A Thermal Casing Connection Test for Geothermal Wells in KS ORKA

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Abstract. Determining the proper casing and its connection for geothermal wells is very crucial. The casing and its connection experience various loads not only during drilling operations but also during production operations. In order to determine the suitable connections, various loads to the casings and connection during drilling and production are simulated. This paper presents the testing protocol used to qualify the Premium NS-CC connection used by KS ORKA (Sorik Marapi and Sokoria), a geothermal operator in Indonesia on the 13 3/8” 68# L80 Type 1 production casing. The testing protocol is referred to the ISO/PAS 12835:2013, Thermal Well Casing Connection Evaluation Protocol (TWCCEP), with some abbreviation. The test was conducted using 2+2 casing specimens at PT Citra Tubindo testing facility in Batam, Indonesia. Total of 30 thermal load cycles at the temperature range of 35º – 290ºC have been used to anticipate geothermal well life time as requested by KS ORKA drilling team. This paper summarizes the testing process from beginning to the end and the successful testing result of the NS-CC Premium casing connections that are used in KS ORKA (Sorik Marapi and Sokoria).

1. Introduction
KS ORKA is one of the geothermal operators in Indonesia that currently has two concession areas operated by its subsidiaries. The first one is located in Mandailing Natal District, North Sumatra which is operated by PT. Sorik Marapi Geothermal Power (SMGP). The second one is located in Ende, East Nusa Tenggara which is operated by PT. Sokoria Geothermal Indonesia (SGI). Since August 2018, KS ORKA has drilled a total of 24 wells, both in Sorik Marapi and Sokoria. All wells are mostly using NS-CC connection for its Production Casing section (Liner & Tie Back). NS-CC Connection is a Premium Gas Tight Connection that has the same performance as the pipe body, which was considered as a suitable connection to handle KS ORKA well challenges. One of the challenges faced by KS ORKA is the reservoir condition where the steam production temperature could be as high as 280ºC during its production activity. The other challenge is the profitability of all of their projects must be maintained for a minimum of 30 years of production. To provide additional assurance to KS ORKA, PT. Citra Tubindo Tbk (PTCT), a subsidiary of Vallourec Group, has conducted a Thermal Test using 13-3/8” 68# L80 Type 1 NS-CC Premium Connection at CDEC Facility (Connection
Development & Evaluation Center), that can mimic the actual wellbore condition, especially during the production. CDEC facility is PTCT inhouse tubular testing facility that can simulate a testing protocol based on ISO 13679 [1], API 5C5 [2], or ISO: PAS 12835:2013 TWCCEP [3]. The objective of this technical paper is to report the qualification test conducted to NS-CC Premium Connection from beginning to the end.

2. What is TWCCEP?
Casing connections in thermal wells experience extreme loads due to exposure of high temperatures steam between 180-350°C in cemented condition. Thermal Well Casing Connection Evaluation Protocol (TWCCEP) was published as ISO Publicly Available Specification (PAS) 12835 on 2013–12-15 purposely for oil and gas Industry.

The thermal casing connection test for KS ORKA was conducted as part of the assurance drilling program and refer to ISO/PAS 12835:2013 TWCCEP [3] protocol with several abbreviation on Casing 13-3/8" 68# L80 Type 1. 30 thermal load cycles with ASL 290 are chosen to simulate the conditions.

3. Geothermal Well Design
Figure 1 shows two geothermal wells design in KS ORKA: Standard Well Design and Big Hole Well Design. The well trajectory for both designs is simple 2D model “J” type profile with hole inclination up to 40 deg inclination or 3-5 deg/100 ft Dogleg. The anticipated static reservoir temperature is up to 280°C with bottom hole pressure not exceeding 1000 psi at the surface. Multiple fractures are anticipated when drilling the reservoir section covered by perforated production casing liner.

![Figure 1. Geothermal Well Design](image-url)
The production casing – Liner & Tieback (13-3/8” casing for Big Hole and 9-5/8” casing for Standard Hole) is the casing that experienced the highest load not only during drilling operations but also during production operations. During Production Operations, there is at least three activity that resulting different temperature range: Shut in, Flowing and Injection. This gives an axial load cycling that causes production casing in compression or in tension mode.

Failure in selecting the right type casing connection could cause casing or connection problem that leads to losing the well integrity, hence create a catastrophic condition. KS ORKA, since the beginning of Drilling Project, has used an NS-CC casing connection for most of its Production Casing, either for Big Hole or Standard Hole wells. There are 24 wells have been drilled up to date and all production casings are mostly using NS-CC premium connection.

