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ADVANCED WELL STIMULATION METHOD APPLYING A PROPELLANT BASED TECHNOLOGY

1. INTRODUCTION

The usage of explosives in petroleum engineering starts almost along with the first oil production. In the USA, in 1859 – just a year after Captain Drake has drilled in Tituswille (Pennsylvania) the first rotary oil well, H.H. Dennis performed the first well stimulation – applying the explosive [1]. The black powder had been used initially, not a long time after that (1866), the liquid explosive – nitroglycerine (NG) has been employed. Unfortunately, such high explosives detonate and create a shockwave and high pressures that last only a few microseconds resulting in a zone of residual compressive stress which actually can cause a reduction in permeability in near wellbore region. This led to many fails in usage of high explosives to improve well productivity.

The usage of explosive as alternative method of well stimulation was revitalized again in 1970' s during the world's oil supply shortage. In this period the intensive research of application of explosives as complementary alternative well stimulation methods, originally based on findings in military and space technology, was considered. The propellants do not detonate supersonically, they deflagrate at subsonic velocities. Deflagration burning process takes place without an outside source of oxygen. Propellants have energy densities approximating those of high explosives, and are thus more compact than any other prime energy source other than nuclear. The propellants typically produce a high pressure event lasting on the order of a few milliseconds to perhaps a few hundred milliseconds for high explosive shots. This longer event time is the furtive to producing multiple fractures around the wellbore due to propellant stimulation.

Even if the alternative method of multidirectional fracturing using propellants has been successfully applied in USA [2–8], ex USSR states [9] and P.R. China [10–12], this pro-

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cedure is not well known in Europe [13]. In this paper according to literature data the application of propellants for mechanical multidirectional fracturing of reservoir rocks in the means of high energy gas propulsion along with initial petrophysical laboratory investigation and results of well stimulation jobs on two wells is shown.

2. FORMATION DAMAGE VS. CONVENTIONAL STIMULATION METHODS

There are a lot of sources of formation damage: during well drilling (drilling mud and mud filtrate invasion), well cementing (cement slurry filtrate invasion), well completion (incompatible completion fluid rock/formation fluid interactions), pay zone perforating (ea. compaction in perforating tunnels) production process (water cut, emulsions, asphaltenes, scale deposition etc.) well stimulation (incompatibility of stimulation fluids and products of chemical reactions with formation and formation fluids).

As the answer to this challenge two categories of conventional well stimulation methods, in order to overcome or remove formation damage and establish original formation permeability are recognized: chemical treatment (using acids or other chemicals – solvents) and mechanical methods (mostly hydraulic fracturing). In case of chemical methods in some cases the chemical interaction could result with insoluble precipitants which could secondarily plug the rock pore space, on the other hand, hydraulic fracturing (Fig. 1), in principle producing a single fracture with two vertical wings from wellbore indirection perpendicular to minimal principal rock stress (Figs 2 and 3). The operations are very expensive.

