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2016 LATIN AMERICA PERFORATING SYMPOSIUM, BUENOS AIRES

Multi Zone Stimulation Technology: JITP Aplication with an Eco-Friendly Degradable Mechanical Diverting Agent

SLAP-16-31

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AGENDA

- Current Context
- JITP - Historical Context
- Theoretical Concept
  - Vertical Wells
  - Horizontal Wells
- Analysis Methodology
- Variation with a Eco-Friendly Degradable Mechanical Diverting Agent
- Time analysis Plug&Perf vs JITP
- Challenges
- Key Factors & Considerations
- Conclusions
- References

Current Context

In the current market and economical context of the Oil & Gas Industry, we required work methods and technologies that allow us and our clients:

- Reduce the operational time and cost of well completion,
- Reduce the operational time for well reconditioning or repair,
- Increase the number of productive wells each year.

JITP - Historical Context

Just-In-Time-Perforating (JITP) was developed by ExxonMobil over a decade ago to improve multi-zone simulation in vertical and S-shaped wells in the Piceance basin, Colorado.

With this technology, multiple single-zone fracture stimulations are performed on a single wireline run using ball sealers and perforating guns that remain downhole during the fracturing treatment.

This results in substantial cost reductions and productivity uplift because perforation intervals are individually and effectively treated one at the time with less horse power, smaller number of frac plugs and fewer wireline runs.

The method has been successfully implemented by ExxonMobil in more than 350 wells and over 10,000 treatments.

In 2011, JITP was deployment in horizontal wells, including 29 shale's gas wells and more that 1,400 treatments.

Theoretical Concept – Vertical Wells

According to the paper ISSN 1451-107X, once the perforating guns are ensemble, separating each gun with an Stand Off and placing the magnetic and mechanical centralizer, the steps for the JITP implementation are:

a) First stage begins with first gun firing the charges
b) BHA moves upward allowing for treatment to be pumped with ball sealers
c) Perforations are sealed and second gun is fired
d) BHA moves upward for third pay zone allowing for second zone treatment

In figure 1 we can see the BHA parts involved in these systems. Several perforating gun sets are included depending on how many pay zones are to be treated (three in this case). Each perforating gun is separated with a stand-off for differential sticking mitigation and treatment fluid passage allowance. There is also a magnetic centralizer at the BHA top providing for better BHA-towall attachment and CCL, as a logging tool for reservoir conditions evaluation **[1]**.