4. Qualification Context

4.1 Testing Procedure and Reference Documents

The testing procedure was developed by PTCT, reviewed and agreed by KS ORKA. An Official Testing Procedure (OTP) number VRCC 18-0204 [4] that refer to ISO/PAS 12835:2013 TWCCEP [3] protocol with several main conditions of testing as it mentioned in Table 1, and several abbreviations was finalized with highlights as following:

- Two sealability test sampel with 2 spare samples are prepared based on ISO/PAS 12835:2013 TWCCEP [3] Worst Case configuration, WST (Worst Sealability on Tension at low temperature) and WSC (Worst-case for Sealability in Compression at high temperature).
- Total of 30 Thermal cycles is targeted instead of 10 Thermal Cycle (exceed TWCCEP requirements).
- Optional Bending Test represented by Task 4.3 of the ISO/PAS 12835:2013 TWCCEP [3] is not performed, since the 13-3/8” NS-CC Connection has already been evaluated on bending as per ISO 13679:2002 [1].
- Limit Strain Test to be performed as per Task 4.4 of ISO/PAS 12835:2013 TWCCEP [3].
- Temperature tolerance during hold times is ± 15°C both on Pipe body and Coupling.
- Maximum of 6 thermocouples to be placed on to monitor the temperature. No insulation method is used during testing.
- No strain gauges to be placed on test samples.
- Both test sample to be tested separately.

| Application Level | Galling Resistance Test | Thermal Cycle (30x) | Limit Strain Test |
|-------------------|-------------------------|---------------------|------------------|
| ASL 290 | 2x Make and Brake | 290ºC, maintain at Zero strain | Tension to failure (exceed tensile strain threshold) |

4.2 Connection Main Characteristic

NS-CC (NS Connection for Casing) is PTCT Proprietary Thread and Coupled (T&C) Gas Tight Connection providing the most field worthy tubular for oil and gas and geothermal application. KS ORKA drilling team has experience using NS-CC and has selected this casing connection for geothermal Production Casing application. This connection is also interchangeable with API BTC connection which gives more flexibility on selecting the casing accessories. On Figure 2 we can found NS-CC Connection Design and Dimension for 13-3/8” pipes with 68 pound per foot (ppl/#).
Figure 2. NS-CC Connection Design and Dimension.

NS-CC is a high performance gas-tight connection for critical environments such as high compression, bending, fatigue resistance. The “Two-Step pin nose” allows the metal to metal seal to be protected from running, over torque damage, and also provide a high compression performance. NS-CC connection has a flush ID Design, which very important to prevent localized erosion that could lead to the actual destruction of the connection.

NS-CC is rated 100% Pipe Body Yield in Tension, Compression, Internal, and External Pressure, making it the best choice for Thermal Well application in KS ORKA fields. NS-CC Performance on 13-3/8” 68# L80 Type 1 could be found in Table 2.

Table 2. 13-3/8” 68# L80 Type 1 NS-CC Performance.

| Connection Performance | Make up Torque |
|-------------------------|---------------|
| Tension (kib)           | Comp (kib)    |
|                         | Burst (psi)   |
|                         | Collapse (psi)|
|                         | Min (lb-ft)   |
|                         | Opt (lb-ft)   |
|                         | Max (lb-ft)   |
| 1,545                   | 1,545         |
|                         | 5,020         |
|                         | 2,260         |
|                         | 12,300        |
|                         | 14,100        |
|                         | 15,900        |

4.3 Material Main Characteristic
13-3/8” 68# L80 Type 1 Material was used to prepare 2 Test Samples and 2 Spare Samples addressed for this test. L80 Type 1 material is a Group 2 material based on API 5 CT 9th Edition [2] dedicated for Sour Service (Hydrogen sulphide) Environment. On Table 3 we could found the chemical composition of L80 Type 1 Material based on API SCT 9th Edition, Table C.4 [2].
The green pipe was produced by Anhui Tianda Oil Pipe Co ltd, a Vallourec subsidiary Rolling Mill in China. The green pipe was delivered to PT. Citra Tubindo Tbk in Batam, Indonesia for Heat Treatment and Threading Process. In Batam hardening, quenching, and tempering process has been done to achieve L80 type 1 mechanical properties. The Plain end pipe was inspected based on API 5CT 9th Edition Annex H for Product Specification Level (PSL) 2 [2]. On Table 4 below we can find L80 Type 1 Mechanical Properties based on API 5CT 9th Edition, Table E.5 [2].