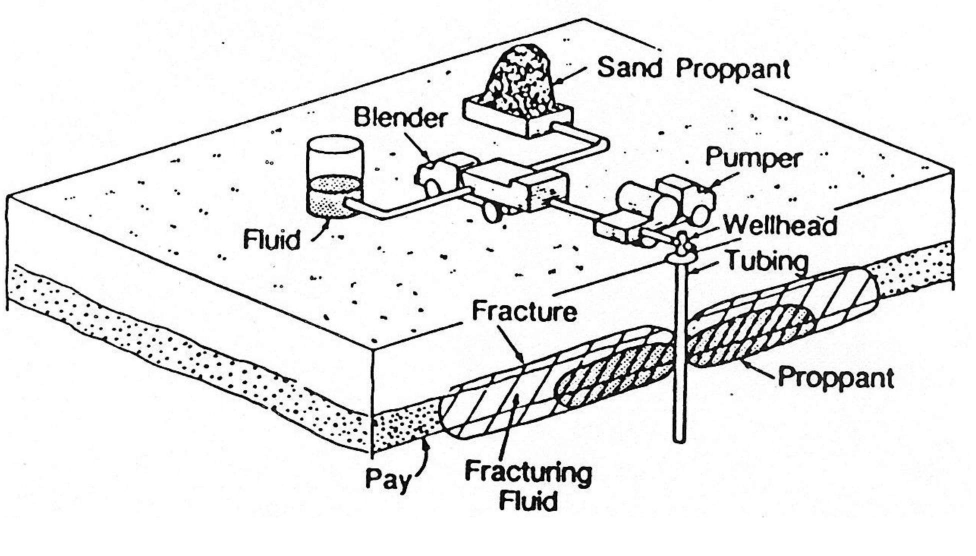

Fig. 1. Hydraulic fracturing operation setup

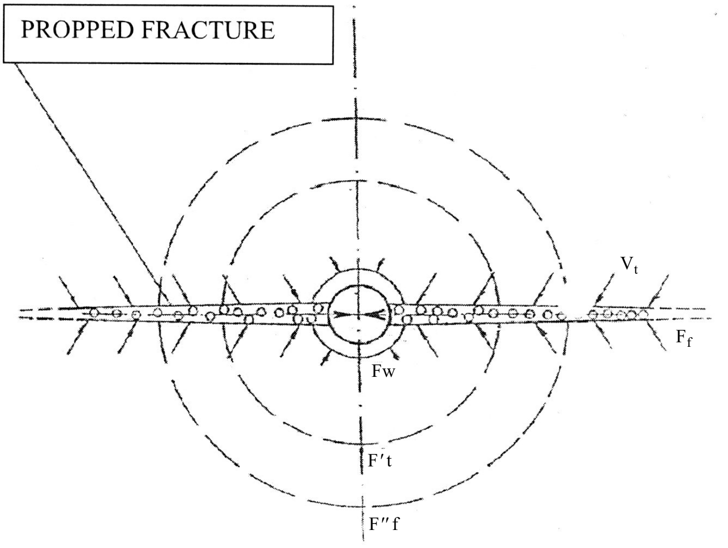

Fig. 2. Propped hydraulic fracture, fluid flow capacity much higher than original rock

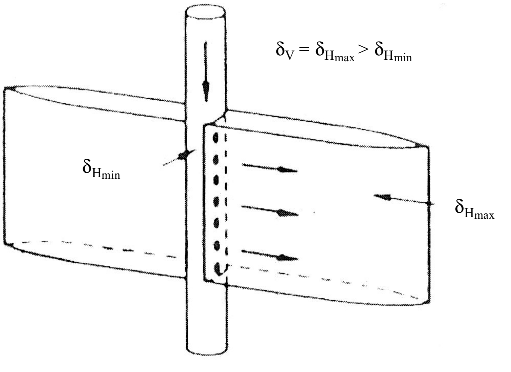

Fig. 3. Two wings of hydraulic fracture, direction perpendicular to minimal stress (σ_{min})

3. PROPELLANTS – PROPERTIES AND USAGE

Propellants are solid or liquid explosive materials which in very short time ($t < 1$ μs) deploy the high quantity of gaseous products with high energy potential, to be converted into mechanical impact. Burning velocity is about 1000 times less than in case of strong explosives. The exothermal decomposition process is more controllable, effecting if deployed in near wellbore zone with maximal pressure 10 to 100 MPa and temperature 2000 to 5000 K. The propellants could be classified in three groups: mono component, two component and multi component. The basic constituent of majority of propellants is nitrocellulose [14].

The fundamental research results directing the investigations to practical usage of propellants in well stimulation are published in U.S. patent of H.H. Mohaupt (1965) [2]. Theoretical explanations for application of propellants in mechanical well stimulations by high energy fracturing could be found in publications of Yang [10, 15], Miniszewski *et al.* [16] and Schmidt *et al.* [17]. The typical pressure diagram downhole, during high energy gas fracturing by means of propellants is shown in Figure 4.

