REPAIRING INJECTION PORTS AND CASING BEFORE FRACING USING EXPANDABLE STAINLESS STEEL PATCHES

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Optimising the recovery of hydrocarbons has led to an increasing need for remedial applications in both production and injection wells. The increasing use of multi-zone horizontal completions, both for shale and more traditional formations, means thousands of frac ports are now being run every year.
In 2010 a new technology was launched in North America to expand stainless steel patches using a high pressure inflatable packer. This has now become a regular service, both for perforation shut-off and casing repair. The versatility of the technology has also enabled it to be used to seal leaking cementors and frac ports, with the unique ability of creating a high pressure resistant inner lining and yet enabling the passage of large size balls to activate the ports below.

This paper will describe rapidly how the technology works and follow up on the progress made over the last year. The first US operations base has been set up in Midland, Texas. Some of the first US field applications including both casing repair and perforation shut-off will be described. The paper will also present the testing process to validate using the Patch with differential pressures up to 10,000 psi, and describe the first field operations repairing frac ports. It will conclude by presenting the development of possible future applications of expandable stainless steel for improving completions.

1) HOW IT WORKS

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.

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 a suitable pumping unit can be used or a Saltel Industries hydraulic skid can be supplied.

2) CASE HISTORIES: EXAMPLES OF RECENT APPLICATIONS IN USA

After several years of research and development the first operations showed the technology to be a practical and cost effective solution adapted to solving a variety of problems, and regular operations started in 2010 in Canada, Europe, and the Middle East. Activity started in the USA in 2012, here we will describe two typical case studies from some of the first jobs that took place earlier this year..

2.1 Case history No.1, 4 ½ in 11.6# Collar Leak – Uintah County, Utah

Well Type and Conditions: Gas producer, Casing leak in collar
4 ½ in 11.6 lb/ft (ID=3,875in / 98.4mm)
Hole identified using packer pressure test, @ Depth 3,076 ft / 937m (Damage over 3 ft /1m)
Work over rig, Tubing 2-3/8 #4.7lbs

Running Assembly, Setting
Patch 4 ½ in slimline, 304L Stainless steel thickness 0.079 in /2mm
Total assembly length 21.85ft / 6,7m, weight 420 lbs / 190kg
Patch length 13 ft / 3.95m before expansion (Patch 40 lbs / 18kg)
Patch RIH OD =3.425ins /87mm

Patch specifications and Results
Set Patch ID = 3.64in / 92.4mm
Patch thickness 0.12in / 3.04mm
Expansion Pressure 4,854 psi / 335bar
Well drifted real time to 3.60 in /91.44mm
Patch length 12.40ft/ 3,78m after expansion
Internal differential pressure rating unsupported: 2,135 psi / 147bar
Internal differential pressure rating when supported (1in hole) : 20,000 psi / 1,380bar (Restore original casing rating)
External service differential pressure rating 724 psi / 50bar

Patch was successfully set between 3070ft and 3082ft, with 11 steps taking 2 hours. Patch was drifted with an ID of 3.60 all the way through. Well was then pressure tested at 4500psi for 15 minutes. Patch held solid, zero leak.

2.2 Case history No.2, 4 ½ in Perforation Shut off, Uintah County, Utah

Well type and conditions: Gas producer
4.5 in 11.6lb/ft casing
Two patches were set in the same well to cover perforations at different Depths
A.Bottom Patch (1st set) 23ft
B.Top Patch (2nd set) 40ft
Perforation to shut off @
A.6,582ft – 6,595 ft
B.6,240 ft – 6,259 ft
Perforation length:
A.13ft / 3.96m
B.19 ft / 5,8m
Drilling rig, Drill pipe is 2-7/8 #7,8 lbs/ft

Running Assembly, Setting Patch
2x 4.5in Slimline, 304L Stainless Steel

Thickness: 0.08in / 2mm
Patch length
A. 23ft / 7m before expansion (71lbs / 32kg) ;
B. 40ft/ 12.2m before expansion (124lbs/56kg)
Total assembly length
A. 31.88ft /9.72m, (451bs /204kg)
B.48.94ft /14.92m, (504lbs/228kg)
RIH OD =3.425in / 87mm

Patch specifications and Results
Set patches ID = 3.64in/92.5mm
Patches Thickness: 0.079in / 2mm
Expansion pressure 5,000 psi / 345bar
Well drifted real time: 3.62in / 91.9mm
Patch length after expansion
A.21.98ft/ 6.7m after expansion
B.38.30ft / 11.68m after expansion
Internal differential pressure rating: 2200psi/150bar
External differential rating: 732psi / 50bar
Setting Time and Steps
A.17 steps, 4 ½ hours
B.28 steps, 5 ½ hours

Both patches were successfully set in the same well to cover two perforated zone, the well will be perforated after the job below the Patches.

3) VALIDATING USE FOR SEALING FRAC PORTS

The advantages of the technology include the ability to expand into a variable diameter, to have a minimal diameter loss, and to make an efficient seal even with high pressures.
Some tests were carried out to demonstrate that the sleeve could resist frac pressures when set over a leaking cementor or a frac port which was blocked open.