Theoretical Concept – Vertical Wells

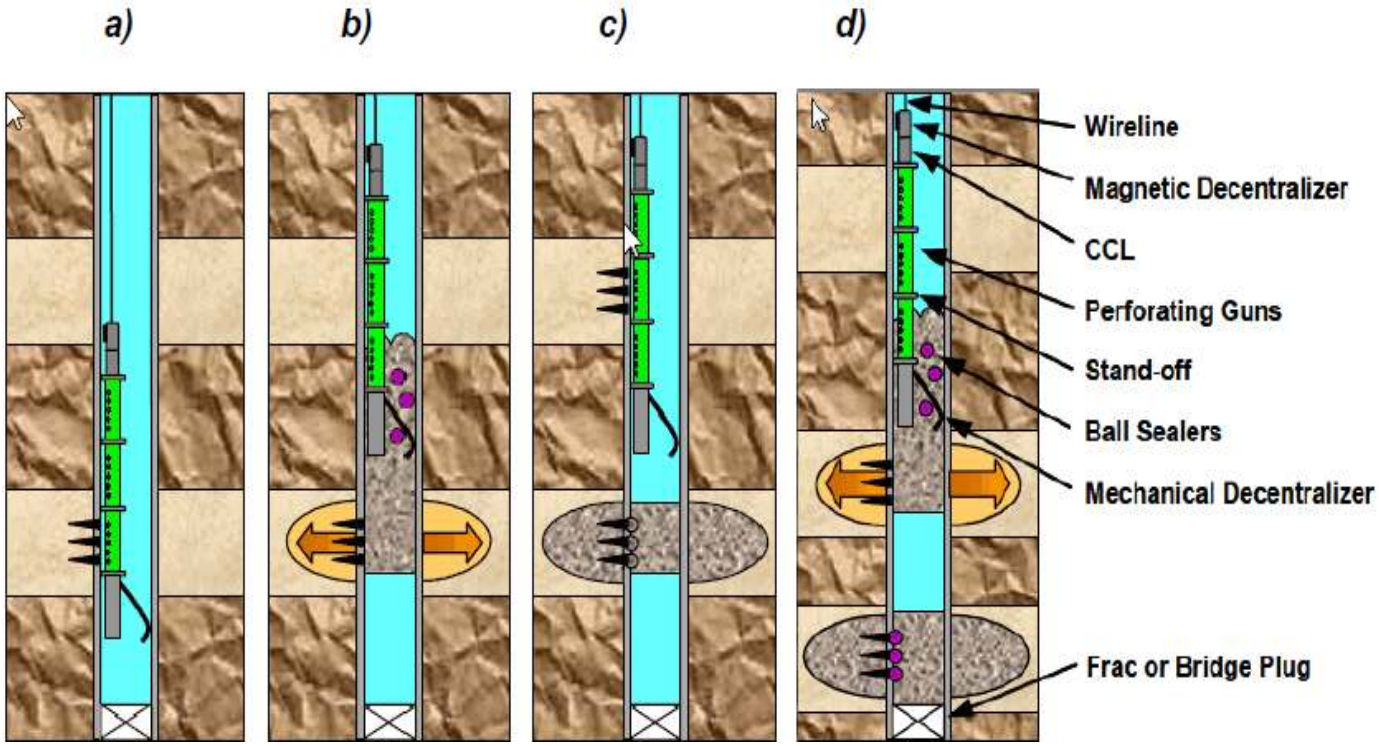


Figure 1.

NOTE: Figure from paper ISSN 1451-107X.

Theoretical Concept – Horizontal Wells

The JITP process in horizontal wells is similar in concept to the used for vertical wellbores, but with significant operational changes to procedures and contingency plans. The basic steps are:

a) Open Frac sleeve or perforate the toe stage
b) Frac the first set of perforations
c) At the end of treatment, pump down the gun assembly and position it at the second set of perforations.
d) Drop ball sealers to seal off the open perforations. When ball sealers seat on the perforations, a sharp rise in wellbore pressure is observed ("ball-out" event) and guns are fired which initiates the subsequent treatment (without shutting down the pumps)
e) Move the gun assembly to the next perforation cluster while fracturing the newly-created set of perforations (guns remain downhole during fracturing)
f) The process is repeated throughout the lateral. When necessary, a Frac bridge plug is set in the stimulated zones to provide insolation from the next set of treatments **[2].**

