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Connection Selection for Tie Back Production Casing in Geothermal Wells According to Finite Element Analysis and Physical Thermal Well Testing Protocol

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ABSTRACT

Determining the proper connection for tie back production casing in geothermal wells is crucial. This casing and its connection experience various loads not only while drilling but also in the production phase. In order to assess the suitable connections, various loads to the casings and connection during drilling and production are simulated. Three types of connections are compared i.e. standard API buttress connection (BTC), semi premium connection and manufacturer premium connection. We evaluate the premium connection design (thread and seal), with L-80 grade material that generally uses by a geothermal operator, using finite element analysis (FEA) and physical testing following international standard qualification protocols based on guidelines of ISO/PAS 12835:2013 Thermal Well Casing Connection Evaluation Protocol to simulate load in geothermal well. After two evaluation method, the proper connection for tie back production casing is determined.

1. INTRODUCTION

There are three main challenges that commonly appear on geothermal operation. The first challenge is reservoir condition of geothermal where the steam production temperature mostly above 250°C. Second challenge is about the drilling string to produce steam from reservoir. Lastly the economic challenge where geothermal power plant should sound economic for the operator, therefore the most effective drilling technology should also cost effective.

Effective well design can be started by selecting most suitable material and connection for tie back production casing. It has been stated before that the main challenge from reservoir condition is its temperature can reach above 250°C. During operation of the geothermal well, cycles with considerably high temperature variations may occur (production – shut in – injection). These high-amplitude temperature cycles can degrade casing material and its threaded connections, due to the high stresses induced by the temperature range (high temperature will induce compression, and low temperature will induce tension). Repeated cycles will lead to material degradation phenomenon and it may have a negative impact on the performance of the connection.

The objective of this paper is to justify the best suitable and applicable specification tie back production casing in term of connection selection. We use the well parameter from one of geothermal well that operated by one of geothermal company in West Java. Furthermore, we use finite element analysis to justify the connection capability and also stress check to see the performance of each type of connection in reservoir.

2. GEOTHERMAL WELL DESIGN AND RESERVOIR PARAMETER

Geothermal well design has common string design as can be seen on figure 1. The production casing has two sections, the liner and tie back. The high temperature steam will flow through the production casing. Hence it should capable to accommodate high temperature loading. In cases where gas (CO_2 and or H_2S) are in certain pressure, the production casing might need to have gas tight property to preserve the string from leakage.

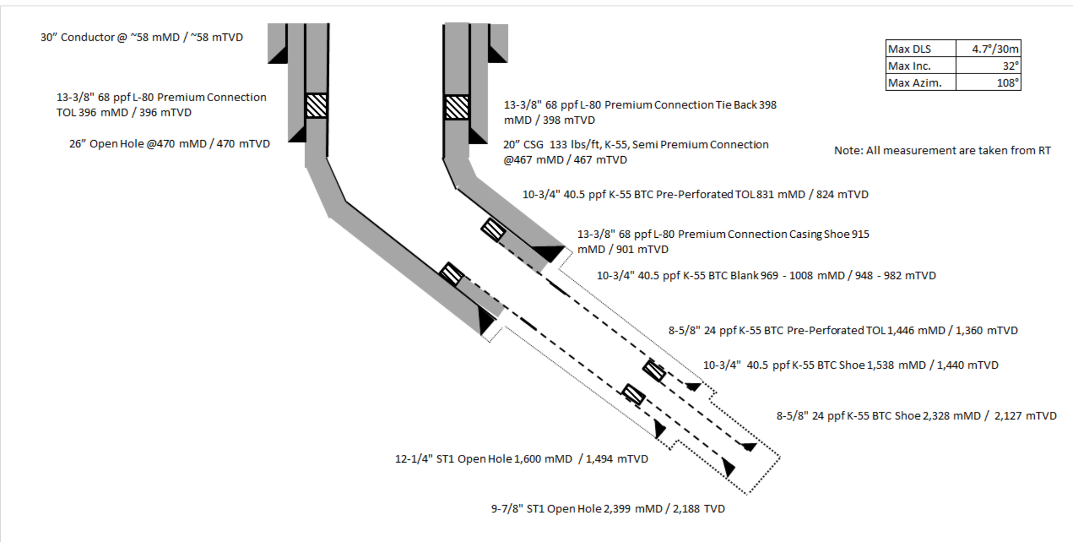


Figure 1: Example of geothermal well schematic.

