

Casing Patches – Expanding from the Oilfield into Geothermal

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ABSTRACT

Oil wells are sometimes faced with the need to repair casing due to unexpected situations during operations. To address such challenge the industry has developed expandable steel patches as a permanent solution to repair a compromised section of tubing or casing, shut off unwanted perforations, or perform other remedial operations.

As the Geothermal industry continues to grow, the availability of such expandable casing patches that can perform under extreme high temperatures increased as well. Originally designed for steam-assisted gravity drainage (SAGD), they are now commercially available for geothermal wells. These expandable tubulars are made from high-quality stainless steel to resist severe temperature and corrosion conditions. The material selection enables the patch to seal effectively at low temperatures and high temperatures and in different mediums, such as water, vapor, and nitrogen. This expandable tool creates a high-pressure inner lining with minimal loss of diameter. Due to the unique setting mechanism of expandable patches, it allows itself to conform to irregular geometries while exerting minimal pressure on the fragile casing.

This paper will present the detail workings on high temperature expandable packers. It will present the results from two case histories of repaired leaking casing in thermal wells from California to the SAGD wells in Western Canada, where these tools selected for its easy conformance to irregular geometries and its ability to be set gently against fragile tubulars, while offering strong sealing characteristics.

1. Introduction

High temperature is always a challenge when it comes to wells, of any type. The apparent anticipated difficulty is material corrosion, but it constitutes only one part of the difficulties related to high-temperature environments. Also, the temperature variations from high-temperature formations' production exert significant stress on casing tubulars, completion equipment, and their connections. Failures are common and require interventions to restore casing integrity and ensure paramount protection of aquifers and the well surroundings. The deployment of internal casing patches is a remediation service that has been used for years in the Oil and Gas industry, that creates a solid metallic barrier inside the casing without a severe internal diameter loss. Those have though limitations for use in higher temperature conditions. Until recently, no solution was available to treat well integrity issues with a high-temperature rated patch, able to sustain significant temperature variation while still restoring casing integrity without a considerable reduction of internal diameter inside the injection/production casing.

We will present these difficulties in the coming paragraphs. We will first introduce the challenges of selecting metallic and non-metallic materials for high-temperature conditions and detail the specific selection of expendable systems for internal casing patches in such environments.

We will then review the various options available today for casing remediation interventions for different temperature ranges and describe the rigorous testing protocol the internal casing patches can be going through. Case studies will demonstrate the efficiency of high-temperature patches for casing remediation.

We will then be able to extend the talks on existing limitations of expendable steel solutions for geothermal applications, ways to get around them, and the foreseeable improvements that will unlock future deployments in this field.

2. Thermal well specific difficulties

The temperature of a well is one of the most essential parameters for equipment and material selection. It is as crucial to know the specific temperature of the targeted formation as its pressure. Material selection is critical to ensure long-lasting well integrity, and the equipment used will need to be selected to bring the performance required to sustain the highest and lowest temperature met. Indeed, the temperature span between static and flowing temperature can be wide, and causes contraction and expansion of materials, which can be at the origin of integrity loss and tremendous loads due to the thermal effect on tubular, leading to connection failures and tubular ovalization.

2.1 Corrosion resistance

Like any other environment, the material selection needs to use the best for purpose grades and elastomers to provide long-term corrosion resistance. The corrosion mechanisms are

- Cracking and stress corrosion cracking (SCC)
- Pitting
- Intergranular corrosion
- Galvanic corrosion

Metallic material selection is mainly considering corrosion and mechanical resistance. The casing and completion equipment needs to be considering the following parameters to validate the compatibility with the environment:

- Downhole temperature
- Downhole pressure
- Fluid composition from the produced or injected brines and packer fluids, if any.

The often-corrosive fluids that are produced in a geothermal well can have a dramatic effect on the life span of the equipment. For intergranular corrosion or SCC, for instance, the penetration speed of the corrosion can be fast and degrade the well barrier within weeks.

