The International Journal of
TRANSPORT & LOGISTICS

Medzinárodný časopis
DOPRAVA A LOGISTIKA
Mimoriadne číslo 8/2010

ISSN 1451-107X

MULTIFRACTURING WELL COMPLETIONS

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Keywords: Hydraulic fracturing, Well stimulation, Well completions, Hydrajetting, Packers, Coiled tubing

Abstract: Hydraulic fracturing has been very well known well stimulation method since many decades back and continues to prove its worthiness enhancing the well productivity if applied properly. But, without a proper technology update on the design management and wellbore tools involved, limited additional improvement is experienced. Over the last 10 years many technical developments and solutions have been made to better stimulate pay zones containing hydrocarbons. New well completion assemblies, to accompany with formation fracturing technology, have to be more reliable, efficient, profound and cost effective in extreme downhole conditions. Many times, with layered complex reservoirs, more than several individual pay zones are required to be stimulated and completed with specifically designed treatments. Multistage fracturing technology is an effective solution for less costly treatment of such complicated reservoirs. This paper demonstrates technological solutions for multizone treatments and its application to different well conditions (temperature, pressure, open hole, cased hole etc.). Multistage fracturing can be done differently, and well completion and treatment design is done with intention to access the reservoir the best possible way. Systems like Wireline operated systems, Coiled tubing applications, Jointed pipe applications and other, are described and introduced.

1. Introduction

Since its introduction to oil industry in Oklahoma, USA, in 1949. [1], hydraulic fracturing is and probably will remain a major well stimulation technique for a long period of time. As being one of the most reliable tools for well productivity improvement, this method is done by placing a conductive channel through a damaged near wellbore zone bypassing it and allowing for undisturbed hydrocarbon production. Just as every other operation in the oilfield, hydraulic fracturing operation has to be properly designed to achieve expected results.

To fracture the reservoir, a substantial amount of fluid has to be pumped through the completion to get a strong tensile stress inside formation by the internal pressure and thus fracture it. As many wellbore shapes existing due to well engineering projects, as many completion types are introduced to comply with it. So, completions have to be able to withstand downhole conditions, weather vertical, deviated or horizontal wells are involved. Each of the completions situated inside the mentioned well types have its own specific completion procedures, with horizontal ones being the most demanding.

Performance of multiple single-fracturing operations has become time and money consuming

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considering all the runs for each fracturing job. To solve this issue a new approach to well stimulation has been introduced, affiliating multiple fracturing jobs only in one completion run. Multistage fracturing can be performed in a lot of different ways depending on the well design, but the key point is to efficiently access the reservoir without unnecessary complications on well completion. Based on different types of completions, different stimulation systems are available. So, the systems to mention are *Wireline operated systems, Jointed pipe systems* and *Coiled tubing systems*, each of them having different advantages or disadvantages. Interesting technologies and tools applied in systems like *Hydrajetting*, *Swelling packers and Expandable tubulars* will be overviewed in further chapters [2].

2. Wireline operated system

A quite new multizone stimulation technology comprising of wireline operated perforating assembly and the ball sealers to seal the perforations right after the treatment, allows for multizone stimulation of one pay zone after another moving the assembly from down to uphole. As shown in Figure 1(a-d), the gun is positioned at the lowermost pay zone to be treated with first gun. After the gun fires, assembly is raised up hole to the next zone and the first treatment is pumped. Tail fluid end contains ball sealers having a task to seal the perforations after the treatment. There has to be at least one ball per perforation. When the balls reach the destination (perforation entrance), a certain pressure increase is observed. Next gun fires up and assembly moves upwards to the third pay-zone. Second treatment is pumped through the perforations also containing ball sealers for the zone seal. This process can be repeated for up to six times per deployment of the gun assembly.

When using a ball sealer system, the most important key factors are the proper BHA handling having it close enough to the wall with mechanical decentralizer and keeping in mind not to become differentially stuck due to high pumping pressures involved. Before firing with next gun set, balls have to be already in place. Otherwise, the operation can be endangered if the balls are damaged.