There are three sequences of well testing operations that we use as reference to see the downhole condition. Those processes are flowing process, shut in process and injection process. These figures below will show the pressure and temperature graph on different sequences.

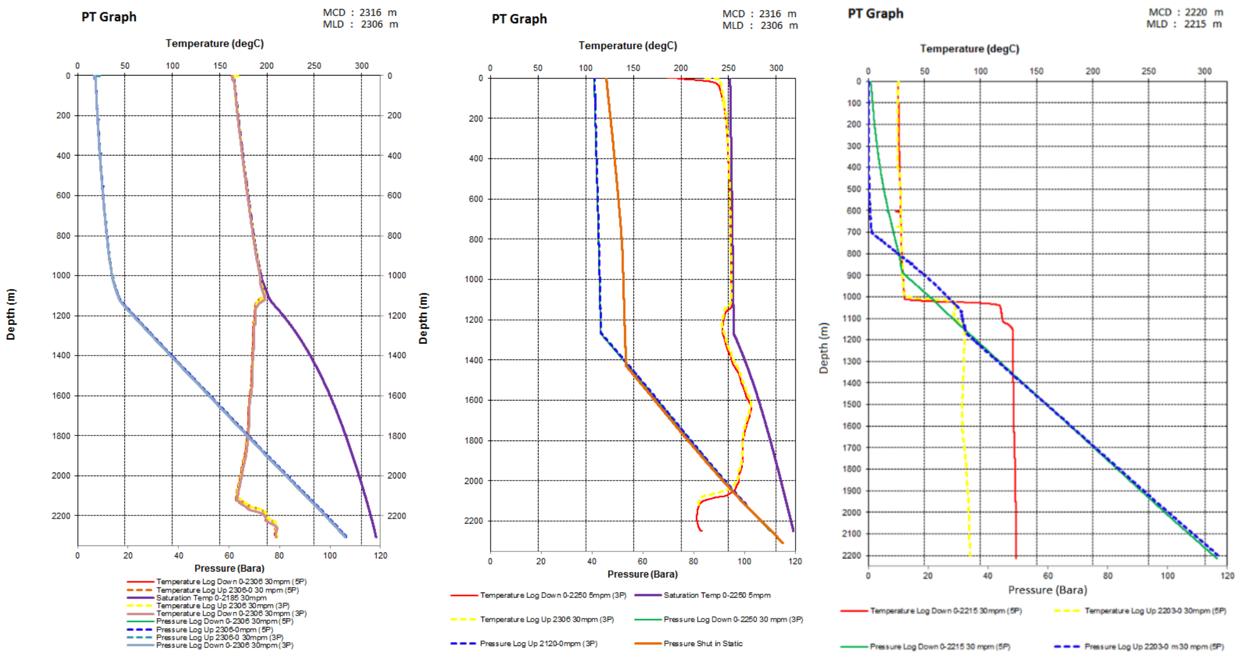


Figure 2: Pressure – temperature graph of flowing operations (left), pressure – temperature graph of shut in operation (middle), pressure – temperature graph of injection operation (right).

From those three operations sequences, there are several consequences and critical conditions that happens on the liner production casing on depth 915 m and tie back casing on depth 398 m as per below:

Zone		Flowing		Shut In		Injection	
		Pressure (bar)	Temperature (°C)	Pressure (bar)	Temperature (°C)	Pressure (bar)	Temperature (°C)
Tie Back	Upper	6.8	163	40.7	251	0.6	26
	Bottom	9	174	41	252	4	28
Liner	Upper	9	174	41	252	4	28
	Bottom	12.5	190	42	254	13.6	30

Table 1: Pressure and temperature during different sequences.

From the above sequence we can see that shut in operation generate the highest pressure and temperature. Followed after shut in operation is injection operation where the reservoir is injected with water therefore the temperature and pressure went down. The injection operation might be affected the casing material and connection where pipes were heated and then cooled with huge temperature difference.