2.2 Casing patch materials

Understanding the necessary long lifespan for geothermal projects that are not affected by formation depletion that anticipate a limited production efficiency in oil and gas well, the materials of geothermal well casing needs to be often high-grade. If unanticipated conditions are met and casing corrosion occurs, an internal casing patch can be a reliable and long-lasting repair using materials that are necessarily of the same or higher grade than the casing it is expanded in.

Here are the grades that are used for casing patch mechanical structure, issued from the Schlumberger Saltel expandable steel patch)

- Austenitic Stainless 300 series (321 and 316L)
- Super-austenitic stainless steel (904L)
- Nickel-based (C276)

The materials from this list were selected for their corrosion resistance and ductility, helping to control the expansion process, which is necessary for high deployment reliability accurately. Depending on the surrounding fluid composition, pressure, and temperature, the simplest grade from this list will be chosen:

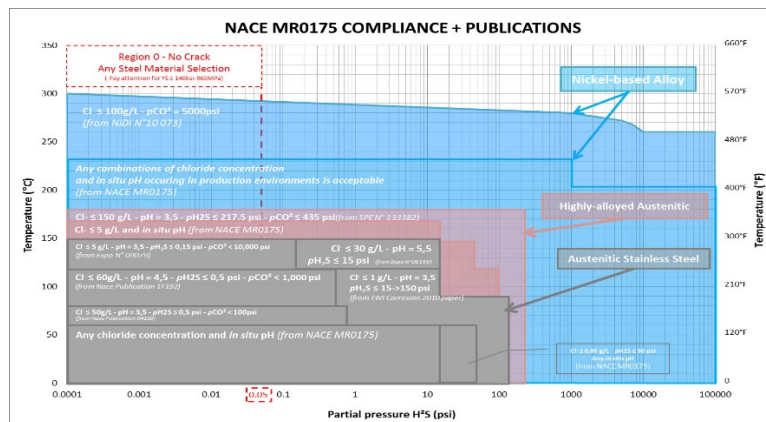


Figure 1: NACE material compliance and publications

On top of the steel material expanded inside the casing, a thin sealing layer must be squeezed in between the patch and the casing. Depending on the well environment, those can be:

- Hydrogenated Nitrile Rubber (HNBR)
- Tetrafluoroethylene and propylene (TFE-P – AFLAS)
- Fluoro-rubber (FKM - Viton)
- Synthetic material for non-elastomeric

These materials are used to handle the spring-back effect of the expandable steel material. The spring-back effect applies after the expansion, right after the pressure has been bled off inside the setting tool. The patch reaches its maximum expansion before relaxing slightly: the compressed sealing system handles this gap created and is still energized or compressed after this effect.

This remaining compression of the sealing system also helps maintain an efficient seal during temperature variations. For instance, during circulation at high rates, the temperature drops in an injection well, and a casing patch naturally contracts faster than the casing surrounding it. The sealing profile handles these temperature variations, as it dampens the casing and patch interface that is subject to movement during temperature and even pressure cycles.

3. Casing patch for thermally affected casing issues

In oil and gas wells, the hottest environments are met in wells targeting tar sands or heavy oil, whose viscosity is so low that traditional production techniques are not possible. Steam is used to liquefy the viscous bitumen, which is then pumped out or drained out more easily. There are two different techniques commonly used:

- On the one hand, Steam Assisted Gravity Drainage or SAGD, which uses a steam injector well right above a producer.
- On the other hand, Cyclic Steam Stimulation or CSS uses the same well to alternatively inject and produce heavy oil.

The steam injection's high temperature causes severe casing deformation and even casing collapse when an enclosed volume of fluids around the casing heats up and sees its pressure spike. Temperature variations that are seen during the cycles of CSS can also stress connections until their yield and can disconnect. Saltel patch is the only casing remediation technology that allows to take care of casing deformation and adapt to provide a high-performance seal.

At surface, the Down Hole Expansion Tool (DHET) is placed inside the patch, and the inflatable packer element is pre-inflated with up to 15 bar - 220 psi. This pressure is sufficient to grip the Patch during the RIH, but not enough to expand it.

The expandable steel patch is also held by the Patch Holder (PH), which supports and protects the lower end of the patch. The assembly is run into the setting zone with tubing, drill pipe, or intelligent coiled tubing.

