

ISO/PAS 12835 (TWCCEP) Qualification of the EVRlock QB2 Premium Connection

Overview

Development of the EVRlock QB2 premium connection began in the mid-1990s. The goal was to create a connection that would provide high strength and a gas tight seal for the emerging in-situ oil sands industry in western Canada.

In 2000, the 177.8 mm OD, 34.23 kg/m (7" OD, 23 lbs/ft) Grade L80 QB2 successfully met requirements equivalent to an ASL 325 ISO/PAS 12835 (TWCCEP, Thermal Well Casing Connection Evaluation Protocol) evaluation. This confirmed the QB2 as one of the first premium connections to reliably meet the minimal seepage rates required for thermal wells.

In 2012, EVRAZ again led the industry when the EVRlock QB2 was the first premium connection to successfully complete an open evaluation to the ISO/PAS 12835 (TWCCEP) standard. In this program, a 244.5 mm, 59.53 kg/m (9-5/8" OD, 40 lbs/ft) Grade L80 QB2 connection was tested to an ISO/PAS 12835 ASL of 290 and achieved average seepage rates two orders of magnitude lower than the protocol's thresholds.

As well as formal qualification, EVRAZ has worked closely with its customers to test the EVRlock QB2 physically and with finite element modeling to understand the connection's performance in bending scenarios beyond conventional testing.

EVRAZ believes strongly in transparent communication of its EVRlock QB2 testing, and full reports are available for customer review. Due to the volumes of data available the time to perform such a review would be considerable, so this white paper will summarize the connection's extensive qualification process.

Thermal Qualification

177.8 mm OD, 34.23 kg/m (7" OD, 23 lbs/ft) Grade L80 EVRlock QB2 Thermal Evaluation

A formal thermal evaluation began on the EVRlock QB2 in 1996 with CFER Technologies when EVRAZ introduced the final, swaged revision to market. At the time, there were no formal procedures to evaluate a thermal connection. EVRAZ (then IPSCO) partnered with a major thermal operator to develop an evaluation method that would not only replicate the harsh operating conditions of in-situ thermal oil extraction, but also ensure that actual connections and materials were tested to reflect the worst case combination of tolerances required in the field. The method was also unique in that it took advantage of a relatively new technique, computer assisted finite element analysis, to investigate worst case scenarios prior to preparing actual test specimens.

The resulting test method is one that is very similar to ISO/PAS 12835 (TWCCEP), the protocol which was first released in 2010. These similarities and the justification for why the EVRAZ 177.8 mm OD (7" OD) study should be accepted as a full TWCCEP evaluation are discussed in the following paragraphs.

Testing began in 1996 with a thermal evaluation of the design taking into account what affect material variability, post elastic properties, and tolerance variation would have on the connection during all aspects of the thermal cycle, including initial make up. Further evaluation continued into 1998 to include analysis of the effect of curvature loading and extended thermal cycling.

From these evaluations, tolerances were identified for worst case performance. This analysis is analogous to the "front end evaluation" identified in ISO/PAS 12835 (TWCCEP).

For the full scale thermal evaluation, connections were machined with tolerances that demonstrated worst case tolerances for thread and seal galling. These connections then underwent three consecutive make and breaks. The make and breaks demonstrated that the 177.8 mm OD (7" OD) EVRlock QB2 can be successfully made up and broken out three successive times when using QB2-50M thread dope applied per EVRAZ field procedures.

Four connections were then machined with tolerances for worst case sealability. They were made up into a continuous string for thermal testing with two of the connections undergoing multiple makes and the remaining two connections being made up a single time. The test specimen selection and make-up procedures are identical to those described in TWCCEP with pup length and specimen orientation in the string also meeting the requirements of the protocol.

As with a TWCCEP evaluation, the test string underwent 10 thermal cycles between 336°C/14 MPa and 20°C/14 MPa. At the upper and lower temperatures, the string was pressurized with an inert gas and any seepage from the connection measured. Like the TWCCEP, each connection had a gas port drilled into the dope release groove to directly measure the seal effectiveness of each side of each connection.

During the test, the connections met current TWCCEP thresholds of < 10 ml/min average seepage under tension (cold cycle) and < 1 mm/min average seepage under compression (hot cycle).

