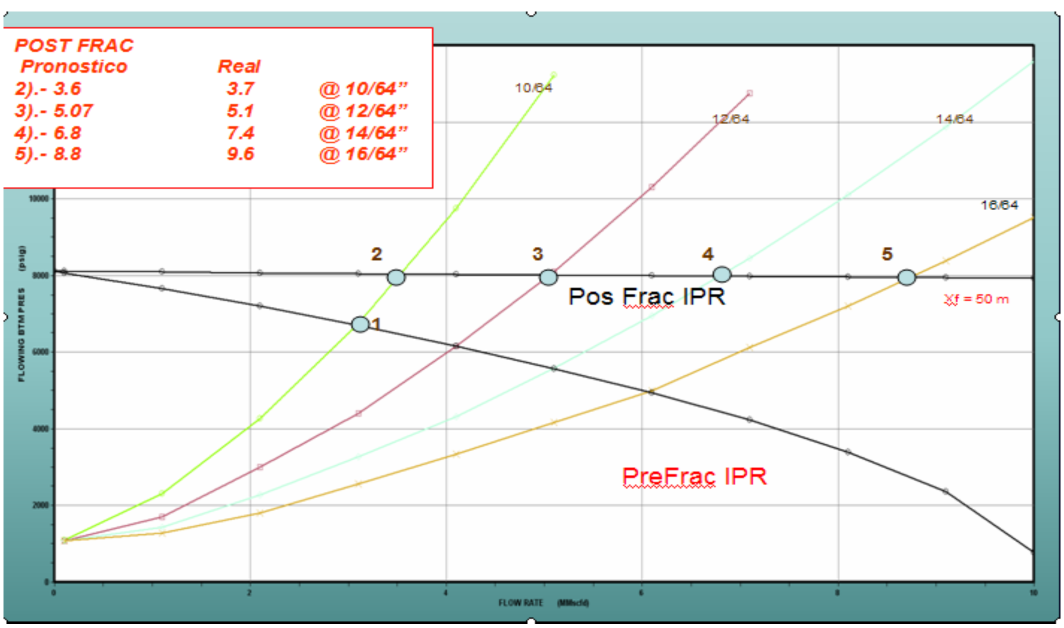

Fig. 5—Productivity Analysis of the well once fractured.

Production from this well was also gathered for 12 months.Fig 6 shows how the production has maintained in a range of 10-12 MMSCFD without manifest the rapid production decline observed in some other wells from the ADM area and mentioned early on this paper. Fig 7 also shows a comparative graph of cumulated gas versus time where the well treated (red curve) is outperforming the other wells in the same field. These wells were treated with similar volumes of proppant, size and type.