TEST OBJECTIVE

It is conceivable for any horizontal completion that a frac port may become blocked in the open position, limiting the possibilities for fracing the zones below. Saltel Industries have developed a very slim expandable steel patch with a high pressure rating, set using an inflatable packer. The modeling had shown this Patch should be able to seal inside an open frac port, resist the frac pressures, and still leave passage for a 3 ½ in ball to pass through. These tests were performed at Saltel Industries in Midland (TX), to :

- Validate the patch setting process inside a milled sleeve ID 3.875in
- Establish the internal pressure resistance for the Patch is > 9,000 psi
- Demonstrate the possibility of running through the set Patch with a 3 ½ in ball

Setting Conditions

To simulate real well conditions, a Drillable Frac Port was used including a sliding sleeve which is normally 3.510 inches ID but has been milled out to 3.845 inches for the test, maximum ID inside the port was 4.560in. The patch had to seal the open port, hold the frac pressure after repeated cycling, and leave passage for a 3.5in ball.

For this test, a Saltel Industries “Pre-frac” Patch for 4.5in completions has been used. This was identical to the Patch which would be used downhole excepting that the length was reduced for the Test configuration.

Running Assembly

Maximum running OD:	3.50in	69mm
Initial ID	3.15in	80mm
Thickness of steel	0.12in	3mm
Steel type:	321 stainless steel	

Elastomer outer skin: Hydrogenated nitrile (HNBR)

OD of running tools	3.50in	69mm.
Patch length:	13ft	12meters

Patch Setting

The setting assembly (milled frac port + 4 ½ in pup joints) was laid out horizontally.

The downhole expansion tool was run into the Patch, then the patch was run into the setting assembly .
The Patch was expanded in ten cycles of 5,600psi/390 bar. After each step the pressure was bled-off and the tool then run in for the next step.

Pressure Test setup & Results

For the pressure test, the completion was plugged on one side and connected to the Saltel Hydraulic Pump by a Weco 1502 Connection.

- For the safety, the pump has been remote controlled from another room.
- The test pressure has been limited by the maximum pressure of the pump, to 10,000 psi.
- The test was performed at room temperature, around 25°C / 77°F.

The patch was pressured up for **20 times to 700b / 10,000 psi for 5 min** at each cycle. There was zero leak. (See Figure 2 below).

After the pressure test, the patch has molded to the maximal diameter of the Frac Port.
The maximum external diameter of the patch reaches 120,62mm / 4.75in.

The 3 ½ in OD running tool passed through the Patch without difficulty.

Conclusions

- The Saltel Industries Expandable Stainless Steel Patch can be successfully set in the variable ID of a milled frac port
- With a port ID of 3.875in the Patch leaves a passage for a 3.5in tool
- The Patch can work with pressure of up to 10,000 psi.

The SI "Pre-frac" Expandable Stainless Steel Patch is a suitable and effective solution for repairing blocked or damaged frac ports.

4) CASE HISTORY REPAIRING A 4 ½ in FRAC PORT – RED EARTH, ALBERTA, CANADA

Following the successful test of the Patch a first job was carried out in Canada.

Well Type and Conditions: 4 ½ in Frac completion, leaking frac port
Zone to seal: 7094ft (2162.4m) to 7098ft (2163.6m), 5900ft TVD (1800m)
The port, 2.6ft long (0,8m long), was milled to 3.84in (97,66mm)
The pup joints above and below the port are 4 ½ in 11.6 lb/ft:
Nominal ID=4in (101,6mm) - Drift ID= 3.88in (98.43mm)
Down hole temperature 140°F (60°C)
Work over rig, Tubing 2-3/8 - 6.6lbs/ft

Running Assembly, Setting:
Patch 4 ½ in Reinforced, 321 SST – Wall thickness 0.118 in (3mm)
Total assembly length 28.7ft (8,75m), weight 500 lbs (225 kg)
Patch length 19.7ft (6m) before expansion (Patch 60lbs / 27kg))
Patch RIH OD =3.5in /89mm

Patch specifications and Results after setting:
Set Patch ID = 3.65in (92,8mm)
Expansion Pressure 5,200 psi (360bar)
Well drifted real time to 3.53in (89,6mm)

Patch length 19.3ft after expansion (5,9m)
Internal differential pressure rating 1in hole : 20,000 psi (1380bar)
External differential Service pressure 1,625psi (110bar)

The Patch was successfully set, as programmed and with no lost time
Patch was pressure tested immediately after setting to 3,000psi (200bar): Solid

After the job the customer continued with the frac program:
18 frac stages at 1,850gal/min (7m3/min)
Peak pressure of 9,000psi (620bar)
850,000 lbs of sand injected (425 Ton)

The Patch was still sealing effectively after the fracing was completed.

