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Casing Connection Selection for Geothermal Applications Using New Input From HPHT and Thermal Wells Testing Protocols

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ABSTRACT

OCTG connection selection for Oil-Gas wells has evolved over the past 10 years, switching from field proven technologies to fully qualified products. This change has been pushed by the O&G end users' need for more reliable and better sealing connections in both challenging well conditions (HPHT) and thermal wells where plastic deformation occurs (SAGD – CSS). This paper contains a summary of the evolution of Premium Connections main design concepts, as well as the applicable testing protocols used to validate premium connections performance within the elastic limit and in the plastic region due to thermal effect.

Detailed explanations of the characteristics of the testing methods currently in place, ISO 13679 and TWCCEP protocol, are included. The paper also contains an additional study to correlate the geothermal casing needs in terms of thermal cycles/loads and newly available testing data to make designs more reliable. Finally, the paper concludes with recommendations on connection selection based on the existing testing data.

1. INTRODUCTION

There have been numerous published cases showing failures in geothermal wells due to improper casing connection selection. Casing connection selection is commonly driven by past experience, where the end user would start out with the lowest cost solution until a failure occurs. A modification to the design might be implemented to mitigate a particular problem that was encountered, but the bigger picture has not been fully understood.

It is interesting to point out that, unlike the O&G industry, there is no undisputed standard or organization covering all or most activities or products related to geothermal operations. While best practices and knowledge are increasingly shared by industry members in congresses and exhibitions, research and development of casing connections used in O&G could benefit geothermal industry. The connection testing result could be used to create a more reliable design in geothermal wells. Such testing methods as ISO 13679 and TWCCEP collect data on connections capability in the elastic and plastic region. Furthermore, these methods also cover the basic test of run-ability; such make and break tests evaluate galling resistance of connections after several make-and breaks.

Due to past failures and desirability for more reliable design, O&G operators and government regulating bodies have been requesting for tested connections especially in critical services (Carcagno 2005). Traditional O&G well loads are well within the elastic limit of the connection and thus the tests performed have been evaluating the connection performance in these regions.

However, in geothermal wells the main loads are thermally driven (Dench 1970; Maruyama 1990). Such thermal loads exceed the elastic limit of the material and thus strain-based design would have to be considered. The thermally-induced loads are experienced due to severe temperature changes during production and cool-down phases. Rise in temperature causes the casing to expand thus creating a compression force on the string. As the string is constrained, several phenomena related to the structural integrity of the pipe body might occur:

- Collapse. Due to imperfect cementing, fluid can become trapped in voids and expand when the temperature rises, creating high external pressure on the casing.
- Buckling when annulus between the casing and formation does not support the structure of the string.

Due to the reasons above, the behavior of the connections in a thermal cycling test must be evaluated for proper selection process. Thus, experiences from other thermal well operations such as CCS or SAGD should be considered when designing a geothermal well.

2. TUBULAR CONNECTIONS

2.1 API Connections

The most common connection being used in geothermal industry is the API Buttress (API BTC). The connection is well established based on years of use in geothermal operations worldwide. The API BTC utilizes a trapezoidal thread form that improves tension capacity of the API 8 round; it utilizes a "V-shaped" thread form which is relatively easier to "jump" during high tension and compression. Further benefits of API BTC connection include easy manufacturing and accessibility. Also, the lower amount of threads per inch (tpi) of API BTC (5 tpi) compared to API 8 round (8 tpi) improve the run-ability by reducing the turns required to make-up resulting in faster casing installation.

However, the API BTC still has weaknesses that might not make it the best solution in a geothermal well. The connections make-up process is dependent on observing the box member "reaching" the triangle mark on the pin OD (API 5B, 2008). In addition, there is no loading area for compression and torque besides the thread itself. This makes the connection relatively easy to overtorque during the make-up process as there is no significant torque necessary to push the pin into box past the triangle mark.

Figure 1: Cross sectional of API Butress (API BTC).

Both API 8 round and API BTC does not feature a metal to metal seal. Sealability of the connection is dependent on the thread compound within the gaps of thread. After a prolonged period of pressure and/or exposure to high temperature, the thread compound would most likely squeezed out of the thread and/or baked off.

