Proceedings World Geothermal Congress 2023
Beijing, China, April 17 – 21, 2023

New challenges in casing design for deep geothermal wells

David Hernández Morales

86050 Tenaris. Villahermosa, Tabasco, México

Email: dhernandezm@tenaris.com

ABSTRACT

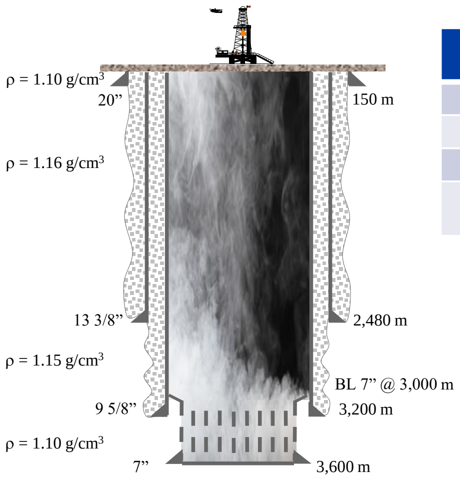
The new challenges in drilling deeper geothermal wells in the Cerro Prieto field, Baja California, Mexico, force the different areas to reengineer the selection of the casing settling depth with a new well structure, by incorporating a contingency casing, a new diameter using an integral connection. This configuration is planned to isolate areas that cause cross-flow contribution of water with different temperatures, causing problems of hole instability that directly increase operative time and drilling costs.

This solution consists of isolating the problematic area, maintaining the same completion clearance of the well. The design incorporates the corresponding adjustments due to the phenomenon of thermal degradation of materials, which causes a reduction of the pipe's yield strength, and as a consequence, a direct reduction in the mechanical properties of the materials; this occurs under dynamic conditions during the steam production, mainly on the production casing. In addition, an adequate material selection to resist corrosion by CO_2 is required, this phenomenon is a given during steam production, for instance, these materials have been successfully tested in the laboratory and in the field.

Finally, the incorporation of a premium special coupled connection for the slotted pipe allows greater mechanical resistance to reactive torques that can cause disconnections during the operation of mechanical cleaning tools, for the removal of carbonate scale, which reduces the steam production over time and cleanup will be required in future well interventions.
Keywords: New design of the casing, material selection, corrosion of CO_2, premium connection for greater mechanical resistance to torques, carbonate scale.

THE CHALLENGES IN CASING DESIGN FOR DEEP GEOTHERMAL WELLS

The casing design has been used for Cerro Prieto field; the steam reservoir is reached at average depth of 3,600 meters. The casings structure complies with design criteria and the technical guidelines established by the Federal company in Mexico (Comisión Federal de Electricidad) (see figure No 1). The casing design is to the technical limit of the mechanical properties of the material, so if the project ever needed to reach forward at deeper length or any special loads; the integrity of the well structure could be put at risk[8].

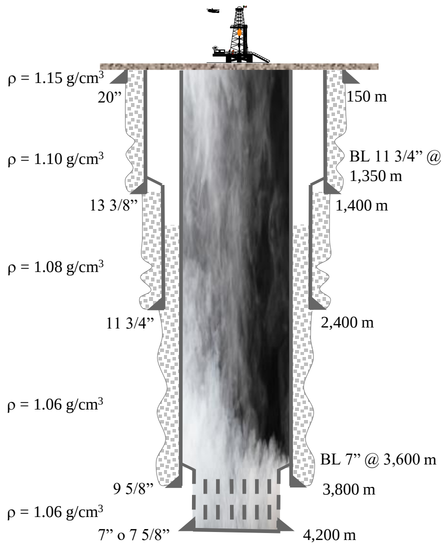


Hole diameter	Casing diameter	Type	Grade	Weight (lb/ft)	Type of connection	From (m)	To (m)
26"	20"	Casing	K 55	94.00	BTC	0	150
17 ½"	13 3/8"	Casing	K 55	68.00	BTC	0	2,480
12 ¼"	9 5/8"	Casing	L 80	47.00	TSH WEDGE 563	0	3,200
8 ½"	7" 7"	Liner Slotted Liner	L 80 L 80	29.00 29.00	TXP BTC TXP BTC	3,000 3,200	3,200 3,600

Figure 1: Well structure typical of the Cerro Prieto field, Mexico[8]

The new challenges in drilling a deeper geothermal well in Cerro Prieto field, Baja California, Mexico, force the different areas to carry out the selection of the settling depth of each of the casing with a new structure: therefore, the incorporation of a contingency liner of 11 ¾" is being technically suggested. The new diameter with an integral connection can be used to isolate areas that cause cross-flow contributions of water at different temperatures, causing instability problems in the hole, which directly affect drilling times and associated cost at that stage. Subsequently, the 9 5/8" exploration casing could be introduced and finally, the well will be completed with a 7" liner, maintaining the same diameter at the bottom of the well[3, 4 y 8].