| Group | Grade       | Elongation (%) | Yield Strength (Ksi) | Tensile Strength (Ksi) | Hardness (Max) |
|-------|-------------|----------------|----------------------|------------------------|----------------|
|       |             |                | Min  | Max  | Min | Max | Min | HRC | HBW |
| 2     | L80 Type 1  | 0.5            | 80   | 95   | 95  |     | 23  | 241 |

5. Qualification Program and Reports

5.1 Testing Flow Chart

The scope of the full-scale tests (Figure 3) has been structured to reflect the loading encountered by casing and connection systems during assembly and field service. The Galling Resistance Test is conducted to verify that the candidate connection can withstand multiple make-ups and break-outs (M&B) without severe galling of thread surfaces or appreciable deterioration of seal surfaces. Two M&B tests will be done with min dope and max torque configuration. One final Make Up will be done with max dope and min torque configuration. A high boiling point running dope such as Topco Greenseal II Thermal has been used for the test.

Bending Analysis is recommended for applications in which severe bending is anticipated during installation or during well operation. As this is not anticipated in KS ORKA field case, it was then agreed to skip the Bending Test with the considerations that the typical well design has a low dogleg situation and NS-CC Connection bending performance has already been evaluated based on ISO 13679:2002 CAL IV Protocol [1].

The Thermal Cycle Test assesses NS-CC Connection sealability and structural integrity under combined, thermally-induced cyclic loading. This test includes specimen bake-out and multiple thermal cycles with temperature and pressure changes consistent with ASL 290. Two specimens are cycled individually. Every specimen have to pass an average of 1 ml/min leak rate at 290°C Temperature and 10 ml/min at ambient temperature during the hold time. Upon completion of the Thermal Cycle Test, both of the specimens are subjected to the Limit-Strain Test, in which limits of connection structural integrity and (optionally) sealability are assessed under increasing, tensile axial strain. The test will be on ambient temperature with a leak rate similar to the thermal cycle test of 10 ml/min.
Galling resistance, structural strength, and sealability measured in the full-scale tests are the only full-scale test results that contribute to the pass-fail assessment. Program reporting is conducted based on ISO/PAS 12835:2013 TWCCEP Task 5.1 Evaluation Report [3]. The Evaluation Report contains all analytical and test data collected in the Evaluation Program. The Inspection Report is prepared based on Task 5.2 and attached to the Evaluation Report. The Inspection Report where describes in section 13, verifies compliance of the conducted Evaluation Program with TWCCCEP’s procedures. To maintain the transparency of the full-scale test, we invited Third Party Inspector from Bureau Veritas Indonesia to be present during the test with the activity description as listed in Table 5.

Table 5. Inspection Activity Description

| Operation   | Machining Sample | Visual Dimension Inspection | Galling Resistance Test | Thermal-Cycle Test | Limit Strain Test |
|-------------|------------------|------------------------------|-------------------------|--------------------|------------------|
| Verification| Monitoring       | Monitoring/Reporting         | Witness                 | Witness & Monitoring | Witness & Monitoring |

5.2 Sample Preparation
Mother pipes and coupling material were heatreated in PTCT Heatreatment facility and transfeered to CDEC facility on plain end condition. CDEC lead the sample preperation as per ISO/PAS 12835:2013 TWCCCEP Section 11.3 [3]. The sample was mapped and cutted before the maschining process.
beginning. NS-CC Connection was threaded on each Test Pin and Box. And For the Test Caps sides were using VAM® TOP Connection as the default connection for Test Caps in CDEC facility for 13-3/8” pipes. The final samples configuration can be found in Figure 4 below.

5.2.1 Sample Machining. FEA simulation can identify the worst-case scenarios on metal to metal seal and threads. Mainly the connection taper, threads interferences, and seal interference are the targets. Vallourec R&D departement in France ran a simulation on the nominal case and they ran additional simulations to simulate different taper or interferences configurations and compare them to the reference.

The worst configuration from all 3 aspects will be chosen for the tested specimens. The worst-case specimen configurations (Table 6) are as follows:

- Worst-case for sealability in tension at low temperature (WST).
- Worst-case for sealability in compression at high temperature (WSC).

