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High Energy Gas Fracturing: A Technique of Hydraulic Prefracturing To Reduce the Pressure Losses by Friction in the Near Wellbore - A Colombian Field Application

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Abstract

One adequate management and optimization of mature fields requires the use of techniques, methodologies, technologies and analysis of the behavior of the wells to generate recommendations of production optimization with the highest probability of exit.

One alternative that today has proven successful and is widely applied worldwide to maximize the profitability of the fields, consists in the implementation of hydraulic fracturing jobs, to improve the flow capacity of the wells, which is achieved to go through the formation damage, speeds up the reserves, etc. However, one of the main difficulties of hydraulic fracturing, are the high friction pressure losses in the near wellbore (NWBF), which require high pressures to break the formation and equipment of higher power in surface. This means work over more expensive and with a lower economic profitability.

An evaluation of new technologies, allowed the identification of the alternative called High Energy Gas Fracturing (HEGF), as a pre-fracturing technique to reduce pressure losses by friction in the near wellbore (NWBF). HEGF is a perforating technique with propellants, which not detonate, but they blaze with high heat, but unexploded (deflagrate), releasing a high energy gas that reaches a sufficient pressure pulse (10,000 to 50,000 psi) and combustion time (5 - 30 milliseconds) that creates fractures in all radial directions at short distance.

For different operational areas of the Colombian state owned oil company, Ecopetrol SA, was performed an evaluation of pressure loss by friction in the near wellbore (NWBF), during hydraulic fracturing operations that have been executed. This allowed to make recommendations to implement HEGF and thus optimize the hydraulic fracturing operations. This paper presents the results of the assessment in the fields Apiay, Austral, Gavan, Suria and Yarigui.

Finally, the main findings, conclusions, recommendations and field results obtained in this study are shown.

Introduction

Since 2005, Colombia's state oil company, Ecopetrol, beginning a process of adaptation of the technology of hydraulic fracturing in different oil fields, for which design and run different campaigns for mass this technique, which now can reach 120 jobs per year . Like any new technology there were some drawbacks in its implementation, one of the most important, high frictional pressure losses in the Near Wellbore, presented during the work of fracture. To meet this challenge, an assessment of new technologies, allowed to identify HEGF as a pre-fracturing technique to reduce these losses.

This evaluation included: state of the art, methodology for implementation, selection of candidates in Colombia, evaluation of the technical benefits and assessment of economic benefit (net present value).

State of the art

Oil and gas wells were stimulated from the late nineteenth century, with a technique called "shooting well", which involved the detonation of high explosives, thereby producing a rapid release of energy in the face of formation, which ended up fracturing the rock and start producing wells. The problem of damage in the face of well generated by compaction, security risks and unpredictable results reduced the number of wells stimulated with explosives.

Time after appears on the scene, the conventional perforating of penetration low or high , which creates small channels in the face of formation, which allows the production of hydrocarbons.

In the 60's appears Hydraulic fracturing, which is to break formation using a fluid or gel fracture and proppant agent . The fracturing was designed to traverse the radius of damage and ensure proper communication between the reservoir and the well in areas of very high permeability or to enhance the conductivity of those areas of very low permeability. At present, features sophisticated techniques, equipment, fracturing fluids and proppant, that increase the exit of operations and the productivity index.

HEGF technology (High Energy Gas Fracturing) was originated and developed in mid-1956 and consists of a perforating with propellants, which are transported to the area of interest for Wireline, coiled tubing or tubing. The propellant is an oxidizing agent consisting of potassium perchlorate particles and epoxy resin. For this not to be regarded as an explosive and its activation requires instantaneous conditions of pressure, temperature and further confinement. Once ignited the propellant becomes a product of combustion by the deflagration, releasing gas (contained in a column of fluid in the face of the well), which in turn in the final stages produces the pressure pulse of large-scale and by the expansion, it is responsible for generating multiple fractures of short length (up to 21 feet in sand and 50 feet in Shale gas), in all radial directions in the well where the perforating was oriented.

Fractures become highly conductive flow channels that allow free movement of oil into the well, increasing production, or injection of fluids to and from the formatión. Figure 1 shows a test with HEGF in surface, Fig. 1.

Figure 1.Test with HEGF in surface, conducted in China.

Research on the technology allowed the development of mathematical simulation and identification of the following parameters for a proper design of its use:

Differences between stimulation techniques.