It should be noted that finite element analysis (FEA) indicated that the EVRlock QB2 has low sensitivity to bending, therefore a physical bend test was not performed as part of the evaluation.

244.5 mm, 59.53 kg/m (9-5/8" OD, 40 lbs/ft) Grade L80 EVRlock QB2 TWCCEP Evaluation

In 2010, the 244.5 mm, 59.53 kg/m (9-5/8" OD, 40 lbs/ft) Grade L80 EVRlock QB2 was selected for qualification to revision 1.1 of the TWCCEP. For a successful TWCCEP evaluation, activities from four different sections of the protocol must be successfully completed. These four sections are discussed below. As with the 177.8 mm OD (7" OD) evaluation, FEA analysis determined that the EVRlock QB2 has low sensitivity to bending, and thus the optional bend test was not included as part of the evaluation.

Front End Evaluation/Material Characterization

FEA evaluation determined that mechanical property variation of API Grade L80 casing has little effect on the performance of the EVRlock QB2 connection. For the purposes of the evaluation, pin material was restricted to material with yield strength in the lower 50% of the range allowed by API (80ksi-87.5ksi). Coupling material was not restricted as it was shown to have no effect on performance.

The front end evaluation identified the same test specimen configuration as the original 177.8 mm OD (7" OD) evaluation. Test specimens were manufactured with tolerances that gave the connection the following conditions: worst case galling in the threads, worst case galling in the seal, worst case sealability in tension (cold cycle), and worst case sealability in compression (hot cycle).

Galling Resistance Testing

Initial galling resistance tests showed opportunities to restrict EVRlock QB2 tolerances to make it more robust during makeup. The restrictions in tolerances were adopted across the connection's geometry range, and were incorporated into a new revision of the manufacturing specification. Note that the restrictions do not invalidate the geometry configuration tested in the 7" OD thermal evaluation. Test specimens passed the galling resistance test with no damage observed on either the seal or thread after three consecutive make and breaks.

Thermal Evaluation

A four connection test string was cycled between 290°C/7.3 MPa and 20°C/7.3 MPa, with gas seepage measured at the hot and cold holds under pressure. As with the 177.8 mm OD (7" OD) EVRlock QB2, the 244.5 mm OD (9-5/8" OD) connection exhibited seepage rates well below 1 ml/min in the hot cycle (compression) and 10 ml/min in the cold cycle (tension).

Limit Load Test

In service, a connection may undergo significant localized strain. To ensure that the EVRlock QB2 is able to maintain integrity in these conditions, the TWCCEP states the connection should be able to withstand 1.5% strain before losing integrity.

To evaluate the load capability, a connection used in the galling resistance tests, as well as a connection that had been made up multiple times and used in the thermal testing, were selected to undergo axial tension to failure testing.

Both test specimens failed well past 1.5% strain with the first surpassing 4% and the second surpassing 6% strain. Each test specimen failed in the pipe body and not the connection, proving that the EVRlock QB2 geometry results in a connection that is stronger than the pipe body.

Additional Studies

EVRAZ manufactures the EVRlock QB2 connection in a number of different sizes and grades. Performing a full TWCCEP evaluation can be extremely costly and time consuming. Consequently, EVRAZ has worked closely with industry experts to develop numerical models that verify the performance of each new size and grade for which the connection is manufactured.

EVRAZ also works to understand the performance of the EVRlock QB2 outside of conventional thermal applications. The following summarizes significant studies the company has performed to ensure that every variant of the connection meets the highest standards in performance.

EVRlock QB2 Design Review (Noetic Engineering, 2003)

This FEA study was conducted to parametrically evaluate the EVRlock QB2 connection in a range of new sizes from 114.3 mm (4-1/2") to 339.7 mm (13-3/8"). Property data typical of L80 was employed.

In general, the connections required only minimal alterations to dimensions to keep the performance consistent with the thoroughly tested 177.8 mm (7") base case.

FEA modeling was also performed to evaluate connection performance under external pressure. It was concluded that larger connections are less resistant to external pressures. The FEA was also used to determine the torque range for make-up specifications and identified some inconsistencies between the FEA results and the factor employed by EVRAZ to scale the torque to other connection sizes.

Runnability was also evaluated, and recommendations for modification to running equipment were provided to address a greater susceptibility to galling in larger sizes. These recommendations were incorporated into subsequent field running procedures.