The packer is inflated by applying pressure from the surface to expand the top of the patch and anchor it in place. The packer is then deflated, run further downhole, and expands the subsequent section. This process is repeated as necessary until the whole length is expanded. During the run-in-hole, the Setting Controller acts as a drift to control the Patch setting.



Figure 2: Patch setting sequence

- ⇒ Run-in and position the assembly
- ⇒ Increase pressure through the tubing to expand and anchor the Patch
- ⇒ Deflate the packer, the Patch is now released from the running tools
- ⇒ The string is run in below the first step
- ⇒ The packer is inflated to expand the second step
- ⇒ Surface pressure is bled-off to deflate the packer
- ⇒ The assembly is run in to the next step, the setting controller verifies the inside diameter
- ⇒ These steps are repeated as much as necessary until the Patch is fully expanded

The well can be put immediately back in operation with the perforations well sealed and a large through bore diameter

There are two very different scenarios when using internal casing patches:

- In-zone,
- and Out-of-zone interventions.

3.1 In-zone patches

The in-zone interventions are using casing patches in the zone of production. The need for casing integrity inside the producing formation is not necessary. To clarify, most of the time these types of well come equipped with slotted liners at such depths.

The patch is used to prevent excessive sand production from a section of the slotted liner or hotspot inside a standalone screen. As there is no need to provide a patch that restores gas-tight or liquid-tight integrity, the patch sealing expectations are rather low. In that particular case, the patch covering does not need to guarantee a long-lasting seal. Patches set in-zone can therefore be using standard sealing systems made of HNBR elastomer.

Nevertheless, to ensure a permanent barrier that will consistently block the sand production, the steel grade selection of the expandable tubular must be compatible with the surrounding fluids and conditions.

3.2 Out-of-zone patches

When casing integrity issues arise above the lease line, where the quality of the casing integrity can guarantee the well control barriers, both mechanical structure of the patch and its sealing systems must be life of the well. The elastomers for standard patches - HNBR - are therefore not suitable for out-of-zone thermal applications.

High-temperature elastomers such as Aflas and Viton can help sustain temperatures up to 450 degF (230 degC) and short exposures up to 480 degF (250 degC). This feature can be acceptable for cyclic steam stimulation (CSS) wells.

For instance, in California, Saltel expandable steel patch HT –for high temperature– was deployed in three similar wells, deeply affected by corrosion. The regulatory pressure tests failed, stalled all production operations. The HT patch was deployed to selectively reline the casing where the corrosion had fully penetrated the casing material, reinforcing it prior to pressure tests and production resuming.

Nevertheless, the temperature limitation of the HT patch is always exceeded in geothermal wells:

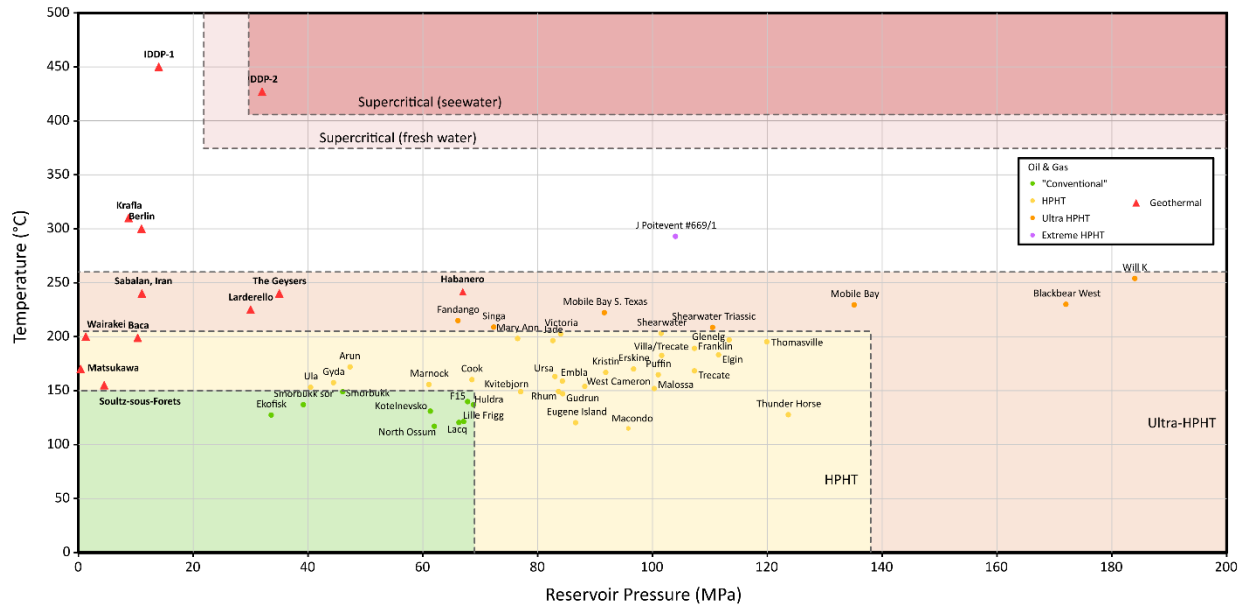


Figure 3: Geothermal wells vs. HPHT in Oil & Gas. Image by R. Castilla under CC BY-SA 3.0

For temperatures exceeding 450 degF (230degC), elastomers are not a suitable solution. To be able to reach temperatures above 630 degF, synthetic materials is a qualified and field-proven solution, capable of withstanding cycles of high and low temperatures. The following chapter describes the qualification process used to pass the ISO certifications for this particular product.

4. Extreme High-Temperature patch

The Extreme High Temp casing patch (EHT) is composed of the best possible grade for supporting corrosive fluids met in geothermal wells (<https://www.thinkgeoenergy.com/nickel-helps-on-corrosion-issues-in-geothermal-wells>).

The development program of this technology has been through phased R&D program stages over years, to develop a comprehensive patch product for Cyclic Steam Stimulation (CSS):

- seal designs
- material choices
- seal deployment and sequencing
- setting process and procedures

The expandable material is composed of Hastelloy® C276, covered with graphite and Polytetrafluoroethylene (PTFE) compounds.



Figure 4: Saltel expandable steel patch, Extreme High Temp – 335C-635F

The patch is set thanks to the traditional method of expansion of Standard Saltel expandable steel patches, that use hydraulic pressure to mold the tubular towards the ID of the casing it treats.

The inert material of the sealing system is trapped in between stop rings that act as anti-extrusion devices, that hold in place. Once compressed, the seals provide a long-lasting barrier pinched in between the casing and the expanded patch, capable of shutting off fluids and gas, despite irregularities in the casing (due to corrosion or casing deformation such as ovality).

4.1 Qualification program

To validate the effectiveness of the solution, the following protocol has been used in accordance with ISO 14310 V3 standards and from requirements expressed by a major Operator Canadian subsidiary, specialized in heavy oil production:

- Setting temperature 75 degC-167 degF
- High-temperature levels at 335 degC-635 degF
- Low temperature at 60 degC-140 degF
- Allow 1 hour of stabilization after reaching temperature target
- Pressure of 21MPa – 3,000 psi internally
- Pressure of 5MPa – 730 psi externally
- Leak rate measured for 15 minutes, Acceptance criteria 1%
- 7in #23 casing
- Tests with fluid (water)

- Test with Gas (Nitrogen)
- Ability to rework patch (“repress”)