3. CASING CONNECTION TYPE

There are three types of threaded connections that are commonly used for geothermal wells which are buttress thread and coupled connection (BTC), semi-premium connection and premium connection. The texts below will explain the description of those different connections.

3.1 Buttress Thread & Couple (BTC)

Buttress connection or commonly known as BTC is standard connection based on American Petroleum Institute (API) 5CT. This type of connection has high capacity of tension, collapse and burst in term of structural strength compared to other API 5CT standard connections (such as STC, LTC and EUE). Those API connections have its biggest weakness where it has J area or blank area between pipes which means that these connection’s performances only depend on the thread design.

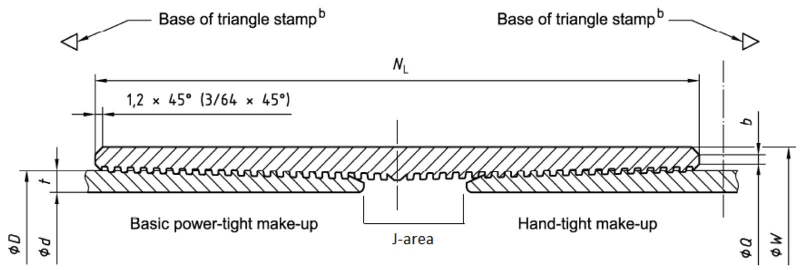


Figure 3: Buttress thread & couple connection (source: API 5CT 9th ed., 2012).

Figure 3 show that the make-up practically base on triangle base of pipe to run BTC connection. Although there is some torque recommendation, but most of drilling operation only depends on triangle base. It can be seen also that the contact zone between pin and coupling only appear on the threads. Figure 4 below show the FEA result to see where the stress concentration area mostly appears on BTC design under cyclic temperature 20°C – 350°C – 20°C.

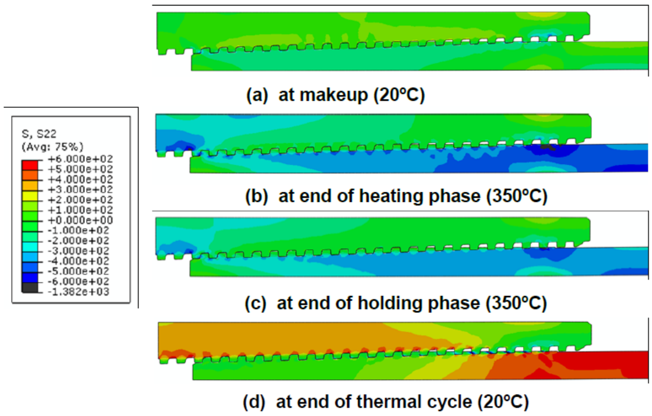


Figure 4: BTC connection 7” 23ppf grade 80ksi FEA under different temperature (source: J.Xie, 2010).

The above figure shows us that the stress concentrations appear along the thread zone. The stress concentration becomes higher in the end of the pin thread under high temperature. It also can be seen that in high temperature, the axial load appears to be compression and the stress concentrated in the end of pin thread. This can indicate that there is a possibility for pin to jump-in since there is nothing that can hold the over-compression. On the other hand, in the low temperature the stress concentrated on the imperfect thread area. Also connection jump-out might be appeared when over tension.

The seal integrity of BTC connection depends on the thread gap (source: J.Xie, 2010) where it can be tighten with higher make-up torque and the type of dope that can fill the gap between threads. However, in the field practice those seal integrity factors are not applicable. First, BTC make-up depends on the triangle base, therefore the thread didn’t achieve optimum tightness. Second, mostly dope has its own boiling point which is usually lower than the applied temperature and will vanish due to high temperature.

3.2 Semi-premium Connection

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

- Pin to pin connection: connection where pin end of each pipes touching one another to prevent jump in.
- Internal shoulder connection: connection with additional shoulder from the coupling. This design is similar to pin to pin connection, but with additional performance in term of torque capacity.
- Quick run connection: connection with thread design below 5 threads per inch (TPI). BTC connection has 5 TPI, therefore with lower TPI (usually 3TPI) give better running time to make-up.