This option provides another technical advantage in the cementing operation of the 9 5/8" casing exploration, as it is more maneuverable by having a greater length of cement between the 11 ¾" and 9 5/8" casing; which will guarantee better tightness and performance during the productive life of the well (see figure No.2)



Hole diameter	Casing diameter	Type	Grade	Weight (lb/ft)	Connection	From (m)	To (m)
26”	20”	Casing	K 55	94.00	BTC	0	150
17 ½”	13 3/8” 13 3/8”	Casing	K 55 P 110	68.00 72.00	BTC BTC	0 1,100	1,100 1,400
12 ¼”	11 ¾”	Liner	P 110	65.00	TSH WEDGE 511	1,350	2,400
10 5/8”-12 ¼”	9 5/8” 9 5/8” 9 5/8”	Casing	L 80 L 80 L 80	47.00 47.00 53.00	TSH WEDGE 513 TSH WEDGE 513 TSH WEDGE 513	0 1,300 2,800	1,300 2,800 3,800
8 ½”	7” 7”	Liner Slotted Liner	L 80 L 80	29.00 29.00	TXP BTC TXP BTC	3,600 3,850	3,850 4,200

Figure 2: New design of the well structure for deep well in Cerro Prieto field, México

Based on the experience of drilling and requirements of future designs for deep wells, we can conclude the use of an additional liner in the project; without altering the structural geometry of the exploration diameter. This situation allows reducing potential problems that arise during drilling of the 12 ¼” stage, which will help reduce drilling times and related costs.

CHALLENGES IN THE DEGRADATION DUE TO THE EFFECT OF TEMPERATURE ON THE MECHANICAL PROPERTIES OF THE CASING.

During the design of the casing, one of the most important parameters is the yield strength of the material. It has a direct influence on the resistance of materials with mechanical properties such as tension, compression, internal pressure, collapse, bending, etc.
The yield stress is a nominal value given by API 5CT. This value is obtained through a laboratory test, under room conditions. However, it is obvious that the working conditions of these pipes are very different from the environment since the temperature of above 350°C has been recorded in geothermal wells.

Casing design is generally based on mechanical forces: collapse, internal pressure, tension, compression, biaxial and triaxial stresses; and in most cases, the effect of temperature is not taken into account explicitly, because in some cases this risk is absorbed by the safety factors. However, for those pipes that are in front of the reservoir where the temperature will be close to 350°C and the pipe where the steam flow will pass from the reservoir to the surface, high temperature will be noticed; so under this concept, the application of degradation due to the effect of temperature is recommended [5, 6].

Within the joint investigation between a Federal Company in Mexico (Comisión Federal de Electricidad) and Tenaris, where simulation tests of different grades of steel were carried out; test tubes were prepared from steel samples N 80, L 80, P 110, TRC 95 SS, TRC 110 SS, TAC 110 HC and TAC 140 HC, which were subject to hot tensile test at temperatures of 20, 100, 125, 150, 175, 200, 300 and 400°C.

The result obtained in the laboratory test confirmed that the materials suffer degradation in the yield strength and, as a consequence, a decrease in their mechanical properties as the temperature increases; this concept is known as degradation due to the effect of temperature[6].