Theoretical Concept – Horizontal Wells

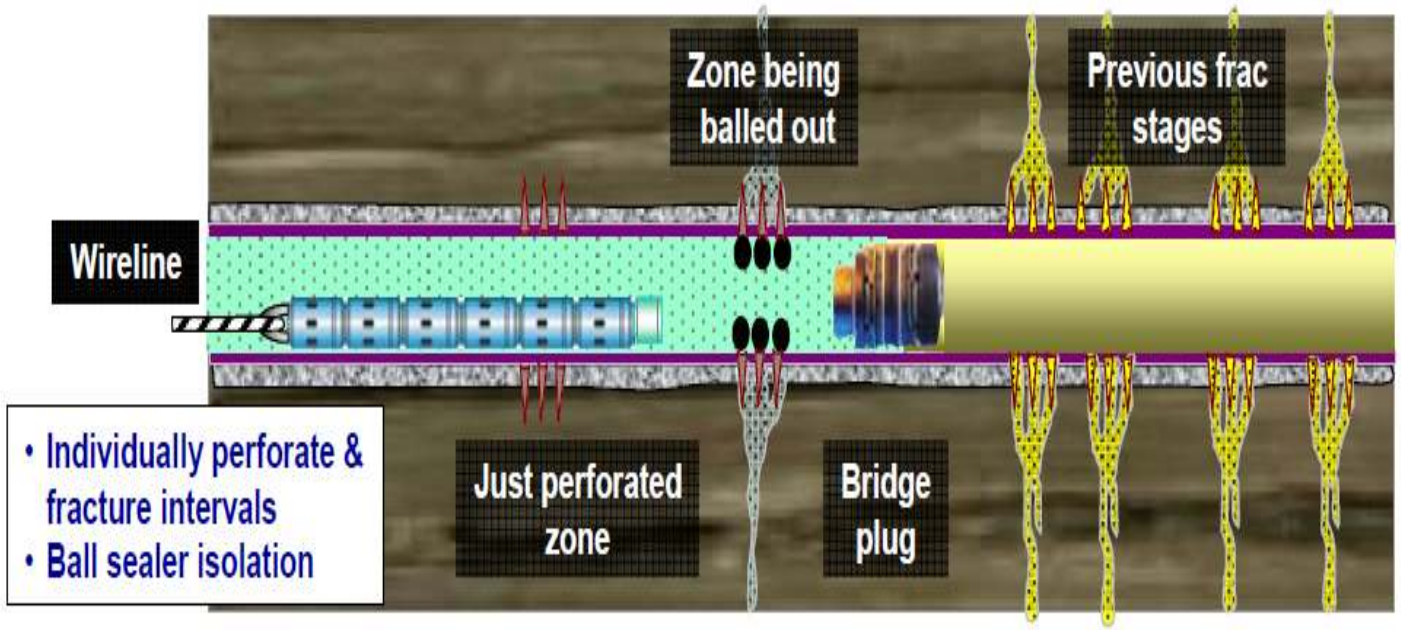


Figure 2.

NOTE: Figure from paper SPE-152100-MS

Methodology Analysis

JITP Method has been deploy successfully by ExxonMobil over 350 wells and more that 10.000 treatments, in vertical and horizontal wells.

The paper SPE160034 [3] describes the results and learned lesson after the deployment of JITP in 29 horizontal shale gas wells, with more than 1.400 treatments.

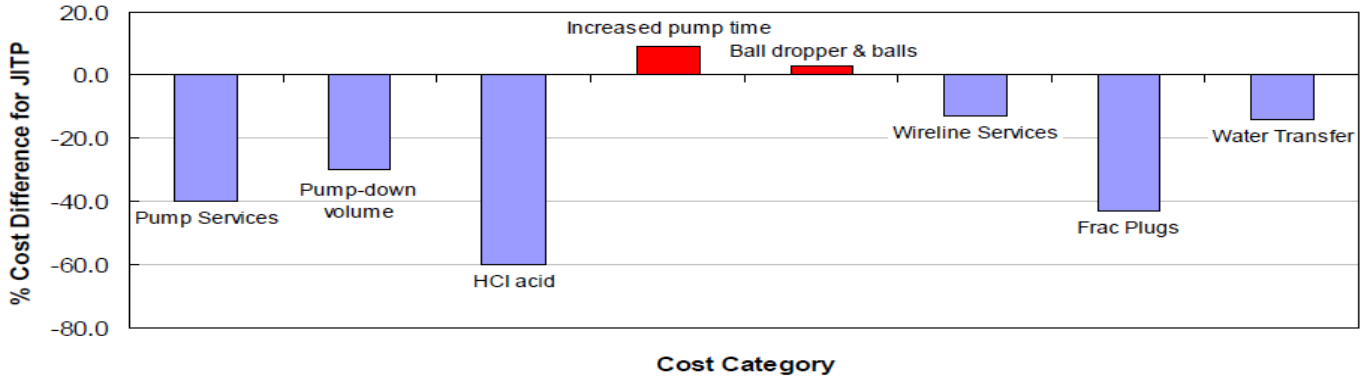
Now, we will proceed to show the results detailed in the papers SPE152100 and SPE160034, that described JITP deployment:

- Cost Benefit,
- Risk Managements,
- Wireline Drag Model,
- Plug setting tool clearance,

Methodology Analysis

Cost Benefit:

According to the paper SPE152100, (1) horizontal well completed with 7 stages using JITP, may have the follow cost reduction, respect P&P:



As we can see, there is an increase in the cost of pump time and ball dropper (red color), but in comparison to the other points, we can see a significant reduction of cost on pump services, Frac plugs, water transfer, among others.