Vallourec provides this type of semi premium connection called DWC/C-IS™ where it has similar thread design as BTC connection, but with additional internal shoulder to give better structural design. Figure 5 below give the sketch of DWC/C-IS™ connection.

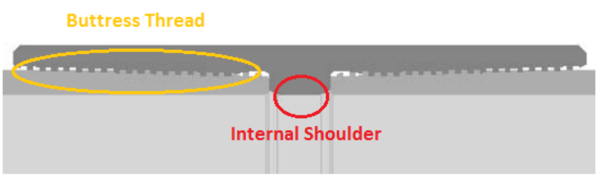


Figure 5: DWC/C-IS™ thread design.

This type of connection is designed to have better structural performance compared to BTC connection due to internal shoulder feature, but there is no gas tight or sealing integrity to prevent leakage of production fluid. The sealing capability of semi premium connection is similar to BTC where it depends on the thread and dope to prevent leakage.

3.3 Premium Connection

Premium connection has better performance where it has gas seal ability (gas tightness) where it can preserve the string from leakage of gas and liquid. Premium connection is a non-standard API connection which means each company has their own proprietary premium connection. However the connection performance, in term of sealing integrity (liquid or gas phase), should be tested by using several protocols. Below are some protocols that can be used to justify the connection performance:

- ISO 13679 and API 5C5 are connection testing procedure that resulted the connection level of integrity which called Connection Acceptance Level (CAL). There are four levels in this protocol where each increment of level gives higher severity level of load cycle, load types (tension/compression, burst/collapse), bending and testing temperature.
- ISO 12835 is thermal well connection protocol where this protocol is applicable to qualify the connection performance under high-amplitude cyclic temperature variations. The performance integrity level of connection by this protocol is called Application Severity Level (ASL) then followed by the temperature applied. For example, if the connection is passed under temperature 290°C, then the performance integrity level is ASL 290. Application Severity Level goes from ASL240 (181°C – 240°C) to ASL350 (326°C – 350°C).

There are some additional designs that commonly appear in premium connection which are:

- Shoulder: this additional feature is used to give better compression performance.
- Metal to metal seal: this feature is used to give sealing integrity to prevent any kind of fluids (especially gas) from leaking.

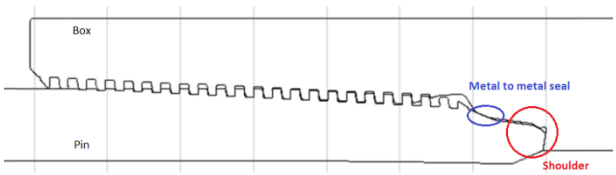


Figure 6: VAM® 21 premium connection design.

4. FINITE ELEMENT ANALYSIS

It has been justified before that BTC and semi premium connection has several weaknesses in term of seal ability of gas and compression limit, therefore it won't be useful to apply it as production casing or tie-back casing where seal integrity is desired. Therefore, simulation will be done with premium connection called VAM® 21 that has been developed by Vallourec which is designed to withstand the most severe protocol from ISO 13679, API 5C5 and ISO/PAS 12835:2013 (thermal well casing connection evaluation protocol). VAM® 21 is extensively used in the field by the main Oil & Gas companies and for Geothermal application.

4.1 Finite Element Analysis (FEA) Simulation

The simulation approach using FEA method was done by using pipe specification 13-3/8" 68# L80 VAM® 21 connection with derating material condition. We simulate the connection with condition refer to ISO 12835:2013 Thermal Well Casing Connection Evaluation Protocol (TWCCEP) approach in term of temperature with ASL290 level where the temperature condition is 290°C, then cooled down into 5°C. It means this simulation condition is higher than applied well condition. Table below shows the sequence of condition applied for FEA test.

Simulation Time (ST)	Operating Point	Temperature (°C)	Internal Pressure (MPa)
1	Connection assembly	5	0
2	Commence steam circulation	5	7.4
3	Heat to maximum temperature	290	7.4
4	Shut off steam circulation	290	0
5	Cool to minimum temperature	5	0

Table 2: Simulation sequences of each simulation time.