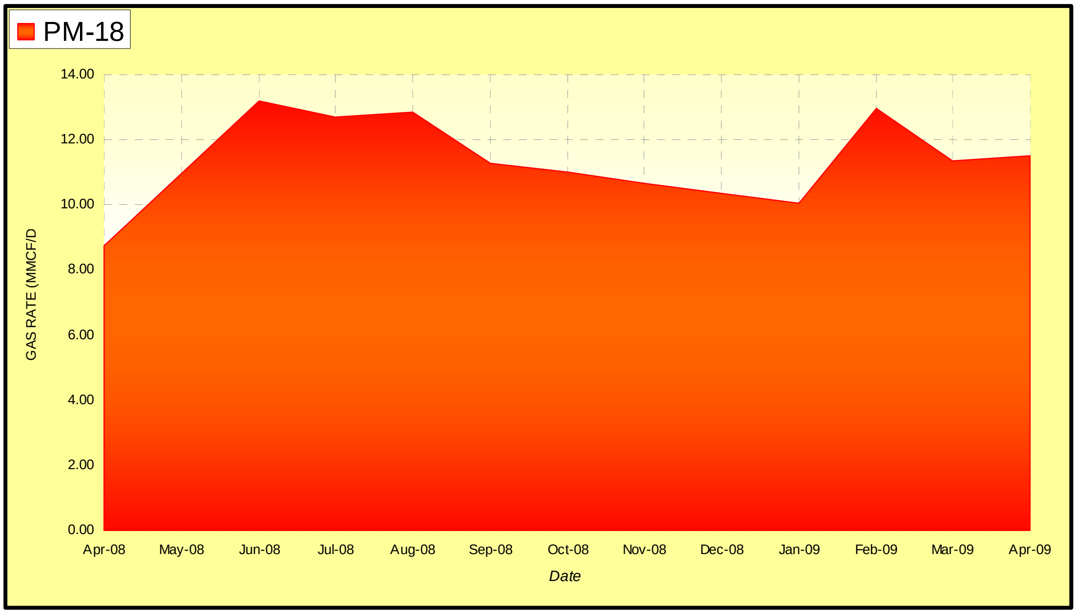

Fig. 6—Production History from the well treated with LRS

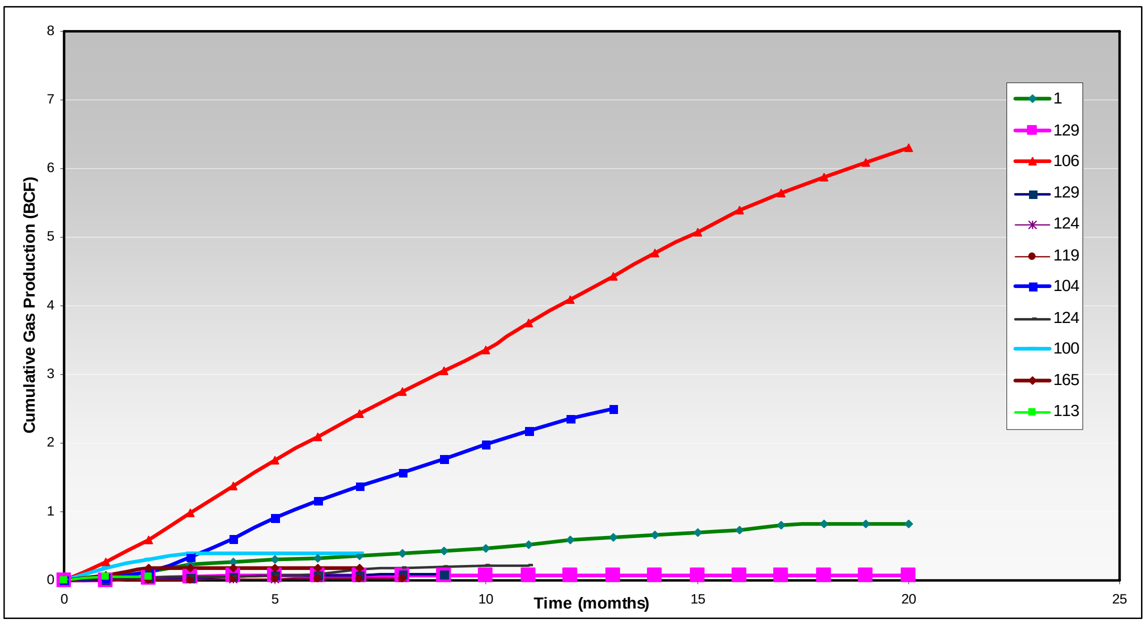

Fig. 7— Case 1. cumulative production from one well treated with LRS and offset wells left untreated.

Case 2

Filed B is also located in the Burgos Basin. Wells located in this field are producing from the Oligocene Vicksburg trend. This formation has also very low permeability, and drainage is therefore controlled by stimulation, propped fracture length, and fracture conductivity. Permeability ranges from 0.01 to 1 mD in some areas. Bottomhole static temperatures are around 250°F and reservoir pressure is approximately 6,300 psi. Formation stress ranges from 6,500 to 7,500 psi.

The potential of each sand was determined by using data from a pressure buildup test performed before each frac job where "kh" values were obtained.

After each pressure buildup test was matched according to the best model fitted to the features of each sand, a synthetic profile of "kh" was generated (Fig. 8).