The main differences between the various techniques of inducing the formation fractures are related to rates of overpressure in the well, and exposure time during the event. This process allows for simultaneously initiating numerous fractures oriented-multi at the depth and well conditions. In Figure 2, these differences are better explained.

Hydraulic Fracturing

Is performed by isolating the formation in the face of the well, for exert enough hydraulic pressure to overcome the efforts around the same. The quasi-static pressure is applied until the tensile stresses are created and a break occurs, creating a fracture oriented perpendicular to the minor principal stress In Situ. However, hydraulic fracturing has no control over the vertical growth of the fracture, nor prevents frictional pressure losses near the perforated (NWBF), and the pressure required to break formation is often high. The pressure generated during the fracturing is much lower than the pressure created in the stimulation with hEGF and explosives, while the exposure time at pressure is much greater in the fracturing that in the stimulation with HEGF and explosives.

Explosives

The high explosives detonate rapidly; the pressure is extremely high with duration of microseconds, creating a shock wave that causes that the nearby rock is compacted (plastic behavior). Due to the effects of inertia, the tensile stresses are not produced and instead compressive stresses are created that increase the size in the face of the well by embedding and compaction of the rock. The Face of the formation remains with a compressive residual stress zone to help prevent the growth of the fracture. These compressive residual stresses and compacted rock can reduce the permeability around the face of the formation.

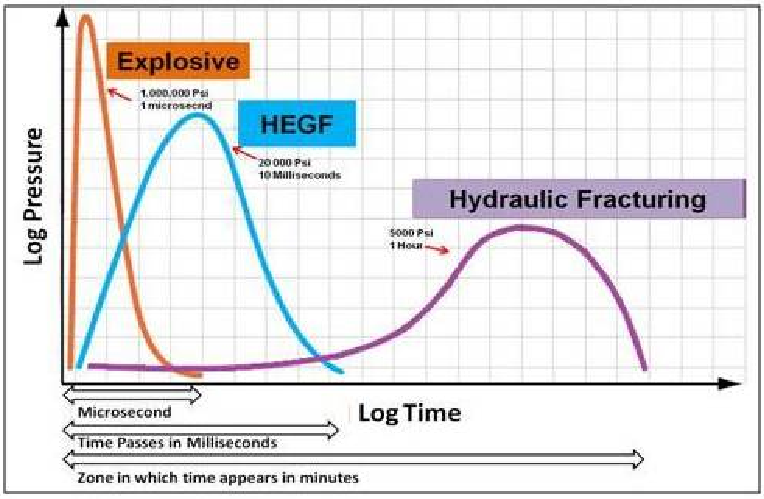


Figure 2. Maximum pressure vs time

High energy gas fracturing
Unlike explosives, deflagration of propellants is slower than the speed of sound and thus the combustion rate can vary over a wide range. The behavior of pressure and time of the stimulation with propellant , is different of the stimulatión with explosives , in which the maximum pressure generated in the first is lower and the burning time is longer. The gas released by the propellant during deflagration, generates a pressure pulse (10,000 to 50,000 psi) and burning times (5 - 30 milliseconds) that creates fractures in all radial directions at close range. Although the concept of using solid propellant to stimulate oil and gas wells is not entirely new, the propellant incorporates a new design to burn progressively. Progressive burning means that the propellant burning rate increases with time producing gas faster, before the material is consumed. This feature is achieved with propellant grain multiperforated that increase its surface area as the propellant burns. The progressive burning of the propellant is most effective when maximum pressure is controlled, allowing more energy to the propellant to be given to the formatión. When the combustion process is longer, more gas is produced and created longer fractures. Figure 3 shows the different types of propellants