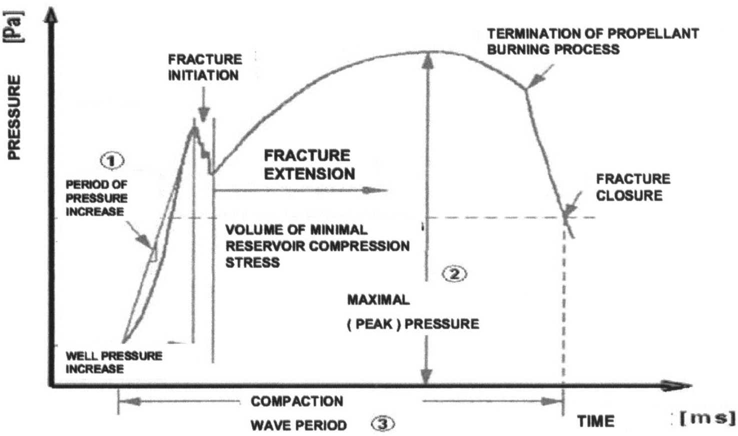

Fig. 4. Typical time-pressure diagram of propellant fracturing process

The most important parameter by which the process of fracturing of reservoir rocks, using propellants, could be period of pressure increase, t_m (from the moment of propellant deflagration start till the moment of fracture initiation). This could be expressed by the relation [10, 18] which defines the creation of multiple, multilateral fractures in reservoir rock:

$$\frac{\pi D_W}{2V_R} \langle t_m \langle \frac{8\pi D_W}{V_R}$$

where:

t_m – time of pressure increase (s),
V_R – critical velocity of impact gas wave expansion (m/s),
D_w – wellbore diameter (m).

The result of propellant deflagration in wellbore is the impact of propulsion to the formation, causing the dynamic pulsation of gas in natural microfractures. Due to it the rock has been fractured and the cracks, 0.5 to 1.5 mm wide and 2 to 6 m long are formed around the wellbore (in moderate compacted sandstone formations). In the most cases [10, 20] 3 to 10 such fractures are being generated in such manner (Fig. 5). The fracture length is quite enough to break trough damaged zone, overcoming a skin effect. The comparison of typical fracturing data [18] for hydraulic fracturing, fracturing using explosive and fracturing employing propellants are shown in Table 1.

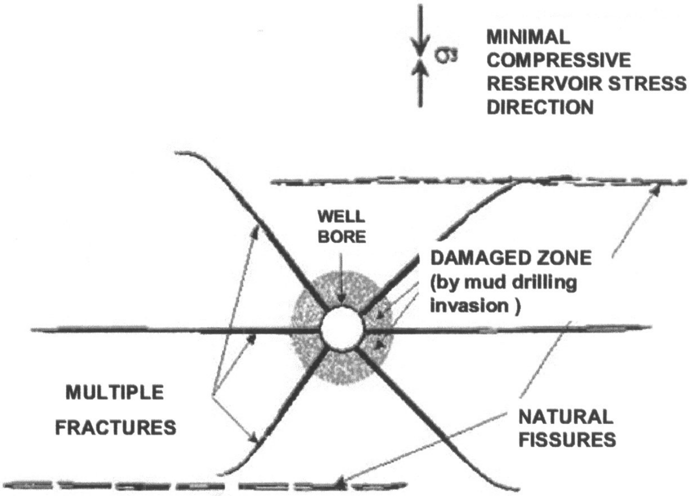

Fig. 5. Multiple (four) fractures generated around wellbore as a result of propellant deflagration

Table 1

Fracturing data comparison

	HYDRAULIC FRACTURING	FRACTURING USING EXPLOSIVE	FRACTURING USING PROPELLANT
PERIOD OF PRESSURE INCREASE [s]	10 – 100	$10^{-7} – 10^{-6}$	$10^{-4} – 10^{-3}$
IMPACT PRESSURE PERIOD [s]	10^{3} - 10^{4}	10^{-6} – 10^{-5}	10^{-2} – 1
PEAK PRESSURE [MPa]	10	$10^{4} – 10^{5}$	10 – 100
NUMBER OF FRACTURES GENERATED	1	high	3 – 10
FRACTURE LENGTH [m]	10 – 300	< 1	< 10
SHAPE AND DISTRIBUTION OF FRACTURES	SINGLE FRACTURE (TWO WINGS)	IRREGULAR (thiny, serpentine shape)	REGULAR, multiple, radial shape
COMMENT	- fracture orientation dictated by direction of the minimal formation stress	- Possibility of mechanical damage of casing and well bore wells	

4. LABORATORY TESTING

In order to investigate the effects of propellant deflagration [19] to the reservoir rocks from Pannonian basin (Croatia), the sandstone core material from the gas well (payzone depth 2850 m) was used. Tests were carried on three laboratory plugs 101.6 mm dia. and 200 mm long. The initial permeability to air was determined (Tab. 2), then inside each core plug the concentric hole 25 mm dia. and 120 mm deep was drilled (Fig. 6).