Methodology Analysis

Risk Management:

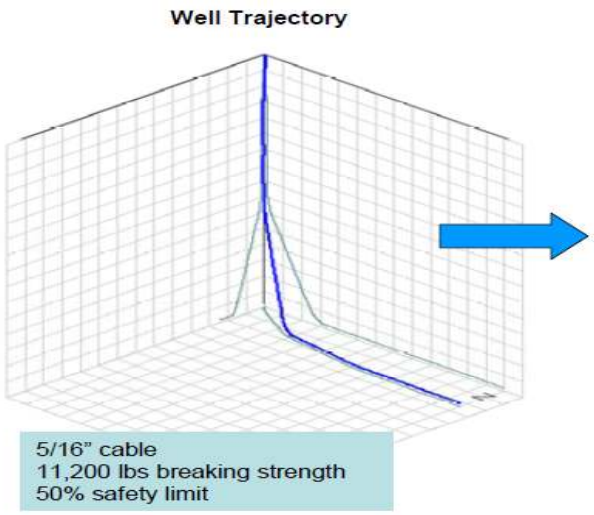
The next Table, identifies some of the major potential risk and mitigators for the technology deployment.

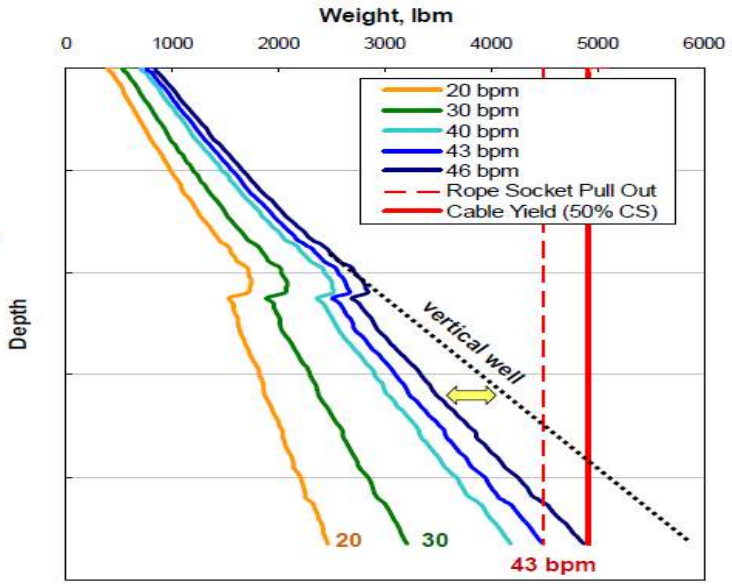
Risks	Mitigators
Wireline drag	+ Run wireline drag model for anticipated conditions + Monitor drag rates when pulling wireline from well in current fracs
Sand build-up behind perforating gun	+ Pump rate at appropriate sand suspension velocities
Ball sealing in horizontal well (selection of buoyant and non-bouyant ball sealers, ball arrival rate)	+ Conduct CFD modeling, confirm with experimental data + Field trial - ball out a conventional limited-entry frac
Overall gun length and number of guns for successful deployment (spacing between guns)	+ Drag and torque modeling for dog legs + Evaluate lubricator / crane requirements + Reliable select-fire system selection
Inadequate hole size and penetration (reduced gun OD for ball passage)	+ Extreme overbalance perforating helps initiate fracs + Evaluate potential gun combinations to get best hole size & penetration
Cable damage due to sand erosion or acid on the wellbore	+ Use EM proprietary frac heads + Maintain tool assembly under continuous movement + Implement guidelines for acid wash off and perf clearance
Plug setting tool clearances for ball passage	+ Evaluate / select from current systems suitable for selected perforating gun
Safety and contingency plans	+ Review past experience and incorporate appropriate guidelines in field procedures + Follow safety protocols for management of process change
Human factors	+ Identify / prepare technical champions
Contractor qualifications	+ Extensive training

Methodology Analysis

Wireline Drag Model:

The bellow figure shows the surface cable tension predicted from wireline drag model to determine the maximum pumping rate during JITP, based on well conditions and well trajectory. For a 5 ½” 20 lb/ft casing with 2.5” gungs deployed on a 5/16” cable.