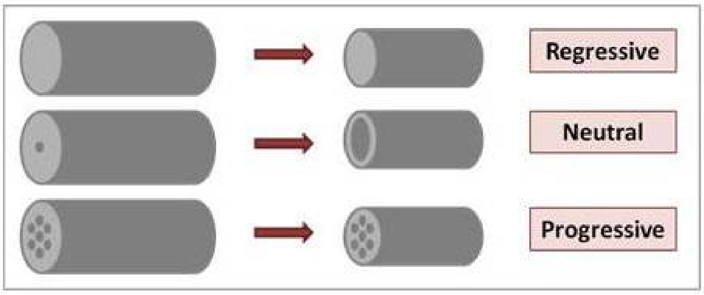


Figura 3.Different types of propellants

It is necessary to control the relationship between the magnitude of the pressure pulse and the time at which it occurs, so that it can produce a fracture. In the opposite case when the relationship is not proper, a compaction unwanted is generated. Actually propellants do not detonate, but burn with high grade heat but unexploded (deflagrate).The deflagration is the process of combustion that takes place without any external source of oxygen and creates large amounts of high-pressure gas at a rapid rate. The propellants offer a wide range of duration of burning, from milliseconds to seconds and not all produce the desired fracture behavior. If the rate of deflagration is high enough, the pressure reaches levels sufficient to create multiple fractures that propagate in directions that are not governed by the in situ stress state. This provides the desired benefits for optimal drainage near the face of the well and that the spread in height of the fracture is contained in the area of interest. The resulting fracture geometry of the three methods of stimulation in Figure 2 is shown in Figure 4.

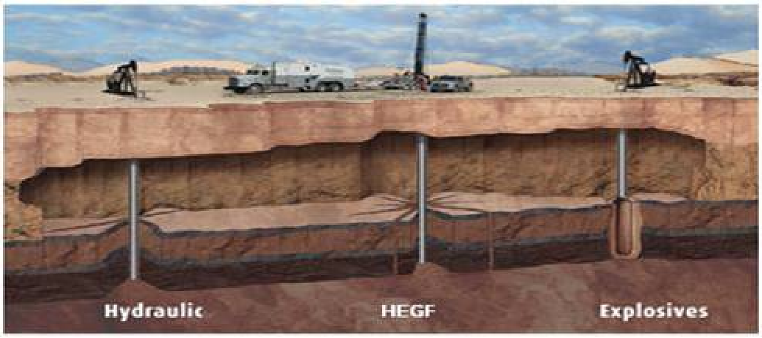


Figure 4. Rock Failure for Three different scenarios

Advantages of HEGF

- Go through of the damage zone for communicate the well with the reservoir.
- Conditions the well for hydraulic fracturing and acid stimulation
- Increased rates of production or injection compared with a conventional operation of perforating.
- Stimulation of naturally fractured reservoirs, wells geothermal and horizontals
- In water sensitive formations is ideal because it does not require the presence of water in the face of the well to implement.
- Produces multiple radial fractures in all directions to create greater permeability near the face of the well
- uses less equipment in surface and has a lower cost
- Use a system of ignited without detonation .
- Minimum vertical growth outside the producer zone and generation of fractures in each perforating
- Stimulation of the selected areas without the need to isolate them.
- Perforating clean and minimal formation damage from incompatible fluids.
- can be used in open and case hole

Disadvantages of HEGF

- Propellant in the surface, if not handled properly it can ignite dangerously.
- Created fractures parallel to the minimum in situ stress close quickly.
- The length of the fracture generated is very limited in sand formations, being less than 25 feet.
- The design requires specialized software, both open hole completions as in case hole.

HEGF assembly.

There are different names for the HEGF technique depending on the company that marketed it and assembly differs little from one company to another. It consists of a normal tube used in any perforating system (charges carrier), which is armed with explosives, charges, booster, Primacord (detonating cord), and at this set is added a propellant sleeve. This sleeve is sure to perforating system through two rings. Figure 5 shows a general scheme of HEGF assembly in well.

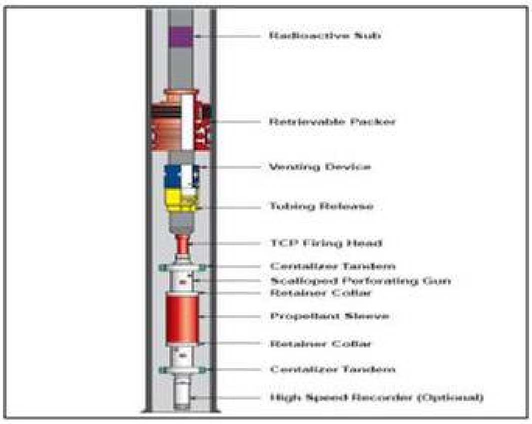
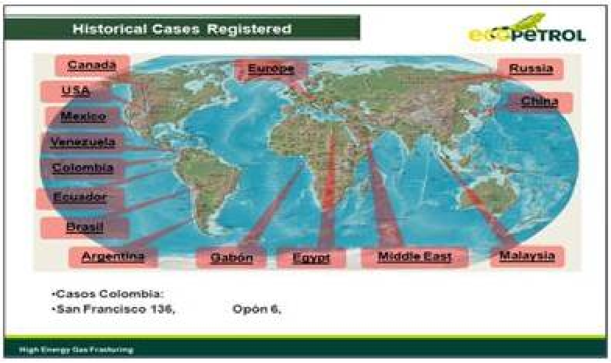


Figure 5.HEGF assembly

Benchmarking.
In literature are reported more than four thousand applications of HEGF worldwide. The Figure 6. show as has been the use in worldwide.