Table 2

Rock-core laboratory core permeability data before and after propellant treatment

Laboratory Designation of core / quantity of PCF propellant	PERMEABILITY (by air) [$\mu m^2 \times 10^{-3}$]	
	BEFORE deflagration PCF	AFTER deflagration PCF
No. 6991/3g	14.84	13.61
No. 6996/3g	11.98	11.60
No. bb/1g	24.69	29.69

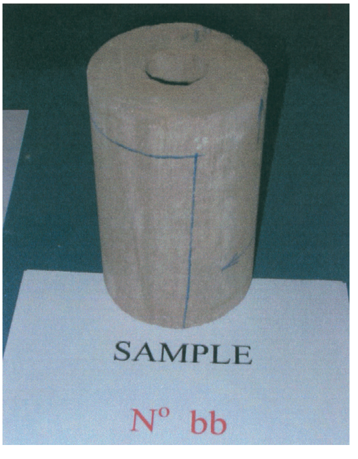

Fig. 6. Laboratory core plug with contrentic hole drilled. After deflagration of 1 g PCF propellant, no visual destruction observed

The holes were filled with various quantities of PCF propellant. At a field polygon from distance of 30 m the propellant was electrically activated (Fig. 7). In case of using 3 g of PCF propellant cores were fragmented (Fig. 8) and four fractures were generated – just as theoretically predicted [10, 15, 18], but in case of 1 g PCF deflagrated the core plug remained compact (Fig. 6).

The measurement of permeability on remained rock material after exposure to propulsion destruction (Tab. 2) shows decrease in case of 3 g propellant used but permeability increase when less quantity of PCF was employed. The decrease in permeability can be explained by impact of very strong propulsion wave which caused the compaction of rock structure (similar to the detrimental effects on the walls of perforation tunnels during conventional jet perforating [19]). On the other hand, the permeability increase, from initial 24.69 to 29.69 $\times 10^{-3}$ μm^2 (sample bb, Tab. 2) when limited amount of 1 g of propellant has been used, the expanded gaseous products of deflagration enlarged the dimensions of natural microfractures inside integral specimen (Fig. 6). Consequently, the described experiments showed the way to conclusion of importance of proper dosage of propellant according to particular reservoir rock properties to avoid secondary formation damage in case of high energy wave stimulation.

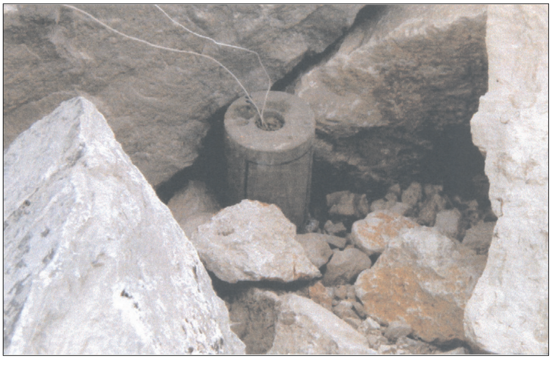

Fig. 7. Laboratory core plug N^o 6966 photographed at polygon ready to be blasted by electrically activated a 3 g PCF propellant charge, positioned inside concentric hole