2.2 Proprietary Connections

Proprietary connections were initially designed to improve the weaknesses of API connections in the following areas: compression, torque, run-ability and seal-ability.

To improve compression and torque, a load bearing area commonly referred to as the torque shoulder is introduced in the box area of proprietary connection. During the make-up process, the pin member would be rotated into the box until the torque shoulder is reached. Additional rotation of the pin into the box is physically stopped by the torque shoulder. The capacity of a shouldered connection in torque and compression is related to the area of the torque shoulder. To achieve the largest possible torque shoulder area, the proprietary connection's pin member is often swaged. In the swaging process, the pin member is nosed creating a smaller ID than the initial pipe body dimension. This process allows for the connection to utilize a greater surface area for the torque shoulder.

Proprietary connections are also designed to reduce risks of cross threading, galling and other common make-up problem typical to API connections. Most often, proprietary connections are designed with optimum taper and low thread per inch to enable faster make-up time. By reducing the risk of make-up rejects and reducing the make-up time, the overall cost of casing running could be reduced.

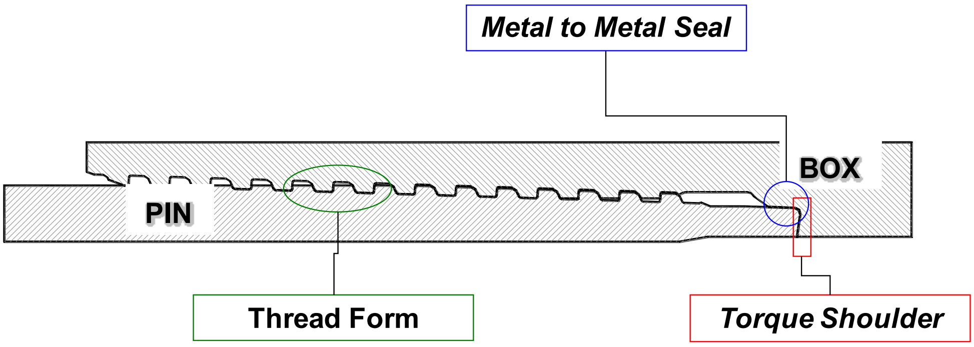

Figure 3: Cross sectional of representative proprietary premium connection.

While API connections could only provide low pressure water sealability and no gas sealability, proprietary connections aimed to provide a 100% internal yield gas sealability. This is achieved by machining a small high contact stress area known as metal-to-metal seal into the pin and box member. Connection manufacturers go to great lengths to achieve high sealability connections in various loading conditions that can be made-up and broken-out several times. While there are various type of metal-to-metal seal designs, the latest premium connection technology utilizing toroidal seal design has achieved great results in thermal well testing protocol (as described in subsequent section).

3. CONNECTION TESTING PROTOCOL

Due to the significant amount of proprietary connections in the market, several initiatives were taken to standardize the connection testing procedure and allow for comparison of the various connections. The O&G industry has adopted a premium connection testing protocol known as API 5C5 and ISO 13679. A separate procedure called Thermal Well Casing Connection Evaluation Protocol (TWCCEP) was developed for service of intermediate or production casing string for thermal recovery wells.

3.1 API 5C5/ ISO 13679

The latest official documents, API 5C5 (2003 edition) and ISO 13679 (2002 edition), are identical. One of the primary objectives of these protocols is to examine the performance of the connection in the elastic limit region (stress based design). While stress based loads are not the primary driver for casing selection in geothermal wells, casing which is not exposed to geothermal production (and resulting thermal affects)—such as surface casing—would be a relevant case to compare to these tests. Furthermore, stress based loads in thermally affected casing, such as production casing, could also be justified based on these tests.

There are several levels of connection testing recognized by these protocols, specified as Connection Application Level (CAL) I to IV with the later being the most stringent. Several specimens (ranging from 2 samples to 8 samples based on CAL) are threaded to the manufacturing extremes; the intent is to simulate the worst connections that could be found in the field.

The following paragraphs describe the CAL IV test procedure as it would be the most applicable level for a high temperature production string:

First, the protocols call for make-and-break testing, which attempts to analyze the galling resistance of the connection. Tubing sizes are made-up and then broken-out 8 times, while casing sizes undergo two make-and-breaks. The specimens are then made-up a final time for the subsequent testing.