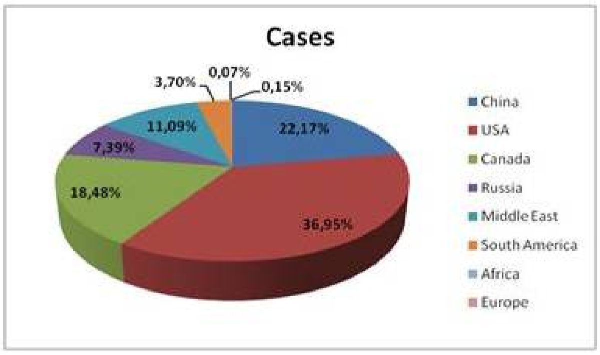


Figure 6.Applications of HEGF worldwide

Below are the results of applying HEGF in some wells water injectors and oil and gas producers:

HEGF Vs fracturing in gas wells
In December 2005 in Canada, hEGF was tested and compared with a traditional stage fracturing in shallow gas wells in the Basal Belly River formation. The results are shown in Table 1.
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	Number of wells	BHP (Psi)	Skin Factor	Frac half length (ft)	Keffective (mD)	Production Q(Mft^3/d)
HEGF	5	213	-4.58	86	0.60	20
HF	6	176	-4.51	92	1.27	21

Table 1.Case study of hydraulic fracturing jobs compared with HEGF

HEGF compared with explosives in water injection wells
Four water injection wells in Cattaraugus County (New York) that did not support injection were stimulated, two with HEGF and two with nitroglycerin. The wells stimulated with nitroglycerin involved significant costs in cleaning, and got water injection rates of 15 BPD. The wells that were treated with HEGF did not involve cleaning costs and achieve water injection rates of 60 and 90 BPD. Based on these results, most of the producing and injection wells were stimulated with HEGF.

HEGF in water injection wells
In the Table 2 the results of application de HEGF is show.

				Injection (Bl/d)			
Case Number.	***Country***	***Name***	***Type of Well***	***Before***	***Response***	***(6 Months After)***	***Incremental (Qafter/Qbefore)***
64	CANADA	6-22-12-18W4	Water Injection	125.8	N.D.	314.2	2.498
65	CANADA	4D-1-45-6W4	Water Injection	2515.9	N.D.	6604.3	2.625
66	CANADA	14-23-16-19W3	Water Injection	125.8	N.D.	4402.87	34.999
67	CANADA	16-25-49-8W5	Water Injection	45.3	N.D.	496.9	10.969
68	CANADA	16-11-48-1W5	Water Injection	75.5	N.D.	207.5	2.748
69	CANADA	8-10-16-17W3	Water Injection	0	N.D.	3333.6	…
70	CANADA	11-27-70-26W4	Water Injection	0	N.D.	679.3	…
71	CANADA	10-18-74-5W5	Water Injection	N.D.	N.D.	N.D.	…

Tabla 2.Case study of application de HEGF in water injection wells

HEGF in oil and gas producers wells

In the figure 7 the results of application de HEGF is show.