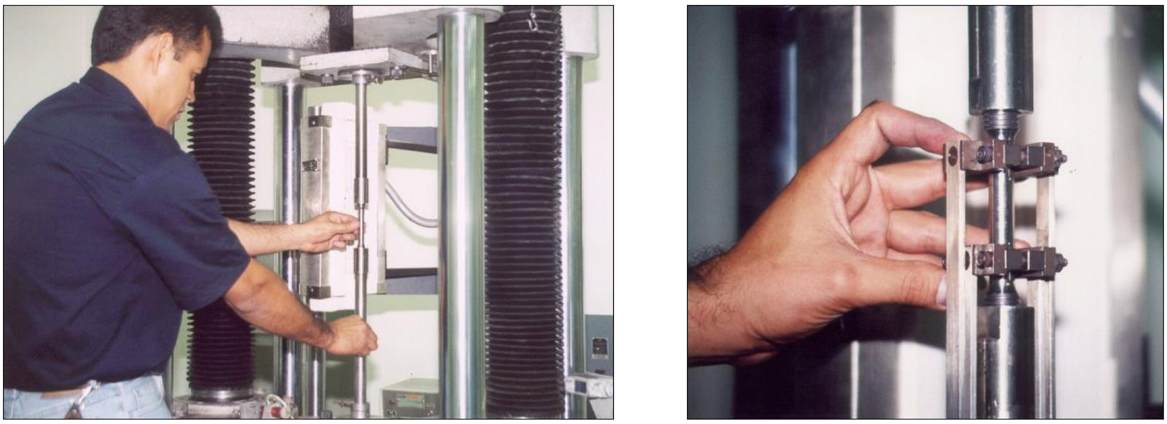


Figure 3: Placement of the sample in the special equipment for the tension test at different temperatures.

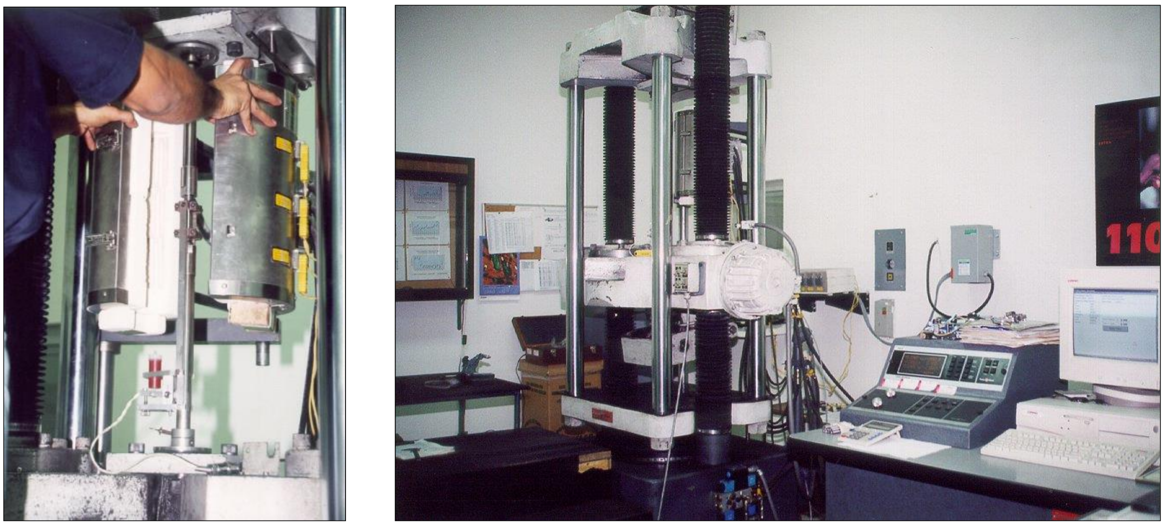
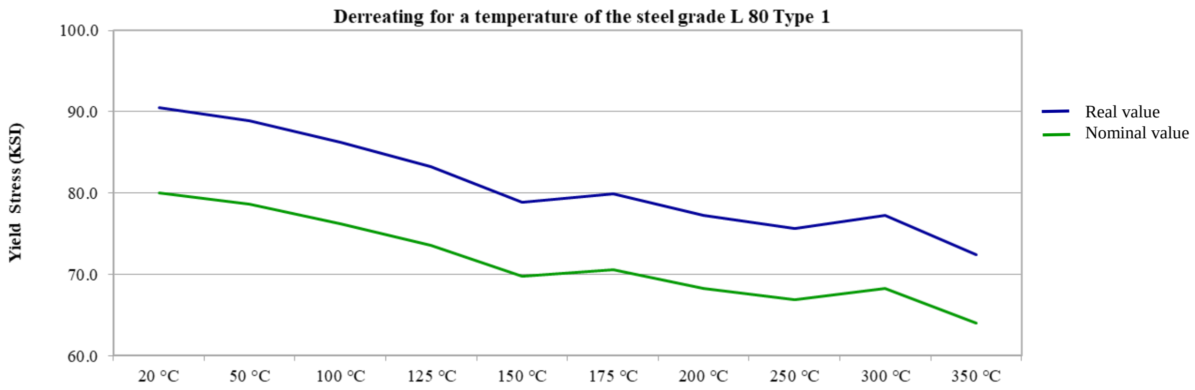


Figure 4: Thermal equipment where the stress tests were carried out at different temperatures

For this paper, the behavior of the steel grade L 80 was selected, which is one of the materials installed in the structures of the geothermal well and the results can be seen in figure 5.