In the subsequent testing, the specimens undergo a Series A test, which subjects the specimens to a combination of tension, compression, internal pressure and external pressure. The specimens are typically tested to 80-95% of the connection's Von Mises Envelope (VME). During a Series A test, the connection undergoes a combination loading test that traces the testing VME in clockwise and counter-counter wise directions. This test is often done in ambient temperature, however, more recent testing has included elevated temperature.

Next, the protocols call for a Series B test, in which the specimens undergo combinations of tension, compression, and internal pressure. Moreover, the specimens are subjected to bending. Similar to Series A, a Series B test is often done in ambient temperature, however, more recent testing has included elevated temperature.

Then the protocols call for a Series C test, in which the specimen is subjected to alternating thermal loads. To simulate thermal cycling in the well, specimens undergo alternating elevated temperatures up to 175°C and cooling to ambient temperature. For tubing connections, this is repeated for up to 100 cycles; casing sizes undergo a maximum of 10 cycles.

Finally the specimens undergo testing to failure, where the various samples are subjected to a specific combination of tension, compression, internal pressure and external pressure until they fail.

A representative result of a API 5C5/ ISO 13679 test is shown in Annex A.

3.2 Thermal Well Casing Connection Evaluation Protocol (TWCCEP)

TWCCEP was a joint development between operators and connection manufacturers involved in Canadian thermal-well operations. The document's intention is to evaluate the performance of proprietary connections in the laboratory under typical conditions of thermally-stimulated wells (Nowinka 2009). The testing program evaluates a specific connection's galling resistance, structural integrity and sealability under thermal loading through analytical and experimental procedures.

The test is separated into four Application Severity Levels (ASL), which govern the maximum operating temperature and maximum internal pressure of the test. Based on the specific requirement of the project, the end user could choose the appropriate ASL that the intended connection should be qualified for.

Definition of Application Severity Level		ASL derivative
ASL	Maximum operating temperature	Maximum internal pressure
(°C)		(MPa)
not applicable (*)	180	1.0
240	240	3.3
290	290	7.4
325	325	12.1
350	350	16.5

Figure 4: TWCCEP Application Severity Levels (ASL).

After six samples of proprietary connections are threaded to various extreme thread and seal interferences, the samples undergo make-and-break test at room temperature with different number of make and break (from three to one) depending on the particular sample. Then, four samples are subjected to thermal cycling test. Prior to the test, a groove is machined on the shoulder to avoid shoulder sealing effect. The thermal test cycle consists of 10 thermal cycles, with temperature and pressure as prescribed by the intended Application Severity Level (ASL).

The following diagram shows an example of the first two thermal cycles of ASL 290 thermal test. The blue line plots the first constrained heating (from 40°C to 290°C) and a hold time of 5 days. It can be seen that the sample yields in compression at approximately 170-190°C. During hold at 290°C, stress relaxation occurs, which reduces the compressive axial stress. The red line plots the first constrained cooling (from 290° to 40°C), which generates axial tension. At 40°C, additional amount of strain in tension is applied to simulate the 5°C lower-bound temperature.