**Table 6. Specimen Worst-case Configuration**

| Specimen | Seal Interference | Thread Interference | Taper                        |
|----------|-------------------|---------------------|------------------------------|
| WST      | Min               | Max                 | Pin Slow / Box Fast (PSBF)   |
| WSC      | Min               | Max                 | Pin Slow / Box Fast (PSBF)   |

![Figure 4. Samples Layout and Marking.](image)
5.2.2 Connection End Finishing. The end finishing for NS-CC Connection has followed the Surface treatment procedure of TS-06 for Carbon Steel material. NS-CC Pin side was left as machined and the Box side has a Manganese Phosphate treatment to improve its galling resistance.

5.2.3 Port Holes. In order to evaluate the sealability performance of connection metal to metal seal, two port holes were drilled on the coupling of test samples, according to ISO/PAS 12835:2013 TWCCEP, Section 12.1.4 [3]. The port holes were drilled on the coupling for each pin end. The port holes are connected to a bubble meter device located in the control room.

5.3 Test Guidelines and Acceptance Criteria

5.3.1 Make up and Break out Test. Make-up was conducted in the horizontal position with the specified torque and dope application range according to ISO/PAS 12835:2013 TWCCEP, Section 12.2.5.2 [3]. Dope quantity and make-up torque are calculated within the Official Testing Procedure (OTP), reference number VRCC 18-0204 [4].

Connections shall meet the performance requirements in galling resistance test. Requirements are as follow:

- Each connection must be achieved 2 number of M&B cycles.
- Make-up torques have been within limits specified for this test between a min recommended is the torque of 12.300 ft-lb and max recommended make torque of 15.300 ft-lb.
- No severe galling on seal or threads during testing.

Following each M&B test, the specimens are visually inspected with the following criteria:

- The connection must be free of heavy damage.
- For the threads, it is acceptable to have light damage (scratches, indentations, knocks), provided it can be completely removed with a small file with the original profile. No galling is acceptable.
- For the seals, it is acceptable to have small circumferential scratches, but no repair is allowed.

5.3.2 Sealability Test. Test samples follow Thermal Cycle Tests per ISO/PAS 12835:2013 TWCCEP [3], Section 12.3 with amendments listed in Section 1.1. Detail set-up and instrumentation process as per TWCCEP are shown below:

- Controlled Elongation Interval (LCEI): Control of a specimen string’s elongation within the Controlled Elongation Interval is measured by using LSD (Long Stroke Displacement) transducer. The LSD placed apart from the surface of the specimen string to minimize heat effects on the instruments. The LSD is connected to DAQ (Data Acquisition).
- Axial force: Axial force on each specimen string measured and recorded for each thermal cycle test and limit strain test.
- Heating: Heating on the specimen string performed by a ceramic heater. Rate of temperature increment at any thermocouple location along the specimen string does not exceed 5°C (9°F) per minute.
- Cooling: The cooling system is using pressurized ambient air. Rate of temperature decrement at any thermocouple location along the specimen string does not exceed 5°C (9°F) per minute.
- Temperature measurement: At least six thermocouples shall be placed on the samples. During holding times, temperatures tolerances to be ± 15°C on both pipe body and coupling. The ambient temperature selected within the range of 5 °C and 40 °C. The high cycle temperature as close as reasonably possible to 290°C.
- Internal mandrel:
An internal mandrel made of aluminium shall be used, in order to reduce the volume of gas used to pressurize the test sample.

- **Internal pressure:**
  Internal pressure applied using Nitrogen with pressure around 7.4 Mpa (approx 1074 psi) as per ISO/PAS 12835:2013 TWCCEP ASL 290 [3]. The internal pressure in each specimen string measured continuously during the test and recorded by the data acquisition system.

- **Seepage Detection:**
  The seepage detection system is connected to a bubble meter device via ports drilled radially through the coupling wall. The ports diameters roughly 2.4 mm (3/32 in) and enlarged at the outer ends for attachment of seepage monitoring tube. The OD of the tubes is 3.2 mm (1/8 in). The tubes are connecting specimens and the bubble leak trap in the control room.

- **Data acquisition (DAQ):**
  A computerized data acquisition system is recording continuously for the Temperatures at all thermocouple locations, Elongation of the specimen string within the controlled elongation interval, Axial stroke of the test frame actuator, Axial force imposed on the specimen string, Internal pressure, Date and time.