5) 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 some of the Packers are limited to less depending on the model and the pressure.
Some more test and improvement on the Packers are still pending for 2012

- 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 ratings; 20,000 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 of 56ft/17m and even one of over 220ft/67m have been set when the well economics justified it.
Saltel Industries is working to extend the available length in 2012 using Expandable thread connections

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, 304L, 316 stainless steel and hydrogenated nitrile used in the manufacturing ensure a long lifetime.
- **Real Time ID 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

6) CONCLUSION AND POTENTIAL FUTURE DEVELOPMENTS

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.
A full range of Patches, packers, and setting tools for casings from 4 ½ in through to 13 3/8 in are now in stock in Canada and in Midland/Odessa to make the service available throughout Texas and the surrounding states for next day delivery.

The use of inflatable packers and the use of Stainless steel to make expandables opens up a wide of range of potentially interesting and cost effective solutions in the oilfield.
Products and services under development based on the same or similar concepts include:

- A range of high temperature Patches working temperatures of up to 600°F (315°C)
- An expandable thread for running longer lengths of Patch
- An Inflatable Steel Packer for zonal isolation, capable of sealing on open hole, even if damaged or ovalized, with a pressure rating greater than 10,000 psi.

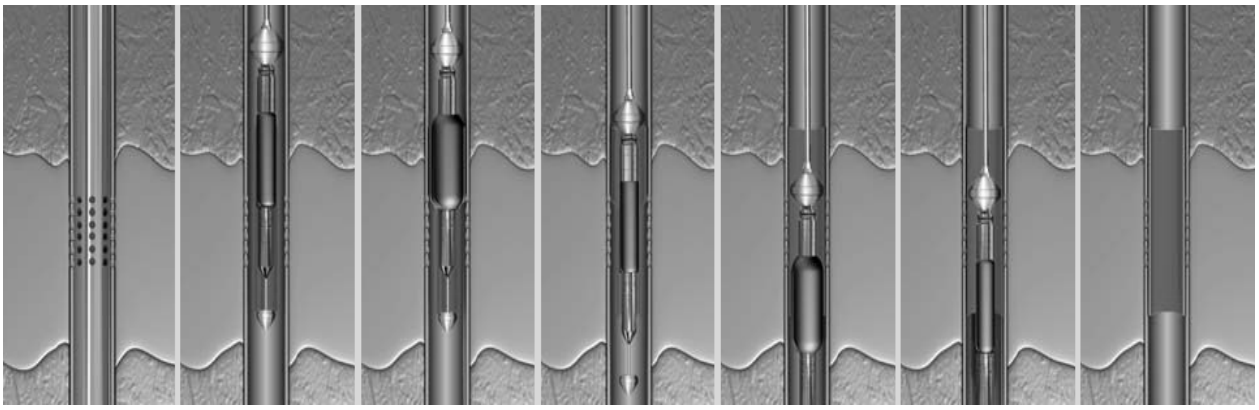

Figure 1 - Progressive Expansion of a Saltel Stainless Steel Patch[ii]

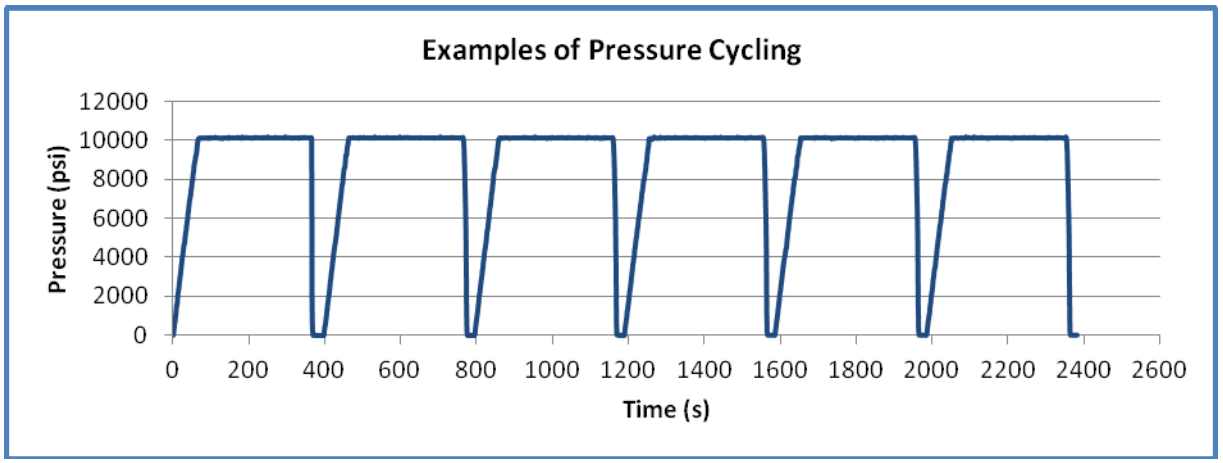

Figure 2 - Pressure cycling the Pre-frac patch (The patch was pressured up for **20 times to 700b / 10,000 psi for 5 min** at each cycle. There was zero leak)

[i] TM Saltel Industries
[ii] TM Saltel Industries