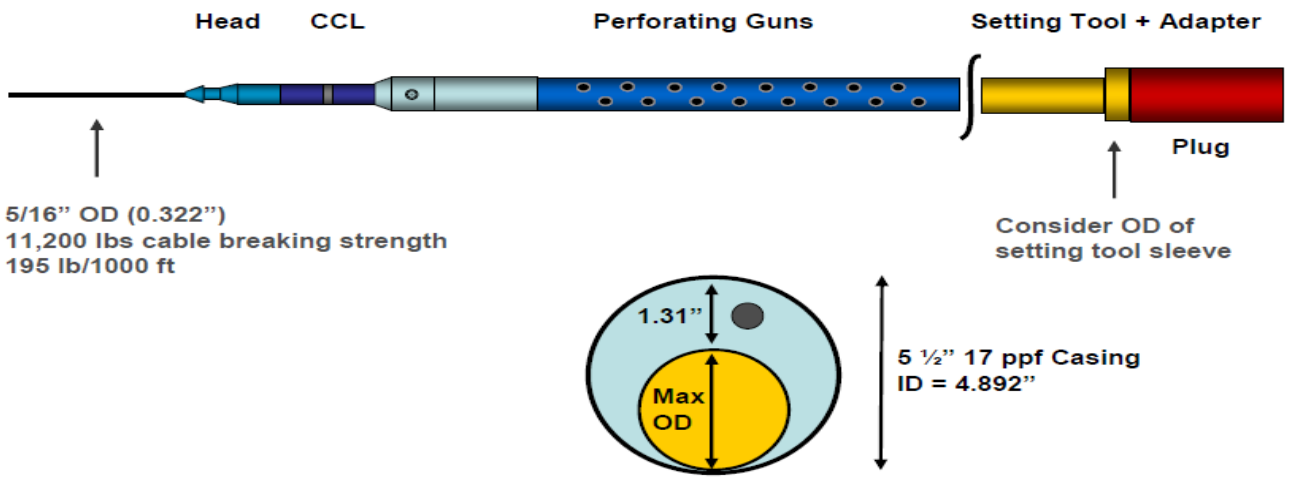




Methodology Analysis

Plug setting tool clearance:

Ball sealers have to pass by the annulus between the casing ID and tool string ID. This applies to all components of the bottom hole assembly with or without plug.



Methodology Analysis

Sand Build-Up Around Perforating Gun:

The objectives of this study were to quantify and mitigate the risk of perforation guns getting stuck due to sand build-up at pumping rates of 45 bpm, lower > 100 bpm rates typically used in conventional shale-gas fracturing.

1. The first model was derived from Chien (1994):

$$v_t = 1.2\left(\frac{\mu_m}{d\rho_m}\right)\left[\sqrt{1+0.0727d\frac{\rho_p-\rho_m}{\rho_m}\left(\frac{d\rho_m}{\mu_m}\right)^2}-1\right]$$

2. Walton (1995):

$$v_t = g\frac{\rho_p-\rho_m}{\rho_m}\frac{d^2}{18\nu_m} \qquad \mathrm{Re} < 1.4$$