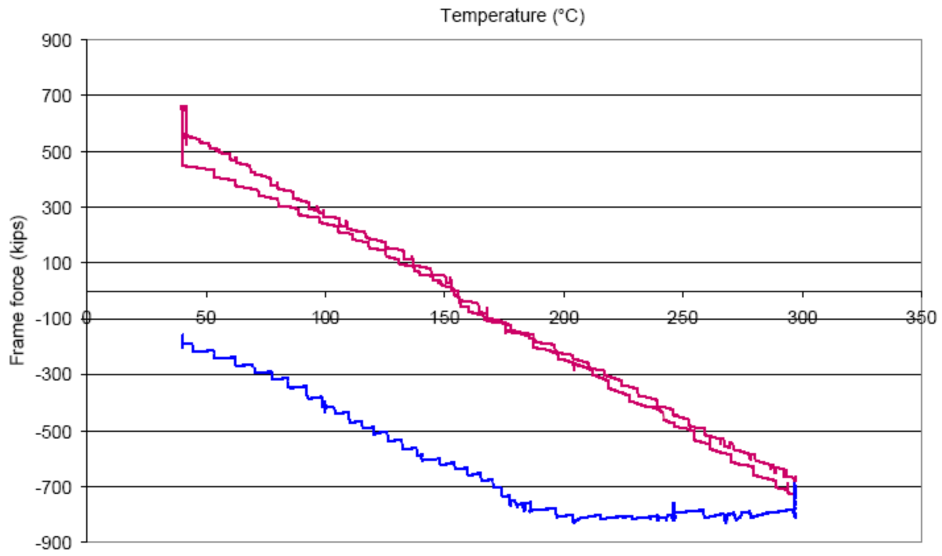

Figure 5: First two thermal cycles of a representative ASL 290 thermal test.

After completing the thermal cycles, two of the samples are taken through a limit-strain test. The test consists of pulling the samples up to structural failure, while the axial deformation is measured.

A representative summary of TWCCEP test is shown in Annex B.

4. CONCLUSION

Proper connection selection is critical for a proper geothermal well design. While API BTC has been widely used in the geothermal industry, providing a low-cost and well-known solution, proprietary connections could provide a more reliable and higher performance solution.

A closer look on the traditional choice of API BTC shows that several limitations arise when considering the lowest cost solution. First of all, its limited compression capacity, which results from a design without a torque-shoulder, makes it far from ideal when exposed to bending and thermally-induced compression. Jump-out and jump-ins occur from time to time, and the connection's poor sealability is further diminished beyond 200°C (Maruyama, 1991).

Geothermal wells with temperatures as high as 250°C may cause the casing to be exposed to compression in excess of the yield strength of the pipe body, even before considering yield strength temperature de-rating. Without a torque shoulder that could withstand the compression load, the threads are exposed, causing the material to yield and deform. The deformation of the threads will then be prone to failure when exposed to tensile loads when the well is cooled down rapidly.

Furthermore, the open J space in the coupling of API BTC could lead to turbulent flow. A turbulent flow in this area exposes the threads to erosion and may trigger failures.

Proprietary connections with a positive-stop shoulder and special thread profile could mitigate the issues above, while providing an easier and faster tubular running solution. A particular consideration should be taken to select connections with 100% tension and compression capacity. These connections would be equivalent or greater than the pipe body in tensile and compressive strength, eliminating a weak point in the string with regards to these aspects.

As the thermal efficiency of converting geothermal steam/water to electricity is not particularly high (±20%), loss of mass flow and volume flow should play a bigger role in the design. More geothermal well designers are now considering a big bore design that utilizes a larger production string to increase productivity. However, these efforts might not be fully optimized if a connection is utilized that could not prevent steam from escaping the string. Careful consideration of design, such as using a connection with a metal-to-metal seal, might be prudent. Furthermore, a connection that has been qualified through an API 5C5/ ISO 13679 CAL IV test and TWCCEP with applicable ASL could ensure a more reliable casing design.