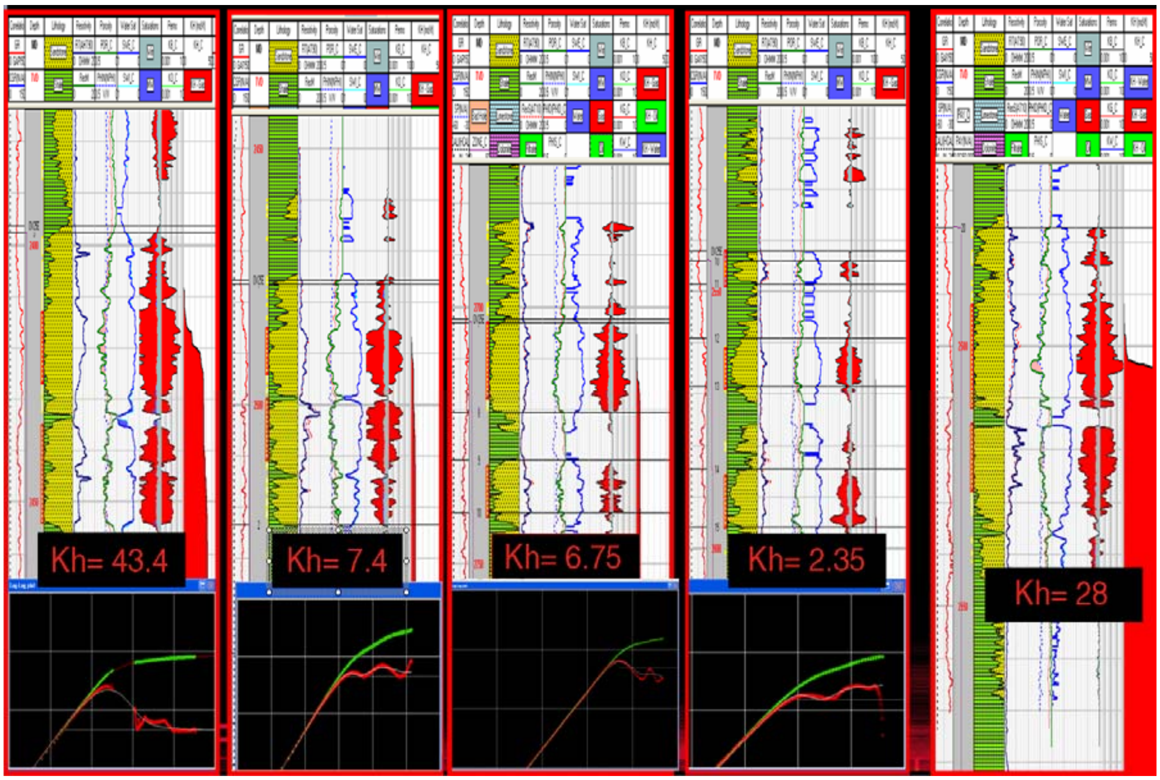

Fig. 8—Synthetic potential log from wells in Case 1 calibrated using pressure buildup tests.

The production data presented in this paper was gathered for almost 12 months from six wells fractured in this field. Three of the wells were treated with LRS-coated proppant and three offset wells were not. The simulated fracture lengths are shown in Table 1 along with additional information about the formation. Fig. 11 shows the post-fracture cumulative production story of the wells. The wells treated with LRS are marked in red. The untreated offset wells are marked in blue. It is observed from the graph that Well 3 shows apparently no improvement compared with the offset wells. To make a fair comparison of the productivity of the wells, the data was normalized by the “kh” of the pay zone , again, it can be seen that the wells treated with LRS shows better results compared to those not treated with LRS. In fact, in some of the untreated wells it was necessary to gain additional production from upper sands or by isolating intervals following low recovery after the eighth or ninth month; once isolated, the new intervals were perforated to maintain production. A review of the cumulative production it is found 1.3 Bcf more recovered gas from the LRS-treated wells.

Well	BHST, °F	BHSP, psl	kh, mD-ft	Fracture Length, ft	Fracture Conductivity, mD-ft	Proppant, lb	Fracture Fluid	Proppant Type
Wells Fractured with LRS								
1	226	6138	61.9	249	5946	290,800	CMHPG	IS Ceramic+LRS
2	232	4720	28.5	259	7017	350,000	CMHPG	IS Ceramic+LRS
3	215	6480	11	308	7735	338,700	CMHPG	IS Ceramic+LRS
Wells Fractured without LRS								
4	246	6320	18.4	371	1787	253,600	CMHPG	IS Ceramic/RCP
5	249	6200	15.4	374	2143	200,000	CMHPG	Ceramic
6	243	5523	54.4	459	3023	300,000	CMHPG	IS Ceramic