During FEA simulation, the expected outputs are:

- Seal and shoulder contact stress intensity
- Seal and thread contact stress distribution
- Equivalent low-stiffness and high-stiffness length in the threaded pin-box interval

4.2 Finite Element Analysis (FEA) Result

4.2.1 Seal and Shoulder Contact Stress Intensity

Galling susceptibility in the threads and seal is assessed based on peak contact stress in threads and seal area after make-up. Assessment of seal ability performances is based on the seal contact stress intensity upon make-up under maximum compression with operating temperature (ST 3) and under maximum tension at the end of cycle (ST 5). Figure 7 below show the contact stress intensity of seal and shoulder area. Applying high temperature generates compression which increase the intensity up to 7% without deteriorating the structural performances of VAM® 21 connection. On the other hand at the end of cycle, the contact stress intensity is decrease around 25% because tension is induced by thermal contraction when temperature decreased. It appears that even under low temperature after cycle (ST 5), the seal area is still engaged to preserve seal ability. Meanwhile, the shoulder contact stress is low when make-up (ST 1) and disappear when temperature is released (ST 5). Contrary under high temperature (ST 3 and ST 4) the contact stress on the shoulder is increase exceed the seal contact stress, it means that under high temperature the connection has high compression.

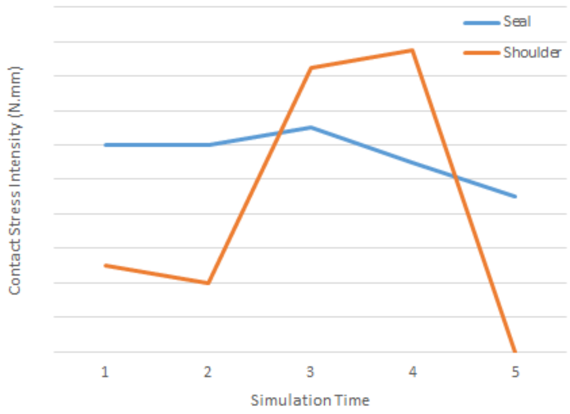


Figure 7: VAM® 21 contact stress intensity.

4.2.2 Seal Contact Stress Distribution

Figure 8 below shows that seal contact stress distribution of seal and shoulder area. It appears that stress distribution doesn't highlight critical behavior at full make-up (ST 1), high temperature (ST 3) and at the end of cycle (ST 5). The contact stress distribution on the shoulder area is low under full make-up (ST 1) and end of cycle (ST 5), while it has high contact pressure under high temperature (ST 3). This figure is in line with what already shown in figure 12 where the seal contact stress is always appear on every simulation time. It means that the seal area is still well engaged at the start until the end of cycle, while in the high temperature the seal is safe because of the shoulder that preserve the structure. It also can be seen that, in high temperature condition, the stress compression is distribute mostly at the lip (end) of shoulder which prevent the distribution on the seal area.

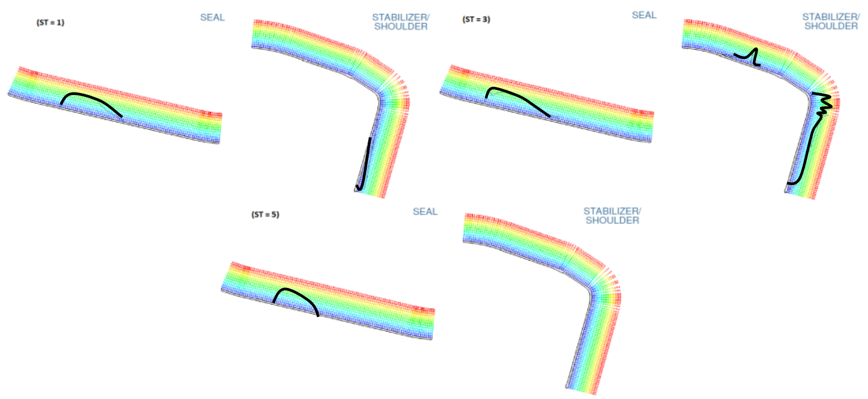
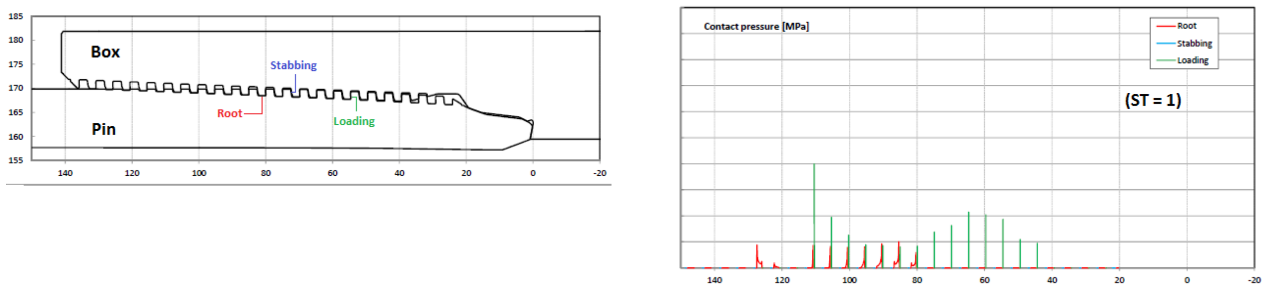