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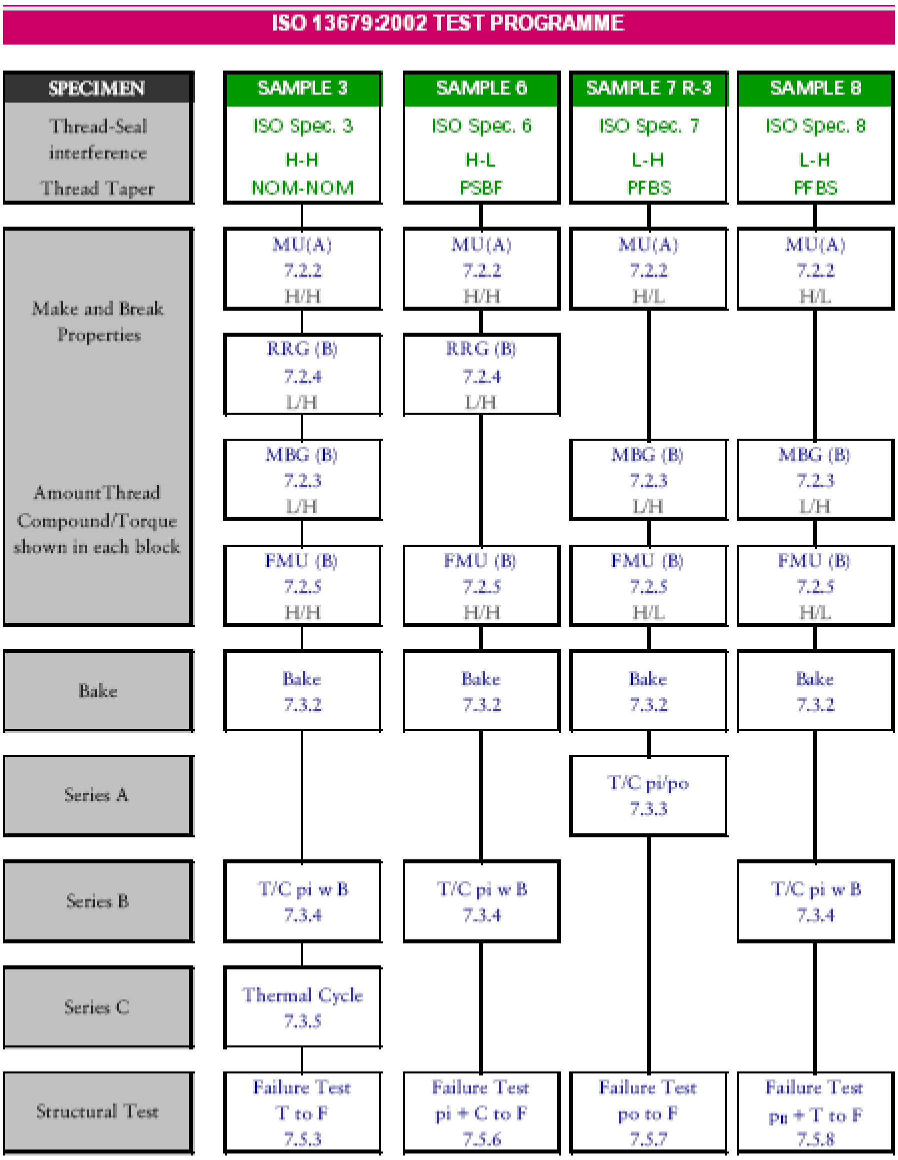
ANNEX A. REPRESENTATIVE API 5C5/ ISO 13679 TEST RESULT



- H: High
- L: Low
- PSBF: Pin slow box fast
- PFBS: Pin fast box slow
- NOM: Nominal
- T: Tension
- C: Compression
- IP: Internal pressure
- EP: External pressure
- B: Bending
- F: Failure
- MU: Make up
- RRG: Round robin galling
- MBG: Make & break galling
- FMU: Final make up
- MU(A): 1 make up on A end, total 4 make ups
- RRG(B): 2 M&B on B end interchanging pins among specimens, total 4 M&B
- MBG(B): 2 M&B on B end, total 2 M&B
- FMU(B): 1 make up on B end, total 4 make ups
- Bake: 24 hours at 180°C
- Series A: Tension/Compression and Internal Pressure/External Pressure up to 95% VMES
- Series B: Tension/Compression and Internal Pressure with Bending up to 95% VMES
- Series C: 1) 5 mechanical cycles (IP + T) at ambient temperature (95% VMES)
  2) 5 thermal cycles at 180 °C, with fixed IP and T (90% VMES)
  3) 5 mechanical cycles (IP + T) at 180°C (90% VMES)
  4) 5 thermal cycles at 180 °C, with fixed IP and T (90% VMES)
  5) 5 mechanical cycles (IP + T) at ambient temperature (95% VMES)

Figure 6: Representative API 5C5/ ISO 13679 representative test program.