Grade 80 KSI	Behavior of the Steel grade L 80 Type 1 for a different temperatures									
Temperature (°C)	20 °C	50 °C	100 °C	125 °C	150 °C	175 °C	200 °C	250 °C	300 °C	350 °C
Real Value (KSI)	90.5	88.9	86.2	83.2	78.9	79.9	77.3	75.7	77.3	72.4
Derreating (%)	100.00	98.23	95.25	91.93	87.18	88.29	85.41	83.65	85.41	80.00
Nominal Value (KSI)	80.0	78.6	76.2	73.5	69.7	70.6	68.3	66.9	68.3	64.0
Derreating Factor	1.00	0.98	0.95	0.92	0.87	0.88	0.85	0.84	0.85	0.80

Figure 5: Results and behavior of the grade steel L 80 at different temperatures

The results show that steel grade L 80, under a standard temperature condition of 20°C, it's a nominal yield value is 80,000 psi. When this material is subjected to high-temperature conditions, as is the case of the 9 5/8" and 7" exploration casing, where temperatures of 300°C have been observed, then this yield stress reduces its values to the order of 69,500 psi; this represents a degradation due to effect of temperature, so the design, engineering and field operators engineers must adjust this value with a reduction factor of 0.87 for this phenomena[6].

Based on the results obtained during the laboratory test, we can conclude that the exploration casing that will be exposed to the conditions of steam flow and high temperature must be designed and analyzed, including the degradation factor due to the effect of the high temperature at which the casing will be exposed.

CHALLENGES ON CORROSION IN THE EXPLORATION CASING DUE TO THE EFFECT OF CO_2

One of the great challenges present in geothermal energy is the phenomenon of corrosion in carbon steel pipes. The combination of CO_2 gas and water vapor generates a highly corrosive environment.

Corrosion generated by CO_2 known as sweet corrosion and there is historical knowledge since 1947 that has been recorded about cases worldwide. Corrosion is the deterioration of metallic material by chemical or electrochemical action with the environment. Corrosion begins with the dissolutions of CO_2 with water, in this reaction carbonic acid is formed, which produces a generation of protons that generated carbonates and the steel donates its electrons, causing the oxidation of the material and the reduction of pipe, which is also known as a plateau or spot corrosion, where it is concentrated and located in some area, causing spot corrosion, such as pan or pitting. Now, if the condensation water has an acidic pH, which is what happens in most cases, this variable will increase the level of corrosion; this phenomenon will not stop and will continue at all times until the complete deterioration of the materials[7]. Reported field experiences have observed iron fragments staying in the upper part of the production tree (see photograph No. 6) what was relevant was that only six months had passed since steam production had started. These fragments are mainly from the 9 5/8" exploration casing and the 7" slotted liner in the steel grade L 80, caused by a highly corrosive environment of CO_2.

Based on this phenomenon, this new challenge; where Federal company in Mexico (Comisión Federal de Electricidad) and TenarisTamsa worked together over the corrosion phenomenon cannot be controlled, but knowing the important variables of the phenomenon, materials can be proposed to extend the life span of the pipe and, as a consequence, of the well. It is important to know the different areas of the field, where low corrosion is expected the steel grade L 80 can be used. However, there are wells with a high concentration of CO_2 and low pH that if combined can cause high levels of corrosion, so the material must be carefully selected, seeking not to increase the cost of drilling or well intervention.

Figure 6: Steel pieces in the head of the well due to the corrosion phenomenon of CO_2

One of the Cerro Prieto well formation was selected for the investigation, due to its high concentration of H_2S and CO_2, with an acidic water pH, which temperature recorded at the bottom and at the head of the well as shown in the following table[8].

