PERFORATION SHUT-OFF AND CASING REPAIR USING STAINLESS STEEL PATCH'S EXPANDED BY HIGH PRESSURE INFLATABLE PACKERS

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As optimizing the recovery of hydrocarbon reserves has grown in importance, and effective reservoir management has become increasingly complex, the need for shutting-off unwanted perforations in both production and injection wells has been growing.

A new technology now exists to expand solid stainless steel tubulars for downhole remedial applications. Very different from other expandable technologies, mainly due to the setting process and the capacity of the tools to expand until they're in contact with the casing, this technology has now been used successfully in several countries as a precision intervention to resolve a variety of downhole problems, in particular perforation shut-off and casing repair

This paper will:

- Provide an introduction to inflatable packer expandable steel technology, what it is and how it works
- Discuss some of the issues identified and resolved during the development of the technology
- Provide case histories using 3 examples of casing repair, gas shut-off and water shut-off jobs from 4 ½ , 5 ½ , and 7in operations in Europe, the Middle East, and Western Canada
- Summarize the features, benefits, and limitations of the technology
- Present the solutions available today in Texas and neighboring states.

1) THE CONCEPT

The working principle is quite straightforward. A high pressure inflatable packer is inserted into a Saltel Expandable Steel Patch[i], connected to drill pipe or tubing, and run in hole opposite the zone to be sealed. Surface pressure is applied through the tubing to inflate the packer and expand the top of the Patch, anchoring it in place. The Packer is then deflated, run-in just below the expanded section, and re-inflated to expand the following section. This is repeated as often as necessary until the entire Patch is fully expanded, as shown in Figure 1 below:

Running Procedures:

- The Down hole expansion tool is positioned inside the Saltel Expandable Patch
- The inflatable packer section is then inflated enough to make it grip the inside of the expandable liner, (not enough to allow the packer to start expanding the sleeve).
- The assembly is RIH on tubing, drill pipe, or coil tubing.
- The packer is inflated using pressure from surface to expand the top of the Patch, anchoring it in place
- The packer is then deflated, RIH another 3ft, and the next section is expanded.
- This is repeated as often as necessary until the full length is expanded, and BHA is pulled back to surface.

An elastomer outer skin is used to ensure a good seal between the body of the patch and the inside of the casing. The hydrogenated nitrile (HNBR) selected gives a good ageing performance in the aggressive environments encountered down hole. A machined sealing profile has been designed which will be energized by the setting pressure, and maintain a good seal with both internal (burst) and external (collapse) pressure differentials. A sealing zone of 3ft either side of the perforations or damaged zone is recommended.
The setting process means the Patch can be manufactured with a tapered entry cone machined into the steel top and bottom, to facilitate the future passage of tools.

2) SPECIALIZED RUNNING EQUIPMENT

The operation constraints will vary with the application, an expansion pressure of 4,000psi will be sufficient to expand a thin walled Patch, the thicker Patch's may require up to 8,000psi.
Some specialized equipment is required to run the Expandable Steel Patch:

- A Down Hole Expansion Tool is connected between the tubing and the inflatable packer. This will manage the down hole cycles and open the packer directly into the wellbore for rapid deflation. It includes various safety and emergency features, and a mechanism to compensate for a differential pressure between tubing and casing (for example if the static fluid level is several hundred feet below ground level).
- A hydraulic unit to pressurize the packer through the tubing. This needs to have a high pressure rating combined with the possibility of pumping at a low flow rate, a means of limiting the pressure, and a pressure recording system. Either an sitable pumping unit can be used or a Saltel Industries hydraulic skid can be supplied.

3) EXAMPLES OF RECENT APPLICATIONS

After several years of research and development the first field trials in 2009 showed that the technology is a practical solution adapted to solving a variety of problems, and regular operations started in 2010 in Canada, Europe, and the Middle East. Three case histories of typical jobs are described below.

3.1 Case history No.1, 4 ½ in Casing Repair - Onshore Europe

Well Type and Conditions: Oil producer, Internal Corrosion
4 ½ in 11.6 lb/ft (ID=3,875in / 101,6mm)
Hole identified using packer pressure test, @ Depth 3,500 ft / 1065m (Damage over 3 ft /1m)
Down hole temperature 150°F / 65°C
Work over rig, Tubing 2-3/8 4.6lbs
Running Assembly, Setting
Patch 4 ½ in reinforced, 321 Stainless steel thickness 0.118 in /3mm
Total assembly length 27.6ft / 8,4m, weight 656 lbs / 292kg
Patch length 19 ft / 5,8m before expansion (Patch 86 lbs / 38kg))
Patch RIH OD =3.62ins /91.9mm
Patch specifications and Results
Set Patch ID = 3.71in / 94,1mm
Patch thickness 0.15in / 3,74mm
Expansion Pressure 6,000 psi / 415bar
Well drifted real time to 3.5 in /88,9mm
Patch length 18.4ft/ 5,6m after expansion
Internal differential pressure rating unsupported: 2,660 psi / 180bar
Internal differential pressure rating 1in hole : 13,000 psi / 900bar (Restore original casing rating)
External service differential pressure rating 1,600 psi / 112bar

