

Casing Solutions in High or Very High Temperature Geothermal Environment

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ABSTRACT

The geothermal energy development in East Africa will need to take into consideration two of the most challenging downhole environments: The High Temperature Geothermal Energy (HTGE: 90°C to 150°C) and the Very High Temperature Geothermal Energy (VHGTE: above 150°C).

Very high temperature brings the most critical challenges in geothermal drilling where Casing and Tubing connections have to be properly selected to ensure the wells integrity. The operators worldwide have progressively moved from an only field-proven approach to a standard-based approach with the ISO 13679:2002 as the test protocol reference, like in Djibouti geothermal field, which is an example of VHGTE downhole environment.

We will focus the presentation on different Casing solutions and associated test protocol per downhole environment (HGTE or VHGTE). This approach of capitalizing from the O&G standards to satisfy the demanding requirements of geothermal industry will be illustrated by a case study.

1. Introduction

There are three main challenges that are commonly linked to geothermal operations. The first one is reservoir condition where the production fluid temperature can reach high values. Two of the most challenging downhole environments are defined as The High Temperature Geothermal Energy (HTGE: 90°C to 150°C) and the Very High Temperature Geothermal Energy (VHGTE: above 150°C). Second challenge is about the tubing strings determination which produce steam from reservoir. Third challenge is an economical one: geothermal power plant shall be cost-effective for the consumer thanks to appropriate drilling technologies.

Effective drilling technologies start with a smart selection of the most suitable combination of metallurgy and connection for casing and tubing strings. As mentioned earlier, the main challenge from reservoir condition is its temperature which can reach values superior to 250°C. Such high temperature will lead to derated mechanical properties such as Yield Strength, especially on carbon steel. This phenomenon also impacts the performance of the threaded connection. Also, gradient of temperature on different parts of the string will generate high level of tension and compression.

The objective of this paper is to justify the best suitable and applicable specification for casings and tubings in terms of material and connection selection.

2. Geothermal Well Design

A geothermal well follows the same global design rules as Oil & Gas wells.

Conductor pipes are run firstly, then the surface casing is run just before the production casing (in which the fluid will be produced, which is one significant difference with O&G practices). In the bottom part of the well a liner or a perforated liner is installed.

These tubulars will be submitted to a range of loading cases, corrosion, temperature cycles and much more during its life. The key point is to do the right choices at each step (i.e size, material, connections, which will undoubtedly have an impact on well integrity) while keeping in mind the optimization of the total cost of the geothermal well.

There are three typical well design for geothermal wells: Slim Hole (Exploration), Standard Production and Production with Big Bore where we identify common sizes as 20'' for surface casings or 13 3/8'' for production casings and 7'' for perforated liners.