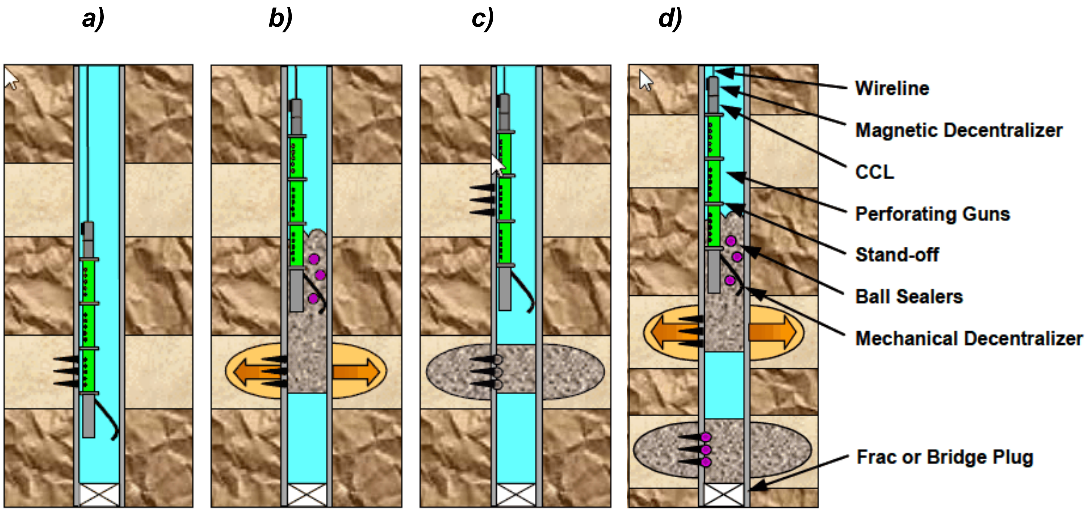

Fig. 1 *Wireline operated perforate-and-frac ball sealer system [3].*
a) First stage begins with first gun firing the load,
b) BHA moves upward allowing for treatment to be pumped with ball sealers,
c) Perforations are sealed and second gun fires the load,
d) BHA moves upward for third pay zone allowing for second zone treatment.

In figure 1d we can also 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 decentralizer* at the BHA top providing for better BHA-to-wall attachment and *CCL*, as a logging tool for reservoir conditions evaluation [3].

Before every job start a detailed quality laboratory testing and design is needed to try to predict any unusual and unwanted occurrences that might happen. That means a tool failures or balls not sealing the perforations good enough (which is closely connected to pressure induced on the surface). If a pressure rise is not observed on the surface after treating the zone and ball sealing, evidently something should be wrong with balls. The whole BHA is ran out of hole and the bridge plug is set between the zones. A usual procedure is to set a drillable bridge plug after every set of guns fired up and zones fractured in a row [3,4].

3. Jointed pipe systems

If extreme downhole conditions like high pressure and high temperature (HP/HT) are encountered, jointed pipe systems are used. As managing to withstand a harsh environment conditions, comprising of casing/tubing joints, jointed pipe applications provide for larger rates to propagate a fracture by having a larger ID. In combination with premium flush threads, these systems procure minor pressure loss due to friction.

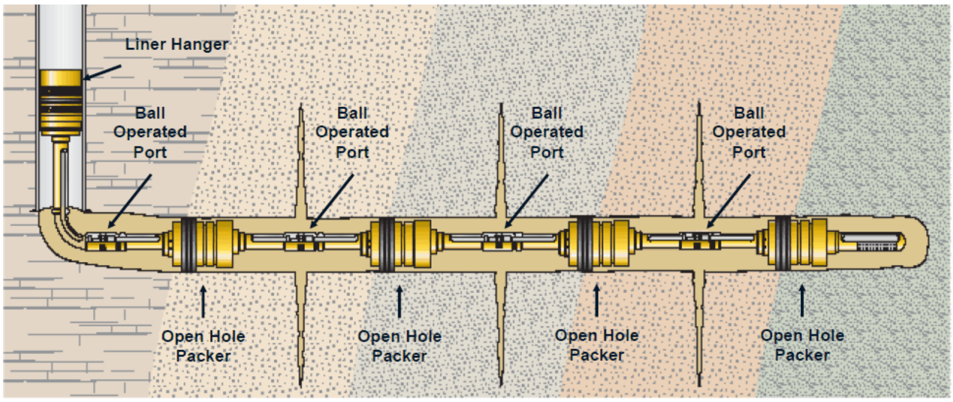

Fig. 2 *Jointed pipe system containing fracturing ports and mechanical packers to isolate each pay zone [5].*