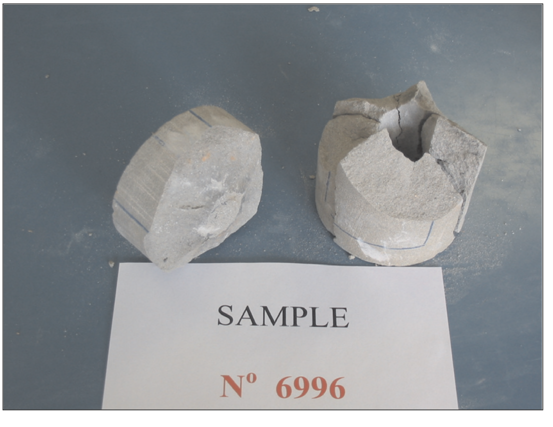

Fig. 8. Laboratory core plug N^o 6966 (Fig. 7) photographed after destruction with a 3 g PCF propellant charge. Bottom part, broken by deflagration is shown at the left side. At right positioned fragment four fractures could be clearly noticed

5. FIELD OPERATIONS EXPERIENCE

The described method was employed recently at two oil wells in later phase of production, located at Pannonian sedimentary basin, Croatia. Well data are shown in Table 3. “Gas Gun” tool [20, 21] was used in both stimulation operations (Fig. 9).

Table 3

“Gas Gun” propellant stimulated wells data

	Well L	Well S
Total depth (m)	1708.0	993.5
Production csg. O.D. (in.)	5.5	5.5
Bridge plug depth (m)	1579.0	918.0
Payzone – perforated intervals (m)	1561.0 – 1559.0 1557.0 – 1555.5 1539.0 – 1536.0	873.0 – 869.0 853.0 – 843.0
Type of formation	sandstone	sandstone
Oil production before stimulation (m^3/d)	0.8	1.6
Oil production immediately after stimulation job (m^3/d)	3.5	8.0
Oil production six months after propellant stimulation job (m^3/d)	2.6	5.0

Fig. 9. “Gas Gun” propellant stimulation tool ready to be run into Well L (Tab. 3)

Job procedure included the preliminary operations: well production test, well killing (using degassed crude oil), scrapping the production casing string walls, bridge plug setting below production intervals and well logging (CBL, caliper, temperature). After carrying out propellant stimulation (deflagrating the charges throughout the intervals) the Cement Bond Logging (CBL) was run again (to investigate if any destruction of cement sheet has been caused by gas "Gas Gun"). Production tests (pressure build up) were performed after the putting the well into production.

6. WELL PRODUCTION ENHANCE RESULTS

Production history for the both wells treated (Tab. 3) is shown in Figures 10 and 11, indicates the significant increase in oil production rate after the well propellant stimulation. Well L before this stimulation job has produced only 0.8 m^3 oil per day from three perforated intervals (Tab. 3). Immediately after "Gas Gun" stimulation the daily rate has been 3.5 m^3, afterward stabilized at 2.6 m^3/day (Fig. 10), which means 3.25 fold production increase.

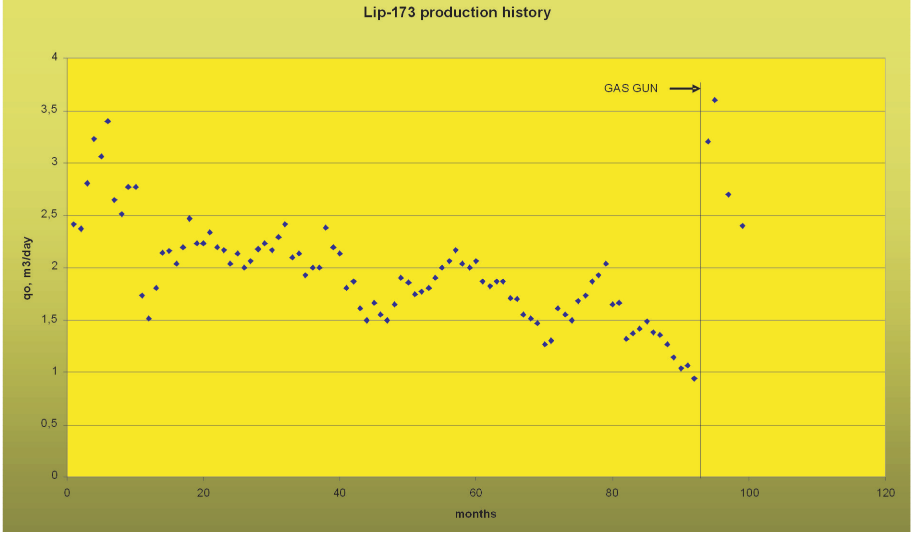

Fig. 10. Production history, Well L. Daily oil rate before and after "Gas Gun" propellant stimulation