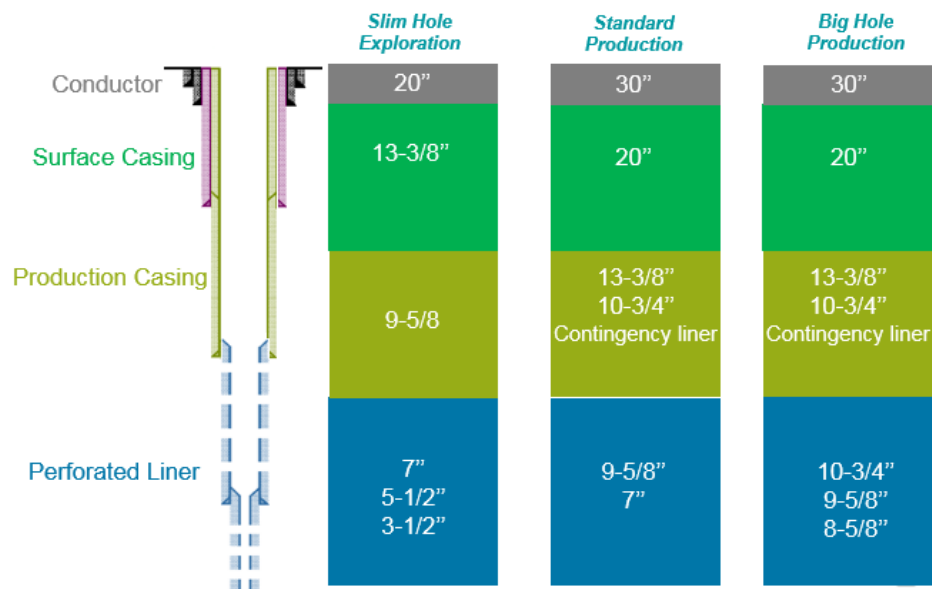


Figure 1: Geothermal typical well designs

For such designs, the high temperature fluid will flow through the production casings. Hence, it should be capable to accommodate high temperature loading. In case of gas presence (CO₂ and/or H₂S) with certain pressure, the production casing might need to have gas tight properties in order to preserve the string from leakage. As a basis, proper liquid-tight threaded connections will always be required to maintain sealability even at High Temperatures.

3. Material selection

Casing material selection in geothermal application are limited and focused in cost effective solution due to economic constraints. As an example, Corrosion Resistant Alloys (CRA) grades used in Oil & Gas applications are suitable for temperature above 150°C/302°F. Depending the alloying elements and manufacturing process, the CRA grades can be 4 times to 20 times more expensive that standard carbon steel. Such CRA steels have been preferred in specific VHGE environment but remains minority in geothermal wells.

Therefore, casings are mainly in carbon steel materials, which demonstrated good performances in geothermal wells. We will focus in this family grades and the material properties to be considered for geothermal application.

3.1. Yield strength derating at high temperature

At high temperature, all materials are subject to deration of the yield strength. This thermal effect and its impact on mechanical properties have to be integrated during the well design process. The table 1 herein below shows respectively the deration of L80 grades depending the temperature.

L80		deg F	77	212	302	392	482
		deg C	25	100	150	200	250
Temperature derating	Yield strength	reduction coefficient compared to 77 deg F / 25deg C	1	0.95	0.91	0.88	0.89
	Ultimate Tensile strength		1	0.95	0.93	0.94	0.98

Table 1: Derating of Yield and Ultimate Tensile strength at elevated temperature

3.2 Compressive yielding

Cemented casings can yield in compression exceeding the elastic limit. At elevated temperature, the steels expands due to thermal expansion properties. As the casings are cemented and it cannot expand, the casings are under compressive loads and can reach or exceed its elastic limits. For conventional Oil & Gas casings, the materials are selected in order to never go over the Yield strengths of the material.

3.3 Bauschinger effect

The Bauschinger effect is the result when plastic deformation of a metal increases the yield strength in the direction of plastic flow and decreases the yield strength in the opposite direction. The Baushinger effect shall be taken into account in geothermal wells where thermal cycling induce tension and compression.

3.4 Thermal relaxation

This effect appears while casing is holding at high temperature inducing the decrease of axial and radial stresses after years of operations. The well lifetime can be highly impacted in case this phenomenon is not well evaluated during the material selection phases.

As mentioned above, there are several challenges such as thermal cycling inducing tension and compression, thermal relaxation, derating ratio of material. Figure 2 below is the example of the performance of L80 material in thermal cycle conditions. Axial loads are defined in Y axis (tension or compression) and temperature range (VHGE environment) defined in X axis. When the well start to produce, the temperature increase which induce compression on

the L80 casing. Above 200deg C, the compression loads stay constant up to 350deg C. When the well temperature decreases, the compression loads are reduced constantly depending the temperature and it induces tension on the casings for temperature below 200deg C. After 3 thermal cycles, compressive loads reaches the same maximum whereas at lower temperature (25deg C), the tension loads are increasing on each cycle. The maximum tension should not exceed the elastic zone of material after derating caused by temperature.