Table 1—Reservoir Properties and Fracture Parameters from Case 1

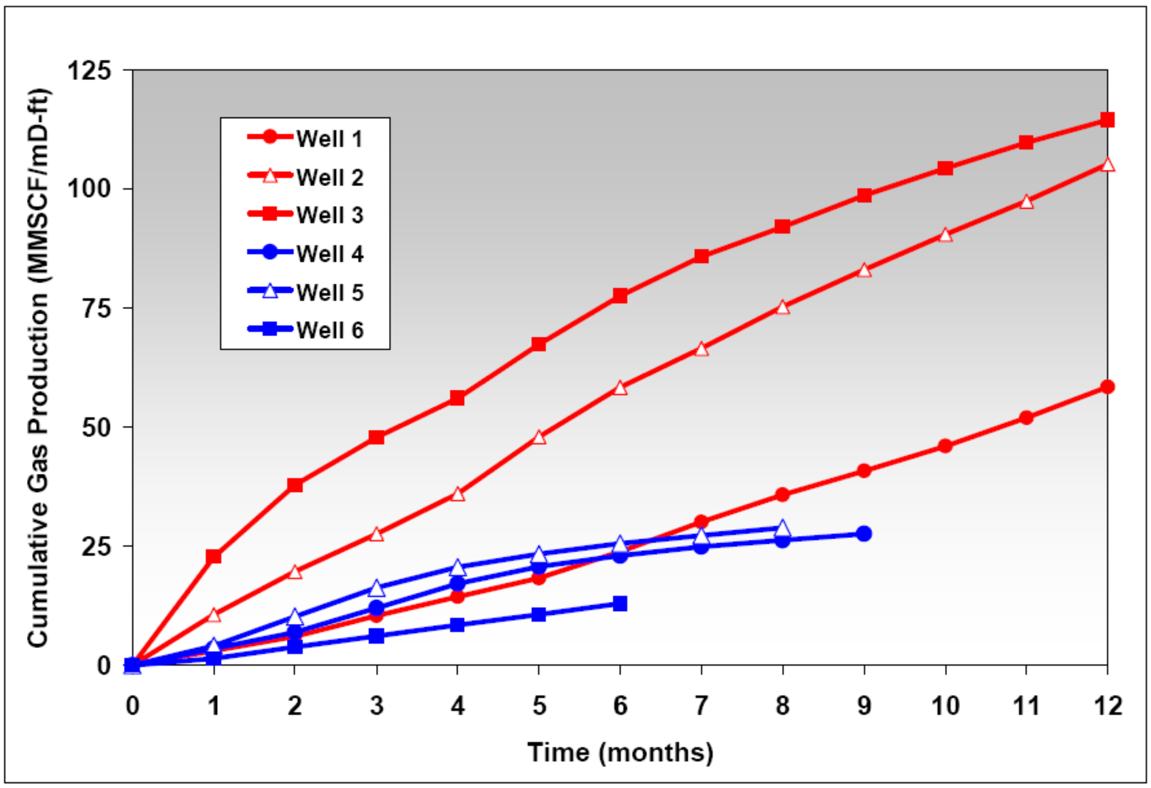

Fig. 9— Case 2. Normalized cumulative production from three wells treated with LRS and three offset wells left untreated.

Conclusions

- It is recommended to treat the entire volume of proppant with LRS (even wells with high hydrocarbon potential) to help assure optimum results, especially in proppant diagenesis protection.
- It is crucial to normalize production data by the potential of hydrocarbon to compare productivity between wells,especially for mid- and long-term expectations.
- Wells treated with LRS sustained productivity after 12 months, opposite to the classic declination curve characterized by an initial high production followed by a rapid declination, normally associated with proppant diagenesis damage.
- The productivity of the wells fractured with LRS-coated proppant outperformed the offset wells treated with non- LRS-coated ceramic by 68 to 109% even after 12 months of post-frac production.
- The cumulative normalized production of a well treated with LRS exceeded that of the RCP-treated well by 272% after 12 months of production.
- The substantial difference in the productivity performance between the wells fractured with and without LRS-coated proppant seems to be strongly related to severe proppant diagenesis conditions of their reservoirs, given the relatively high stress and intermediate BHT.

Nomenclature

BHST = bottomhole static temperature
BHT = bottomhole temperature
BHSP = bottomhole static pressure
IS = intermediate strength

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