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Application of Progressively Burning Propellants to Increase Effective Permeability in Heavy Oil Reservoirs

Stephen Newton, Southern Cross Energy; Diana Ahmet, Ecopetrol

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ABSTRACT

A progressive burning propellant is one in which the rate at which the propellant burns increases with time, producing gas in increasing volume as the material is consumed. There are various propellant designs with a solid configuration resulting in a regressive burn as surface area decreases as the material is consumed. Boring a single concentric hole serves to maintain the surface area constant and results in gas being generated at a stable rate. A progressive burn is achieved by including multiple round holes or the star pattern. The proprietary design of the GasGun propellant includes the multiple hole option to achieve the desired progressive burn characteristics (Figure A).

The GasGun is a solid multi perforated propellant, progressive burning; fracturing device based on proprietary ballistic technology from the U.S. military. The propellant generates high-pressure gases at an accelerating rate that creates a fracturing behavior dramatically different from either hydraulic fracturing or explosives. The time to peak pressure is approximately 10,000 times slower than explosives but 10,000 times faster than hydraulic fracturing (Figure B). The ability to propagate these fractures to bypass near well bore damage zones has been demonstrated experimentally and verified through extensive field applications.

The development of software is ongoing and will incorporate all available data including earth stress data, well bore configuration, log data, core analysis and pvt analysis. Post frac test data will then be used to refine the model, particularly as it pertains to applications in the same field, formation and basin.

KEY WORDS

Propellants, Progressively Burning, Heavy Oil, Colombia, Skin, Damage, Injection, Production

INTRODUCTION

Many companies in the Oil and Gas sector have been dedicated to maximizing the production from reservoirs with near well bore damage. Very sophisticated and expensive muds and kill fluids, acid, chemical washes and fracking have been used to either avoid damaging the formation in the first place or to reduce the impact of the flow restriction near well bore damage can cause in the event the preventative measures fail. The viscosity of the long chain hydrocarbons that characterize heavy oils exacerbates the choking effect. The correct application of progressive burning propellants has been proven to bypass near well bore damage, increasing the effective permeability, the 'KH' of the interval. This can be achieved through the application of the technology associated with progressively burning propellants without the negative effects associated with chemical treatments or in the case of fracking, the high cost and the risk that a vertical fracture may communicate with other zones, perhaps water or gas bearing. This technology has the potential to add production hence revenue very cost effectively if applied to address the specific problems associated with near well bore damage.

STATEMENT OF THEORY AND DEFINITIONS

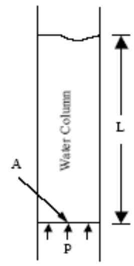
A progressively burning propellant is consumed at an ever-increasing rate as by virtue of it's design, more surface area is exposed as it burns, producing gas at an accelerated ate as the propellant is consumed.

The idea for a progressively burning propellant originated long before the technology was applied in the oil industry and as is the case for many new technologies, it was driven by the military who wanted to launch their shells much further than allowed by the traditional gunpowder charge utilized in the naval and land battles of the 19th century. Basically, if a shell is to be accelerated up a long barrel using a propellant, it is essential that high-pressure gas be generated faster and faster at ever-higher pressures to fill the rapidly increasing volume in the barrel behind the shell and to accelerate the shell. This concept is not very different to what it takes to propagate fractures originating in a well bore in that after the fracture is initiated, increasing volumes of gas are required to ensure the fracture continues to propagate and thus bypass a near well bore damage zone or intercept and existing fracture system.

Practical benefits from the correct application of the technology can include the following:

- Creation of multiple radial fractures originating in open hole, perforation tunnels or slotted liners, 25+ feet have been observed in the Sandia tests
- Near well bore damage caused by drilling mud, completion fluids, cement, fines, scale, asphaltine, paraffin or other chemical deposition can be bypassed leading to significant improvements in effective KH
- Increase production from naturally fractured reservoirs by intercepting more fractures
- Reduce costs of traditional fracking by reducing pressure and hydraulic horsepower requirements
- Improve effectiveness of acidizing by allowing more of the reservoir to be contacted
- Increase injection rates in waterfloods, waste disposal, and gas storage wells
- Reduce risk of communicating with other zones as 98.5 % of energy is focused laterally hence vertical fracture growth out of the zone of interest is minimal often a major downside to conventional fracking. To illustrate why the energy is contained to the zone of interest, the following calculation is presented:

- movement of water column above GasGun stimulation



P = Pressure
L = Length
A = Area
t = Time
F = Force
m = Mass
a = Acceleration

V = Volume
v = Velocity
W = Weight
g = Acceleration due to gravity
ρ = Density
s = Distance

Values:
P = 20,000 psi
t = 20 msec.
L = 1000 feet
$\rho = 62.4\ lb/ft^3$ (density of water)
$g = 32.2\ ft/sec^2$
$A = 0.213\ ft^2$ (6 ¼" open hole)

Formulas:
$F = ma$ or $a = F/m$
$F = PA$
$m = W/g$
$W = V\rho$
$V = AL$
$s = \frac{1}{2}at^2$

$a = F/m = PAg/W = PAg/ALp = Pg/Lp$

Distance water column moves in 20 msec is: $s = \frac{1}{2}at^2$

In this example, the water movement is 0.04 m, implying that the energy should have been well kept within the chosen interval.

DATA AND OBSERVATIONS

The testing performed at Sandia National Laboratory's Nevada Test Site included the ability to excavate a cross section of the rock impacted by the various technologies.

The Stressfrac technology includes propellant with regressive burn characteristics. While the initial burn creates high pressures and does in fact generate multiple fractures, the regressive burn characteristics of the propellant makes it very difficult to achieve fracture propagation limiting the ability to bypass near well bore damage to significantly increase flow rates (Figure C).

These direct observations demonstrate that the GasGun produces multiple fracturing. Although the induced fractures are approximately aligned at 90 degrees to the least principle stress, there are still considerable shear forces present. This, coupled with the disruption at the fracture face caused by the energy released in the very short time of the burn, results in the fracture staying open even in less consolidated formations (Figure D).

The fracture patterns have been mapped out to more clearly indicate the generation of multiple fractures and the fact that many are not aligned at 90 degrees to the least principle stress and thus the fracture faces are displaced due to the shear stress (Figure E).

RESULTS

Ecopetrol ran the GasGun in a number of wells in various basins and producing horizons throughout Colombia where pressure data indicated the presence of significant near well bore skin or wells were inferred to have significant damage based on the behavior of adjacent wells with similar petrophysical characteristics. Table A summarizes the results in these initial wells.

Castilla is a very large heavy oil accumulation located in the Llanos Basin of Colombia. Discovered by Chevron in 1969, Ecopetrol assumed responsibility for the operation of the field in 2002 and since that time has built production to over 100 MBOPD. The main producing stratigraphic units are the Massive Guadalupe, or K2, and Upper Guadalupe, or K1. The K2 is a sand dominated system deposited in braided and meandering channels. The deposits are primarily gravels and sandstones, generally poorly sorted, fine to medium grained. The K1 Inferior unit consists of coastal plain sandstones and mudstones. The K1 Superior is predominantly a shale and siltstone interval. Several initial wells in Castilla were chosen based on the presence of significant skin damage pressure inferred from build up analyses. These initial results are outlined in Table B.

CONCLUSION

The technology cost effectively increased production in a wide range of wells in various basins and reservoirs with the specific results depending on the degree to which the effective permeability was impaired by near well bore damage, positive skin. Ideally, the decision to employ the GasGun technology outlined in this discussion would be based on pressure build up analysis however this is not possible or cost prohibitive in many wells hence the decision can be based on poor well performance where petrophysical evidence suggests the presence of significant damage.

ACKNOWLEDGMENT

I would like to thank Ecopetrol for having recognized the potential and having been willing to test the technology in a number of basins, fields and producing intervals in Colombia, and with reference to this conference, specifically in the Castilla heavy oil field. Diana Ahmet, my co-author and a member of Ecopetrol's Improved Recovery team, reviewed the candidates and in conjunction with Diana Chaparro and the Ecopetrol operating regions, oversaw the stimulations and monitored the results. I would also like to thanks SmartStar for having shared their experience in deploying the GasGun in Castilla and the other basins of Colombia.