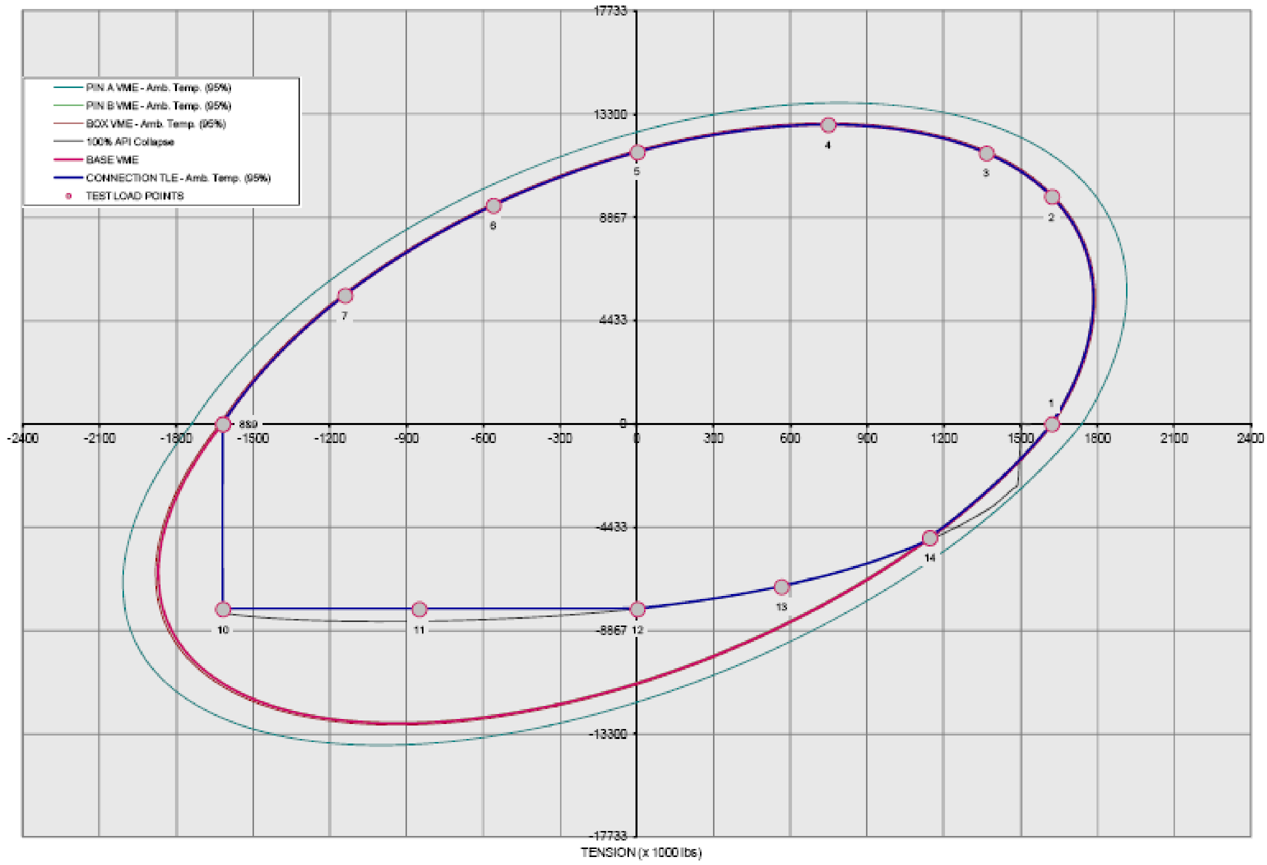


Figure 7: Representative API 5C5/ ISO 13679 Series A test

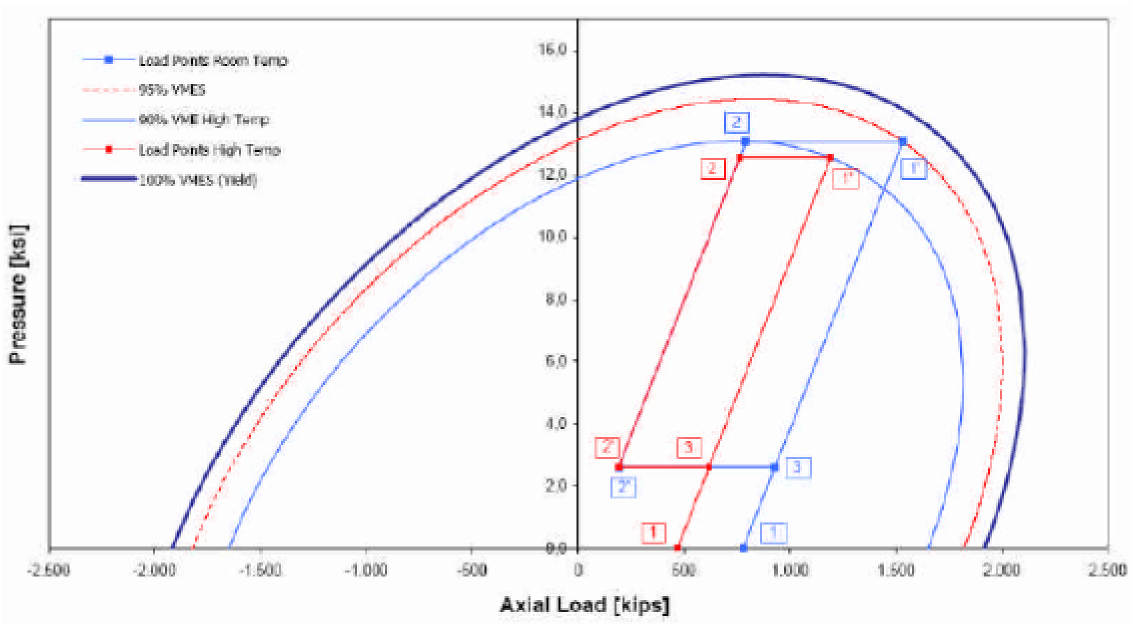


Figure 8: Representative API 5C5/ ISO 13679 Series C test

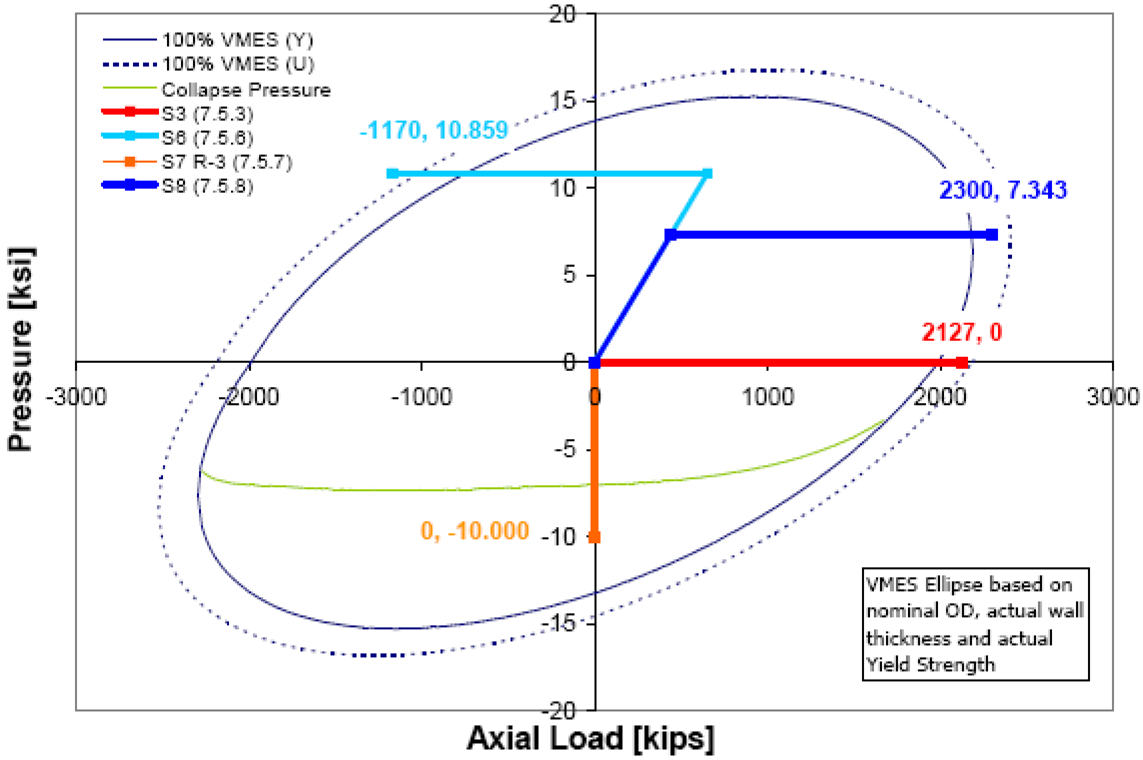
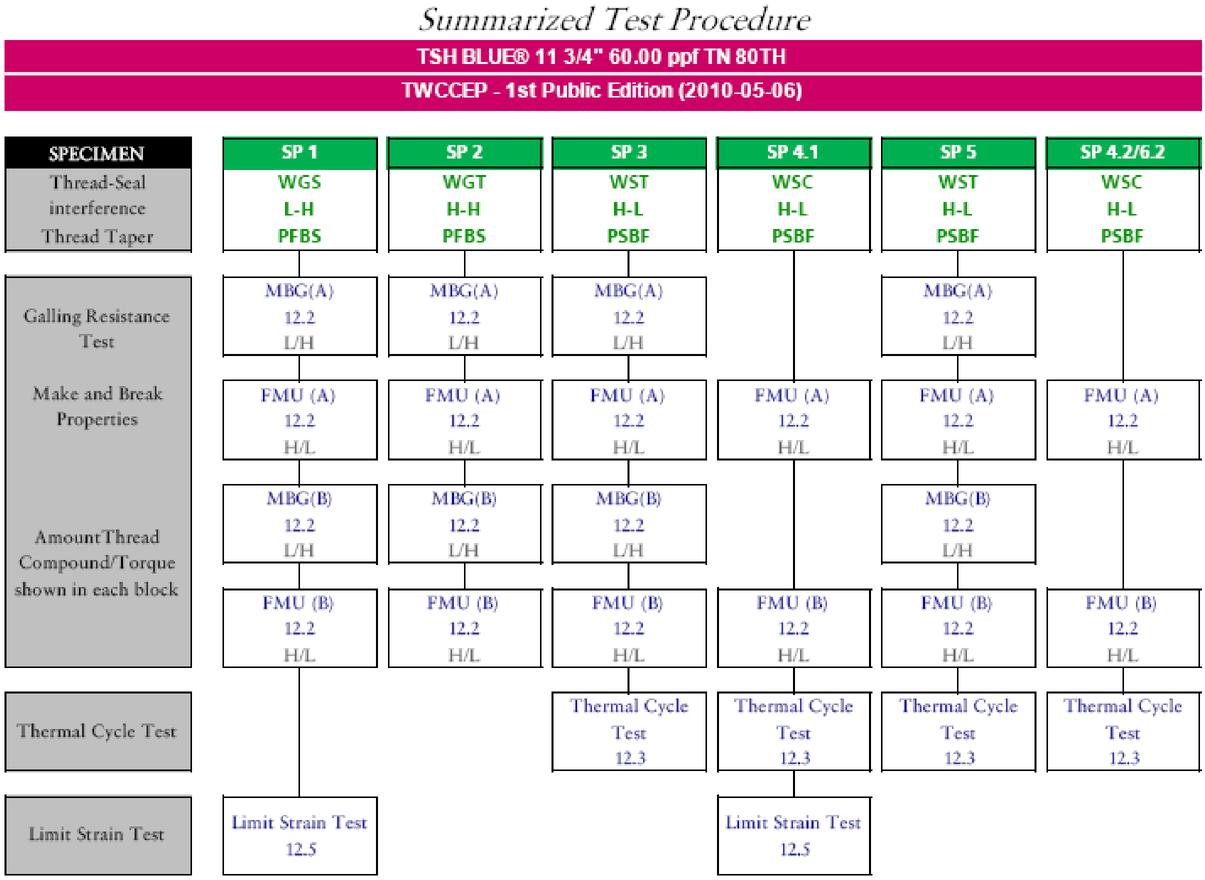


Figure 9: Representative API 5C5/ ISO 13679 Failure test.

ANNEX B. REPRESENTATIVE TWCCEP TEST



H: High
L: Low
PSBF: Pin slow box fast
PFBS: Pin fast box slow

WGS: Worst Galling Seal
WGT: Worst Galling Thread
WST: Worst Sealability in Tension
WSC: Worst Sealability in Compression

MGB: Make & break galling
FMU: Final make up

MBG (A): 3 M&B on A end (Specimens #1 & #2), 2 M&B on A end (Specimens #3 & #5)
MBG (B): 3 M&B on B end (Specimens #1 & #2), 2 M&B on B end (Specimens #3 & #5)
FMU (A): Final make up on A end
FMU (B): Final make up on B end

Figure 10: Representative TWCCEP test program.