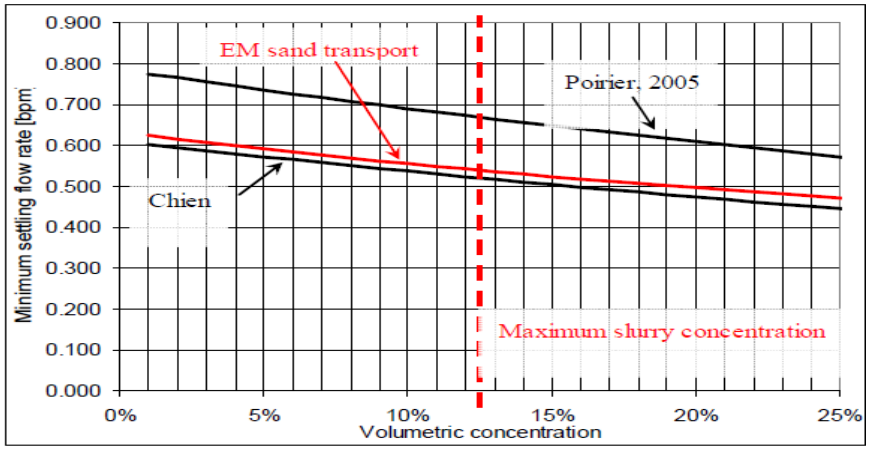
$$v_t = 0.13\left[g\left(\frac{\rho_p-\rho_m}{\rho_m}\right)^{0.72} d^{1.18}\nu_m^{\,0.45}\right] \qquad 1.4 < \mathrm{Re} < 500$$

$$v_t = 1.74\sqrt{g\frac{\rho_p-\rho_m}{\rho_m}d} \qquad \mathrm{Re} > 500$$

Methodology Analysis

Sand Build-Up Around Perforating Gun:

The figure bellow, compares the analytical methods for a 5 ½" casing with 4.892" internal diameter (ID). Volume concentrations of 12.8% correspond to a maximum proppant concentration of 2 ppa. The conclusion was that no relevant deposition of proppant along the well would be expected because the sand deposition and re-suspension velocities are at least one order magnitude less that expected JITP rates.



Variation with a Eco-Friendly Degradable Mechanical Diverting Agent

In the original JITP method, XTO used ball sealers to temporally insolate the zones already treated, in order to continue the perforating and treating the next ones, but, the use of traditional mechanical diverters, are most often only effective for one stage.

When operations are suspended, ball sealers will fall away from the perforations, rock salt and flake diverters rapidly dissolve.

What we propose, is to substitute the ball sealers with a Biodegradable Mechanical Divergent Agent that will insolate the treated zones for 24 – 48 Hs.

We need a material that will remain in the perforations for multiple stages and dissolve over time.

Degradable mechanical diverters are an environmentally friendly, mechanical diverter that addresses these criteria.

Variation with a Eco-Friendly Degradable Mechanical Diverting Agent

In 2014, Weatherford presented in Abu Dhabi International Petroleum Exhibition and Conference, the paper SPE 171707-MS [4], to explain the application of a Biodegradable Divergent Agent.

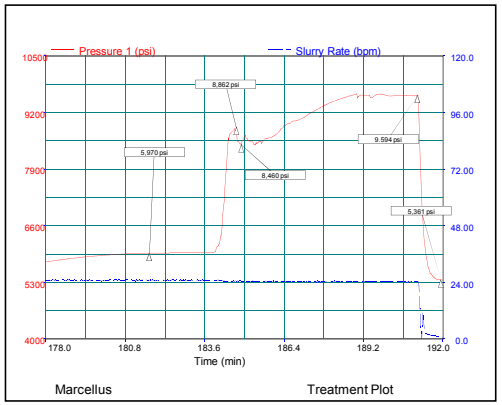
In alternative to current diverters method, we have a:

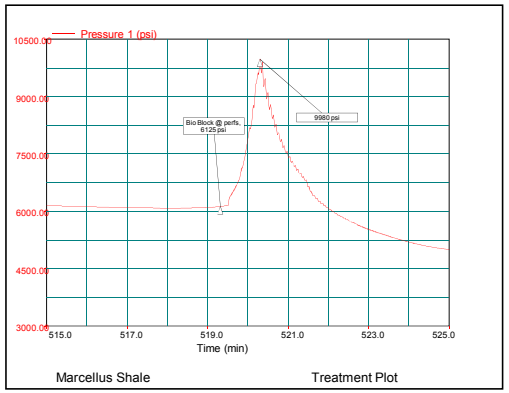
- **Mechanical Bridging Agent**
- **Water Soluble / Degradable**
- **Extensive Temperature Range**
  120˚F to 300˚F (50˚C-150˚C)
- **Aqueous Fluid System Compatibility**
- **Solid Pellets & Powder Combination**