NOMENCLATURE

MBOPD thousands of barrels of oil per day

KH permeability times thickness

TABLES

Table A

Well	Well Type	Before GasGun	After GasGun	Interval (Feet)	Increase
Los MangosX X	Production	0	40	38	40
ACAEXX	Production	40	836	50	796
ACAEXX	Production	71	103	90	32
SantosXX	Injection	4176	7344	68	3168
SantosXX	Injection	2592	4176	205	1584

Table B

Well	Well Type	Before GasGun	After GasGun	Interval (Feet)	Increase
CastillaXX	Production	101	616	139	515
CastillaXX	Production	20	80	96	60
CastillaXX	Production	8	384	59	376
CastillaXX	Injection	0	2300	150	2300

FIGURES

Figure A

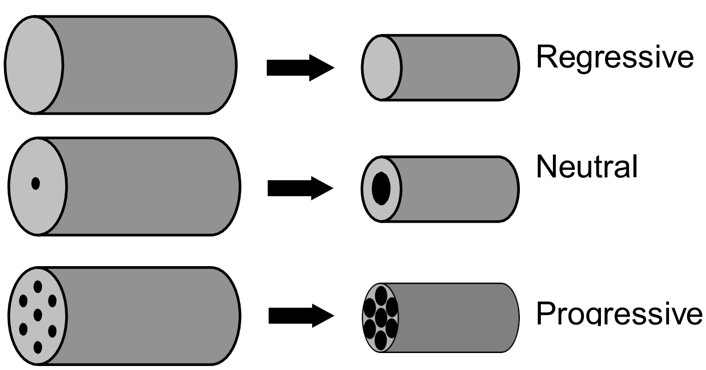


Figure B

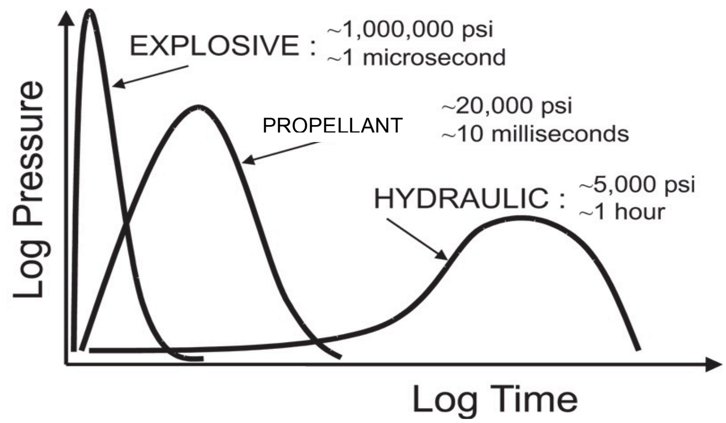


Figure C

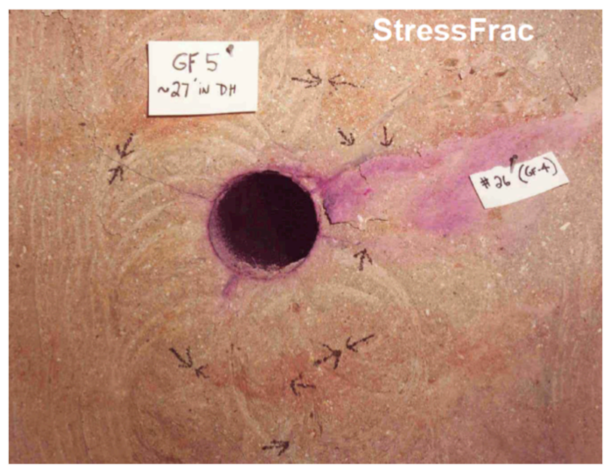
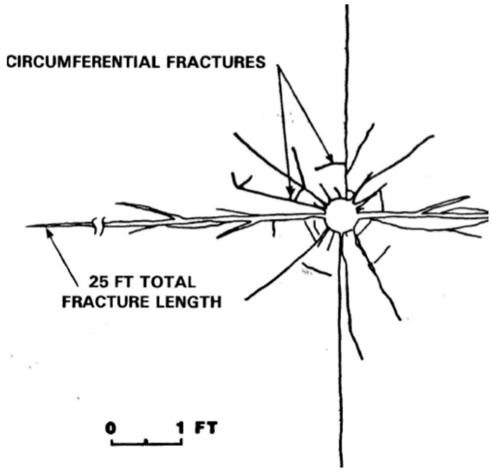


Figure D

Figure E


CIRCUMFERENTIAL FRACTURES
25 FT TOTAL
FRACTURE LENGTH
0
1 FT