Condition Test	Partial Pressure of CO_2	Partial Pressure of H_2S	pH	Temperature
Head of the well (surface condition)	0.435 bar 6.36 psi	0.027 bar 0.393 psi	5	313° C
Bottom hole	0.789 bar 11.60 psi	0.049 bar 0.714 psi	5	348° C

As a premise of the investigation, the product should have a high resistance to the corrosive environment of CO_2 for Geothermal wells, which is better for resistance to the corrosion phenomenon when compared to the traditional grade of steel L 80 that has been used for years.

Metallurgy researchers from Tenaris found that increasing the amount of the chromium element during the manufacture of micro-alloyed steel will help the product to be more resistant to corrosion by CO_2. This element, during the presence of the corrosive phenomenon, will form a passive layer of oxide on the pipe, helping to reduce the rate of corrosion and allowing the useful life span of the pipe to be extended[7].

For the actual verification, a 7" casing casting was manufactured in steel grade TN 80 with 3% Cr in the alloy (TN 80 CR3), where special samples were obtained that were prepared and sent to simulation laboratories. Material from the University of Pittsburg in the USA for its characterization.

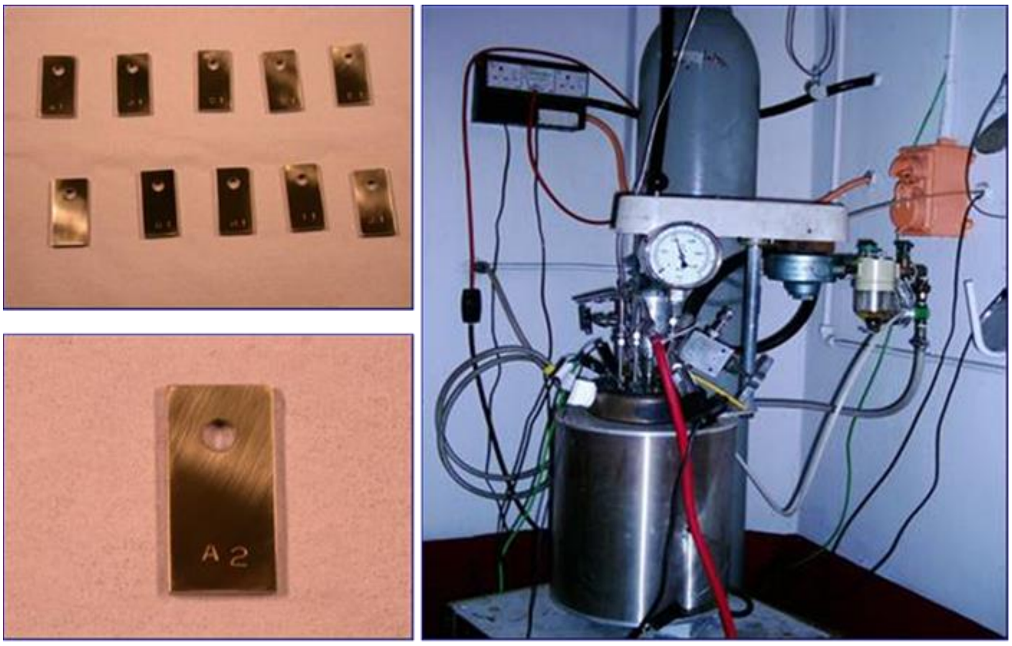


Figure 7: Simulation chamber of materials in the Pittsburg University, USA

In the simulation chamber, the samples were placed in a 5% NaCl solution with 0.41% CH3CaNa plus a mixture of CO_2 and H_2S gas; were subjected to the pressure and temperature conditions of the Cerro Prieto well. The results obtained was the loss of material per year, as shown in the following table[7].

Name of the sample	Temperature of the test	Velocity of the corrosion (mm/year)
A1	313 °C	0.41
F1	313 °C	1.06
G1	313 °C	1.30
D2	313 °C	1.20
D2	313 °C	1.08
F2	313° C	1.58

The results obtained from the new technological development TN 80Cr3 were excellent, as it was observed in the simulation that the corrosion rate was 1.58 mm/year under the conditions of the Cerro Prieto well. This result, when compared with the corrosion rate obtained from the degree of steel L 80 of 10 mm/year; represented an increase in the durability of the TN 80 Cr3 pipe in its operating life span beyond seven years, against the six mounts that were reported with grade L 80. Now, if coupon A1 is considered with a deterioration of 0.41 mm/year in the TN 80 Cr3 steel grade can have an "extrapolated" useful life span of up to 24 years of operation. However, the corrosion phenomenon depends on many variables, including the concentrations of H_2S, CO_2, and the water pH in each well[7].