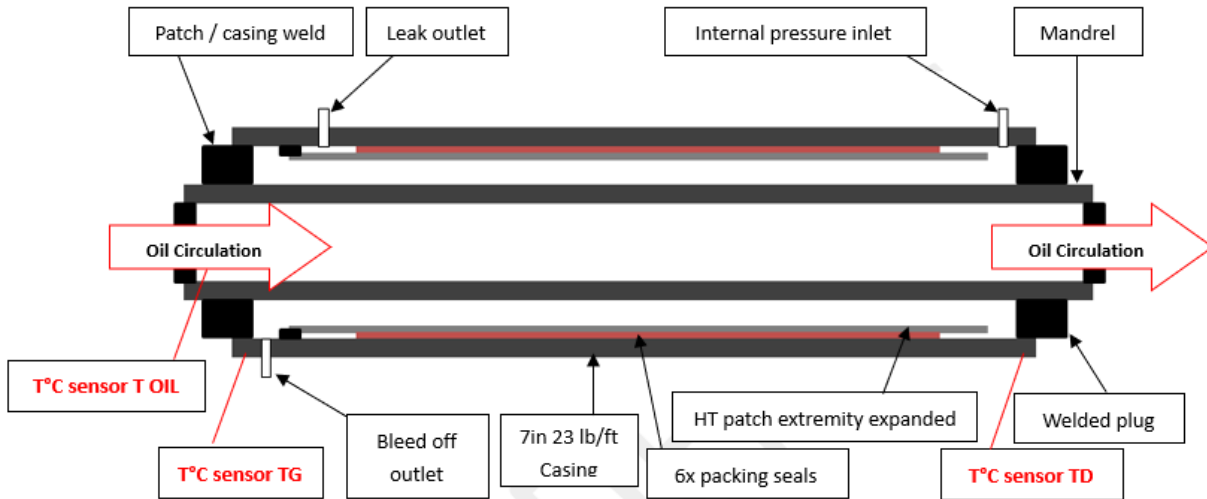


Figure 5: Test setup

Temperature cycles are applied as the following:

High temperature Vapor test : 14 MPa, 335°C - Vapor bleed off

High temperature N₂ test : 14 MPa, 335°C - N₂ bleed off

Cooling to go under 60°C

Low temperature Water test : 21 MPa, <60°C - Water bleed off

Low temperature N₂ test : 14 MPa, <60°C - N₂ bleed off

There are 3 main sequences:

1. CSS simulation test: Thermal cycle between 60 degC and 335 degC with water and N₂ pressure test
2. ISO 14310 V3 confirmation: two pressure reversals and a thermal cycling after the reversal to validate the product is still water tight. A pressure reversal is done after cycle 10 (the pressure is injected at the other side of the patch extremity) and then, another cycle with initial configuration is done.
3. Patch re-work procedure (setting process after a N₂ pressure test), to validate a remedial method to improve patch sealing capability. After the re-work, another complete cycle is done with water and N₂ pressure test to confirm the improvement.

The schematic below shows all test pressure test done on the product.