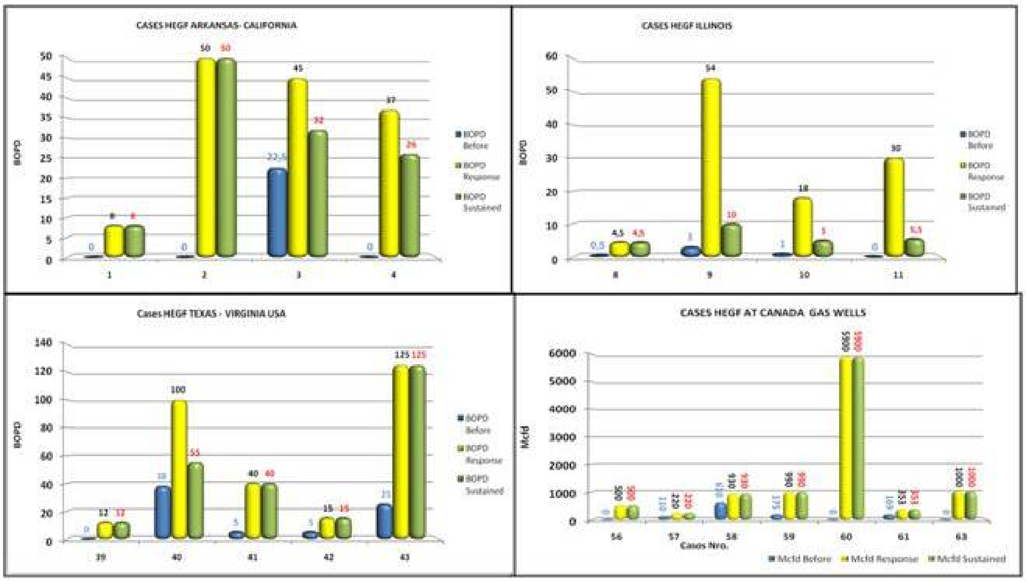


Figure 7.Results of application de HEGF in oil and gas producers wells documented in the literature

Cases of application of HEGF.

Below is a list of cases where it was implemented with satisfactory results.

- Oil and gas wells in consolidated sand formations, dolomite, shale, coal, chert, limestone, marlstone y diatomita.
- Naturally Fractured Reservoirs
- Gas and water injection wells with permeabilities varied (from low to high).
- Do not perform stimulation to less than 50 feet from the bottom of the well for safety recommendations.
- Aquifers below or above the area of interest were not contacted by the fractures.
- Static temperature at the bottom of the well less than 350 ° F
- Not less confining pressures to 500 psi.
- Formations that through its history of fracture has NWBF loss values greater than 500psi.
- Formations where the Breakdown Pressure is very high

Integrity of the casing.

Research led by J. F. Cuderman, sought to identify four main aspects: it was possible to achieve the multiple fractures? Scope of these fractures, pressure required for optimal stimulation and damage to the casing by stimulation with hEGF. The scope of fractures has not been clearly defined, but other aspects were answered with the investigation of J. F. Cuderman, which identified that the major variables that influence stimulation with hEGF are: diameter, density and orientation of the perforating, burning rate, size and charge of the propellant, hydrostatic column on perforating, casing type and diameter, etc. This research also allowed them to establish the equation 1, which defines the calculation of the rate of pressurization, which is the expression that regulates the pressure pulse and will be it the that determines if this pulse, will damage or not, the well casing.

$$\frac{dP}{dt} = cte\frac{d^2PNA_0kT}{VM} \qquad \text{Equation….. (1)}$$

Tests conducted during the investigation for different conditions of stimulation with hEGF, identify the involvement or not the integrity of the casing, as shown in Figure 8. Case A: the failure occurs because the diameter of the perforated is very small and the mass of propellant is over sized, Case B: the failure occurs because the diameter of the perforation is very small, despite having appropriate design of propellant mass, C and D, same as A, B, but additionally the orientation is not favorable; E: Appropriate design; F: the orientation, density and size of the perforating and propellant were appropriate. The failure was oversizing of the mass of propellant.