A common multistage horizontal jointed pipe fracturing system in openhole is described in figure 2. The system is usually completed with openhole *mechanically set packers* able to withstand high differential pressures of more than 70 MPa and temperatures more than 200 °C. Packer design has to be adjusted for possible doglegs and unusual wellbore build rates with setting enlargement 50 % of its original OD. A special attention has to be considered when designing *Fracturing ports* which are located between the packers. They are supposed to open at specific time and withstand extremely abrasive fracturing fluids sometimes laden with proppant. Based on the initial parameters set forth, this part of the system is to provide functionality and efficiency [5, 6]. There are different fracturing port types like:

- **Standard fracturing ports**
  Initiation of the port is accomplished with balls that are dropped from the surface during pumping operation. After dropping the ball, it is pumped with flushing fluid of the previous fracturing interval landing in a specific seat to activate the port for next interval.

- **Drillable fracturing ports**
  This type of port has to be erosion resistant and drillable at the same time, as it is hard to design a soft erosion resistant material. It is drillable with regular carbide mills. The seats are designed much like the standard port seats.

- **Re-closable fracturing ports**
  With re-closable ports all stages can be closed, leaving only last one open and well can be re-fractured just as it was initially by dropping balls and pumping specifically designed fracturing treatments. Unfortunately, re-fracturing cannot be done without running the string to close the ports [6].

When the well is completed (fig. 2), multifracturing job execution starts with lowermost pay zone (vertical wellbore). After the ball is dropped from the surface, it reaches the seat and activates the fracturing port. Right after, the pay zone is stimulated by pumping a fracturing fluid and flushing it afterwards. Second ball is pumped downhole within the first stage flushing fluid and activates second fracturing port by seating inside the second port seat. Second pay zone treatment is followed after that.

This procedure continues up to the last pay zone to stimulate, with the option of drilling the ports and re-fracturing desired interesting intervals.

4. COILED TUBING SYSTEMS

In general, when exposed to large pressure differentials, coiled tubing installations may fail (burst or collapse). So, if designing a high pressure hydraulic fracturing operations, CT is not appropriate stimulation string. But, if low to moderate pressures are involved, coiled tubing can give many benefits when properly used. It can be applied in cementing, acidizing, fishing, well killing, drilling and milling, pipeline servicing and well stimulation operations. As a part of modern well completion solutions, coiled tubing is used in cased hole completions because of large friction forces induced when ran inside open hole.

Well stimulation with coiled tubing is possible with or without the packer installed. Today, it is basically used without packer in conjunction with hydrajet jetting tool [4, 7, 8].

4.1. Hydrajet hydraulic fracturing

Hydrajet assisted fracturing is a relatively new technology combining hydrajet perforation tunnel creation and hydraulic fracturing. Although the hydrajet system can be deployed on jointed tubing pipes, coiled tubing, drill pipes or combination of jointed pipes and coiled tubing, the most frequent usage is with coiled tubing. Basically, the technique consists of three separate processes and that would be:

- Hydrajetting,
- Hydraulic fracturing through tubing, and
- Injection down the tubing/casing annulus.

As hydrajetting is applied without the packer as a sealing barrier, it uses dynamic sealing relying on fluid movement as a hydraulic seal. Dynamic isolation is based on Bernoulli's law saying that the energy level of fluid is generally maintained constant. While pumping the fluid downhole through tubing, it's high-pressure energy within the tubing is transformed into kinetic energy resulting in high velocity fluid stream as described by Bernoulli [9]:

$$\frac{V^2}{2} + \frac{p}{\rho} + gz = C \quad (1)$$

where V- is fluid velocity [m/s],
ρ- is fluid density [kg/m^3],
p- is local fluid pressure [Pa],
gz- is gravitational constant [m/s^2],
C- is pressure inside jetting tool as a constant [Pa].