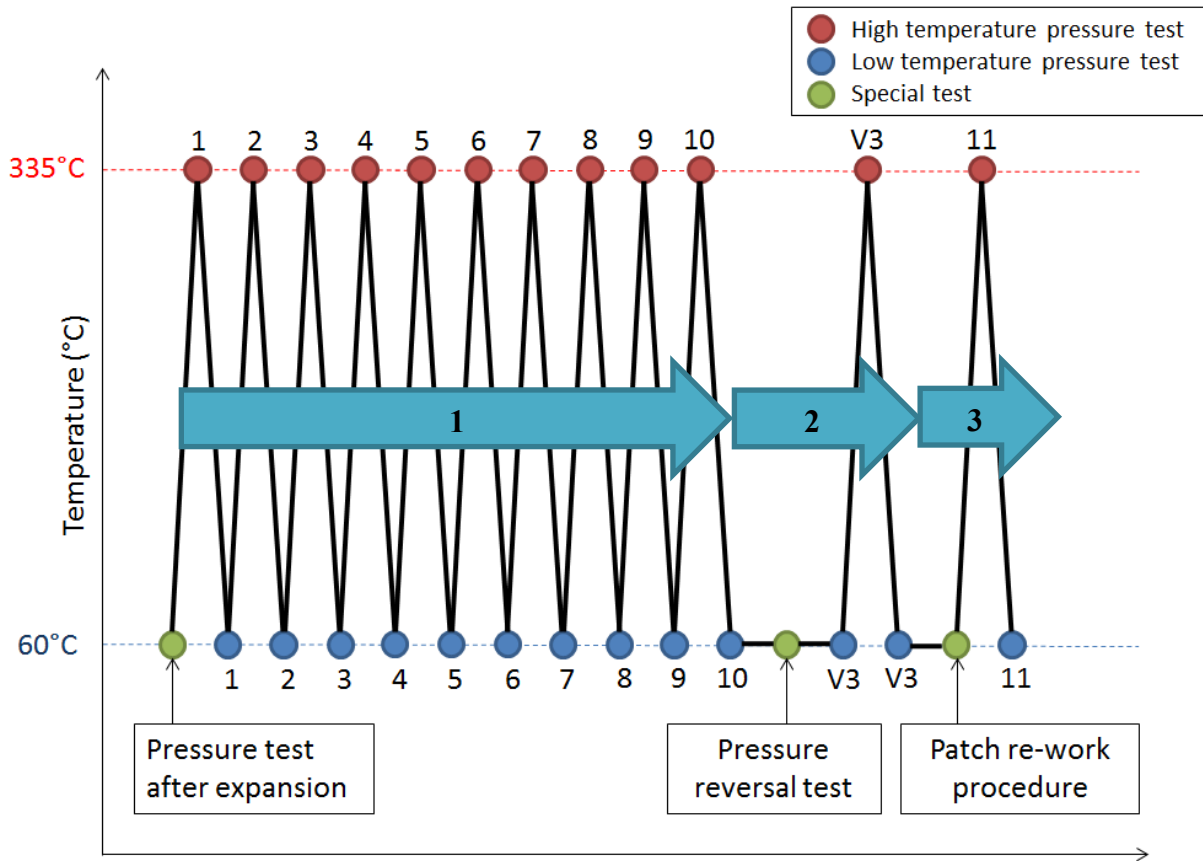


Figure 6: Test procedure

The ISO part of the test will complete the qualification in accordance with ISO 14310 V3 specifications. According to the ISO 14310, the product must hold two pressure reversal and still be water tight.

Extract from ISO 14310:

- Perform a minimum of two pressure reversals at or above the maximum rated pressure from above to below or vice versa.
- Test a minimum of one temperature cycle. Start the temperature cycle at or above the maximum rated temperature and cool down by at least the maximum rated temperature-cycle range. A pressure hold is required at the low end of the temperature-cycle range and after heating back up to the maximum rated temperature.

During the thermal cycles, the patch is tested with internal pressure (the pressure is applied inside the patch).

To do a pressure reversal, we need to test in external pressure (outside of the patch). In this configuration, the patch will collapse if the pressure is too high. The external service pressure will be 5 MPa and the theoretical collapse pressure is above 12 MPa.

Here is the test procedure:

- HT Patch cycling test (CSS simulation) – internal pressure from 14 to 21 MPa – 2,000 to 3,000 psi
- **HT Patch ISO 14310 V3 – external pressure at 5 MPa – 700 psi**
- **HT Patch ISO 14310 V3 – internal pressure from 14 to 21 MPa – 2,000 to 3,000 psi with a thermal cycle to confirm the patch is still water-tight (LT - HT - LT).**
- HT Patch rework procedure

Test results

| Test name | Pressure (MPa) | Medium | Target temperature (°C) | External / Internal pressure | ISO 14310 V3 criteria (L/min) | Leak during 15 min (mL) | Leak (L/min) |
|---------------|----------------|--------|-------------------------|------------------------------|-------------------------------|-------------------------|--------------|
| V3 EXT | 5 | Water | 60°C | External | 0.0085 L/min | 0.12 | 0.0080 |
| V3 INT 1 | 21 | Water | 60°C | Internal | 0.0375 L/min | 0.198 | 0.0132 |
| V3 INT 2 (HT) | 14 | Water | 335°C | Internal | 0.025 L/min | 0 | 0 |
| V3 INT 3 | 21 | Water | 60°C | Internal | 0.0375 L/min | 0.188 | 0.01 |

The test program concluded in the successful qualification of the expandable steel patch EHT under ISO 14310 V3 standards.

4.2 Field trial program

Once the EHT patch fully qualified, the technology went through a thorough field test program to validate the efficiency in actual wells and real conditions. The casing impairments at the origin of the technology qualification and field trial implementation was connection failures in the Colorado shales sections of the Cold Lake oils sands. The thermal stresses induced by temperature cycles created loads at the origin of parted connections at shallow depths.