Jointly between Federal Company in Mexico (Comisión Federal de Electricidad) and Tenaris, it was decided to carry out a real field test when the TN 80 Cr3 grade was introduced in a slotted liner at a depth of 2 840 m, and later on at witness with two sections above the L 80 pipe and the other in TN 80 Cr3, at the close of this report, we have been informed by CFE that this well continues to produce steam since 2008[8,] with actual production the 8.9 Ton/hr of steam (see figure No. 8).

Based on the results obtained during the simulation at the University of Pittsburg, USA, and the convincing results in the Cerro Prieto well test, we can present the following conclusions:

1 The development of the TN 80 Cr3 products has proven to have excellent performance against CO_2 corrosion by extending the life span of the casing and maintaining stable steam production.

2 The simulation of the laboratory tests showed that the TN 80 Cr3 grade for critical conditions would have a useful life span of more than seven years compared to the six months of the steel grade L 80. However, for conservative corrosion, the duration of the pipeline could extend up to 24 years.

3 Currently the TN 80Cr3 steel grade has been used in wells with high levels of CO_2 corrosion in the Cerro Prieto and Humeros Fields, with satisfactory results.

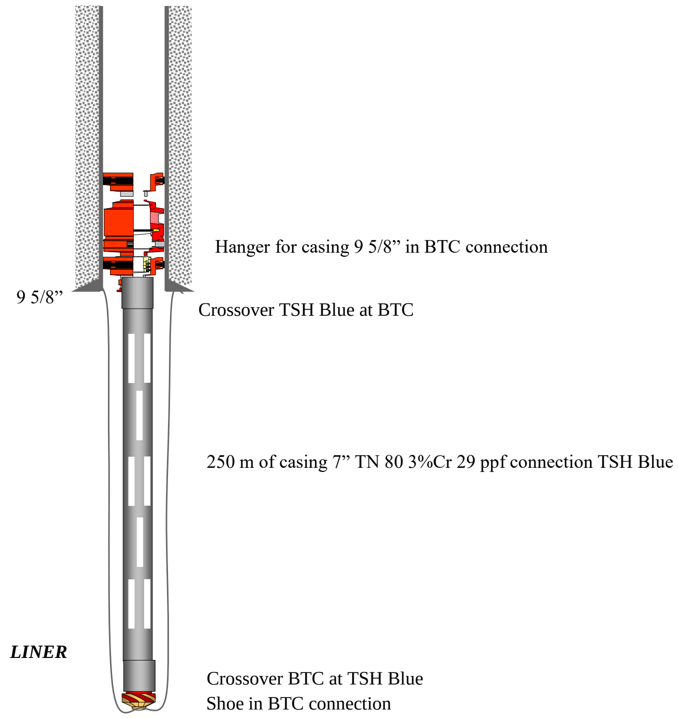


Figure 8: First liner of 7” TN 80 Cr3 that was running in the Cerro Prieto field, México

CHALLENGES IN SELECTING THREAD CONNECTIONS BY SLOTTED LINER TO WITHSTAND SCALE CLEANUP OPERATION.

During steam production, carbonate and silica deposits are common inside the liner or casing, causing a reduction in the natural flow of steam, sometimes leading to complete blockage of the flow.

The solution to those problems is mechanical cleaning inside the liner to eliminate carbonate and silica deposits; seeking to reincorporate the steam flow again. This operation requires drilling equipment and a special tool such as mills and reamers. Removing the embedded compounds in the slotted liner is necessary for the mechanical force of the weight on the mill and rotations, which can generate high reactive torques that will be transmitted to the liner its connections, and in many cases, the connections have become detached; being the most critical phenomenon in a hole with high deviation angle.

The typical liner connection BTC (Buttress connection) could be disconnected when the mill and drill pipe string transmit high torque to the right side over the slotted liner that was suspended through a hanger. Consequently, the detachment generates a “fish” remaining off-center the hole, thus complicating the intervention of the well and increasing the cost of the project (see Figure No. 9).