So, according to figure 3, the tool is first placed at the wellbore toe for first stage and jet-perforated the casing and formation forming three, at least 4-6 in long perforations (120° phasing). If it is done in open hole, perforation length may reach 15-20 in. As pressurized fluid exits the jetting nozzles, due to very high velocity and low pressure, it does not tend to leak off elsewhere and follows the flow direction from the nozzle towards the perforation cavity. Usually, fluid contains some abrasive matter to help penetrate more easily. As cavity is formed by the jet, high velocity fluid impacts cavity bottom. When velocity of the fluid becomes zero, pressure is large enough to fracture the formation. At that time casing/tubing annulus pressure is increased by pumping the fluid to assist the fracture extension.

When the first stage stimulation is done, jetting tool moves to next one, which means upwards (vertical wellbore) or toe to heel direction (horizontal wellbore) [10].

4.2. Swelling packers

Packers based on swelling capability of their elastomers, called swelling packers, provide for effective seal in both open hole and cased hole applications. Basically, there are two types of swelling packer systems: Water swelling packers and Oil swelling packers. In the case of water swelling elastomers, swelling process is based on the principle of osmosis. Water enters the rubber matrix and swells the element. Elastomer and surrounding fluid (water) salinity levels are very important to consider as osmosis process depends on it. Any changes in downhole conditions and fluid properties can reverse the swelling process.

Oil swelling elastomers swell by the diffusion process- rubber molecules absorb the hydrocarbon molecules causing the elastomers to stretch. Crosslinked polymer network of swelling packer rubber traps the hydrocarbon molecules due to their natural affinity. Reverse process is not available.

Unlike the other packers, deployment time of swelling packers can be few hours to several weeks, depending on the job design demands. Simple handling and well proven efficiency make this technology very promising for the future. Figure 4 (a and b) shows the swelling packer with its belonging parts. End rings are used to direct the swelling rubber expansion perpendicular to packer, and thus forcing it to seal the annulus [4, 8].