Figure 8: Contact stress distribution on seal and shoulder area of VAM® 21 connection.

Figure 9 below shows the contact pressure in the threads area from all simulation time. It appears that the contact pressure area is on the loading flank when the situation is in low temperature and inflicts high tension (ST 1, 2 and 5). On the contrary, stabbing flank and root flank is higher under high temperature (ST 3 and 4) which was inflicted thermal compression.



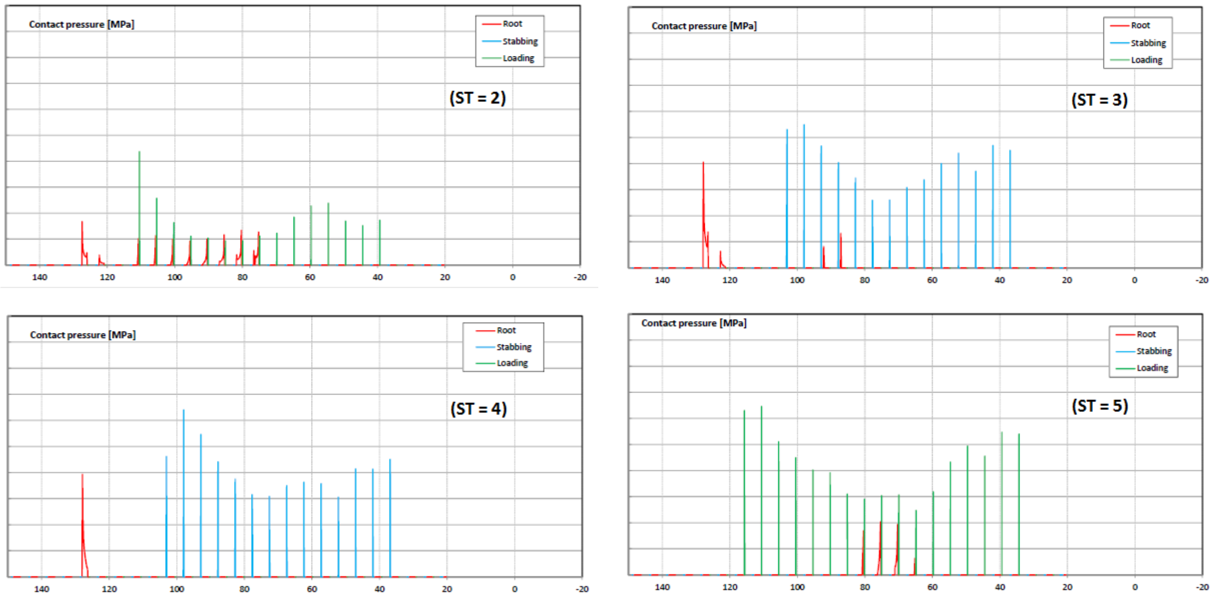


Figure 9: Contact stress distribution of VAM® 21 connection on thread area.

5. ISO/PAS 12835:2013

According to FEA test result, we found out that there were two critical conditions which are high tension at low temperature and high compression at high temperature. VAM® 21 connection has passed ISO 13679 CAL IV test with 100% pipe body yield strength (PBYS) envelope, but this testing protocol is not sufficient for high temperature above 180°C. Therefore for the physical test, we conduct the worst condition selected in ISO/PAS 12835:2013 testing protocol.