3.2 Case history No.2, 5 ½ in Gas shut off, North America

Well type and conditions: Oil producer
5.5in 14lb/ft casing (ID=5.01in /127,3mm)
Perforation to shut off @ 1625ft /495m
Perforation length: 7ft / 2,1m
Down hole temperature 75°F / 23°C
Drilling rig, Drill pipe is 2-7/8 7,8 lbs/ft
Running Assembly, Setting
Patch 5in Ultraslim, Stainless Steel
Thickness 0.08in / 2mm
Total assembly length 29.38ft /8,95m, (162bs /72kg)
Patch length 19ft / 5,8m before expansion (32lbs / 14kg)
RIH OD =4.12in / 104,6mm
Patch specifications and Results
Set patch ID =4.72in /119,9mm
Patch Thickness 0.106in / 2,7mm
Expansion pressure 3,720 psi / 260bar
Well drifted real time 4.53in / 115mm
Patch length 17,71ft / 5,4m after expansion
Internal differential pressure rating 2000psi /138bar
External differential rating 500psi / 35bar
12 steps, 9min per step, Total expansion time 2:15

2 patch were successfully set in the same well to cover two perforated zone, the well was immediately perforated after the job below the Patches.
Well went back on production, with no more gas production.

3.3 Case History No.3, Water production shut off in a 7in casing Middle East
Well type and conditions: Oil producer
7in 32lb/ft casing (ID=6.09in /154,8mm)
Perforation to shut off @ 10,000ft /3048m
Perforation length: 21,3ft / 6,5m
Down hole temperature 212°F / 100°C
Drilling rig, Drill pipe is 3-1/2" 13.3 lbs/ft
Running Assembly, Setting
Patch 7in Slimline Stainless Steel
Thickness 0.157in / 4mm
Total assembly length 43.52ft /13,3m, (690lbs /307kg)
Patch length 32,8ft / 10m before expansion (330lbs / 150kg)
RIH OD= 5.67in / 144,1mm
Patch specifications and Results
Set patch ID =5.6in / 142,2mm
Patch Thickness 0.208in / 5,3mm
Expansion pressure 4,630 psi / 319bar
Well drifted real time 5.43in / 138mm
Patch length 32.05ft / 9,77m after expansion
Internal differential pressure rating 1936psi /133bar
External differential rating 1542psi / 105bar
15 steps, 25min per step, Total expansion time 8:15
A GR-CCL log confirmed the clad is correctly in place across the target perforated interval.
A PLT survey showed that the well was producing at 22% BSW vs. 61% BSW before the operation

4) FEATURES, LIMITATIONS, AND BENEFITS OF THE TECHNOLOGY
Although the feed-back from the field shows many benefits from this technology, there are also a certain number of **limitations**. These include:

- Setting Temperature

The maximum temperature rating of the Down hole expansion tools is 300°F/150°C, however the Packers are limited to less depending on the model and the pressure. Testing is ongoing to qualify all models for temperatures up to 250°F/120°C, this is expected to be completed during 2011.

- Working Pressures

The Down Hole Differential Working Pressures will vary depending on casing size and thickness of Patch. The thinner models leave maximum passage to the well below, and an excellent internal differential pressure rating, (burst) but the external differential pressure rating (collapse) is fairly low. The thicker patches have slightly less passage after setting but reach higher pressure ratrings, 15,000 psi internal differential and 4,000 psi external are the highest that can be obtained.

- Maximum Length

Although there is no theoretical limit to the patch length, as many steps as necessary can be used to expand the steel, practical constraints will limit their length. The longest which can be easily transported is 40ft/12m.
Most jobs have therefore been limited t o 40ft/12meters, although in exceptional circumstances a Patch o f 56ft/17m and even one of over 200ft have been set when the well economics justified it.

- Maximum Expansion

Expansion tests have been carried out with packers and stainless steel tubulars at ratios of up to + 40%
After safety margins have been included the largest expansion will be limited to plus 25%

Some of the most appreciable **benefits,** which distinguish the quality of an expandable stainless steel Patch from other possible solutions, include:

- One Patch will fit several diameters, the progressive expansion of the Patch means one model will fit a large range of different sizes, for example a Patch designed for 7in can be set in casing from 17 lb/ft to 35 lb/ft, and also in most 7.625in casings.