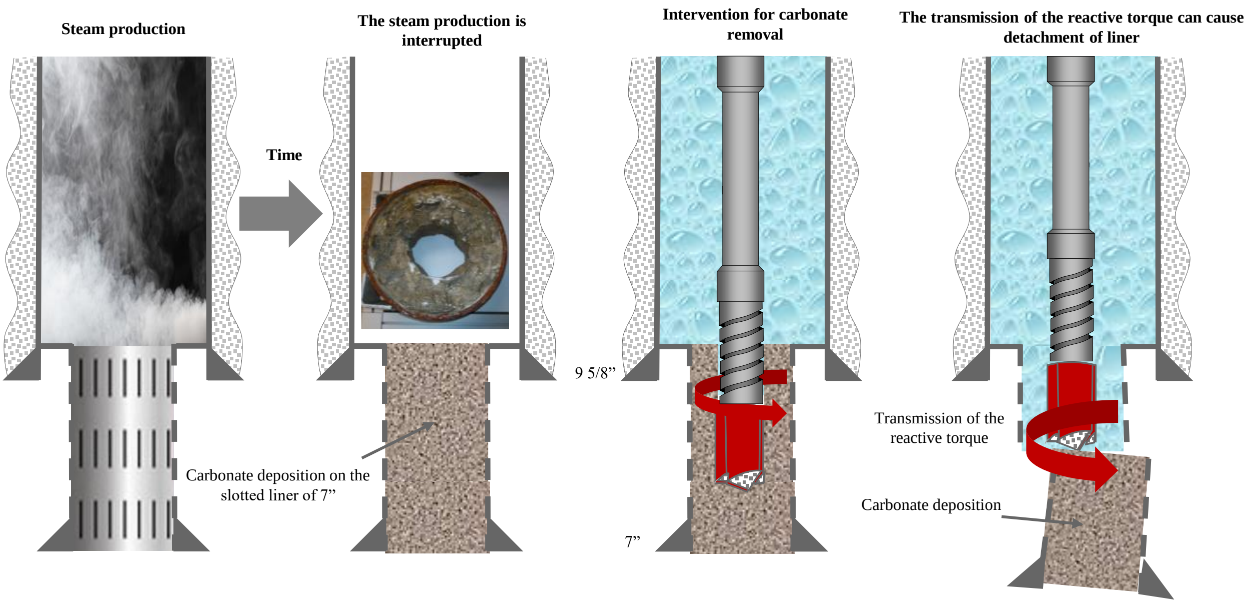


Figure 9: Graphic description of the phenomenon of the high torque to the right in the suspended slotted liner.

By mutual agreement between Federal Company in Mexico (Comisión Federal de Electricidad) and Tenaris various connections available in the market were reviewed. That study could provide greater resistance to handling the reactive torque expected during mechanical cleaning operation seeking not to increase the investment costs of the project. The TXP BTC connection (see figure No. 10) was selected to withstand the high reactive torques expected during operations and due to its special positive torques shoulder design, which offers the following characteristics:

1 Greater resistance to torque.
2 High compression efficiency.
3 Greater stability during tightening.
4 It is compatible with the standard Buttress connection.
5 Its smooth internal profile minimizes erosion damage during steam production.
6 It is applicable in rotation operations such as reaming, casing drilling, or liner drilling.

Figure 10: Connection TXP BTC that was used in slotted liner of 7”, with special coupling torque shoulder, design provides high torque and compression capacity for rotating applications.

Since 2015, the TXP BTC connections have been introduced in the slotted production liners, where interventions have been carried out in the wells regarding the cleaning of carbonates and registering reactive torques in the drill string, which are transmitted to the connections of the liner that have a higher resistance to torque; and so far, there have been no disconnections or landslides, resulting in efficient and economical interventions (see figure No. 11).