Connections shall meet the performance requirements in the thermal cycle test. Requirements are as follows:

- No structural failure has occurred during the 30 Thermal Cycle operation.
- Per-connection average leak rate at hold time in high temperature cycle does not exceed 1 ml/min.
- Per-connection average leak rate at hold time in the low temperature cycle does not exceed 10 ml/min.

5.3.3 Limit Strain Test. Both test specimens follow limit-strain tests as per ISO/PAS 12835:2013 TWCCEP [3] Section 12.5, with amendments as described in Section 1.1 of this document. The Limit-Strain Test can be performed in any test configuration that gradually applies tensile axial strain to the test specimen. Both Localized Strain Seepage and Tension limit test to be performed. Each test specimen shall be pulled from zero strain to failure. An internal mandrel shall be used to minimize the gas volume and then to reduce energy stored in the compressed gas.

For Localized Strain Seepage, the connections shall meet the performance requirements in a limit-strain test. Requirements are as follows:

- No structural failure occurs before the average pipe strain equals the localized strain value.
- Average seepage rate is measured and reported for all holds at constant strain less than or equal to the localized strain value for each sample.

For Tension Limit, the Connections shall meet the performance requirements in the limit-strain test. Requirements are as follows:

- No structural failure occurs before the average pipe strain in each limit-strain specimen exceeds the tensile strain threshold.
- No decrease in axial force with the increase in average pipe strain is observed for two consecutive strain increments before the average pipe strain exceeds the tensile strain threshold.

5.4 Test Result

5.4.1 Make up and Break out. The results of two times make-up and break-out applied on the sample 3A with the specified torque and dope are listed in Table 7 below.
Table 7. Make up and Break out Result

| Pin | Coupling | M&B Sequence | Make-up Final Torque (ft.lb) | Break-out Torque (ft.lb) | Result |
|-----|----------|--------------|------------------------------|--------------------------|--------|
| 3A  | 34A      | 1            | 15,307                       | 21,941                   | ACCEPTED |
| 3A  | 34A      | 2            | 15,478                       | 28,434                   | ACCEPTED |
| 5A  | 56A      | 1            | 15,285                       | 17,643                   | ACCEPTED |
| 5A  | 56A      | 2            | 15,207                       | 26,178                   | ACCEPTED |

All final torque values are compliant to NS-CC recommended Torque value. All shouldering Torque is within the acceptance range. No deformation and galling observed.

5.4.2 Thermal Cycle Sealability Test. 2 main samples and 2 spare samples have been tested separately with 30 Thermal Cycles. The result of all samples with a final make up can be found in Table 8 below.

Table 8. Thermal Cycle Test Result

| Sample | Final MU | Thermal Cycles Test |
|--------|----------|---------------------|
|        | Max Dope / Min Torque | Result |
| 3A     | OK       | OK                  |
| 4B     | OK       | OK                  |
| 5A     | OK       | OK                  |
| 6B     | OK       | OK                  |

All Samples survived after 30 Thermal Cycle with no structural and sealability failure recorded.

5.4.3 Limit Strain Test. For Localized Strain page, all samples survived the test with no structural failure. All average seepage rate is measured and reported for all holds.

For Tension Limit result, structural failure occurred before the axial strain reached the tension strain threshold of 30,000 µε. Specimen 3.4 was broken at 28,200 µε and axial load at 800 tons. Meanwhile, Specimen 5.6 survived the test with no structural failure before the average pipe strain (Figure 5).
Figure 5. Limit Strain Test for Specimen 5.6.

6. Conclusion
- Selecting a proper production casing and casing connection for a geothermal well is very crucial as the production casing and its connection will experience various loads not only during drilling operations but also during its lifetime production operations.
- In geothermal, the thermal load caused by the temperature cycle during the production operations could potentially the highest load experienced by the production casing and its connection.
- The NS-CC connection for 13-3/8” 68# L80 Type 1 production casing has passed the TWCCEP for geothermal application with 30 Thermal Cycle. Hence this connection is considered suitable for a geothermal operator, and in this case for KS ORKA.

7. Recommendation
It is recommended to use proper production casing connection for geothermal wells, especially those that have passed an applicable test. One of the applicable tests that can mimic geothermal condition is TWCCEP test protocol. The NS-CC connection for the 13-3/8” 68# L80 Type 1 production casing, which has already passed the TWCCEP test, is one of assured option for geothermal well in Indonesia and worldwide.

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