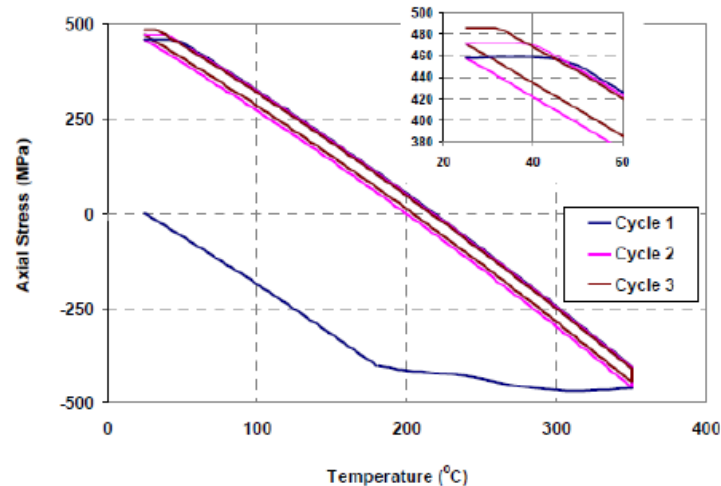


Figure 2: Stress – Temperature L80 (source: J.Xie, 2008)

4. Casing Threaded Connection Type

There are three types of connections that are commonly used for geothermal operation: Buttress Threaded and Coupled connection (BTC), semi-premium connection and premium connection. Those different connections are described below.

4.1 Buttress Threaded & Coupled (BTC)

Buttress connection or commonly known as BTC is a standard connection based on American Petroleum Institute (API) 5CT and API RP 5B (Threading, Gauging, and Thread Inspection of Casing, Tubing, and Line Pipe Threads). This type of connection has fair capacity of tension, collapse and burst in terms of structural strength compared to other API 5CT standard connection (such as STC, LTC and EUE). However, BTC connection has a significant weakness: the J area or blank area between pipes (increase of the erosion sensitiveness).

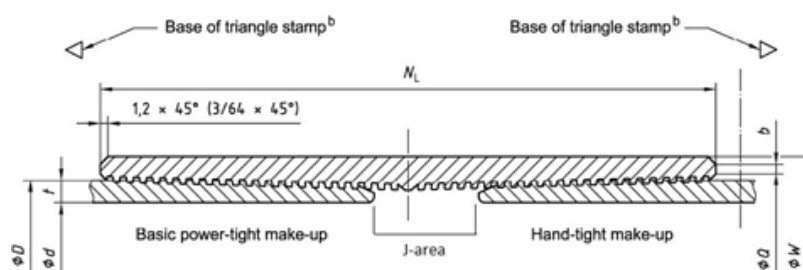


Figure 3: BTC connection (source: API 5CT 9th ed., 2012)

Figure 3 shows that the make-up position is made according to triangle stamp. Although there is some torque recommendation, most of drilling operations only depend on triangle base.

Also, the drawing highlights the fact that the contact zone between pin and coupling only appears on the threads.

4.2 Semi-Premium Connection

Semi premium connection is a type of connection which has performances between API standard connection and premium connection. There are several types of semi premium connections according to thread and coupling design:

- Pin to pin connection: pin ends are in contact in order to prevent jump in.
- Internal shoulder connection: connection with an additional shoulder on the coupling. This design is similar to pin to pin connection but with additional performances in terms of torque capacity and therefore compression.
- Quick run connection: connection with thread design below 5 threads per inch (TPI). Lower TPI (usually 3TPI) gives better running time (compared to 5 TPI design with BTC connection).

For example, DWC/C-IS™ connection has similar thread design as BTC connection, but has an additional internal shoulder to give better structural design (see Figure 4 below).



Figure 4. DWC/C-IS™ thread design.

This type of connection is designed to have better structural performances (100% compression strength, high torque capacity...) compared to BTC connection. However, such connection usually has a limited and temporary gas tight properties to prevent leakage of production fluid.

4.3 Premium Connection

Premium connection has better performances thanks to gas sealability (gas tightness) which preserves the string from gas or liquid leakage. The two main design features for premium connection are:

- The Shoulder: this additional design is used to give better compression performances.
- The Metal to Metal seal: this design is used to give sealing integrity to prevent any kind of fluids (especially gas) from migrating from the inside to the outside of the threaded connections and vice versa.

Premium connections are not codified by an international standard as API 5CT for casings and tubings. However, connection performances in terms of sealing integrity (liquid or gas phase) should be tested and qualified by using several protocols. Some of those protocols are described the 4th paragraph.

Figure 5 below is a sketch of VAM® 21 premium connection.