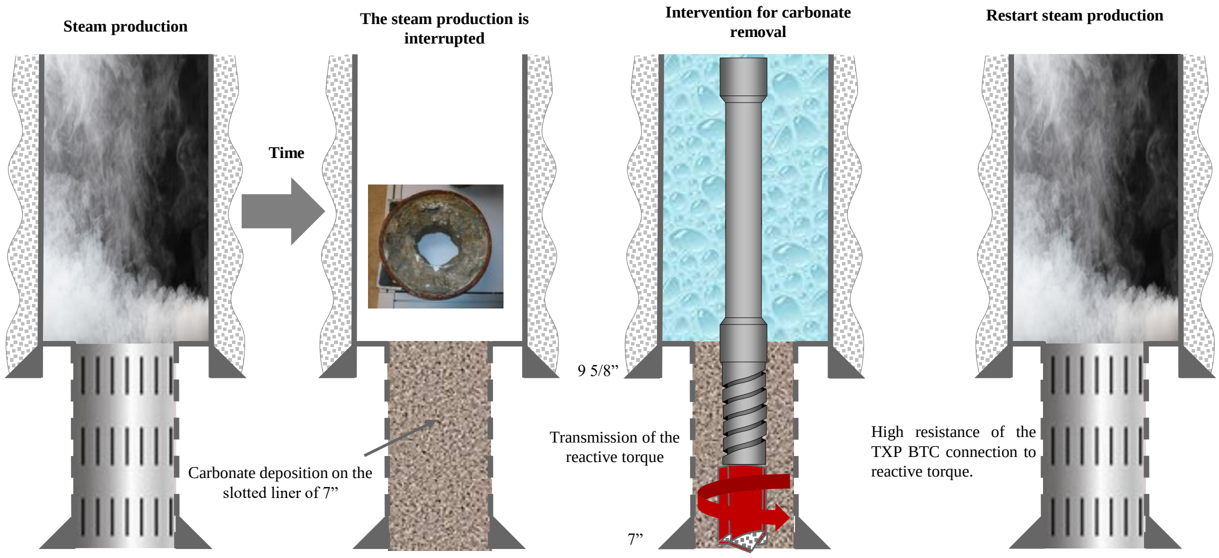


Figure 11: Graphic description of the phenomenon of the high torque with special connection TXP BTC; with special coupling torque shoulder, design provides high torque and compression capacity for rotating applications.

This new technology has been a great achievement for CFE over well interventions and repairs will be much faster, more efficient, and safer and with a significant reduction in costs, due to the fact of not having any detachment that traditionally occurred with the standard BTC connection.

CONCLUSIONS

- In the new casing design, the incorporation of an additional 11 ¾" contingency liner is being suggested. This is a new diameter with a flush connection that will be used to insolate areas that cause cross-flow contributions of water of different temperatures, causing problems of hole instability, which directly affect the drilling times and costs of that stage and subsequently, the 9 5/8" exploration casing will be introduced and finally, the well will be finished with a 7" slotted liner maintaining the same explorations diameter at the end of the well.
- The exploration casing that will be working in front of the steam flow and high temperature conditions must be designed and analyzed, including the degradation factor due to the effect of the high temperature at which the casing will be working.
- The development of the TN 80Cr3 product has shown to have excellent performance against CO_2 corrosion, by allowing the life span of the pipe for critical conditions to be extended for more than seven years compared to the six months of steel grade L 80 observed in some cases. However, for conservative corrosion, the life span of the pipe could be extended for more years. Currently, the TN 80 Cr3 steel grade has been used in well with high levels of CO_2 corrosion with satisfactory results.
- The application of the TXP BTC connections in the slotted productions liners where carbonate cleaning interventions have been carried out with mills, registering reactive torques in the drill string, which are transmitted to the liner connections. This has shown to have an increased resistance to torque, where no detachment have been recorded, resulting in efficient and less economical interventions.

REFERENCES

1. API. "Specification for casing and tubing. API Specification 5CT". Tenth Edition, June 2018.

2. API. "Calculating Performance Properties of Pipe Used as Casing or Tubing. API Technical report 5C3". Seventh Edition, June 2018.

3. Adam T. Bourgoyne Jr, Keith K. Millheim, Martin E. Chenevert, F.S. Young Jr. "Applied Drilling Engineering". First Edition, 1986.

4. Hussain Rabia: "Fundamentals of Casing Design. Petroleum Engineering and Development Studies". Vol 1, 1987

5. Mexican Petroleum Institute. "Study of the mechanical behavior of materials used in casing with increasing temperature". 1992.

6. Heberto Ramos Rodriguez – Pemex y David Hernández Morales – TenarisTamsa. Effect of the temperature on the behavior of steel in yield stress. Edition 2003 and last revision 2013.

7. Tenaris. Investigation and development of the specification for steel grade TN 80CR3, TN 95Cr3 and TN 110Cr3. First Edition June 2007.
8. Federal Company of the electricity in Mexico (Comisión Federal de Electricidad). Technical Information and files of the geothermal well in Cerro Prieto Field, Baja California, México.