5.1 Testing Sequence and Preparation

We used four testing samples of 13 3/8" 68# L80 VAM® 21 with two different worst-case configurations to conduct this testing. The first two samples called sample 3 and 4 were tested for sealability in tension at low temperature (WST) and the second two samples called sample 5 and 6 were tested for sealability in compression at high temperature (WSC). Below is the sequence of the test:

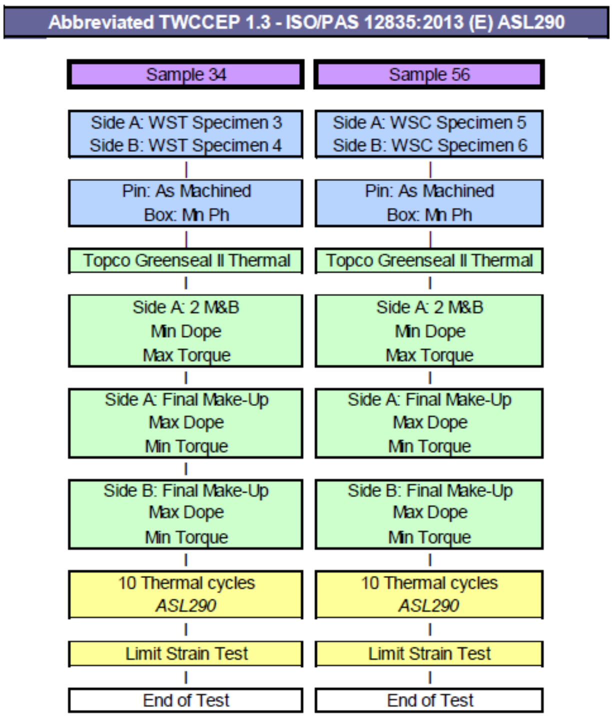


Figure 10: Thermal Cycle Testing sequences.

There are three main sequences for this test which are galling test, thermal cycle test and limit strain test. Galling resistance test is represented as make-up and break-out to verify the connections ability to withstand multiple make-ups and break-outs (TWCCEP point 12.2.1). According to TWCCEP protocol, thermal cycle test is the most severe test matrix where it's conducted to evaluate the connection's structural integrity and sealability under cyclic thermo-mechanical load representing thermal-well application (TWCCEP point 12.3.1). Limit strain test is to simulate the load of casing strings in thermal wells which dominated by thermal expansion that leads to casing yielding and post-yield deformation (TWCCEP point 12.5.1).

Each configuration has thermal cycle up to 10 cycles with configuration of each cycle are summarized as per table below:

Cycle Number	Temperature (°C)	Axial Force (x10kN)	String Strain (με)	Internal Pressure (bar)	Holding Time
0	35	0	Resultant	74	15 min
	35	-233	Resultant	74	15 min
	35	233	Resultant	74	15 min
	35	Resultant	-337	74	15 min
1	180	Resultant	0	10	15 min
	240	Resultant	0	33	15 min
	290	Resultant	-379	74	120 hours
	35	Resultant	379	74	120 min
2 to 10	290	Resultant	-379	74	240 min
	35	Resultant	337	74	120 min
Post Cycle	35	0	Resultant	74	15 min

Table 3: Sumary of thermal cycle.

To test the specimen, we placed long stroke displacement (LSD) that used to achieve controlled elongation interval (LCEI). The LSD equipment placed apart from specimen string to minimize heat effect, LSD is then connected to data acquisition. The result of the data acquisition is used to determine the elongation of pipe during thermal test.

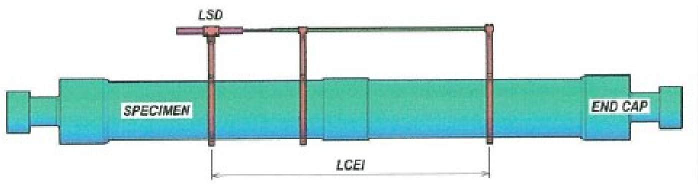


Figure 11: LSD placement during test.