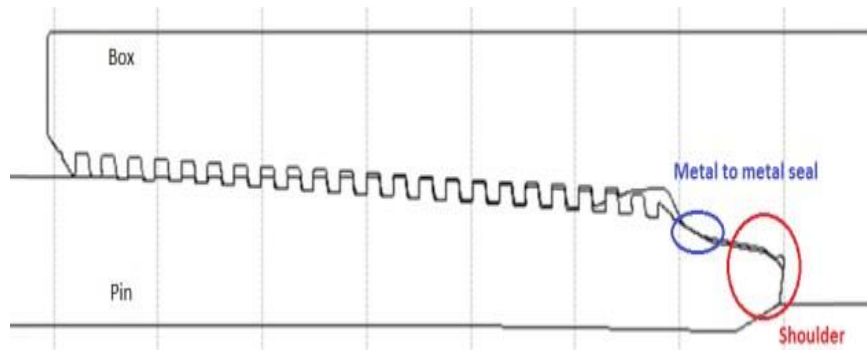


Figure 5. VAM® 21 premium connection design.

4.4 Conclusion

Connection selection shall be performed taken into account the severity of a geothermal well (mainly temperature and flow rate during production).

For the most basic applications, where temperature and flow rate are low, most basic connections like API Buttress are a good enough and cost-effective solution.

In case of high temperature and flow rate, while designing a geothermal well, more robust connections should be considered (semi-premium or premium). Those connections provide highest performance and integrity thanks to properties like the metal to metal seal (gas tightness) or the internal shoulder. Also, in order to withstand the severe conditions of a geothermal well, most of premium connections available are designed within a standard framework normally used in the Oil and Gas Industry but compatible with geothermal projects.

	Severity ➔			
	Low	Moderate	High	Extreme high
Resource Temperature	< 90°C Low	90 < ... < 150°C Moderate	150 < ... < 250°C High	> 250°C Extreme high
Flow rate & Pressure	Low	Medium		High
Connection integrity	No requirement	Limited testing		Full qualification
Casing string	API	API / Semi-Premium		Semi-Premium
Production string	API	Semi-Premium		Premium

Figure 6. Connection segmentation for production string

5. Connection qualification and protocols – Standard framework

5.1 ISO 13679 / API RP 5C5

ISO 13679 and API RP 5C5 give recommended practices on procedures for testing casing and tubing connections. It gives guidance to the end-users in order to select the most appropriate connection.

The document standardizes the way connections are tested in order to prove their reliability. Those standards describe test programs to respect in order to reach a level of integrity called

Connection Application Level (CAL). There are 4 levels in this protocol. The higher the level is the higher the testing severity is.

For ISO 13679, 3 series are taken into account:

- Series A: internal and external pressure cycles with tension and compression
- Series B: internal pressure cycles with tension and compression
- Series C: thermal cycles / Internal pressure

Table 2 below described the API 5C5 / ISO 13679:2002 Testing protocols

CAL	# of samples	Pressure envelope	Internal Pressure	Series A IP / EP + T/C	Series B IP + T/C, bending	Series C Thermal Cycles IP
I	3		Liquid	No	YES Bending optional	No
II	4		Gas	No	YES Bending optional	YES 135°C
III	6		Gas	YES	YES Bending optional	YES 135°C
IV	8		Gas	YES	YES Bending required	YES 180°C

Table 2. ISO 13679:2002 testing protocols

Where IP, EP and T/C are respectively the Internal Pressure, the External Pressure, the Tension and Compression

5.2 Thermal Well Casing Connection Evaluation Protocol (TWCCEP)

TWCCEP / ISO PAS 12835, Thermal Well Casing Connection Evaluation Protocol, provides procedures for assessing the suitability of threaded and coupled connections for service in production casing strings of thermal recovery wells. It highlights the connection performances under cyclic temperature (up to 350°C). The performance of the connection results in an Application Severity Level (ASL) then followed by the temperature applied. For example if the connection passed under a temperature of 290°C, then the performance integrity level is ASL 290.