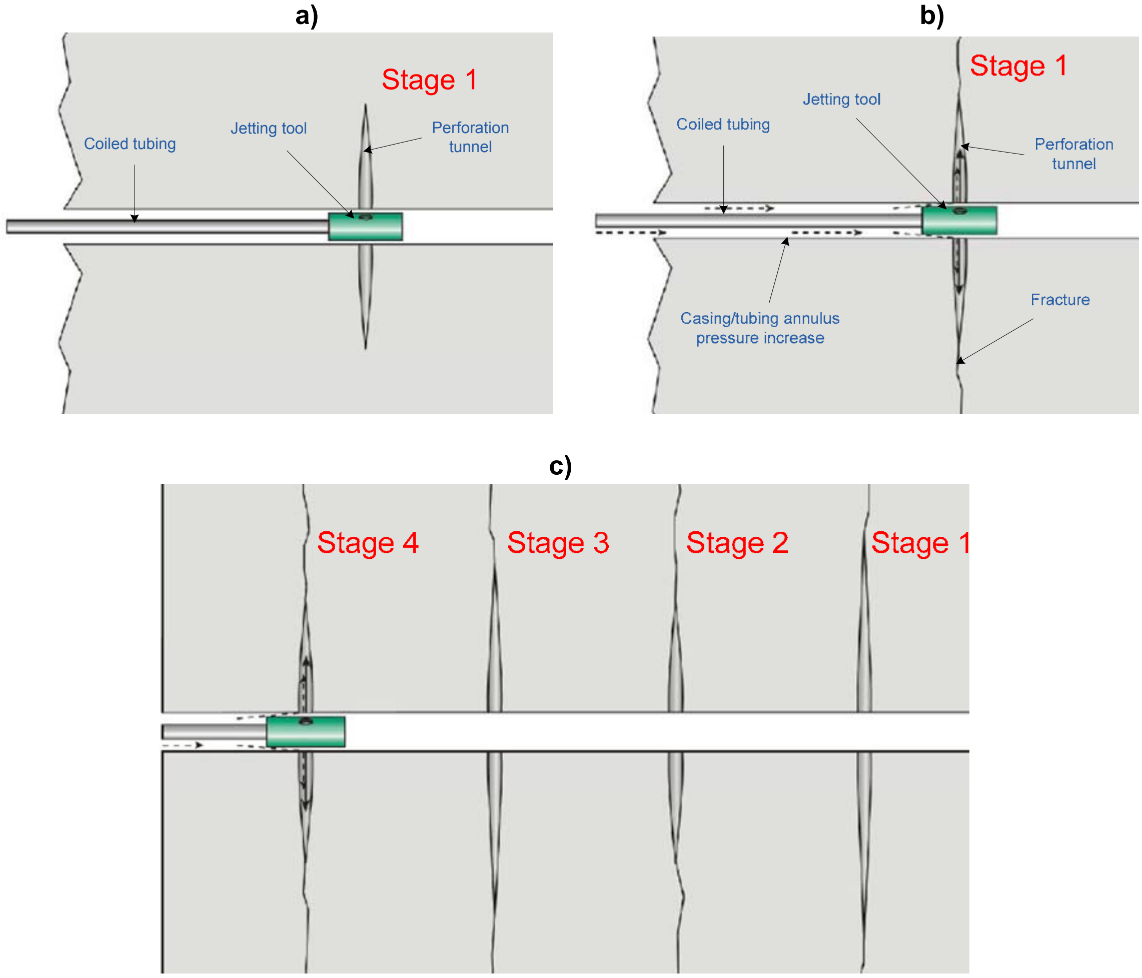

Fig. 3 *Hydrajet multifracturing process description (a-c) [11].*

Fig. 4 *Swelling packer cross-section view (a) and outside overview (b) [8].*

Swelling technology has an excellent application in smart well systems, multilateral systems, gravel pack systems and multifracturing systems, creating a superb seal necessary for zone isolation when stimulating each of them in a row. In combination with expandable tubulars, swelling packers can divide and seal many zones allowing for better multifracturing tools handling because of greater tubular ID.

4.3. Solid expandables and swelling packers assisted multifracturing

As already mentioned, expandable tubulars in tandem with swelling packers provide for many alternative completion solutions by creating a wider pathway for tool systems and excellent zone isolation (fig. 6). Deployment of expandable tubulars also allows for coiled tubing applications usage as comparing to jointed pipe systems, coiled tubing usually has many resistance difficulties when running in through open hole sections. Expandable system with swellable elastomers offers a single trip multizone completion and stimulation in conjunction with multifracturing systems like Hydrajetting, which is deployed with coiled tubing. Some important benefits of this system are [12]:

- enhanced management and zone control during the hydraulic fracturing process with coiled tubing,
- almost unlimited number of zones to be treated because no sliding sleeves or fracturing ports with balls are used,
- more control of fracture initiation point,
- remedial interventions for refracturing easily done,
- large expanded wellbore ID allows for large OD coiled tubing,
- reduced non productive time,
- better sealing performance because of swelling technology.

Hydrajetting seems to be the best option to use with expandables and swelling packers. Capability of moving the jetting tool through coiled tubing, perforating the pay zones and fracturing it gives this technique the opportunity to save time and money by stimulating many pay zones only in one run. Placing a *proppant plug* after each stimulated zone is optional and creates a good hydrocarbon filtering zone.

Figure 5 shows jet perforation and zone stimulation process in several stages, starting with jet perforation and fracturing first zone with expandable system and swelling packers in place (1). Jetting tool retreats for certain distance and gelled proppant is pumped down the annulus and into the fractures (2). Proppant slurry is pumped until screenout occurs (3). If there is slurry excess to be removed, it is done by reverse circulating through coiled tubing (4). Picture 5 shows the approximate amount of proppant plug left inside. It covers the first stage area without invading the second one. Jetting tool is then positioned to jet perforate and stimulate second pay zone (6). This procedure repeats as many times as pay zones to stimulate [8, 12].