Here are the different steps for each patch deployment:

1. Confirm well conditions:
 - a. Pressure test above and below repair interval
 - b. Run Scraper/Drift to confirm wellbore alignment
2. Run in patch with setting tool on drill pipe (setting pressures up to 60 Mpa – 8,700 psi) and log into place
3. Set patch and pressure test with water to 21 Mpa (3,000 psi), and Nitrogen gas with 10 MPa+ (1,450 psi)
4. Drill out suspension plug and run production string
5. Inject steam at planned rates and pressures.
6. Put well on production until desired reservoir pressure is reached

7. Pull production string, run 138 mm drift through patch and set inflatable packer below repair interval
8. Pressure test patch to 21 MPa – 3,000 psi with water and 10 Mpa+ N₂ -1,450 psi
9. Pull inflate and rerun production string.

All trialed patches behaved according to specifications. Feedback from customer representatives was positive. Spread out of a few years in between the start of the development program and the first field deployments, it is perceived that the multiple cycles of extreme temperature spans and high pressures enabled a thorough de-risking of the technology, proving its superiority in terms of reliability, performance and longevity.

4.3 Geothermal applications

The Saltel expandable steel patch for Extreme High Temperatures now proven for cyclic steam stimulation is now available for Geothermal interventions. The casing sizes qualified for this EHT environment (235 degC – 635 degF) are:

- 7in 23ppf
- 9-5/8in 40ppf

The sizes for High Temperature patches (230 degC-450 degF) are

- 4.5in (from 9.5 to 15.1ppf)
- 5in (11.5 to 24.1ppf)
- 5.5in (from 14 to 26ppf)
- 7in (from 17 to 41ppf)
- 7-5/8 (from 24 to 39ppf)
- 8-5/8 (24 to 44ppf)
- 9-5/8in (71.8 to 220ppf)
- 10-3/4in (40.5 to 71.1ppf) and 11-3/4in (47 to 71ppf)
- 13-3/8in (48 to 80.7ppf)

Some casing sizes, such as the 6in casing, were not represented but can still be treated. One of the main points to address on the patch setting is the limitation on the maximum temperature that can be met during the installation. Today's highest tolerated temperature is 300 degF (150 degC). The reason behind this is the deformable membrane that needs to be sustaining the high pressures necessary for the steel plastic deformation. Installations in temperatures higher than this limit will prematurely age this deformable element (inflatable packer element of the downhole expansion tool), leading to its failure, ultimately.

Nevertheless, this does not prevent a successful setting as a patch can be set in several trips, using new packer elements to expand the length of the patch fully. As the patch is expanded in sequence, the patch expansion will progress until each elements needs to be replaced.

A recent patch deployed in the Eagleford fields of south Texas utilized this possibility. During the application study, it was realized that the 6in casing size, the length of the patch and the bottom hole temperature would induce rapid aging of the inflatable setting tool, and require several runs.

The failure mechanism of the setting tool is a leak that is measured during the pumping sequence. Large expansion ratios, coupled with high temperature and setting pressure lead to a leak of the inflatable packer element. When this leak is high enough that it cannot be compensated by pumping rate at surface, the tools need to be retrieved. An additional set of tools was brought up to location to be prepared for a second trip. This was done with limited downtime, and the length of the patch remaining to be expanded was handled by the spare tools.

This ensures, even in extreme environments, to anticipate difficulties and propose solutions for issues that precedingly involved new well drilling or relining that reduced the internal diameter of the well significantly, jeopardizing future interventions.

5. Future Xpandable developments

With a thorough knowledge of the behavior of steel expansion in various temperature environments and the expertise to deliver long-lasting sealing systems in extreme conditions, the industry is now capable of delivering tailored solutions responding to the unique needs of the geothermal industry. As we see an increased appetite in Enhanced Geothermal Systems (EGS), a need is expressed for high-pressure equipment under high temperatures. The Xpandable steel solutions are a field-proven solution for casing interventions and zonal isolation in the open hole that will help push the frontier of drilling EGS wells. Indeed, cemented completions have temperature limitations that can be avoided by using uncemented completions using open-hole packers.