EVRlock QB2 Connection Analysis for Thermal Operation, Grade 55 Casing (Noetic, 2004)

In this report, 244.5 mm, 59.5 kg/m (9-5/8", 40 lbs/ft) and 298.5 mm, 89.3 kg/m (11-3/4", 60 lbs/ft) connections were evaluated for thermal service in SAGD applications. Loading conditions up to 4.5 MPa internal differential pressure and temperatures to 275°C were considered. The study employed the material properties typical of K55. Tolerances specified were those from drawing "QB2-92-100 Rev. 8."

The results demonstrate a substantial reduction in primary metal-to-metal seal contact strain in the primary seal region. In general, the larger diameter (298.5 mm) EVRlock QB2 connection demonstrated increased sealing contact intensity. While reduced compared to L80 products, significant seal contact intensity was retained at the primary radial metal-to-metal seal for both K55 connections throughout the course of three thermal cycles.

298.5 mm, 89.5 kg/m (11-3/4" OD, 60 lbs/ft) L80 EVRlock QB2 Connection Analysis for Thermal Operation (Noetic, 2007)

FEA analysis was conducted on 298.5 mm, 89.5 kg/m (11-3/4"OD, 60 lbs/ft) L80 using SAGD operating conditions of 210°C and 280°C. After analysis of the effects of machining tolerances on seal contact intensity, the geometry providing the worst sealing was employed to evaluate the connection in a thermal environment. It was demonstrated that torque shoulder contact does not provide an effective seal. However, the primary radial metal to metal seal maintained 68% of its make-up seal intensity in the most extreme SAGD load path. Comparing the results to similar results for K55 material shows that the higher yield strength of L80 results in a significant increase in the primary radial seal contact intensity.

Large Diameter EVRlock QB2 Development Make and Break Summary Report (EVRAZ, 2008)

A pre-production make and break analysis of the 298.5 mm OD and 339.7 mm OD (11-3/4" OD and 13-3/8" OD) EVRlock QB2 connections was performed. Connections underwent repeated makes without showing galling on the seals or threads.

Analysis of 244.5 mm OD (9-5/8" OD) EVRlock QB2 in Bending (EVRAZ, 2011)

Previous work identified that the EVRlock QB2 has little sensitivity to bending; however, that analysis focused on fairly gradual builds. This study looked at the effect of increasing wall thickness on the stress in the connection under builds of 16°/20 m and 19°/20 m.

The study showed that the EVRlock QB2 continued to be resistant to bending, with the seal maintaining adequate sealability and the thread form exhibiting less than 3% localized strain. This is well below the limits observed in the 244.5mm OD (9-5/8" OD) TWCCCP limit load test.

244.5 mm, 59.5 kg/m L80 (9-5/8" OD, 40 lbs/ft) EVRlock QB2 Connection Rotating Fatigue Evaluation (EVRAZ/Noetic, 2014)

In order to establish guidelines for use of the EVRlock QB2 connection in wells that will undergo rotation, EVRAZ North America performed an evaluation to determine the effect rotation would have in the connection under varying dogleg severities.

Coupon fatigue testing, combined with application of established failure mechanics and finite element modeling, were employed to determine critical stress areas in the connection when subjected to bending fatigue. Finally, an expected rotational life for each critical area was calculated.

For dogleg severities of 10°/30 m and less, thread 11 (the fifth-to-last engaged thread) was identified as having the greatest stress concentration during bending rotation and was predicted to have a failure life greater than 10,000 rotations. At dogleg severities greater than 10°/30 m, the life is significantly reduced, eventually dropping below 5,000 cycles at approximately 13°/30 m.

When applying this data to practice, it should be noted that these numbers are theoretical; therefore, when planning rotational life of a connection a significant safety factor should be considered. In addition, although the model takes into account both low cycle and high cycle fatigue damage, the model can show sensitivity to cycle speed in cases of large dogleg severities where the fatigue life of the connection is significantly lowered.

Summary

With its introduction in the mid-1990s, EVRlock QB2 has proven to be an industry leader in performance. Since then, EVRAZ has continued to analyze and improve the connection, taking advantage of new manufacturing techniques and exploring new applications with its customers to ensure that after 20 years of reliable field service, the connection will continue to provide superior performance for years to come.