The applications linked to this protocol are

- Cycling Steam Stimulation (CSS)
- Steam Assisted Gravity Drainage (SAGD)
- Geothermal Wells

The full protocol is long and costly (6 test specimens are required). The protocol includes all the following tests:

- Preliminary FEA (Finite Element Analysis): worst-case scenario is taken into account in terms of geometry and material configurations
- Material properties tests: tensile and thermal expansion coefficient

- Make & Break test (to assess galling resistance)
- Thermal Cycle test (to assess connection structural integrity and sealability)
- Bending test
- Limit strain testing (test to failure)

Figure 7 below shows a typical thermal load path for a L80 at ASL 290

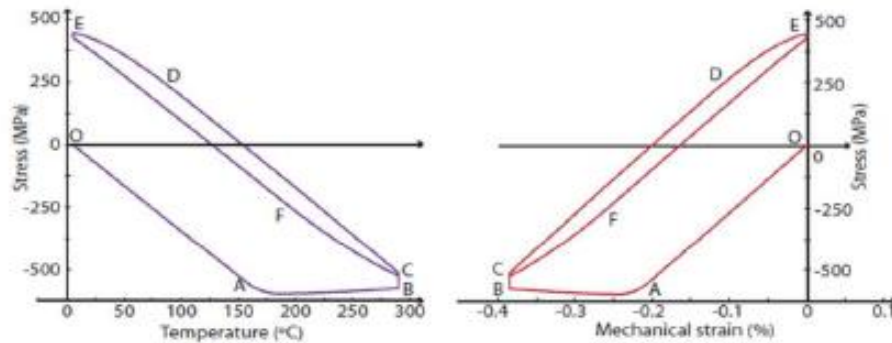


Figure 7. Thermal load path for a L80 at ASL 290

As TWCCEP is long and costly, there are possibilities to abbreviate the protocol by

- Optimizing the number of samples to be tested
- Reducing testing time while keeping the severity level
- Building the protocol thanks to technical exchanges with customers

5.3 A Tailor-Made Protocol

The objective of a Tailor-Made Protocol would be to have qualification procedures not over specified for geothermal wells.

In addition, such simplified and abbreviated protocols would be more cost-effective by, for example, optimizing the number of samples to be tested, reducing testing time while keeping the severity level, etc. Such qualification tests have to be built thanks to technical cooperation between Customers and Manufacturers in order to better assess the performance desired.

6. Conclusion

This paper gives an overview of industry practices for material and connection selection for casings and tubings in geothermal well application.

- Material selection:

Economic constraints make geothermal operators to choose carbon steel, which has demonstrated good performances for decades. Nevertheless, in VHYTE environments, an appropriate steel grades designed for 20 years of operations can make big savings considering the CAPEX/OPEX. As opposite to Oil & Gas sector, casings are used as production wells in geothermal application which make difficult for repair or perform work overs. In case these wells are not efficient enough, new wells should be drilled in order to maintain the flow/pressure.

Therefore, standard carbon steel as per API 5CT are recommended to use for application where temperature, thermal cycling, compression loads, derating ratio are not critical. A research and development of new material depending the specific VHYTE geothermal environment are needed in order to minimize the work overs/number of wells and guarantee good efficiency of production wells.

- Connection selection:

Premium connection is able to maintain sealing integrity which is an important feature in order to prevent the steam gas from leaking and gives better steam production efficiency. Also, a premium connection has better structural integrity than an API BTC connection even under thermal cycle condition (high temperature – low temperature simulation). Table below gives a summary of the performances from the three type of connections described in this paper.

Production string	API	Semi-Premium	Premium
Sealability	Liquid sealability limited pressure	Liquid fluid sealability with limited pressure	Gas tight metal to metal seal
Torque capacity	Low torque (triangle)	High torque for drilling with casing application	High torque capacity with sealability
Joint efficiency	Limited for compression	Higher than BTC in compression	100% joint efficiencies for T&C design
Fluid flow capability	Have turbulence in J area	Some design can give better flow than BTC	Flush ID to prevent any turbulence
Connection design	Limited as per API 5CT	Some design has shoulder and some has pin to pin	Various design available: T&C, better clearance (SC, semi flush, flush)

Table 3. Connection type comparison

- Tailor-Made testing protocol:

Qualification tests have to be built thanks to a technical cooperation between Customers and Manufacturers in order to better assess the connection performance desired in accordance with the reservoir conditions.

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Vallourec Webcast on Geothermal Application organized with World Oil (April 25th, 2018)