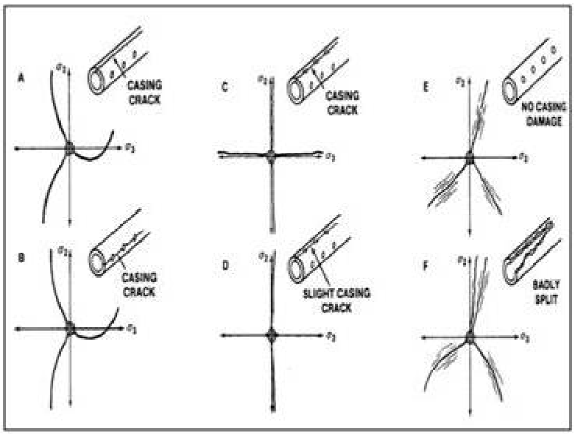


Figure 9.Scenarios of impact on the integrity of the casing with HEGF

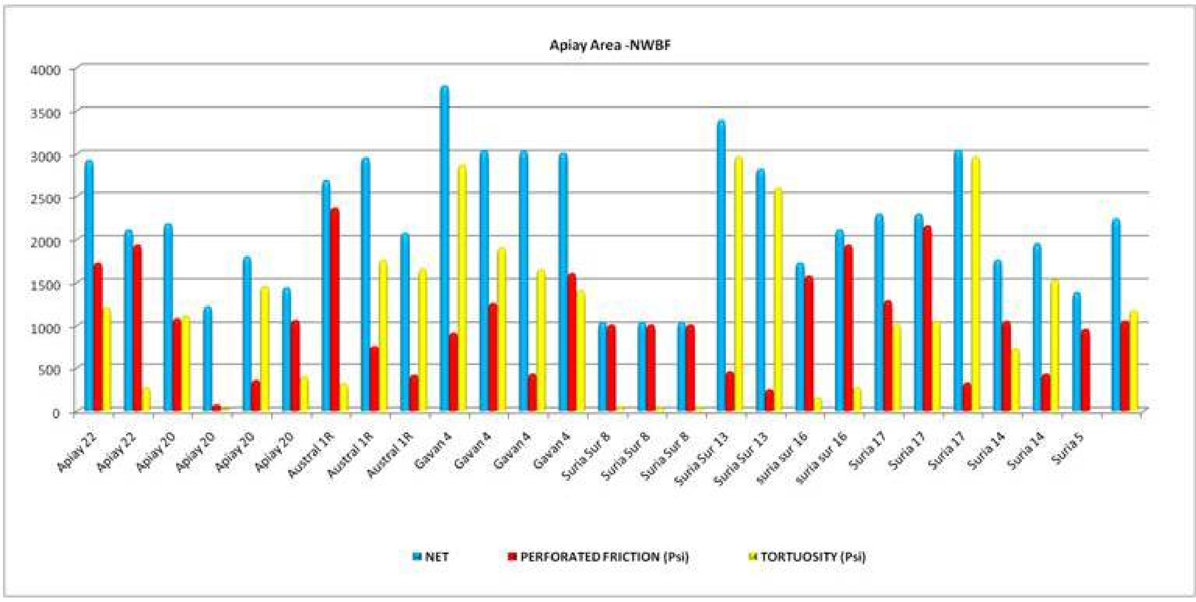
To avoid these situations, the differents companies that marketing the HEGF technology have developed software to perform an adequate design, which prevents damage to the integrity of the casing.

Candidate selection methodology and design implementation

Annex A details the flowchart for decision making in candidate selection and design of implementation of HEGF.

NWBF assessment in fracturing job in fields Colombian

The following chart shows the NWBF presented for fracturing job in Colombian fields.