Temperature during testing was measured by placing thermocouple 10cm in each axial location (figure 12) with temperature tolerance ±15°C. The ambient temperature ranged between 5°C to 40°C and the cycle temperature at 290°C. The test was done with 10 cycles for each configuration with cooling and heating rate not exceeds 5°C per minute.

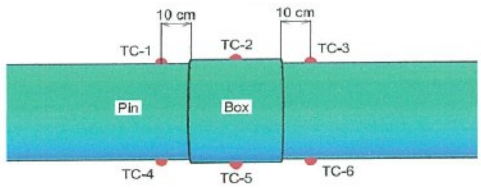


Figure 13: Thermocouple placement.

The sealability test is done by measuring the leakage of each side of connection with seepage detection equipment. There are four portholes of each testing configuration that placed in the coupling behind the metal to metal seal as shown in figure 14 below to detect any leakage during testing process. The acceptance criteria of this test are:

- No structural failure occurred.
- Average leak rate per connection at hold time in high temperature does not exceed 1 mL/min.
- Average leak rate per connection at hold time in low temperature does not exceed 10 mL/min.

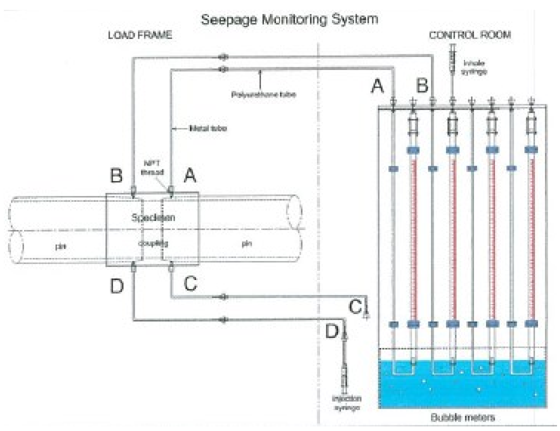


Figure 14: Configuration of seepage detection.

5.2 Testing Result

All samples successfully completed the whole test series as per testing sequences given. Below is the summary of the test result:

Sample	Make Up / break Up	Final Make Up	Thermal Cycle Test	Limit-Strain Test
3A	Pass	Pass	No structural failure occurred, no leakage in high and low temperature.	No structural failure occurs, no decrease in axial force with increase of strain.
4B	N/A	Pass		
5A	Pass	Pass	No structural failure occurred, no leakage in high and low temperature.	No structural failure occurs, no decrease in axial force with increase of strain.
6B	N/A	Pass		

Table 4: Summary of TWCCEP test result.

The specimens exceed the tensile test 3% of specimen strain without leak or failure occurred during this test and the test was stopped on 8410KN axial load due to equipment capability.

6. CONCLUSION

According to the FEA and thermal cycle test results above, casing 13-3/8” 68# L80 VAM® 21 premium connection has passed an abbreviated ISO 12835:2013 TWCCEP ASL290 protocol without any degradation in term of structural integrity and sealing integrity. It also can be justified that the analysis and the physical test have higher severity condition, in term of temperature and pressure, compare to well condition in every operating sequence (flowing – shut in – injection). Table below gives the severity comparison of both conditions:

Description	FEA condition	ISO 12835 Test	Well condition
Highest temperature	290°C	290°C	254°C
Lowest temperature	5°C	35°C	26°C
Highest internal pressure	74 bar	74 bar	42 bar

Table 5: Temperature comparison between FEA, physical test and well condition.

According to the well parameter, the operating process sequence is flowing – shut in – injection. The operating temperature on flowing to shut in is high (174°C to 254°C) which mean these operating sequences can give thermal expansion on material and inflict thermal compression. This situation has been simulated with FEA in simulation time 3 and 4, also in physical test during heating up to 290°C. Afterwards, the injection sequence is operated and the temperature drop with high difference from 254°C into 26°C. This sequence inflicts material to shrink and inflict tension in the connection which simulated in simulation time 5 and in accordance to physical test at post cycle.

According to the simulation and physical test result, VAM® 21 premium connection can maintain its sealing integrity that is important to prevent the steam gas from leaking and gives better steam production efficiency even under thermal cycle condition (high temperature – low temperature simulation).

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