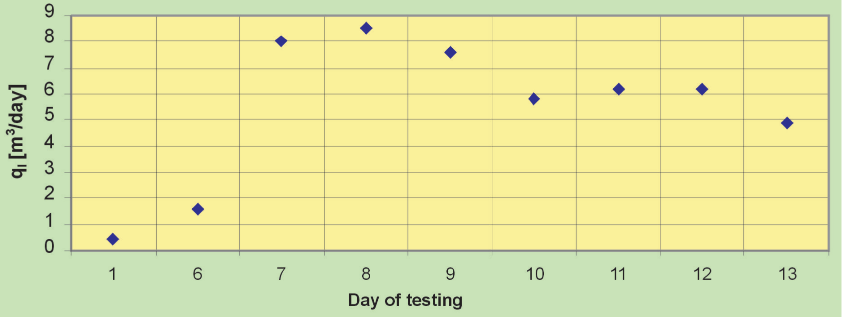

Fig. 11. Production history, Well S. Daily oil rate before and after "Gas Gun" propellant stimulation

In case of well S (Tab. 3), the production prior to stimulation from two opened payzone intervals was 1.6 m^3 oil per day. Immediately after "Gas Gun" propellant stimulation the daily rate has been 8.0 m^3, then, after 13 days was stabilized at 5.0 m^3/day (Fig. 11), resulting with 3.125 fold production enhancement.

Comparing above successful results with the published figures of production increase after propellant stimulation achieved at other similar oil fields worldwide (Appalachian Basin, USA: 280% average production increase [1, 19], or in P.R. China: 100% average enhancement in case of 1200 wells stimulated by propellants [12, 18, 19]) it confirms the same range of positive effect accessible using the considered method in real life.

Due to analyze of CBL logs carried out after "Gas Gun" stimulation [21] any changes in cement bond quality was not indicated, which means that propellant deflagration did not adversely impact the wellbore integrity. Also, the results of skin damage evaluation [20] provided at well L indicated the reduction of skin from S=7.8 (before propellant stimulation) to S = 2.7 after "Gas Gun" job was completed (Fig. 12).

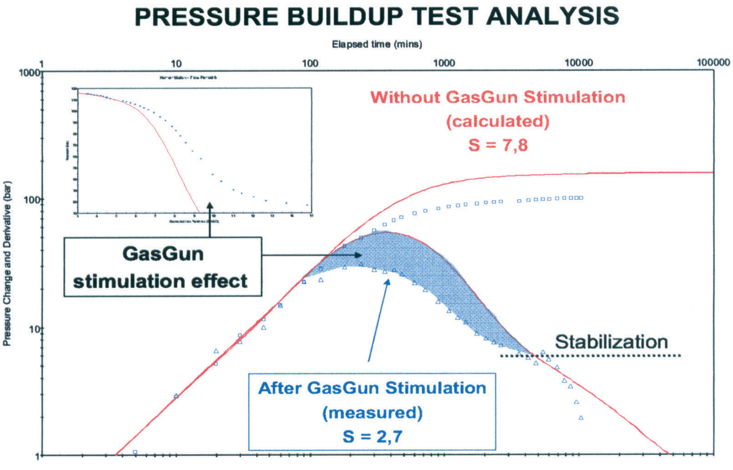

Fig. 12. Pressure build up analysis, Well L. Reduction of skin damage from S = 7.8 before "Gas Gun" stimulation to S = 2.7 after propellant treatment

7. CONCLUSIONS

1) The propellant stimulation technique is an effective method well stimulation, confirmed with two case well histories in Croatia.
2) Achieved oil rate enhancement exceeded by factor of 2 to 3 for the wells in later phase of production.
3) Laboratory test results demonstrated the importance of proper amount of propellant to be used for particular formation to be stimulated.
4) Case studies performed suggest no adverse effect on wellbore integrity due propellant burn process downhole.
5) The cost of propellant well well stimulation job is much more less than in case of hydraulic fracturing operation.

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