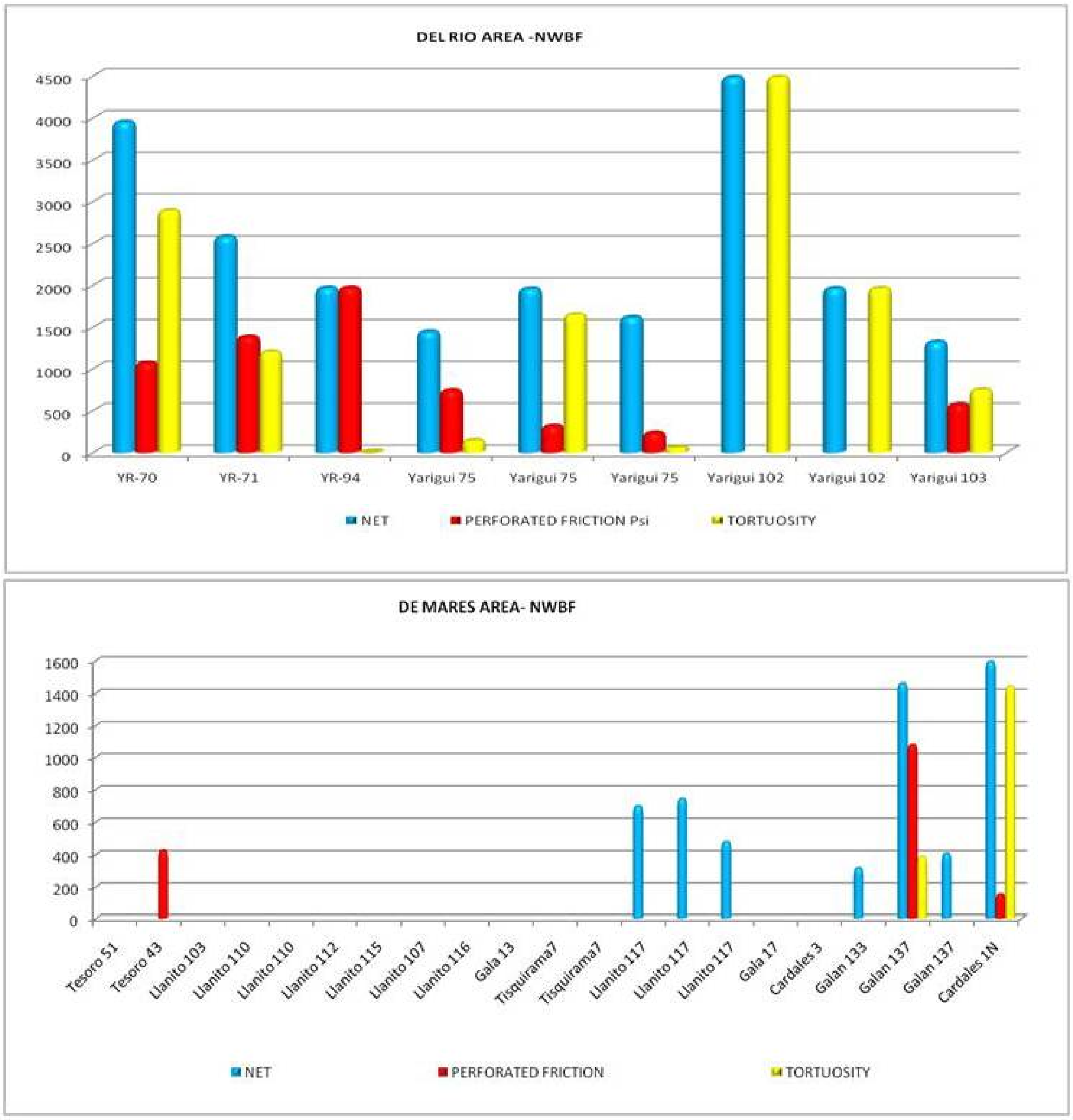


Figure 10. NWBF presented for fracturing job in Colombian fields.

As a rule of tumb a near well bore friction higher than 500 psi is not desirable because this increases the risk for premature screen out (especially when dominated by tortuosity). This condition was experienced in the majority of the cases shown above, mainly because wells were not originally completed to be fractured. In order to address this undesired condition for new wells to be fracture during the initial completion it was necessary to improve the perforating process, in some cases when higher fracture gradient was anticipated, the HEGF was the chosen alternative.

Case History

Well A was perforated with HEGF because the geomechanical model anticipated a higher fracture gradient, additionally the stactistics for this near by fields showed that near well bore friction was high. This well was planned to be fractured at the intervals: 13742-13762 ft MD, 13557-13578 ft MD.

Interval 13742-13762 ft MD:
During the initial injection test the breakdown was not observed, althought the well was admiting brine at 18.9 bpm / 12400 psi (STP) under fracture regime (Pre ISIP 12116 psi, ISIP 10200 psi, FG = 1.18 psi/ft). It is evidence that HEGF induced a

failure by tension in the rock at the well bore, reducing the initial pressure required to created and extend the fracture, which is one of its benefits.
The SDT was performed using 88 bbl of 3% KCL Brine. Total NWBF was 430 psi at 19.8 bpm.