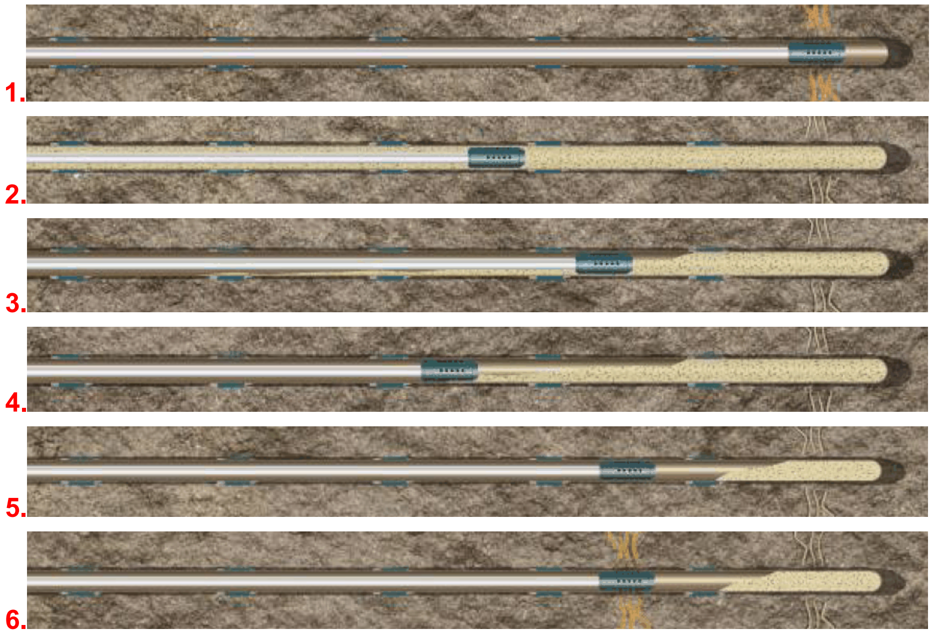

Fig. 5 *Jet perforation and stimulation of the zones inside expandable tubulars [12].*

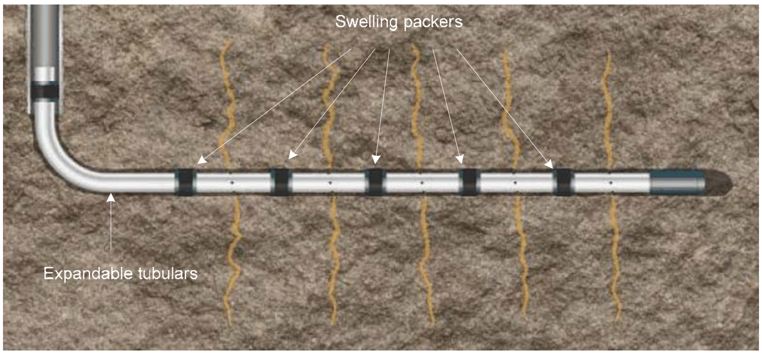

Fig. 6 *Expandable tubulars in tandem with swelling packers providing for effective pay zone stimulation [12].*

5. Conclusions

Nowadays, many new technologies in well stimulation sector are rapidly emerging to improve operational efficiency, hydrocarbon productivity and save time and money. As described, multifracturing well completions can be deployed on wireline, jointed pipe string or coiled tubing string. So far, the most promising technique is Hydrajetting system with jetting tool deployed on coiled tubing which guarantees good movability and fast, efficient perforation and stimulation in only one run. It is useful in eliminating early screenouts caused by improper perforating with shaped charge guns. Expandable systems with swelling packers are commonly used and integrated in many advanced completions and workover production solutions. In combination with perforating and fracturing technologies and coiled tubing, they continue to expand their utilization in the oilfield. Wireline assisted stimulation is also very applicable within different well conditions, but mainly inside cased hole. Like in CT applications, one run is enough to stimulate many pay zones (depends on number of gun sets installed), but a bridge plug installation is required after every few stimulation jobs performed. To make a final decision which particular stimulation technique suites downhole environment, well stimulation simulation softwares are used.

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