- The patch will work effectively with irregular or uneven diameters, tests and trials have shown the Patch will set and seal in corroded or washed out conditions, even in ovalized casings. They have even been used to seal in open hole.
- Large clearance while running in, compared with other mechanical solutions the expansion ratio means the Patch can be run in hole with a large annular clearance, avoiding the risk of hanging up or swabbing the well.
- Good through bore access after setting, The wall thickness can be as low as 0.14in., which leaves a large access to the well below.
- Good corrosion resistance, the 321 or 304L stainless steel and hydrogenated nitrile used in the manufacturing ensure a long lifetime.
- Real Time Control, a calibrated drift integrated into the running tool will control the inside diameter of the Patch as it is being set. Any problem or anomaly would be immediately detected and cured.
- Repeatability, a second patch can be run through the first and set below, as many times as the well requires.

Other features which have become evident include the simplicity and reliability of the system, and the multitude of possible applications

5) POTENTIAL FUTURE DEVELOPMENTS

In conclusion a full range of standardized Patch's for casings from 4.5in up to 13.375in (and all intermediate sizes) is available, with an ultraslim or slimline model to maximize through passage or a reinforced model to maximize pressure rating. Typical job will take 2-5 hours once in place downhole, depending on length and depth.

The availability of very high pressure inflatable packers which can be inflated repeatedly in a down hole environment opens up a wide range of original applications for expandable steel technology.

- Following developments using different perfluoro elastomers (FFKM) in 2011 a range of high temperature Patches will be available with service temperatures of up to 570°F/300°C, opening up applications in steam injection wells
- The capacity to adapt to different diameters could be used for treating leaking liner hangers, sealing inside sliding sleeves, and other "exotic" applications.
- Testing is ongoing to validate the use of Expandable Pup Joints, capable of sealing in out-of- gauge or ovalized boreholes, and enabling horizontal wells to be segmented into as many sections as necessary. Pup joints could also be installed and left for expansion at a later date, depending on the evolution of production data.

The use of high pressure inflatable packers to expand solid steel or stainless steel Patch's has shown this can provide a reliable and cost effective solution for perforation shut-off and casing repair. Many other applications have become feasible, and no doubt others will appear as the technology becomes established for providing effective solutions to complex down hole problems. Following the successful introduction of the technology in Canada in 2010 a first base is being opened in Midland/Odessa in June 2011 to make the service available throughout Texas and the surrounding states. A full range of Patches, packers, and setting tools for casings from 4 ½ in through to 13 3/8 in will be in stock for next day delivery.

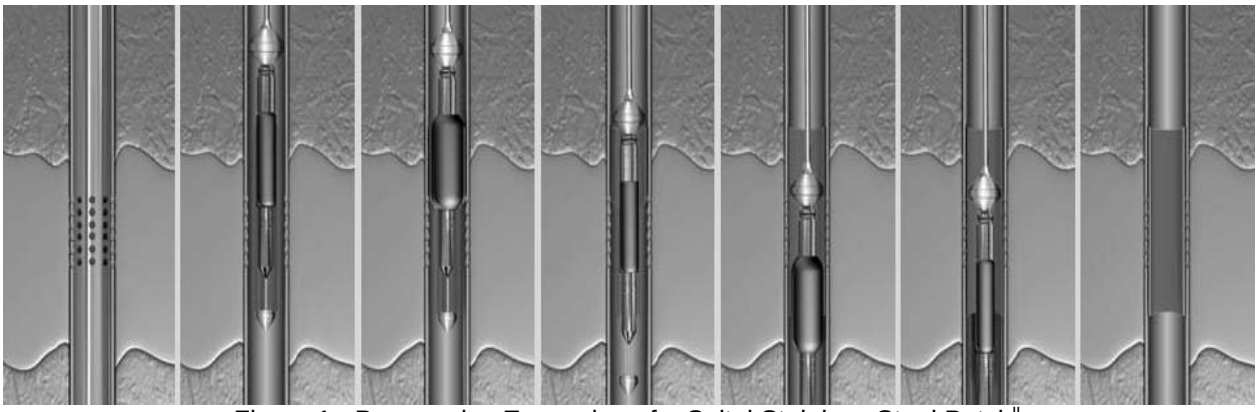

Figure 1 - Progressive Expansion of a Saltel Stainless Steel Patch[ii]

[i] TM Saltel Industries
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