Variation with a Eco-Friendly Degradable Mechanical Diverting Agent

Technology Benefits:

- **Effectively Blocks Existing Perforations**
  300 – 1,200 psi increases typical
- **Stable Under Large Pressure Increases**
  4,000 psi pressure increase achieved
- **Diverts Fluid to New Perforations**
- **Divert Fluid to Understimulated Clusters**
- **Remains in Perforations/Near Wellbore**
- **System Dissolves Over Time**
- **No Plug Millouts / No Squeezed Perforations**





Variation with a Eco-Friendly Degradable Mechanical Diverting Agent

How the Diverter System Works:

- **Combine diverter materials in a viscous fracturing fluid**
- **The diverter material bridge-off in perfs/NWB fractures**
- **When to pump the system**
  - Before treatment to seal existing perforation clusters
  - During the actual treatment as a diverter stage
  - During the flush to seal current zone
- **Degrades over time**
  - Bottom-hole temperature
  - Presence of water & pH

Time Analysis Plug&Perf vs JITP

Now, we will analyze a theoretical operative program (split by program point) with the times defined for the client in the case of P&P, against the theoretical times defined for JITP. In both cases the well is the same.

Well Characteristics:

1. Zone: Lajas – Neuquén.
2. (6) Perforating stages.
3. (6) Fracture.
4. (1) Well test.

Time Analysis Plug&Perf vs JITP

N° PP	Program Point	P&P (Hours)	JITP (Hours)
1	DTM	18	18
2	Conditioning – Install STACK FRAC JITP Y and BUNDLE equipment	28,5	28,5
3	Perforating Zone 1: 2633/2638 m	8	8
4	Treatment in 1: 2633/2638 m	6	3
5	Plug Zone 1 and Perforating Zone 2: 2365/2368 m (In JITP there is no Plug)	5	2
6	Treatment in Zone 2: 2365/2368 m	4	2,5
7	Plug Zone 2 and Perforating Zone 3: 2256/2258.5 m (In JITP there is no Plug)	5	4
8	Treatment in Zone 3: 2256/2258.5 m	4	2,5
9	Plug Zone 3 and Perforating Zone 4: 1989/1989.7 - 2014/2014.7 m (In JITP there is no Plug)	5	3
10	Treatment in Zone 4: 1989/1989.7 - 2014/2014.7 m	4	2,5
11	Plug Zone 4 and Perforating Zone 5: 1885/1890 m (In JITP there is no Plug)	5	1,5
12	Treatment in Zone 5: 1885/1890 m	4	2,5
13	Plug Zone 6 and Perforating Zone 5: 1831/1832 m (In JITP there is no Plug)	5	1,5
14	Treatment in Zone 6: 1828/1831 - 1831/1832 m	4	2,5
15	Conditioning – CTU Cleaning	18	18
16	Conditioning - Rotar tapones y limpieza CTU	54	18
17	Conditioning - Montar armadura de surgencia	8	8
18	Well test	54	54
19	Conditioning - Constatar fondo de pozo	6	6
20	Desmontaje de BUNDLE	16	16
Total hours:		**261,5**	**202**
Total days:		**10,9**	**8,4**
Dif Days:		**2,5**	
Av Dif:		**23%**	

Note: All times are Theoretical.