As we stated previously, the high temperature tends to age the elastomers prematurely and can reduce the compression set of sealing systems with time. The Xpandable packers use patented technology that isolates the surrounding pressure, re-energizes the packer seals, and compensates for the loss of compression set.

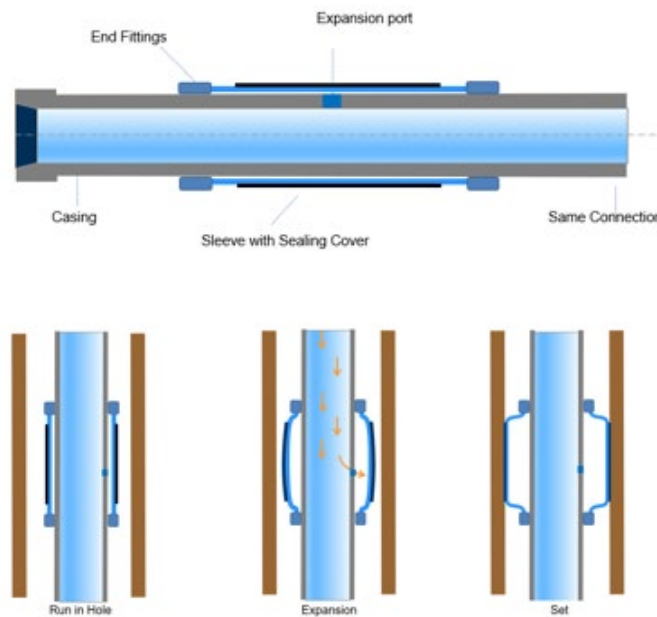


Figure 7: Xpandable Packer principle

In a similar fashion to the expandable steel patches detailed in the precedent chapters, the Xpandable steel packers are using high expansion materials to be deployed, and create a solid, long-lasting barrier, outside the casing string. As only pressure applied inside the casing string is necessary to deploy an Xpandable steel packer, there is no temperature limitation related to a setting tool. Maximum temperatures are anticipated around 400F to 500F for elastomeric seal equipped packers, but synthetic materials could greatly increase this limit, for non-elastomeric sealing open-hole packers.

6. Conclusion

The constantly evolving complexity of oil and gas wells gives birth to adapting technologies. These adapting solutions push the boundaries of performance, enabling operators to drill deeper, longer laterals in harsher environments. Casing intervention also benefits from significant investments that have pushed the frontier of remedial technologies. The Geothermal industry can greatly benefit from this expertise by capitalizing on years of developments and field expertise. As the geothermal energy community is looking at different technologies to enhance the performance of its operations, the Oil and Gas industry is proud to be able to help and propose various expertise to accept any challenge. The Xpandable steel technology is one of those, that can remediate wells working in complex conditions and extend their life expectancy, but that also can provide the alternative to cement that will be necessary for the ultra-high temperature energy sources that cannot be tapped today.

Acknowledgement

We would like to thank the Geothermal community for its encouragement and its never-ending openness to describe the particularities of the geothermal challenges. Moreover, we would like to specially thank the Xpandable Engineering and Operation departments, whose input and investment enabled to exceed the performance envelope of casing patches and annular packers. Finally, the highest word of appreciation goes to our partners that put their trust in our technology and expertise, and that contribute to improve efficiencies and safety that help to supply the world with affordable and diversified energy sources.

Glossary

BHA bottom hole assembly

CSS Cyclic steam stimulation

DHET Downhole expansion tool

EGS Enhanced geothermal systems

EHT Extreme high temperature

FKM Fluoro-rubber

HNBR Hydrogenated nitrile butadiene rubber

HT High temperature
N2 Nitrogen
PH Patch holder
PTFE Polytetrafluoroethylene
R&D Research and Development
SAGD Steam assisted gravity drainage
SCC Cracking and stress corrosion cracking
TFE-P Tetrafluoroethylene and propylene

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