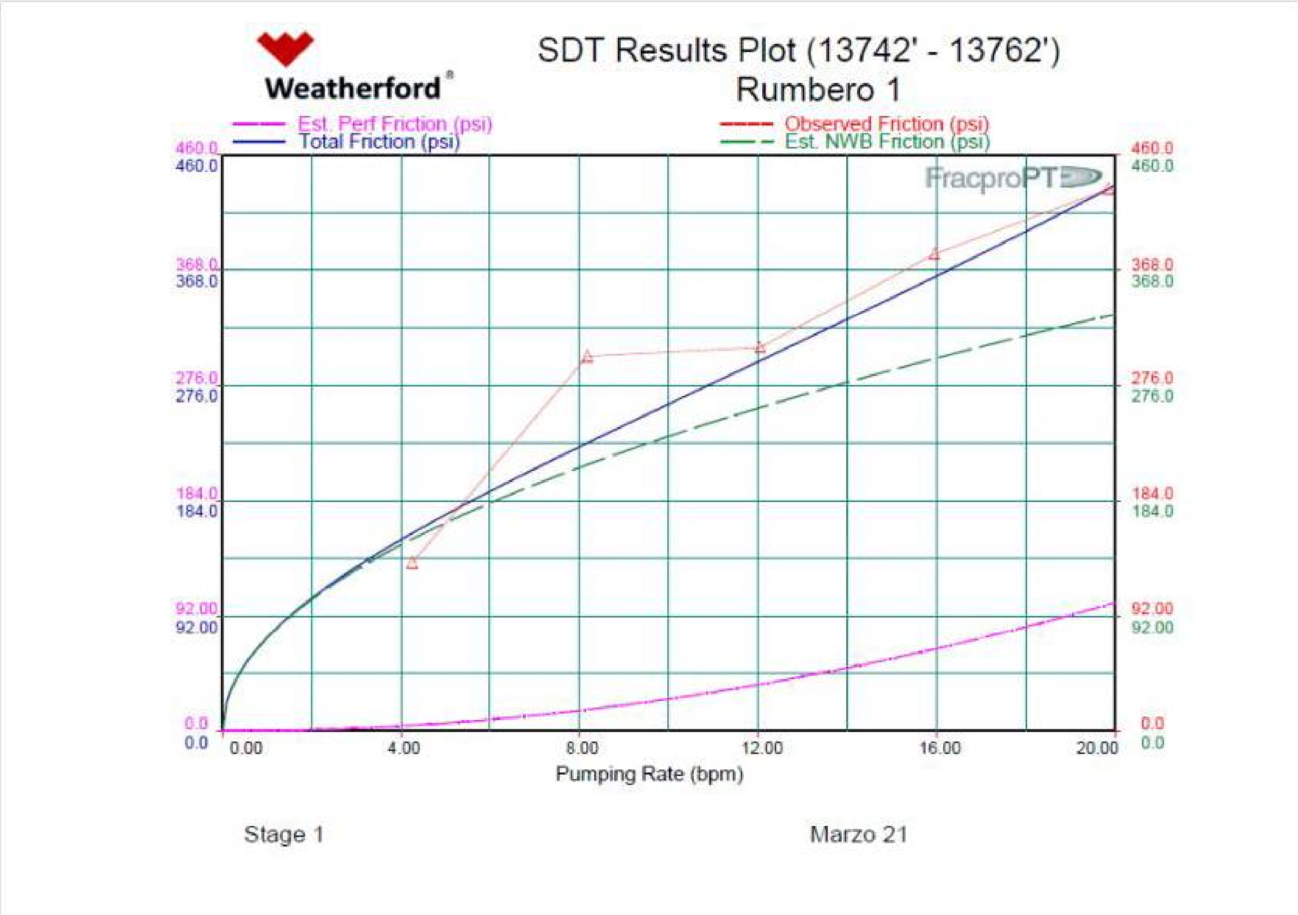


Figure 11.SDT Interval 13742-13762

Interval 13557-13578 ft MD:
This interval could not be fractured because the maximum rate without exceeding the maximum permited pressure was only 9.5 bpm / 13160 psi. Although the interval was perforated with HEGF and perf washed with Formic-Acetic Acid.

Conclusions

1. Technology HEGF has a proper development and sufficient historical cases around the world. In the past 40 years, over 8000 stimulations with propellant (HEGF) were performed in USA, Canada, Europe, Russia, Africa, Latin America and the Middle East.
2. HEGF technology should be considered as an option in the initial completion strategy of wells to be fractured.
3. Proper selection of candidates and the appropriate design of hEGF will achieve satisfactory results.
4. The HEGF has been successful in a diverse range of petrophysical properties and different lithologies including sandstone, limestone, dolomite, shale, coal, chert, limestone, and diatomite Marlston.
5. For proper design of hEGF and avoid damage in the casing should be taken into account the diameter, density and orientation of the perforating, burning rate, size and propellant charge, hydrostatic column on the perforating, casing type and diameter, etc.
6. HEGF is a valuable tool to reduce surface pressure requirements during hydraulic fractures, due to its efectiveness to reduce total near well bore friction.
7. From the autors experience, for those cases at which the rock first fails by compression instead of tension, HEGF is not effective and the fracture cannot be achieved.