Time Analysis Plug&Perf vs JITP

Analysis comparing both methods, operative point by operative point:

JITP													
P1	**F1**	**P2**	**F2**	**P3**	**F3**	**P4**	**F4**	**P5**	**F5**	**P6**	**F6**	**TOTAL HS**	**TOTAL DAYS**
8	3	2	2,5	3	2,5	3	2,5	1,5	2,5	1,5	2,5	34,5	1,4

PLUG&PERF													
P1	**F1**	**P2**	**F2**	**P3**	**F3**	**P4**	**F4**	**P5**	**F5**	**P6**	**F6**	**TOTAL HS**	**TOTAL DAYS**
8	6	5	4	5	4	5	4	5	4	5	4	59	2,5

Method	DIF Total Time in Days
JITP	1,4
Plug&Perf	2,5
Dif %	42%

Assumption: 24hs work for all crews.

Time Analysis Plug&Perf vs JITP

Comparison between actual times and theoretical:

JITP													
P1	F1	P2	F2	P3	F3	P4	F4	P5	F5	P6	F6	TOTAL HS	TOTAL DAYS
8	3	2	2,5	3	2,5	3	2,5	1,5	2,5	1,5	2,5	34,5	1,4

PLUG&PERF - LAJ XX6													
P1	F1	P2	F2	P3	F3	P4	F4	P5	F5	P6	F6	TOTAL HS	TOTAL DAYS
5	3,5	3,5	2,5	3,25	2,5	4,75	2,25	4	3	4	2,5	40,75	1,7

PLUG&PERF - LAJ XX9													
P1	F1	P2	F2	P3	F3	P4	F4	P5	F5	P6	F6	TOTAL HS	TOTAL DAYS
7,5	4,75	3,25	6	3	6,5	3	3,25	3,25	2,75	2,5	2,75	48,5	2,0

Method	VS LAJ XX6
JITP	1,4
Plug&Perf	1,7
Dif %	15%

Method	VS LAJ XX9
JITP	1,4
Plug&Perf	2,0
Dif %	29%

Av. Time per perforation and treatment:

AV Perforating Time (Hs)	
JITP	3,2
LAS-XX6	4,1
LAJ-XX9	3,8
Dif %	22%
Dif %	16%

AV Treatment Time (Hs)	
JITP	2,6
LAS-XX6	2,7
LAJ-XX9	4,3
Dif %	5%
Dif %	40%

Key Factors & Considerations

- Stimulations effectiveness of each individual perf cluster.
- Better understanding of geologic variation .
- Reduced uncertainty in development optimization.
- Reduced horsepower & footprint requirements.
- More efficient use of water.
- High fracture propagation rate.
- Fewer plugs.
- Scaling operations to available logistics.

Conclusions

Based on the time analysis performed for JITP, we can conclude:

1. If we use JITP should be possible to reduce the operational time of the perforations and stimulation, around 42%, respect P&P.
2. If we compare the JITP theoretical times, against actual time of the wells LAJ-XX6 and LAJ-X9 (without NPT), in average, the operative sequence will have a time reduction between 15% and 29%:
   - Perforating: time reduction between 16% and 22%.
   - Fracture: time reduction between 5% and 40%.
3. This method will allow as to do more perforations and fractures in the same time (compared with P&P).
4. We will have a reduction in the number of Plugs required and lower onsite water storage requirements.
5. The use of a biodegradable divergent agent would allow us to be able to provide the simulation without surrounding the ball sealers.
6. Equal hole size perforating could help assure the fracture treatment and the diverters reached the formation at the same pressure and time, helping to equally distribute the hydraulic fracture fluids and proppant.
7. We will have a reductions costs in the frac fleet and maintenance, because the reduced hydraulic horsepower and pumping volumes.

References

[1]: Lonnes, S.B. et al.: ''Advanced Multizone Stimulation Technology'', paper SPE 95778, 2005 SPE Annual Technical Conference and Exhibition, Dallas, Texas, USA, 9-12 October 2005.
[2]: SPE-152100-MS: First aplication of Just-In-Time Perforating in a Horizontal Well
[3]: SPE-160034-MS: One year of Just-In-Time Perforating ad Multi-Stage Fracturing Technique for horizontal Wells
[4]: SPE-171707-MS: Eco-Friendly Degradable Mechanical Diverting Agents for Combining Multiple-Staged Vertical Wells: Case History from Wasatch Formation

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QUESTIONS?
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